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*Editorial Note.* The following surveys of geological-palaeontological research of the Northern Crystalline are of the greatest general interest: (1) it is shown with exemplary clarity how the national efforts of such a small nation as Denmark have made it possible, over several decades, for a large international research team to work on a very wide basis; (2) the significance is shown of the unique natural findings (East Greenland) for the consequent, direct research on the development of the Northern Crystalline and the origin of the mountains; (3) the palaeontological work on the zoological connecting links found in the very old formations has achieved a decisive step forwards for research on evolution.

MISLIN

# Some Geological and Palaeontological Results of the Danish East Greenland Expeditions 1926–58, conducted by LAUGE KOCH

## Greenland's Morphological and Geological Features and their Problems


By LAUGE KOCH*


In 1913, when the present author first came to West Greenland, the country from Cape Farvel to Melville Bay was divided into two administrative areas, South and North Greenland, the boundary between the two districts passing close by the settlement of Holsteinsborg. In the eighties, a settlement had been established at Angmagssalik on the east coast, where a few years before a Danish expedition had encountered a hitherto unknown Eskimo tribe. A third Eskimo tribe lived in the so-called Thule district, the areas north of Cape York. In the first decade of the twentieth century, a Danish mission and trading station was erected here by the Danish polar explorer Dr. K. RASMUSSEN. North Greenland from Cape Alexander, the westernmost point of Greenland, to the east coast of Peary Land had hardly ever been visited by Danes. Similarly, vast areas of East Greenland had not yet been visited by Danes, though they had been partially explored by foreign expeditions.

In 1931 our knowledge of the ca. 3800 km long stretch of coast northward from the Upernavik district, along North Greenland and the east coast as far as Kangerdlugssuak (ca. 68° N. lat.) in South-East Greenland, was very sporadic. The rough outline of the outer coast was known in most places, but the ice-free areas along the coast and the nunataks farther inland were practically unknown.

In the course of the past fifty years, the present author has spent 34 summers and six winters investigating these regions of North and East Greenland. The fifty years do not, of course, represent the saga of polar exploration, but an enormous development of travelling technique. During the first decade of the present century, the Canadian explorer V. STEFANSSON and the Danish explorer K. RASMUSSEN employed a travelling technique termed 'to live on the country', that is to say, to travel as done by the Eskimos for centuries, securing food by hunting. RASMUSSEN, however, introduced the use of kerosene for cooking. PEARY's many advances towards the North Pole about the turn of the century were based on the sledging technique of the Eskimos, but the members of the expeditions were equipped with modern weapons, the sledges were built of choice wood, spirits were used for heating, and water-free pemmican as food for dogs and men.

The first large expedition in which I participated (1916–18) was led by RASMUSSEN and based on his technique, which had stood its test a couple of years previously on a journey across the inland ice to Danmarks Fjord and Independence Fjord in North-East Greenland, and back, much game being secured, especially musk-oxen. In 1916–18, on the sledge journey from Thule to De Long Fjord in North-East Greenland, this technique failed, the game encountered being insufficient. We therefore lost all our dogs, and two members of the expedition died, one from starvation shortly after crossing the inland ice on our return journey to the north coast.

On an expedition under my leadership in 1920–23, with the support of numerous auxiliary sledges for the first 1000 km and employing PEARY's travelling technique, and the establishment of an Eskimo camp in 80° N. lat. to support us on our return journey, we travelled in the course of 200 days from the Thule district around the north of Greenland and back across


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Fig. 1

the inland ice, returning in the autumn to the headquarters of the expedition in the Thule district. As four years previously, the return journey across the inland ice was characterized by starvation; thus, after crossing the inland ice we had only one dog left.

The old travelling methods made great demands on the physique of the men, and the scientific results of the exhausting journeys were, of course, modest, our dependency on good hunting often forcing us to leave scientifically interesting regions, or, in case of successful hunting, we sometimes had to make prolonged stays in regions of little scientific interest. The mapping was very primitive, being done by means of a theodolite and a watch carried quite close to one's body and only taken out during observations in order that the rate of the watch should not be too much affected by temperature differences. Still, owing to the many observations for latitude, also by night in midnight sun, we knew the rate of the watch very exactly. In these northern tracts the horizontal intensity is so faint that a compass is of no use, and on my journeys around the north of Greenland I did not even carry a compass. Only the man who has tried to construct, in the evenings, the first primitive chart on the basis of many hundred daily angular measurements, knows what narrow coastal strips constitute the cartographic result. On the two inland ice journeys, in 1917 and 1921, however, I also mapped the boundaries of some large, hitherto unknown, areas towards the inland ice.

As a contrast I may mention two flights in North-East Greenland, starting from an expedition ship which had pushed northward to near 79° N. lat. On these flights, lasting for a few hours, a preliminary map of large ice-free areas located between the outer coast near Danmarks Fjord and the regions west thereof were drawn. In 1938 I flew from Spitsbergen across the interior of Peary Land, and there, too, I succeeded in solving various geographic problems.

My first expedition to the east coast had as its base the newly established settlement of Scoresbysund, to which about 100 Eskimos from Angmagssalik had been moved the previous year. But they had no experience in sledging, so we got dogs and drivers from West Greenland. On our sledge journeys from Scoresbysund to Danmarkshavn we secured abundant game, so the question of provisions gave us no trouble. While so far the journeys had more or less been one-man shows, with Eskimos as dog-drivers, this expedition was joined by two geologists working near the settlement.

The new expedition technique, started in 1929, had as its model the expeditions by A. E. NORDENSKIÖLD and A. G. NATHORST at the end of the previous century. A ship was placed at the disposal of the expedition, which was joined by a number of scientists who were set ashore by means of motorboats to investigate the regions near the boats. In 1931 two ships were at our disposal, and a few winter stations were erected and fitted with wireless, electric light and numerous motorboats, with some Eskimos with dogs and sledges to assist the scientists.

Thus, at the beginning of the thirties a lively activity was going on in East Greenland, in spring and autumn with dog-sledges and motorboats, in summer with a large personnel, two ships, several motorboats and many wireless stations (up to a dozen). In addition to the mapping, now undertaken by the Geodaetic Institute, the work of the expedition included aerial photography from two seaplanes, and zoological, hydrographic, botanic, and archaeological investigations. This activity ended in 1934, but was started again by private means in 1936–39, when, owing to the impending world war, all the expedition members returned home.

Beside air photography to serve a more systematic mapping, it was necessary, on long flights, to acquire a general view of vast land areas and the innermost nunataks between Peary Land and 68° N. lat.; thus, in the summers of 1932 and 1933 all the unknown fjords and some unknown land areas and nunataks were preliminarily mapped from the air. As the seaplanes were open and could only carry one passenger, the object of the flights prior to World War II was chiefly reconnoitring; on rare occasions only could geologists make observations of their working fields from the air. In the inter-war years, Icelandic ponies played a role, up to a dozen of them, plus hay, being taken on board the ships when they called at Iceland. They were well suited for transportation of heavy collections of fossils on level ground and in low-lying valleys.

After World War II the expedition work was resumed in 1947. During the war all the stations were destroyed with the exception of the Ella Ø station, where only the wireless installation was damaged. In 1947 and 1948 we used closed aircraft of the Norseman type, which were transported up by ship. In subsequent years they were flown from Iceland to the headquarters on Ella Ø and back to Iceland in the autumn. A distance equal to once round the earth was covered by these aircraft every year.

At the beginning of the thirties it was ascertained that East Greenland north of Scoresby Sound consisted of a geosyncline in a favourable stage of development, and covering an area of ca. 1400 km from south of Scoresby Sound in the south to Nordostrundingen in the north. With the exception of the southernmost part of Scoresby Sound, the geosyncline is largely concealed by the inland ice.

From the primitive exploration journeys with dog-sledges in North and East Greenland up to the year 1927, the travelling technique changed considerably, in particular after the establishment of an air-strip at Mesters Vig (ca. 72° N. lat.) near the lead and zinc deposits discovered by the expedition, and the ships then gradually lost their importance. In 1950 the expedition still had two ships at its disposal, but since that time the ships calling at East Greenland transported only supplies, the transportation of personnel taking place by aircraft. At the same time the wintering of personnel in East Greenland ceased, and dog-sledges were no longer used. A few motorboats, however, were still used in summer. Aerial photography and reconnoitring increased enormously. The geologists as a rule made repeated flights (sometimes up to twenty) across their working area (which they had carefully studied on air photographs before their arrival in Greenland) observing it from different angles. Specially intricate tectonic regions were thoroughly studied and photographed in order to localize particularly important localities. Thus, even a short stay in such a locality might clarify questions of far-reaching significance. Even helicopters were used.

Work in an arctic country like Greenland, with its very variable climate, when snowfalls may occur all summer, and the ice may impede or prevent every communication between the headquarters of the expedition and the individual camps, requires a close cooperation between the leader of the expedition and the chiefs of the individual teams, that is to say, before the start of the expedition discussions of working plans as well as alternative plans, in case the weather and ice conditions should necessitate an alteration of the program.

Two attempts have previously been made to explain the configuration of Greenland. The first attempt was made in 1923[1], when the present author on the basis of the data available at the time put forward the supposition that Greenland consisted of two ancient shields, both attaining their highest altitudes to the south and sloping northward, and separated by a fault zone located in ca. 70° N. lat. This fault zone was supposed to be associated with the rise expanding from Scotland via the Faroes and Iceland to Greenland. In both East and West Greenland, basalt was found along the coast at the ends of the fault zone.

In 1924 the late Professor ALFRED WEGENER (personal communication) formulated his view as to the geography of Greenland as follows: Greenland is comparable to a deep plate filled to the brim with ice. The centre of the plate was forced down below sea-level by the heavy ice masses, while its margins rose to form coastal mountains. If once the ice should melt, the centre will rise somewhat, the marginal mountains will subside, and a rather level horizontal flat will result.

In 1954 Professor BAUER[2], on the special basis of the many journeys of the Victor-Expedition and its measurements of the thickness of the inland ice of Greenland, prepared a map of the configuration of the underlying land surface. This sketch presented entirely new points of view. It should, however, be regarded as a mere sketch, for vast stretches still remain unmeasured, and as regards the existence of a mountain range, extending parallel to the northwest coast, as assumed by BAUER, we have no actual knowledge.

Before starting an analysis of BAUER's sketch-map it will be necessary to consider briefly the altered views of the hydrography of the seas both east and west of Greenland resulting from the exploration during the last forty years.

On recent oceanographic maps it will be noted at once that the so-called Nansen Ridge, formerly supposed to connect Spitsbergen with northernmost Greenland, has been replaced by a trough (3000 m deep) extending from the Nansen Basin in the Polar Sea into the Greenland Basin in the North Atlantic.

The supposition of a continuation of the European portion of the 'Caledonian' folding to Greenland and Ellesmere Island cannot, therefore, be maintained. Our knowledge of the Scotland–Iceland–Greenland rise, however, has been increased.

As for Baffin Bay and Davis Strait, we know the water depths in some more detail, but during the last 30 or 40 years no essentially new geological data throwing light on the developmental history of the waterways, in particular Baffin Bay, have appeared. The intensive investigations in recent years of the Innuitian geosyncline show that some young faults fan out from the north coast of Ellesmere Island. In places they are accompanied by basalt intrusions, and the questions now arise: (1) whether this fault zone extends southward as far as Baffin Bay; (2) whether it is connected with the fault zone of unknown age in the Thule district; and (3) whether the post-basaltic faults located around 70° N. lat. in West Greenland are associated

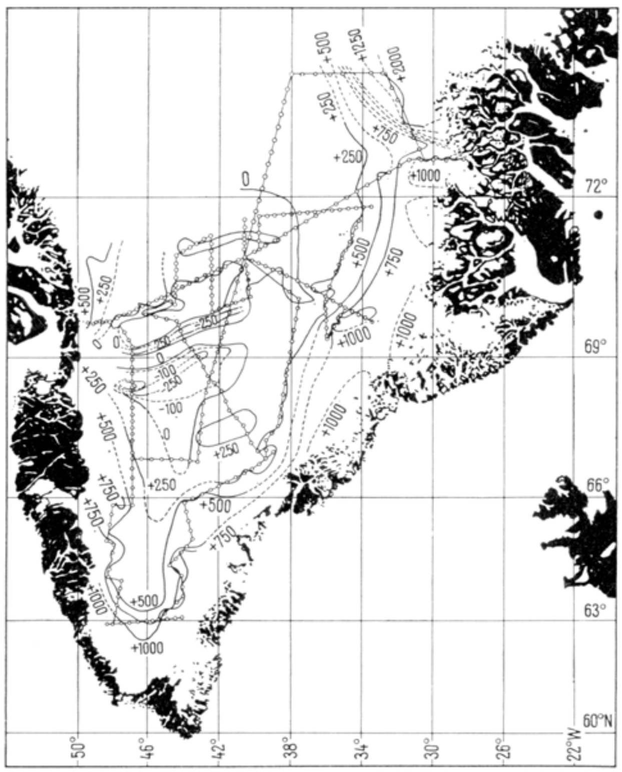


Fig. 2. Contour map of the ice-rock interface of South Greenland (after HOLTZSCHERRER[27]).
○ points at which measurements were made,
–○– routes followed by expedition parties,
–250– contour (250 m intervals) of the bedrock underneath the ice,
------ extrapolated contour.

[1] L. KOCH, J. Geol. *31*, 42 (1923).
[2] A. BAUER, *Contribution à la Connaissance de l'Inlandsis du Groenland.* II[e] Partie: *Synthèse glaciologique* (Paris 1954), p. 27.

with the faults farther north. Tertiary basalt has been found rather far to the south in Baffin Island, while the basalt locality postulated in 1906 by Low[3], in northern Baffin Island, has not yet been found. Surfaces at an altitude of about 1000 m are found along the west side of Baffin Bay, on Ellesmere Island, North Devon Island, and Baffin Island; are they to be interpreted as due to an uplift in connection with a subsidence of Baffin Bay? The areas observed on the hydrographic expeditions prior to 1929, in which the sea-bottom consists of limestone, may be indicative of a Silurian basin similar to the large Silurian basins west of Baffin Island, but nowhere have Silurian sediments been found along the coasts.

Returning now to BAUER's map, we shall see that a block with the greater part of its surface at an altitude of 1000 m is indicated south of 66° N. latitude. No rocks younger than 1000 million years (m.y.) tell anything of the later fate of this block. In the area between 66° and 72° N. latitude the map is very detailed, extensive changes of level with steep walls being indicated. They were first supposed to be due to rift valleys below the inland ice. Although ice-age glaciers may in places have deepened the relief within this area, the configuration of the surface below the inland ice as well as the coast mountains indicate the presence of a broad zone marked by large faults in many places, not, as first supposed by me[1], a single or a quite narrow fault zone. If we draw a line along the northern margin of the Atlantic rise, it will hit Cape Brewster, the central part of Milne Land, and the northernmost basalt area on the west coast of Greenland a short distance south of Upernavik, while another line along the southern margin of the rise will reach Greenland near Angmagssalik, continuing to the southern border of the lowland on the west coast very near Holsteinsborg. Between these two lines large alterations in level may have taken place both along the east and the west coast and below the inland ice. I shall make no attempt here to indicate the individual faults, but merely point out that I consider the high-lying land area between Angmagssalik and Kangerdlugssuak, where BAUER supposed the lower margin of the inland ice to occur at an altitude of even 2500 m over a wide area, as a fault block.

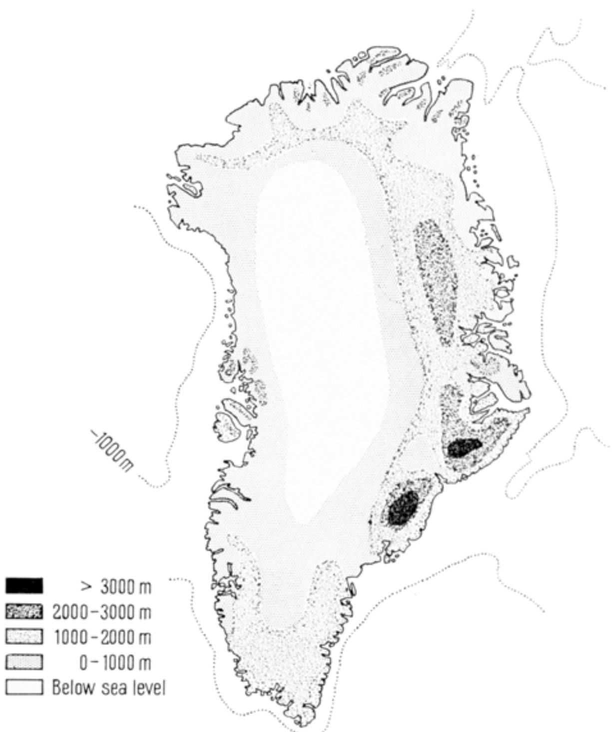


Fig. 3. Contour map of the ice-rock interface of Greenland (after BAUER[2]).

One of the most interesting, but unfortunately also most unknown regions of BAUER's map is the stretch from 72° N. lat. to near 80° N. lat. We are greatly in need of altitudinal measurements from the central parts of the area, but judging by various measurements along its margins, an extensive plain probably occurs here almost at sea-level. I am not going to try to explain this phenomenon. As the average thickness of the inland ice is ca. 1500 m, corresponding to a sandstone bed of a thickness of ca. 400 m, it would seem that WEGENER in some measure overvalued the isostatic pressure of the ice. At any rate, the past forty years have shown that the surface of the earth is not so plastic everywhere as to yield immediately to a pressure.

Turning now to one of the most interesting phenomena of the picture rendered by the Victor Expedition, it would be wise to start at Cape Farvel and follow the coast northward to Angmagssalik, continuing along the western margin of the steep mountain range right up to some distance north of 80° N. lat. (BAUER's map). My assumption, that the southernmost part of this mountain range has been elevated to form a horst, and that the glacier in Kangerdlugssuak is accordingly situated in an ancient fault zone, does not alter the total picture of this geographic mountain range, which extends, more or less concealed by the inland ice, from Angmagssalik to northernmost Greenland. South of Kangerdlugssuak the folding strikes northward. The same direction of strike is found in Gaaseland in the small 'window' whose age was determined by means of isotopes to be 2300 m.y. (HALLER and KULP[4]). A study of erratic blocks farther north and of the ancient beds on Dronning Louise Land may perhaps confirm that an Archaean folding chain or possibly several chains of varying age extend parallel with the coast.

A much better known pre-Cambrian mountain range, called the Carolinidian (pre-Cambrian age unknown), is found along a stretch of 800 km, starting in 76° N. lat. and disappearing, near Peary Land, below younger sediments in the direction towards Ellesmere Island. It

[3] A. P. Low, *The Cruise of the Neptune* (Ottawa 1906), p. 1.

possibly forms the original margin of the Canadian Shield in the northeast.

Still better known is the 'Caledonian' folding system, of a length of ca. 1200 km, which disappears below the basalts north of Kangerdlukssuak, but continues northward as far as Nordostrundigen. Recent investigations have shown that a series of folds, roughly parallel with the coast, occurs here, according to HALLER[4] representing a period of 150 m.y.

If this geographic mountain range is regarded as an ancient geosynclinal area with folds running roughly parallel with the present coastline, we know one Archaean mountain range (2300 m.y.), one Proterozoic mountain range (age unknown), and one fold system with movements ranging from the Silurian till the Permian system.

The observations of the thickness of the inland ice in northwestern Greenland are unfortunately very sparse. This part of Greenland evidently forms an eastern continuation of the Innuitian geosyncline in northernmost Canada. We know that a belt of unknown width, built up of pre-Cambrian Thule sandstones, for the most part coarse, unsorted conglomerates with numerous well-rounded quartzitic blocks, must extend from the Thule district to the regions around Danmark Fjord. We further know that north thereof Cambrian and Ordovician deposits form a belt of sediments deposited under quiet conditions and overlain, from Washington Land across Warming Land to the regions east of Frederick E. Hyde Fjord, by Silurian beds deposited under very unstable conditions. We must therefore still maintain that the fold range extending from Hall Land along the north coast of Greenland to eastern Peary Land was initiated in Silurian times. As no Devonian rocks have been found north of 76° N. lat., it cannot be definitely stated when the folding activity culminated. It is probably natural to assume that this folding range, which is most strongly developed in northern Peary Land, like the folds to the east and in northeastern Ellesmere Island, has been affected by several revolutions. Additional investigations in northeastern Ellesmere Island may show this. The only thing we can say definitely is that the movements within this folded area in Greenland started in Silurian times.

On comparing, now, our geological world picture of forty years ago with our present knowledge, we must admit that a number of theories and views have been considerably altered. WEGENER's *theory of continental drift* had special reference to Greenland. However, a few points still seem to argue against any at any rate major displacements along the lineament between Ellesmere Island and Greenland, often indicated on maps in the literature. A short distance north of Smith Sound, a low-lying *Olenellus* shore-line nonindicative of major displacements occurs on either side of the sound. Another point is the tectonics between northern Hall Land in the east and the conditions on Bache Peninsula. Great points of similarity seem to occur in these areas on either side of the strait. In the literature, Greenland has often been associated with the theory of continental drift. CAREY[5] e.g. straightens out Novaya Zemlya, making it resemble a 'Vienna' sausage, and then places it along the north coast of Greenland adjoining the mountain range in northern Ellesmere Island. KING[6] lets the mountain range at Cape Tjeljuskin in northern Siberia hit the east coast of Greenland almost opposite Sabine Island at a right angle. Many of these attempts to connect continents do not support the theory of moving continents; however, to the theory as a whole no attitude will be taken here.

The present theories as regards *foldings* likewise differ greatly from those current forty years ago. Prior to 1924 (STILLE) it was generally assumed that folding took place at the transitions between the geological systems. In America the existence of twelve periods of folding was assumed, the earliest of which was pre-Cambrian (WELLER[7]). In the period 1924–49 STILLE erected a great many short-lived, but world-wide folding phases. However, after being criticized by GILLULY[8], this system is constantly losing adherents. At present the folds are considered to have arisen from deep-seated earthquakes in the mantle, and investigations in recent years have shown that in geosynclines folding takes place in series following one upon the other, and such a series may cover hundreds of millions of years, e.g. from 100 m.y. to 1000 m.y. or perhaps more. Before long the earlier terms, not only those applied by STILLE, will probably be devaluated, and replaced by a number of 'revolutions' indicated by figures (m.y.) for the individual geosynclines. The *concept of a geosyncline* has been much altered during the last 40 years, and new terms have been applied to the different types of geosynclines. The most modern concept is perhaps that of KING[9], who modernized KAY's[10] pioneer work (1951) on geosynclines. Today the terms mio- and eu-geosynclines are being increasingly used.

All over the world circular or oblong basins filled with sediments are found in many places. What 'motor' is active below such a basin, we do not know. Typical is the Michigan Basin, which during the first half of the Palaeozoic was slowly filled with sediments not

[4] J. HALLER and J. L. KULP, Medd. om Grönland (Copenhagen, *171*, 1 (1962).

[5] W. S. CAREY et al., *Continental Drift*. A Symposium. (Tasmania 1958), p. 1.

[6] L. C. KING, *Morphology of the Earth* (Oliver & Boyd, Edinburgh, London 1962), p. 1.

[7] J. M. WELLER, *Stratigraphic Principles and Practice* (Harper & Brothers, New York 1960), p. 387.

[8] J. GILLULY, Bull. Geol. Soc. Amer. *60*, 561 (1950).

[9] PH. B. KING, *The Evolution of North America* (Princeton University Press, Princeton 1959), p. 1.

[10] M. KAY, Geol. Soc. Amer. Memoir *48*, 1 (1951).

subsequently affected by folding. Other basins may remain undisturbed for millions of years and perhaps be folded long after their formation. One folding activity may combine a number of sediment-filled basins (ENGEL[11]). The majority of geosynclines have an initial stage—it may be termed a 'sleeping' stage—when the basin, while constantly subsiding, acts like a trap, a catchment basin for huge sedimentary series. Some geologists do not term such an unfolded sedimentary series a geosyncline; in their opinion the term should only be used if revolutions have taken place. Several geologists, e.g. DE SITTER[12], think that when the sediments have subsided to sufficiently great depths, they will be intruded by ultrabasic eruptives from the interior of the earth—perhaps the initial stage of a later folding. Several revolutions may succeed one another, and, if so, they are on the whole parallel. This is the case with vast areas of the Cordilleran and the Appalachian in North America. Other folds of different ages may occur at a rather low angle below an older fold. Thus, according to DE SITTER, the Appalachian north of New York should be regarded as Caledonian. South of this city the folds are chiefly Variscan and have a somewhat different trend, but both series rest a at low angle on a little-known late pre-Cambrian folded series.

Similar conditions are met with in North-East Greenland, where the Carolinidian extend in a southward direction, then eastward, and finally arch westward to disappear towards the folding on the north coast of Ellesmere Island, and on the ruins of the pre-Cambrian folded range the North Greenland and the East Greenland zones of folding rest at a low angle. The intricateness of the geology of Europe, as compared e.g. with that of North America, is no doubt due to the fact that many of the European fold systems evidently cross each other at broad angles, sometimes at right angles. In 1948, STAUB[13] put forward the supposition that Archaean and Proterozoic rocks were also present in the Alps. At present no Swiss geologist holds this view, though very little is known about what happens when a fold crosses another, older one. Quite possibly some blocks have remained unmigmatized, and may be remnants from such a crossing of two patterns of widely different ages. Isotope age determinations and other determinations of the geological age of a fold show, the rigid system of STILLE having been abandoned, that a number of revolutions affecting a geosyncline often extend over a period of hundreds of millions of years.

A vast pre-Cambrian fold system is now being visualized in America, starting in southern Baffin Island and continuing across Labrador, where the following revolutions may be assumed: revolutions dating back (1) more than 2000 m.y., (2) ca. 1750 m.y., (3) ca. 1350 m.y., (4) the Grenville revolution 1000 m.y., and, as a continuation of this latter, the Grenville area with such a wide-spread granitization that for the present we have a definite knowledge of only the youngest one, dated at ca. 1000 m.y. A westward continuation is (5) the Penocean geosyncline, probably with revolutions in the interval between 2000 and 1000 m.y. Whether other pre-Cambrian mountain ranges, e.g. the Belcher Range and the Great Slave Range, have been subjected to some of these revolutions at the same time, has not yet been definitely settled.

It may now be asked: What happens between two revolutions? A revolution arises when heat is supplied to a geosyncline from below, giving rise to the intrusion of granite and to metamorphism. When the heat decreases, the revolution is, in all essentials, over; but in the lower part of an eugeosyncline, a varying amount of heat will still be present and will make itself felt, even though the upper part of the geosyncline is cooling and consolidating. The Appalachian geosyncline is generally assumed to have died out in Triassic time. The last movements known resulted in the formation of narrow and deep basins or graben, called taphrogeosynclines by KAY[10], probably the last stages of a dying geosyncline.

In East Greenland (south of the 74th parallel) several basins were formed during and after the Middle Devonian revolution, with rapid deposition of sediments, often with subsequent elevation and denudation, that is to say, short-lived basins in rapid succession. Movements of another kind are met with in the Upper Devonian, most often in the form of faults several hundreds of kilometres long. The eruptive activity ceased in the Middle Devonian, but notably the formation and filling of enormous basins continued all through the Triassic and Jurassic periods and, with decreasing intensity, through Cretaceous times. At the transition between the Cretaceous and the Tertiary a new revolution set in, giving rise to a mild folding activity in the southern and northern parts of the geosyncline only, but many of the earlier fault lines were reactivated, and in Tertiary times enormous eruptions of Tertiary plateau basalts took place, and subsequently occasional sub-volcanoes with acid eruptives arose. Whether the East Greenland geosyncline died out with the strong basalt eruptions, is still unknown.

Owing to the studies of isotope age determinations in various shields carried out by HOLMES[14] (notably his paper entitled 'The sequence of pre-Cambrian orogenic belts in South and Central Africa', but also his earlier and later papers), a constant flow of fresh age determinations is received every year from many countries.

It is in fact to be wondered at that after the appearance of GILLULY's[8] criticism of STILLE's theory of the

[11] J. S. BROWN and A. E. J. ENGEL, Bull. Geol. Soc. Amer. *67*, 1599 (1956).
[12] L. U. DE SITTER, *Structural Geology* (New York 1956).
[13] R. STAUB, Schweiz. Min. Petr. Mitt. *28*, 422 (Zürich 1948).
[14] A. HOLMES, Int. Geol. Congr. 1948 (London 1951).

existence of many short-lived world-wide orogenies, his idea, though rejected by an increasing number of geologists, still has adherents in the most recent literature. Four authors should be mentioned who hold the earlier views, *viz.* VOITKEWICK[15], who records the following pre-Cambrian orogenic periods: 550, 1030, 1800, 2650, and 3350 m.y., GASTIL[16] records the following periods: C = 900–1150, D = 1300–1500, E = 1000–1900, F = 2000–2200, G = 2450–2750, H = more than 3000 m.y., STOCKWELL[17] mentions: Grenville 900 m.y., Hudsonian 1700 m.y., Kenoran 2500 m.y., WILSON[18] et al. mention 'several more or less important orogenies', and conclude in saying: 'The major age divisions in Canada and Australia appear to be closely comparable'.

For more than one hundred years, the world has got its pre-Cambrian age determinations from Canada, and when in 1957 Canada[19] moved the earlier boundary between the Archaean and the Proterozoic down to 2000 m.y., this view was widely accepted. In Africa, in particular, it was customary to operate with the pre-Cambrian I, II, and III, and it was often understood that the pre-Cambrian I should be ascribed to the Archaean, while the pre-Cambrians II and III should be referred to the Upper and the Lower Proterozoic, respectively, without mention of duration. However, no definite limit has been established, but it may for instance be mentioned that according to FISHER[20] the Archaean comprises cycles dating back between 2500 and 2800 m.y., while the Lower Proterozoic extends from 1300 to 2000 m.y. As to the Ukraine, SEMENENKO[21] et al. regard pre-Cambrian I (the oldest known rocks) 2900 m.y. = Katarchean, a name given by SEDERHOLM[22]; pre-Cambrian II, several cycles between 2300 and 2900 m.t. = Archaean; pre-Cambrian III, several cycles beginning at 1000 m.y. = Proterozoic, and pre-Cambrian IV, 630–570 m.y. = Riphean. The lower limit of the Cambrian in the Ukraine is estimated at 540 m.y.

The most complete picture of the Fenno–Scandian Shield and a comparison with the whole Fenno–Sarmatia are given by POLKANOV and GERLING[23], who associate the term Katarchean with two cycles older than 3000 m.y. Two cycles, the Saamides and the Belomorides = the Archaean. With the Rapakivi volcanic rocks, 1640–1610 m.y., the oldest eastern part of the Baltic Shield reached its final consolidation. Geosynclines arising after that time appear as 'girdle belts'.

Two important papers reject the existence of world-wide cycles, viz. QUENNELL and HALDEMANN[24] ('world-wide revolutions may never have occurred') and HARPUM[25] ('Geological cycles are not necessarily world-wide, nor need they be synchronous from episode to episode in different areas'). If it were agreed that all isotopic figures beginning with 3 (3000 m.y.) were termed Katarchean, all those beginning with 2 (2000 m.y.) Archaean, and all those beginning with 1 (1000 m.y.) Proterozoic, we should get a classification which could be easily remembered and be entirely independent of cycles and local divisions, which merely give rise to confusion and it would be possible to regard each shield as a unit with its own history. Even now great differences in the development of the individual shields can be visualized. Thus, for instance, the Katarchean is found in the Baltic Shield and the South African Shield, but has not yet been found in the Canadian, Indian, and Australian Shields. As to the pre-Cambrian IV (900–600 m.y.), hardly any beds from this period are known from the Canadian Shield. In the years 1900–1959 Norwegian geologists employed the term Eo-Cambrian, but now they seem to have abandoned it. The term Infra-Cambrian (PRUVOST[26]) is not applicable either, PRUVOST stating the duration of this system to be about 100 million years, or about the same duration as that of the Cambrian. It would seem that at present the Russians have taken the lead in the studies of the Riphean rocks from that period (900–600 m.y.), so I should suggest that this term be applied to the pre-Cambrian IV, at any rate provisionally. The many late pre-Cambrian ice ages and probably also the Torridonian, Sparagmitian, etc., rocks should then be referred to this period, the straligraphic details of which are very little known.

*Zusammenfassung.* Im Verlauf der letzten 50 Jahre verbrachte der Verfasser dieses Forschungsberichtes 34 Sommer und 6 Winter auf Expeditionen in Nord- und Ostgrönland. Die Entwicklung der arktischen Reisetechnik, angefangen von den Eskimo-Hundeschlitten (Nordgrönland) bis zu den Flugbooten und modernen Kleinflugzeugen der letzten Expeditionen, hat er von Anfang an selber mitgemacht. Die grosse Serie der Ostgrönland-Expeditionen begann 1926 und hat eine Grosszahl von Wissenschaftern der verschiedensten Länder zusammengeführt, von denen eine kleinere Teilnehmerzahl im Arbeitsgebiet selbst jeweils über-

[15] G. V. VOITKEWICH, *A Unified Timescale for Pre-Cambrian* (1958), (Engl. transl. 1959, D.S.I.R., Lending Library Unit, London).
[16] G. GASTIL, Int. Geol. Congr. Proc. Pt. IX (Copenhagen 1960), p. 162.
[17] C. H. STOCKWELL, Geol. Surv. Canada, Paper 61-17 (Ottawa), (1961), p. 108.
[18] A. F. WILSON et al., J. Geol. Soc. Australia *6*, Pt. 2, 179 (1960).
[19] *Geologic Survey of Canada*, Economic Geology Series No. 1, 4th Ed. (Ottawa 1957).
[20] N. H. FISHER, Int. Geol. Congr. Proc. Pt. IX (Copenhagen 1960), p. 179.
[21] N. P. SEMENENKO et al., Int. Geol. Congr. Proc. Pt. IX (Copenhagen 1960), p. 108.
[22] J. J. SEDERHOLM, Int. Geol. Congr. Proc. (Vienna 1903), p. 609.
[23] A. A. POLKANOV and E. K. GERLING, Int. Geol. Congr. Proc. Pt. IX (Copenhagen 1960), p. 183.
[24] A. M. QUENNEL and E. G. HALDEMANN, Int. Geol. Congr. Proc. Pt. IX (Copenhagen 1960), p. 170.
[25] J. R. HARPUM, Int. Geol. Congr. Proc. Pt. IX (Copenhagen 1960), p. 201.
[26] P. PRUVOST, *L'Infracambrien* (Bruxelles 1951).
[27] J.-J. HOLTZSCHERRER, *Contribution à la Connaissance de l'Inlansis du Groenland.* I[ere] Partie: *Mesures Séismiques* (Paris 1954), p. 1.

winterte. Das erste Gesamtbild über die Physiographie Grönlands wurde vom Verfasser 1923 publiziert: (1) Der von Inlandeis überdeckte Felsgrund Grönlands besteht aus zwei nordwärts gekippten Blöcken. (2) Die Trennfuge hängt mit der aus Basalt gebauten Querschwelle Färör-Island zusammen. Gestützt auf Messungen der Inlandeisexpeditionen von P. E. VICTOR, skizzierte BAUER[2] eine erste topographische Karte des grönländischen Felsgrundes (Figur 2). Die Darstellung bringt eine quer durch Grönland streichende Bruchblockzone konkret zum Ausdruck (Figur 3).

Neuere bathymetrische Forschungen im arktischen und atlantischen Ozean erweiterten diese physiographischen Erkenntnisse über Grönland.

Die Küstengebirge Nord- und Ostgrönlands sind paläozoische Orogensysteme. Es wird in diesem Zusammenhang der Wandel des geologischen Bildes von Geosynklinal- und Gebirgsbildung und der Kontinentaldrift erwähnt. Ein Grossteil der Gesteine Grönlands besitzt präkambrisches Alter; Korrelationsprobleme des Präkambriums und einige neuere radiometrische Einteilungen werden diskutiert.

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# The Cambro-Ordovician Geology of East Greenland

By J. W. COWIE*

That part of East Greenland which now lies between latitudes 72° and 75°N was the site of sedimentation during part, at least, of the Cambrian and Ordovician Periods. No Silurian rocks or fossils have been found in this region. The strata, which attain a maximum thickness of 3000 m, are part of a thick pre-Devonian sequence which has been folded and in places, metamorphosed. The Cambro-Ordovician rocks (COWIE and ADAMS[1]) in the roughly north–south zone of outcrops show a striking uniformity of succession—in both lithology and faunas they vary little along the regional strike: if rocks of the same age occur to the east or the west they have either not yet been discovered or are now covered by ice.

On structural grounds the Lower Palaeozoic outcrops of Northeast Greenland between latitudes 79° and 82°N. can be linked with those of East Greenland: they are west and east respectively of the main folded belt. The successions and faunas of this region in the north-east show affinities with those found in Peary Land, in Northwest Greenland and in the Queen Elizabeth Islands of Canada and from the stratigraphical and palaeontological points of view they are better discussed with them. They are excluded from consideration here.

The pre-Devonian sediments of East Greenland do not display striking unconformities with angular discordance of bedding. By careful detailed study of well-exposed sections and consideration of regional relationships, however, it can be shown that an important regional unconformity, which must represent a considerable period of time, is present at the base of the Kløftelv Formation (see Table). This horizon is taken as the base of the Cambrian System. The Tillite, Canyon and Spiral Creek Formations are therefore considered to be of late Pre-Cambrian age; they have yielded no recognizable fossils except for stromatolites which may be algal in origin.

The glaciation represented by the East Greenland tillites continued for a considerable time and this cold climate was interrupted by an interglacial period of long duration. The *Canyon Formation* contains rhythmic deposits which have often been called varves. If correct, this diagnosis indicates the proximity of glaciers with an annual melt cycle giving laminated sediments. The *Spiral Creek Formation* indicates a change in climate and in depth of the sea from those prevailing when the underlying formations, including the tillites, were deposited in cold seas. Sun-cracking, ripple-marking, cross-bedding, intraformational breccias, salt casts and the presence of felspar all indicate shallowing, intermittent drying-out and pene-contemporaneous erosion in a warm, humid climate (SCHAUB[2]).

The unconformity at the base of the *Klöftelv Formation* is expressed by overstep from the Spiral Creek Formation on to the Tillite series. The main lithology of this formation is a massive pure quartzite which varies considerably in colour, and frequently shows cross-bedding, ripple-marks and 'swash' marks. The uniformity of the thickness and of the lithology over the whole region suggests rapid marine transgression over a peneplained land area. The only indications of the existence of organisms in the Kløftelv Formation are numerous tracks and trails and these are also seen in the lower part of the *Bastion Formation*. The sandstones of this subdivision succeed after a stratigraphical break with a basal conglomerate containing phos-

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[1] J. W. COWIE and P. J. ADAMS, Medd. om Grønland, Copenhagen *153*, 1 (1957).

[2] H. P. SCHAUB, Medd. om Grønland *114*, 1 (1950).