DET KONGELIGE DEPARTEMENT
FOR HANDEL, SJØFART, INDUSTRI, HÅNDVERK OG FISKERI

NORGES SVALBARD- OG ISHAVS-UNDERSØKELSER
LEDER: ADOLF HOEL

# SKRIFTER OM SVALBARD OG ISHAVET

Nr. 78

ANDERS K. ORVIN

# OUTLINE OF THE GEOLOGICAL HISTORY OF SPITSBERGEN

WITH 1 GEOLOGICAL MAP, 3 PLATES, AND 12 TEXT-FIGURES

OSLO
I KOMMISJON HOS UNIVERSITETSFORLAGET
1969

# RESULTS OF THE NORWEGIAN EXPEDITIONS TO SVALBARD 1906—1926 PUBLISHED IN OTHER SERIES

(See Nr. 1 of this series.)

The results of the Prince of Monaco's expeditions (Mission Isachsen) in 1906 and 1907 were published under the title of 'Exploration du Nord-Ouest du Spitsberg entreprise sous les auspices de S. A. S. le Prince de Monaco par la Mission Isachsen', in Résultats des Campagnes scientifiques, Albert Ier, Prince de Monaco, Fasc. XL—XLIV. Monaco.

ISACHSEN, GUNNAR, Première Partie. Récit de voyage. Fasc. XL. 1912. Fr. 120.00.

With map: Spitsberg (Côte Nord-Ouest). Scale 1 : 100 000. (2 sheets.) Charts: De la Partie Nord du Foreland à la Baie Magdalena, and Mouillages de la Côte Ouest du Spitsberg.

ISACHSEN, GUNNAR et ADOLF HOEL, Deuxième Partie. Description du champ d'opération. Fasc. XLI. 1913. Fr. 80.00.

HOEL, ADOLF, Troisième Partie. Géologie. Fasc. XLII. 1914. Fr. 100.00.

SCHETELIG, JAKOB, Quatrième Partie. Les formations primitives. Fasc. XLIII. 1912. Fr. 16.00.

RESVOLL HOLMSEN, HANNA, Cinquième Partie. Observations botaniques. Fasc. XLIV, 1913. Fr. 40.00.

A considerable part of the results of the ISACHSEN expeditions in 1909 and 1910 has been published in Videnskapsselskapets Skrifter. I. Mat.-Naturv. Klasse. Kristiania (Oslo).

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GOLDSCHMIDT, V. M., Petrographische Untersuchung einiger Eruptivgesteine von Nordwestspitzbergen. 1911, No. 9. Kr. 0,80.

BACKLUND, H., Über einige Olivinknollen aus der Lava von Wood-Bay, Spitzbergen. 1911, No. 16. Kr. 0,60.

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GUNNAR ISACHSEN has also published: Green Harbour, in *Norsk Geogr. Selsk. Aarb.*, Kristiania, 1912—13, Green Harbour, Spitsbergen, in *Scot. geogr. Mag.*, Edinburgh, 1915, and, Spitsbergen: Notes to accompany map, in *Geogr. Journ.*, London, 1915.

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The following topographical maps and charts have been published separately:

Maps:

Bear Island. 1 : 25 000. 1925. Kr. 10,00.

Bear Island. 1 : 10 000. (In six sheets). 1925. Kr. 30,00.

East Greenland. Eirik Raudes Land from Sofiasund to Youngsund. 1 : 200 000. 1932. Kr. 5,00.

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# Content.

## Preface.

The purpose of this paper is to give a brief review of the geological history of Spitsbergen, more especially of the tectonics, as I see it to-day. I have also incorporated descriptions of the stratigraphy, which, although already known, have been included to make the geological description of the map more complete and connected. The Quaternary geology of the islands has not been dealt with in this paper. I have tried to make the geological map as detailed and accurate as is possible at the present state of our knowledge of the geology of Spitsbergen, but I am fully aware of its many shortcomings, and that much will have to be altered as the country is further explored. It does represent, however, a distinct improvement on the older maps of a more or less sketch-like nature, and I have therefore no hesitation in publishing it now, inasmuch as many years will probably pass before essential improvements can be introduced.

Those who wish to study the geology of Spitsbergen more in detail are referred to the geology of Spitsbergen by Frebold, and the various special papers.

The present paper has been translated into English by Dr. Gunnar Horn of Norges Svalbard- og Ishavs-undersøkelser for which I am most grateful.

Oslo, December 15, 1938.

*A. K. O.*

## Introduction.

All who have done surveying and geological work in the arctic regions know how difficult it is to obtain satisfactory results. Fog and bad weather may for days make field work almost impossible, and as large areas are covered by ice it is frequently difficult to connect the different field observations. Usually the preliminary geological traverses are liable to be very incomplete, as the proper topographical base is lacking and the time is short. Often it is not possible to return to the most outlying areas, and the first work will then remain half-finished or incomplete for years. Such scattered geological information is also difficult to put on the map.

It is therefore not to be wondered that it has so far been impossible to work out anything more than schematic or sketchy general maps of Spitsbergen.

Much has to be done before it will be possible to publish an accurate geological map of Spitsbergen on a large scale. Nevertheless I have ventured to publish the accompanying map because the many new facts gathered during the last years make it possible to improve the map essentially. In constructing the map I have in the first instance used the older printed maps and descriptions and also various MS maps in preparation. I have further studied all the air photographs from the expeditions in 1936 and 1938. The air photographs have proved to be of inestimable value to the geologist. The photographs give in fact much more information about the country than any map can give. As a rule it is possible to transfer the greater part of the superficial deposits direct from the photograph to the map, and on the photographs it is possible to follow the more conspicuous beds throughout large areas. In many cases it is therefore sufficient to limit field work to a few sections. It is very easy when walking in the field to find the corresponding position on the photograph. Especially in Svalbard, where there is so much fog, the air photographs have proved to be extremely useful.

During the mapping the geologists have unfortunately not had the benefit of air photographs, and many fatiguing trips have been taken, but with small results. The conditions for carrying out the geological work successfully will from now on be much better, even when the weather conditions are bad. We have now, in fact, in the photographs an excellent topographical base for a detailed geological survey of the islands, as all the observations may be put on the photographs, and later transferred to the map when it is constructed.

Of the unpublished maps used for the construction of the present general map should be mentioned the maps on the scale of 1 : 50 000 of the inner part of the peninsula between Isfjorden and Bellsund, of the Midterhuk peninsula in Bellsund, and of the Hecla Hoek area between Hornsund and Bellsund. The two first maps have been prepared from photographs and partly from notes in the field. The map of the region south of Hornsund is chiefly based on only partly published results by Hoel and Werenskiold. The younger formations in the inland south of Van Keulenfjorden were mapped in 1934 by a Polish expedition, but as the map has not as yet been published, I have had to prepare this part from the air photographs. The country here is, however, so glacierized that it is impossible, from the air photographs only, to follow up the beds and locate tectonic disturbances in this area, this being also the case in several of the eastern and northern areas, where, in addition to the air photographs, only schematic maps and descriptions are available. In these parts the general map is therefore only schematic and preliminary. Generally speaking, however, I believe that boundary lines and tectonic lines are now approaching their final position, especially as regards the post-Hecla Hoek systems.

Some errors in the topographical base have been corrected with the help of the air photographs, and with regard to Nordaustlandet the map of the Glen expedition 1935—36 has been most useful.

No additional information about the geology of Bear Island has been published since the paper by Horn & Orvin was published in 1928. The present paper will therefore only deal with Spitsbergen and the islands to the east of it; only in a few cases have I dealt with conditions on the well-known Bear Island.

A section through the sequence in Spitsbergen will roughly appear as the section of the legend to the geological map (Pl. I). The thicknesses given are, however, more or less approximate, as nearly all the series and the separate beds show quite a varying development. This is not only due to the original deposition, but to a large extent to subsequent elevations with erosion followed by deposition of other beds. The younger beds have frequently been deposited nearly parallel to the older, so that the unconformities are only very slightly pronounced and frequently not to be proved except by inference.

The examination in detail of the beds are not yet so far advanced that all the variations and their origin are known. Even the boundaries between the different systems are not fixed everywhere, so that thicknesses and boundaries cannot be given accurately. The pre-Downtonian, metamorphic series are still little known and therefore no sequence applicable to the entire area can be worked out.

In the following pages I shall try to give a chronological record of the geological development of Spitsbergen.

## The Hecla Hoek Formation.

In spite of all that has been done, it has not been possible to delineate or separate possible pre-Cambrian rocks from the younger. We have a distinct break between all the pre-Downtonian, in parts highly metamorphic rocks, collectively known as "Hecla Hoek", and the younger non-metamorphic sequence. In Spitsbergen it is therefore natural to recognize the main break in Younger Silurian, grouping all the older beds conveniently as the "Hecla Hoek" of Nordenskiöld. It is still necessary to maintain this group for all the pre-Downtonian sediments, as their age can only partly be fixed.

Even the highly metamorphic sediments, originally referred to the Archean, are now considered to be contemporaneous with the less metamorphic Hecla Hoek rocks. The fact is that the igneous rocks, considered to be Archean and which have also had a metamorphic effect, were found to be younger than the sedimentaries and belonged to the Caledonian mountain-building. This led to the belief that Archean rocks were not present at all in Spitsbergen. This may be so, but it is not quite certain. In 1931 Kulling discovered at Kapp Hansteen on Nordaustlandet a porphyry series lying below Algonkian (eo-Cambrian?) sediments. The porphyries are therefore of Algonkian age or possibly still older. They are probably the oldest rocks in Spitsbergen. The Glen expedition 1935—36 also found these rocks to extend eastwards to Zorgdragerfjorden.

Even if the Archean has not been proved with certainty in Spitsbergen, it is safe to assume that the Archean is nevertheless of great importance in these regions. There can be no doubt that the Barents Sea Shelf forms a continuation of the Fenno-Scandian Archean Shield, as the boundary between Svalbard with the Barents Shelf and the deep Norwegian Sea forms a direct continuation of the same boundary off the Norwegian coast. This hidden Archean shield has then a rather thin cover of younger sediments. The trend of the Caledonian mountain chain also indicates the presence of a large, continuous, and very resistant part of the Earth's crust to the east.

It is highly probable that parts of the Svalbard area previous to the Cambrian submergence formed dry land connected with the Scandinavian peninsula. This vast area was perhaps even by that time bordered by the ocean in the west and the north.

The Hecla Hoek formation is throughout large parts of Vestspitsbergen and Nordaustlandet covered with younger sedimentary series or glacier ice, so that the accessible areas are scattered and isolated. Consequently it is not possible to trace the various beds continuously. The greater part of the Hecla Hoek rocks are highly metamorphosed with the result that possible fossils have been destroyed, and no help is thus to be had from palaeontological evidence. Then the varying degrees of metamorphism have produced different rocks of the same bed, making stratigraphical correlations extremely difficult. There are also strong foldings, overthrusts, and faults; in places parts of the sequence are probably also missing owing to unconformities so that it is no easy task to correlate the various sections. It may even be difficult to decide what is up and what is down.

In this paper I shall make no attempt to describe the sequence in detail and the development at various points. That has been done by Frebold (1935). Determinable fossils have been found only at two points in Svalbard, viz. on Bear Island, and at Kapp Sparre on Nordaustlandet. Both localities are possibly on the outskirts of the Caledonian mountain zone.

Holtedahl has found that the beds on Bear Island belong to the Lower and Middle Ordovician, and their oldest members are possibly eo-Cambrian. The thickness of the entire Hecla Hoek sequence on Bear Island is not more than about 1200 metres.

At Kapp Sparre, Kulling discovered brachiopods, apparently of Lower Cambrian age. They were found uppermost in a series having a thickness of 3600—4300 metres or more, consisting chiefly of sandy and argillaceous sediments, in the middle part of thick dolomites, and in the upper part of alternating beds of dolomites, shales, and some sandstones. About 800—850 metres below the fossil horizon comes a tillite, most probably representing a break in the sedimentation and perhaps inaugurating the Cambrian. The entire sequence rests on the porphyries of the Kapp Hansteen Formation, whose thickness is not known. The age should be Algonkian and eo-Cambrian, and the beds may partly correspond to the lowest Hecla Hoek beds on Bear Island. The total thickness of the eo-Cambrian and older beds at Hinlopenstredet together with the Ordovician on Bear Island thus runs to about 5000 metres.

The remaining Hecla Hoek must then be correlated with the mentioned beds or belong to other parts of the sequence Algonkian—Silurian. It is perhaps not very likely that the beds between the Middle-

Ordovician and Downtonian have been preserved, considering the enormous denudation which must have taken place subsequent to the folding, but remnants may be found involved in the main folding. It is more probable that the greater part of the Hecla Hoek can be correlated with the stratigraphically known beds from Bear Island and Nordaustlandet, and the intervening beds.

The section measured by Odell in Ny-Friesland, and which he estimated to represent a sequence of a thickness not less than 10 000 metres, is, according to Kulling, to be explained as a repetition due to folding, possibly folding overthrust, so that the section of Odell really represents only a part of the Kulling section. It is thus probable that all the beds east of Wijdefjorden belong to the Lower Cambrian and older systems.

Along the west coast of Spitsbergen from Norskøyane to Sørkapp the Hecla Hoek beds have mostly a strike roughly parallel to the coast, and are only cut by the fjord mouths and glaciers. On the coastal plains the solid rock is more or less hidden by superficial deposits. It should be possible, despite these difficulties, to work out a section applicable to this stretch of coast, but so far little has been done. In the northern part determinable fossils cannot be expected to be found, but in the southernmost there are chances of finding fossils, if the beds do contain such.

It is practically certain that all the metamorphic beds and the igneous rocks along the west coast are younger than the Archean. Holtedahl has rightly pointed out that the degree of metamorphism increases towards the north. To fix the age of the beds in the northern part is very difficult, if not impossible, unless one is able to follow up the beds southwards into less metamorphised areas, or establish the same sequence as in these.

In 1936 I mapped the greater part of the Hecla Hoek area between Bellsund and Hornsund. The rocks here are partly gneiss, garnetiferous mica-schist, mica-schist, and marble. In a small area north of Hornsund gabbro occurs, and partly completely remolten rocks with transitions to granite, but, generally speaking, the sequence is here less metamorphic. The most common rocks are limestones, dolomites, phyllites, quartzites, conglomerates, and clay-slate. Despite intensive search for fossils I only succeeded in finding a tube-like fragment in a partly dolomitized limestone on the east side of Gåshamna in Hornsund. It is certainly a fossil, probably a crinoid stem. These limestones are at any rate younger than Algonkian, most probably Ordovician. The limestones of this carbonate series are very similar to the Tetradium Limestone on Bear Island, but without better fossil evidence I would hesitate to correlate it with the Bear Island limestone, although it cannot be far off, stratigraphically speaking.

These strata run southwards to the southernmost promontory of Spitsbergen, and I am inclined to believe that just here the solution of this particular Hecla Hoek problem will be found, and it is also likely that fossils will be found in these very limestones. Unfortunately, the limited time at my disposal did not allow of my carrying out any work here.

The beds between Hornsund and Bellsund are strongly folded, partly overfolded, overthrust, and faulted so that it is very difficult to give a connected section throughout the entire series. There are also two horizons with big conglomerates apparently representing breaks in the deposition, and perhaps big unconformities, even if these may be difficult to prove directly. As the sequence has a thickness of several thousand metres it represents a considerable space of time.

## The Caledonian Mountain Folding.

It must be taken as proved that the pre-Downtonian sequence (Hecla Hoek) in Spitsbergen contains strata from pre-Cambrian to Middle Ordovician. To judge from the rocks there have been many changes and partly interruptions in the sedimentation. Generally speaking, however, we may assume that the beds have been deposited in a shallow sea with a steadily subsiding sea-bottom. Deep-sea deposits have not been found among the sediments of the Hecla Hoek, corroborating the belief that the geosynclinal zones are shelf zones or *Flachmeere*.

The strata were all strongly folded, overthrust and faulted during the Caledonian mountain-folding. A series of igneous rocks were also intruded. The deeper zones were subjected to a strong metamorphism and here remelting and crystallization, giving rise to new rocks, have taken place.

There have not been found within the Hecla Hoek any manifest unconformities with different degrees of metamorphism of the rocks above and below it; one must therefore believe that the main folding and the metamorphism have affected the entire sequence simultaneously. On the other hand, extensive, thick, and coarse conglomerates in the Hecla Hoek show that the subsidence during the sedimentation has not been uniform. It must have been interrupted by elevations, perhaps accompanied by a gentle folding, followed by erosion into rocks already subjected to diagenetic changes. The age of these interruptions is by no means clear, but future investigations may throw light upon this question.

Among the conglomerates which have come to my notice in southern Spitsbergen, there are two which are so conspicuous that they must represent big breaks. The oldest is distributed from Sørkapp to Dunderbukta; occurs north of Kistefjellet (according to W. Solheim), in Fannytoppen, Orvinfjellet, coastal mountains south of Dunderbukta, and in the mountains east of Torellbreen. This conglomerate has locally a great thickness and contains chiefly quartzitic more or less rounded fragments, having a diameter up to one metre. In places the conglomerate resembles morainic material, but whether it represents an eo-Cambrian tillite horizon I cannot say for certain.

The other conglomerate occurs west of Recherchefjorden and contains chiefly pebbles and boulders of limestone and dolomite having a diameter up to half a metre and more. This thick series bears in places some resemblance to tillite, but can also be found without such. The rocks of the boulders are similar to the older calcareous Hecla Hoek rocks, and there can be no doubt that the boulders originate from these. The boundary below the conglomerate series is everywhere hidden by scree deposits. It is, however, likely that we have here an unconformity and quite a considerable hiatus in the sequence. None of the conglomerates rest on the underlying beds with a *pronounced* unconformity, indicating that they represent the termination of periods of a slow rise of the land accompanied perhaps by a gentle folding. The strongest earth-movements are at any rate younger than the Kapp Lyell conglomerate, whose boulders are much deformed and stressed. The latter folding process has taken place in Silurian times, previous to the deposition of the non-metamorphic Downtonian strata. It is probable that the main phase of the folding corresponds to the Ardennian (Stille), between the Middle and Upper Silurian, as in the Trondheim region in Norway. It may also be somewhat older (Taconian). All that can be said with certainty is that it is not older than Middle Ordovician as found on Bear Island. (See Pl. IV.)

During the Caledonian folding igneous rocks were intruded and are chiefly found in the north. Most common are granites, occurring as is well-known, in two main types: 1) Grey strongly foliated granite, and 2) red, not foliated granite. It has been suggested that the grey granite is older and has been intruded during the folding. It occurs at many points: Dei Sju Isfjella, Magdalenefjorden, Danskøya, Amsterdamøya, Norskøya, coast from Raudfjorden to Smeerenburgfjorden, in the Newton massif, and in the northern part of Nordaustlandet. The granite is frequently interstratified with a grey gneiss, and many pegmatite dykes occur along the margin of the granite. Most of it is a biotite granite, but from Smeerenburg an amphibole granite has also been described.

The other type is red and not foliated, apparently younger and belonging to the last phases of the folding. It is distributed west of Raudfjorden, covers a large area west of Liefdefjorden and thence southwards into the inland east of Kongsfjorden; it occurs in the Tsjernysjov massif in Ny-Friesland, in the central part of Nordaustlandet, and at Isispynten along with a diorite. The latter rock is also known from Smeerenburgfjorden and the northern part of Storøya.

Generally speaking the grey granites are found in the northern part of Spitsbergen and seems to belong to a deeper zone of the mountain folding.

In a recent paper Erwin Schenk (1937) maintains that the grey granite of North Spitsbergen is a para-granite resulting from the re-melting of Hecla Hoek rocks (anatexis of Sederholm). Schenk says that this granitization took place under a hydrostatic pressure, when the Caledonian folding had already terminated. Only thus is he able to explain the gradual transition from typical Hecla Hoek rocks to granites, and the transition stages which had the structure of the Hecla Hoek, but otherwise the composition and appearance of the gneiss and granite.

I would like to mention that before this paper came to my notice I came to similar results in a small highly metamorphic area near the coast north of Hornsund. The original beds here are limestone, sand-stone, clay-slate, etc. They are penetrated by various basic rocks having a coarse grained, porphyritic, and also a fine grained texture; partly they are foliated. Near these gabbros is found the ordinary mica-schist with garnets, but there is also to be seen a most remarkable change of the original sandstone, from a pure quartzite into a micaceous quart-zite, then into a rock composed of quartz and mica with streaks and grains of not resorbed quartzite, and finally into a greisen-like mica-quartz rock which must originate from a complete remelting of the quartzite with infiltration of micaforming substances. Locally, where the addition of foreign material has been sufficient to give the remolten rock the chemical composition of a granite, such a rock has in fact been formed, with crystals of feldspar as in an ordinary granite. Transition types between these rocks are evident, and nothing in this area points to larger granite intrusions, or well limited granitic dykes. Thus is likely that we have here reached the upper part of completely remolten Hecla Hoek rocks. This mode of formation explains readily the gradual transition and the large amount of various transition rocks in or near the zone of remelting. It also explains the fact that in the north of Spitsbergen we find in some places biotite granite, in others amphibol granite, diorite, or syenite. The melts must have been for-med locally and with a fortuitous composition, only dependent upon the composition of the remolten sediments.

North of Hornsund the gabbros were, we must believe, intruded during the Caledonian mountain folding, and they have obviously con-tributed to the metamorphism within this area.

In the north of Spitsbergen it is possible to follow the change of the Hecla Hoek sediments into paragneisses, and of these into granites with about the same composition. It is therefore reasonable to assume that the source has been the same in all cases, viz. the Hecla Hoek sediments. On the other hand, granitic magmas might also have been intruded, causing a remelting of the rocks and formation of various transition links. The result is the same in both cases: remelting of the Hecla Hoek into rocks with the texture of an igneous rock. In future investigations this explanation should not be ignored.

Apparently Hinlopenstredet and Bear Island are situated on the outskirts of the folding zone, but it is also possible that these areas were in the upper part of the folding, which is probably the case with the southernmost part of Spitsbergen. If the Hecla Hoek east of Hinlopenstredet be in the eastern part of the metamorphic zone, the Hecla Hoek rocks on either side of Rijpfjorden should be expected to be less metamorphic, but little information is available about the conditions here. Nordenskiöld describes them as quartzite, slate, and limestone, partly as phyllite, so that these beds are probably metamorphic to the same degree as the rocks on the east side of Hinlopenstredet.

The Hecla Hoek of the outer coast from Bellsund to Torellbreen appears to be less metamorphic than the strata farther east. This coastal area seems to have been lowered considerably in relation to the inland and the coast on the north side of Hornsund. The fault line runs along the Recherche- and Torellbreen. In Tertiary times the part to the west of it has at any rate been much lowered, but it is possible that this line of weakness is much older. A big fault runs through Orvindalen, north of Torellbreen, and displaces the whole sequence southwest of Dunderdalen, but it is difficult to say whether this fault is very old or not, as its continuation into the younger fault system has not been ascertained.

The trend of the Caledonian folding varies somewhat from the direction of the Tertiary folding. Generally speaking it runs north-and-south, whereas the latter has a more westerly trend. But the angle between the folding axes is not great. At some points the pre-Downtonian beds have been strongly influenced by the Tertiary folding so as to change their strike.

The details of the Caledonian folding will not be dealt with in this paper. I shall only mention that it has been very intense, so that the beds have been isoclinally folded several times, that they have been partly overthrust to the east, or overfolded into big flat-lying folds as seen in the limestones of Tsjebysjovfjellet on the southern shore of Hornsund and in Luciakammen on the north side of Burgerbukta, Hornsund. The tectonics of the Hecla Hoek are very complicated, and much remains to be done to get the problems solved.

The Caledonian mountain folding has played a very important rôle in the geological history of Svalbard, changing it from a geosynclinal area covered by the sea, to a mountainous country extending from the present Svalbard southwards to Norway, and northwest perhaps to Greenland, which then might have had a position more to the east, and nearer to Svalbard.

Deep valleys were now cut into the ground, and the material was transported down to the sea and deposited as *molasses* unconformably on the folded and metamorphic Hecla Hoek beds. We have reached the youngest Silurian or Downtonian; the Caledonian mountain folding has come to an end.

## Younger Silurian and Devonian.

The first sediments of the molasse type occurring on the ruins of the Caledonian "Mountains" is the *Raudfjord Series*, of Younger Downtonian and Dittonian age, and consisting of coarse conglomerates and sandy sediments. Without any break this series seems to pass into similar sediments of Lower Devonian age. There is, however, a possibility of an unconformity between the Raudfjord Series and the following Woodfjord Series, as Hoel has found that the Woodfjord Series in the Pretender mountain east of Kongsfjorden rests on granite. This may be due to a deposition of the Upper Silurian beds in depressions, and that the sea has transgressed across the higher parts of the ground. If that be so it is probable that the strata on Brøggerhalvøya, resting directly on the Hecla Hoek, also belong to the Woodfjord Series.

The first conglomerates and sandstones were at any rate deposited in valleys, but as the country was denuded the weathering products became finer, and were transported towards the sea and deposited in deltas, estuaries, and partly in the open sea.

The Raudfjord- and the Woodfjord Series contain both red, sandy beds stained by iron oxides. They were probably deposited under desert or very dry conditions, whereas the overlying Gråhuk- and Wijdefjord Series — being more fine-grained and grey — were deposited when the climate had turned more humid, this being more pronounced in younger Upper Devonian of Bear Island. According to Heintz the Woodfjord Series belongs to the lower part of Lower Devonian, Gråhuk Series to the upper and middle part of the Lower Devonian, and the Wijdefjord Series and the Fiskekløft Series in Mimerdalen to the middle and upper part of Middle Devonian. The question of the occurrence of the missing beds has not yet been decided.

Hoel and Holtedahl have estimated the total thickness of the entire Downtonian-Devonian sequence at about 9000 metres. This great thickness indicates a very considerable subsidence of the sea-bottom. But the thickness given is probably not the total thickness at one particular point, but has been found by adding up the thicknesses from Raudfjorden to Wijdefjorden. The lower beds were at any rate deposited in deltas from west to east, and an adding up of the thicknesses would lead to figures giving a false impression of the amount of subsidence. Schenk (1937) is of the opinion that the Devonian has *not* that great thickness, and that the Wijdefjord Series lies *below* the Gråhuk Series. Heintz (1937), however, does not agree with the latter.

As the beds, generally speaking, seem to have been deposited from west to east, a land area west of Spitsbergen was probable in Lower and Middle Devonian times.

There was probably also land to the south, because Bear Island appears to have then been a degradation area. Upper Devonian rests here unconformably on the Hecla Hoek, and it is not unlikely that the sea during Downtonian to Upper Devonian times has trangressed southwards from North Spitsbergen to Bear Island.

The Devonian of Hornsund has not yet been sufficiently examined. When there in 1936 I found no fossils in the lowermost, partly red, series of limestones. sandstones, and conglomerates, and it is consequently undecided whether these belong to the Woodfjord Series (Lower Devonian) or are older. But above these I found marine, grey, sandy strata with masses of lamellibranchs, apparently in parts identical with those determined from the Gråhuk Series in the north. It must be regarded quite certain that the beds in question do correspond to that series.

## Earth Movements in Upper Devonian Times.

Previous to the deposition of Carboniferous sediments in Spitsbergen, the thick Downtonian and Devonian sequence suffered great changes. The land in general became elevated, the beds were faulted and partly folded, erosion set in through a long period, so that the metamorphic Hecla Hoek strata again became exposed throughout considerable areas. Devonian sediments were only preserved in a big *Graben* between north-and-south faults, and here it is possible to see the Downtonian-Devonian sediments, unless they have been covered by younger sediments. The probable extension of the D.-D. beds, previous to the deposition of the Culm, will be seen from Fig. 1, which also shows the known faults from that time.

In the north the *Graben* has a width of about 50 km (Fig. 2). It is bordered on the east side by the big fault along Wijdefjorden, across Pyramiden, Bille- and Sassenfjorden with a direction towards Kvalvågen on the west side of Storfjorden.

The southern portion of the fault traverses Tertiary strata, and it is only possible to trace it here because the faulting was partly repeated in Tertiary times. A small branch of the fault runs, after information by Th. Vogt, east of Kapp Petermann, and towards Mimerdalen. The main fault passes through the mountain Pyramiden, where the Carboniferous rests on the Devonian in the west, and on Hecla Hoek in the east.

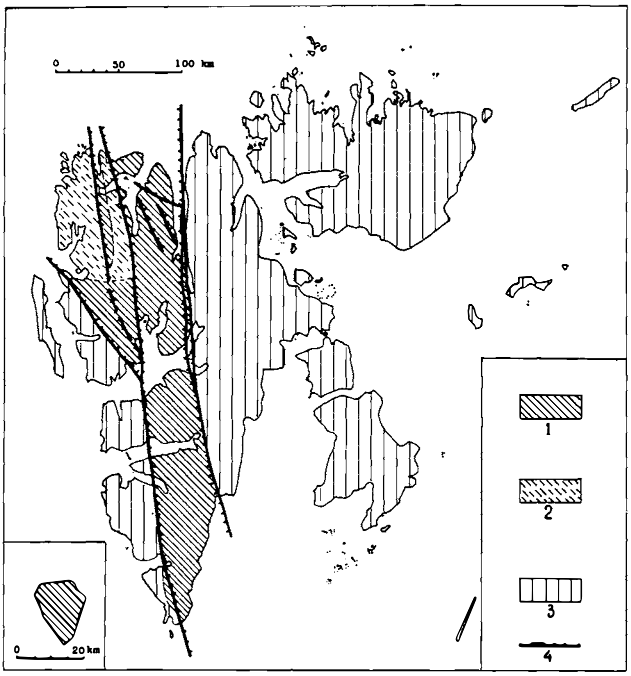


Fig. 1. Geological map of Svalbard before the Culm sediments were deposited.
1. Devonian and Upper Silurian. 2. Probably Devonian and Upper Silurian. 3. Hecla Hoek and eruptives. 4. Upper Devonian faults.

In the west several faults occur. The western main fault crosses Liefdefjorden, and runs towards Ekmanfjorden, but is here covered by glaciers and younger formations. It probably continues southwards below these to the inner part of Hornsund and along Samarinbreen and Mefonna to the west side of Keilhaufjellet where the fault enters the sea. Along the Hecla Hoek boundary in Hornsund the geology is very difficult to make out, the more so because the boundary on the north side of the fjord is hidden by large glaciers. There can be no doubt, however, that the Devonian beds to be seen below the younger strata on the north side of Hornsund are connected with the Devonian north of Isfjorden, and limited by a fault in the west. In Tertiary times the beds were also folded and overthrust, so that some kilometres north of Hornsund we find Devonian with *overlying* Hecla Hoek limestone thrust over the Carboniferous and Triassic.

South of Hornsund, from the eastern slopes of Hornsundtind to Hilmarfjellet, the Devonian rests (according to Hoel) unconformably on the Hecla Hoek, and in Kistefjellet, where Triassic rests on Hecla Hoek, it is missing. In Bredikinryggen farther to the east the Devonian strata seems to be conformable with the younger beds and are folded along with these. On the west side of this mountain Hoel has found metamorphic rocks which must be of Hecla Hoek age. This is only to be explained by a fault along the glacier with a downthrow on the west side. This earth movement is of Tertiary age, but it seems probable that the Tertiary fault follows the Devonian fracture line, which as mentioned above, is believed to follow about the same trace as the Tertiary fault. This Devonian fault makes it easier to explain the absence of Devonian at Sørkapp. If the eastern part has been lowered in relation to the western, we should expect to find Devonian below the younger strata east of the fault, whereas it has been removed by erosion on the west side. The Devonian between Hilmarfjellet and the east side of Hornsundtind thus becomes an erosion remnant on the west side of the fault, which here must have a lesser throw than in northern Spitsbergen. From the fault evidence in the north it is clear that the throw already here diminishes towards the south: North of Sigurdfjellet the Woodfjord Series outcrops on the east side of the fault, whereas the Raudfjord Series (the lowermost series) outcrops against the fault plane farther south.

The greater part of the Devonian is situated between this fault and the Wijdefjord fault, but as the latter has a much greater throw the beds have, generally speaking, an easterly dip.

A fault parallel to the Liefdefjord fault limits the Raudfjord Series in the west and runs along the west side of Raudfjorden southwards to the inland east of Kongsfjorden. Here it either dies out or continues southwards to Isfjorden, eventually joining the Liefdefjord fault. It is also to be assumed that there is a branch fault from Isfjorden, running some distance inland from St. Jonsfjorden, and across Brøggerhalvøya, on whose east side the Devonian occurs between the Carboniferous and the Hecla Hoek, but is missing on the west side. If this fault does exist, Devonian should be expected to occur next to the Hecla Hoek north-east of St. Jonsfjorden and east of the fault but be missing west of it, as the Devonian here was denuded before the Culm strata were deposited. To judge from the air photographs Goldschmidtfjellet consists of a dark rock, whose colour and type of weathering resemble those of the Devonian. On the map I have plotted it as Devonian?, as it has not been possible to find any information about the rocks in this mountain.

In addition to the mentioned Devonian faults, Schenck (1937) has traced NW—SE faults on the peninsula between Wijdefjorden and Liefdefjorden, with a downthrow on the NE-side (step-faults between two main faults). Signs of rather strong foldings have been found in the Devonian west of Billefjorden (Vogt) and west of Wijdefjorden (Schenk). Vogt is of the opinion that these foldings are not only due to the vertical displacements, but are also the result of a horizontal force.

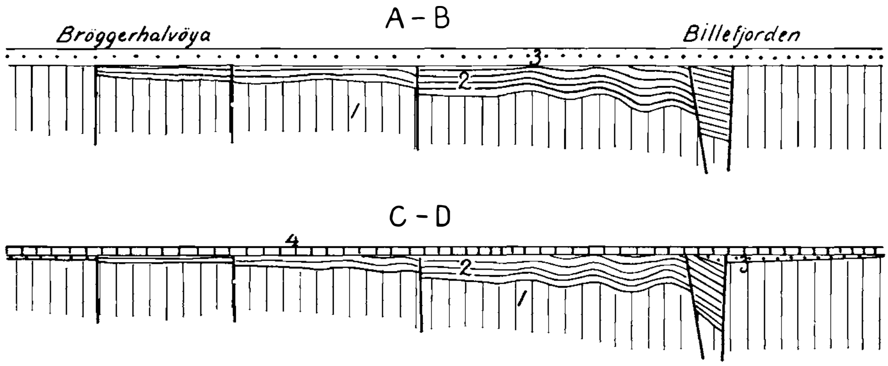


Fig. 2. Schematic section of the Devonian graben from Brøggerhalvøya to the east side of Billefjorden.

A—B. After the deposition of the Culm beds. C—D. After the deposition of the Lower Permian. 1. Hecla Hoek, 2. Devonian, 3. Culm, 4. Middle Carboniferous, Upper Carboniferous, and Lower Permian. Sections as seen from the south.

In Spitsbergen the unconformity below the Culm strata seems to indicate that these tectonic disturbances are contemporaneous with the Bretonian phase of folding (the oldest Variscian folding). Vogt, however, thinks that they are somewhat older — beginning of Upper Devonian — the upward limit being fixed by the unconformity below the Upper Devonian of Bear Island, where the Culm succeeds the Devonian, apparently conformably. He has given the name *Svalbard Folding* to this tectonic disturbance, and regards it as a posthumous Caledonian movement. This folding phase has also been found in Norway and England.

It is not probable that the Devonian just before the deposition of the Culm had any considerable greater extension than it has to-day. It may, however, have covered, entirely or partly, the area north of Kongsfjorden. Erosion was active throughout the Upper Devonian in Spitsbergen, then being a land area, whereas sedimentation took place on Bear Island, which must have been situated near the shore, i. e. the reverse of what was the case in the older Devonian. In Novaya Zemlya marine beds of Lower and Middle Devonian age have been found, showing that the sea extended right from Spitsbergen to these parts.

## Carboniferous and Permian.

At the beginning of the Carboniferous a general submergence of the entire Svalbard area commenced, but was accompanied by an intensive sedimentation. Throughout the Culm period the surface of the sea-bottom and adjoining parts of the land was near sea-level, so that the sediments deposited were mostly sandy and of littoral and continental character. At the advent of Middle Carboniferous the sea encroached on the land, and marine sediments, mostly calcareous, were deposited throughout the remaining part of the Carboniferous. However, interruptions in the sedimentation are known, with emergence of the land and erosion particularly in the southern part of Svalbard.

### Culm.

The humid, sub-tropical climate which on Bear Island is manifest in the Upper Devonian is also evident throughout the greater part of the Lower Carboniferous. The slight subsidence, which on Bear Island commenced as early as in the Upper Devonian, continued in the Lower Carboniferous throughout the Svalbard area. But this subsidence was balanced by an intensive sedimentation from the high land near by, so that the sea did not encroach on the land. Deposition took place of conglomerates with well rounded pebbles, a great thickness of rather pure quartz sand indurated into a hard, light grey, rather coarse sandstone. On account of the humid climate and the action of the humic acid originating from the luxuriant plant growth, the more easily soluble components, such as oxides of iron, were dissolved and removed. The air temperature at that time is estimated to have been about 30° C higher than it is now.

In periods with the land remaining at about the level of the sea there were extensive sub-tropical forests. The Culm sediments are all to be regarded as continental (and littoral), and deposited, as Nathorst has pointed out, in fresh water, but also in brackish water.

Originally they extended probably throughout the entire Svalbard area, but great tectonic movements with elevation and erosion of the land previous to the subsidence in Middle and Upper Carboniferous times have caused the removal of the greater part of the Culm sediments, and only remnants are left in various localities. In Fig. 3 will be seen the distribution of the different systems previous to the Middle Carboniferous subsidence.

It is not possible to find out whether the Culm occurs underneath the younger strata in the south-east of Spitsbergen. The central Culm area is now found on the peninsula between Isfjorden and Bellsund. At the mouth of Isfjorden the thickness is, according to Holtedahl, about 1200 metres, and in the area north of Bellsund 980 metres (Hoel). Wherever the Culm is found there is at the base a conglomerate with well-rounded pebbles, resting with a pronounced unconformity on the Hecla Hoek (Devonian plane of erosion). As the conglomerate has a wide distribution it seems likely that the surface of the land was eroded down to base-level. Especially in the lower part of the Culm there are several layers of black shale, and in one horizon of carbonaceous

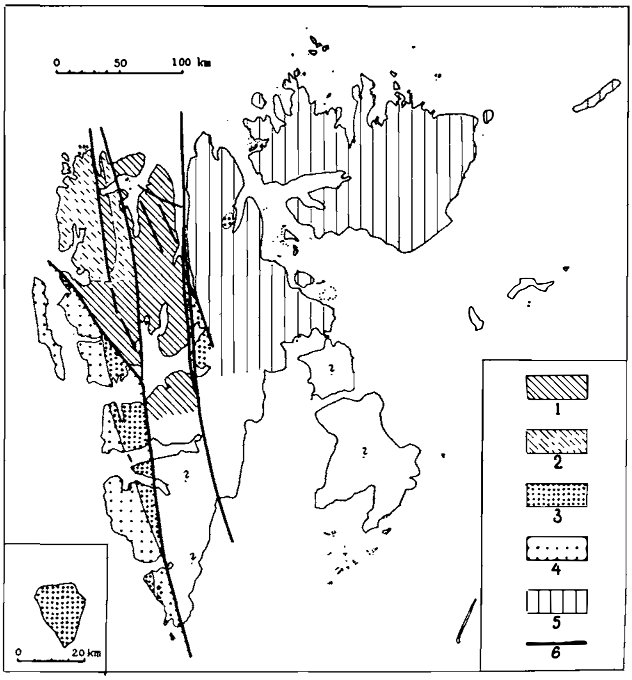


Fig. 3. Geological map of Svalbard before deposition of the Middle Carboniferous beds.
1. Upper Silurian and Devonian. 2. Probably Upper Silurian and Devonian. 3. Lower Carboniferous. 4. Probably Lower Carboniferous. 5. Hecla Hoek and eruptives. 6. Old faults re-faulted before the deposition of the Middle Carboniferous.

shale streaks and lenses of coal occur. In 1913 The Northern Exploration Company examined the Culm seam on the north side of Bellsund, but the coals were found to be too thin and high in ash. Shales with plant fossils also occur in the lower part of the Culm. Its thickness decreases southwards from Bellsund, and in the Reinodden section I measured from below in 1936: sandstone 200 metres, diabase 45 metres, sandstone, etc. 350 metres. The total thickness is thus at least 550 metres, and is probably more, for the lowermost beds are covered by the sea. Farther east, at Ahlstrandodden, I found the thickness to be roughly 200 metres. (See Pl. II.)

On the north side of Hornsund I examined a few localities in 1936, but owing to lack of fossils it was very difficult in the short time I had to my disposal to prove the occurrence of Culm beds, or whether the entire succession below the Permian chert is Upper or Middle Carboniferous right down to the marine Devonian. Unfortunately it is not possible to trace the section continuously on account of tectonic disturbances. To judge from the air photographs one should be able to follow almost the entire succession to about midway between Hornsund and Sørkapp. Investigations here would probably lead to the solution of the quite complicated geology in the inner part of Hornsund. In the northernmost part of the mountains east of Burgerbukta there are beds of arenaceous limestone, limestone, and sandstone of perhaps Middle Carboniferous age. Below these come 60 metres of grey sandstone. and then a thickness of 300 metres with grey sandstones — in benches up to three metres thick — and thin conglomerates, thick beds of red, loose sandstones, and sandy shales. Between this set of beds and the 60-metre sandstone there is either an unconformity or a tectonic disturbance, perhaps only a small fault at a low angle with the bedding, and younger than the folding. This sequence might be of Culm age, but I am more inclined to believe that it belongs to the Middle Carboniferous and is equivalent to the partly red beds between the Cyathophyllum Limestone and the Culm at Reinodden. South of the Hornsund entrance there is also an area with Culm deposits, having a thickness of about 1000 metres, but here the Culm has the same development as in the Isfjord area, viz. thick grey sandstones, dark shales with fossils and coal-seams. It is not probable that the character of the beds should be much different in the inner part of the fjord. The beds at the Hornsund entrance are dipping 10—15 degrees to the south, but do not reappear in the mountains on the north side of the fjord, as the Culm base runs clear of the summits. This Culm area lies *west* of the Devonian *Graben*, and the Devonian beds have been eroded away before the deposition of the Culm, as is also the case at Isfjorden and Bellsund. North of the former Holtedahl has traced the Culm from Trygghamna to the region east of St. Jonsfjorden. At Billefjorden there is Culm in the mountain Pyramiden and around the fjord.

According to Lutkewitch the section in Pyramiden is the following:

(top) Upper Carboniferous limestone and dolomite with Fusulina, and lowermost grey sandstone with beds of limestone.
75—300 metres of reddish conglomerates and sandstones, disappearing towards Bertilbreen.
200—250 metres of sandstone and gypsum, tapering out towards the west in Pyramiden.
80—150 metres of sandstone, shale, and coal (Culm).
Unconformity.
Devonian.

Whether the red conglomerates and the gypsum series are of Culm age is rather uncertain (Lutkewitch). As gypsum and anhydrite were deposited in lagoons, and as the red series seems to indicate a dry climate, in contradistinction to the moist climate of the Culm, it is more likely that these beds belong to the Middle Carboniferous. From their position in the sequence there can be no doubt that the red series here, and perhaps also the gypsum-anhydrite series, correspond to the red beds between the Culm and the Cyathophyllum Limestone at Reinodden on the eastern side of Recherchefjorden, and also to the red, sandy beds occurring east of Burgerbukta in Hornsund, below certain Middle or Upper Carboniferous. (See Pl. II.)

The sedimentation of the beds following the Culm at Billefjorden appears to have been very irregular (Fig. 10), and I consider it very probable that the various sets of beds are separated by unconformities, as there must have been several periods with elevation and subsidence at the entrance to Middle Carboniferous times.

Culm has also been found on the west side of Brøggerhalvøya, where there is a coal-seam. Here, too, partly red conglomerates occur above the Culm, being of Middle Carboniferous age. Some sandy beds on the west side of Lomfjorden probably also belong to the Culm, but may be of Middle Carboniferous age.

On Bear Island the thickness of the Culm varies from 110 to 230 metres, and the series is followed by partly red conglomerates, but the exact boundary is difficult to fix.

## Earth Movements Culm—Middle Carboniferous.

The Culm sediments are irregularly distributed, or may even be entirely missing in the sequence, as they are between Ekmanfjorden and Hinlopenstredet. These conditions are due to the quite strong earth-movements which supervened when passing from Lower to Middle Carboniferous times. These movements consisted in an elevation of blocks of the land followed by erosion, and the displacements took place after the Devonian lines of fracture. The entire coastal area west of the Devonian *Graben* was relatively lowered, and during the period of erosion the Culm sediments were removed from the surface of the *Graben*, excepting a small area west of the inner part of Billefjorden, where a lowering of the fjord area relative to the east side of the fjord caused a part of the succession to be preserved locally. Otherwise the biggest subsidence took place west of the westernmost Devonian fault in the Isfjord area, and at Bellsund and Hornsund, for which reason most of the Culm is preserved here. It is doubtful whether the Culm beds exposed here extend farther east than to this fault. It is more likely that the Middle or Upper Carboniferous east of the fault rests directly on the Devonian as is apparently the case in the inner part of Hornsund. It is possible that the fault limiting the Culm on the south side of Hornsund also was formed by this time, at any rate it is pre-Triassic.

From Fig. 3 will be seen which faults were re-faulted by this time, and the distribution of the Culm previous to the deposition of the marine Carboniferous.

The elevation and the block-faulting are likely to have taken place on the border of Lower and Middle Carboniferous, and correspond to the Sudetian phase of folding. Vogt (1929) is of the opinion that the unconformity above the Culm belongs to the Upper Carboniferous — that time which is represented by the unconformity between the Fusulina and Cora Limestone on Bear Island — and is the equivalent or the Asturian phase of folding. This is in agreement with the conditions on Bear Island where this phase is represented by a pronounced angular unconformity, but not with the geology in Kongsfjorden where the Middle Carboniferous rests partly on Culm, partly on Devonian. As will appear from the following the Cora Limestone on Bear Island is probably younger than previously assumed; it is of the same age as the Lower Spirifer Limestone below the Chert in the Festning section, i. e. also younger than the Cyathophyllum Limestone.

The tectonic disturbances must have taken place before the sea transgressed on the land, and left the extensive conglomerates below the Middle and Upper Carboniferous limestones and dolomites. But the age of these conglomerates may vary from Middle to Upper Carboniferous as the transgression advanced. It has been thought that the Middle Carboniferous was absent in the central and southern part of Spitsbergen, but this is apparently not the case. At Isfjorden, Bellsund, and at Hornsund there occur conglomerates, sandstones, and limestones strongly resembling the beds at Kongsfjorden and on Bear Island, but they are not as yet sufficiently studied.

## Middle Carboniferous—Permian.

Now followed a slow and extensive subsidence of the entire Svalbard area, which continued into the Permian period. The depression was not even, so that the marine deposits do not represent a continuity.

The sedimentation was interrupted several times, either because the surface of the land was so low that no erosion, transport, and sedimentation of material could take place (*hiatus* in the succession); or because the land became uplifted, and some of the beds were removed by erosion. In Spitsbergen it is difficult to point out pronounced unconformities because the beds have been more or less horizontal all the time, but on Bear Island there are marked unconformities below and above the Cora Limestone showing earth-movements with uplift and erosion, followed by subsidence and again sedimentation.

When the ocean in Middle Carboniferous times encroached upon the land it left behind littoral deposits such as conglomerates, sandstones, and calcareous beds, partly with corals and a marine fauna, having a thickness of 470 metres on Bear Island, in Spitsbergen less and so far with no fixed boundary upwards. Holtedahl found these beds on the south side of Kongsfjorden in Spitsbergen; otherwise it was thought that the Middle Carboniferous was absent from central and southern Spitsbergen. If that is so this part of Svalbard would have been a land mass between the advancing sea to the north and south; or the Middle Carboniferous beds, if deposited here, have been removed later by erosion. Opinions have differed as to the direction of the transgression, but before this question can be settled it is necessary to find out which of the different beds are oldest, and if they really are wanting in southern Spitsbergen. To judge from the resemblance with the Russian Middle Carboniferous there should have been a connection with the sea to the east.

Middle Carboniferous is known to exist with certainty at Kongsfjorden. But, as already pointed out, I think it is very likely that Middle Carboniferous beds are found in many localities in Spitsbergen below the Upper Carboniferous, and partly with a considerable thickness, as at Reinodden and in the inner part of Hornsund.

The Lower Gypsum-Anhydrite Series at Billefjorden indicates lagoons and desert or very dry conditions, whereas the Culm period had a moist climate. Nathorst reports that this series rests partly on Culm and partly on granite, and should consequently be younger than the mentioned earth-movements at the base of the Middle Carboniferous. Both stratigraphically and climatically the beds are thus more of the Middle Carboniferous than of the Culm type. The same conditions are met with somewhat higher up in the Upper Carboniferous limestone, also at Billefjorden, with a gypsum-anhydrite series nearly 100 metres in thickness. The same series is also found at Bellsund, but here with a thickness of 30 metres only. On the south side of Isfjorden, on the point east of Russekjeila, there is on top of the Culm a conglomerate about 15—20 metres in thickness, and in the scree above is seen a red conglomeratic and sandy passage series to the Cyathophyllum Limestone. There is nothing to prevent this series being older than the Upper Carboniferous.

At Reinodden on the south side of Hornsund I measured roughly in 1936 a series about 200 metres thick consisting of red conglomerates and sandstones lying between the Culm and the Cyathophyllum Limestone. I got the impression that they strongly resembled the Middle Carboniferous beds on Bear Island and the lowermost strata at Kongsfjorden. At Ahlstrandodden, however, I did not find this series, which was therefore probably deposited quite irregularly.

Northernmost in the mountain on the east side of Burgerbukta in Hornsund we have the following section of this stage:

| | | |
|---|---|---|
| 12 | metres | Fossiliferous, cherty limestone. (Permian?) |
| abt. 40 | — | Grey fine-grained dolomitic sandstone, yellow weathering |
| - 4 | — | Hard sandstone |
| - 4 | — | Bench of limestone with corals |
| - 50 | — | Benches of limestone and sandy limestone |
| - 60 | — | Grey sandstone and conglomerates |
| - 300 | — | Benches of grey sandstone with thin conglomerates and many thick beds of loose red sandstones and sandy shales. |

These beds are more of the Middle than of the Upper Carboniferous type, but may represent a local development of the latter.

Farther south in the same mountain we have similar passage beds, but here the cherty beds rest unconformably on a coral limestone. Thus the Cyathophyllum and the Spirifer Limestone are wanting in this section. I think it highly probable that they were removed by erosion. In this period the Svalbard area must have been alternating a shallow sea with broad bays, and low-lying land. According to Staff and Wedekind Fusulina also lived in brackish water — in lagoons and bays.

The Cyathophyllum Limestone is distributed throughout the central and northern part of Spitsbergen; and in the Isfjord—Bellsund area it is followed by a bed of limestone, 10—20 metres thick, packed with marine fossils. Nathorst was of opinion that this bed was the same as the Spirifer Limestone beneath the chert rocks in Tempelfjellet, but the latest determinations by Frebold (1937) of the fossil collections brought home by the author in 1923 from the section of the Upper Carboniferous—Permian west of Festningen, show that the Spirifer Limestone in Tempelfjellet corresponds to a stage in the Festning section situated in the *middle* of the cherty series, whereas the bed beneath this series is identical with the Cora Limestone of Bear Island. This has already been emphasised by A. M. Grabau in his paper: The Permian of Mongolia, where he also points out that the Spirifer Limestone of Bear Island corresponds with the Schwagerina Limestone of Ural, and is partly identical with the Spirifer Limestone in Tempelfjellet. If this is correct, and there is no reason to doubt it, the Cyathophyllum Limestone stage is entirely wanting on Bear Island, and there must have been land with erosion from South-Spitsbergen to Bear Island, before the deposition of the Cora Limestone.

The pronounced unconformity between the Bear Island Fusulina and Cora Limestone thus represents a long period and a big break (hiatus) in the succession as well. The tectonic disturbance and erosion represented by this unconformity should correspond approximately to the Asturian phase of folding.

The fossiliferous bed between the Cyathophyllum Limestone and the cherty series in the Festning section, is, according to the above, identical with the Cora Limestone on Bear Island, and should also bear this name on Spitsbergen to prevent it being mistaken for the Upper Spirifer Limestone of Tempelfjellet. Nathorst found that the Cora Limestone of Spitsbergen (Lower Spirifer Limestone) was a typical shallow-water deposit formed in brackish water. It contains sandstone strata and water-worn fossils. When it is born in mind that the Cora Limestone of Bear Island lies above a big unconformity, Nathorst's opinion seems still more natural. He was also aware that these repeated transgressions and disturbances might bear some relation to the contemporaneous formation of the Uralides with their branch Timan-Kanin.

I observed the Cora Limestone in 1936 in Midterhuken in Bellsund and on Reinodden on its south side, but at Hornsund I could not trace it. On Bear Island it occurs as an erosion remnant between two typical unconformities.

Going upwards in the succession we find in the Festning section that the Cora Limestone is overlain, apparently conformably, by Upper Carboniferous cherty rocks, then Schwagerina Limestone (Upper Spirifer Limestone) and about 100 metres of Lower Permian chert, followed conformably by eo-Triassic beds. In Tempelfjellet there are no cherty rocks beneath the Schwagerina Limestone. At Bellsund the succession has about the same development as at Isfjorden. In Midterhuken the Cora Limestone (Lower Spirifer Limestone) is exposed at the bottom of the cherty rocks. This is also the case at Reinodden where we have above the Middle(?) Carboniferous strata 140 metres of Cyathophyllum Limestone, 4—5 metres of Cora Limestone (Lower Spirifer Lmst.), and 285 metres of cherty and calcareous rocks of Upper Carboniferous and Lower Permian age. Then follow sandy beds (Lower Triassic). As it was difficult to examine the sea-cliff without a boat I could not make out whether the Upper Spirifer Limestone (Schwagerina Limestone) was present. At Ahlstrandodden there is a limestone bench 7 metres in thickness, and about 140 metres above the base of the cherty rocks. It contains less fossils than the Upper Spirifer Limestone farther north, but is perhaps identical with it. The series of cherty rocks has a thickness estimated to be about 250 metres, and the Cyathophyllum Limestone to about 140 metres.

At Hornsund there is only 12 metres left of the cherty rocks, and both the Cora and the Spirifer Limestone are absent. The fossils of the Hornsund chert have so far not been determined, and it is therefore not possible to say whether it represents the beds above the Schwagerina limestone, i. e. Permian, or the beds beneath, i. e. Upper Carboniferous.

It is most probable that the unconformity below the chert at Hornsund corresponds to the unconformity below the Spirifer Limestone (Schwagerina Limestone) on Bear Island. At Isfjorden and in the northern part of Spitsbergen uninterrupted sedimentation seems to have taken place during this period. On Bear Island it is quite clear that this unconformity represents the final stage of a rather long period with elevation of the southern area, accompanied by a slight folding and dislocation. At Hornsund the Cora rock seems also to have been removed by erosion. During the deposition of the Spirifer Limestone to the north and south it is possible that there still was land at Hornsund. This cannot be fixed before the beds have been more closely examined.

In Svalbard there has been much doubt as to which system the various stages of this succession should be referred to. Formerly the cherty sequence was considered to represent passage beds to Permian and termed Permo-Carboniferous, whereas the Cora Limestone (Lower Spirifer Limestone) and the Cyathophyllum Limestone were referred to the Upper Carboniferous. Grabau puts even the upper part of the Cyathophyllum Limestone as Permian. In the Festning section Frebold places the line between Upper Carboniferous and Lower Permian above the Schwagerina Limestone (Upper Spirifer Limestone). A part of the cherty series thus becomes Lower Permian, and another part Upper Carboniferous. As it is very difficult to divide the series from Middle Carboniferous to Lower Permian, be it from fossils or rocks to which should be added conflicting opinions — the entire succession has been put together on the map and in the description. Petrographically the beds are, however, much related.

The cherty rocks of Spitsbergen are thought to have been deposited in a sea not more than 300 metres in depth, and it must have been connected with the sea at East Greenland and the Ural. But towards Bear Island the cherty beds are partly replaced by a highly fossiliferous shallow-water limestone with a littoral fauna, and the shore must have been quite near. These conditions must bear relation to a slow submergence of the sea-bottom in the north during the passage from Carboniferous to Permian times. The uppermost layers have probably had a greater thickness both on Bear Island and in the south of Spitsbergen, but has suffered erosion in Permian times. In Spitsbergen, these beds are succeeded by Lower Triassic and on Bear Island by Upper Triassic, and thus a great part of the Permian is wanting, making it probable that the land-surface during this time has been above sea-level. The uplift towards the end of Permian or beginning of the Triassic Period must have been fairly regular, but greatest in the south. A bed of glauconitic sandstone, abt. 40 metres thick, occurring near the top of this succession at Kongsfjorden and north of the inner part of Isfjorden, is absent in the Festning section and southwards.

The uplift is probably equivalent to the last two of the Variscian orogenetic phases, viz. the Saalian or more likely the Pfalzian, the latter falling on the border of the Trias.

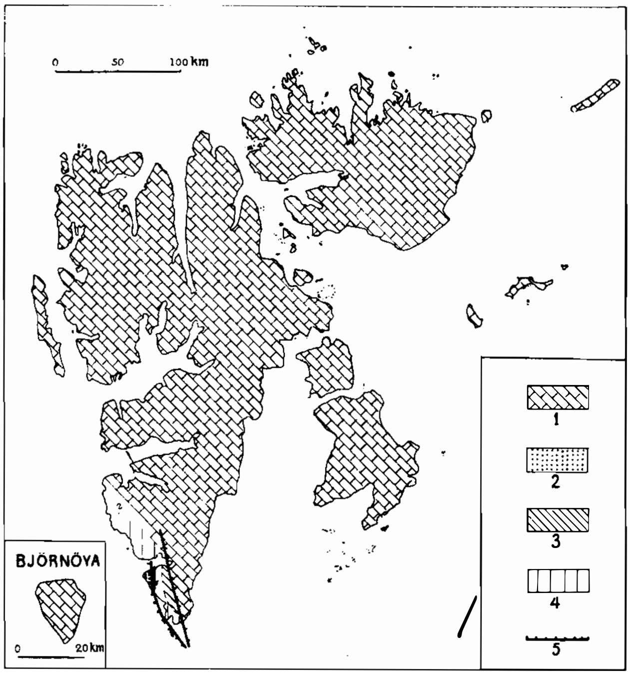


Fig. 4. Geological map of Svalbard before the Triassic beds were deposited.
1. Upper Carboniferous and Lower Permian. 2. Lower Carboniferous. 3. Devonian.
4. Hecla Hoek and eruptives. 5. Pre-Triassic faults.

At the same time block-faulting took place, as is manifest in the extreme southern part of Spitsbergen, where, according to Hoel and Werenskiold, the Triassic beds are resting directly upon the Hecla Hoek in Kistefjellet, along the coast, and in some mountains to the north, whereas east and west of these localities the beds rest upon the Lower Carboniferous or Permian. The explanation must be that the part west of the Devonian fault from the bottom of Hornsund to the Keilhaufjellet has been uplifted in relation to the part east of the fault, and perhaps also in relation to the Carboniferous beds on Sørkappøya along a fault on the east side of the island, but we have little information about thicknesses and succession here.

From fig. 4 will be seen the situation before the deposition of the Triassic rocks.

## Triassic.

After the erosion period of the last part of the Permian, the Svalbard area underwent an extensive an prolonged subsidence, which commenced in the Lower Triassic. We now meet sediments of Triassic age, and almost the complete succession southwards to Hornsund and eastwards to Barentsøya and Edgeøya. South of the outer part of

Hornsund there is apparently only eo-Triassic, whereas Kistefjellet at Sørkapp and Bear Island only have Upper Triassic beds.

The greater part of the eo-Triassic beds, formerly thought to be of Permian age, consists of sandstones, calcareous sandstones, marls, and limestones. They are poor in fossils. The succession, littoral or marine, increases in thickness from the inner part of Isfjorden to the south side of Bellsund, decreases on going south to Hornsund, and disappears in Kistefjellet. In Sassendalen the thickness is hardly more than 150 metres, in the Festning section 245 metres, in Midterhuken in Bellsund probably about 500 metres, on Reinodden about 400 metres and very sandy, and in the Hornsund area 180 metres and less.

Following these beds come chiefly black and black-grey, partly sandy marls from the younger eo-Triassic and Middle Triassic. These beds contain many remains of reptiles, fish fossils, ammonites, bivalves, layers of coprolites, etc. indicating a prolific marine life. The thickness varies from less than 100 to more than 400 metres. The greatest thickness has been found in the Festning section, but it is possible that the soft shales have been folded together during the Tertiary folding.

Then follows a smaller series with conspicuous sandstones, shales, etc. It is partly continental with plant fossils and even thin coal-seams. I have seen streaks of coal at Sassenfjorden, Gripp has observed coal at Agardhbukta, and Heuglin (1870) reports that Count Zeil discovered coal in the broad valley at Tjuvfjorden. Falcon (1928), too, says that the Triassic of the western part of Edgeøya consists of: uppermost alternating fissile sandstone and sandy shale with thin coal-seams, then abt. 80 metres of blue and red shale, and down to the sea abt. 130 metres of oil shale. The same section is, according to this author, also found at Kapp Heuglin. He suggests that faults may occur at Tjuvfjorden, and says that the beds occupy their highest position in the valley of this fjord, where the oil shale has a thickness of abt. 230 metres. According to this information the coal in this valley must be Triassic. Hunters have also told me about "thick coals" here.

Falcon mentions an unconformity between the sandstone series and the shale near Kvalpynten, corresponding to the unconformity below the Upper Triassic in Kistefjellet.

The uppermost portion of the Triassic is again marine, and consists of alternating calcareous and arenaceous beds having a thickness of abt. 250 metres in the Festning section. Formerly this set of beds was considered to be Jurassic, but recent observations tend to show that they are of Upper Triassic age.

The total thickness of the Triassic sediments varies very much. In the Festning section, for instance, it is 1150 metres, apparently a maximal value, at Bellsund it is 500—600 metres, north of Hornsund abt. 350 metres, and in Kistefjellet 174 metres.

Gothan (1910) has observed weak growth rings in Triassic wood. The yearly climatic changes have then been very small, but it appears to have been warm.

The large amount of ammonites, saurie-remains, and phosphorite proves that the animal life of the Triassic sea has at times been very prolific. The beds contain some asphalt, and I have also seen traces of asphaltic oil, but this succession hardly incorporates in it suitable reservoir rocks for the accumulation of any oil. It is therefore a very doubtful venture to drill for oil on the west coast, particularly as the Triassic beds in the anticlines are situated at a considerable depth.

In Kistefjellet, and probably also on Bear Island, the Upper Triassic rests on Hecla Hoek or Carboniferous beds. Everywhere else — north and east — eo-Triassic strata are found lowermost. The Upper Triassic beds have thus at their base a widely distributed unconformity.

The fact that older Triassic beds are missing in the south cannot be explained by a transgression of the sea southwards throughout Triassic times, but it must be assumed that after the deposition of Middle and Upper Triassic (and before the continental Upper Triassic beds were laid down) an extensive elevation of the land with erosion occurred. South of Hornsund, there must be *two* unconformities, one Triassic-Permian present throughout the Triassic area from the southern side of Hornsund to the north and east, and another beneath the Upper Triassic. The latter has not been observed directly elsewhere than on Bear Island, in Kistefjellet, at Stormbukta, and on Edgeøya, probably because its existence has not been quite evident. Before the deposition of Lower Triassic, the Upper Permian land-surface must have been fairly stable and not much above sea-level in the north, whereas the central part of the then land, south of Hornsund, was subject to a strong rise and erosion as far down as into the Hecla Hoek (fig. 4). Following the submergence and deposition of Lower and Middle Triassic beds, a similar rise seems to have occurred, and the older Triassic beds deposited at Kistefjellet and northwards to Stormbukta and on Bear Island were again removed before the sedimentation of the Upper Triassic beds. The unconformity beneath the Upper Triassic should be traceable in the folding zone from the inner part of Hornsund to Keilhaufjellet.

The submerging has not been regular throughout the Triassic period, as regressions have taken place in Skytian and Ladinian times. Frebold suggests that the last elevation perhaps had some connection with the strong earth-movements from this time discovered by Obrutchew on the New Siberian Islands. He also emphasises that the Triassic transgressions and regressions were not always simultaneous, but may have been more or less local. It seems likely that the areas east of the Barents Sea: Franz Josef Land, Novaya Zemlya, Petchora, and North Siberia as far as Olenek, were undergoing a uniform and extensive rise in Triassic times. The same holds good in North-east Greenland; with the exception of the Skytian and Rhaetic when marine sediments were formed. In Carnian time of the Upper Triassic the entire Svalbard area was apparently submerged, but in the Rhaetic parts of it were above sea-level and only little of the older sediments was removed. Fresh sediments were not formed until Upper Liassic time, when the sea during a short period buried the land and left a layer of conglomerates. According to Frebold this land emergence may have had some connection with the Old-Kimmeridgian mountain-building in the Western Thetys or Mediterranean.

Everywhere in Spitsbergen we find the Jurassic resting on the Triassic without any angular unconformity, showing that the rise of the land was only slight and uniform, not permitting any considerable part of the Triassic to be removed. The Triassic beds were probably present throughout the entire Svalbard area below the younger formations — in the north until this part of the archipelago became uplifted and eroded in Cretaceous times, and on the west coast even up to Tertiary times.

## Jurassic and Cretaceous.

In Upper Lias the sea encroached on the land following a period of rise and denudation, but the sedimentation was not prolonged for the land soon rose to sea-level again. The Liassic conglomerate had a widespread and uniform distribution owing to the configuration of the then land-surface. It has been found at Agardhbukta, Kroghberget, Dunérbukta, Sassendalen, in the inland south of Bellsund (Information of the Polish expedition 1934) and in Kistefjellet at Sørkapp; everywhere resting on Triassic beds. In the Festning section the Lias conglomerate has not been proved with certainty. Whether more than the conglomerate was deposited in Liassic times we do not know; and such beds were in that case removed by subsequent erosion. It is probable that the land-surface has been more or less quiet and "awash" until the succeeding prolonged depression followed in Callovian times. The entire Svalbard area has apparently participated in this subsidence, for Lias — or Trias, if the Liassic beds have been removed — are everywhere succeeded by marine shales and marly shales of Jurassic age. According to Frebold the Liassic sea had about the same distribution as the sea to-day. In England, North-Germany, and on the islands north of Canada we find marine Upper Lias, and at the Lena delta in Siberia Middle Lias. In Lower Callovian the sea had a much more extensive distribution and covered the New Siberian Islands, the lower Lena, the middle Katanga, Petchora, Novaya Zemlya, Franz Josef Land, Kong Karls Land, Spitsbergen, and North-east Greenland.

Svalbard remained submerged below sea-level well into the Cretaceous period, and a fairly monotonous sequence — often called the Aucella shales — with at thickness of 4—600 metres were formed. They consist chiefly of marl shales with calcareous concretions and thin limestones, along with some clayshales and sandy beds. There are also layers of clay ironstone and ferruginous carbonates. The line between Jurassic and Cretaceous lies approximately in the middle of the beds from Lias to continental Cretaceous (the Festning Sandstone), but it can be fixed only after a careful examination of the fossil content. An approximate determination of the line can be made from the weathering colour of the calcareous beds and concretions. The Jurassic ones contain less iron and have a yellowish weathering, whereas the Cretaceous contain more iron and weather more red.

These beds are all shallow-water deposits containing a fairly rich fauna of ammonites, lamellibranchs, etc.

Middle Callovian is apparently wanting, but Upper Callovian, Kimmeridge, and Lower Portlandian are found. According to Bodylevsky and Frebold Lower Callovian occurs at Deltaneset, in Botneheia on the south side of Sassenfjorden, and in Kistefjellet; and Upper Callovian to Lower Kimmeridge on the east coast. Upper Kimmeridge and Lower Portlandian are also known to occur on Andøya in North Norway, at Petchora, in East Greenland, and in Alaska. These areas were then all submerged. The upper part of this marine succession is of Lower Cretaceous age, with Valanginian (containing the Volga horizon) lowermost. Then follow continental beds of Upper Valanginian, Hauterivian—Barremian age, the marine Aptian being the uppermost part of Lower Cretaceous. On the east coast and at Bellsund there is also Albian, being the youngest member of the Cretaceous on Svalbard. Still younger members of this formation have probably also been present, but they were removed by erosion before the coming of the Tertiary.

Some horizons of the Continental Cretaceous contain large amounts of plant fossils, of which elatides, pityophyllum, and ginkgo are profusely represented, but the greater part of the division consists of sandy sediments with a lower sandstone, the Festning Sandstone, occurring everywhere in Svalbard where this horizon is present. West of Grønfjorden Hoel measured its thickness at a maximum of 21 metres. The thickness of the Continental Cretaceous is here abt. 150 metres. Where this series is exposed east of the Tertiary syncline the arenaceous development is still more pronounced. The Festning Sandstone is here more coarse-grained, partly conglomeratic, and with typical current-bedding. Then follow alternating beds of shale and sandstone; and also a layer consisting, according to Hagermann, of a tuff-conglomerate with pieces of wood, and above it a layer of clay ironstone with the maximum of 33 per cent of $Fe_2O_3$. Then again a conspicuous big sandstone, termed by Hagermann the Shore Sandstone, because it was probably formed in a delta. Above this sandstone Hagermann found in Innkjegla east of Braganzavågen a quartz conglomerate indicating a transgression of the sea in Aptian time, for the following loose sandstones (Lower and Upper Lamina Sandstone of Hagermann) are marine and contain seams of limestone and clay ironstone. Northwards they pass to a certain extent into clayshales. Fossils, determined by Stolley in 1910, from the Middle Neocomian of Adventfjorden come, according to Hagermann, from a horizon corresponding to the Upper Lamina Sandstone.

Obrutchew says that the continental sequence on the east coast of Vestspitsbergen has a maximum thickness of more than 200 metres, and the upper marine member has a maximum thickness of 790 metres, making a total thickness of the Jurassic and Cretaceous of 1500 metres.

The continental member of the Cretaceous can be traced southwards to Sørkapp, and has also been found on the island of Hopen where there are coals just about sea-level. Nathorst thinks that the Festning Sandstone is absent from Kong Karls Land; the horizon is probably present, but differently developed. Here, too, we have a tuff conglomerate similar to the one occurring below the Shore Sandstone, but it is resting on Dogger. In Johnsenfjellet on the eastern promontory of Kongsøya we have uppermost a plant-bearing horizon of the Continental Cretaceous, followed below by a *Belemnites*-bearing horizon of the Lower Cretaceous, and at the foot of the mountain Aucella Shale (Cretaceous and Jurassic). In Tordenskjoldfjellet east of Kapp Altmann J. G. Andersson found *Ginkgo digitata* above the Aucella Shale, and therefore there probably exists here an unconformity at the horizon of the Festning Sandstone.

It is difficult to say how land and sea were distributed during this period, but the deposits of both the Continental and the overlying marine Cretaceous may have come from the south, which is also supported by the evidence given by Hagermann that the Lower Lamina Sandstone passes northwards into a thick clayshale. The unconformity probably present below the Continental Cretaceous of Kong Karls Land may also indicate land in that direction, whereas the current-bedded sandstones were formed farther to the west. Jurassic and Cretaceous beds were probably also formed at Bear Island, but have later been removed by erosion.

The development of the Jurassic and Cretaceous is boreal, and resembles that of these formations in the Russian Arctic area. The marine sediments of these periods have the character of shallow-water deposits formed near coasts. According to Frebold the material of the beds originates from neighbouring land-masses within the shelf-area, but he does not believe in any extensive mass of land within the confines of the present polar sea. The frequent change of rocks, he explains as being due to variation of currents in very shallow water.

Frebold has also investigated the development of the marine mesozoic strata bordering the present polar sea, and has come to the conclusion that the Trias is developed so differently that a land connection between Spitsbergen and North-east Greenland, as assumed by Wegener, is improbable. On the contrary, there must have been an open sea here, as it is now, throughout the entire Mesozoic Era. By comparing the Festning section with sections farther to the east, Frebold thinks that a Mesozoic land-mass of considerable area was present west of Spitsbergen. But the Continental Cretaceous increases in thickness and shows typical current-bedding on going east, hence a land-mass to the south and south-east appears to be more probable.

The Jurassic and Cretaceous climate must have been rather warm, but with a distinct difference between summer and winter. Thus, Gothan (1910) has found indubitable year rings in tree trunks from these periods. Sago-palms — now only found in the tropics — then grew in Spitsbergen, and also the ginkgo of which there is now only a single species living in China and Japan. The forests of the continental division of the Cretaceous have been capable of forming a coal-seam, which some years ago was worked at Advent City.

A summary of the earth-movements of the Barents Sea shelf in Jurassic and Cretaceous times would run as follows (after Frebold): In Upper Lias the sea commences to encroach upon the land, as the western border zone sinks. Following a slow rise the transgression reaches Franz Josef Land in Dogger times as the western part of the Barents Sea Shelf becomes submerged. In Callovian the encroachment upon the eastern part — accompanied by local rises — terminates. In Lower Kimmeridgian and Oxford the submergence is continued and the general conditions are the same. Young-Kimmeridgian earth-movements elevate the land, which in Lower Portland even appears above sea-level. In Lower Volgastufe and Valanginian there is a general depression with some parts (islands) remaining above sea-level, and in Upper Valanginian follows a rise, with continental deposits being formed in Hauterivian and Barrêmian. At this time we had probably erosion east of Novaya Zemlya and perhaps to the south. In Aptian we get a new transgression, and the marine development is continued into Middle Cretaceous. As the beds above the Albian are wanting, we do not know the age of the youngest Cretaceous members in Svalbard, for these were removed by erosion following quite strong earth-movements in Younger Cretaceous times. We shall now deal with these.

## Earth Movements in Younger Cretaceous.

So far we have dealt with the development of the Cretaceous up to the lower part of the middle division of the system. The next member of the sequence is everywhere Older Tertiary; in southern Spitsbergen resting on Aptian (west) and Albian (east), but at Kongsfjorden it overlies Lower Permian chert and a glauconitic sandstone of perhaps the same age, but this sandstone may also be younger. From the west coast we have also cases of Tertiary rocks resting directly upon the Hecla Hoek, at Forlandsundet and Kapp Lyell. If these strata were of Lower Tertiary age it would have been necessary for the west coast area of Spitsbergen to have been elevated along a pre-Tertiary fault, and that also the entire Spitsbergen area would have been lifted and subjected to erosion, increasing northwards and resulting in the exposing of older and older beds on going northwards and as far down in the sequence as to the Hecla Hoek farthest north.

It seems, however, extremely likely that the isolated Tertiary areas resting against the Hecla Hoek belong to the youngest fossil-bearing division of the Spitsbergen Tertiary or are still younger. The development of the beds of these areas bears little resemblance to the main Tertiary basin, and amongst their fossils is *Sequoia Langsdorfii*, which has never been found in the lower division, but only in the division of the Uppermost Plant-bearing Sandstone. As the isolated areas are not far distant from the main Tertiary basin a transgression from the west seems unlikely. The conditions are difficult to explain unless one assumes an uplift of the west coast in the latter part of the Spitsbergen Tertiary. This disturbance might manifest itself in an unconformity below the Uppermost Plant-bearing Sandstone farther east, but I have not been able to find it, despite the fact that I made a special search for it in 1936. The unconformity, however, may not be easy to discover amidst a series of beds with a frequent varying character. But the unconformity may still exist, and the Tertiary of Forlandsundet and Kapp Lyell may be contemporaneous with the Upper Plant-bearing Sandstone farther east. I am also aware of the possibility that the isolated Tertiary areas may be younger than the Tertiary of the main basin, and the uplift of the west coast must then be younger, too.

If that be so, the Cretaceous uplift has only consisted in an oblique rise of the land, greatest in the north, followed by an intensive erosion. De Geer maintains that the uplift of the northern part followed a flexure running from Kongsfjorden to the inner part of Isfjorden and south of

Nordaustlandet. This flexure was at any rate not a very marked one. Owing to the oblique rise the greatest thickness of Cretaceous strata is found on the east coast. When did this uplift take place? An enormous amount of erosion has taken place in the north of Spitsbergen subsequent to the uplift, which might therefore reasonably be assumed to have taken place rather early, perhaps already when passing from Lower to Middle Cretaceous times, i. e. during the Asturian phase of folding; but it is more probable that the movement is younger, Subhercynian or Laramian. (See fig. 5.)

### Volcanic Activity in the Cretaceous.

In Spitsbergen and on Kong Karls Land we find a series of basic igneous rocks, differently developed according to their mode of consolidation. Along the west coast of Spitsbergen dykes of diabase cut the beds up to and including the Triassic. Frequently the diabase forms intrusive sheets or sills, which can be followed for many kilometres before they cross the bedding or taper out. Such sheets are still more common at Storfjorden and Hinlopenstredet, where they consist partly of a coarse-grained dolerite. On the north coast Hoel and Holtedahl have found lava flows resting on Devonian rocks exposed in the Cretaceous peneplain. Goldschmidt has described the rocks as typical plagioclase basalts probably belonging to the same eruption epoch as the basalts of Kong Karls Land and Franz Josef Land. The age, however, is somewhat uncertain. Originally they were considered to be of Neocomian age or still older, as the dykes were never seen to cut Cretaceous beds. But they are younger than the mentioned peneplain, which means younger than both the Cretaceous uplift and erosion, unless the uplift of "The northern Oldland", as suggested by De Geer, already commenced in Jurassic times, and that the erosion was carried through already in Neocomian time.

On Kong Karls Land, however, Nathorst has found basalts younger than the Continental Cretaceous, but as the underlying sediments also contain particles of basalt, it seems most likely that at least two eruptions have taken place. It is thus not certain that the basalts on the east coast and the diabases on the west coast are contemporaneous. Some basic eruptives found only in the Hecla Hoek rocks are as mentioned before of pre-Downtonian age.

If the eruptions had taken place early in the Cretaceous it is strange that no effusives covered by younger Cretaceous beds are found. That the magma has been forced for great distances as sills between the soft Triassic and Jurassic beds seems to show that there has been a considerable thickness of rigid sandstones above, which have prevented it from reaching the surface. Consequently I think it is probable that the igneous activity took place in Younger Cretaceous times, or even as late as the end of the Cretaceous or the beginning of the Tertiary — perhaps in the Laramian phase of folding — which in America was accompanied by volcanic effusions.

Backlund has pointed out that the dolerites and basalts occur along certain fracture lines in Storfjorden and Hinlopenstredet, and along one running SE—NW — separating Isfjorden from its inner branches. De Geer, too, maintains that Edge- and Barentsøya have been lifted along such a line, relative to the west side of Storfjorden. However, none of these faults have actually been observed. According to Falcon the basalts of Edgeøya have been intruded from the west, because eastwards the intrusive sheets rise higher and higher and also thin out gradually. On the south side of Sassenfjorden I have observed a similar rise and thinning out towards the south-east, and the fissure feeder of the basalt was probably situated near the fjord. The basalts have such an extensive distribution that there can be no doubt that the eruption of magma has taken place at several points. Tyrrell and Sandford consider that they have distinguished large volcanic vents at some points at Hinlopen. In Alkefjellet south of Kapp Fanshawe is seen a dolerite 400 metres in thickness, having cut the Cyathophyllum Limestone at Lomfjorden. The islands in Hinlopenstredet are also made up of that rock. The mentioned authors believe that we have here a big occurrence of the cedar tree type with a visible feeder. At Kapp Eremitt occurs a big dyke, branching from a mass of dolerite the base of which is hidden. Bastianøyane may also have a vertical feeder, and such may also occur between Torrellneset and Ulvebukta, as well as in Heleysundet.

## Tertiary.

Fig. 5 shows how a geological picture of Spitsbergen would have appeared previous to the deposition of the Tertiary beds. Almost the entire Middle and Upper Cretaceous is missing, and the older systems have been removed by erosion over large areas.

At the beginning of Tertiary times a land-mass to the west was believed to have existed, because the base of the Tertiary at Forlandsundet contains big conglomerates. As has been pointed out (page 36), these conglomerates are probably considerably younger than the lowermost beds in the Tertiary sequence of the big syncline, hence it is likely that the land-mass was quite low, if it did exist at all at the beginning of the Tertiary. The difference in age of the lower beds of the big Tertiary syncline and of the series at Forlandsundet is not only evident from the different fossil content, but the rocks themselves are also developed differently. At the base of the Tertiary beds in the syncline there is locally developed a small conglomerate, and the coal-seams lie near the base. At Forlandsundet there is lowermost a thick, coarse

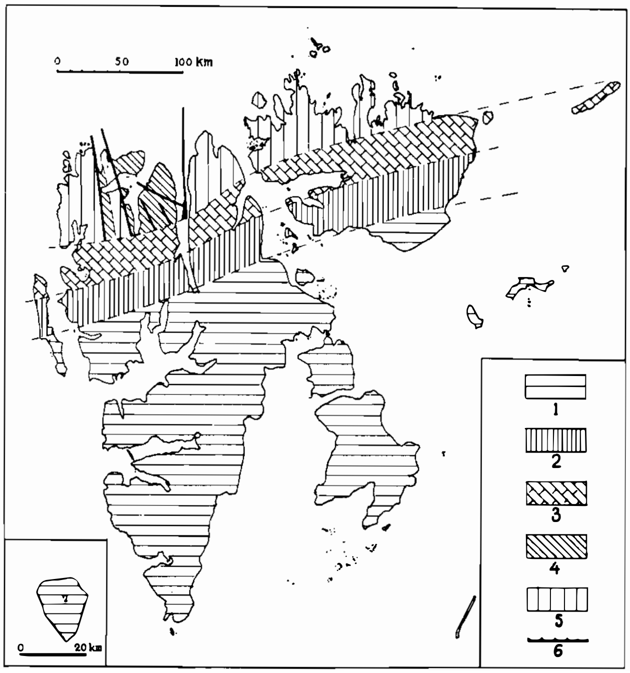


Fig. 5. Geological map of Svalbard before the deposition of the oldest Tertiary beds.

1. Cretaceous and Jurassic. 2. Triassic. 3. Permian and Carboniferous. 4. Devonian and Upper Silurian. 5. Hecla Hoek and eruptives. 6. Older faults.

conglomerate and no coals worth mentioning. In view of the uniform development of the lower part of the Tertiary sequence throughout the syncline, — this also holds good for Kongsfjorden as far as the principle is concerned — it is not very probable that beds of a very different character should have been formed in the nearby area of Forlandsundet. The rocks thus confirm the fossil evidence that the Tertiary series of Forlandsundet is younger.

The lowermost Tertiary beds are continental and have several coal-seams, but some horizons contain marine bivalves. It is consequently safe to assume that the central Tertiary area has been a flat land near the sea, covered by swamp forests, and at times the sea encroached and deposited marine sediments. Prior to the deposition of the Tertiary strata the northern part of Svalbard had been lifted more than the middle, and the Tertiary beds at Kongsfjorden belonging to the same horizon, i. e. basal Tertiary, are more coarse and continental with coal-seams having a much more varying thickness and extent. Marine horizons are apparently absent. The conclusion is that the land formed by the Cretaceous upheavel was situated in the north, whence the rocky material originated and was transported in a more or less southerly direction. The deposition probably took place east and west of the present syncline as well, and there is in fact nothing to prove a land-mass to the west.

In the following will be given a short description of the Tertiary sequence based upon the Nathorst division.

During a prolonged depression of the land the *Lower Light Sandstone Series* was deposited at first. It consists of light grey to buff sandstones, with some greenish and fissile sandstones, shales, and coal-seams near the base. The succession has a continental and lake development, but encroachments of the sea are also in evidence. The basal bed is locally a conglomerate (Grønfjorden, Braganzavågen, and at Kongsfjorden). The thickness of the series is: east side of Grønfjorden 130 metres, south of Adventdalen 110 to 125 metres, at Braganzavågen 110 metres. The coal-seams occur just above the base.

The *Lower Dark Shale Series* follows. It consists of a blackish-grey clayshale weathering into angular often prismatic pieces, and often contains small pebbles of Permian chert. In Heerfjellet at Grønfjorden Hoel has given the thickness of the shale at 130 metres. Eastwards parts of the shale pass gradually into sandy shales and partly fissile sandstone. Thus the clayshale proper gets thinner and less pronounced. Nathorst gives the thickness at 60—90 metres, and at Braganzavågen J. Braastad has found a pure shale thickness of 35 metres only, whereas Hagermann measured 113 metres, but including in it sandy layers. South of Bellsund the thickness is much greater. The shale series is marine and must have been deposited not far from the coast. Arthur S. Lewin, Mining Engineer, thus discovered marine bivalves in the limestone balls occurring in the upper part of the series at Colesbukta. Tuffs have also been found in this shale by Gripp, who thinks that they may possibly have some connection with the glassy basalts from Woodfjorden, as described by Goldschmidt.

The succeeding member of the Spitsbergen Tertiary is a division of medium-grained greenish sandstone, called by Nathorst the *Green Sandstone Series.* This sandstone is frequently found in the edges of the plateaux, below which the slopes are covered with numerous talus-cones. Marine fossils have been found in the uppermost part of the series, which was deposited in more shallow water than the shales below. In the eastern part of our area there is no distinct boundary between the sandstones and the shales, but the latter become more sandy upwards. On the Isfjord—Bellsund peninsula Nathorst gives the thickness at 200—250 metres. In Liljewalchfjellet it is, according to Hagermann, 175 metres. In the summit of Basilikan south of Van Keulenfjorden the sandstone proper has not that thickness, but the loose sandy, partly argillaceous rocks below it attain here a greater thickness than in the north. However, the boundary between the two series is difficult to fix.

The *Upper Black Shale Series* comes next and consists entirely of black fissile clayshale weathering into small angular bits. The series gives rise to smooth slopes and, often, cone-shaped summits rising from the plateaux of the green sandstone. The thickness varies from 240 to abt. 300 metres. The shale is of marine origin, and was deposited at a somewhat greater depth than the other Tertiary divisions. It contains marine bivalves and some small pebbles of chert, which, according to Nathorst, were brought out to sea by algæ. The marine deposits of this series show that the sea-bottom had been lowered considerably.

The *Flaggy Sandstone Series*, which succeeds, was deposited in more shallow water. Whether the shallowness of the sea be due to silting up or to the rise of the sea-bottom it is difficult to decide. The sequence consists of alternating beds of black clayshale and grey to greenish-grey sandstone which splits into slabs and plates along the bedding. This sandstone contains badly preserved marine bivalves, worm tracks, and some plant remains. The thickness has not been measured at many points. In Sundevallfjellet on the northern side of Van Mijenfjorden G. Nordenskiöld found about 200 metres.

The *Upper Plant-bearing Sandstone Series* is the last division and consists of light grey and greenish, usually fine-grained, sandstones and slaty sandstones with clay ironstone, clayshale, marly shales, and thin coals. The beds are found in the summits of the mountains and attain in Aspelinfjellet 500 to 600 metres and west of it still more. No marine fossils have been found in this series, but the coal-seams and the abundance of plant-fossils and petrified wood show that the beds represent continental deposits. The fossiliferous strata are frequently somewhat ferruginous, suggesting silting up in big lakes. It looks as if the area was undergoing a slow subsidence just keeping pace with the sedimentation.

With regard to the two uppermost divisions I think they are difficult to separate, at any rate south of Van Mijenfjorden. In 1936 I did a section at Colinderodden and found here an abundance of ripple-marks and even streaks of coal in the first 200 metres above the upper black shale, the upper limit of which is here situate at sea-level. When ascending up to the height of 925 metres, this figure corresponding roughly to the aggregate thickness of the two divisions, I noticed a number of thin coal-seams up to the height of 850 metres, and only at the elevation of 800 metres was there appreciably more sandstone than in the lower part. The Flaggy Sandstone Series and the Upper Plant-bearing Series are thus, generally speaking, of continental or littoral type, and they were apparently formed under similar conditions.

The present distribution of the Tertiary sequence will appear from the map. The greatest total thickness within the central syncline is nearly 2000 metres. The Tertiary has certainly had a greater extension than the beds show to-day. De Geer suggests that the northernmost part of Spitsbergen never had any Tertiary beds. This is, however, rather doubtful, as the Tertiary of Bröggerhalvøya does not indicate any small original thickness. What has been left here has a thickness of about 200 metres.

The vegetation, now represented by coal-seams and imprints of leaves, etc., was undoubtedly autochthonous, and the immense distribution of *Equisetum* shows the presence of vast moors where this species dominated. The climate has been estimated to have been as in southern Europe to-day, i. e. the average temperature was about 20° higher than it is in Spitsbergen now.

With regard to the stratigraphical position of the Tertiary sequence it is well-known that originally Heer from the plant fossils gave the age as being Miocene, whereas Ravn (1922) from the bivalves of the five lower divisions judged the age to be Paleocene and probably Eocene.

The Upper Plant-bearing Sandstone Series *might* thus be considerably younger, but the evidence is decidedly in favour of a close connection with the Flaggy Series below. It is therefore highly probable that the entire Tertiary sequence, at any rate in the syncline, is of old Tertiary age.

## Tertiary Foldings, Overthrusts, and Faults.

The preceding chapters have dealt with a number of earth-movements older than the Tertiary. With the exception of the Caledonian mountain building, the greater part of these earth-movements has been in the nature of an uplift of the land, with vertical displacement of the blocks, followed by erosion giving rise to more or less pronounced unconformities beneath the younger strata.

In Tertiary time there were again strong earth-movements the magnitude of which was only surpassed by the Caledonian mountain building. The present aspect of Spitsbergen is largely due to these Tertiary crustal movements. All along the west coast of Spitsbergen the younger formations are strongly folded, and partly overthrust. This zone of folding can be traced right from Kongsfjorden to Sørkapp. The steep strata form, as a rule, long ridges separating big glaciers, and the harder the rocks are, the more precipitous are the crags. Eastwards the structure becomes gradually flatter, and the mountains are more of the plateau type. They frequently rise in steps and may have the appearance of some huge building, i. e. Templet west of the entrance of Tempelfjorden and many others.

Within the Tertiary sequence no angular unconformity has been seen which might correspond to the unconformity underneath the Tertiary layers at Kapp Lyell and Forlandsundet. These Tertiary fields are as mentioned on page 36 supposed to be about contemporaneous with the youngest Tertiary strata in the great syncline and due to a rise of the west coast along a fault line (fig. 7). We must therefore conclude that the entire Tertiary folding process is younger than the youngest Tertiary strata in Svalbard.

The Tertiary zone of folding may be followed from Sørkapp to Kongsfjorden where it runs into the sea and in a northwesterly direction. The southwards continuation is unknown, and it is difficult to ascertain whether this folding also has been active on Bear Island and in North Norway as the Tertiary is absent there. The folding zone is especially well exposed where it traverses the fjords: in the inner part of Hornsund, at Ahlstrandodden, Midterhuken and Ingeborgfjellet at Bellsund, and in the Isfjord area: west of Grønfjorden and east of Trygghamna. The folding zone is in fact broader than it would seem from the younger beds to-day, as the zone has also had a westerly extension where the younger beds later have been removed. Within the Hecla Hoek formation the Tertiary movements are difficult to trace, unless they have caused a shift in the trend of the Caledonian strike, as is the case on Brøggerhalvøya on the south side of Kongsfjorden.

Views on the Tertiary earth-movements have varied considerably. Originally the belief was held that the west coast had a *horst* character. With a pressure from the west the formation of the horst was deemed to have been the cause of the folding, the latter thus being a secondary phenomenon.

De Geer has emphasised that the rise of the west coast could be due to a subsidence of the ocean floor in the west and north, whereby semiplastic magma had been squeesed in below the edges of the continents, causing these to rise. The eruption of the basalts of Iceland, the Faeroes, and Greenland would then also be due to similar causes.

It was assumed that the fault on the east side of the "horst" followed the junction of the Hecla Hoek and the Culm (in the Isfjord—Bellsund area) and was always shown thus on the maps. The "fault", however, is only apparent as the junction is really a steep angular unconformity, as shown on fig. 6. The Culm basal conglomerate is everywhere to be seen just above the unconformity no matter how the beds are inclined, and this conglomerate may be traced from Bellsund to Isfjorden, and is also to be seen north of this fjord, at Trygghamna. Brecciated rocks have never been seen to accompany it, and no slickensides, so there has been no faulting here. A fault-plane crossing strata, originally horizontal, would naturally *cut* these, and not run along the bedding for miles in the direction of the strike and several hundred metres along the dip. A number of in part quite big Tertiary faults also occur, but it can be shown that they cut through *folded* strata, and must consequently be younger than the folding itself. This has apparently been caused by a pressure from the west, causing overfolding and partly

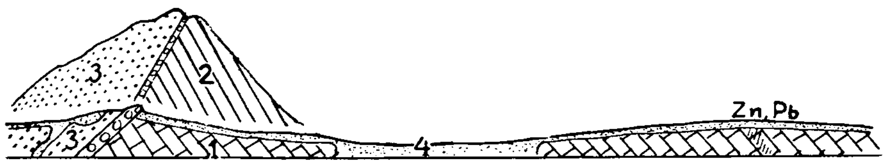


Fig. 6. The boundary between Hecla Hoek and Culm west of Russekeila with Griegfjellet behind

1. Hecla Hoek limestone and dolomite. 2. Hecla Hoek quartzite and phyllite. 3. Culm with basal conglomerate. 4. Cover of loose material. Zn, Pb indicate small occurrence of galena and blende. Sections as seen from the north.

overthrusts in an easterly direction. But this is in no way necessarily due to a crustal movement in this direction. By assuming a flow of the magma whereby the crust in the east has been moved towards WSW, a reaction would arise in its upper part, which might easily cause folding towards the east, this direction being dependent on which part of the crust had the most elevated position. In our case it was the westernmost, which during the folding rose and rose until it became overturned, as it were, eastwards.

The most intense folding took place at Brøggerhalvøya, where it finally turned into an overthrust towards the north-east with a local development of an overthrust from east towards west, probably owing its origin to the strong resistance of the granite massif north and east of Kongsfjorden. The area between the two overthrusts has at the same time been forced downwards.

On the north side of Isfjorden the main folding occurs at Trygghamna and east of it where the beds are inverted, with the Hecla Hoek apparently resting on the Culm (see Pl. III). According to De Geer there are also folds and overthrusts farther east, giving the folding zone a much greater width than both north and south of this region. Thus there are folds in Vermlandryggen, Helsinglandryggen and Jemtlandryggen, and an overthrust in Umefjellet (see Pl. III, fig. 2). On the aerial photographs it is possible to trace the latter towards Kongsfjorden and it is almost certain a direct continuation of the overthrust from south-west at Kongsfjorden. De Geer mentions that small overthrusts have been observed at Colesbukta and Adventdalen. I have myself seen an overthrust-fault at Bjørndalen, and G. Horn has a section from Mine No. 1 in Longyeardalen showing an overthrust from the east. Thus there can be no doubt that these disturbances represent the petering out of the great tectonic disturbance running southwards from Kongsfjorden.

South of Isfjorden the great main fold is only evident from Grønfjorden and westwards to the sea. There is in the area between Isfjorden and Bellsund a western *main fold* with a parallel *subsidiary fold* to the east of it, but the latter is only visible in a few spots, being hidden

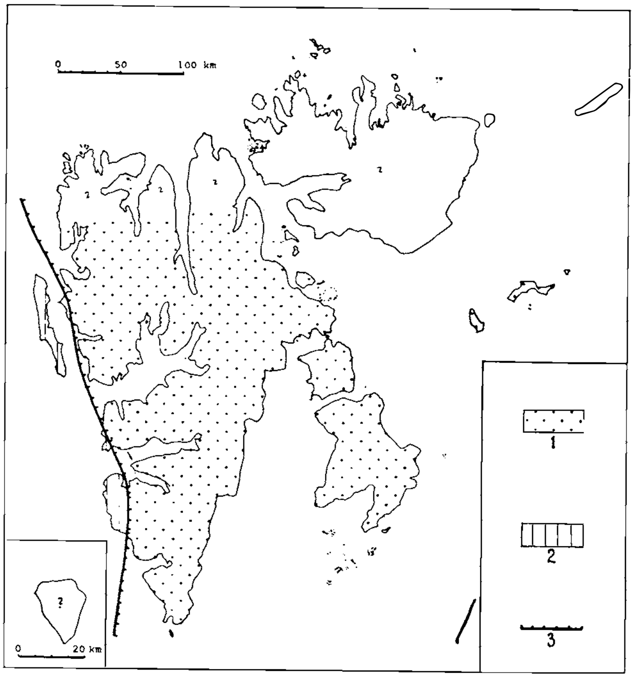


Fig. 7. Geological map of Svalbard in Tertiary time before the beds at Forlandsundet and Kapp Lyell were deposited.
1. Tertiary. 2. Hecla Hoek. 3. Fault from the younger part of the older Tertiary.

by the waters of Grønfjorden and the glaciers. There are also indications of a folding overthrust (see Pl. III, figs. 4—5).

In Midterhuken in Bellsund we have a beautiful section of the eastern portion of the folding zone. This section has not been sufficiently investigated, but, generally speaking, it has the appearance as shown on Pl. III, fig. 6—7. A great fault traverses the folded strata, causing the sequence to appear twice. See fig. 9.

At Reinodden on the south side of Bellsund a part of the younger sequence from Culm to the Cretaceous occurs inverted, surrounded by Hecla Hoek rocks. The explanation will be clear from Pl. III, fig. 8. The fault cuts the fold in such a way that the beds of the sunken part have become inverted. Farther to the south the folding zone has been examined by the Polish expedition in 1934, but the results have so far not been published. I have, however, been able to trace the folding zone on the aerial photographs southwards to Hornsund and thence to Sørkapp. Owing to the amount of snow and ice it is not possible to work out the details, unless investigations are carried out in the field.

In the inner part of Hornsund the folding is very pronounced (Pl. III). Here, too, there are quite big overthrusts. North-east of Burgerbukta Palaeozoic beds and the Hecla Hoek have been overthrust above the

Carboniferous and Permian, and in Hyrnefjellet the folded strata are cut by a fault. The principle of the folding is apparently the same everywhere, but at Kistefjellet and Keilhaufjellet (see Pl. III, fig. 12) the structure is very peculiar and masks the folding, giving the impression of an anticline. According to Hoel and Werenskiold the Triassic of Kistefjellet rests on the Hecla Hoek, and in Keilhaufjellet and east of it the whole sequence Trias-Tertiary has an easterly dip. It looks as if from Keilhaufjellet to Kistefjellet the Triassic beds are continuous and uninterrupted. However, the beds from Keilhaufjellet have a strike bringing them into the sea, whereas the Kistefjell-beds have a southerly and westerly dip and reappear at the shore. This seems to show that there is a great rupture just west of Keilhaufjellet, and as the beds farther north have clearly a steep dip, the structure of Keilhaufjellet might be explained as shown in the section, i. e. an inclined fold, the western portion of which has been lowered by later faulting. The Triassic of Keilhaufjellet is most probably underlain by Carboniferous beds, as the fracture line is probably very old and has been re-faulted several times, but it may also happen that the pre-Triassic beds just east of the fault were all removed by erosion when the great sub-Triassic unconformity was formed.

Along the west coast there are now only remnants of Tertiary, Culm, Upper Carboniferous, etc. which have been preserved through faulting. It looks as if the beds just west of the main folding have formed an anticline. This is most clearly to be seen at Sørkapp, where the youngest beds at the coast have a fairly steep westerly dip.

An interesting question, difficult — if possible at all — to answer, is whether the whole breadth of the Tertiary folding zone is exposed or not. From the sections it is clear that the post-Hecla Hoek sequence in eastern Svalbard is practically undisturbed, with the exception of the syncline of Central Spitsbergen, and anticline at Barentsøya and Edgeøya. As regards the geology of the sea-bottom west of Spitsbergen we have very little information. According to Kober the submarine ridge of the Atlantic represents an orogenic zone also passing through western Spitsbergen to Grant Land in Arctic North America, whence a branch is sent off to East Siberia and Alaska. This zone is necessary to show the existence of orogenic or mountain-building zones around the great continental blocks or kratogenic elements, as termed by Kober. This theory has perhaps not much to support it, but one cannot ignore the possibility of the folding in Spitsbergen being only an eastern, and perhaps smaller part, of an alpine folding out at sea west of Spitsbergen. There is, however, little evidence to support it so far. However the petrographical character of the Tertiary sequence on the east side of Forlandsundet indicates that there probably has been considerably more land to the west of the present Vestspitsbergen when this sequence was

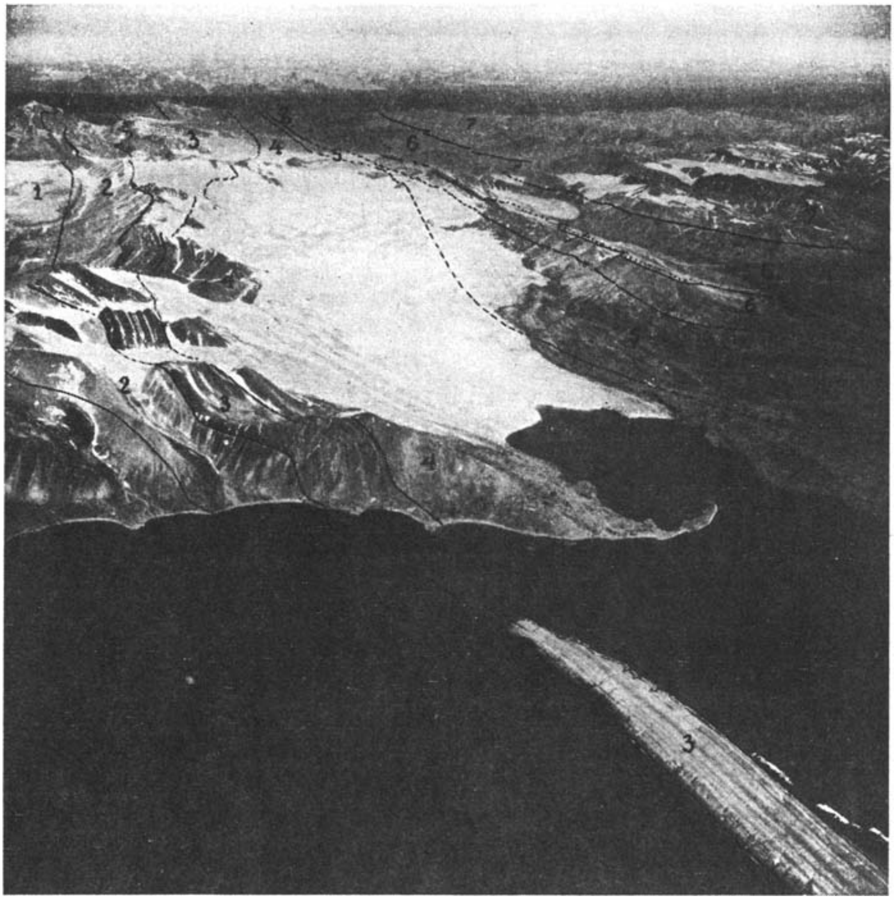


Fig. 8. The Tertiary folding zone between Bellsund and Isfjorden seen from the south.
1. Culm. 2. Cyathophyllum Limestone, Upper Carboniferous. 3. Cherty beds from the Upper Carboniferous and the Lower Permian. 4. Triassic. 5. Jurassic. 6. Cretaceous, with the Festning Sandstone. 7. Tertiary with the coal-seams lowermost.
Photographed from an altitude of abt. 3000 m by B. Luncke in 1936.

deposited than the narrow island of Prins Karls Forland. This ancient land has disappeared, whatever the reason may be: erosion and subsidence, or continental drift. The land-mass might originally have been formed by ridging up of the land west of the fault-line on the east side of Forlandsundet and through Recherchefjorden, or this upheaval may also have some relation with an older alpine folding west of this line. This uplift must, as far as we can judge, have taken place at the time just before the deposition of the Tertiary at Forlandsundet and Kapp Lyell, which, as already mentioned, seems to belong to the youngest Tertiary strata in Spitsbergen.

After the deposition from west of the sediments at Forlandsundet and Kapp Lyell and probably also of still younger beds than those now

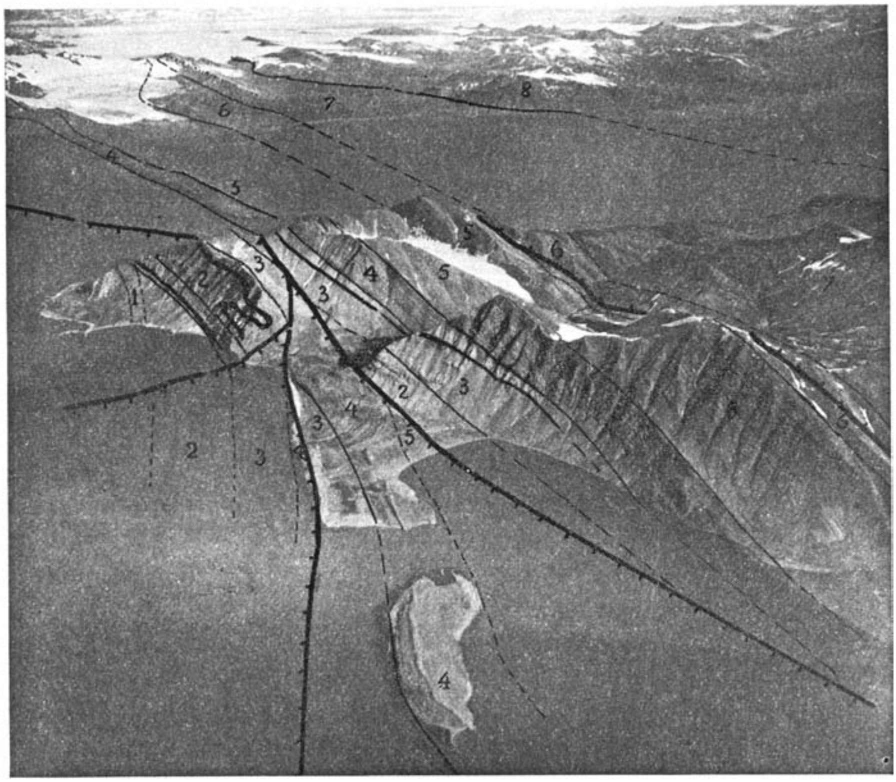


Fig. 9. Midterhuken in Bellsund seen from southwest.

1. Hecla Hoek. 2. Culm. 3. Cyathophyllum Limestone, Upper Carboniferous. 4. Cherty beds from the Upper Carboniferous and the Lower Permian. 5. Triassic. 6. Jurassic. 7. Cretaceous. 8. Tertiary. Thick lines without cross lines indicate diabase, with cross lines they indicate faults. Thin lines are geological boundaries.

Photographed from an altitude of abt. 3000 m by B. Luncke in 1936.

present, the last Tertiary folding set in along the west coast of Spitsbergen, and when this process had finished the zone collapsed along fault-lines, partly following older fractures. Later erosion by water and ice during different stands of the sea-level has given Spitsbergen its present shape.

Th. Vogt suggests that the Tertiary folding also traverses Jan Mayen, Iceland, and the Faeroes. If that be so the ridge discovered by Miss Boyd 1937 halfway between Jan Mayen and Bear Island must also be considered. Yet, it is more likely that this ridge has a volcanic origin connected with the volcanic zone across Jan Mayen and Iceland. However, the material is too scanty to allow of safe and further conclusions in this matter.

The Tertiary folding in Svalbard represents an orogenetic earth-movement and comes within the category "Faltengebirge" (fold mountains) of Stille.

The folding of the succession Downtonian—Tertiary along with the roots of the Caledonian mountain chain was due to strong lateral forces. Metamorphism proper did not take place, but the beds became indurated and partly squeezed. Nathorst and Horn have noticed that a feature of the sediments of the islands east of Spitsbergen is their generally unconsolidated nature: loose sands, etc. This is never the case in the area of the folding zone; nor are the fossils here as well preserved as beyond it. Whether folding itself has had any influence upon the coalification process is doubtful. Apparently the weight of the superincumbent beds has in that respect played the most important rôle, as the coals highest in rank occur at Hedgehogfjellet, i. e. at the *bottom* of the syncline.

The submarine ridge running north-west from Spitsbergen must be a feature of the Caledonian folding, but the Tertiary tectonics have also a trend in this direction; how far is not possible to determine.

The *Tertiary faults* have nearly all been proved to be younger than the folding. This is to be observed directly at Kongsfjorden, on the north side of Bellsund, in Midterhuken, at Reinodden, inner part of Hornsund, and at Sørkapp. Either the faults cross beds that have already been folded, or the position of the beds near the faults shows that these beds were already folded previous to the faulting. This is the case on Prins Karls Forland where the beds have a steep easterly dip, whether situated on the one or the other side of the faults; and also on the coastal plain north of Bellsund where the Carboniferous beds have a steep easterly dip at the faults.

We are led to believe that the pressure of the Tertiary folding kept the beds in a kind of bend so long as the forces were acting, and when these came to an end, or diminished, the folding zone collapsed along great faults roughly parallel to the folding axis. The case may be compared to a stone arch collapsing when the foundations are pulled outwards. In several areas the faults follow old fracture lines, but several are "new". Frequently they are composite.

The main faults run parallel to the west coast of Spitsbergen, where the most elevated part of the folding zone has broken in (see map and pl. III). In Forlandsundet a *Graben* was formed, where the Tertiary is preserved. The fault on the east side of the sound is certainly very big, whereas the one on the west side is composite, with faulting in steps. It is highly probable that these western faults limit the Sentinelle Bank on the inner side, and are in some way connected with the fault west of Kistefjellet, where Carboniferous beds terminate against younger beds on its east side.

A continuation of the eastern fault in Forlandsundet is probably to be found on the plains north of the Bellsund mouth, where there are several faults with east dipping Culm beds on their west side. The aggregate throw of the easternmost faults here is about 3000 metres, whereas the western have about 500 metres (fig. 5, pl. III). The islets of Sinkholmen and Husholmen are apparently situated between the faults.

The main faults run southwards across Recherchefjorden, with an eastern branch appearing in Midterhuken, where there are also some minor fractures. With the exception of the western fault at Kapp Martin (the promontory east of Lågneset) the others seem to join, cross the northern part of Reinodden, and cutting the main fold here, causing the beds to occupy an inverted position surrounded by Hecla Hoek rocks (see Pl. III, fig. 8). The fault assemblage then reaches the inner end of Recherchefjorden, and west of the Tertiary fold (overturned to the east), but as there are here only Hecla Hoek rocks, and the country is much covered by glaciers, it is very difficult to trace the faults farther. Either these faults run towards the coast beneath Recherche- and Torellbreen, or they take a more easterly course being connected with the fault at the bottom of Hornsund and west of Keilhaufjellet. Faults may, however, exist in both places. The strike of the Hecla Hoek rocks on either side of Torellbreen seems to corroborate the presence of a great fracture beneath this glacier.

The fault with a course from the inner part of Hornsund to west of Keilhaufjellet follows an old fracture which must have been re-faulted in pre-Culmian and pre-Triassic times, and perhaps in the Upper Triassic as well. A Tertiary displacement of the sequence, younger than the folding, is evident from (1) the position of the Devonian beds on either side of the glacier, (2) the geological conditions at Kistefjellet and Keilhaufjellet, and (3) is further born out by the fact that Hoel in the middle of the Devonian area south of Hornsund discovered a rocky crag consisting of quartzite, marble, and mica-schist. The folds and faults here are tentatively explained in the sections Pl. III. As will be seen, the western part has usually been lowered in Tertiary time. The Devonian strata, inverted towards the east on the east side of Samarinbreen south of Hornsund, must be identical with those beds with a normal position on the west side of the same glacier.

De Geer first assumed that also on the south side of Hornsund the Devonian on its west side was limited by a great fault, but, as mentioned above, Hoel has shown that this boundary is a fortuitous erosion boundary. The conditions are, in fact, very similar to those on the north side of Bellsund, but with the Devonian instead of the Culm.

Another fault zone runs from Kongsfjorden towards the southeast, and the fjord itself is a *Graben*. The most southeasterly of the faults follows the boundary between the Hecla Hoek and the Carboniferous right to St. Jonsfjorden. Otherwise these faults have not been traced farther south, and they will also be difficult to follow in detail owing to the glaciers.

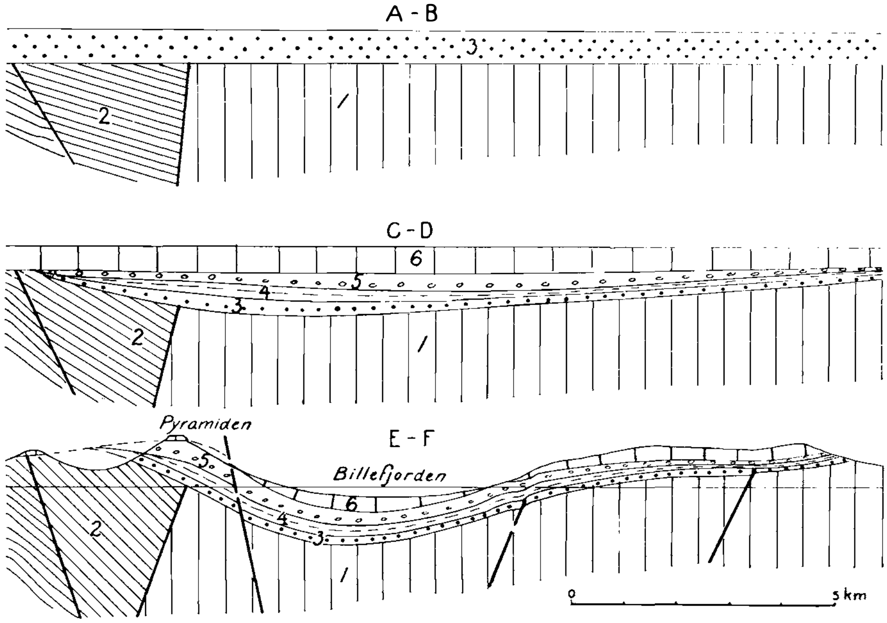


Fig. 10. Geological sections across Billefjorden.
A—B Post-Culmian. C—D Post-Permian. E—F Present-day section.
1. Hecla Hoek. 2. Devonian. 3. Culm. 4. Lower Gypsum divison. 5. Red conglomerates.
6. Upper Carboniferous and Lower Permian. Sections as seen from the south.

The great Devonian fault line along Wijdefjorden, Billefjorden, and across to Sassenfjorden has also been re-faulted in Tertiary time: there are thus minor faults along Billefjorden and at the "Inland" fault from Sassenfjorden to Advent- and Kjellströmdalen east of Van Mijenfjorden. South of the latter valley the fault cannot be found on the air photographs, and it is likely that it has died out somewhat south of this valley. The fault zone is shown in the sections of fig. 11. South of Sassenfjorden the western part has sunk as much as 600 metres. Farther south it splits into two (in Gattytoppen). There are now two parallel fracture lines: the western being a flexure, and the eastern a fault. In both cases the part to the west has been lowered. In Reindalen still farther south the *western* branch has now become a slight flexure, which disappears farther south, whereas the eastern flexure branch has turned into a fault, but with a downthrow on the east side. This is also the case north of Kjellströmdalen (Hagermann). Stensiö has found a branch of this fault in the inner part of Gipshuken, and some minor branches farther to the west.

About 40 kilometres to the east there is also a Tertiary fault roughly parallel to the "Inland" fault. Odell has found it south of Lomfjorden, here along the western boundary of the Carboniferous, and Gripp has seen it immediately west of Agardhbukta. The east side of the fault is

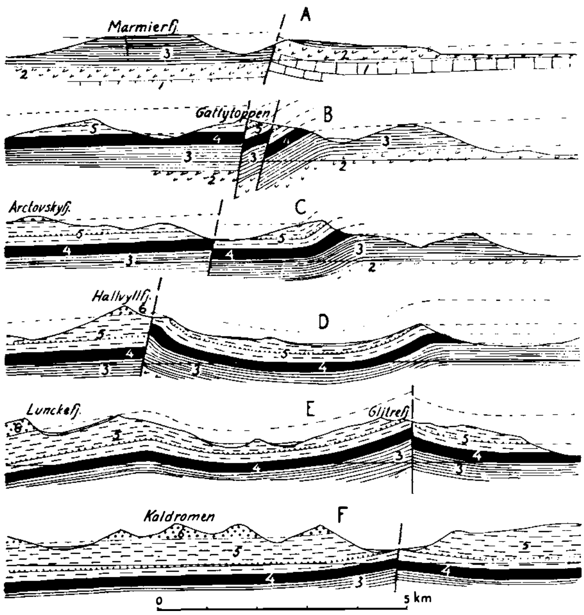


Fig. 11. Sections of the Inland Fault between Sassenfjorden and the south side of Kjellströmdalen.

A South side of Sassendalen. B Between Sassenfjorden and Adventdalen. C North side of Adventdalen. D South side of Adventdalen. E South side of Reindalen. F South side of Kjellströmdalen.

1. Upper Carboniferous. 2. Permian. 3. Triassic. 4. Jurassic. 5. Cretaceous with the Festning Sandstone. 6. Tertiary. Sections as seen from the south.

the downthrow side, but the throw is only slight. This fault possibly continues northwards in Lomfjorden and Hinlopenstredet. Several geologists maintain that Hinlopenstredet also is a Tertiary *Graben.*

It is likely that there has been some movement along the Bockfjorden fault at this time or later, as the Quaternary volcanoes (Hoel and Holtedahl) are situated along this line.

It should also be mentioned in this connection that Nathorst has introduced a probable fault along the Isfjorden in order to explain the apparent shift of the boundary Hecla Hoek—Culm on either side of the fjord. A closer study of the strike shows the boundary to be quite normal, without any fault at all. If the connection line from the formation boundary at Trygghamna on the south side of the fjord is to be drawn, it must be carried to the corresponding part of the fold *in the depth*, situated four kilometres nearer to Grønfjorden than the Culm boundary on the surface. This "fault" can thus safely be left out, particularly as no sign of it has been observed in the country to the east of the inner part of the fjord. Further, this fault would have had a course at right angles to all the others, in itself not very probable. As it will be evident from the map and sections, the slight displacement is due to the northward rise of the synclinal axis.

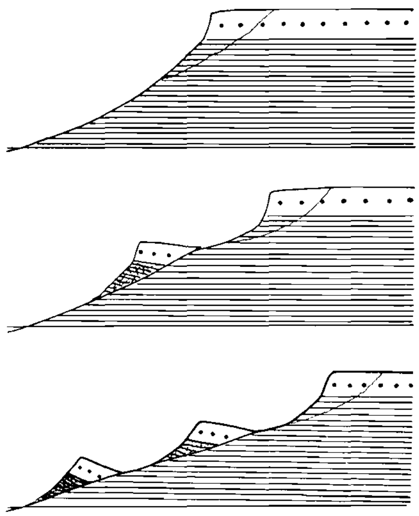

Fig. 12. Schematic representation of landslips, where sandstone from continental Cretaceous has slidden down on the underlying, soft, marine shale.

A number of other faults are given in the literature, most of them introduced by De Geer, but they are largely based upon assumptions, and have been found to be non-existant; they have consequently been left out on the map. On the other hand, faults still unknown are certain to exist.

It should also be mentioned that the big landslips so common at certain geological horizons in Svalbard, particularly where massive sandstones overlie the thick, soft shales, may have led to misunderstandings and have been interpreted as ordinary faults. This applies more especially to the Cretaceous where the soft shales of this formation and the Jurassic form the foundation for the stiff Cretaceous sandstone beds. When the shales have been removed by erosion and the slopes sufficiently steep, the foundation yields and huge sandstone parts slide downwards. The slided part has nearly always a dip towards the mountain side because the shale in front of it becomes piled up. In some mountains east of Adventfjorden, e. g. Arctowskifjellet, these landslips are so numerous that the entire mountain side has a "disorderly" aspect. These landslips are perhaps most spectacular on the north side of the mouth of Adventfjorden in Forkastningsfjellet (= Fault Mt.) where the whole mountain side has slid, not once, but three times for a length of a few kilometres. The Festning Sandstone has here been repeated four times, and with a steeper dip the more it has slipped. Cholnoky has realized that they were landslips, but has given a wrong explanation. The principle will be clear from fig. 12.

Some of the fjords and straits of Spitsbergen owe their origin to the faults of various age, for instance, Forlandsundet, Kongsfjorden, Wijdefjorden, Billefjorden, and possibly Hinlopenstredet and Storfjorden, whereas other fjords (Trygghamna and Grønfjorden) as well as many valleys are originally due to the direction of the folding, the rivers having followed the synclines or the outcrop of soft beds.

Sediments from the younger divisions of the Tertiary are entirely absent in Svalbard, and we have thus no means of fixing the age of the folding and faulting processes, but they are probably contemporaneous with the well-known earth-movements of Miocene age (the Alps etc.).

From the presence of large submarine valleys in the Barents Sea we may conclude that this area in comparatively recent times has been at a level about 500 metres above the present. This happened probably in the latter part of the Tertiary. The land surface has therefore been subject to a large amount of erosion before the land again became submerged and Spitsbergen was separated by a shallow sea from the land to the south and east. This subsidence was probably due to the large ice cover which came into being at the close of the Tertiary and beginning of the Quaternary.

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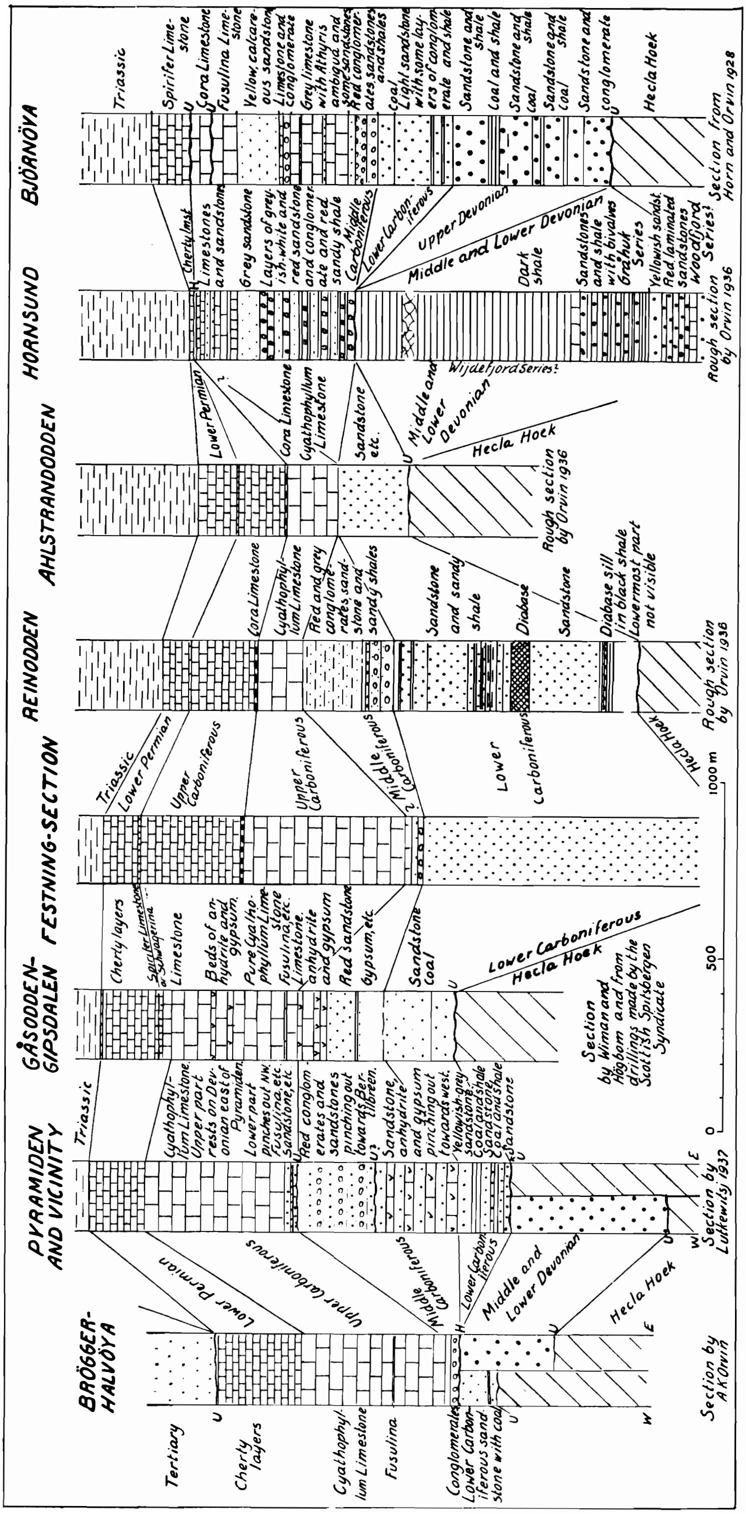
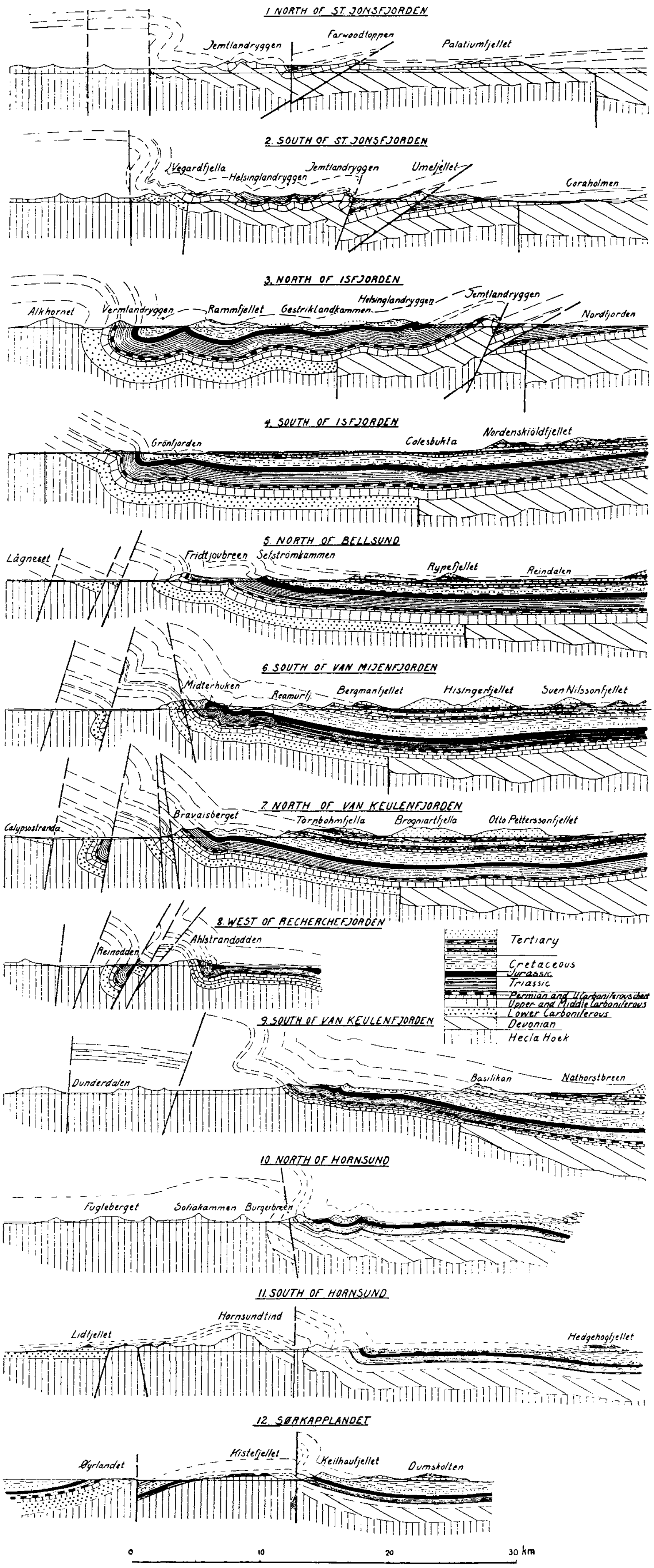
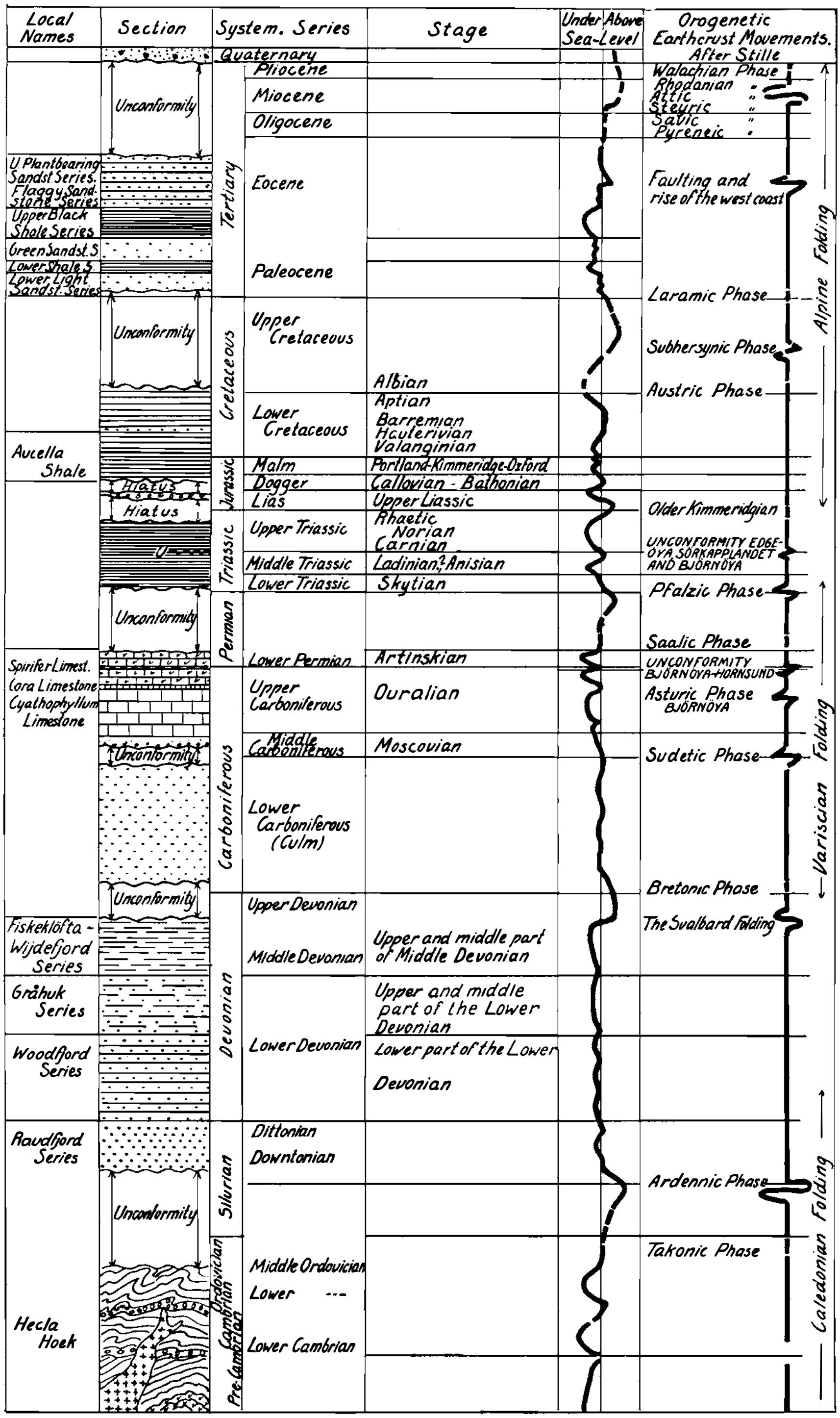



Sections of the Carboniferous and Permian sequence.




Sections across the Tertiary zone of folding along the west coast of Spitsbergen.




Columnar section of the sequence including variations of the sea-level as well as orogenetic earth-movements.

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