SOME PROBLEMS OF ARCTIC GEOLOGY.

I. THE POLAR BASIN.[1]

UNTIL the return of the *Fram* from its epoch-making drift, the belief was almost universal[2] that the Arctic Ocean is a shallow, island-strewn sea; and the evidence for this view was thought to be so conclusive, that theories of Arctic geology might be safely based upon the hypothesis. Facts inconsistent with the theory were not unknown. Scoresby had let out two miles of line west of Spitsbergen, and Parry had sounded with a 500-fathom line at his furthest north, and on neither occasion was the bottom reached; Nordenskjold, in the *Sofia*, had found that the sea at 81° 32′ N. and 17° 30′ E. was 1300 fathoms deep. But this direct evidence did not shake the widespread belief in the general shallowness of the areas where no direct evidence was available. This theory was originally based on the notion that ice cannot be formed on the sea except where it is shallow; and after this view was proved to be mistaken, the old conclusion was maintained by various authorities from many different considerations. Thus Petermann, the great German Arctic geographer, deduced the extension of Greenland across the Pole to Wrangel Land near Behring Straits, from the distribution of drift-wood. It is well known that the Siberian rivers carry down vast quantities of tree-trunks, which float across the Arctic Ocean, and are cast upon its shores. But there is very little of this drift-wood in the Robeson Channel, and at the northern end of Smith's Sound. Petermann, therefore, concluded that there can be no direct sea communication between that strait and the coast of Northern Asia. While Petermann inferred the existence of a land connection between Greenland and the Asiatic islands from the discontinuity of the sea, Sir Allen Young, even as late as 1893, held that there is direct evidence of its actual existence; for the Governor of Upernivik, the most northern Danish settlement in Greenland, received from a native hunter a reindeer skin which had been branded with one of the marks used in Siberia; hence Young argued that this reindeer must have walked across from Siberia, which it could only have done along a line of continuous land, or, at least, a chain of islands. The existence of land to the north of Greenland was also maintained by Captain Tyson, the chronicler of the Hall Expedition, owing to the very moderate current that flows southward down Robeson Channel, which, it was said, could only be explained by the assumption that a northern archipelago acted as a weir. Again, Admiral Sherard Osborn contended that the sea to the north of the Parry Islands is a land-locked basin, as its characteristic icebergs never pass out through either Smith Sound or along the eastern coast of Greenland; and the occurrence of land to the north of Spitsbergen was asserted, as flocks of birds fly northward as if on their way to a safer breeding-place.

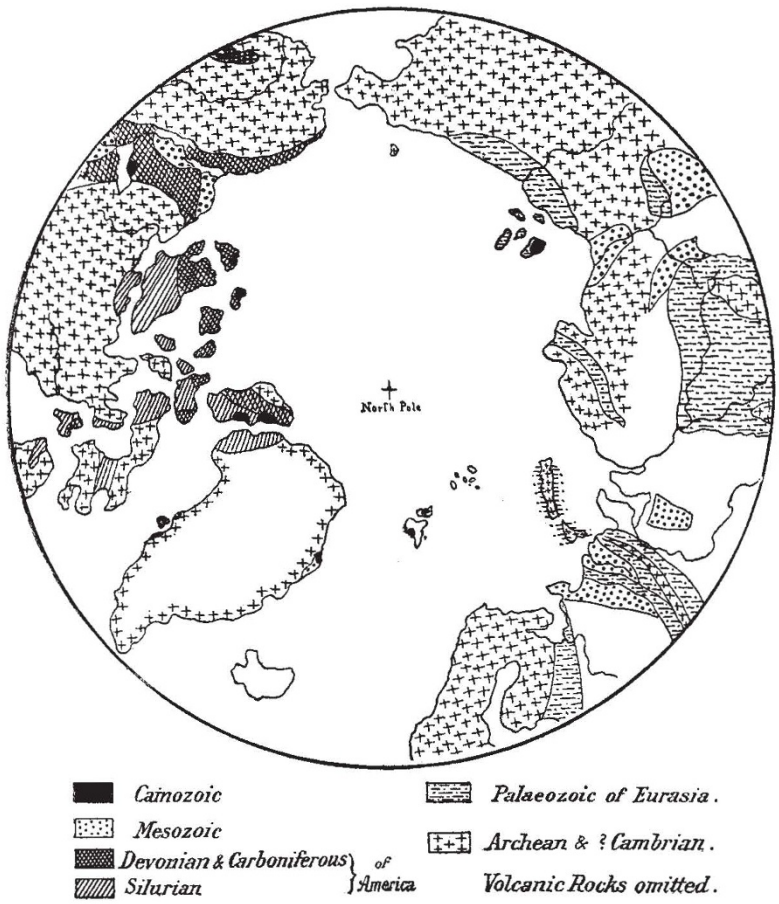

FIG. 1.—Geological Sketch Map of Polar Regions.

How firmly ingrained this view of the shallowness of the Arctic Ocean had grown, cannot perhaps be more strikingly illustrated than by the fact that the *Fram* was only supplied with apparatus for sounding in comparatively slight depths. Accordingly, geologists and biologists were permitted to introduce great changes in the size and position of the Arctic Ocean without any objections being raised. Thus Sir J. D. Hooker was allowed to call up great land areas from the Arctic deeps, to account for the apparent eccentricities of plant distribution. When Sir Chas. Lyell explained the vicissitudes of Arctic climates by a different arrangement of land and water in the North Polar regions, no *à priori* protests were made. But the sounding-line of the *Fram* has changed all that, for it has introduced into Arctic geology the theory of the permanence of oceanic basins. If that theory be true, then throughout the æons of geological time a large part of the Polar area has been occupied by a vast, deep reservoir of water. In that case many of the problems of British geology require solutions, different from those which have hitherto been deemed satisfactory.

The question whether the Polar Basin has been permanent, and, if not, at what age it has been formed, is the problem of greatest geological importance raised by the voyage of the *Fram*.

In the case of the other oceans, biological evidence is fortunately available. Thus a map of the world marked off into botanical regions, shows that in the tropics and the southern hemisphere the ocean basins separate distinct floras. Thus South America, Africa, and Australia now belong to different botanical regions, so that these three continents must have been separated from one another for a very long period. But palæo-botanical evidence shows that in Triassic times they were inhabited by the same flora; and therefore, during or immediately preceding that period, they were not so completely separated by ocean barriers as they are to-day. But in the case of the Arctic Ocean we get no such assistance from biological evidence, for one flora and one fauna extend uninterruptedly through all the Arctic lands. This uniformity may have resulted from the original development of this flora and fauna in some land around the Pole, whence they spread radially into Europe, Asia and America. But, on the other hand, it may have resulted from an east or west diffusion along the circum-arctic belt of land. That this land has not always been arranged as it is at present, is rendered almost certain by the minor differences that occur in the floras of different parts of the Arctic zone. For example, the line of separation between the American and European subdivisions of the Boreal botanical realm does not run between Greenland and Iceland, but between Greenland and the rest of the American archipelago. In fact, according to Hooker and

[1] As limits of space prevented the insertion of adequate references to authorities, it has been thought advisable to omit them altogether.

[2] The principal opponent of this view was Dr. J. Murray.

Nathorst, Greenland botanically belongs to Europe, and not to America. Though this throws doubt on the permanence of the separation of Greenland and North-west Europe, it does not prove any change in the Arctic Ocean inconsistent with the theory of the permanence of ocean basins. As we, therefore, cannot prove that the resemblances between the inhabitants of the Arctic lands on opposite meridians have been established by migration across the Arctic Ocean, instead of around it, we cannot hope for much help from biological evidence in determining the age of the Arctic Basin.

We are therefore compelled to rely on the facts of the stratigraphical geology of the Arctic regions, of which a short outline is accordingly advisable. This is illustrated by the accompanying sketch map (Fig. 1). The rocks of the Arctic regions belong to the following systems: the Archean, Cambrian, Silurian, Devonian, Carboniferous, Triassic, Jurassic, Cretaceous, Lower or Middle Tertiary, and Pleistocene.

The largest part of the Arctic land is occupied by rocks belonging to the Archean system. They form the whole foundation of Greenland, and occur in Baffin's Land, Labrador and the eastern part of British North America; westward they plunge below the Devonian and Cretaceous rocks of the Mackenzie River Basin, and reappear in the Yukon River and in Alaska. They occupy an enormous extent of Siberia, reappearing at intervals beneath Palæozoic rocks and Pleistocene tundras: they form the backbone of the Ural mountains, and of their northern continuation the islands of Nova Zemlya; west of the White Sea they cover nearly the whole of Finland, the Kola Peninsula, and Scandinavia, and a ridge of them extends up Western Spitsbergen, and forms most of North-East Land and its off-lying islands.

The age of the next series is somewhat uncertain. Its members overlie the Archean rocks unconformably, while they are always earlier than any fossiliferous beds with which they may be associated. The series consists of red sandstones and coarse conglomerates, with quartzites and dolomites. The rocks are regularly bedded, and are often horizontal; but they may be violently contorted and roughly cleaved. This series does not form huge continental blocks like the Archean, but occurs as a belt which may at one time have been continuous around the Arctic Ocean. Representatives now occur in northern Norway and Spitsbergen; in eastern, western and southern Greenland, in Labrador, the basin of the Coppermine River, and at one or two places on the Siberian coast. Fossil remains occur occasionally, but none have yet been described which settle the age of the series. But from stratigraphical considerations this series is probably of Lower Cambrian, or possibly Torridonian age.

In the next system representative fossils are abundant, and they show us that in Silurian times a large part of the Arctic area was covered by a sea, whose waters were warmer than those of the present Arctic Ocean. The Silurian rocks occur in belts. One belt runs down Smith's Sound, and then, bending westward, crosses the islands of North Devon, North Somerset, and Victoria Land. So that the Silurian Sea apparently covered most of the American Archipelago, and extended up two gulfs, of which one ran across Baffin's Land, and another up Hudson's Bay. But most of Arctic North America was then above the sea. The shore line of the Silurian Arctic Ocean skirted the American coast as far west as Cape Parry; thence it swept northward, and it is not until we reach the Indigirka River and the new Siberian Islands that we again find exposures of Silurian rocks. In the basins of the Indigirka, Lena, and Yenesei the Silurian limestones occupy a wide extent of country; but approaching Europe the land again extended northward, and it is even possible that there was no direct communication between the Silurian Arctic Ocean and the seas that then covered parts of England and occupied the basin of the Baltic. If any connection existed, it probably occurred as a strait from the Gulf of Finland to the White Sea.

In the succeeding Devonian period the Arctic Sea was larger: one arm of it ran up the basin of the Mackenzie River, and covered a wide tract in British North America. In North-eastern Europe a similar inroad of the sea had occurred; for marine Devonian deposits are known from Nova Zemlya and the flanks of the Ural Mountains, and they cover a large part of the district of Timan and the Petchora Basin.

The accompanying sketch map (Fig. 2) illustrates the probable limits of the Arctic Sea in the Silurian period, and the extent of its transgression in the Devonian.

In addition to the marine Devonian deposits, others are known which were probably formed on land or in inland seas; but more satisfactory evidence of land conditions occurs in the Carboniferous period, when the extent of the land was probably much greater. In Arctic America the sea had withdrawn to the north, and only covered the north-western part of the American Archipelago, the central belt of Grinnell Land, and part of

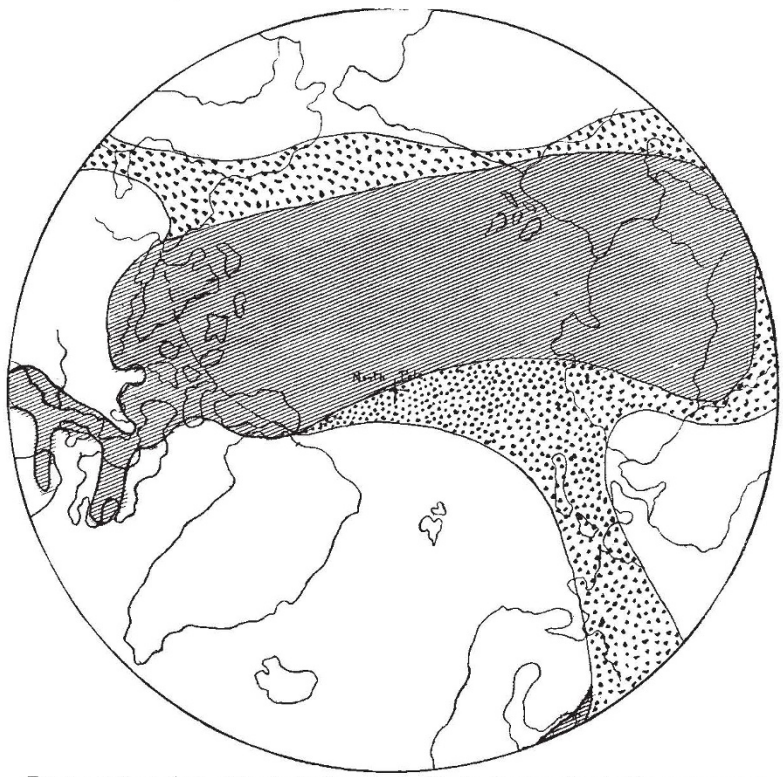

FIG. 2.—Probable limits of the Arctic Ocean in the Silurian (lined area) and of its transgression in the Devonian (dotted area).

Southern Alaska. All Europe north of the sixtieth parallel was a land area, except for a gulf in the Timan region of North-eastern Russia: Nova Zemlya was then an island chain, while most of Spitzbergen was submerged. But the advance of the sea in this area was more than counterbalanced by its recession from Eastern Siberia.

The Triassic Arctic Ocean was probably smaller than that of the Carboniferous period. The retreat of the sea from the American Archipelago, which had been gradually taking place throughout Palæozoic times, was now complete, but marine Triassic rocks in Arctic America are known from Alaska. In the Old World the best-known Triassic deposits are the barren red sandstones of various parts of north-western Europe; but a sea, inhabited by a very rich and interesting fauna, then occupied the Mediterranean area, covered most of Switzerland, and stretched eastward across the Balkan Peninsula into Russia, and possibly into India. At the same time a great Triassic sea lay to the north of Europe and Asia; it covered Spitsbergen and, probably, also Franz Josef Land, and skirting the Eurasian coast-

line as far as the Lena, then spread southward into the Amur Valley; it thus reached the sea of Okhotsh, whence one coast ran southward across Japan, and the other eastward to Alaska. From many Arctic localities these Triassic rocks are rich in fossils; but the fauna of the Triassic Arctic Ocean is so different from that of the contemporary Mediterranean Sea, that it is doubtful whether there was any direct connection between them.

After the close of the Trias there is a considerable gap in the annals of the Arctic Ocean. When the record is resumed in the middle and upper parts of the Jurassic period, we find that the sea has either again grown very considerably, or has materially shifted its position. Thus the sea, instead of ending near Spitsbergen, has encroached to Greenland on the west, and extended southward to the Lofoten Islands, to southern Sweden and to England, France and Germany; and further east a series of gulfs ran southward up the valleys of the Petchora, Obi, Yenesei, and the Lena. The Jurassic Arctic Ocean, therefore, appears to have been connected with whatever sea there may then have been in the North Atlantic; but, unlike its Triassic predecessor, it was separated from the Pacific by a broad belt of land.

In the succeeding Cretaceous period we get the last geological proof of an Arctic Ocean before that of the existing period. The sea had receded in the Old World, but it had gained considerably in America; for marine Cretaceous deposits occur in Central British North America, and the sea seems to have entered that area by the Mackenzie River depression. In the Tertiary era all the positive evidence relates to land conditions, excepting some obscure fossils in one or two localities, and some patches of Miocene shell-beds bordering the Pacific, as on the shores of the sea of Okhotsh. The Arctic Ocean therefore appears to have shrunk very considerably, and the land areas to have once again broken up the basin of the northern sea.

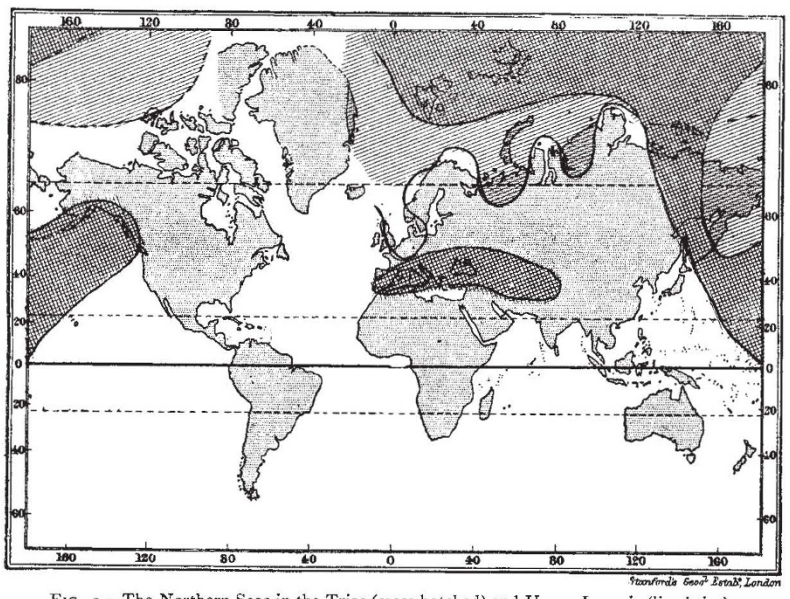

FIG. 3.—The Northern Seas in the Trias (cross-hatched) and Upper Jurassic (lined tint). [In Eastern Asia, the lined area should not come south of the broken line in lat. 75°.]

A general summary, therefore, of the facts of Arctic geology show that the Arctic Ocean has varied greatly, both in position and size. The Arctic Basin is at the present time bounded by a rim of land which is supported by five great blocks of Archean rocks; these blocks form, respectively, Scandinavia and North-western Russia; Labrador and North-eastern British America; Greenland; Alaska and North-eastern Asia; and the Archean block of Central Siberia. These Archean blocks were each more or less completely surrounded by bands of sedimentary rocks. At least two of them have never been below sea-level; and there is no satisfactory evidence to prove that the other blocks have been submerged, at least, since Middle Palæozoic times. In fact, the geological history of the Arctic Basin is the record of the alternate enlargement and diminution of the Arctic seas by the elevation and depression of parts of the bands of sediments, which surround the Archean blocks. The blocks themselves are of great geological antiquity, and the successive earth movements have been moulded upon them. As the main nuclei of the great land masses of the Arctic regions are therefore of vast antiquity, it may be thought only reasonable to assume an equally great age for the central ocean basin. But if we look at a map of the Polar regions showing the strike of the rocks and the trend of the mountain chains, we see that these all run north and south, and end abruptly on the margin of the Polar Basin. This meridianal trend occurs in the branch of the Rocky Mountains that forms the western boundary of the Mackenzie River, in the Archean axes of Boothia and Melville Peninsula, in the strike of the rocks of Northern Greenland and Western Spitzbergen. In Asia it is particularly well shown by the Ural and Verkhanoysk Mountains and their respective geological continuations, Nova Zemlya and the New Siberian Islands, and by the parallel chains between the Lena and Behring Straits.

Analogy with similar truncated mountain lines elsewhere renders it probable that all the mountain ranges, having what von Tol calls a "Ural orientation," once extended further to the north. If they did so, they would have effectually broken up the existing Polar Basin. At the present time our knowledge is insufficient for a final conclusion. But the evidence of the historical geology, physical structure and earth movements of Arctic lands are all consistent with the origin of the Arctic Basin as a great area of subsidence (a "senkungsfeld" of Suess) later than the deposition of the lower Tertiary plant beds. The geological facts attest such great geographical changes in that region, that geologists are not at present bound to abandon helpful explanations, which are in themselves probable and are in harmony with the geological evidence, simply because they may be inconsistent with the permanence of the Arctic Basin.

J. W. GREGORY.

SCIENTIFIC INVESTIGATIONS OF THE SCOTTISH FISHERY BOARD.

THE third part of the Fifteenth Annual Report of the Fishery Board for Scotland, dealing with the principal scientific investigations conducted under the auspices of the Board in 1896, has just been published. The work done may be judged from the subjoined summary, which is abridged from the general statement prefixed to the detailed reports on the investigations carried out.

In the course of the year, the investigations which were carried on under the supervision of the Scientific Superintendent, Dr. Wemyss Fulton, were prosecuted on the same general lines as in previous years, and have resulted in further extensions of knowledge respecting the life-history and habits of the food fishes, and by the physical conditions and changes in the sea which bear upon fishery problems. Special attention was given to certain hydrographical questions concerning the circulation of the water in the North Sea and the adjacent parts of the North Atlantic. In addition to such inquiries, the hatching and artificial propagation of some of the important food fishes have been continued at the Board's Marine Hatchery at Dunbar.

One of the most important results of the work has been to show that the food fishes which form the basis of the fishing industry—such as plaice, cod, haddock, ling, turbot, &c.—do not spawn on the east coast within the three-mile limit, as was previously supposed. On the other hand, it is not known at what distances from the shore or in what precise localities the spawning areas are chiefly situated. It would obviously be of great advantage to obtain accurate information on this subject, and to be able to map out on a chart the regions where the various species of the food fishes spawn.