RECENT GEOLOGICAL RESEARCH IN THE ARCTIC.

H. K. E. KRUEGER.

During the last fifteen years many geological data have been collected in different parts of the Arctic and the knowledge thus gained not only represents a valuable addition to the regional geology of these areas, but makes important contribution to general problems of geology and petrology. It may be worth while mentioning that these scientific advances owe nothing to the very expensive air expeditions of the last few years.

Exhaustive bibliographies, covering the whole of our present knowledge of the Arctic regions, have been compiled by W. L. Joerg, L. Mecking and O. Nordenskjoeld.

Reviewing the more important results of this work, we find that the general outlines of the geological structure of Spitsbergen have been worked out by Nathorst, De Geer, Holtedahl, Backlund, Hoel, Tshernysheff and, more particularly, Nansen, so that the time is now ripe for more detailed investigation. This is now in progress by the work of K. S. Sandford, N. E. Odell or S. Obrutsheff. The last named has ascertained the occurrence of Upper Jurassic and Lower Cretaceous rocks on the east coast (1925), and K. Gripp has published important matter regarding our knowledge of glaciers and moraines and on the question of the structural movements of Arctic drifts and soils. As regards other islands in this region, G. W. Tyrrell has contributed petrographical notes on Jan Mayen.

Russian scientists have been particularly active during recent years in Arctic Europe and Asia. Naturally a great part of their geological exploration has been concentrated on the Kola Peninsula, since this region has become relatively easily accessible through the construction of the Murman railway. N. Kassin and A. Palkanoff were working there in 1917; and in 1918, P. W. Wittenburg and N. N. Jakowleff paid particular attention to the Island of Kildin where they discovered dolomites and limestones resembling those described by Holtedahl from Finland as of Lower Ordovician age. From 1920 to 1924 geological work was carried out on the Childin Massif under A. E. Fersmann. These expeditions, though primarily undertaken with an economic object, have nevertheless yielded

important scientific results, such as the discovery of fifty-two new minerals. Wittenburg's research around the Varanger and Kola fjords proved that the iron ore deposits known to exist near the Russian-Norwegian border extended for a great distance to the shores of the Kola fjord. The existence of similar deposits of iron near the Murman railway is surmised by W. M. Kusmin in explanation of the great magnetic anomalies that he found to exist there.

The islands of Nova Zembla have been the field of numerous expeditions, including that of Ch. Bénard in 1914, the geological results of which have been worked out by Russanoff and Kruglowski; and the Norwegian expedition under O. Holtedahl in 1921, which determined the general geological structure of the islands. The latter expedition established the fact of sea connection between Nova Zembla and Arctic America during late Cambrian and early Ordovician time, and that this marine transgression in the Silurian period was followed by orogenetic uplift in the Lower Carboniferous and still later by "Hercynian" folding of the strata. Furthermore, it proved the absence of Cretaceous and Tertiary rocks.

Other expeditions, partly for economic, partly for purely scientific purposes, complete our geological knowledge of these islands. Of these, the expeditions under R. L. Samoilowitch, 1921, 1923 to 1925 and 1927 demand special mention. In the course of all the expeditions here mentioned, the southern island was crossed five times and the northern three times.

The regions south of Nova Zembla, Waigatch Island and the Jugor Peninsula, have been explored under N. Kulik, who discovered deposits of Silurian age on the Jugor Peninsula and, as early as 1914, proved the existence there of Upper Devonian sediments and coals resembling those found on Nova Zembla.

In connection with the country between the White Sea and the Ural Mountains, Th. N. Tshernysheff must be mentioned first, for although his expeditions are earlier than the others here noticed, his observations dealing with the geomorphology and tectonics of the Timan Hills have only recently been published. The geological survey of the district around the river Petchora and its tributaries, carried out between 1920 and 1925 under A. Tshernoff and W. Warssonofjewa, is important work.

The expedition into the territory east of the Yenisei led by N. Urwantzeff was undertaken for the purpose of examining the coal beds near Noril. This district is composed of undis-

turbed Tertiary and Quaternary formations overlying strata affected by "Hercynian" folding.

Holtedahl's work also merits mention. By comparing the Paleozoic faunas from the various regions between Nova Zembla and Alaska, he came to the conclusion that the Uralian geosynclinal extended across Nova Zembla and the Polar Sea north of Siberia to Alaska. In his opinion, folding was progressive; for while in the western part of the syncline the latest orogenetic movements coincided with the end of the Paleozoic epoch, in the eastern part their effects continued until post-Jurassic time.

The country east of the river Lena has been neglected for a long time, and it is only during recent years that a systematic study of the geology of the Yakutsk region has been started. A great deal of information and material collected during the survey remains to be worked out and it is much to be regretted that most of the remarkable scientific results published are printed in Russian and therefore remain almost unknown in other countries. The Yakutsk Commission of the Academy of Science in Leningrad started its work in 1915 by appointing A. Grigorjeff to explore part of the basin of the rivers Lena and Aldan, and in pursuance of the program of the commission, S. Obrutsheff proceeded in 1926 into the regions between the Lena and Indigirka. East of the latter river, Obrutsheff discovered a great mountain chain reaching heights of 10,000 feet and forming a range 625 miles long and up to 185 miles wide, lying parallel to the already known Verkhoyansk-Stanovoi Mountains. To this new range, he gave the name Tsherski Mountains in honor of the geologist who died on an expedition into these regions in 1892. The strata found there are mainly Paleozoic and Triassic. An expedition was appointed in 1927 to extend these explorations into the regions between the rivers Kolyma and Omolon.

Other contributions to the geology of eastern Siberia have been made by Backlund, Tolmatsheff, Diener and Pawloff. Backlund and Tolmatsheff have given an account of the geological collections brought home by the Hydrographical Surveying Expedition of the Polar Seas during the years 1911 to 1915 which discovered Nicholas II Land north of Cape Chelyuskin. Diener has described the Triassic formation of Kotelny Island in the New Siberian Archipelago and A. P. Pawloff a number of Cephalopoda from the Jurassic and Cretaceous of northern Siberia. Lastly I. P. Tolmatsheff has

commented upon the map of the Chatanga region and has added to our knowledge of the geology of Wrangel and Herald islands.

In 1918, the members of the Maud Expedition investigated Taimyrland by means of numerous sledge trips and brought back considerable geological information.

H. Backlund has made other valuable contributions to Arctic geology besides his joint work with Tolmatsheff. To his earlier publications on the geology of Desolation Island, the Arctic parts of the Ural Mountains and other areas, he has added a detailed study of the rock specimens obtained by the late Baron Toll, 1900 to 1902, from the west coast of Taimyrland, supplemented by material from the collections made by the Hydrographical Expeditions of 1912 to 1915, which Kiritshenko had previously described. Considering that the only information he had concerning these rocks was a list accurately recording their localities, but giving no other details, Backlund's investigations are in a remarkable degree exact and thorough. Interpreting their chemical analyses and the evidence of shearing movements evinced by even the smallest fragments of rock, he was able to deduce their geological relationships and the tectonic events for not only the whole of Taimyrland, but also for the newly discovered Nicholas II Land to the north. He concluded that in all probability there is, in this region, a great overthrust from the northwest to the southeast with a southwest to northeast strike. His methods of investigation may be found to be applicable to tectonic problems in other regions of crystalline schists and to tracing out the evolution of such areas. Consisting essentially of a detailed microscopic analysis of the orientation of the minerals produced by tectonic movements (Sander's "Gefuege"), they are very similar to the methods developed by B. Sander within the last few years.

Finally some reference must be made to the work on Pleistocene glaciation of Siberia. J. A. Moltshanoff's observations have led him to infer the existence in glacial times of a great ice-locked lake extending from the present Lake Baikal to the Caspian Sea, the waters of which were ponded back by the ice sheet which covered northern Siberia. Samoilowitch, collating the observations made by Kulik, Amalitzki and Grigorjeff, is of the opinion that whereas in the more southern part of Arctic Europe there were two periods of glaciation, in the extreme northern there was only one, due to marine transgres-

sion over these regions during the time occupied by the later ice advance. For Siberia he turns to the researches of A. Borisjak, W. A. Obrutsheff, Gordkoff and Grigorjeff, whose recent work points to a more widely extended glaciation than previously assumed, and distinguishes two distinctly separated periods of maximum glaciation.

By all this research, our knowledge of even the most northern part of Siberia has been sufficiently advanced to enable W. A. Obrutsheff to write a book on the general geology of that country.

Compared with these notable attainments in Europe and Asia during recent years, little has been done to advance our geological knowledge of Arctic parts of Canada. Only the results accruing from Stefansson's, MacMillan's and Rasmussen's expeditions can be mentioned here. These expeditions, having as their chief aim other objectives, did not contribute very much to the geology of these regions. O'Neill's report on the coastal region between the mouth of the Mackenzie River and the eastern shores of Coronation Gulf makes known the existence there of Paleozoic formations ranging from Silurian to Carboniferous and overlying the Archean rocks of the area, as well as the extension of copper ores around Bathurst Inlet, which hitherto were practically unknown. It has also supplied useful data relating to coastal uplift. Strand terraces were found near Darnley Bay at a height of 500 feet and others further east at heights of 45 and 170 feet. Macmillan reports that Finlay Island and the adjacent land masses also show evidences of recent uplift.

Rasmussen has also published material on the question of isostatic movements in the territory around Baffin Land. According to these notes, a great part of Southampton Island and Melville Peninsula was covered by sea subsequent to the glacial period. Strand terraces are found in Pond's Inlet up to a height of 600 feet and west of Milne Inlet up to 1,200 feet. A well defined range of strand ridges is cited as definite proof that the whole country is rising rapidly at the present time. Should these observations prove correct, there is marked contrast in this respect between that region and Greenland, where, after elevation since the glacial period, subsidence has now set in, as proved by the partly submerged Viking settlements. The existence of strand ridges does not, however, conclusively prove uplift. In a subsiding area, the submerging ridges are destroyed very soon by wave action. The mere

existence of such ridges therefore can not prove uplift or subsidence of a shore line.

Following Nansen's discussion on problems of strand flats and isostatic movements, De Geer has applied these ideas to Arctic regions and concludes that the boundary line of the Atlantic part of the Polar basin which runs from Banksland, along the Canadian Archipelago, north of Greenland and across to Spitsbergen and Franz Josef Land, is formed of "strand flats" which have been elevated and dissected by fjords.

It is only lately that a new impetus has been given to geological exploration of the Canadian Archipelago. G. P. Putnam's work in the southwest of Baffinland in the summer of 1927 proved the existence there of sediments, presumably of Cambrian age, resting discordantly upon the Archean gneisses. Officers of the Geological Survey of Canada have been working in the southern part of that island since 1924, but their results have not yet been made accessible.

An excellent general account of the geology of Greenland has now been written by O. B. Boeggild. The University of Cambridge sent out an expedition in 1926 to explore the district around Franz-Josef Fjord in east Greenland which, among other geological observations, found that the Caledonian folding extended into these regions. The full results of the expedition still await publication.

The most outstanding work yet accomplished in Greenland is that of L. Koch, indubitably the foremost scientist who has devoted his attention to the far north. He has mastered the art of Arctic travelling beyond all others and to this fact his remarkable achievements are undoubtedly due.

He is perhaps surpassed in popular estimation by his countryman K. Rasmussen, but Rasmussen's claim to distinction rests on his remarkable studies of Eskimo folklore rather than on scientific work. Rasmussen's topographical and geological observations have been considerably amplified and corrected by the careful and exact surveys made by Koch. Koch worked out the stratigraphy of the whole northwest of Greenland and the importance of his work is shown by Schuchert's remark that American stratigraphy needs these results since many of the earlier American Paleozoic faunas have come from the Arctic zone.

During 1926 and 1927 Koch continued his researches on the east coast and succeeded in linking up his results with those obtained in earlier surveys on the northwest coast. I have on

a previous occasion, from preliminary information communicated to me by letter, given a detailed report on the results he obtained during this last expedition; but two of his contributions to our knowledge of Arctic geology are in my opinion of outstanding importance.

In the first place, he has found definite proof that Caledonian folding persists into northern Greenland, extending from the northernmost point along both the east and the west coasts, thus establishing beyond doubt the unity of Greenland with western Europe and Spitsbergen. Secondly, he has conclusively shown that the glaciation of Greenland never reached very much farther north than it does at present. If we may assume from this fact that the outline of the ice cap over Greenland, with its distinctly marked channels of drainage, has remained the same since the Glacial Period, we can draw definite conclusions regarding the outline of the mainland. This I propose to do in a forthcoming paper.

Furthermore, Koch has been led from his extensive knowledge of the coast of Greenland to conclude that the island consists of two separate blocks. This theory may prove of the utmost importance in any hypothesis for unravelling the orogenesis of Greenland when the criteria afforded by the petrological characters are taken into account.

Koch has been compelled to sacrifice detailed petrological research in the interest of more general and more purely stratigraphical exploration. Yet for such work, Greenland offers a field almost unequalled elsewhere. Between the coast and the inland ice the rocks—partly smoothed by ice action and free from detritus and vegetation—are admirably exposed to view and one is able to investigate over an area of many square miles their relationship and stratigraphical succession.

Under such circumstances as these, a petrological approach to the geological problems of Greenland is likely to prove highly successful, as some of my own observations will show. These are based on material which I collected during the Hessian Expedition to Greenland in 1925.

Working in collaboration with F. K. Drescher, it has been possible, from the study of the peridotites intruded into the Cretaceous on the north coast of Nugsuak Peninsula, to describe a series of differentiation products, ranging from ultrabasic to acidic, produced within the original magma itself, and to trace effects of the acidic products injected into the overlying strata. Considering that basic fusions as material of injections have

never been found in the deeper zones of folding, one may have here a demonstration on a small scale of those processes whereby aplitic material, split off by differentiation from underlying simatic masses, has intruded into higher beds.

In another paper I have tried to prove that the lowest layers of basalts on the island of Disco and other Tertiary areas of this region are not basaltic breccias as originally believed, but "Sonnenbrenner" basalt—a type of rock which, due to conditions of physical structure and chemical composition not yet properly understood, is prone to very rapid disintegration when exposed to the atmosphere and to sudden changes of temperature.

Although, at first sight, these remarks may seem to be of technical interest only, yet, when the chemical composition of these rocks is taken into consideration, the facts are found to possess general significance. This basalt is the most basic one known from Greenland. O. Diehl and W. Schottler from their study of material collected in parts of the world remote from Greenland have also found that the particular physical condition called "Sonnenbrenner" occurs only in the basic members of the basalt family. Furthermore, a comparison of the analyses of the basalts from the Disco region points to the later flows being more acidic than the earlier ones, from which one infers a progressive differentiation of the magma. Very similar observations have been made by K. Holler, who found the same increasing acidity in the rocks of Rhoen in Germany. He was able to prove that this differentiation occurs in those places where intermittent eruptions produced successive sheets of basalt, so one may reasonably assume that here in West Greenland also, separate eruptions alternated with long intervals of inactivity.

When we express these analyses according to Niggli's standards of stereographical projection, the Greenland rocks show a great resemblance to the basalts from Iceland as given by K. Burri. With their low "alk" and high "c," they certainly belong to the Pacific group; but with a "fm" value very high at the expense of the "al," they correspond to those little differentiated basalts from other extensive regions of subsidence. R. A. Daly regards magma of such composition as characteristic of effusions from fissures of rupture opening up in the rear of moving continental blocks. But as the movement of Greenland, according to Wegener's theory, takes place in a westerly direction, the composition of the magma on the

west coast of Greenland does not support Daly's contention. It would be extremely interesting therefore to compare the chemical character of the basalts from the west coast with that of the same rocks from the Scoresby Sound region on the east coast, particularly as it is certain that no basaltic sheet of any size is situated beneath the inland ice, since boulders of basalt are never found in its moraines.

A curious rock corresponding to no other rock yet reported from Greenland has been found as dikes in the basalt. It contains, in addition to feldspar, primary calcite up to 20 per cent of its bulk. A description by F. K. Drescher will be published shortly.

The most important results of all, however, are those obtained in the Archean. It has been possible to prove two different formations separated by a discordance. The lower gneisses, which at first appeared to be of igneous origin (orthogneisses), when carefully studied proved to be sediments split up and separated by a great amount of acid magma. Their sedimentary origin is proved by the occurrence of garnetiferous mica schists and even metamorphosed coal shales. The rocks have undergone a succession of movements causing in many places intensive folding of the bands even within the smallest area. A number of separate movements are to be distinguished, since angular fragments (xenoliths) of older gneisses occur in the amphibolite.

The few available analyses of the grey gneiss, claimed by older authors to be a typical orthogneiss, make a mixture of sedimentary and igneous material not improbable. The analyses of rocks mentioned as diorites correspond almost completely to that of a typical sedimentary amphibolite. Of course, metamorphosed peridotites are also found, but generally speaking it may be said that we are dealing here with a sedimentary rock which has been indurated by the injection of much granitic material, has undergone severe diastrophism, and has been much intersected by aplite veins and dikes of comparatively late date since these have not been affected by earth movements.

The formation may be assumed to be Archean. These gneisses correspond very closely to the gneisses described by M. E. Wilson from the Laurentian Highlands in Canada. Nevertheless I, personally, cannot accept the reasons he gives for supposing the gneisses to be igneous, especially as he is compelled to resort to very far fetched assumptions in explaining the banding of such igneous magma.

One should consider that all geological processes, the effects of which can be observed, have taken place within the uppermost strata of a crust which, already solidified, underwent decomposition and sedimentation. Therefore we may expect even the oldest Precambrian rocks to consist—with the exception of comparatively few cases—of sedimentary and igneous material, and thus to show a dual composition, a point emphasized by J. Pompeckj.

Resting unconformably on these gneisses is another series of metamorphosed sediments which are preserved in places and are particularly well seen on the north side of Umanak Fjord and (I believe) in the eastern part of Nugsuak Peninsula.

A period of erosion appears to have intervened between the deposition of the two series, since a conglomerate concordant with the overlying strata, and therefore the base of the higher formation, is found in Nugsuak.

The aplites of the lower series do not anywhere penetrate into this formation and there are only few pegmatite veins. The finest development of this formation is to be found on Agpat Island in the Umanak Fjord, where amphibolites, quartzites, marbles and sedimentary gneisses form a more or less undisturbed and level series. I have proposed to designate this formation until further investigation the Agpat formation.

Finally, on Svartenhuk Peninsula and the opposite part of the mainland, there are found, according to older observations, slates which may also belong to the Agpat formation. But it remains an open question whether these slates may not form an even younger formation.

The Agpat series still waits detailed investigation, and this work is very desirable since it may throw light upon the important question of the distinction between orthogenesis and paragenesis.

TECHNISCHE HOCHSCHULE,
DARMSTADT, GERMANY.

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