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TREAAARSEXPEDITIONEN TIL CHRISTIAN DEN X'S LAND 1931-34

UNDER LEDELSE AF LAUGE KOCH

PRELIMINARY REPORT
ON THE CALEDONIAN OROGENY
IN CHRISTIAN X'S LAND
(NORTH-EAST GREENLAND)

BY

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WITH 11 FIGURES IN THE TEXT AND 3 PLATES

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INTRODUCTION

In November, 1934, Dr. LAUGE KOCH asked me: "Do you believe in a Caledonian orogeny in East Greenland; could you soon give me a short report on this problem?" The following pages are an attempt to answer this question very shortly by putting together some results of the investigations done up till now. This report, which is to be taken as a mere preliminary one, will give some results without attempting to prove them. These proofs will be found in the thorough study, which will be published in a few months.

The author took part in the exploration of North-East Greenland as a member of the "Treaarexpeditionen til Christian X. Land 1931—34 under Ledelse af LAUGE KOCH", during the years 1932—33 and in the summer of 1934. The territory of my investigations was bounded on the south by Segelselskapet Fjord and Alp Fjord, on the north by Geolog Fjord and Franz Josef Fjord.

The results of former investigations are to be found in LAUGE KOCH's works (14, 15, 15a). These treatises have set modern research work further goals. Of the following studies those will be mentioned which concern us directly. So before going into the matter from our own point of view, a short survey of the conditions and former interpretations will be given.

BRIEF SURVEY

1) Situation and classification.

The fjord district north of Scoresby Sound may be divided into the following units:

I) The younger sediments, from the Devonian to the Cretaceous, form, generally speaking, the outer zone. In the south they are separated from the sea by Liverpool Land, farther north often by a stripe of basaltic rocks. Between Hudson Land and Hochstetter Foreland they form various stripes and as such they leave the present topography toward the north. These sediments consist entirely of Devonian molasse. They represent traces of various posthumous activities of the former mountain chain (comp. especially BÜTLER's thorough investigation of the Devonian).

II) The basement of these sediments. Apart from the younger basalt series, the basement of these younger sedimentary rocks forms the whole surface of N.E. Greenland. According to the character of the rocks we distinguish:

- 1) The crystalline massifs.
- 2) The sedimentary zones.

1) The crystalline rocks appear to be arranged in several series of larger and smaller areas.

For their distribution see KOCH's map (14, 15b)¹⁾. For this report the Vela massif is the most important. It extends over the zone of the inner fjords, from Scoresby Sound Fjord to some distance north of Geolog Fjord.

Farther west lies Liverpool Land, which, towards the north, disappears below younger sediments. In Musk-ox Fjord small crystalline massifs protrude from underneath the Devonian (comp. BÜTLER)²⁾. Farther north whole series of small massifs appear at the surface.

¹⁾ The numbers in brackets (14) refer to the bibliography p. 57—59.

²⁾ BÜTLER, H. Some investigations of the Devonian Stratigraphy of East Greenland. Medd. om Grøn. Bd. 103, No. 2. København 1935.

Erratics found in the Nordenskjöld Glacier seem to prove the existence of crystalline rocks in the extreme west (37).

Between the crystalline rocks

2) Zones of Caledonian sediments are to be found.

Mainly two will be considered here. The zone extending from the region of Wordie Glacier as far as Nordostbugt in the inner Scoresby Sound Fjord we call the Fjord-zone of Caledonian Sediments or Caledonian Fjord-zone.

The other — extending across the inner Goodenough Land northward through the regions of alimention of Jätte Glacier, De Geer Glacier, and Adolf Hoel Glacier, probably also through Queen Louise Land (14), till it reaches the coast near Norske Island — we call the Nunatak-zone of Caledonian Sediments, or Caledonian Nunatak-zone.

The stratigraphic elements of the Caledonian Fjord-zone are:

The Lower Palaeozoic group

The Tillite series

The Eleonore Bay Formation.

The stratigraphic elements of the Caledonian Nunatak-zone are:

The Lower Palaeozoic group

The Petermann series.

(Up to the present no tillite series has been discovered in the Nunatak-zone). According to KOCH, the Eleonore Bay Formation and the Petermann series belong to the Greenlandian, the youngest of the Pre-Cambrian formations (15, 15a, 15b). The following formations may also be assigned to this period:

The Thule formation in North Greenland (16), the Varanger formation in the northern part of Norway (35) and on the Murman Coast (34), the Hecla Hook formation on Spitzbergen (28, 29) and Björnöya, sparagmites in Scandinavia, and Torridonian in Scotland.

In the Lower Palaeozoic group POULSEN ascertained a series of levels from Lower Cambrian to the lowermost Ordovician (22).

So far these decisions hold true for the Palaeozoic group of the Fjord-zone.

2) Previous Interpretations.

The relationship between these zones has been very differently interpreted. Here a short survey of only the latest explanations will be given, which, regarding the conciseness of the report, must necessarily be very sketchy. Two opinions are opposed to each other:

1) The adherents of a deep-going Caledonian orogeny. As early as 1927 KOCH considered part of the crystalline rocks to be granitized

Eleonore Bay Formation, and postulated for the first time a Caledonian mountain zone of great depth. In 1929 BACKLUND expressed the same opinion based on modern petrography concerning the Vela massif (2,6).

2) The adherents of a superficial Caledonian deformation. The members of English expeditions (WORDIE, WHITTARD, PARKINSON, WISEMANN (37, 36, 21)) took the crystalline rocks to be Archean, but in no case to be transformed Greenlandian. Only for small massifs they admit such a metamorphism. They describe also some granites as Caledonian.

According to these authors, the sediments of the Greenlandian are sheared off their Archean basis and folded. These authors describe major thrusts and minor thrusts (21), i. e. they take tangential movements on a large scale for granted. An extreme point of view is that of TEICHERT (26). He describes the folds drawn by him as a surface phenomenon which has no relation at all to deeper-lying intercrustal processes. Therefore he considers the Caledonian folding in East Greenland to be of a more Germanotype character (26, 10).

If, according to TEICHERT, we take the East Greenlandic Caledonian to be Germanotype, the logical consequence is that the infrastructure of the Canadian shield is not interrupted here. STILLE has shown this in a tectonic survey (24). According to him, the boundary of the "Laurentia" runs from the foreland of the Hebrides along the Norwegian coast and farther northward. Lately the question was tackled again by FREBOLD, without, however, the allegation of any new arguments (10).

If one knows the conditions, one can easily understand these two antagonistic opinions. The contradictory views are the results of the methods applied. The essentials shall be shortly mentioned here.

It is the great merit of BACKLUND to have made use on a large scale of the theories of migmatitization and granitization of J. J. SEDERHOLM (23), and to have deduced all that was possible from petrographical investigations (2, 6). BACKLUND tries to construct a history of the mountain chain out of local investigations and petrographical characteristics; he investigates the causes of the movements and finds them in the granite.

WISEMAN — from the mineralogical composition of the rocks — tries to prove that this is not the case.

The English scientists put the stress on the thrust under their "Franz Josef Beds". They start from the state of things on both sides of the thrust-plane. So their method comes nearer to that of structural geology.

For TEICHERT the small degree of disturbances in the sedimentary zones of some districts (especially in Strindberg Land) and the frequency of faults in some places, seem to have been the most impressive phenomena. His great merit is not to have avoided graphic representation (26).

As far as can be seen, FREBOLD's mode of procedure consists in comparing critically the results of other scientists (8, 10).

Since all these eminent scientists, starting from different points of view, were not able to come to an agreement, further investigations had to march along different paths. An attempt was made to differentiate between separate structural units. Their inward and outward form, and the movements having caused these forms, were to be determined as correctly as possible. In this report some of the results gained in this way — especially as regards the character of the orogeny — will be briefly outlined, by which I hope to contribute towards the solution of the problem.

3) Problems.

If like FREBOLD (10) we divide the explorers of the Greenlandic Caledonian into two camps, those who support the theory of strong and those who support that of weak folding, the question will arise: what is strong and what is weak folding? When PARKINSON and WHITTARD use the term "thrusts", most geologists will take these to be "strong" movements. It might be clearer to speak, with TEICHERT, of superficial movements, i. e., to look for the difference not in their violence, but in their vertical extent. The vertical extent can be ascertained by a study of the structure. During an orogenic cycle not only the structure but also the material undergoes certain changes. Hand in hand with elevations and subsidences of the earth's crust go erosion and sedimentation with their material differentiations. They produce new material for the cycle concerned. In the depths the material may be transformed by metamorphism; so changes as to structure and material may also take place there. Consequently a crustal segment may be transformed as well from above as from below. Such a thoroughly transformed segment has to be considered as something new, i. e. as "reconstruction", or "recasting".

I should like to put the question as follows: Is there a crustal segment in East Greenland in which structures corresponding to those of Fennoscandia or of the Canadian shield are so recast in the Caledonian cycle as to be considered as something new?

Changes of place and of material may be brought about in different ways. For the sake of clarity we arrange them in three groups. Changes due to

¹⁾ If a clastic sediment compared with the original rock has to be considered as a reconstruction (e.g. sandstone compared with granitic rocks), then granitized and migmatitized rocks should also to be looked upon as "reconstructions". Perhaps the term "transformation" might be preferred by some scientists.

- I) Erosion and sedimentation,
- II) Changing of place in the igneous state,
- III) Orogenic movements.

That these changes are connected with and overlap one another, is natural. Yet I shall try to separate them for the sake of a more lucid arrangement, and shall show their cooperation in the thorough study which is to follow later.

There are three sub-problems:

- I) How great are the changes due to supercrustal movements (erosion and sedimentation) and the differentiations caused by these changes?
- II) What part do the igneous movements play?
- III) How deep-going are the orogenic movements?

We shall try to answer these questions in three short chapters.

I. SUPERCrustal Movements

The sediments of the Caledonian cycle give us the best measurement for this process. So far these sediments have been described by many scientists (LENZ, NATHORST, NORDENSKJÖLD, LAUGE KOCH, WORDIE, WHITTARD, PARKINSON, BACKLUND, KULLING, CHR. POULSEN, and TEICHERT). The places in which they principally occur, and the series to which they belong, have been mentioned above (p. 6—7).

1) Caledonian Fjord-zone.

A. Eleonore Bay Formation.

As proved by KOCH, this formation belongs to the youngest Pre-Cambrian, the Greenlandian. Various scientists have divided it differently, some into two, others into three parts, but without achieving any new results. On the whole we agree with the classification given by TEICHERT (26). The designations themselves suggest something regarding the contents. We discern

- (a) a lower quartzite-schist series,
- (b) a middle multicoloured series,
- (c) an upper dolomite-limestone series

So far a transgression-level on top of an older basement is not known in East Greenland. Wherever the lower part has been discovered, it was

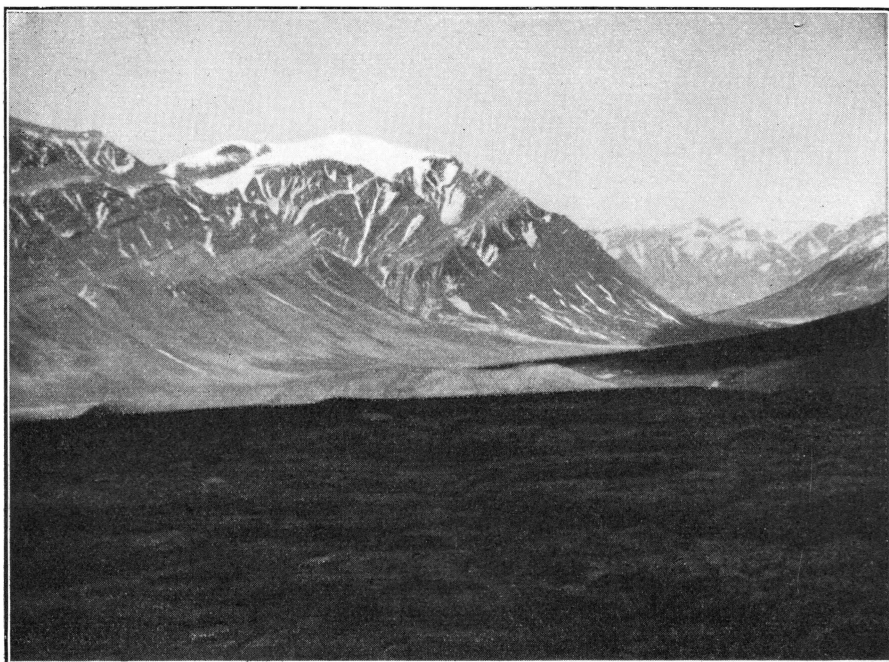


Fig. 1. Mt. Berzelius, seen from Polhem Valley. View from the northwest. In the middle the upper part of the quartzite-schist series; the various levels can be traced over large areas. In the background the lower part of the quartzite-schist series in the mountains south of Alp Fjord.



Fig. 2. Quartzites with cross-bedding at Cape Alfred. On the boundary between the beds ripple-marks. The pencil points towards the upper part of the series.

metamorphic. But the investigations point to some places where in future this problem might perhaps be gone into.

a) The quartzite-schist series consists on the whole of light and dark quartzites and schists. Now and then carbonatic cement is found in thin layers and concretions; beds containing more carbonate are rare. Otherwise we find mostly siliceous or argillaceous cement. More than half of these formations are composed of quartzites. Often we come across brown or yellow spotted quartzites. In some beds large or small

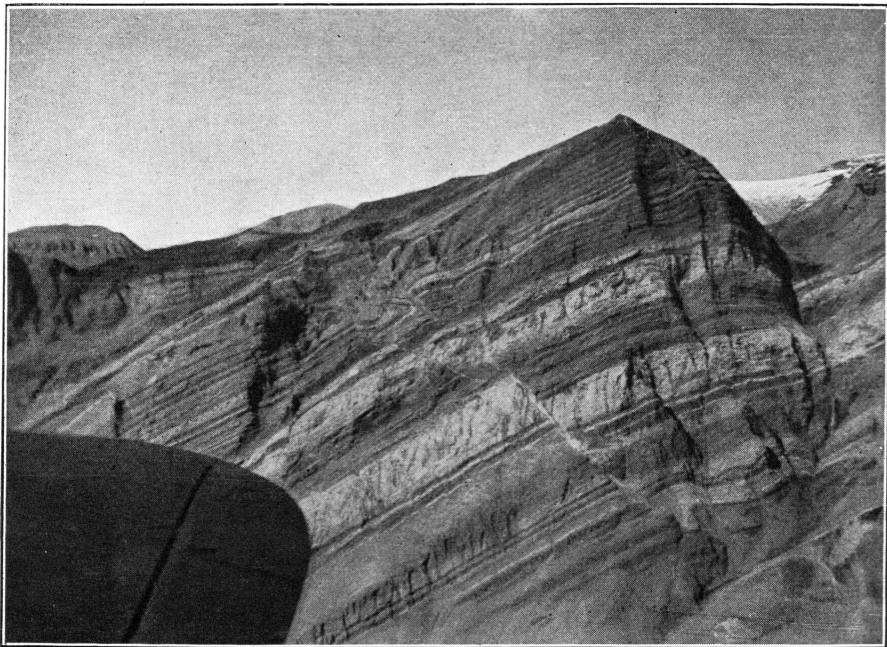


Fig. 3. Dolomite-limestone series in Mt. Johnstrup. Folds and faults visible.
Aërial view.

spots are spread over wide areas on exactly the same level. These spotted sandstones are also one of the most outstanding characteristics of the Varanger sandstones (35, 34). In the whole series, often from strata to strata, ripple-marks, cracks, and cross-bedding occur over and over again. The sedimentation, when seen in detail, is often rather irregular. Conglomerates have not been found in this series, though the sands may be rather coarse-grained. Here and there, in between the individual beds, small gaps, of some metres at most, have been ascertained. Also traces of subaqueous slides during the sedimentation are found there, similar to those ascertained by me on Fischer Peninsula and Varanger Peninsula (35, 34).

b) The multicoloured series is composed in the lower parts

mainly of quartzites and schists, in the upper parts mainly of schists, dolomites, and limestones. These rocks are white, grey, red, yellow, or green. This gives the mountains their varicoloured aspect, which was already reported enthusiastically by the first explorers. Many of these beds contain ripple-marks, cracks, and cross-bedding. Especially in the upper part of the series the carbonate strata often begin with the brecciation of the underlying strata. There is still a considerable supply of elastic material. Many of these rocks resemble the varicoloured rocks of the Varanger series in the north of Norway as well as on the Murman coast.

c) The dolomite-limestone series consists to a great extent of dolomites and limestones of different colour and different structure. In these beds also cross-bedding and cracks are frequent. Ripple-marks occur more rarely. Sometimes dolomitization may be observed issuing from old surfaces; in such cases the dolomitization ensued before the next bed was deposited. The structures of dolomitization are very different. Surfaces of discontinuity of the sedimentation are very frequent in this series. They occur as working-up with formation of breccia or as surfaces of corrosion. There exist a great many different breccias. The limestones are often partly siliceous. The silicification then is mostly older than the deposition of the following bed and the formation of the breccia; but the silicification and the dolomitization may also be younger than the breccia. Formations which were described as being of an oölitic texture, or as remains of fossils, and a great many so-called cryptozoic reefs, are characteristic of this level. (For further details the reader is referred to the thorough study to be published later). On top of the Eleonore Bay Formation rest

B. The Tillites.

The number and colour of the tillite-beds vary in different localities. Quartzites and schists lie between and above them. Also "varv"-sediments often occur. So far they have not been numerated. In the quartzites we find cross-bedding and ripple-marks. The tillite-series is taken to be the transition from the Greenlandian to the Lower Palaeozoic.

C. The Lower Palaeozoic series.

Except the lowest parts, this series consists mainly of limestones and dolomites of different structure. Most of them are grey, but there are also white, reddish, and yellow ones. For their stratigraphic succession see CHR. POULSEN (22). Here, too, cross-bedding and cracks, plains of discontinuity — frequently with breccias — often occur. According to POULSEN, they correspond to stratigraphical gaps. The largest of these gaps separates the Cass Fjord Formation from the Cape Weber Forma-

tion. According to POULSEN it comprises Upper Ozarkian and Lower and Middle Canadian. There are no unconformities in the strict sense of the word. The youngest formation is the Narwhal Sound Formation, according to POULSEN (22) not older than the upper Canadian and not younger than the lowermost Ordovician. Here the series ends.

2) The Nunatak-zone of Caledonian Sediments

comprises

A. The Petermann series

B. The Palaeozoic.

A. The Petermann series

was discovered by WORDIE and WHITTARD near Petermann Peak. ODELL, partaker of the Miss Boyd Expedition, studied it in the same district. MEHREN and HÖYGAARD brought home samples of it (13, 12). TEICHERT studied it in the erraticum. In the inner fjords, in the Cecilia Nunatak, on the southern border of Goodenough Land, the author made great collections of glacier-transported pebbles. It is possible to form an idea of the contents of this series, but not of its stratigraphical conditions, as the investigations, also by the British geologists, include only the lower part of it. This lower part consists of light and dark quartzites and schists. Some limestones and dolomites of different colour and structure occur erratically. So far no Cryptozoons and no formations of oölitic character have been ascertained. Whether they do not occur at all or only rarely, or whether they are destroyed more easily when transported by glaciers, cannot be decided. On Queen Louise Land a quartz conglomerate was found; also greenstones are mentioned. Greenstones were found erratically in Cecilia Nunatak as well. Of tillites nothing is known. On the whole the Petermann Series has much in common with the Eleonore Bay series. Compared with the latter, it seems to be stratigraphically somewhat impoverished. Both belong to the Greenlandian.

B. Old Palaeozoic.

In 1933 KOCH found fossils near Norske Island, which point to the early Palaeozoic¹⁾. They lay erratically near the district where the Caledonian Nunatak Zone strikes towards the coast. In 1934 the author brought home fossils from the moraine on Cecilia Nunatak. They were found in the dark limestone which originated from the hinterlands of the division of the Caledonian mountain chain treated here. These fossils

¹⁾ For details I refer to Dr. KOCH's treatise on the geology of Greenland to be published in the collection "Geologie der Erde"; Dr. KOCH had the kindness to show me the manuscript.

are not well preserved. CHR. POULSEN had the kindness to examine them — for which I wish to thank him also here. One species he designates as “cfr. Genus *Ectomaria* KOKEN; the vertical distribution of gastropoda of this type is great: Lower Ordovician — Carboniferous”. The other kind he designates as “cfr. Genus *Hormotoma* SALTER; vertical distribution: Lower Ordovician — Devonian”. Thus the stratigraphic designation of these fossils is but vague.

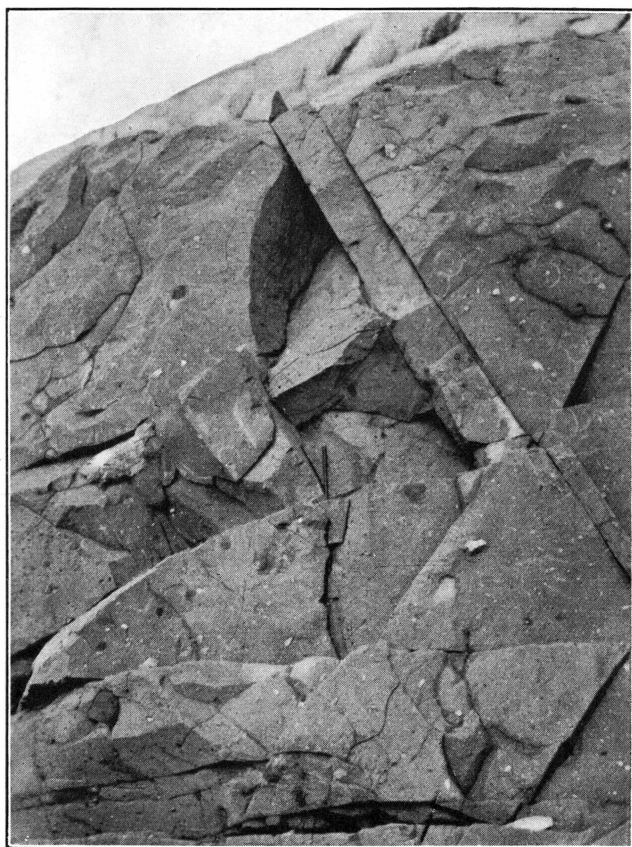


Fig. 4. Lower tillite at Cape Oswald.

3) Caledonian Sedimentary Rocks in general.

A. Thickness.

Various authors differ in their statements of the thickness of the sediments. For the Eleonore Bay Formation the following estimates have been given: LAUGE KOCH (15, p. 223) estimates its thickness in Mount Berzelius to be 2000 m (which very likely includes only the uppermost part); on the same mountain complex BACKLUND measured 16 200 m (2, p. 219); KULLING's (17) estimate of the two upper divisions, the

dolomite-limestone series and the multicoloured series (he calls them quartzite-schist series) amounts to more than 4000 m. TEICHERT gives the following values:

quartzite schist series.....	ca. 2000 m
multicoloured	ca. 1250 m
dolomitic limestone	600— 800 m
total	3850—4050 m.

The thickness, especially of the middle series, varies considerably because of the folding. As an average thickness of the non-metamorphic Eleonore Bay Formation the author suggests 5000 m.

The Tillite series varies very much; POULSEN gives estimates from 300—1000 m (22, p. 300—304), KULLING of more than 1000 m for this complex. As the different authors begin their measurements in different places, it is clear that these statements vary considerably — especially so because on these levels there are distinct disharmonies in the folding. To state a “normal” thickness is difficult. Where the thickness is not modified by movements, it lies between 500 and 1000 m.

The Palaeozoic series is said by POULSEN to be of a thickness between 2100 and 2200 m. As a great part of these rocks consists of massive limestone, their thickness fluctuates less. Thinking it not quite admissible to take the lower strata of the anticline of Ella Island to be typical, I should like to reduce POULSEN's figures a little, to c. 2000 m.

So the whole thickness of the non-metamorphic sediments would amount to 7500—8000 m. (This estimate seems to be very inexact. But it must be taken into consideration, that the bases of the non-metamorphic levels lie not everywhere in the same depths, or in other words: the metamorphism does not everywhere begin on the same level).

In some places, in the underlying metamorphic parts, rocks typical of the Eleonore Bay series are to be seen; consequently the Eleonore Bay Formation may be considered to be even thicker. But as these rocks are often very much folded, it is difficult to ascertain their original thickness. If, for the present we assume a thickness of 9000 m, we may consider this estimate to be rather conservative.

So far nothing is known of the thickness of the Petermann Series. WORDIE and WHITTARD take the thickness of the quartzites of the lower Petermann Series to be about 1200 m. Aërial observations and photographs show that the whole thickness also of this series should be reckoned at several thousand meters.

B. Conditions and area of the sedimentation.

As mentioned above, cracks, cross-bedding, ripple-marks, and brecciation as working-up of underlying beds occur again and again

throughout the whole thickness of the Caledonian sedimentary rocks. Ripple-marks, cross-bedding, and brecciation may occur under water, but not the cracks. Many cross-beddings seem to result more from the accumulation done by the wind, than from the action of water.

Without going too far, it may be stated that such sediments have always originated near the water-level. So since the surface remained always on about the same level, i. e. the substratum had to subside continually.

Thus we get here the model of a geosyncline, i. e. of a geosyncline in which nothing but shallow water-deposits could be formed.

In modern literature the term "geosyncline" seems to have been applied to phenomena of not always the same character. To some scientists a geosyncline is simply a crustal stripe which sinks continually; others add that this subsiding crustal stripe must contain deep-sea sediments, i. e., it must once have been part of the deep-sea. A third group of scientists assume that also younger foldings are necessary to allow the use of this term. This last condition may be omitted here. Concerning the second condition, it seems to be just as unnecessary. For if such a stripe is always sufficiently supplied with sediments, the possibility of deep-sea deposits will be excluded. The quantity of the sedimentary supply will be controlled by the movements of the surrounding regions, in other words: the height or depth of the surrounding region would have to be included in the definition. This seems to be unnecessary. If accordingly we apply the term "geosyncline" simply to a trough with constant subsidence of great proportions, then the Caledonian trough in North-East Greenland falls under this heading. The continual supply of sediments gives us at the same time an idea of the movements of the district furnishing these sediments. Whether we call these movements orogenic or epirogenic, is of no importance. At any rate we are dealing with a mighty elevation which, as to time and tonnage, must — roughly speaking — correspond to the subsidence.

These sediments are known in the Fjord-zone to extend for more than 350 km (N—S). On Ella Island, Lyell Land, Suess Land, and Ymer Island they occur continuously and cover a surface of 30—35 km in breadth. But this zone is folded; if flattened out, it would cover a surface of over 40 km in breadth.

So much to give an idea of the proportions of the Caledonian sediments in the Fjord-zone.

It is fairly certain that the Eleonore Bay Formation continues eastward below the younger sediments; for according to Mr. NOE-NYGAARD's kind communications it reappears in Canning Land. If on the other hand we take the Petermann Series to be the continuation of the Eleonore Bay Formation in cross-section towards the west, then the zone of the Cale-

donian sediments in North-East Greenland must be estimated at more than 200 km in breadth; very likely it is much broader still. Though we cannot assume the same thickness for the whole breadth, especially not for the Nunatak-zone, we have nevertheless to realise that we are dealing with a huge trough of sediments. For the present we have considered only the part extending from Strindberg Land to Scoresby Land. But it is not probable that conditions undergo a sudden change north and south of this district.

In the part just mentioned we have a Caledonian sediment series, composed to the greater part of clastic material. At certain places its thickness may amount to 9000 m. It should be noted that no real unconformities occur, but only discontinuities (with the exception of the tillites). Where earlier deposits have been worked up, it can only be a question of the next-oldest beds. This is at any rate sure in the Fjord-zone; in certain parts of the Nunatak-zone conditions may be different.

A great part of the material of the tillites originates from elements of the Eleonore Bay Formation. Part of the Palaeozoic material may have been moved from emerged Greenlandian areas and deposited, viz. from the peripheral parts of the geosyncline, perhaps from the ascending cover of the Vela-massif. In order to ascertain this, it would be necessary to study the contact of the tillites on top of the disappearing part of the Vela-massif (N. of Geolog Fjord). To Greenlandian elements of the tillites other material, which is not known from the zone of the Greenlandian sediments, has been added. Especially the great amount of crystalline pebbles might be mentioned. These were described by the British scientists (21, 26) as well as by BACKLUND (2, 6) and compared partly to the "Archean", partly to the effusive rocks known from Musk-ox Fjord. The latter comparison lost ground, since BÜTLER was able to prove that in Musk-ox Fjord these rocks are imbedded in the Devonian. Thus for the present the problem as to the origin of the pebbles in the tillite is still unsolved. Regarding our problem, it is important to note that part of the material is Greenlandian, part originated from a crystalline area; both of these sources continued to supply material. In the central zone we have a downward movement of the basement in great proportions. Since the uppermost beds, viz. the Lower Ordovician, were deposited below sea-level, the whole series had to lie there, its lowermost parts about 9000 m below sea-level, the basement deeper still.

The discontinuities may be explained in detail as traces of small uplifts if they are not interpreted as evidence of the interference between deposition and eustatic movements of the sea-level. They are details of the whole and do not influence the tendency of the great movement.

The greater part of the material is of clastic origin. For several reasons it must be assumed that these sediments originated in the west.

The great supplies of quartz-sands show that the original rocks were of a sial-character. It would take us too far afield to discuss here for what part of the destructed mountain-complex the elastic sediments might stand. The estimates as to the thickness and the extension of the sediments give an idea of their importance.

In order to constantly produce new sediments, these mountains had to rise over and over again. Though the denudation may extend over a greater area than do the sedimentary deposits, the erosion must nevertheless have been deep-going. Without going further into the matter in this report (we refer again to our thorough study), we come to the following results:

A tilting-movement led in the west to the elevation of an area producing sediments, in the east to the formation of a collector-trough.

A thorough understanding of these tilting-movements would make it necessary to study the sediments of the Nunatak-zone in different places.

4) Conclusions.

The sediments of the Caledonian geosyncline should be looked upon as new material of the Caledonian cycle. Their tonnage (maximum of thickness 9000 m, in breadth, conservative estimate, 200 km) is considerable, and exceeds that of germanotype districts.

For comparison we may mention the thickness of the geosyncline-series of Ouachita, which according to WATERSCHOT VAN DER GRACHT (30) is 12,000 m, and that of Wichita, which is 10,000 m, flysch and molasse formations included. In our series neither flysch (cf. below) nor the molasse of the old red and of younger formations are included. The corresponding series in the Alps are not by far so thick.

Thus in answering our first question, we may make the following statement: The supercrustal transformation of the East Greenland geosyncline is so great that it may be compared to the transformations of such collector-troughs which are commonly known as geosynclines, and even surpasses some of them. Also without the subsequent folding, this "transformation" is such a deep-going interruption of the Greenlandic shield that we cannot very well assume the shield to continue over it. The East Greenlandic geosyncline must be looked upon as a tectonic element of first order in the construction of the earth's crust.

From the Lower Greenlandian to the Lower Ordovician the movements which caused the exogenic transport of material were always directed the same way. Fluctuations are only possible on a small scale;

on the whole the tendency is constant. That is what distinguishes these districts which supply sediments from districts with oscillations of small amplitude. The extent of the upward movement on one hand and of the downward movement on the other hand surpasses the extent of the movements in "epicontinental" areas. The tonnage of the transformed material far surpasses the balance of epicontinental basins, e. g. the Anglo-Parisian basin.

II. IGNEOUS ACTIVITY

We distinguish between two groups differing as to time and area.

1) Volcanism.

The sediments of the Fjord-zone contain no volcanic rocks. What BACKLUND described as such (2, 6), BÜTLER identified as Devonian volcanism. Thus in the geosyncline proper the sediments were not increased by any masses coming up from the depths. How much of the sediments has originated from the igneous rocks of the Caledonian cycle, must for the present be left an open question.

Mention has been made of greenstones in the sediments of Queen Louise Land. They were also found in the glacial boulders of the Petermann Series; in this instance we are most likely confronted with lavas and scories. They were found erratically especially in Cecilia Nunatak. Immense flows of diabase are said to exist in the Thule Formation (15, 16). Consequently the volcanic supply might be expected to begin only in the periphery of the geosyncline. In point of time this action coincides with the period of the tilting-movement, during which the geosyncline was filled up.

Traces of volcanic activity are not absent in the Vela massif between the two sedimentary zones. It is not certain, however, that they reached the surface. In the lowermost zones of the now transformed Eleonore Bay Formation we find in different places remnants of ultra-basic dykes. They are much transformed. In the district of the inner Røhs Fjord, Dickson Fjord, and on Cecilia Nunatak remnants of small massifs of a basic character are found; in some places the ophitic structure is clearly discernible, in spite of the metamorphosis. In most places they are much deformed, and except where structural relics and transitional forms have been preserved, they cannot be recognized any more. If deformed, they are mostly also granitized. Up till now they have been found in the deeper-lying parts of migmatite-areas; they do not seem to occur at higher levels. Perhaps they are older than the Greenlandian, but this is not certain.

2) Abyssal igneous activity.

Without giving first a petrographic description and a genetic interpretation, two groups are distinguished: The actual granites and diorites, and the migmatitic crystalline schists.

A. Granites and diorites.

If, proceeding from the sediments of the Eleonore Bay Formation, we approach the Vela massif, a zone of white granites is found to lie below a zone of contact-metamorphic Eleonore Bay Formation.

Most of these granites are muscovite-granites, here and there containing some biotite, more often transformed garnet, which is mostly visible as dark spots only. Sometimes these granites are of a pink shade; but even-grained pink granites mostly occur in deeper-lying zones only. The white granites are mostly medium-grained, equigranular. The pink or red granites of this zone exhibit greater feldspar phenocrysts; they show a great similarity then to J. J. SEDERHOLM's 3rd group in Fennoscandia (23, p. 116). In common with these they also have relatively well visible miarolitic spaces and a more than average content of fluorite. Most frequently they occur in the Murchison Alps.

In some places this zone of white granites is very thin, sometimes almost entirely crushed, in other places it becomes thicker again. This zone may be traced from Alp Fjord to Geolog Fjord. It is thickest in the Philipphorn, to the south of Forsblad Fjord, at the upper Argand Glacier, in Snöhättan, and in the innermost Geolog Fjord. (In some places its thickness far exceeds 1000 m). These granites are mostly massive, but in some places they show mylonitic transformations; they send out apophyses into the overlying rocks. On the other hand they frequently contain inclusions of the overlying rocks. Ruptural deformation is an indication of movement at the point of contact. But on the whole this zone of white granites has been astoundingly little subjected to movements. The locality in Junction Valley is an exception; but this place has been discussed over and over again (2, 6, 21, 36).

From the west side of the Vela massif the same white granites are mentioned by WORDIE (37). Furthermore they are mentioned by WHITTARD, who found them between the Petermann Series and the "Archean basement" (37).

Below Petermann Peak they form a huge mass; on the southern periphery of Goodenough Land they are most likely thinner. In the metamorphic zone of Isfjord dioritic rocks of a massive structure are to be found.

All these plutonic rocks are indisputably younger than the sediments of the Eleonore Bay Formation, but also younger than a great many orogenic movements.

B. The crystalline schists.

It will be shown later that the formation of these crystalline schists is closely connected with igneous activity. We distinguish between two principal groups:

a) The contact-metamorphic sediments of the Greenlandian.

These sediments of varying thickness lie above the previously mentioned zone of white granites. On the whole they have been so little subjected to intimate movements that their sedimentary structures have been preserved, and sometimes have been made even more distinct by metamorphosis. In different places they comprise various levels. Wherever in the Greenlandian the granites lie higher, the metamorphic parts lie higher too, and vice versa.

The contact metamorphic sediments may be considered to be attendant phenomena of the granites.

Underneath the white granites we find the main mass of

b) The gneisses and amphibolites of the Vela massif.

The British geologists and BACKLUND disagree as to the significance of this group. The former consider it to be "Archean"; BACKLUND — with one exception (2, p. 236—246) — interprets it as metamorphic Greenlandian.

In this group we distinguish again between lesser and stronger migmatitization. The Isfjord-zone (cf. p. 31) is less migmatitized than the other districts. In the Isfjord-zone relictic structures of Caledonian sediments are still visible, though here they are in a state much more metamorphosed than in the above-mentioned group. There is already an important igneous supply in the form of localized pegmatite- and aplite-veins and dykes, or, when in a diffused form, of gneissification. In some places these igneous supplies determine the character of the rocks, in other places their importance lies more in their metamorphosing effect.

In the other groups where the migmatitization is stronger, the rocks acquire a new character by it. Original qualities disappear almost entirely.

In such rocks the gneissification is often older than are the swarms of pegmatite.

The effect of the granitic "Ichors" (23, p. 89) may be traced in various states, for the rocks were not everywhere solidified in the same state of their development.

BACKLUND has already pointed out the importance of the "Ichors" during these processes and has described many phenomena (2, p. 217—236), especially those near the junction of the crystalline massifs and the sediments. By his observations the metamorphosing effect of an ascer-

tained Caledonian igneous activity was made certain. We can only support his opinion and shall try to expose it from still another point of view. WISEMAN's theory (36) that the sediments were transformed by heat during the thrusting-process cannot hold true, for the mylonitisation is always younger than the recrystallization. For these zones the age of the chemical changes and migrations can be ascertained; for these processes took place mostly after the flowing — but before the crushing movements.

During the granitization various processes overlap one another. Consequently it is not easy to separate them for the sake of a clear arrangement, without distorting the true state of affairs. In the following some principal points will be shortly mentioned:

In the peripheral zones of the crystalline areas quartzites and schists have been more and more subjected to recrystallization. Biotite is formed in small lumps and on the planes of schistosity. The carbonatic spots of the sandstones are often transformed into garnet and further on into biotite. On the border of the granitized zones, in nearly pure quartzites more and more feldspar occurs — in the quartzites it is mostly red, in the schists white. A great amount of feldspar may be fixed in the planes of mechanical discontinuities, schistosity, joints, etc. Later on these accumulations become veins in the rocks. While for this progression along the discontinuities of the rocks we may assume an injection, this will hardly be admissible for the material of feldspar which occurs in the texture of e. g. the quartzite. Here we must assume a migration of material, viz. an impregnation (39). TERMIER has compared this phenomenon to the expansion of an oil-spot on paper (27). To me this seems still the best comparison, if a comparison is necessary, and this granitization is not to be taken as just the type of such an imbibition. Where quartzites and schists are interwoven with feldspar, they have become gneisses or granites. In smaller fragments, these — especially the former quartzites — are often of a massive type, while in greater outcrops thicker beds may still be discernible. Consequently not all the material has migrated, but only part of it, viz. precisely the part which rendered the formation of feldspar possible. How much for this formation was furnished by the original rock, how much came from other sources, can only be discussed from case to case, and can only rarely be ascertained. Other transformations are those taking place in quartzites which contain carbonate, and in shales: first we observe a formation of hornblende, mostly on planes as "Garbenschiefer" (a spotted rock in which the spots resemble caraway seeds). Further on the hornblendes are transformed into biotites. Hereby the supply consists principally of potassium in some form or other, which reacts upon the hornblende-substance. Also for the formation of feldspar a supply of potassium-compounds is to be taken into consideration. The

granites which have come into existence in this way are, according to the original material, either equigranular, or they form — with feldspar phenocrysts — so-called porphyritic granites.

Both these structural types may change from one to the other of the former beds.

In contrast to the migrating elements a frame-work of other substances preserves the former structure — sometimes even details of the former sedimentation are preserved. The chemical structure of this



Fig. 5. Amphibolites in the first stage of granitisation. The granitic material fills up the discontinuities and is deformed. The amphibolites form boudinage-structures and by stronger deformation are more impregnated by the granitic supplies.
Sylva-Maria wall.

frame-work is not always the same. What in every particular case migrates and what is stationary, will be discussed in another place, as here it would take us too far.

The former structure may be traced from the metamorphic into the non-metamorphic areas, whereby subsequent dislocations must of course be left out of consideration. Thereby it becomes clear that the margin of granitization and the bedding of the sediments are not parallel-going surfaces, but that they intersect each other. This was already boldly conceived and postulated by BACKLUND (2, p. 267), whereby, however, the so-called sub-Cambrian eruptives (2, p. 261—267; 6, p. 39—56)

played a rôle which does not become them any more, since they were proved to be Devonian (cf. BÜTLER). Nevertheless this postulate was evinced to be true, though for the present no metamorphism could be ascertained in Eo-Cambrian beds; but — as pointed out by BACKLUND — the lower and middle parts of the Greenlandian were subject to it.

The fact that we still come upon former structures shows that here we are not dealing with a "re-melting", but that certain elements of the rocks have not given up their geometrical situation (which is, as a rule, the case with a substance in its liquid state — except where special restrictions are at hand). This again is important for the following movements.

On the whole a distinction must be made between a migration of elements through a stationary frame-work and a migration through a frame-work with internal and external movements. Up till now we have discussed the first case. For the movements which are older than the migration the boundary of the imbibition is, of course, to be left out of consideration, while on the other hand it is important for the younger ones. Migration of elements and deformation alter the mobility of the rocks to a great extent. Thus we find the above-discussed case only in some places; in most places also the frame-work has been subject to movement.

There are many variations in the movements of the frame-work during and after the granitization. We may pursue structures of relics flowing in folds; feldspars appear in orbicular (augen) structure; biotites are drawn out. The rocks get a new gneiss-habitus, very different from the former one. If the rock becomes solidified in this state, it will be preserved. If a possibility for further development is given, the crystallization may outlast the movements, and then the former structures disappear. By the effect of the flowing folds, greater areas become homogeneous. The final result is a granite of more or less massive character, with rare relics. Thus in some places granite is but a mixed rock which has emigrated from its original place. It was not crystallized before the migration was over; consequently only a few marks of its movements are left. The different phases of this development have been preserved in various places. But this is not the place to describe all these different types of migmatite.

In some places the folds are still visible. Sometimes they are of a more simple, sometimes of a more complex type. During the folding the boundary of the granitization was shifted towards the outside. Consequently areas which had to begin with been situated near the periphery came to lie more inside. The folds which had originated in the outer zone, continued to develop in the inner zone; their style underwent certain changes. In this way types of flowing and "rolled-in"

folds were formed which can be seen in many places (comp. fig. 8, 9). Thus part of the formation of the folds allows us to pursue the outward migration of the boundary of activated mobility.

These structures are intersected by still younger movements; these movements recast the massive granites into gneisses, and at last they transform them into mylonites. That these traces can now be ascertained is only due to the fact that the mobility decreased; i. e. from these traces we may pursue the progression of cooling. The progressions of cooling surfaces and of granitization-surfaces are not parallel, but intersect each other.

The problem as to the question of the source of the migration of elements is very difficult to solve. The deepest disclosed depths show traces of migration. Consequently the source of migration must be in still greater depths. It is not permissible to make particular massifs of granite responsible for it, for most of these massifs came to a standstill after the migrations were over, or they had themselves been subject to immigration. Consequently migration of elements and movements must have taken place in an area reaching far below the now disclosed surface, and we can hardly reckon with a threshold (2, 6) untouched by these phenomena in still greater depths. At any rate this would be a hypothesis not based on observations.

We will not assert, however, that a basement of the Greenlandian did not exist. This basement did exist, but except for a few relics, it has been transformed to such a degree that it has become something new. So we cannot very well speak simply of a "basement", but shall have to designate it as "former basement". Some further details will be given below (p. 39).

Perhaps the whole process of granitization might be taken to be Pre-Greenlandian (36). But against this assertion stands the fact that great parts of the Greenlandian have been subject to granitization.

3) Conclusions.

In Caledonian times mighty subcrustal displacements due to igneous activity took place, viz. great migrations of material. Some parts of the material migrated as mobile masses without preserving in their interior clear traces of their migration. Their massive structure developed after the migration was over. Of this type are the granites and diorites.

Other parts of the material penetrated the rocks by means of "molecular migration" (32), fixing themselves differently in different rocks. In this case traces pointing to the fact that during the migration the penetrated rock had been subject to movement, too, have often been preserved. Typical for this group are big feldspar phenocrysts, which, in the course of time, develop into "Augengneisses".

The vertical extent of these phenomena reaches below the visible level of the landscape; and it cannot be assumed that they end there.

So we come to the conclusion that the infrastructure of the Caledonian geosyncline was changed by igneous phenomena of the Caledonian cycle to such a degree that now it must be considered as something new.

Thus the controversy regarding the old basement seems to be the following: Those who support the opinion that it is "Archean" will stress the fact that it is a rigid mass with no intimate deformation. Also TEICHERT's expression "germanotype" seems to stand for this.

By considering the outermost stripe to be granitized, KOCH made it take part in the Caledonian movements. BACKLUND defined the mode of transformation more precisely, and extended the theory to the inner complexes. Our present investigations aimed at a more thorough comprehension of the development as to time and area. Further investigations might follow the lines drawn by KOCH and BACKLUND.

By extending the vertical extent of the Caledonian processes below the known surface of the earth, the tonnage of transformed Caledonian material has become bigger too. Thus the conception of the East Greenlandic Caledonian as a mountain-complex of germanotype character, is deprived of a further important foundation.

III. OROGENIC MOVEMENTS

In order to discuss the movements, it is necessary to consider the structure. The structure results out of a series of movements which belong partly to the Caledonian cycle, partly to younger phases. Most distinct are the Devonian and the Tertiary movements (reaching perhaps into the Quaternary). To the latter belong the enormous upwarplings as we find them e. g. in the Staunings Alps, in the district of Goodenough Land, of western Fränkel Land and adjacent areas. In the main they appear as warpings of old peneplains.

There exist various surfaces which intersect one another like facettes, a problem which it would take too much time to discuss here. The intersection of the sub-Jurassic base-levelling by the lower basalt is very distinct in the region of Cape Leslie and has been mentioned already by ALDINGER. WAGER (31) mentioned a peneplanation on top of the basalts. Most distinct are the traces of Devonian movements, best seen in the Devonian material (cf. BÜTLER). They may also be observed in at least two phases in the Caledonian basement of the Devonian. These two

phases are separated by the intrusions of quartz-porphyrries and diabases of the Cape Fletcher series. Some of the movements did not affect these intrusions, others left traces of crushing, polish, etc. The latter might also be the results of more recent movements. These movements result in warpings with faults, displacements, and locally in foldings and drags. For the present, however, we shall take no account of these phenomena, but consider the Caledonian structure as a whole.

1) The structure —

may be divided into

A. Zones of non-metamorphic Caledonian sediments.

a) Zone of the Fjords

b) Zone of the Nunataks.

a) Zone of the Fjords.

The highly schematic stereogram (pl. I.) explains some of the forms and interconnections, a few of which shall be briefly discussed here.

Beginning in the south we see two main-anticlines in Segelskapet Fjord and Forsblad Fjord. The eastern one strikes in a rather flat up-warping over Polhem Valley, the other is partly visible over Randenes. The core of the latter contains metamorphic, partly little moved schists with many veins of pegmatite. On top of it we have the Eleonore Bay Formation.

The eastern anticline is broad and flat towards the south; it dips to the north (pl. II, fig. 1) while at the same time it becomes steeper, the overlying beds being more compressed. On Ella Island the anticline is narrow and crosses the Island from Narwhal Sound to Cape Oswald.

Near Narwhal Sound it is complicated owing to a great many faults.

From Cape Oswald the crest of the anticline is traceable from the foot of Johnstrup Mountain and Skiltvaktén as far as Ymer Island. From Margerie Valley the anticline strikes through the mountains towards Noah Lake, then across Franz Joseph Fjord into the great wall at Eleonore Bay; it is flattened on its way to Geolog Fjord, but is still visible in Strindberg Land. The anticline is disturbed by many faults, especially so near Skiltvaktén and from Noah Lake to Geolog Fjord. North of Ella Island its axis ascends, but continues then on about the same level.

The central syncline, west of the anticline just mentioned, is in its southern part only a kind of flattening out of the sediments falling down from the Vela massif. In the north of the southern side-valley it forms a level trough, which becomes increasingly deeper towards the northern side-valley (pl. II, fig. 2). At Narwhal Sound and on the Bastion the syncline is rather narrow, its bottom is levelled out, its limbs are rather steep — about the reverse of what in German is called

"Kofferfalte". In Rud.-Johansen Valley the syncline is much disturbed by younger faults. In Antarctic Sound the eastern limb is steeper than the western. On Ymer Island (Franz Joseph Fjord) the trough is much reduced, on Andrée Land nearly compressed. The base of this syncline is deepest under the Bastion, whence it ascends to both sides.

Part of the Western Anticline is preserved on Randenes. It is only complete farther north, where it forms the anticline of Cape Alfred; viz. one limb runs across Lyell Land, the other along Kempe Fjord (pl. I). The anticline dips under Mount Marcel Bertrand at Deceit Bay (pl. III, fig. 2), lies deeper in Ymer Island, strikes behind Cape Mohn, where it lies deepest, towards Andrée Land and presses there with more disturbances towards the White Wall, in the west of Teufelsschloss. North of Ymer Island the axis ascends rapidly; the sediments of its western limb disappear over Andrée Land.

The trough west of this anticline strikes from Kempe Fjord over Deceit Bay, Cape Buxtorf, Lower Murgang Valley, Nanortalik Valley into the wall east of Junction Valley. To the north of Kempe Fjord it pitches down, but rises again in the north of Franz Joseph Fjord. It may be assumed to lie deepest near Cape Mohn. It is but little probable that much of the sediments is left in Andrée Land, on account of the pitch there.

So we see that the eastern elements lie deepest on Ella Island, the western on Ymer Island, between Antarctic Sound and Franz Joseph Fjord. Consequently it is impossible to speak of a general dip of the whole mountain-complex towards the north (6, p. 103). Other possibilities, as to the metamorphic interconnections, result out of the comprehension of the geometrical position.

b) Zone of the Nunataks.

So far very little is known about the tectonics of the Petermann Series. Aërial observations and photographs point to the possibility that in between Petermann Peak and the Inland Ice these sediments form a rather flat syncline. Seen from the south of Goodenough Land, the lowermost beds, which very likely are contact-metamorphic, seem to appear in wavy folds. From Goodenough Land the syncline strikes west of Cecilia Nunatak. North of Goodenough Land the Petermann Series seems to pass west of Victor Madsen Glacier and farther north still to recede again from it. So we see that our knowledge of the structure is only scanty, although it would be of very great importance for the characterization of the mountain district.

B. Vela Massif.

The crystalline zone between the above-discussed sedimentary beds was termed the Vela-massif according to a convention of scientists

working with LAUGE KOCH. My investigations have shown that it is of a complex type. In the investigated district it may be divided into groups of different structural elements.

a) Metamorphic Caledonian sediments.

There are several groups:

α) The contact-metamorphic rocks between the sheet of white granites and the non-metamorphic zones of the Greenlandian. These rocks have only been slightly, or not at all, subject to intimate deformation. Fine-grained sedimentary structures have been preserved. These contact-metamorphic rocks can be traced from Stauning Alps to Geolog Fjord. From a tectonic point of view they belong to the series of the sediments. They were found erratically also in the Petermann Series, in Goodenough Land, and in Fränkel Land.

In the east of the Vela Massif they belong to different tectonic units: at Forsblad Fjord they belong to the E-limb, at Cape Alfred to the crest and at the south-coast of Kempe Fjord to the NW-limb of the western anticline. From the west side of Murgang Valley as far as Junction Valley they lie on the western limb of the most western syncline. Thus we see that it is not justifiable to combine and compare these different places tectonically with one another, as it has been done in previous discussions. They might at most be compared stratigraphically or petrographically.

β) Flowed gneisses of sedimentary origin. They begin mostly under the sheet of white granites. The gneisses are of a more or less quartzitic character, containing garnet, staurolite, cyanite, sillimanite and other minerals of similar order. They originate from schists and quartzites, but are mineralogically much changed; only few sedimentary structures are preserved. At their base we often come upon one or more much folded levels of carbonate; they are mostly dolomitic and spotted with silicate minerals. This series is found from Nanortalik to Cape Lapparent. From this point it may be traced through the high plateaus of SE-Andrée Land, the valley of Renbugten to Isfjord, the north wall of which is nearly entirely formed by this series (from the Lacroix Mountains as far as De Geer Glacier). The eastern part of Miss Boyd Land and a great part of Fränkel Land belong to it. In the middle part of the north coast of Isfjord it ascends, passes behind Niggli Peak, circumscribes Niggli Valley, and dips down toward the fjord west of Ättestupan. The whole south coast of Fränkel Land, as far as the big valley E. of Nordenskjöld Glacier (by the Danish cartographers called "Knægt-dalen") consists of this series. In the south of Franz Joseph Fjord it forms the mountains between Arthur Valley and Kjerulf Fjord, the lower

part of Riddarborgsen, and extends across Kjerulf Fjord and Bocksriet Valley as far as Hisinger Glacier. From the foot of Mt. Emilia the series ascends eastward into the Red Staubhorn in the north wall of Dickson Fjord. South of the fjord and of Hisinger Glacier it circumscribes Mt. Lugano "en cravatte" and strikes westward. Very likely its continuation between the south of Goodenough Land and Cecilia Nunatak is covered by the glacier.

Since this series is of greatest importance round Isfjord, we call it the Isfjord-zone. In this zone dolomites can be ascertained in different places.

The Isfjord-zone separates two important tectonic groups, and contains a further tectonic element.

In the east of the principal Isfjord-zone we have the Sylva-Maria group, west of it the Mt. Hagar-group; the Isfjord-zone contains the Emilia fold. On top of the Isfjord-zone lies

b) The sheet of white granites, which is briefly mentioned above. They separate intimate deformations of weak and strong character. As mentioned above, their thickness varies considerably. But now, the structure of the sedimentary zones being known, the problem regarding the distribution of these granites has become clear, too: they are of great vertical extent in the pronounced arches of an anticline; while in the limbs or in less pronounced anticlines their vertical extent is smaller. Accordingly most of the inclusions of these granites are angular fragments, viz. they form agmatites as termed by J. J. SEDERHOLM.

c) The migmatite groups.

a) The Sylva-Maria group consists mostly of light and dark migmatite-gneisses, amphibolites, ultra-basic rocks, and quartzite-gneisses. As mentioned above, it contains intrusives of coarse-grained ophitic structure but of absolutely transformed mineral contents.

This group comprises a great part of Suess Land, the district of Röhs, Dickson, and Rhedin Fjords, the extreme east of Fränkel Land, and smaller parts on the E. and W. coasts of Renbugten.

The SM-group distinguishes itself from the adjacent districts by its folds, which on the whole strike WSW—ENE. As to the forms of these folds the reader is referred to the pictures (pl. III, fig. 2 and fig. 9). Most of them are migmatite-folds, which will be described more thoroughly later; in the extreme parts we also come across other types of folds. In the west of Murgang Valley they touch with overlying mylonite-levels directly upon the contact-metamorphic Greenlandian sediments (pl. III, fig. 2).

West of Cape Hedlund, near the river, we find mylonite levels on top of the folds of the SM-group. They strike along the SE coast of

Rhedin Fjord. On top of them occurs the mighty massif of white granites of Snöhättan and the upper Argand Glacier. In the innermost parts of Rhedin Fjord and Forsblad Fjord mylonites separate the eastern from the more western parts of the SM group.

From Cecilia Nunatak to Andrée Land the SM group disappears below the Isfjord zone. The direction of its strike differs from that of the Isfjord zone. (More details below).

β) The Hagar group consists of various sorts of migmatites. It is built up of folds, which strike about N—S. From Fränkel Land to M. Lugano they overlie the Isfjord zone. In Kjerulf Fjord these gneisses still strike about N—S; according to WHITTARD (37, p. 496) they turn NW—SE farther north. Thus this zone strikes in an arc from Mt. Hagar northward. Farther north the Hagar group forms the inner parts of Miss Boyd Land. It is separated from the Petermann Series by the sheet of white granites (37, p. 496).

As Cecilia Nunatak is built up of the elements of the SM group, the Hagar group in the south of Goodenough Land must either bend westward or leave the present topography.

γ) The Emilia fold consists mainly of light gneisses, and is inclosed by the Isfjord-zone. It might be included into the Hagar group, but it exhibits so many individual characteristics that a separation is fully justified. It forms Mt. Emilia, which lies between the innermost parts of Dickson Fjord and Kjerulf Fjord. Its southern continuation forms the zone of the upper part of Mt. Lugano. Farther north it appears east of "Knægtdalen" and may still be recognized at Isfjord.

It is impossible to give more than the mere outlines of the structure of the Vela-massif. For particulars we refer once more to the illustrated thorough study to be published later. Yet these summary remarks alone might suffice to show that here we are not confronted with a "Germano-type" mountain-complex, but with one comparable to the Svecofennides (32) and similar mountains with migmatitic infrastructure. This comparison will be justified by a consideration of some of the characteristic movements.

2) Movements.

A. Movements of the Caledonian sedimentary zones.

Only the movements of the Fjord-zone are dealt with here. Those of the Nunatak-zone are too little known. Concerning the latter it can only be stated that most of the erratics found there are not deformed. This means that either the Nunatak-zone contains very few deformed rocks or — if deformed — that they have suffered by the transport of the glacier and were not often to be found. Having compared this zone with the Fjord-zone, the first alternative would seem more probable.

TEICHERT has already characterised the folding of the Eleonore Bay Formation as disharmonious (26) and has attributed special importance to the faults. BACKLUND (2) and the British geologists (21, 37) attribute an equal importance to thrusts and "schuppen"-structure. In the anticlines and synclines series of beds with interstratifications of a greater gliding capacity have moved disharmoniously. As the synclines deepen,

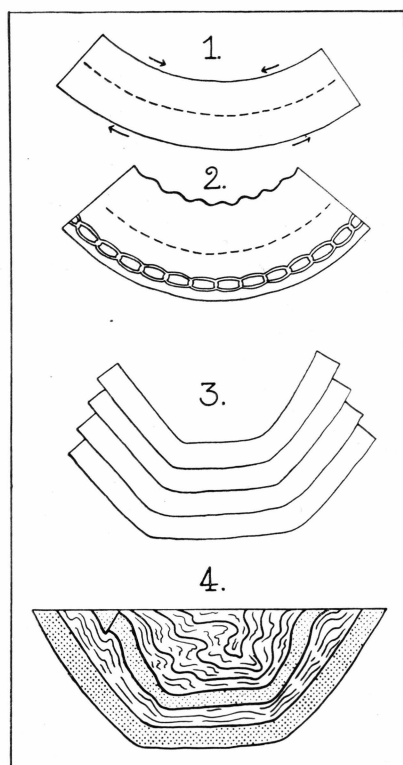


Fig. 6. Different types of synclinal structure from the sedimentary zones.

- 1) By buckling of a plate the upper layer is compressed and the lower layer stretched, while the middle layer represents a neutral stratum. 2) In mobile material the upper part will be folded; in the lower part a less mobile bed surrounded by mobile material will form boudinage structures (cf. fig. 7). 3) The individual beds may slide on each other, and a former uniform boundary may become zigzagged; the latter is evidenced by the movements of the Devonian conglomerate in the Bastion; the large beds slide on the conglomerates in the corners. 4) In an alternation of beds with a greater or smaller sliding capacity disharmonious folds will develop.

the disharmony becomes greater. The development is about as follows: As the synclines suffer compression, the upper strata of the limbs glide over the lower ones toward the anticline (comp. fig. 6, 3). Thereby foldings of the individual strata with contorsion and often very complicated

structures in detail will develop in the limbs. (Cp. pl. II, fig. 2 and pl. III, fig. 1). Particulars with illustrations will be given in the monograph.

In Devonian ages the syncline of the Bastion was accentuated, by which on its eastern limb, on the plateau of the Bastion, Ordovician limestone beds were slightly pushed upon the basal conglomerates of the Devonian (cp. fig. 6, 3).

Strata of greater gliding-capacity are: Some levels of schist in the quartzite-schist group, especially in its lowermost and middle parts;

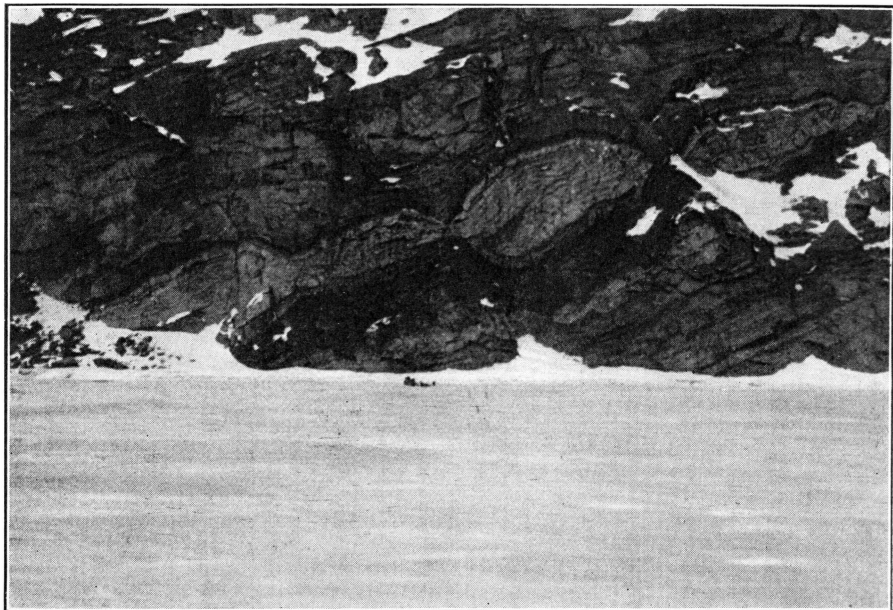


Fig. 7. Boudinage-structure in the eastern limb of the syncline east of Junction Valley. The sledge and the man give an idea of the magnitude of the phenomenon.

some levels in the multicoloured series; the uppermost limestone-schist parts in the dolomite-limestone series.

If we consider the folding of the whole series of strata, we shall realize that the outer strata may be stretched out, while the inner ones are compressed. In between them we have a neutral stratum. In the eastern anticline this neutral stratum rests, roughly speaking, on the base of the multicoloured series. Here the under-lying uniformly warped strata are very thick; consequently it is probable that down to great depths there occurred no bottom-shearing of the individual strata; the warping of the whole pile of strata is either caused by the filling-up of the core of the anticline with granite, or by activated mobility of the deeper-lying strata. The limbs of the western anticline are much steeper even

at Cape Alfred. It is sheared off its base and its core is filled up with the white granite of the upper Argand Glacier.

In the western syncline the neutral stratum lies much higher, on top of the multi-coloured series. The lower beds show mighty boudinages (comp. fig. 7), the higher beds enormous contortions (cp. fig. 6, 4). So here we have a type of movement different from that of the more eastern elements. We note a more differentiated deformation of the rocks and an incipient metamorphism.

In this syncline we find Eleonore Bay rocks of a distinct gliding-schistous character; farther east intimate deformation is rare or does not occur at all, so that fine-grained sedimentary structures are preserved. In the Fjord-zone, rocks which show traces of movements are restricted to certain places and levels.

So our inquiry points to the fact that we are dealing with a series of warped beds mightier towards the east, with interstratifications of greater gliding capacity.

In some places, at the bottom of the series we find mylonite levels. Especially the thrust in Junction Valley has been discussed thoroughly, but it is not possible to ascertain in which direction the various authors assumed it to operate. The observations of the present author point to an eastward movement of the hanging-wall and to a westward movement of the foot-wall. (This would mean a gliding-down of the sediment series, or a bulging-out of the crystalline base). Various mylonite levels in different places on the boundary of the Vela-massif should not be connected with each other; so it will not do to simply make them succeed each other in close connection (6, 21). They appear in different tectonic units, and do not everywhere play the same role.

In the different elements of the beds the boundary of the metamorphizing effect does not everywhere lie on the same level.

This has been recognised already by BACKLUND, who describes the places of contact petrographically (2, 6). The investigations of BÜTLER and of the author add some supplements and corrections and make it also possible to interpret these facts from a kinetic point of view. Below the contact-metamorphic beds the folded Fjord-zone is sheared off from its flowing crystalline infrastructure.

In the first phase inequalities of the movements of the Fjord-zone and of the infrastructure were adjusted by the white granites and rocks of greater mobility. So we might speak of a level of adjustment. In a later phase levels of ruptural deformation penetrate the base of the folded Fjord-zone. In Junction Valley they penetrate the base of the contact-metamorphic sediments, in other places, e. g. underneath the western anticline, they reach below the intrusions of white granites. The course of movement of the mylonites points to a younger age than the "mise

en place" of the white granites; it differs considerably from the courses of movement during the folding of the sedimentary zones and during the intrusions of the white granites. In some parts the shearing-zone of the mylonite runs along the former zone of bottom-shearing beneath the folds of the sediments; i. e., it follows — roughly speaking — the sheets of white granite.

Further details regarding the conditions of the shearing planes may be found north of Geolog Fjord towards Waltershausen Glacier and farther on.

Parts of these movements are faults.



Fig. 8. Flow-folds in the gneisses of Cape Robert (Sylva-Maria group).

B. Movements in the Vela Massif.

The forms of the sedimentary zone (cf. panoramas pl. I, II, III) stand in a striking contrast to the elegant flow-structure of the migmatite zones (cp. fig. 8, 9). Here the deformation is very intimate. In most places the movement is pre-crystalline compared to the formation of many minerals. However, the more we approach the upper boundary of the massif, the more we encounter ruptural and post-crystalline deformations. As mentioned above, younger mylonite-zones may also appear in the inner parts of the massif.

In the extreme east of the SM group the deformation becomes mylonitic, the strike direction of the axes being SSW—NNE. On the whole the axes of the folds and the linear structures of the rocks (cp. fig. 10) coincide. When the conditions north and south of Kempe Fjord were discussed by former authors, the fact that the axes actually stand at about right angles to the suggested direction, (2,6), seems not to have been taken into consideration, neither in the text nor in the figures. So the pre-suppositions of these theories are shaken.

In the SM folds there are often boudinage structures, some of enormous

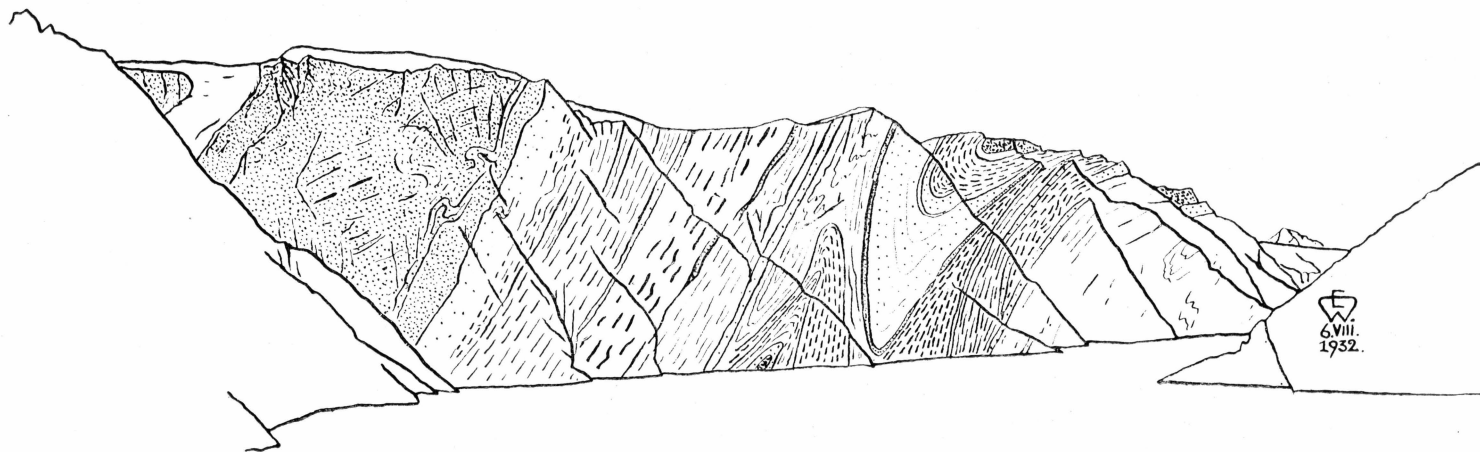


Fig. 9. Sylva-Maria wall (Dickson Fjord). The various gneisses are differently indicated. In the middle a fold with thick beds of transformed quartzites. To the right "wild" migmatites.

extensions. Previously BACKLUND mentioned other phenomena typical of migmatite-districts (2, 6). Migmatitization and movement do not coincide, sometimes the one, sometimes the other has the upper hand. Consequently various local phases must be studied, and then combined into the scheme of larger movements.

It is certain that a great part of the material immigrated (cf. p. 22-26) in Caledonian times; so a great many migmatitic movements must be



Fig. 10. Folded migmatites at Cape Hedlund (SM-group). Pitch and linear structures visible.

of Caledonian age too. As these rocks are characterized in the main by migmatitization and movement, the Vela-massif must be regarded as Caledonian, but older material also may play a rôle.

To sum up we may make the following statements regarding the groups of the Vela-massif: in the inner parts we find mostly pre-crystalline (to the majority of minerals), in the outer parts post-crystalline deformation. The folding is of a flowing type. It is partly older, partly of the same age as the migmatitization; or it is an adaptation to the immigration of large masses of elements. Similar phenomena have been shown for Fennoscandia, which will later be discussed at greater length (32). These movements considerably deepen the vertical extent of the Caledonian orogeny. The deviating strike-direction of the Sylva-Maria-folds is a phenomenon which, though known to the author from other

mountains with migmatitic infrastructure (Fennoscandia, Norway), does not appear with such distinctness in any other place than in North-East Greenland.

a) The deviating strike-direction of the Sylva-Maria Folds.

The SM folds dip — roughly speaking — at right angles below the sediments of the Fjord-zone at Cape Buxtorf and in Murgang Valley. The lowermost contact-metamorphic schists and quartzites are already waved in the strike-direction of SM, which means that the folding is younger than the sediments.

The difference in the strike-direction of the folds in these two elements may be interpreted in two ways:

- 1) The folds of the Fjord-zone describe an arc. Between Kempe Fjord and Franz Joseph Fjord the folds are close together; northward and southward they flatten out and disappear. It might be assumed that this arc is more pronounced in the deeper-lying parts. But the fact that between Frans Josph Fjord and Kempe Fjord the folds run so close to each other, points to special conditions of the infrastructure at the beginning of the folding. Here we already perceive slight traces of elements of pre-Caledonian structure.
- 2) The strike-direction of the Sylva-Maria folds might be considered to be an inheritance of the strike-direction of the old Pre-Greenlandian basement. The old crystalline basement made active again, would have enveloped and transformed the overlying Greenlandian sediments.

The direction of the folding of the SM Group is older than the over-folding of the Hagar Group. From Dickson Fjord as far as Franz Joseph Fjord, the younger, almost NS-striking deformation intersects the folds of the SM direction. This intersection is most distinctly seen in Dickson Fjord. In the region of Röhs Fjord and of Cecilia Nunatak the folding of the SM is only very slightly disturbed by these transverse-striking complications. Consequently it may be concluded that the disturbing effect of the Hagar Group ceases soon, in the south of the upper Hisinger Glacier. From Cape Buxtorf to Cecilia Nunatak, where they are visible, the SM folds cover about 70 km in axial strike.

This explanation, that the direction of the SM folds is a rejuvenation of the old basement, helps towards the understanding of many phenomena of the Vela-massif, and corresponds best to our present knowledge of things. Future investigators of the crystalline massifs in North-East Greenland ought to consider the problems not only from a petrographic, but also from a tectonic point of view.

The rejuvenation of the old basement might be said to have taken

place in the following way: the structures of the relics bear evidence that the old basement also was composed of stripes of granite, gneiss, and other crystalline rocks. Heat and supply of material brought about a mobility which was not the same in the various zones. To begin with the movement seems to have been merely an upward shifting of the more movable segments. This may be seen most distinctly from the forms of the metamorphic Greenlandian overlying mass, which by degrees develops rather complicated folds. The rejuvenation of old basements will be treated more thoroughly in another place. It is most important when we are dealing with the formation of geosynclines and mountains with migmatitic infra-structure.

Only by extending our investigations northward and southward and by the understanding of the peculiar longitudinal disturbances in Liverpool Land, may we help to substantiate these heuristic hypotheses. The author found similar conditions in Fennoscandia, and at the coast of Trøndelagen (Norway).

In order to avoid confusion, it may be mentioned that BACKLUND's "Archean threshold" (2, 6) at the entrance of Kjerulf Fjord does not belong to the SM group, but to the Isfjord-zone, as we understand it.

3) Conclusions.

The movements of the Vela-massif are roughly speaking about as follows: the Vela-massif rose into flowing folds; while this process was going on, it was migmatitized. Greenlandian sediments of varying thickness were also included in the process of deformation and metamorphism. The upper sediments were bent into large folds (cp. pl. I). The depth of their zone of bottom-shearing varies, according to the level of the more intense metamorphism. This zone intersects the bedding-planes in an oblique downward direction from west to east. The cores of the anticlines were filled up with granite. Mylonitic levels are younger, but they also were mostly moved near former zones of bottom-shearing. So we see that at every depth there was a movement of material during the Caledonian orogeny, the character of which changes according to depth and time. In the depths also intimate deformation occurred. Tectonic and kinetic analyses force us to consider this mountain chain as a deep-going interruption of the Pre-Cambrian shield.

Thus the postulates of KOCH and BACKLUND have been confirmed, and in more than one sense they have been enlarged and defined more exactly.

IV. LATER DEVELOPMENT OF THE MOUNTAIN CHAIN

The later development may be comprehended in different ways, according to the observations supplied to us by various regions. In some regions we find material of sediments, formed in various subsequent periods. The erosion surfaces upon which they rest, the origin of the material, its texture and the subsequent transformation supply good information about the development of these regions. Other regions did not receive further supercrustal supplies; they have to be taken into account as furnishing areas. So they must exhibit gaps produced by erosion. For some regions supply of igneous material should be taken into consideration.

The next important deposition after the Ordovician is the Devonian molasse. It was deposited in what has been called King's Bay by KOCH (cf. p. 14).

1) Localization of King's Bay in the Caledonian structure.

Without anticipating the results of BÜTLER's investigations, I shall just touch upon some problems of the later development.

The disconformities and the topographical peculiarities of the zone of contact between the Devonian and its Caledonian basement have been mentioned already by KOCH (14, 15), also by BACKLUND and by KULLING (2, 17).

Seen in cross-section, the surface on which the Devonian was deposited does not incline continuously. On the heights over Cape Lagerberg and Cape Dufva, on the plateau of the Bastion (Ella Island), and on the Munot Mountain (Ymer Island) it lies more horizontal, then it becomes more inclined, and in the end it is perhaps more horizontal again. So the Devonian is deposited, as mentioned by KOCH, on an old cliff with smaller and larger bights. Seen in detail the Caledonian sediments form a "crete and combe" topography underneath the Devonian.

In longitudinal section the western part of King's Bay corresponds to the following peculiarities of the Caledonian structure: In the north this western part begins where the folds of the Caledonian fjord-zone become flatter and disappear (comp. p. 54). Farther south it corresponds to the axial depression of Cape Mohn and of Ella Island. Its southern boundary corresponds to the axial pitch of the Murchison Alps.

In cross-section the cliff corresponds roughly to the eastern limb of the eastern anticline, though the two often intersect each other (cp. pl. I). But as the inliers prove, this Caledonian syncline forms only the boundary, the bottom of the Devonian trough being composed of zones of anticlines. The sub-Devonian relief does not entirely correspond to the Caledonian folding, but shows younger traits. In the interval between the principal

orogeny of our region and the deposition of the Devonian, enormous masses of rocks were denuded and mighty basins were carved in the Caledonian chain. But this denuded material was not deposited in the trough of the later Devonian deposition, or further denudation would have been impossible. The bottom of the trough penetrated into the mountain complex; by doing so, it intersected various zones of the Caledonian mountain chain, viz. various tectonic units, a fact proved by the inliers at Musk-ox Fjord. Consequently the Devonian trough does not lie above an old syncline, but above important old zones of disturbances, which continued their activity in Devonian times. A more detailed study of the basement in Hudson Land will add further proofs. It will not suffice to maintain that always, also in post-Caledonian times, sediments were deposited on top of a former sedimentary zone, and at the same time to assume a continued upward movement of the crystalline massifs. Such a theory has been set forth for East Greenland (3, cp. p. 14), but it will probably not hold true in a strict sense for the regions concerned.

Right below the Devonian important tectonic phenomena characteristic of the mountain chain must occur. We are able to investigate them along the base of outcrop of the Devonian, in Hudson Land.

2) Transports of Late-Caledonian material.

In the above discussion of the Caledonian sediments (p. 16—19) it was mentioned that the working-up process of these (with the exception of the tillites) never begins at a very great depth. Where older beds have been worked up, it is only a question of those immediately preceding in age. Deep erosion begins after the Lower Ordovician. So that the deposition of the Devonian so deep in the old mountain complex was possible, a great quantity of Caledonian material had to be removed first. Thus the material of the Devonian does not originate in these troughs, but has been transported there. So far no sediments have been found between the Ordovician and the Devonian in the inner parts of the thoroughly studied district. During these times — between Ordovician and Devonian — sediments were removed from there. I. a. the big basins of King's Bay were formed at that time.

In most mountain-complexes we find that during the folding activity sediments of the same cycle have been worked up. As deposits they sometimes occur mixed with other material, sometimes nearly pure. These sediments are called *flysch*. From a petrographic point of view they frequently distinguish themselves by the quick process of their redeposition, so the weathering is not intense. Their mode of deposition is often a special one too. In our district these rocks are absent. All we can observe now are the empty places from which the material was

taken. Where these places take the shape of troughs, they have afterwards been filled with the molasse-formations of the Old Red.

So if we say that on one hand the Caledonian mountains of East Greenland do not contain any flysch-formation but that on the other hand these mountains produced flysch, then important elements necessary for a complete mountain chain are absent. What we see to-day is only a fragment of a former bigger mountain complex.

It will be an important problem for future investigations to ascertain the missing elements. Parts of these elements might possibly be found in the innermost nunataks.

3) Localisation of erosive areas in the late Caledonian.

The present relief is the youngest of a whole generation of reliefs. Not the forms of these old reliefs, but only the localisation of the old surfaces at the time of Caledonian orogeny, and its relation to old drainage-systems will be discussed here. Moreover this is not the place to consider the origin of the fjords as typical excavations. But if we take the fjords to be the last remnants of old drainage-systems, it will perhaps be possible to set forth hypotheses as to the conditions of their localisation. Reference will be made in another place to the younger history of the drainage-system. The opinions differ regarding the origin of the fjord-system of East Greenland (9); much has been written on this subject already. BACKLUND brings the fjords into relation to his "Magmafront" and takes them to be trough-faults of early origin, the bottoms of which are still subsiding (2, p. 295). BACKLUND and KULLING have discussed the age of these trough-faults (4, 5, 18, 19); WORDIE and TEICHERT take the fjords to be valleys of pre-glacial origin.

The first drainage-system of the Caledonian mountains which rose out of the Ordovician seas, was situated high above the present surface. It has not been preserved. In the localisation of the present system we might, however, discover some traces as to the localisation of the former. But then we must neither take account of the inland-ice nor of the sea-coast; for transport of water and ice from the inland-ice to the coast made the ways running in that direction more pronounced. Compared with the old drainage-system, greater and smaller parts of these water-ways may have changed their direction as the development went on — river-captures, changes from principal water-ways into by-ways, etc., may have taken place.

The first water-ways followed the deepest lines of the surface of that time, in other words they followed the base-lines of the synclines and axial depressions, the so-called "tectonical relief". That the erosion was to some extent directed by faults, crush zones, etc., is only natural. That

within this range trough-faults were of special importance is equally true. The facts, however, that important parts of fjords, as for instance Narwhal Sound, partly penetrate a horst, does not fit into a theory of faults. The "bursting" theory has long since been refuted in the case of the Alps, and it is of no use to take it up again here.

The size of the various faults is of a minor order compared with that of the folds, the axial culminations and depressions. The axial positions are moreover accentuated by various faults. On the whole the main features are fixed by the tectonic relief; the details by other factors, i. a. by faults:

By transverse drainage (= drainage-system: inland-ice — mountain belt — sea) we understand four systems. They lie in districts of different tectonic order. For the present only those east of the tectonic crest-line of the Vela-massif will be considered.

- 1) The system of Waltershausen Glacier—Geolog Fjord penetrates the Caledonian chain where the folds of the sedimentary zone are flattened out. Behind that bent we might perhaps find an axial depression of the crystalline massif, i. e. a possibility for a drainage of the syncline of the Nunatak-zone.
- 2) The system of Renbugten—Isfjord—Franz Joseph Fjord corresponds in its outer parts to the deep axial position of the inner elements of the fjord-zone of Caledonian sediments. The way Renbugten—Isfjord answers to the dip of the Sylva-Maria group.
- 3) The system Kempe Fjord—Narwhal Sound corresponds to the axial depression of the eastern elements of the fjord-zone; as it proceeds inward, towards the west, it becomes a longitudinal system.
- 4) The system of Segelsällskapet Fjord lies partly in an isoclinal position on the pitch of the Murchison Alps; towards Alp Fjord it too becomes a longitudinal system. In this zone the southern district rose over and over again, often with many faults. The great fault-swarm which may be traced through Kongeborgen, the whole of Traill Island, Geographical Society Island, Ymer Island, Gauss Peninsula, through the region of Musk-ox Fjord, as far as Clavering Island, is seen to continue here into the adjacent Caledonian, and to be partly post-basaltic (cf. Bütler).

Disregarding the system of the Scoresby Sound Fjords for the moment, we shall mention some longitudinal systems:

- 1) The outermost longitudinal system of valleys lies approximately on the present Devonian border; while penetrating downward — before the deposition of the Devonian — it must have glided down towards the east, but one of the limbs of the syncline remained standing.
- 2) The system of the eastern syncline was most likely very short-lived; its different parts led over to the next transverse systems.

- 3) The inner syncline may be traced through the inner Kempe Fjord, lower Murgang Valley, Nanortalik; it lies deepest near Cape Mohn. Its northward continuation ascends very strikingly, and was probably crushed like that of the preceding system. The southward continuation forms the zone of Rhedin Fjord.
- 4) The Isfjord-zone strikes across Hisinger Glacier, Bocksriet Valley, Kjerulf Fjord, Fränkel Land, Isfjord, De Geer Glacier.
- 5) It may be supposed that the innermost zone would be the syncline of the Nunatak-zone.

As our district was not filled up again since late Caledonian times, these water-ways were repeatedly in use — though not necessarily always in the same direction. Along all these fjord-systems, high-lying plains indicating valley-bottoms of different ages, are to be found. Here an enumeration would lead us too far. One is seen along Kempe Fjord (pl. III, fig. 2).

Thus we may conclude that the localisation of the drainage-system is older than the oldest preserved relief-fragments.

4) Age of the Relief.

In the inner parts of our district every relief-generation penetrates with its surface deeper into the mountain-complex. Some carved-out basins were filled again in Devonian times. Consequently the oldest relief-fragments preserved are sub-Devonian. In some places they were laid bare again, in other places they are still partly filled up. Such cavities have been described by KOCH (14, 15), subsequently also by BACKLUND and by KULLING (2, 17).

On the heights west of King Oscar Fjord at a rather long distance from the boundary of the Devonian, remnants of sub-Devonian weathering are still found.

In the west the later erosions are deeper-going than the pre-Devonian sediments; not so in the east, where they intersect the Devonian in its upper parts.

There was a tilting by which the western regions were lifted up, the eastern ones subsided. Such tiltings repeated themselves in the course of time. (The tilting axes moved more and more eastward.) In our district the tilting axis has been shifted towards the outer parts for the later sedimentation-areas, and also its direction has changed. Some tiltings correspond rather to the longitudinal course, others rather to the accentuation of the pitch. The axes do not run in a straight line. They may be joined together into lines circumscribing the basins. Here we refer especially to BÜTLER's important investigations in the district of Musk-ox Fjord.

By the shifting of the pivotal (tilting) axes new relief-“facettes” came into being in the regions of denudation, and the accentuation

of the waterways changed. This is not the place to discuss the observations on the old valleys or to consider their orogenetic interpretation. The problem is mentioned because the district of the great fjords of North-East Greenland is the broadest mountain-zone of Greenland, and, because as such, it contains more possibilities for an investigation of the Mesozoic and of the pre-Glacial relief than other districts do. Future investigations will have to continue these studies. They are studies worth doing, as on one hand they open new aspects regarding the history and influences of the inland-ice in this region, on the other hand they supply important instances as to the development of the Scandinavian mountain-complex.

Over and over again our district supplied sediments. At present Prof. NIGGLI (Zürich) is studying the weathering and the sedimentation. The question as to the part played by the older molasse in the formation of the younger, and as to the part played by the Caledonian basement, has not yet been gone into. The problem of the sedimentary transformation may be tackled from still another point of view, viz. by petrographic investigations of the facies of Quaternary depositions. This is being done, with material collected by the author, by Mr. ZINGG (Zürich). All these investigations are and will be a help towards the understanding of the Post-Caledonian supercrustal and crustal movements.

A consideration of FREBOLD's studies (8) might make us believe that the problem of the post-Devonian movements was solved. However, this is not the case. Only very little is known yet regarding the geometry and the significance of these movements. What FREBOLD interprets as "movements", and what according to STILLE he terms "phases", are gaps in the sedimentation. Now it must be remembered that not only gaps but also depositions register movements. Consequently an enumeration of gaps cannot correspond to an enumeration of movements. Furthermore we get little or no information as regards mode and extent of the movements from an enumeration of gaps. Mode and direction of movements are, however, of special importance where such movements are to be put into a regional frame — more important than the so-called simultaneousness of two dislocations taking place at a long distance from each other. The fact that two events, far away from each other, happen simultaneously, without an observed interconnection of some kind or other, does not mean that both these events are the results of the same causes. (As little as historical events of the same year which take place at a long distance from each other need have the same cause.) On the whole it seems to be rather risky to make a construction of causality from a purely temporal classification. Such a temporal classification represents in reality but a series of events, without giving any information as to the mode of the event. Out of a scheme

of movements in a temporal-geometrical frame we might get more results than the mere "phase-scheme" allows us to see. If the supporters of such a terminology (as the one just mentioned) — which so far seems to be the case — think they can dispense with a geometrical and kinetic investigation of the movements, their mode of procedure cannot be looked upon as very promising.

That the investigations of the author aim more at a geometrical analysis of the movements, whereby he tries to give an appreciation of this limited complex of the earth's crust, should have become clear by now.

V. REGIONAL SITUATION OF THE EAST GREENLANDIC CALEDONIAN

Though our investigations did not touch upon the western border of the mountain complex, we must assume that there is such a border at a not very far distance. Whether the crystalline fragments in Nordenskjöld Glacier originate from there, may not yet be decided (36, 37). It is certain that to the west our mountain-chain comes into contact with the Greenlandic shield. Consequently its tectonic continuation must lie in districts which bound on this shield too (7, 15). This is the case in Scotland, New Foundland, and Canada. The continuation Scotland—New Foundland has been discussed by BAILEY (7).

By the occurrence of Greenlandian in similar facies, connections with Spitzbergen (Hecla Hook), the Scandinavian Highlands (Varanger series, part of the sparagmites), and Scotland (Torridonian), are established. The Varanger series, the sparagmites belonging to that series, and the Torridonian are series of the Greenlandian which have already been rather impoverished, for they lay at the boundary of the trough-collector of sediments. The Scandinavian series especially exhibit such a great similarity in facies and structures that some series of rocks might easily be confused with one another.

During the years 1924—26 the author studied some parts of the Scandinavian Caledonian, especially the important district on the coast of Trøndelagen, which is characterized by deep-going migmatitization and partial activation of an older basement.

No flysch-sediments are to be found in this zone, but they may be observed to a large extent at Trondhjem Fjord and in the mountains east of it. Towards the north, part of the mentioned migmatite zones disappears below the Nordland-zone at the fjord of Inre Folla; another part strikes northward along the coast. Between this latter part and

the flysch-zone of Swedish Västerbotten and Norrland we have the Nordland-zone. In the South-Norwegian arc (33) the activated basement may be seen in axial upwarplings, especially so in the western parts. Flysch-formations are of smaller extent in the south than they are in the north, a fact which might be connected with the "tectonic relief". Towards the eastern border of the mountain-complex the activation of the basement diminishes.

On the coast of Trøndelagen a great erosion took place between the folding of the mountains and the deposition of the Devonian. The interconnections with the flysch-formations of Trøndelagen are to be found here. The Devonian of Smölen, Hitteren, and Fosen has been subject to movements in a style similar to that of the Greenlandic Devonian. The Devonian basins of the district comprising Solund, Bulandet, Kvamshesten, Haasteinen, and Hornelen, lie in a slightly different tectonic position, but as regards structure and movement are very similar to their Greenland analoga.

Thus in the Scandinavian Caledonian the following zones can be distinguished: a) a western zone with migmatitized basement, producing flysch; on the gap where the flysch material was taken, Devonian was deposited, but was disturbed again later. b) an eastern zone containing flysch; its bottom often contains Greenlandian. c) a zone in the extreme east, which is distinguished by large masses of Greenlandian (in Finmark, partly buried underneath thrust masses; in the north of Sweden; in the sparagmite-district of southern Norway).

Starting from different points of view, an area producing sediments was assumed in the west: partly to explain the formation of flysch in different levels (WEGMANN), partly for petrographical reasons (THOROLF VOGT). If both formations — the eastern and western — are combined, we get an organic whole. Also the facies of the Ordovician limestones of Smölen with their fauna, which seems rather to belong to the western part of the Caledonian zone, seem to point to this fact. They are of a Scotch-Canadian type (11, 25).

Consequently we should have to assume a mighty geosyncline, formed by the elements of the Greenlandian, in Greenland, Spitzbergen, Scandinavia, and Scotland. Working-up levels in its border-zones have been ascertained for Greenlandian times already (Varanger and Murman Coast) (34, 35).

The tillite-formations in Greenland, Scandinavia, and Spitzbergen point to further movements during the transition period from Greenlandian to Cambrian. These movements seem to continue the movements of the geosyncline; viz. the trough subsides, while its limbs are lifted up. During this process the tilting axis changes its position. When it is shifted towards the geosyncline, the sediments of the border-zones are put on

dry land, eroded, and collected in the trough. This may be seen most distinctly in the north of Norway (34, 35).

Accordingly a collector-trough, a kind of forerunner of the North-atlantic and Scandic, must be assumed to have existed in pre-Cambrian times bordering on the old Greenlandic, Hebridian, Canadian mass on one hand, and Fennoscandia on the other hand. The Scandinavian part of the Caledonian geosyncline was considered already by ARGAND (1, p. 191—192) to be a forerunner of the Atlantic; at his time the Caledonian of Greenland was an unknown factor. It was only as a result of KOCH's expeditions that the late Pre-Cambrian geosyncline was discovered. In Taconian times the western parts (East Greenland, Scotland, New Foundland, coast of Norway) were folded, uplifted, and exposed to erosion. In the more easterly parts of the Greenlandian geosyncline the sea continued to cover the land (Scandinavian flysch-zone, south of Scotland, North-England, Ireland). This stripe, where land was still covered by water, is narrower than the stripe of the Greenlandian; the shore-lines of both do not run parallel. The younger geosyncline follows another scheme: it collects the sediments of the western regions, which had been uplifted last. Only in the extreme east is Fennoscandian material deposited. After the flysch-trough of Scandinavia had disappeared on account of the foldings, and after the fore-deep had disappeared on account of the thrust, the sea receded southward. In the regions which were subjected to movements in early Caledonian times, the basins were filled with deposits of the Old Red (coast of Norway, Spitzbergen, East Greenland, Scotland). These basins of the Old Red and their later deformation show another scheme compared with that of the early Caledonian folding. It was not before Permian time that the sea reached East Greenland again, and now the much interrupted series of younger sea deposits began, which belong to the direct forerunners of the Scandic.

On tracing the deformations and the disappearance of the Greenlandian sea, its Palaeozoic descendants, up to the forerunners of the present Scandic, one is strongly reminded of the relation in which the Neogenic and Quaternary sea stands to the Mediterranean mountain-chains. It would be tempting to carry this comparison still further.

The question arises: by what has the area of the present Scandic been covered? For the present the answer to this question is based on hypotheses; these hypotheses have been summarized by KOCH (15, p. 314) and reproduced by FREBOLD (8, p. 103—107). According to FREBOLD, the tectonics of East Greenland point to a continual horizontal compression. In contrast to this mention may be made of the many indications of extension movements in the different periods.

It is even possible that the formation of the Greenlandian geo-

syncline corresponds already to an extension. After the Lower Ordovician up to the Devonian and the lower Carboniferous we note a narrowing with intermittent extension. Then the coastal area of North-East Greenland is extended by various systems of faults which occur in a continual series of activity. In late Mesozoic and Tertiary times basalts protruded from beneath, partly in dyke swarms. That this corresponds to an extension, has already been stated by WAGER (31, p. 44). The subsidence of the borders of the basalt beds (31, p. 44) towards the coast indicates the same. Even in the inner zone the younger features of the structures point to an extension. The more the outer coast is approached, the more distinct seem the signs indicating extension to be. Up till now these faults have not been investigated very thoroughly, especially their geometrical condition is but little known. Some suggestions have been made as to their age, which, however, are not very reliable, since the age of the fault-swarm varies in different places. Summarizing we may assume that since the Upper Palaeozoic the coastal zone has been extended.

VI. THE UNITY OF THE NORTHERN CALEDONIAN CHAINS: A SUGGESTION

So far nothing is known about the proportions of the Greenlandian geosyncline in Caledonian times.

If we take the various relics of Caledonian chains round the North Atlantic and Scandic to be parts of a whole, then the development is uniform. Out of the broad Greenlandian geosyncline develops *sensu lato* the Taconian system. The following units belong to it: East Greenland, Spitzbergen, the coastal districts of Norway, parts of Scotland, the Taconian areas of New Foundland, and Canada.

The coastal districts of Norway have the following characteristics in common with Greenland: on Smölen a fauna was found belonging to the western branch of the Caledonian (11, 25). From the basement up to higher parts of the Caledonian series, the strata are migmatitized. In late Caledonian times these regions rose above sea-level and supplied flysch. In Devonian times, old red sandstone was deposited in basins lying on top of the gap which had developed when flysch was formed. There is a difference between the eastern and western parts: In Smölen volcanism was active in lower Ordovician times; in Greenland none has been ascertained so far.

By combining both parts of the chain, we may investigate the wanderings of the sea to the east, its becoming narrower, and finally its

closing in the east. The beginning of the new Scandic can be better observed on the Greenlandic than on the Norwegian side; the new sea lies farther towards the west than the western border of the flysch sea, in the southern parts likewise farther west than the most easterly Devonian basins.

In its northern parts the chain is in some places not highly folded (Greenland, Spitzbergen). Both branches are broad. In the eastern branch, in the north of Norway, large overthrusts are known. In the Finmark-arc the old basement, with its overlying mass of Greenlandian, reaches some distance below the border of the mountain district. In the South Norwegian arc, the character of the mountains changes the farther south we go. Before it reaches the massif of Sörlandet, the train of dislocations leaves the main-direction of the mountain-complex and strikes more E—W.

In the southern part of the western branch of the Caledonian system, viz. in North Scotland, there are dislocations of a very violent type, but with small articulations. If we bear in mind the South Norwegian arc (33), we might assume between Norway and Scotland a mountain-chain of very intensely dislocated character describing an arc; farther south it might strike out on broader lines again.

A further possibility would be to assume the massif of the Hebrides to be a separate massif lying between the two. A great part of the chain would have circumscribed it in the west and ought to be found again in South-East Greenland. A continuation of the North-East Greenland Caledonian in South-East Greenland has already been postulated by LAUGE KOCH (15b).

During the last few years various interpretations as regards the interconnections of the North Atlantic mountain complexes have been published, unfortunately by scientists who know part of the literature, but nothing of the territory; so these suggestions of a geologist who has travelled and worked for several years in the territory of the Greenlandic and the Scandinavian Caledonian may perhaps be of some interest. I shall soon discuss the question from another point of view.

It will be evident from the above that it is of no further use to discuss the interconnections of the North Atlantic mountain-complexes without knowing the conditions in Greenland. It will not do to leave these conditions aside as superficial formations of little importance.

This short and sketchy comparison might have shown that in between the Greenlandic shield and Fennoscandia there is a deep and differently articulated orogeny.

VII. SUMMARY AND FURTHER PROBLEMS

To-day the Caledonian mountain-chain of East Greenland shows the following scheme: the sediments of the chain indicate that they were collected in a subsiding trough; they comprise a thickness of about 9000 m. During the Caledonian orogeny large masses were transformed by igneous activity. A kinetic analysis shows an upper structure of wide folds in the non-metamorphic sediments, and a deeper-lying structure of migmatitic flowing-folds. On top of this, above a deep gap, we get the Devonian molasse. Flysch formation could not be ascertained. But this missing flysch being an element of great importance, the Caledonian mountain-chain cannot be looked upon as a complete mountain-complex, but only as an enormous fragment. It is of great vertical extent and has consequently to be looked upon as a deep-going interruption of the old continental block. In North-East Greenland, the Caledonian chain is most important between 81° and 70° lat. N. in Norway between 71° and 59° lat. N.

These are just some results as to the understanding of the complex. Some more will be given in the thorough study to follow later. A great many problems are, however, reserved to future investigations.

Since in countries as remote as Greenland it is of importance to know the lines along which future investigations may best proceed, it would perhaps be useful to indicate some goals which seem to be most necessary and important for a further investigation:

- 1) Contents, structure, and movement of the Nunatak-zone of Caledonian sediments, in the fjord-district and in Queen Louise Land. To know the contents would further our understanding of the sedimentation-area and of the movements of the basement in the Greenlandian and the Lower Palaeozoic time. A knowledge of the structure might give us a key as to the relation of the Vela-massif to the border of the geosyncline, and perhaps also as to the relation between the border of the geosyncline and the fore-land. Greater tectonic complications are not impossible. Only by a thorough understanding of the above-mentioned instances would their relation to the Archean be thoroughly explained.
- 2) The zone where the Caledonian basement protrudes from underneath the Devonian (from Hudson Land to the region round Wordie Glacier). Important complications must be hidden in this zone. It may not be very difficult here to separate the traces of Caledonian movements from those of a later period and thus to understand their relationship. As regards the problem of the sub-Devonian basin, the understanding of this zone would be decisive.

- 3) The southward continuation of the Vela-massif. The course of the outcrop of the western elements of the Fjord-zone is to be seen in the Murchison Alps. Below these elements the character of the granitization changes. In the inner Alp Fjord and its southward continuation, the character of the Sylva-Maria group seems to continue. Perhaps the transition to a style as described by WAGER (31) farther south might begin already in the district of the Scoresby Sound Fjords. The participation of younger eruptive rocks in the formation of Scoresby Land — as found by BÜTLER — ought to be further investigated.
- 4) The northern continuation of the Vela-massif. The deeper-lying elements of the Vela-massif seem to dip to the north and disappear in Andrée Land. The Isfjord-zone broadens out. An investigation might supply important data as to a comprehension of the relation of movements between non-metamorphic and metamorphic parts. It is still an open question whether the massif dips at all towards the north, or whether it ascends again farther on. Of what structure is the top of the Vela-massif in its deepest axial position?
- 5) Geometry and kinetics of the fault-swarm in the district of the fjords should be studied more thoroughly. This would be important for an explanation of the evolution of the huge Caledonian fragment in post-Caledonian time; the present mountain-complex is a result of the younger movements. The same type of movements as that of these younger movements seems to continue underneath the basalt. Consequently part of the movements of the basalt-district might be comprehended from below and, the type being known, we might, as it were, see the structure of the basement through the overlying mass of basalts. Furthermore these studies would furnish us with many important arguments as to the extension-movement of the coastal area, and consequently as to the evolution of the Scandic.

In the westernmost zone of the Vela-massif traces of younger faults are also found very frequently. Consequently the zone of high mountains in the inner fjord-district must probably be regarded as a "horst". When the Scandic came into being, step-faults were formed on either side of this horst. Thus the area west of Christian X. Land, which is now covered by inland-ice, might have been formed into a basin like the area east of it before the glacial period began. Then this basin, which had perhaps been isolated, might possibly have been filled by ice descending from the mountains. If from the enormous thickness of ice which has been measured by WEGENER's expedition, the conclusion is drawn that the theory as regards the pressure of ice is absolutely and unequivocally correct, in my opinion this conclusion is pre-mature as long as its geo-

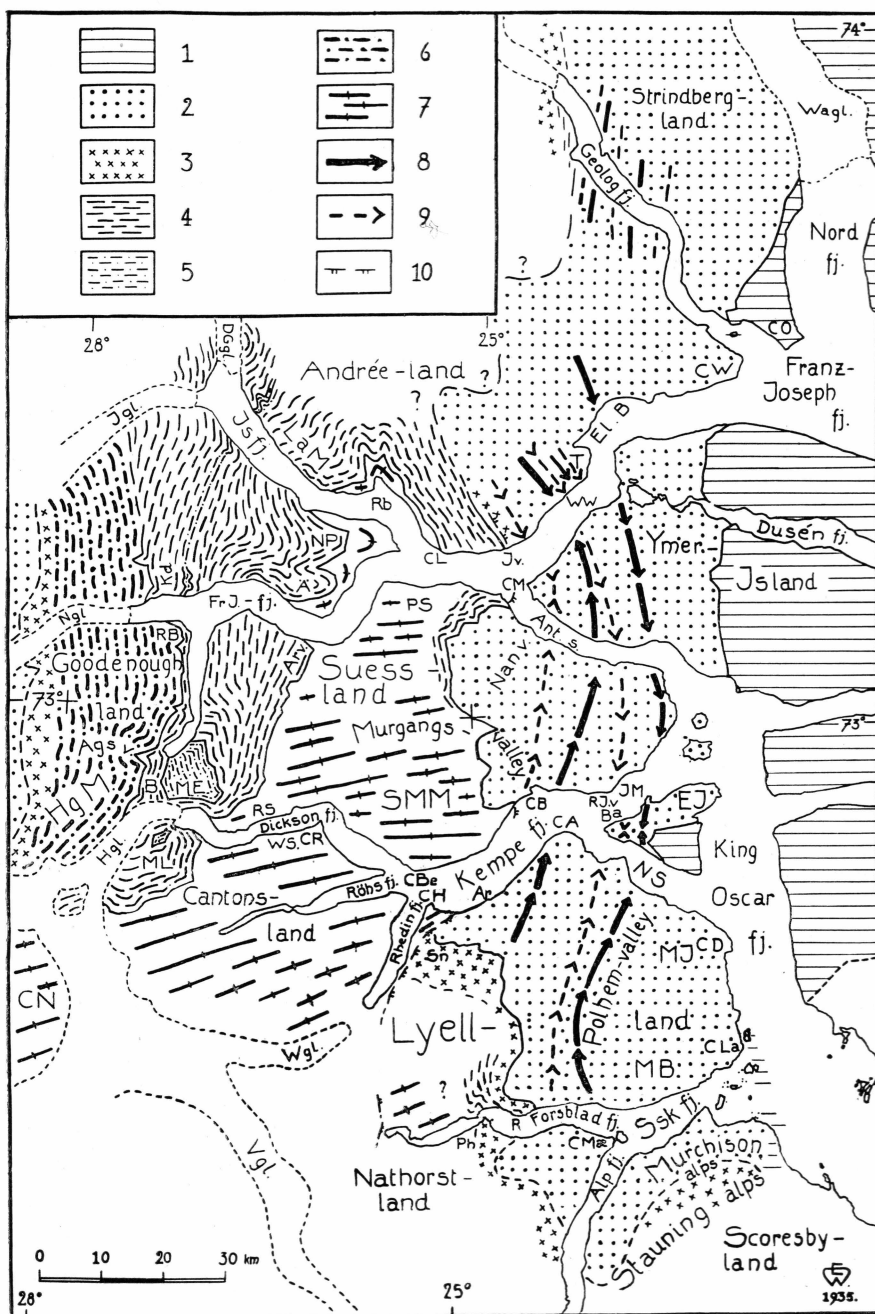


Fig. 11. Sketch-map.

Fig. 11. Sketch map of the Caledonian structures between Alpfjord and Geologtfjord.

- 1 Devonian Old Red Sandstone.
- 2 Sedimentary zones of the Caledonian cycle.
- 3 Granites in the marginal zone of the metamorphic areas.
- 4 Isfjord-zone.
- 5 Emilia group.
- 6 Hagar group.
- 7 Sylva-Maria group.
- 8 Anticlines (the arrow indicating the pitch).
- 9 Synclines (the arrow indicating the pitch).
- 10 Thrust-planes.

Agsv	Agassiz valley	Kd	Knægtaldalen
Ar	Argand glacier	Kjfj	Kjerulf Fjord
Arv	Arthur valley		
Ä	Ättestupan	LaM	Lacroix Mts
B	Bocksriet valley	MB	Mt Berzelius
Ba	Bastion	ME	Mt Emilia
		MJ	Mt Jeannet
CA	Cape Alfred	ML	Mt Lugano
CB	Cape Buxtorf		
CBe	Cape Bejer	Nanv	Nanortalik Valley
CD	Cape Dufva	NP	Niggli Peak
CH	Cape Hedlund	NS	Narwhal Sound
CL	Cape Lapparant		
CLa	Cape Lagerberg	Ph	Philipshorn
CM	Cape Mohn	PS	Payerspitze
CN	Cecilia Nunatak		
CO	Cape Ovibos	R	Randenes
CR	Cape Robert	RB	Riddarborgen
CW	Cape Weber	Rb	Renbugten
		RJv	Rud Johansen Valley
DGgl	De Geer Glacier	RS	Red Staubhorn
EI	Ella Island	SMM	Sylva-Maria Massif
EIB	Eleonore Bay	Sn	Snöhättan
		Sskfj	Svenska Segelsälskapets Fjord
FrJ.fj.	Inner Franz Joseph Fjord		
		T	Teufelsschloss
Hgl	Hisinger Glacier		
HM	Hagar Massif	Vgl	Violin Glacier
		Wagl	Waltershausen Glacier
Jgl	Jätte Glacier	Wgl	Wahlenberg Glacier
JM	Mt Johnstrup	WS	White Staubhorn
Jv	Junction Valley	WW	White Wall

The coast-lines after the maps of the Geodetic Institute, by kind permission.

logical foundations have not been studied. Though the ice is very thick, it is not certain that this thickness is the only and entire cause of the formation of the basin.

We will, however, not go so far as to assert that such a solution of the problem is not possible, at least in part. Without necessarily leading to final decisions, a structural survey combined with geomorphological investigations of the Greenlandic border-zone might further the problem in favour of one or the other of these hypotheses.

VIII. ACKNOWLEDGMENTS

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Furthermore I owe great thanks to the two cartographers, Mr. SIMONSEN and Mr. STENØR, for their valuable collaboration in Greenland and at home. To the Geodetic Institute in Copenhagen I am indebted for allowing me ready access to the maps; they form the basis for the sketch-map in fig. 11.

Schaffhausen, January 14, 1935.

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**Plate I. Structural Diagram of the Fjord-District from
Lyell Land to Andrée Land.**

In order not to make the diagram too complicated the structure is highly schematized; many details are omitted so as to make the principal structural characteristics clearer. The sedimentary series are not subdivided; the lamellae are not stratigraphical levels but only structural groups. The younger faults are not indicated; it is supposed that the conditions were restored before the formation of these faults. The topography is much schematized; only the fjords, the large glaciers, and some alluvial areas suggest the actual topography. In the dolomite-limestone series between Mount Marcel Bertrand and Mount Johnstrup tillites and Lower Paleozoic are included.

STRUCTURAL DIAGRAM OF THE FJORD-DISTRICT FROM LYELL-LAND TO ANDREE-LAND.

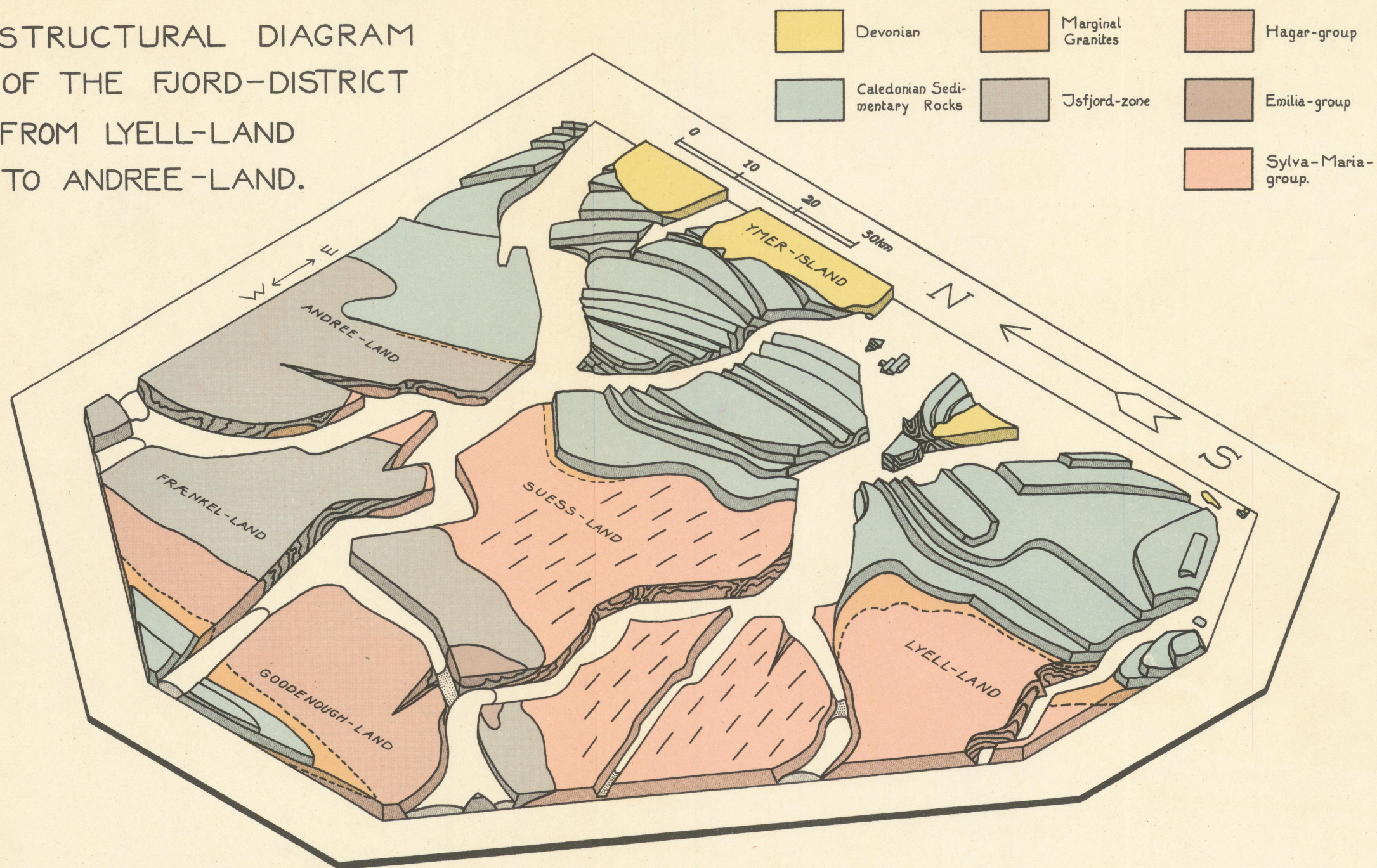


Plate II.

The panoramas (pl. II, fig. 1, 2 and pl. III, fig. 1) are from Lyell Land in the area of Polhem Valley. They give some idea of the not very intricate type of structure there.

Fig. 1. East side of southern Polhem Valley. The west side of Mount Berzelius is seen, that is, the eastern limb of the eastern anticline. The core of this anticline lies above the southern Polhem Valley, but in the middle Polhem Valley strikes through Mount Lugeon into the Arbenz dome (cp. pl. II, fig. 2 and pl. III, fig. 1). The different levels come down in the wall so that the valley touches younger levels in the north than in the south. Such mountain walls are well suited for an estimate of the thicknesses of the levels. In the south the peaks south of Alpfjord are seen; they are built up of the lower quartzite-schist series. Behind them the granite forms the higher peaks of the Stauning Alps.

a = level 3 of KOCH's (14) and level 6 of TEICHERT's (26) stratigraphical tables.

Fig. 2. North side of the northern Side-Valley of northern Polhem-Valley. The valley side show the central syncline (syncline continuing in the Bastion). To the right the crest of the anticline with the top-levels of the quartzite-schist series rises above the valley. Different levels of the multicoloured series are folded and partly laid in lying folds.

In the eastern limb of the syncline the upper series have a tendency to glide upward over the lower series. Here the dolomite-limestone series has this relative movement over the quartzite-schist series. So the folds in the multicoloured series are formed. These folds increase the thicknesses of this series in the upper part of the eastern limb of the syncline. The upper and inner lamellae of the syncline forms therefore a somewhat steeper and narrower trough (cp. fig. 6, 4 p. 33.)

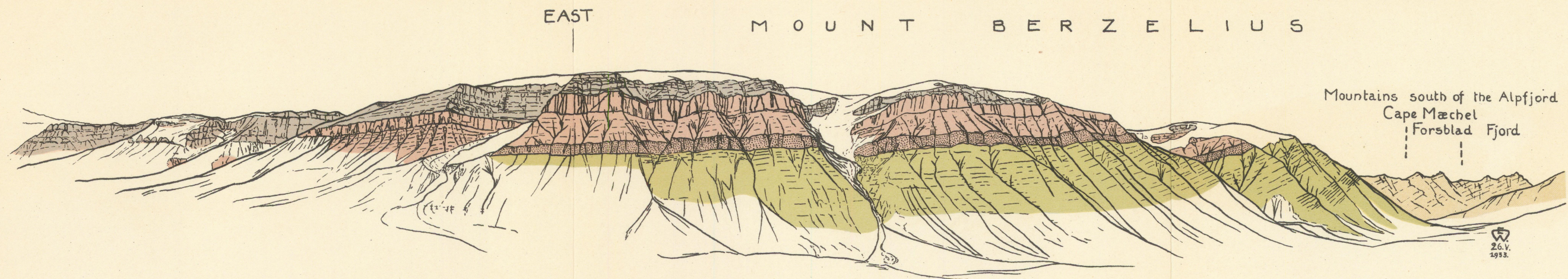


FIG. 1. EAST SIDE OF THE SOUTHERN POLHEM VALLEY.

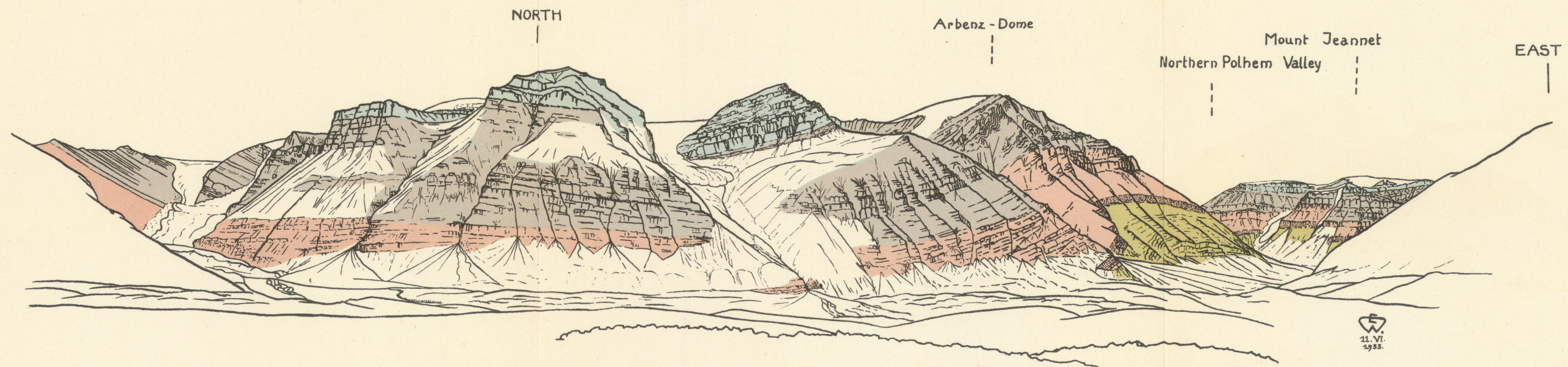


FIG. 2. NORTH SIDE OF THE NORTHWESTERN SIDE-VALLEY OF POLHEM VALLEY.

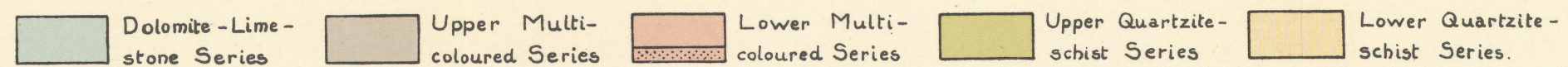


Plate III.

Fig. 1. West Side of Polhem Valley from the Slope of Mount Jeannet.

The Arbenz-dome and Mount Lugeon are built up of the eastern anticline. It pitches to the north. In the mountains north of Arbenz-dome the structure is progressively raised towards Narwhal Sound, through several younger faults. In the side-valley the central syncline is visible (cp. pl. II, fig. 2) The Sander Peaks represent the eastern limb of the anticline of Cape Alfred (cp. next fig.) Upper multicoloured Series = level 7—11 of Koch's (14) and 10—14 of TEICHERT's (26) tables. Lower multicoloured Series = 3—6 of Koch's (14) and 6—9 of TEICHERT's (26) table. a = level 3 of Koch's and 6 of TEICHERT's division.

Fig. 2. Panorama from Cape Hedlund.

In the foreground Kempe Fjord, to the left the entrances to Rhedin Fjord, Röhs Fjord, and Dickson Fjord are seen. These fjords are cut into the folds of the Sylva-Maria group. The rocks in this group are not differentiated in the diagram. The folds are migmatitic folds; they pitch to the right and disappear below the sedimentary zone. In Mount Marcel Bertrand the upper part of the anticline of Cape Alfred is visible. The axis rises towards Cape Alfred, where the core and the eastern limb of the anticline are visible. In the right part of the panorama the western limb dips with the sides of the Argandhorns (cp. pl. I).

