PROBLEMS OF POLAR RESEARCH

A SERIES OF PAPERS

AMERICAN GEOGRAPHICAL SOCIETY

SPECIAL PUBLICATION No. 7

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1949–1954
Faculty, Johns Hopkins University
1954–1961
Professor of Oceanography,
Johns Hopkins University
1961–1975

R B Montgomery

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OF
POLAR RESEARCH

AMERICAN GEOGRAPHICAL SOCIETY
SPECIAL PUBLICATION NO. 7
Edited by W. L. G. Joerg

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A SERIES OF PAPERS
BY
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CONTENTS

A brief biographical notice of each contributor appears on the page facing the beginning of his paper.

Separate Illustration

FOREWORD

Polar exploration has reached an advanced stage of intensive search in critical places. So much is now known that the unknown is rather closely localized. Airplane and airship have vastly increased the speed of surface reconnaissance, and blank areas of substantial size will soon disappear. This impels science to hasten in like degree the search for secrets that only the Polar Regions may yield. A world conference on objectives in polar research seems eminently desirable, and to supply an equivalent the present book has been undertaken by the American Geographical Society. It forms a symposium by thirty-one recognized students of polar problems. The emphasis is on neither past achievements nor heroic adventure but on the major problems remaining to be solved by further field study, where and by what means those problems may best be attacked, and what manner of coöperation between the sciences most concerned may yield the largest harvest of results.

It is fitting to record grateful appreciation for the time and thought that have been given by the authors of these papers and for their willingness to join the Society in making a fresh examination of the outstanding problems that inspire modern polar exploration. The whole assembly of contributions makes it convincingly clear that science, not adventure, will be the ruling motive in future polar work. This represents a great gain for science because it focuses attention upon principles rather than personalities. The Society hopes that increasing support for well-qualified expeditions may be an additional result of the publication of this comprehensive group of distinguished papers and of the companion volume, "The Geography of the Polar Regions."

Isaiah Bowman

PROBLEMS
OF
POLAR RESEARCH

Dr. Nansen is the leading representative of scientific polar exploration today. His field of work being in the Arctic, which consists primarily of a central sea surrounded by lands, his investigations have naturally dealt especially with oceanography. He now holds the chair of oceanography in the University of Oslo. In 1888 he made the first crossing of the Greenland ice cap (see his "The First Crossing of Greenland," London, 1890; the scientific results were published by Mohn and Nansen in *Ergänzungsheft No. 105 zu Petermanns Mitt.*, 1892; another publication resulting from this trip was "Eskimo Life," London, 1894). In 1893–1896, by the drift of the *Fram*, he brilliantly proved his conviction of the existence of a current flowing across the Arctic Basin. The results of this voyage are of fundamental importance; they were published under his editorship in "The Norwegian North Polar Expedition, 1893–1896: Scientific Results" (6 vols., London, 1900–1906). To these volumes he has contributed among other papers: "The Oceanography of the North Polar Basin" (Vol. 3); "The Bathymetrical Features of the North Polar Seas, With a Discussion of the Continental Shelves and Previous Oscillations of the Shoreline" (Vol. 4). Related to the topic of the last paper is his later memoir "The Strandflat and Isostasy" (*Videnskapsselskapets Skrifter: I, Mat.-naturv. Klasse*, 1921, No. 11), Christiania, 1922. The popular account of the *Fram* expedition is entitled "Farthest North," New York and London, 1897. In 1900 he began, in association with Hjort and Helland-Hansen, the detailed oceanographic investigations of the northeastern North Atlantic that have led to the publications of the following major reports: "The Norwegian Sea," Christiania, 1909; "The Waters of the North-Eastern North Atlantic (*Internatl. Rev. der gesammt. Hydrobiol. und Hydrogr.*, 1913); and, with Helland-Hansen, "Temperatur-Schwankungen des Nordatlantischen Ozeans und in der Atmosphäre" (*Videnskapsselskapets Skrifter: I, Mat.-naturv. Klasse*), Christiania, 1917 (English translation, with additions, in *Smithsonian Misc. Colls.*, Vol. 70, No. 4, Washington, 1920). The results of a voyage to Spitsbergen in 1912 are presented in "Spitsbergen Waters" (*Videnskapsselskapets Skrifter: I, Mat.-naturv. Klasse*), Christiania, 1915, and "Spitsbergen," 2nd edit., Leipzig, 1922. In 1913 he made a voyage by sea to Western Siberia to study the development of this route as a trade route (see "Through Siberia, the Land of the Future," New York, 1914). He has recently published "Hunting and Adventure in the Arctic," New York, 1925, dealing with his early sealing experiences in East Greenland, and is also the author of "In Northern Mists: Arctic Exploration in Early Times," New York, 1911. In addition to contributing to the advancement of science Dr. Nansen has served his country and humanity in general. He was at one time Norwegian Minister to Great Britain and, after the war, was active in Russian famine relief and in the League of Nations. He is also President of the recently established Internationale Studiengesellschaft zur Erforschung der Arktis mit dem Luftschiff.

THE OCEANOGRAPHIC PROBLEMS OF THE STILL UNKNOWN ARCTIC REGIONS

Fridtjof Nansen

[With separate map, Pl. I, facing p. 14.]

Submarine Topography

A most interesting feature of the geography of the Arctic Regions is the deep sea basin which extends northwards and eastwards from the region north of Spitsbergen and Franz Josef Land and probably covers a considerable portion of the still unknown area (Fig. 6). The depth of this sea was found during the *Fram* expedition (1893–1896) to range between 3000 and 3850 meters.

This deep basin forms the northern termination of a series of ocean deeps which stretch from the eastern deep of the North Atlantic as a continuous sea northwards through the Norwegian Sea[1]—between Norway-Spitsbergen on the one side and Iceland-Greenland on the other. This series of deep basins forms a striking feature of the topography of the earth's crust, dividing the great continental masses of the Old and the New World. The basins are separated by submarine ridges such as the Scotland-Faeroes-Iceland-Greenland Ridge, the low ridge between Jan Mayen and Bear Island, and the probable ridge between northwest Spitsbergen and northeast Greenland (see the bathymetric map, Pl. I). Whether there may be similar ridges across the Arctic Basin in the region between the New Siberian Islands and the Canadian Arctic Archipelago is still unknown.

Like the basins to the south, the Arctic Basin is surrounded on all sides by a continental shelf, which, at least on the Siberian side, is very broad and has, where it is known, an extremely flat and level surface. The edge of this shelf has been explored only in the region northwest of the New Siberian Islands and north of the Lena delta, along the *Fram's* drift route in 1893. The shelf here has a breadth of more than 600 kilometers between its edge and the Siberian coast, and its depth below the sea surface ranges mostly between 20 and 40 meters. Its surface is remarkably level, and it has a sharply defined edge at a depth of nearly 100 meters. The continental slope, descending abruptly from the edge to the deep basin, is very steep (see Pl. I and Fig. 1). The New Siberian Islands are situated on this shelf.

In the region between the New Siberian Islands and Bering

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[1] Elsewhere in the present work this sea is termed the North European Sea.—Edit. Note.

Strait the Siberian continental shelf has a wide extension. It was over this level shelf with shallow sea that the *Jeannette* (1879–1881) and the *Maud* (1922–1924) drifted from the region north of Bering Strait to the region northwest of the New Siberian Islands. A number of small islands (Bennett I., Henrietta I., Jeannette I., Zhokhov I., General Vilkitski I.) have been discovered on this shelf to the north and northeast of the New Siberian Islands, and farther east is Wrangel Island. The depths of the sea along the drift routes of the *Jeannette* and the *Maud* were mostly less than 60 or 70 meters;

FIG. 1—Section across the Siberian continental shelf north of the Lena delta. Vertical scale exaggerated 25 times. (From the author's paper, *Geogr. Journ.*, Vol. 30, p. 476). For location, see Fig. 3.

in some places farthest away from the Siberian coast they increased to more than 100 meters and in two cases even to 148 and 156 meters. The breadth of the shelf between the Siberian coast and the drift route of the *Jeannette* was as much as 630 kilometers, but how far north of this route the edge of the shelf may be situated still remains unknown.

About midway between the New Siberian Islands and Cape Chelyuskin, in about 77° 24′ N. lat., the Russian expedition on board the *Taimyr* and the *Vaigach* in 1913 made a sounding of 402 meters without reaching the bottom, and here they were probably at the edge of the continental shelf. Off Northern Land, which was discovered by the same Russian expedition, the shelf seems to be comparatively narrow, and, according to the soundings taken, its surface seems to be uneven and traversed by submarine valleys and fiords. Farther west, towards the Kara Sea and Novaya Zemlya, the shelf is again very broad and even and has very shallow depths. Lonely Island (Ensomhed) and Sverdrup Island are situated on this shelf 220 and 150 kilometers from the Siberian coast, but it is unknown how far the shelf extends towards the north in this region, and the extension of Northern Land towards the north beyond 81° N. lat. and towards the west is still unexplored.

In the sea northeast and north of the northeastern end of Novaya Zemlya and east of Franz Josef Land a number of soundings have been taken by the Russian expeditions in the *Yermak* (Makarov, 1901) and in the *St. Anna* (Brusilov, 1912–1913), giving depths between 329 and 603 meters (the farthest, to the northeast of Franz

Josef Land, even of 676 meters). They seem to indicate that there is here a broad depression in the continental shelf (Pl. I).[2]

North of Europe the continental shelf extends from the coast of Novaya Zemlya, Russia, the Kola Peninsula, and Norway far north beyond Franz Josef Land and Spitsbergen, and these island groups are situated on it. In Barents Sea this shelf is traversed by a system of submarine valleys with depths of as much as 400 meters or more. These valleys seem to be of the same kind as the depressions on the shelf east and northeast of Novaya Zemlya.

Judging from the soundings taken in the sea to the northeast and north of Franz Josef Land during the expedition in the *St. Anna* (1913), the surface of the shelf is there very uneven, with deep submarine fiords, and the shelf has probably no very wide extension in these directions. A sounding of 1161 meters without bottom was taken less than 100 kilometers to the northeast of the island group, while on the other hand 219 meters were sounded something like 125 kilometers north-northeast of the northernmost island; and other soundings of 695, of 201, and of 256 meters respectively were taken at similar distances north of this island. Between Franz Josef Land and Spitsbergen there is a depression or submarine channel in the shelf probably coming from the north with depths of 421 meters and probably more. North of Spitsbergen the shelf has no great extension, being 50 to 70 kilometers broad, and its surface is very uneven, being traversed by submarine fiords.

The extension of the continental shelf north of Greenland is unknown except for a sounding of 165 meters 70 kilometers off shore. It may be fairly broad if the conditions are similar to those off the northeastern coast of Greenland, where the shelf has a width of more than 200 kilometers and is traversed by submarine fiords.

North of Grant Land (Ellesmere Island) Peary took a series of soundings indicating that the surface of the shelf may be uneven in this region. About 80 kilometers from land he sounded 201 meters, and about 150 kilometers from land as much as 1509 meters, but about 250 kilometers from land he sounded 567 meters, and a short distance farther north 1280 meters without bottom. If the depths of these soundings be correct, they seem to indicate a very irregular shape of the continental shelf in this region: it may be traversed by deep submarine fiords or there may be deep embayments in its edge.

North of Canada the continental shelf extends for a great distance, embracing the entire Arctic Archipelago; but how far it continues to the north of the northernmost islands hitherto discovered is entirely unknown. It seems hardly probable that the large islands discovered by Captain Otto Sverdrup in 1900 (Axel Heiberg Island, Ellef and

[2] From the drift of the *St. Anna* W. J. Wiese deduces the probability of land in about 79° N. and 82° E. (shown on Pl. I), possibly the western border of Northern Land (*Ergänzungsheft No. 188 zu Petermanns Mitt.*, 1925, pp. 57–58 and Pl. 2, Fig. 4).—Edit. Note.

Amund Ringnes Islands) and the small islands between them and west of them discovered by Vilhjalmur Stefansson in 1916 and 1917 (Meighen Island, Borden Island, Brock Island) should happen to form the northern boundary of this extensive archipelago. The continental shelf may in some places have a considerable extension beyond the known region, and there may be still unknown islands situated on it.

On the whole the Canadian Arctic Archipelago exhibits geomorphological features which are quite unique and exceptional on the earth's surface. This extensive area is dissected and traversed in various directions by fiords and sounds which have dimensions and lengths greater than fiords in any other part of the earth. They may have a certain resemblance to the Baltic, the White Sea, and the great submarine valleys of Barents Sea. We know, however, very little about the depths and submarine configuration of these fiords and sounds, and a systematic survey of them in connection with an exploration of the geological structure of their coasts would be most interesting. How far they may traverse the continental shelf as submarine fiords beyond the islands we know, is impossible to say at present. At Stefansson's farthest in 1917, in about 80° 35′ N. lat., about 140 kilometers north-northwest of Ellef Ringnes Island (Cape Isachsen) he sounded 502 meters,[3] but whether this was in a submarine fiord or near the edge of the continental shelf we cannot tell.

North of Alaska, off the coast eastwards from Point Barrow, the edge of the continental shelf approaches near to the land. During the drift with the ice of Stefansson's ship the *Karluk* in 1913, and during the journey across the drift ice of Stefansson in 1914 and of his companion the Norwegian Storkerson in 1918 in the sea north of Alaska and west of Banks Island, depths of more than 1000 and 2000 meters were found at distances less than 100 kilometers north of Alaska and 170 kilometers west of Banks Island. There seems to be an extensive deep sea off these coasts. Storkerson sounded 2961 meters without bottom about 400 kilometers north of the Alaskan coast.[4]

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[3] This is according to his map in: The Friendly Arctic, New York, 1921, opposite p. 594. I have found no mention of this sounding in his writings. [From Stefansson's unpublished diary, of which a photostat copy is deposited in the library of the American Geographical Society, it appears that two more soundings were made, viz. 498 and 507 meters, respectively about 1 and 5 miles north of the 502-meter sounding (whose latitude is there given as 80° 22′). At the 498-meter sounding no deflection of the wire by currents was noted, whereas there was a good deal of deflection in the case of the 507-meter sounding. Irrespective of these details a general depth of about 500 meters seems indicated in this region.—Edit. Note.]

[4] Storkerson reported a bottom sounding of 4684 meters 200 kilometers nearer shore, in 72° N. and 147° W. (2561 fathoms on map accompanying Stefansson's "The Friendly Arctic"; text reference on p. 701). In the copy of Storkerson's diary deposited with the American Geographical Society it is reported that the wire, on being hauled in after the 13-pound lead attached to it had been let out 2808 fathoms, lacked 260 fathoms and the lead. As 11 fathoms of the remaining end were kinked, it was assumed that bottom had been reached at 2537 fathoms.—Edit. Note.

A task of great scientific importance still to be performed in the Arctic Regions is thus to determine by soundings the extension of the North Polar deep sea in all directions and to establish the boundaries of the continental shelf on the Siberian as well as the American side of this sea. It should be noted that in this manner alone can be solved the problem of the distribution of land, i. e. the continents, and sea, i. e. the deep sea, because the continental shelf must be considered part of the continents and its edge marks the real boundaries

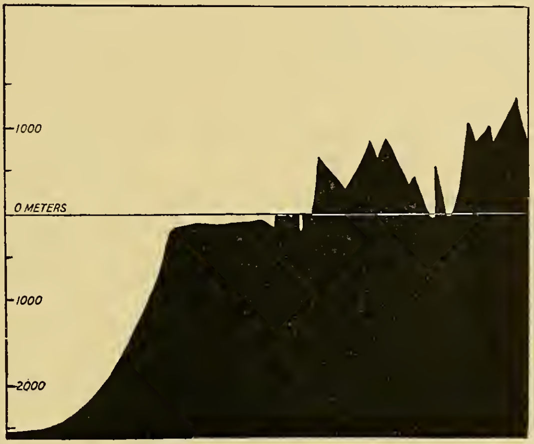

FIG. 2—Section across the continental shelf in a region of hard primary rock, north of the Lofoten Islands, Norway. Vertical scale exaggerated 25 times. (From the author's paper, *Geogr. Journ.*, Vol. 30, 1907, p. 474.) For location, see Fig. 3.

or the "submarine coasts" of the great continental land masses (cf. Fig. 2). The exploration of the extension of the continental shelf, irrespective of whether it happens to be slightly below water level or above it in the shape of islands, is therefore of more geographic or oceanographic interest than the tracing of the coasts of land above sea or the discovery of any new islands situated on the shelf. When we know the edge of the continental shelf round the Arctic Basin we may assume that no land masses of importance will be found in this basin outside the steep continental slope descending from this edge. There may, however, be isolated volcanic islands or cones like Jan Mayen in the Norwegian Sea, or even broad volcanic platforms like that of the Faeroes. There may also be submarine ridges across the Arctic Basin outside the edge of the continental shelf.

We know that the deep basin of the North Polar Sea extends eastwards north of Spitsbergen and Franz Josef Land to north of the New Siberian Islands. As was mentioned above, a deep sea, with depths more than 3000 meters, has also been found north of Alaska, but we cannot decide at present whether it is continuous with the deep sea basin north of the New Siberian Islands or whether it may be separated from it by some submarine ridge. A single sample of water and temperature from depths greater than 1000 meters north of Alaska would have settled this question.

We know that there is open communication in the upper water layers between the sea north of Alaska and Bering Strait and the sea between Spitsbergen and Greenland. This is proved by the drift of several objects, and there is obviously a constant, though slow, drift of the ice across the sea near the north pole from the sea north of Bering Strait, Alaska, and eastern Siberia into the Norwegian Sea, where the ice drifts southwards along the east coast of Greenland. But to what extent this North Polar Sea traversed by the drifting ice is a deep sea, is the still open and important question.

The late R. A. Harris of the United States Coast and Geodetic Survey[5] for several reasons came to the conclusion that a continuous great land probably existed in the region northwest of the Canadian Arctic Archipelago, between the north pole and Alaska. He based this hypothesis chiefly upon computations of the tidal observations made at several places along the coasts of the North Polar Sea, and also on the nature of the polar ice in the different regions of this sea and on the directions and nature of its surface currents. On several previous occasions[6] I have discussed Harris' hypothesis and have pointed out that, according to my view, none of his arguments were conclusive and that they could not be accepted as evidences of the existence of any great land to the north as assumed by him. This view has been confirmed by later observations. By computations of the tidal observations made during Amundsen's *Maud* expedition (1918–1921) at three different places along the north coast of Siberia, Mr. J. E. Fjeldstad[7] has arrived at the conclusion that the tidal phenomena along the coasts of the North Polar Sea do not support Harris' hypothesis and do not indicate the existence of any great land mass in the still unknown region of this sea. This is even more clearly borne out by the numerous tidal observations and current measurements made by Dr. H. U. Sverdrup during the drift of the *Maud* across the continental shelf to the north of eastern Siberia.[8] Dr. Sverdrup considers it "justifiable to conclude that the tidal

[5] R. A. Harris: Evidences of Land Near the North Pole, *Rept. 8th Internatl. Geogr. Congress, Held in the United States, 1904*, Washington, 1905, pp. 397–406 (reprinted and expanded from *idem:* Some Indications of Land in the Vicinity of the North Pole, *Natl. Geogr. Mag.*, Vol. 15, 1904, pp. 255–261).
idem: Arctic Tides, U. S. Coast and Geodetic Survey, Washington, 1911, with map, Cotidal Lines for the Arctic Regions, 1:10,500,000 (reproduced below, p. 20, as Fig. 1).

[6] Fridtjof Nansen: On North Polar Problems, *Geogr. Journ.*, Vol. 30, 1907, pp. 470–487 and 585–601, with bathymetric map of Arctic Basin, 1:20,000,000.
idem: Spitsbergen Waters: Oceanographic Observations During the Cruise of the "Veslemöy" to Spitsbergen in 1912, *Videnskapsselkapets Skrifter: I, Mat.-naturv. Klasse*, 1915, No. 2, Christiania.

[7] J. E. Fjeldstad: Litt om tidevandet i Nordishavet, *Naturen*, Vol. 47, Bergen, 1923, pp. 161–175.

[8] H. U. Sverdrup: Dynamic of Tides on the North Siberian Shelf: Results from the Maud Expedition, *Geofys. Publikasjoner*, Vol. 4, No. 5, Oslo, 1926.

phenomena do not indicate the existence of land within the unexplored area," and like Fjeldstad he thinks that the tidal wave travels directly across the North Polar Sea from the Spitsbergen-Greenland opening to Alaska without meeting obstructions formed by extensive masses of land.

The Amundsen-Ellsworth-Nobile airship expedition in 1926 across the Arctic Basin seems to confirm the correctness of this view, as no land was seen on the route from Spitsbergen via the north pole to Alaska; but we do not know whether the sea over which the flight took place was deep or shallow, and the possibility still exists that there may be a submarine continental mass in some part of this region, e. g. extending north from the Canadian Arctic Archipelago.

Surface Currents and Ice Drifts

The surface currents and the drift of the ice in the North Polar Sea exhibit certain features which are somewhat puzzling. The sea currents on the northern hemisphere are deflected to the right by the earth's rotation and will, as a rule, run along the continental coasts or continental shelf with the land on their right-hand side. In an enclosed sea like the North Polar Sea we might therefore expect that the surface currents would have a cyclonic movement eastwards along the continental shelf north of Siberia as well as north of America. But all observations seem to indicate a drift of the ice very nearly in the opposite direction north of Alaska and Siberia. The *Karluk* drifted in 1913 from the sea north of Point Barrow towards the sea northwest of Wrangel Island; the *Jeannette* and the *Maud* drifted from the latter region towards the sea northwest of the New Siberian Islands; and the *Fram* drifted from the sea north of the New Siberian Islands to the sea north of Spitsbergen. The drift routes of these ships thus seem to indicate an anticyclonic movement of the ice drift and the surface current.

This direction of the current is extremely difficult to explain. The drift of the ice is to a very considerable extent caused by the winds, and the prevailing winds in these regions are doubtless easterly and southeasterly. But, owing to the earth's rotation, we might expect that the moving ice would be deflected towards the right of the direction of the winds, until it met with resistance from a coast or a continental shelf, and would then follow along the coast of the land or the "submarine coast" of the shelf, keeping it on its right-hand side. This would be in accordance with what is observed in other regions of the northern hemisphere. During the drift of the *Fram* across the North Polar Sea from 1893 to 1896 the direction of the moving ice for shorter periods, with few exceptions, deviated to the right of the direction of the shifting winds, and generally the angle of deviation was considerable.[9] But, nevertheless, the direction of the resultant of the whole drift of the *Fram* nearly coincided with the direction of the wind resultant for the same period. This fact might seem to indicate that the movements of the ice met with greater resistance towards the north and northeast than towards the west, southwest, and south. Such a resistance to the movements of the ice would be offered by a land, or a shelf with shallow sea, to the right, i. e. to the north, of the *Fram's* drift route; but the existence of such a land or shallow sea in this neighborhood is highly improbable. Besides the *Karluk*, the *Jeannette* and the *Maud* drifted in a similar westward and anticyclonic direction over a very shallow sea to the north of Bering Strait and eastern Siberia, and they cannot have had any extensive land in their vicinity to the north; on the contrary, the tidal phenomena seem to prove that they had a deep sea to the north and not very far off.[10] The anticyclonic drift of the ice cannot, therefore, be assumed to prove the existence of land masses to the north, above or below the sea surface, in these regions.

FIG. 3—Map indicating the location of the sections shown in Figs. 1 (5 on this key), 2 (12), 4 (C), and 5 (B).

There is naturally the possibility that the heavy ice masses in the interior parts of the North Polar Sea, where new ice is continually formed on any open water lanes, may have a tendency to spread southward towards the more open sea near the coasts of Siberia and towards the opening between Spitsbergen and Greenland. Thus a resistance against a northerly drift of the ice may arise, and the ice may be carried in a more westerly direction. Whether this is sufficient to explain the apparent anticyclonic movement of the drift may, however, be doubtful. It has naturally to be taken into consideration that the direction of the drift of the ice is not merely dependent on the local winds and forces but also on the movements of the ice in the regions to the north, which to a great extent are caused by the winds in these regions, and there is a possibility that these winds have on the average a tendency to be anticyclonic.

It may also be mentioned that the warmer and salter water underlying the cold surface layer of the North Polar Sea flows into the Arctic Basin northwest of Spitsbergen and probably flows eastwards

[8] Cf. Fridtjof Nansen: The Oceanography of the North Polar Basin (The Norwegian North Polar Expedition 1893–1896: Scientific Results, Vol. 3, No. 9, Christiania, 1902), pp. 365 ff.

[10] This was written before Wilkins' sounding of 5440 meters (see p. 396 and Pl. I) and its implication.—EDIT. NOTE.

along the slope outside the edge of the continental shelf north of Siberia. Owing to the earth's rotation the effect of such an eastward current upon the currents of the overlying water layers would be a tendency to deflect them in a southerly direction, and in this manner the surface current might get a less northerly and more westerly course than would otherwise be the case. It has to be considered, however, that the eastward current of the underlying warmer water is probably very slow and that its deflecting effect upon the surface current may accordingly be very small; and besides there is no such warm undercurrent running over the continental shelf where the *Jeannette* and the *Maud* drifted.

By careful calculations Professor Valfrid Ekman has arrived at the conclusion that surface currents running through regions of the sea where the depths increase in the direction toward which the current flows have a tendency to be deflected to the left so as to follow the direction of the isobathic curves of the bottom. If this is correct, it might perhaps afford an explanation of the direction in which the *Jeannette* and the *Maud* drifted, as they probably had a much deeper sea to the north. But the direction of the drift of the *Fram* cannot be explained in this manner.

Circulation of the Water

A methodical study of the water layers and their movements in the still unknown regions of the North Polar Sea will be of much interest. As was discovered during the *Fram* expedition of 1893–1896, this sea is covered by a layer, 150 to 200 meters thick, of cold water with temperatures between 0° C. and −1.9° C. and with a comparatively low salinity owing to the admixture of fresh water, chiefly river water from Siberia, Alaska, and Canada. Below this surface layer there is a layer, some 600 or 700 meters thick, of warmer and salter water, with temperatures above 0° C. and salinities approaching 35 per mille. This is Atlantic water which is carried into the Arctic Basin chiefly by the small branch of the Atlantic Current ("Gulf Stream") running northwards along the west coast of Spitsbergen (see Fig. 5). Below this warmer water there is again colder water filling probably the whole basin to the bottom; its temperature is between 0° C. and −0.8° and its salinity 34.90 per mille (see Figs. 4 and 5). This cold deep-water originates in the northern part of the Norwegian Sea, north-northeast of Jan Mayen, where it sinks down from the surface, which is cooled by the radiation of heat during the winter and spring. The thus cooled water runs into the Arctic Basin across the probable submarine ridge between Spitsbergen and Greenland (see Fig. 3).[11] A study of the condition of these various

[11] Cf. Nansen, Spitsbergen Waters, pp. 37 ff. See also *idem:* Spitzbergen, 2nd edit., Leipzig, 1922, pp. 203 ff.

water layers and their distribution in the various parts of the North Polar Sea would be of much value. While we drifted with the *Fram* across the Arctic Basin our deep-sea observations showed that the boundaries between water layers, especially between the cold surface layer and the warmer underlying water, were subjected to considerable vertical oscillations. By later observations we have found

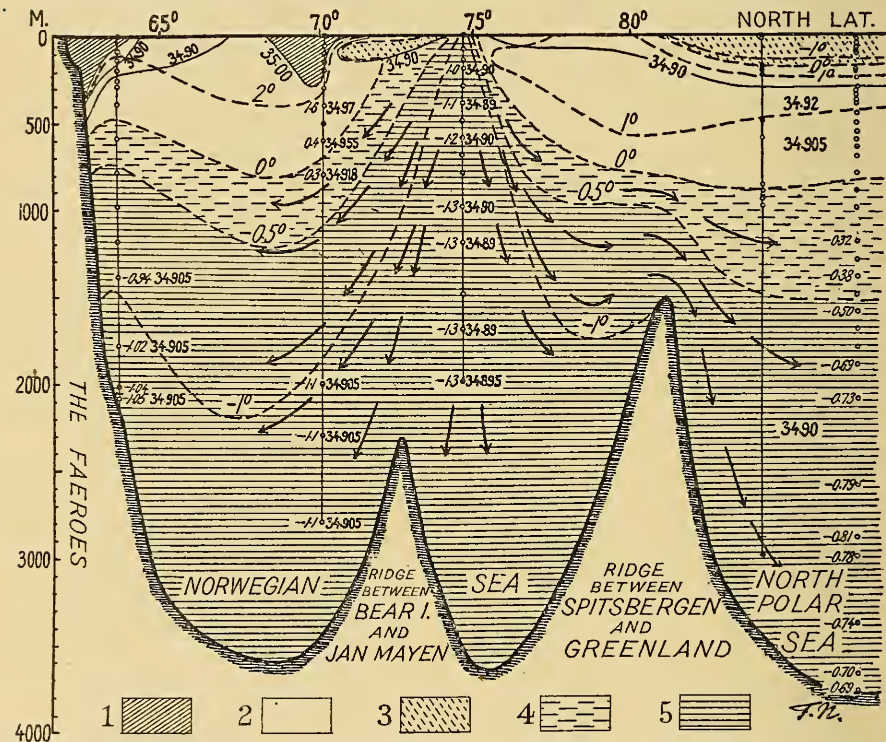

FIG. 4—Section extending from the Faeroes through the Norwegian Sea into the basin of the North Polar Sea, indicating the formation of the cold deep-water north-northeast of Jan Mayen and the distribution of the upper water layers. Vertical scale exaggerated 600 times. (From the author's "Spitzbergen," Leipzig, 2nd edit., 1922, p. 208.) For location, see Fig. 3.

The oblique, thin figures give temperature in centigrade; the vertical, heavy figures, salinity in thousands. Depth in meters at the left. Symbols for water layers as follows: 1, Atlantic water, salinity above 35.00 ⁰/oo; 2, diluted Atlantic water flowing into the basin of the North Polar Sea, temperature above 0° C.; 3, water of the Arctic current, temperature below 0° C., salinity below 34.00 ⁰/oo; 4, deep-water with temperatures between 0° and - 0.5° C., salinity about 34.90 ⁰/oo; 5, deep-water with temperatures below - 0.5° C., salinity about 34.90 ⁰/oo.

that such vertical oscillations, due to subsurface boundary waves, often of very considerable dimensions, probably are quite common phenomena in the ocean; but they have not yet been sufficiently studied methodically. From the drifting ice all movements of the water—the horizontal currents as well as these vertical oscillations of the layers—may be continually and carefully studied at all depths in an ideal manner which is not possible in the open ocean; and many of the greatest problems of oceanography may thus be solved.

Organic Life (Plankton)

Misled by the abundance of vegetable as well as animal plankton they have found in the North Polar Sea near the outskirts of its ice masses, some travelers have assumed that similarly there is much plankton in the water in the interior parts of that sea. This is, how-

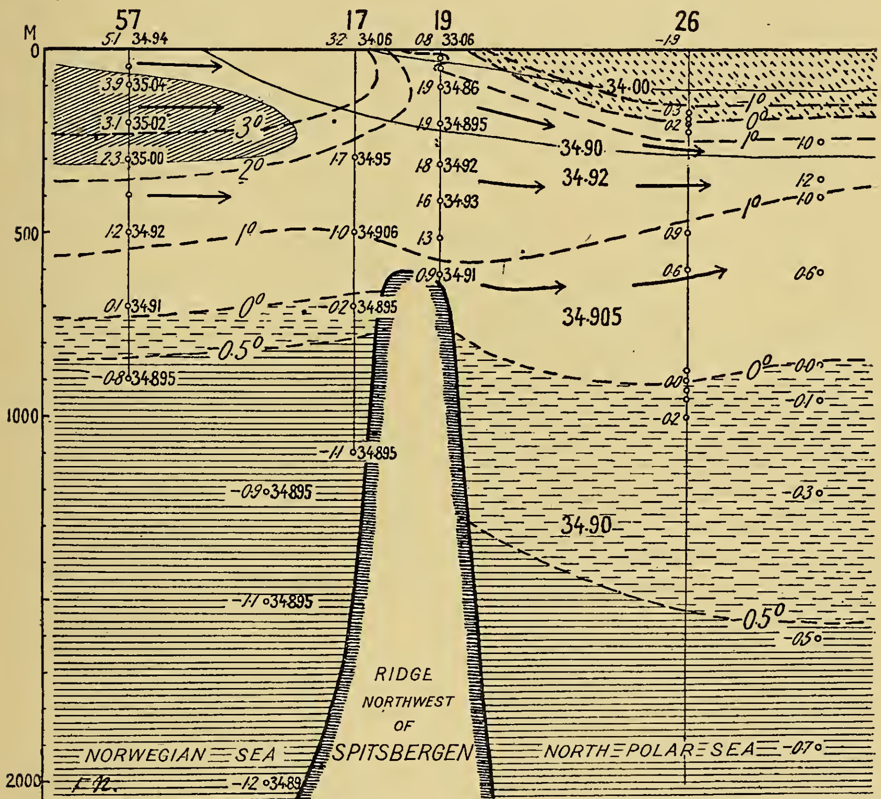

Fig. 5—Section extending from the northeastern part of the Norwegian Sea across the submarine ridge northwest of Spitsbergen and into the North Polar Sea, showing the diluted Atlantic water running over this ridge into the North Polar Sea. Vertical scale exaggerated 600 times. (From the author's "Spitzbergen," Leipzig, 2nd edit., 1922, p. 207.) For location, see Fig. 3. Symbols the same as in Fig. 4.

ever, a mistake. The North Polar Sea, covered in its interior by an almost continuous layer of thick ice, is extremely poor in plant as well as animal life. The sunlight is absorbed by the ice, and hardly any of those rays necessary for plant life are able to penetrate the thick floes and into the cold water beneath them. Extremely little plant life can therefore be developed in this sea—there is only just a little, chiefly in the water lanes between the floes in the short summer; and without plant life there can be no animal life. This interior, continually ice-covered part of the North Polar Sea may therefore be considered as a desert in the ocean, and no mammal or man can find sufficient food there. During our *Fram* expedition across that sea we found many species, especially of small crustaceans, but the fauna was so extremely poor in number of specimens that our townets might hang out for several days and, although we might drift along at a good speed, there was extremely little in them when they were hauled up. The result of these peculiar conditions seems to be that the substances in the sea water generally used to sustain plants,

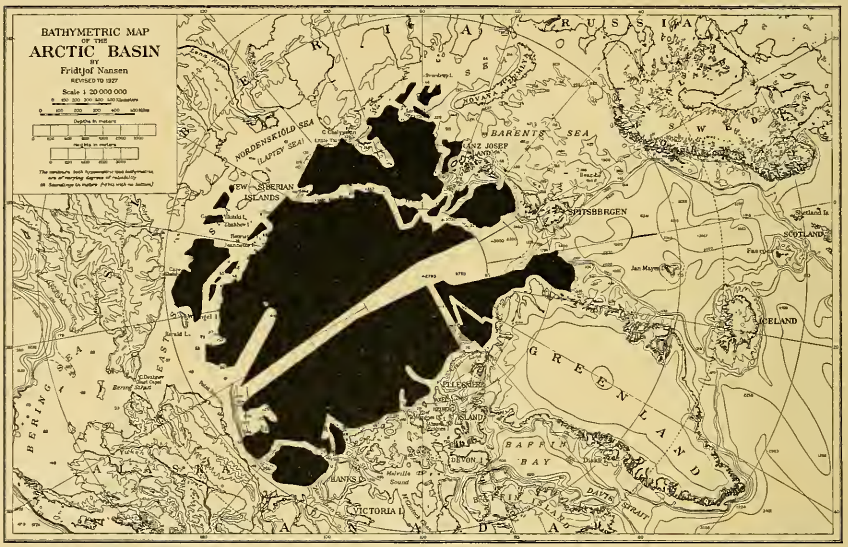

FIG. 6—Map showing, in black, the unexplored areas in the Arctic Basin, compiled by N. A. Transehe of the American Geographical Society's staff. Scale, 1:65,000,000. Areas that were within the mathematical horizon of visibility from sledge, ship's masthead, or aircraft, as the case may be, are assumed to be known. As fog has not been taken into account in the computation the map slightly exaggerates the size of the known areas. The base is the same as that of Plate I opposite, and the two maps are therefore directly comparable.

and through them the animal life, are to a great extent stored in the sea water of this ice-covered sea, as there are so extremely few plants to use them. But as soon as this water with these accumulated riches is freed of the ice, near the outskirts of the polar sea, and is exposed to the sunlight in the spring and summer, an unusually rich plant and animal plankton is developed and flourishes. It would be of much value for the understanding of the biology of the ocean to study in detail the biological conditions in various parts of the North Polar Sea.

A. Hoen & Co. Lith. Baltimore, Md.

Mr. Marmer has for many years been connected with the Division of Tides and Currents of the U. S. Coast and Geodetic Survey and is now serving as assistant chief of the Division. His publications include: "The Tide," New York, 1926; "Tides and Currents in New York Harbor" (*U. S. Coast and Geodetic Survey Special Publ. No. 111*, 1925); "Coastal Currents Along the Pacific Coast of the United States" (*ibid., No. 121*, 1926); "Tidal Datum Planes" (*ibid., No. 135*, 1927); and "Mean Sea Level and Its Variation" (*Annals Assn. Amer. Geogrs.*, Vol. 15, 1925). For the *Geographical Review* he has written "Tides in the Bay of Fundy" (Vol. 12, 1922); "Flood and Ebb in New York Harbor" (Vol. 13, 1923); "Sea Level Along the Atlantic Coast of the United States and Its Fluctuations" (Vol. 15, 1925); "On Cotidal Maps" (Vol. 18, 1928).

ARCTIC TIDES

H. A. Marmer

THE Arctic seas are for the most part characterized by tides of small range. Indeed, on the shores fronting the North Polar Sea there are but few places where the rise and fall of the tide is much over a foot. In comparison, therefore, with the more striking aspects of the Arctic the tide is quite unimpressive in its manifestations; and as a consequence it was rather late in the history of polar exploration that more than casual observations on the tides appear.

Harris' Tidal Investigations

Even after tide observations became part of the day's work with polar expeditions they were regarded as minor matters. They constituted, to be sure, items of geographic information, but they appeared to have no bearing on the major problems and immediate purposes of polar exploration. At the beginning of the present century, however, Harris directed attention to the fact that the characteristics of the tides on the Arctic shores threw light on the geography of the unexplored area lying north of the known land masses.[1]

At this time Nansen's conclusions with regard to the unexplored area were regarded as well established. Following his discovery of ocean depths along the route of the *Fram*, Nansen concluded that the Arctic Sea comprised an open basin of deep water occupying all, or very nearly all, of the unexplored area. But in attempting to correlate the tide observations in the Arctic, Harris found it necessary to postulate the existence of a large tract of land to the north of Alaska.[2] The reasoning which led Harris to this conclusion may be summarized briefly as follows.

The principal tide-producing forces are of two kinds, daily and semi-daily, the daily increasing in magnitude from the equator to the poles, while the semi-daily decrease from the equator and vanish at the poles. And while the response of any sea to the different tide-producing forces is profoundly modified by its configuration and hydrographic features, it appeared, nevertheless, that in an open polar basin the daily tide should be rather well developed.[3]

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[1] R. A. Harris: Some Indications of Land in the Vicinity of the North Pole, *Natl. Geogr. Mag.*, Vol. 15, 1904, pp. 255–261.

[2] *ibid.*, p. 257.

[3] *idem:* Evidences of Land Near the North Pole, *Rept. 8th Internatl. Geogr. Congress, Held in the United States, 1904*, Washington, 1905, pp. 397–406; reference on p. 404.

In this connection, however, it is to be noted that the Arctic Sea communicates directly with both the Atlantic and Pacific Oceans—through the Greenland Sea (or North European Sea) with the former and through Bering Strait with the latter. But, relatively, the connection through Bering Strait is shallow and narrow. In so far, therefore, as the interaction of the tides of the adjacent oceans is concerned, the Arctic is open only to the Atlantic.

In 1904 Harris brought together a number of scattered observations on the tides in the Arctic for the purpose of constructing a cotidal map of this sea, i. e. a map showing the progress of the tide. For certain regions the data were extremely meager. For example, along the north coast of Siberia from the mouth of the Yenisei River eastward to Pitlekai on the Chukchi Peninsula—a distance represented by more than 100 degrees of longitude—there were no tidal observations of any kind. The observations at hand were sufficient, nevertheless, to show that the tide in the Arctic Sea was of the semidaily type and to indicate clearly that the rise and fall here were due primarily to the Atlantic Ocean tide sweeping in through the Greenland Sea.[4]

A number of tidal features, however, were very puzzling. Thus, the observations showed that flood at Point Barrow, on the Arctic coast of Alaska, instead of coming from the north, as one would expect if the tide from the Greenland Sea progressed across a deep unobstructed polar basin, came from the west. Moreover, while the tide at Point Barrow was only about half a foot in range, at Bennett Island, situated about 1000 miles westward but not much nearer the Greenland Sea, the range was two feet or more.

Now if in the unexplored area of the Arctic one assumes the existence of an obstruction to the progress of the tide these perplexing features become explicable. And on the basis of this investigation Harris constructed a cotidal chart for the Arctic Sea.[5] This represents the tide coming from the Atlantic Ocean through the Greenland Sea; but instead of progressing toward Alaska directly across the pole, the tide is shown as deflected to the east by a large land obstruction.

There were other facts enumerated by Harris which appeared to strengthen the conclusion, based on the tides, of a land obstruction to the north of Alaska. Thus, the directions of drift of the *Fram* and of the *Jeannette*, the belief in the existence of Keenan Land and Crocker Land, and the character of the ice in different parts of the Arctic appeared to confirm it.

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[4] *idem:* Manual of Tides, Part IV B: Cotidal Lines for the World, *U. S. Coast and Geodetic Survey Rept. for the Year Ending July 1, 1903, to June 30, 1904*, Washington, 1904, Appendix 5 (pp. 313–400); reference on pp. 381–389 and Figs. 23, 24, 25, and 26.

[5] *ibid.*, Figs. 23, 25, and 26.

Nansen's conclusion that deep water extended continuously from Spitsbergen to Alaska, which had been generally accepted, was based on entirely different considerations. The challenge of Harris' hypothesis therefore stimulated interest not only in the problems of Arctic tides but also in the larger problems of polar exploration. The possibility of discovering a large land mass gave an added zest to Arctic exploration. When in 1908 Peary set out on his successful dash to the pole, he was directed to secure tidal observations along the northern coasts of Grant Land and Greenland because it was believed "that such observations might throw light upon the possible existence of a 'considerable land mass in the unknown area of the Arctic Ocean.' "[6]

In 1911 Harris published his "Arctic Tides."[7] Here opportunity was afforded for a detailed discussion of all the available tide observations in the Arctic and for the publication of a revised cotidal map (here reproduced as Fig. 1). In addition to the observations extant in 1904, he now had for the Arctic Sea additional observations on the northern coasts of Grant Land and Greenland by Peary, at Flaxman Island on the northern coast of Alaska by Mikkelsen and Leffingwell, at Cape Flora and Teplitz Bay in Franz Josef Land by the Ziegler Polar Expedition, and some others. But even after this discussion he still found it necessary to assume an obstruction between Spitsbergen and Alaska in order to unite the scattered observations into a coherent system. It is to be noted, however, that this obstruction is now designated by Harris "a tract of land, an archipelago, or an area of shallow water."[8]

Subsequent Tidal Observations

The decade following brought no further light on this problem of Arctic tides. The Canadian Arctic Expedition of 1913–1918 under Stefansson secured observations on the northern coast of Alaska and on some of the islands eastward.[9] These helped in determining the local characteristics of the tide but were not within the region requisite for throwing light on the progress of the tide across the unexplored area. Russian observations on the Arctic coast of Siberia were known to have been made,[10] but the results were not available until recently.

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[6] R. E. Peary: The North Pole, New York, 1910, p. 339.

[7] R. A. Harris: Arctic Tides, U. S. Coast and Geodetic Survey, Washington, 1911, with map, Cotidal Lines for the Arctic Regions, 1:10,500,000.

[8] *ibid.*, p. 90.

[9] W. Bell Dawson: Tidal Investigations and Results, Report of the Canadian Arctic Expedition, 1913–18, Vol. 10: Plankton, Hydrography, Tides, etc., Part C, Ottawa, 1920.

[10] R. A. Harris: Undiscovered Land in the Arctic Ocean, *Amer. Museum Journ.*, Vol. 13, 1913, pp. 57–61; reference on p. 58.

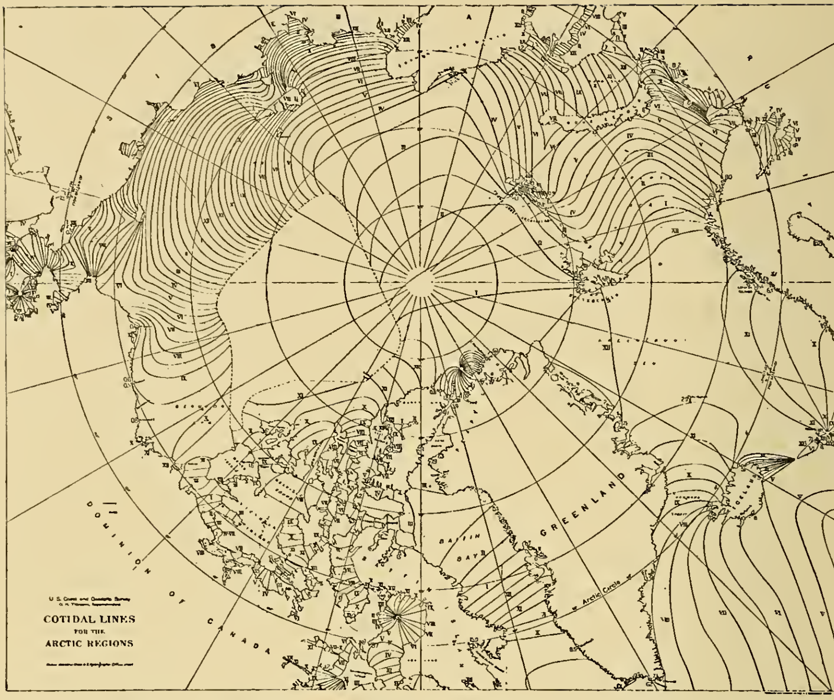

Fig. 1—Harris' cotidal map of the Arctic seas, 1911, illustrating his theory of a polar land mass. Scale, 1 : 82,000,000. (Greatly reduced from work cited in footnote 7.)

Tidal Observations of the "Maud" Expedition:

Fjeldstad's Investigations

During the years 1918–1921 Amundsen's party aboard the *Maud* made tide observations at three points on the northern coast of Siberia. In a preliminary report on the results from these observations Fjeldstad called attention to the fact that the new observations could be correlated with the previous observations and the whole united into a coherent scheme by accepting Nansen's hypothesis of a deep polar basin. On this basis he constructed a cotidal chart (here reproduced as Fig. 2) showing the tide wave progressing from Greenland Sea to Alaska directly across the pole.[11]

In dealing with the progression of a tide wave across a body of water it has been taken for granted that this progression takes place in accordance with the formula $v = \sqrt{g\,h}$, in which v is the velocity of the wave or rate of progression, g the acceleration of gravity, and h the depth of water. This is valid for a tide wave across the deep basin of the open ocean and has been taken as valid also for the progress of the tide over the continental shelf. Fjeldstad drew

[11] J. E. Fjeldstad: Litt om tidevandet i Nordishavet, *Naturen*, Vol. 47, Bergen, 1923, pp. 161–175.

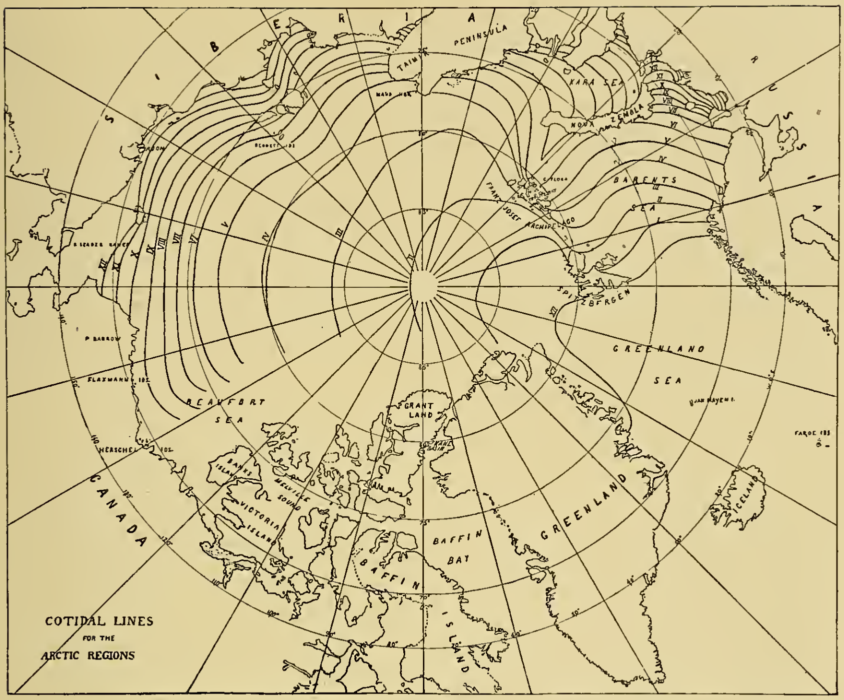

FIG. 2—Fjeldstad's cotidal map of the Arctic seas, 1923, incorporating the preliminary tidal observations of the *Maud* expedition, 1918–1921, and conforming to Nansen's hypothesis of a deep polar basin. Scale, 1 : 82,000,000. (Reduced from work cited in footnote 11.)

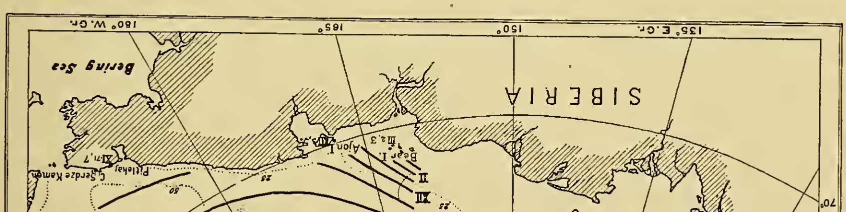

FIG. 3—H. U. Sverdrup's cotidal map of the North Siberian shelf sea, 1926, incorporating the final tidal observations of the *Maud* expedition. Scale, 1 : 30,000,000. (From work cited in footnote 12.) The map is inverted to allow more readily of comparison with Fig. 2.

his cotidal map in conformity with that formula. But it must be noted that, to bring the different observations into agreement, he found it necessary to assume depths across the Arctic Sea less than those given by Nansen.

While Fjeldstad's cotidal map coördinated the times of the observed tides, the wide difference in the range at Bennett Island and on the coast of Alaska remained inexplicable. The obstruction postulated by Harris explained that difference nicely. Likewise the fact that flood at Point Barrow comes from the west and the relatively small diurnal tides remain unexplained on the assumption of a simple tide wave progressing directly toward Alaska across an unobstructed Arctic Sea.

H. U. Sverdrup's Investigations

Recently, H. U. Sverdrup, scientific leader of the *Maud* expedition of 1922–1925, studied these questions anew. During this expedition Sverdrup made a number of tide observations on the North Siberian shelf and also systematic observations on the tidal currents.[12] He found these currents rotary in character—almost circular at considerable distances from the coast. But at all these stations the direction of rotation was clockwise, indicating clearly that this was due to the deflecting force of the earth's rotation.[13]

In the "Dynamic of Tides on the North Siberian Shelf" Sverdrup contributes an important hydrodynamic study of the behavior of the tide wave on continental shelves, taking into consideration the effect of the resistance along the bottom and the effect of the deflecting force of the earth's rotation. The latter varies with the latitude, increasing from the equator to the poles, where it attains its maximum value. Harris had assumed that, notwithstanding the fact that the deflecting force of the earth's rotation reaches a maximum at the pole, its effect on the diurnal tides in a deep polar basin would be small in comparison with the direct effect of the tide-producing forces, since the free period of oscillation of such a deep basin is but a fraction of the period of the diurnal tide.[14]

From Sverdrup's mathematical discussion it appears that in the progress of a tide wave across a continental shelf the effects of friction and of the deflecting force of the earth's rotation are of primary importance and modify profoundly the simple character of the progressive tide wave traveling across deep oceanic basins. The

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[12] H. U. Sverdrup: Dynamic of Tides on the North Siberian Shelf: Results from the Maud Expedition, *Geofys. Publikasjoner*, Vol. 4, No. 5, Oslo, 1926.

[13] In 1912, northwest of Spitsbergen, Nansen had already determined that the tidal currents rotate clockwise (Spitsbergen Waters: Oceanographic Observations During the Cruise of the "Veslemöy" to Spitsbergen in 1912, *Videnskapsselkapets Skrifter: I, Mat.-naturv. Klasse*, 1915, No. 2, Christiania).

[14] Harris, Undiscovered Land in the Arctic Ocean, p. 57.

tide wave on continental shelves does not progress in accordance with the simple formula valid for deep oceanic basins, and strangely enough the dynamics of the case appear to be against the formation of well-developed diurnal tides in the higher latitudes.[15]

Applying the results of his theoretical discussion to the data derived from the observations along the Arctic shores, Sverdrup finds that, wholly on the basis of the nature of wave movement on continental shelves, the flood current should come from the west at Point Barrow; that the range of the tide should vary transversely to the direction of progress of the tide wave, increasing from left to right; and that the tidal currents should be rotary in character over the whole region, the direction of rotation being clockwise. And on the basis of the observations he constructed a cotidal map (here reproduced as Fig. 3) showing the progress of the tide between Cape Chelyuskin and Point Barrow, which differs radically from Harris' map.

Sverdrup makes no attempt to draw a cotidal map for the whole of the Arctic Sea. However his cotidal map for the North Siberian Shelf pictures the tide wave as reaching the coast of Alaska from the north, and he is led "to conclude that the tidal phenomena do not indicate the existence of land within the unexplored area."[16] This conclusion has since received partial confirmation as a result of Amundsen's transpolar flight. This flight was directly across the unexplored area, and while the visibility appears to have been unfavorable the greater part of the time Amundsen is quoted as stating categorically that "there was no land."[17]

Tidal Observations of the Russian Polar Expedition

In this connection the results of Russian tidal observations which have just come to light are of interest. In the winter of 1900–1901 a party of the Russian Polar Expedition under Baron von Toll made tidal observations at Zarya Harbor on the northern shore of Taimyr Peninsula, covering the period December 6, 1900, to May 22, 1901. The results develop the local characteristics of the tide and agree in the main with the other observations in the general vicinity.[18] Another party under Lieutenant F. A. Matisen secured observations in the Nerpalakh lagoon on Kotelnyi Island, for the period November 14,

[15] Sverdrup, *op. cit.*, p. 64.

[16] *ibid.*, p. 14.

[17] *Geogr. Rev.*, Vol. 16, 1926, p. 664.

[18] A. M. Bukhtyeev: Prilivy u sibirskago poberezhya Syevernago Ledovitago Okeana po nablyudeniyam Russkoi Polyarnoi Ekspeditsii v 1900–1903 gg., I: Prilivy na reidye "Zarya" u syevernago berega Zapadnago Taimyra (The tides on the Siberian coast of the Arctic Sea from the observations of the Russian Polar Expedition, 1900–1903, I: The tides of Zarya roadstead on the northern coast of Taimyr Peninsula), Résultats Scientifiques de l'Expédition Polaire Russe en 1900–1903 sous la direction du Baron E. Toll, Section B: Géographie physique et mathématique, Livraison 4, *Zapiski Imp. Akad. Nauk*, Ser. 8, Phys.-Math. Class, Vol. 26, No. 4, St. Petersburg, 1912.

1901 to April 12, 1902.[19] These give a range of half a foot and a cotidal hour of 3.7 which agrees very well with Sverdrup's cotidal map.

Conclusion

Our conceptions in regard to the Arctic tides have thus undergone rather profound modifications, and it is of interest to note that the results brought out by the most recent study of these tides are of wide application. In general, it may be said that the observations on the shores of the Arctic are so few in number that wherever such observations can be made they are bound to add both to a better knowledge of the local characteristics of the time and range of tide and to a better conception of the movement of the tide in the Arctic as a whole. Regions where tide observations are especially desirable are the open coasts of the islands lying northward of Siberia—Wrangel Island and the New Siberian Islands for example—and the northwestern coasts of the islands northeastward from Beaufort Sea to Grant Land.

[19] *idem*, II: Prilivy u ostrovov Anzhu ili Novo-Sibirskikh, v lagunye Nerpalakh na zapadnom beregu o-va Kotelnago (The tides at the Anjou or New Siberian Islands in the Nerpalakh lagoon on the western shore of Kotelnyi Island), *ibid.*, Section B, Livraison 5, *Zapiski Imp. Akad. Nauk*, Ser. 8, Phys.-Math. Class, Vol. 26, No. 5, St. Petersburg, 1915.

Mr. Clayton has long been active in meteorological work, his specialty being the investigation of the fundamental cosmic relations of the subject. He has occupied the posts of meteorologist of the Blue Hill observatory and local forecaster of the U. S. Weather Bureau. While in charge of forecasting in Argentina from 1913 to 1922 he studied methods of prognosticating the weather in that country from solar data. His researches on the relation between solar activity and the weather have been continued in coöperation with the Smithsonian Institution, by which organization they have been published. He has also written a book on the subject entitled "World Weather," New York, 1923, and is the editor of the recent publication "World Weather Records" (*Smithsonian Misc. Colls.*, Vol. 79, Publ. 2913, Washington, 1927).

THE BEARING OF POLAR METEOROLOGY ON WORLD WEATHER

H. H. Clayton

The Circulation of the Air between the Equator and the Poles and the Factors That Modify It

If one constructs an elongated glass box and places under one end a block of ice and under the other end a metal vessel filled with hot water, as illustrated in Figure 1, the air in the box will begin to circulate in the manner shown by the arrows. This circulation may be made visible by introducing smoke or fine dust.

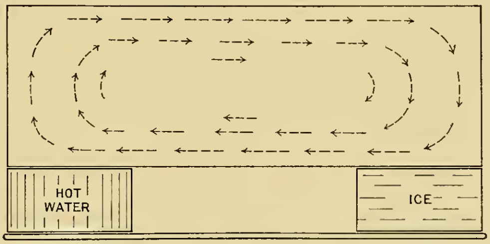

Fig. 1—Circulation of air in a closed glass tank heated at one end and cooled at the other.

If there were no other factors than polar ice and equatorial heat, there would be a circulation somewhat of this nature between the equator and each pole; that is, there would be an air current flowing along the surface of the earth from the poles toward the equator and a return current above. There would be an area of high pressure over the north pole and one over the south pole, and the pressure would decrease toward the equator, where it would be low. Such a simple circulation is interfered with by a variety of conditions: (1) by the irregular distribution of land and water; (2) by the movement of the water; (3) by the rotation of the earth; (4) by the decreasing density of the air with increasing height; (5) by irregular radiation and absorption in the atmosphere, owing chiefly to its water-vapor content.

Distribution of Land and Water

The influence of the irregular distribution of land and water, as is well known, operates as follows. Land surfaces are heated under the direct rays of the sun more rapidly than water surfaces and cool more rapidly at night by radiation into space. This alternating heating and cooling of land surfaces causes inblowing winds (sea breezes) by day and outblowing winds (land winds) at night. The annual movement of the sun causes the continents to heat in summer and allows them to cool in winter, and the result is inblowing winds toward the continents in summer, as in the case of the monsoons, and outblowing winds in winter. In the case of land surfaces permanently covered with ice and contiguous to the open sea, like Spitsbergen, Iceland, and the Antarctic Continent, there is a permanent tendency toward outblowing winds.

Movement of Water

The contrast between land and water is accentuated in many regions by the second factor, movement of the water. In the North Atlantic between Iceland and Europe the drift of the ocean is from the equator toward the pole; and the water, especially in winter, is much warmer than the mean temperature of that latitude, so that the contrast between land and water is greatly accentuated. Along the coast of Chile and Peru the surface of the ocean is drifting toward the equator and is colder than the semi-tropical lands; so that here again, in a different way, the contrast between land and water is heightened. There are other similar cases, but these are the most notable examples.

Rotation of the Earth

The third factor which interferes with the free exchange of air between pole and equator is the rotation of the earth. Everyone is more or less familiar with the rotation of the water flowing out from a bowl with an opening in its bottom. On account of the rotation of the earth, a similar rotation is set up in the air flowing toward each pole to replace the colder air flowing away. The circulation taking place in the northern hemisphere at a height of about 4000 meters is represented schematically in Figure 2. In this diagram the arrows point the direction toward which the air is moving. The direction of the circulation is derived from direct observation combined with the isobars at the height of

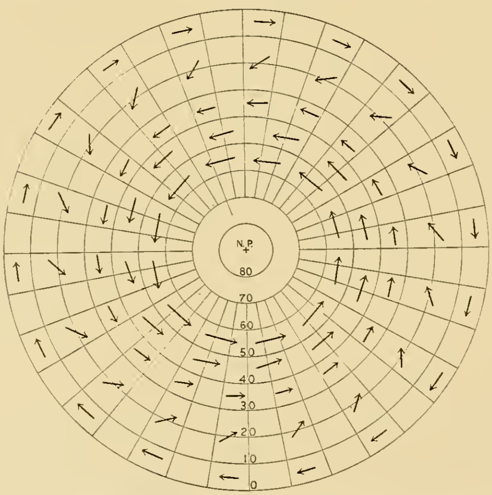

Fig. 2—Generalized circulation of the air around the north pole at an altitude of 4000 meters. Derived from observation, combined with the isobars of Teisserenc de Bort.

4000 meters computed by Teisserenc de Bort.[1] The effect of the circulation is to create a centrifugal force by virtue of which the pressure decreases in the Arctic Basin and increases at 30° latitude, where a ring of high pressure tends to build up under the combined influence of the drift from the east in the equatorial belt and the drift from the west in higher latitudes. This lowering of the pressure in the polar area cannot go so far as to make a low-pressure area at the pole, because in that case the flow of air away from the pole would cease and the circulation disappear. There remains on the average an area of high pressure over the Arctic Basin due to the cold and a ring of higher pressure at about 30° latitude due to dynamic causes. A cross section of the mean pressure at each degree of latitude running from the equator across the north pole is given in Figure 3.

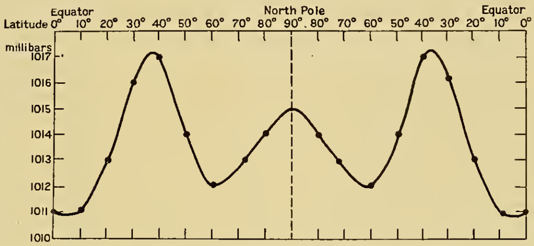

FIG. 3—Mean distribution of air pressure by latitude from the equator across the north pole.

Decreasing Density of Air with Increasing Height

The fourth reason why the simple circulation represented in Figure 1 is interfered with is the decrease of density of the air with height. Ascending air expands and, as a result of expansion, chills. This causes condensation of the moisture always present in the air. The latent heat of the condensing moisture retards the cooling of the air, and part of the condensed moisture falls as rain. When this air begins to descend in the Arctic Basin or within an area of high pressure the air is heated at the rate of one degree centigrade for each 102 meters of descent and soon becomes much warmer than the air it replaces, so that further descent would cease were it not for the cooling of the air by radiation into space.

Absorption and Radiation of Heat

The fifth influence which modifies and changes the simple circulation described at the beginning is the absorption of heat by water vapor in the atmosphere and the radiation of heat from the atmosphere.

[1] Léon Teisserenc de Bort: Étude sur la circulation générale de l'atmosphère, *Annales du Bureau Central Météorol. de France, IV: Météorol. Gén.* 1885, Part II, pp. 35–44, and maps, Pls. 6–14; reference on Pls. 9 and 13, Paris, 1887.

The computations of W. H. Dines[2] based on careful physical measurements and observations in the free air show that in the lower atmosphere in high latitudes, as well as near the equator, heat is being radiated away more rapidly than it is absorbed from solar or earth radiation, so that the air below 8000 meters is continually losing heat which has to be supplied in some other form, as by convection or otherwise. On the other hand the highest strata above 10 kilometers are gaining heat which must be dissipated in some way.

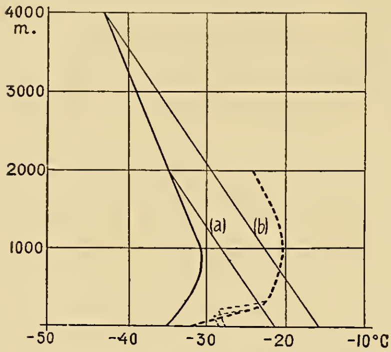

FIG. 4—The temperatures at different heights on the edge of the Antarctic Continent in winter observed by G. C. Simpson with captive balloons (shown by the full curve at the left). For comparison the curve of Fig. 5, Arctic winter temperatures on windy days, is added as a broken curve. (Antarctic curve from Fig. 15 of work cited in footnote 3 as reproduced in paper cited in footnote 4.)

There are hence two causes for the cooling of the air in high latitudes in winter. One is the radiation of heat into space from the earth's surface and the other is radiation from the air itself. This cooling of the atmosphere is the result chiefly of radiation from water vapor. The lowest temperatures are found in the upper part of the vapor stratum, in the polar area at an elevation of about 8 kilometers, because there the amount of heat lost to space is not compensated for in part by heat radiated back from higher strata. The resulting distribution of temperature from these two causes is a marked cooling of the air near the earth's surface in high latitudes in winter and a still more marked cooling at a height of 4 to 8 kilometers.

Observations of conditions in the free air on the edge of the Antarctic Continent made by Dr. G. C. Simpson[3] on the polar side of McMurdo Sound, in the southwestern corner of Ross Sea in about 78° S., show that the mean temperature during quiet weather in winter, on days when it was possible to launch small sounding balloons, was about −35° C. at the earth's surface. At 800 meters the temperature was higher, being but slightly below −30° C. Above 1000 meters the temperature fell with increasing height and was −43° C. at 4000 meters. (See the continuous curve in Figure 4.)

Observations were obtained in the Arctic Sea between the New Siberian Islands and Wrangel Island by Dr. H. U. Sverdrup[4] at latitude

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[2] W. H. Dines: Atmospheric and Terrestrial Radiation, *Quart. Journ. Royal Meteorol. Soc.*, Vol. 46, 1920, pp. 163–173.

[3] G. C. Simpson: Meteorology, Vol. I: Discussion, [Scientific Results of the] British Antarctic Expedition, 1910–1913, Calcutta, 1919, p. 45.

[4] H. U. Sverdrup: The North-Polar Cover of Cold Air: Preliminary Results from the Maud Expedition, *Monthly Weather Rev.*, Vol. 53, 1925, pp. 471–475; reference on p. 471.

about 75° N. and longitude between 155° and 175° E. by means of kites flown from the ship *Maud*. They show the following mean distribution of temperature, with heights, on days when it was possible to fly kites (see also the dotted curve in Figure 4 and the full curve in Figure 5):

Altitude (meters)	0	136	272	1000	1500	2000
Temperature (degrees C.)	−28.4	−28.9	−22.8	−20.3	−21.7	−24.0

On quiet days the surface temperature was lower, averaging −32.4° C.

Cold Waves and Polar Fronts

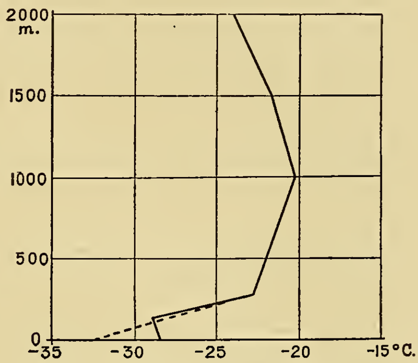

Fig. 5—The temperatures at different heights in the Arctic Sea in winter as observed by H. U. Sverdrup by means of instruments lifted by kites flown from the ship *Maud* (shown by the full curve). The broken curve in lower elevations shows the temperatures on calm days. (From paper cited in footnote 4.)

Both sets of observations show that there is in the polar regions in winter a very cold stratum of air near the earth's surface, with a warmer stratum above at a height of 500 to 1000 meters. Above that height the temperature decreases again. This surface stratum has very little motion; and calm, serene, clear weather is characteristic of the polar winters. The cold surface air undoubtedly flows out slowly, but this cannot be the origin of the fierce cold waves that occasionally sweep southward into temperate latitudes. In the United States these cold waves progress with the velocity of a rapid express train. They move much more rapidly than the surface winds along any part of their path. Their rapid progress is in the upper air at some 2000 to 8000 meters above the earth's surface, and the air is descending as it progresses southward. This is evident from the fact that the air is very clear and the humidity low.

My study[5] of the observations made in the free air at St. Louis in 1905–1907 by the staff of the Blue Hill Meteorological Observatory shows that these cold waves extend to heights of about 10 kilometers. It seems clear that they are not the result of the surface air of the Arctic moving southward but owe their origin to the cold upper air which has been chilled by radiation from the air itself.

The observations of Dr. Sverdrup showed an average temperature of −24° C. at 2000 meters (Fig. 5). If this air descended in the Arctic region it would heat by compression and have a temperature

[5] H. H. Clayton and S. P. Fergusson: Exploration of the Air With Ballons-Sondes at St. Louis and With Kites at Blue Hill, *Annals Astron. Observ. of Harvard College*, Vol. 67, Part 1, 1909.

of $-4°$ C. and hence be much warmer than the surface air. Therefore it cannot descend within the polar zone, but if drawn off into lower latitudes it can descend to the surface and become a cold wave. In the clear dry air of the cold wave the surface radiation is intensified, so that surface radiation becomes a factor in intensifying the cold. The rate of radiation decreases rapidly with decreasing temperature; hence the polar air, if undisturbed, would probably not cool much below $-70°$ C., when absorption and radiation would balance. The air between 1 and 6 kilometers is prevented from reaching these temperatures because it flows equatorward to form the "cold waves" and "polar fronts" of the modern meteorologist[6] and is replaced by warmer air coming from lower latitudes.

The details of the processes and methods of formation of these "cold waves" and "polar fronts" which play so important a rôle in the weather of lower latitudes are not yet determined, and this forms one of the unsolved problems of polar research. For this purpose a network of stations in the polar regions is needed, supplied with kites, sounding balloons, or airplanes for the purpose of observing conditions in the upper air. Professor W. H. Hobbs has recently initiated a praiseworthy attempt to study these processes around and over Greenland, the reconnaissance field work having been done during the summer of 1926.[7] He has secured a corps of able assistants, two of whom have had much experience in the exploration of the free air, Mr. S. P. Fergusson, of the U. S. Weather Bureau, having been active in the study of the upper air at Blue Hill, Mass., and at St. Louis, Mo., and Professor J. E. Church, Jr., of the University of Nevada, at Mt. Rose, Nevada.

My own researches[8] indicate clearly that the impulses which set these cold waves in motion are in some way intimately associated with variations in the intensity of solar radiation as measured by the Smithsonian Astrophysical Observatory.

The physical processes involved are not yet well understood, but my conception of them is that without solar variation the atmospheric circulation set up by the sun would be a balanced circulation disturbed only by the daily and annual changes. The solar variations give rise to the pulsations in the atmospheric circulation which cause the changes we call weather.

With an increased solar radiation the pressure falls in the equatorial belt, presumably because of the absorption of heat by the upper

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[6] See V. Bjerknes: The Meteorology of the Temperate Zone and the General Atmospheric Circulation, *Nature*, Vol. 105, 1920, pp. 522–524; J. Bjerknes and H. Solberg: Life Cycles of Cyclones and the Polar Front Theory of Atmospheric Circulation, *Geofys. Publikationer*, Vol. 3, No. 1, Christiania, 1922. See also, on atmospheric radiation, W. J. Humphreys: Physics of the Air, Philadelphia, 1920, p. 44.

[7] W. H. Hobbs: The University of Michigan Greenland Expedition of 1926–1927, *Geogr. Rev.*, Vol. 16, 1926, pp. 256–263; *idem:* The First Greenland Expedition of the University of Michigan, *ibid.*, Vol. 17, 1927, pp. 1–35 (meteorological results, pp. 20–32).

[8] *op. cit.*, p. 13.

air. Almost simultaneously the pressure rises in high latitudes, and an area of high pressure, accompanied by cold polar air, starts toward the equator and gives rise to the "polar front" with its characteristics of rain and wind. Following the center of high pressure a body of warmer air presses poleward to meet a succeeding "polar front" originating in the same way.

These areas of high pressure form in certain favored regions of the earth which were named by Teisserenc de Bort "centers of action." One of these centers is in the Arctic Basin. Multanovskii[9] investigated the origin of the areas entering northern Europe and found that those coming from the north and northeast came from the Arctic basin north of Greenland and probably from the ice fields beyond the pole.

Simpson[10] found that on the edge of the Antarctic Continent near McMurdo Sound the pressure increased and decreased in an irregular, wavelike manner, which he traced to a series of surges or pulses which originated in the interior of the continent and were the causes of the blizzards sweeping out from the mainland.

Further investigations as to where and how these surges of pressure originate are needed and may have a very important bearing on the meteorology of the temperate zones. It may be that these surges are due to the upsetting of the equilibrium of the atmospheric circulation as a whole by changes in solar radiation, but observations are needed to settle this point.

Interrelation of Polar Ice Conditions, Atmospheric Pressure, and Solar Radiation

Another aspect of the polar problem is that of prolonged weather conditions which make for favorable or unfavorable seasons. Wiese[11] found that in years of abundant ice in August in Barents Sea the pressure averaged above normal in June-July in northern Greenland and to the north of Iceland (see Fig. 6). On the other hand when there was a scarcity of ice in Barents Sea the pressure averaged high over the North Atlantic south of Ireland (see Fig. 7). The question

[9] B. P. Multanovskii: Osnovnyya polozheniya dlya deleniya Evropeiskoi Rossii na raiony po vozdeistviyam polyarnogo tsentra deistviya atmosfery (The basic foundations for the division of European Russia into regions according to the influence of the polar center of atmospheric action), *Izvestiya Glavnoi Fizicheskoi Observatorii*, Pavlovsk, 1920, No. 3. [Abstracted in *Petermanns Mitt. Ergänzungsheft No. 188*, 1925, pp. 67–68.]

[10] *op. cit.*, Chapters 5 and 6.

[11] V. Y. Vize (W. J. Wiese): O vozmozhnosti predskazaniya sostoyaniya ldov v Barentsovom More (About the possibility of forecasting the ice conditions in Barents Sea), *Izvestiya Tsentralnogo Hidrometeorologicheskogo Byuro*, Tsentralnoe Upravlenie Morskogo Transporta, Petrograd, 1923, No. 1. [Abstracted in *Petermanns Mitt. Ergänzungsheft No. 188*, 1925, pp. 66–67.]

idem (W. Wiese): Die Einwirkung des Polareises im Grönländischen Meere auf die Nordatlantische zyklonale Tätigkeit, *Annal. der Hydrogr. und Marit. Meteorol.*, Vol. 50, 1922, pp. 271–280.

idem: Polareis und atmosphärische Schwankungen, *Geografiska Annaler*, Vol. 6, 1924, pp. 273–299.

idem: Die Einwirkung der mittleren Lufttemperatur im Frühling in Nord-Island auf die mittlere Lufttemperatur des nachfolgenden Winters in Europa, *Meteorol. Zeitschr.*, Vol. 42, 1925, pp. 53–57.

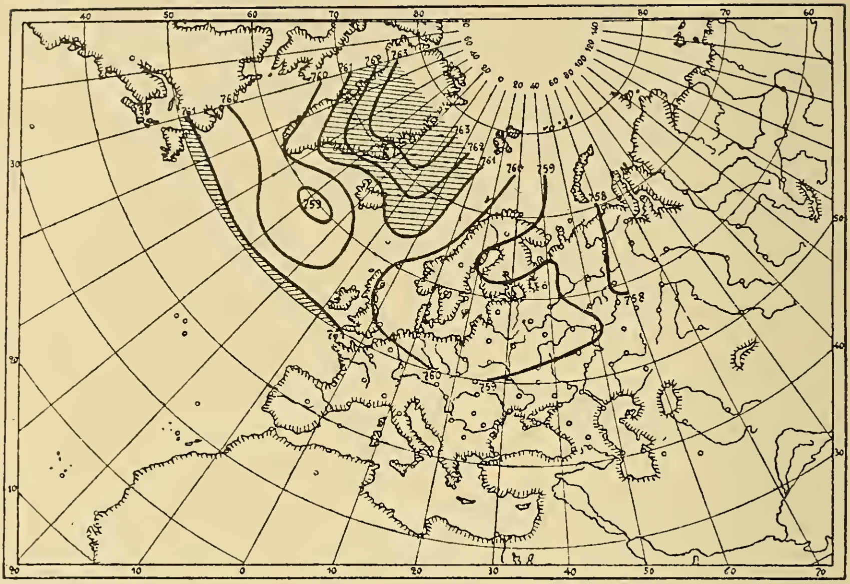

FIG. 6—Mean air pressure in the North Atlantic in June–July during years with an abundance of ice in Barents Sea in August. (After Wiese, first work cited in footnote 11, as reproduced in third work there cited.)

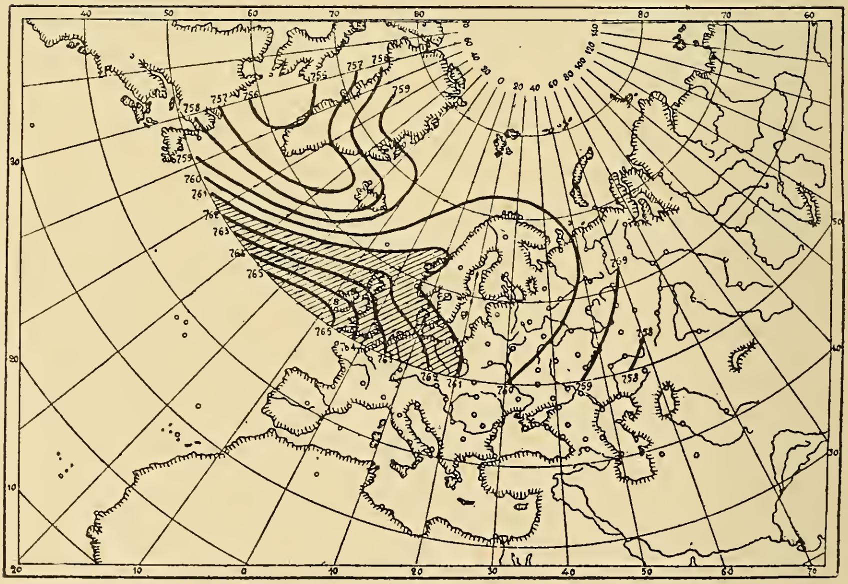

FIG. 7—Mean air pressure in the North Atlantic in June–July during years with a scarcity of ice in Barents Sea in August. (After Wiese, same source as Fig. 6.)

to be solved is whether the abnormal distribution of pressure is due to the ice conditions or whether the ice conditions are due to an

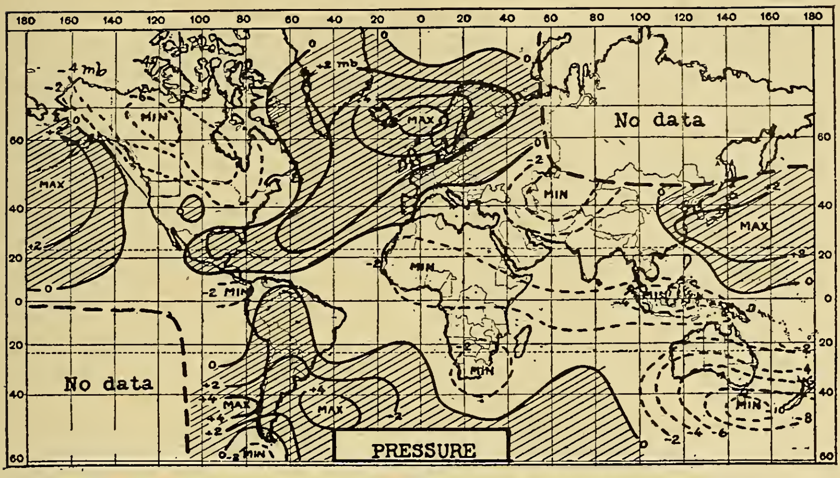

Fig. 8—The departures from normal air pressure over the earth's surface in July, 1910, when the solar radiation was two per cent below normal. (From Fig. 31 in Clayton, second work cited in footnote 13.)

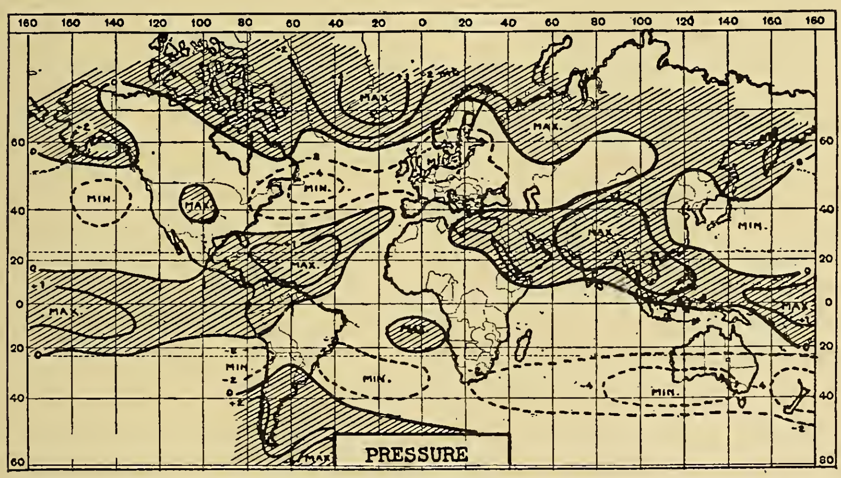

Fig. 9—The departures from normal air pressure over the earth's surface in July, 1917, when the solar radiation was two per cent above normal. From Fig. 28 in Clayton, same source as Fig. 8.)

abnormal distribution of pressure brought about by other causes. The researches of Helland-Hansen and Nansen[12] indicate that the abnormal distribution of pressure is the primary cause and not the

[12] Björn Helland-Hansen and Fridtjof Nansen: Temperatur-Schwankungen des Nordatlantischen Ozeans und in der Atmosphäre: Einleitende Studien über die Ursachen der klimatologischen Schwankungen, *Videnskapsselskapets Skrifter: I, Mat.-naturv. Klasse*, 1916, No. 9, Christiania, 1917. [An English translation, with additions by the authors and by Dr. C. G. Abbot, has appeared under the title: Temperature Variations in the North Atlantic Ocean and in the Atmosphere: Introductory Studies on the Cause of Climatological Variations, *Smithsonian Misc. Colls.*, Vol. 70, No. 4, Washington, 1920.]

result. My own researches[13] indicate that the cause of the abnormal distribution of pressure arises from a change in the amount of solar radiation as shown by the measurements of the Astrophysical Observatory of the Smithsonian Institution. Figure 8 shows the distribution of pressure departures from normal in July, 1910, when the solar radiation averaged two per cent below normal, and Figure 9 shows the distribution in July, 1917, when the solar radiation was two per cent above normal. The conditions in Figure 8 correspond to those found by Wiese when ice was unusually abundant in late summer in Barents Sea, and the conditions in Figure 9 correspond to those found by Wiese when there was a scarcity of ice in late summer.

Cause of Condensation of Water Vapor in the Polar Regions

Another problem to be determined by polar research is the question as to how the water vapor is condensed over the polar areas to produce the dense snow and ice covers observed. The air movements tend outward from these areas, and it is difficult to understand how condensation can occur in the descending currents of air which would prevail under such conditions. Some writers have surmised that the growth of the ice and snow caps over the polar regions comes from deposit of frost. To the writer it seems more probable that it comes from light snows falling from upper currents approaching the pole which under certain pressure conditions have an upward component of motion. The amount of precipitation in the polar regions is very small, and were it not for the very low rate of evaporation both regions would be deserts. A recent estimate by C. S. Wright in *Nature*[14] is that on the floating Ross Barrier in the Antarctic the annual precipitation is less than eight inches of solid ice, and it is probably a good deal less than this over the Antarctic Continent. The source of this additional moisture has not yet been satisfactorily determined. There are frequent blizzards in this region which lift up the surface snow into the air, but it has not yet been shown that these blizzards yield an additional snowfall.

Need for World-Wide Observations

It is becoming more evident each year that the meteorological problem cannot be solved by observations in any one part of the

[13] H. H. Clayton: World Weather, Including a Discussion of the Influence of Variations of Solar Radiation on the Weather and of the Meteorology of the Sun, New York, 1923, Chapters 10 and 12; *idem:* Solar Radiation and Weather, or Forecasting Weather from Observations of the Sun, *Smithsonian Misc. Colls.*, Vol. 77, No. 6, Washington, 1925.

[14] C. S. W[right]: Antarctic Weather, *Nature*, Vol. 118, 1926, pp. 488–490; reference on p. 489.

world. It is essentially a world problem, and before it can be clearly understood a network of stations must cover the oceans and the polar regions as well as the extra-polar land surfaces. The contrasts between pole and equator and between land and water acted on by an ever-changing intensity of solar radiation are the chief factors the play of which must be studied with the aid of physics and mathematics.

Sir FREDERIC STUPART has been director of the Dominion Meteorological Service of Canada since 1894. He has published a number of papers on meteorology and on the climate of Canada, among which is a series of papers published in the *Canada Yearbook* for 1921–1924 entitled "The Climate of Canada Since Confederation," "The Factors Which Control Canadian Weather," and "The Meteorological Service of Canada." He has also written: "The Variability of Corresponding Seasons in Different Years" (*Journ. Royal Astronom. Soc. of Canada*, Vol. 13, 1919); "Meteorological Stations in High Latitudes" (*Bull. Amer. Meteorol. Soc.*, Vol. 4, 1923); "The Climate of Canada" (British Assn. for the Advancement of Sci., Toronto Meeting, 1924: Handbook of Canada, Toronto, 1924).

THE INFLUENCE OF ARCTIC METEOROLOGY ON THE CLIMATE OF CANADA ESPECIALLY[1]

Sir Frederic Stupart

The general circulation of the earth's atmosphere is such that there is no part of the northern hemisphere, outside the tropics, that is not more or less affected by climatic conditions prevailing in the Arctic Regions. Passing northward from the tropics, through the middle latitudes, the periods of direct influence increase with increasing latitudes, until, when the zone north of the mean track of cyclonic areas is reached, conditions normal to the Arctic zone are the predominating influence.[2]

In the winter season the polar area does not have the lowest temperature in the northern hemisphere. In Asia the average mean January temperature of –60° F. (–51° C.) at Verkhoyansk, in the Province of Yakutsk, in latitude 67°, represents the coldest area in the northern hemisphere, while in America observation indicates that the territory north of Chesterfield Inlet on the northwestern side of Hudson Bay, with a mean January temperature of –35° F. (–37° C.), is the coldest area in the northern part of the western hemisphere, unless it be that the ice-covered dome of Greenland is colder. The mean temperature of the polar area in January is probably about –30° F. (–34° C.).

Prevailing winds play a very important rôle in climate, and the phenomena of the traveling cyclonic and anticyclonic areas with their attendant circulating winds lead to the changeable weather of the northern middle latitudes. The mean track of the cyclonic areas marks approximately the line to the northward of which high-latitude influences predominate, while to the southward low-latitude influences are the more prevalent. The normal distribution of the atmosphere over the surface of the globe, in the various seasons, gives exact information as to prevailing winds. The winter charts show that the

[1] On the influence of Arctic meteorology on the weather and climate of the north temperate zone see a number of recent papers in the proceedings of the first (Nov., 1926) meeting of the International Association for the Exploration of the Arctic by Airship published in *Ergänzungsheft No. 191 zu Petermanns Mitt.*, Gotha, 1927, as follows: Sir Napier Shaw: The Influence of the North Polar Region Upon the Meteorology of the Northern Hemisphere, pp. 25–30; the paper by V. Bjerknes cited in footnote 3 below; L. Weickmann: Die 24 tägige polare Druckwelle des Winters 1923–24, pp. 60–63; H. U. Sverdrup; Die meteorologischen Untersuchungen und Ergebnisse der "Maud"-Expedition, pp. 63–68 (see also the references in footnote 4 of the preceding paper by Mr. Clayton in the present volume); W. Schostakowitsch (Shostakovich): Der Einfluss der Arktis auf das Klima Sibiriens, pp. 68–77.—Edit. Note.

[2] A pertinent paper is H. H. Kimball: The General Circulation of the Atmosphere, Especially in the Arctic Regions, *Monthly Weather Rev.*, Vol. 29, 1901, pp. 408–418, with Chart 10.—Edit. Note.

highest pressure in the eastern hemisphere lies over northeastern Asia, indicating prevailing southerly and southwesterly winds along the northern coast of Asia and Europe; hence it follows that the low temperature of these northern coasts results from the extreme cold due to radiation over the wide land area of Asia.

Arctic Influences on the Pressure Movements over North America

A map of the pressure distribution over North America shows that northern Canada lies between two great centers of cyclonic action, one of them situated over the North Atlantic and centered near Iceland, the other over the North Pacific to the westward of Alaska. The winter mean pressure over northern North America is then high, and the prevailing winds of the Arctic coast line are northwesterly.

The northern middle latitudes include a zone of peculiarly intense cyclonic action. The normally deep depression over the North Pacific is the resultant of a succession of cyclonic areas passing from the western portion of the ocean with increasing intensity towards the coast of America, where they seem to disperse, but with strong indications that other depressions born of the Pacific parent continue on across the continent. Towards the Atlantic development proceeds apace, and a succession of deep cyclonic areas passing over or near Newfoundland reach the North Atlantic, the resultant effect being the normal deep Atlantic low pressure south and east of Greenland.

Meanwhile, as depressions pass across America, they are sometimes followed by a wave of high pressure which can be traced from within the Arctic Circle or at times would appear to be an offshoot from the Asiatic high pressure (Figs. 1–8).

These high pressures are usually accompanied by very low temperatures and, as they spread southward over Canada and the United States, cause periods of bitterly cold weather which may extend even to the Gulf of Mexico (Figs. 5–8). In some winters, especially those when the western portion of the continent is abnormally mild, the anticyclonic areas develop farther to the eastward north of Hudson Bay and spread southward (Figs. 5–8). These are the seasons which are particularly stormy in the Atlantic trade routes.

In the warmer seasons of the year, the distribution of pressure and the prevailing winds indicate a marked lessening of Arctic influences—even very remote—over North America, except in the extreme north and northeast. Cyclonic areas are feeble, and it is seldom that anticyclonic areas that affect southern Canada and the United States can be traced back to the Arctic Circle. Such anticyclonic areas as do form in the north are of course characterized by fairly low temperature and, as these pass southward and eastward, furnish the conditions necessary for the production of rain.

Arctic Influences on Labrador

As a concrete instance of the effect of the Arctic, operative the year round, there is probably no better example than that evidenced by the climate of northeastern America, including the major portion of the Labrador Peninsula. Over all this region the prevailing winds have a northerly component in summer as well as in winter, this owing not to abnormally high pressure in the north but to the fact that in all seasons the mean path of cyclonic areas lies to the southward of this region.

In the colder months the barometric gradient for north and northwest winds is steep, owing to the very low pressure south and east of Greenland. In summer the gradient slackens, but, with the ever-present tendency for cyclonic areas to pass from the Gulf of St. Lawrence towards the Gulf Stream to the eastward, northerly winds are all too prevalent.

In the northern portion of this northeastern territory there are vast tracts of land where the climate is so completely dominated by Arctic influences that the country is treeless and agriculture is impossible.

The Northern Limit of Tree Growth and Agriculture in Canada

The region north and west of Chesterfield Inlet probably has the coldest and longest winter, and thence southward and westward conditions improve. The northern limit of tree growth runs from near Churchill northwestward to the head of Coronation Gulf and thence near the coast line to the mouth of the Mackenzie. The whole country to the north of this tree limit is tundra, called in the early days of exploration the Barren Grounds, and to the southward there is a wide zone where agriculture can never be successful. Perhaps a line from Fort Simpson drawn southeastward to Fort Albany on James Bay may roughly represent the northern limit of land where agriculture may be moderately successful in a fair percentage of years.

In the Mackenzie valley south of Fort Simpson the rigors of a sub-Arctic climate are gradually mitigated, and westward to the Rocky Mountains, especially in the region of the Peace River, the climate is intermittently dominated by Pacific Ocean influences as represented by the chinook effect.

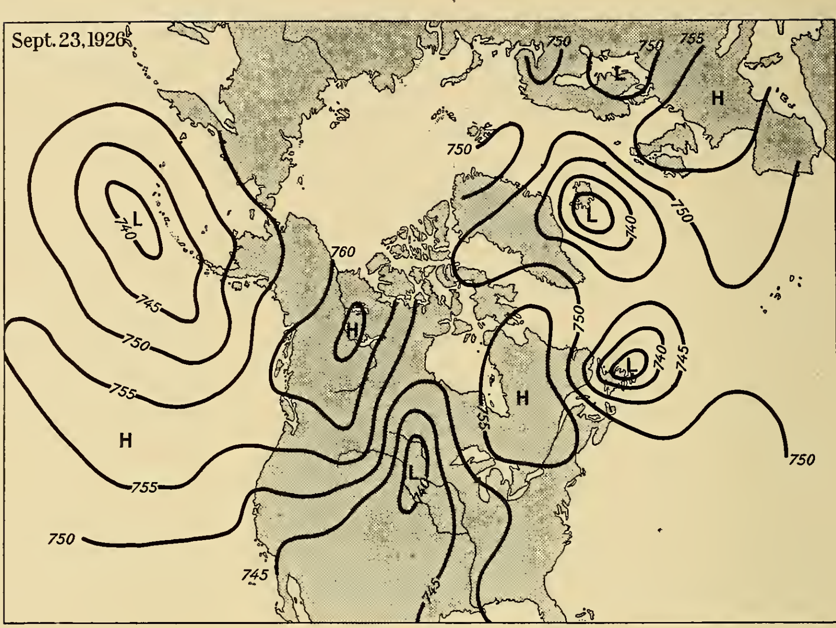

Fig. 1

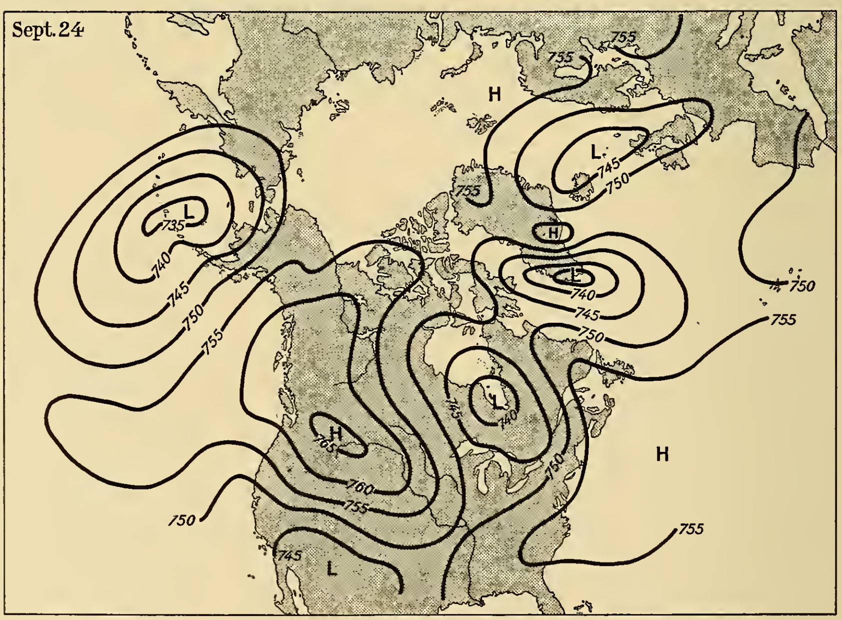

Fig. 2

Figs. 1–4—Maps showing the distribution of atmospheric pressure over North America on four consecutive days in September, 1926, to illustrate Arctic influences. Scale, about 1 : 100,000,000.

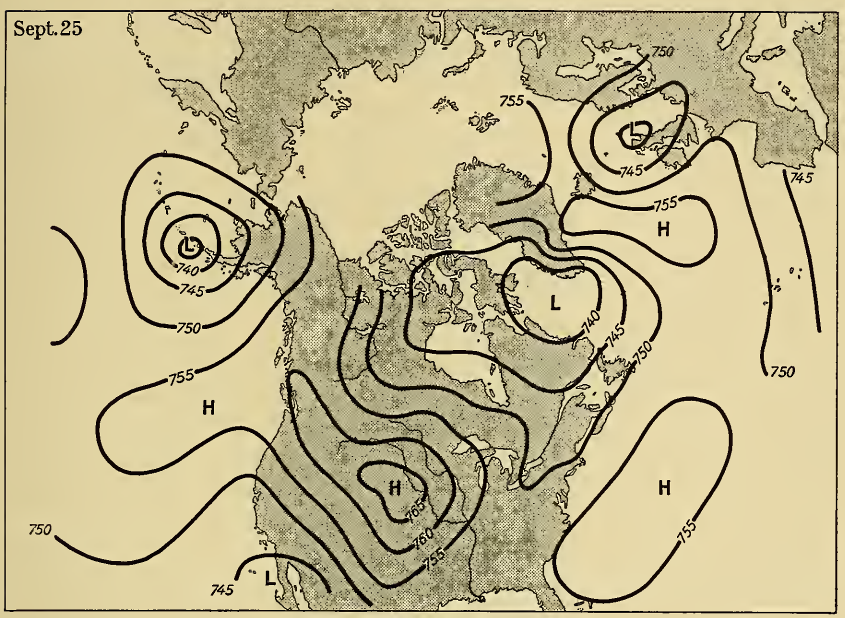

FIG. 3

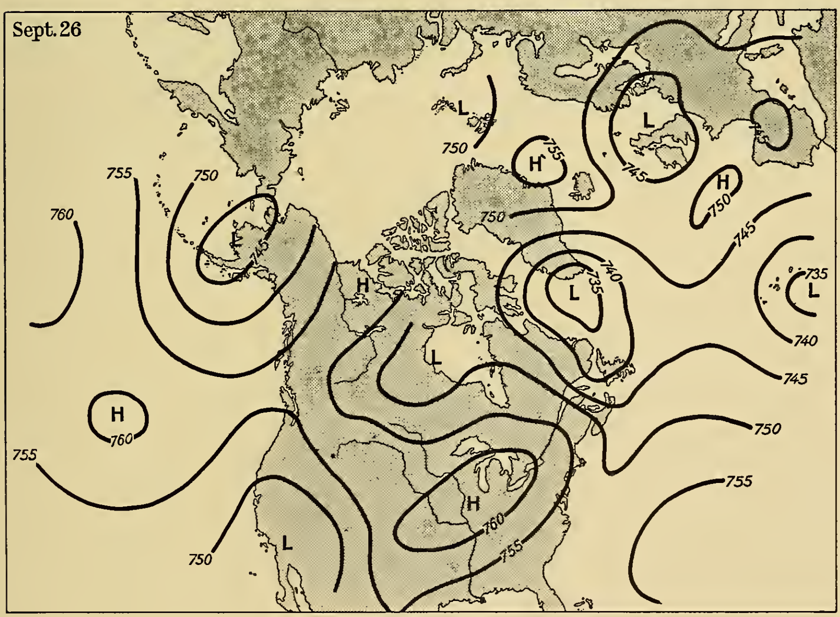

FIG. 4

An anticyclonic area can be traced proceeding from the Arctic Regions to the Central and Atlantic States of the United States which brought abnormally early cold weather in northwestern North America and unusually early frosts in the Canadian Provinces and Northern States.

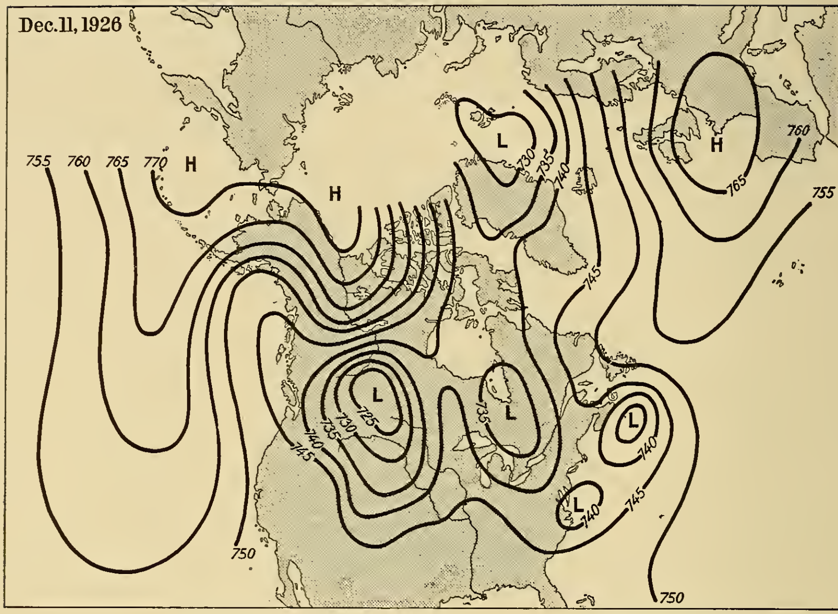

Fig. 5

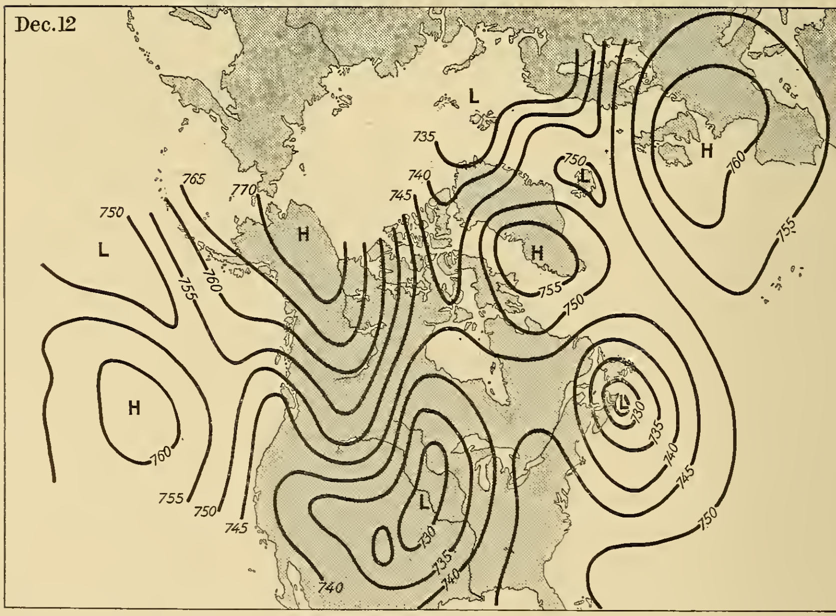

Fig. 6

Figs. 5–8—Maps showing the distribution of atmospheric pressure over North America on four consecutive days in December, 1926, to illustrate Arctic influences. Scale, about 1 : 100,000,000.

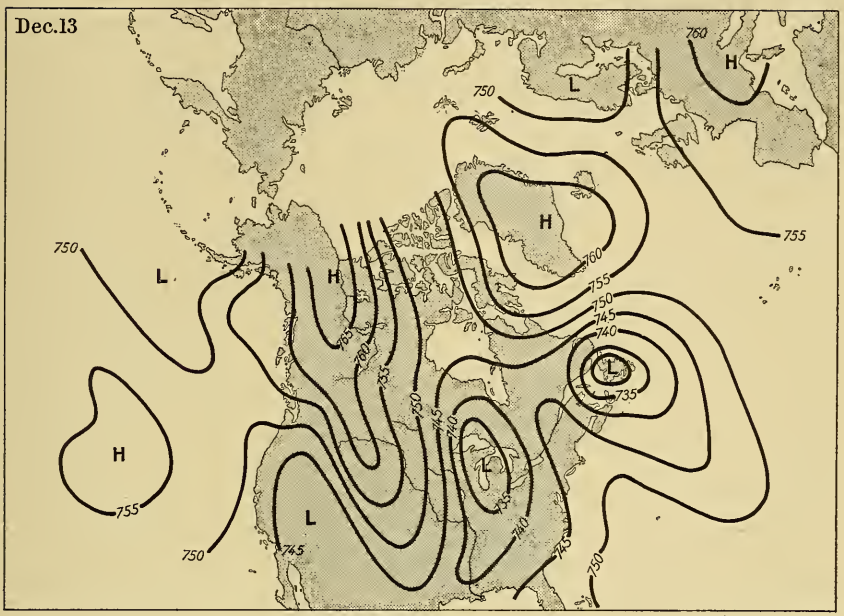

FIG. 7

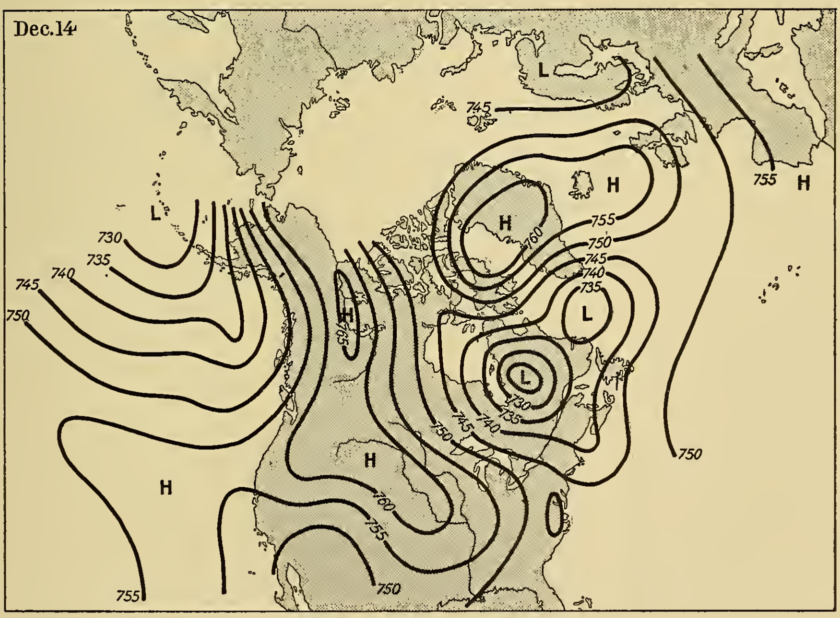

FIG. 8

These maps show another anticyclonic area which first appeared in the Arctic Regions and which later covered the Western Provinces of Canada and the greater portion of the United States, causing blizzards in Western Canada and unusually cold weather even as far south as Texas.

FIG. 9—Map of the poleward part of the northern hemisphere showing approximately the existing net of meteorological stations (based on publications of the United States, Canadian, Danish, and Russian meteorological offices). Mean scale, 1:82,000,000.

The stations are differentiated according to their method of disseminating reports: 1, by wireless; 2, by telegraph; 3, by some slower method. All three types accumulate records of permanent climatological value, whereas only stations of types 1 and 2 provide material for forecasting. Also, reports from all the stations of these two types are not as yet available to all central forecasting offices, such as London, Paris, or Washington. (On stations of type 1 see: Particulars of Meteorological Reports Issued by Wireless Telegraphy in Great Britain and by the Countries of Europe and North Africa, [*British*] *Meteorol. Office Publ. No. 252*, 5th edit., London, 1927.)

TITLE OF FIGS. 10–15 CONTINUED—The only other published maps showing the distribution of atmospheric pressure in the Arctic on consecutive days are, so far as known, the following—all for 1883, being based on the observations of the international polar stations of 1882–1883: Feb. 1–2, by H. A. Hazen (Hann's "Lehrbuch der Meteorologie," 4th edit., Leipzig, 1926); March 8–9, by H. A. Hazen (A. W. Greely: Report on Proceedings of U. S. Expedition to Lady Franklin Bay, Vol 2, Washington, 1888); May 30–June 3 (E. Vincent: Sur la marche des minima barométriques dans la région polaire arctique du mois de septembre 1882 au mois d'août 1883, *Mémoires Acad. Royale de Belgique, Classe des Sci.*, Series 2, Vol. 3, Brussels, 1910); March 1–5, April 8–12, April 17–20, May 7–10, June 4–7 (Das Luftschiff als Forschungsmittel der Arktis: Eine Denkschrift, Internatl. Studiengesell. zur Erforschung der Arktis mit dem Luftschiff, Berlin, 1924).

FIGS. 10–15—Maps showing the distribution of atmospheric pressure on six consecutive days in January, 1924, over the poleward part of the northern hemisphere. (Reproduced from the maps illustrating the paper by V. Bjerknes cited in footnote 3.) Scale, 1 : 215,000,000.

A major high, centered over the Siberian side of the Arctic Basin on January 21, can be traced spreading into central Asia and finally separating into two halves, a Siberian and a Canadian. This high is bordered by a series of lows, the circumpolar progress of the westernmost of which from the lower Mackenzie to Novaya Zemlya is indicated by arrows in Fig. 15. (*Continued at bottom of opposite page.*)

Arctic Influences on European Weather

It is apparent that in winter Canada and the United States are more directly affected by the meteorological conditions of the Arctic Regions than is northwestern Europe, where, with the Gulf Stream to the westward and the mean track of cyclonic areas west and north, the Arctic effect is at least less potent.

The year round, however, areas of high pressure forming in northern latitudes and moving southward have a very important bearing on the weather conditions of all the northern middle latitudes. They form what the Norwegian meteorologists have termed a *polar front*.[3] The air within these boundaries is of a temperature acquired in higher latitudes, and southerly currents set in motion by cyclonic areas overrun the low-lying cooler air of the polar front and lead to the all-necessary rainfall. Daily weather maps will show that the majority of summer thunderstorms have occurred along a polar front.

Factors Leading to the Development of Cyclonic Areas in the North

There has been much controversy as to the normal pressure over the Polar Regions. Naturally, sufficient observations are lacking, but at the present time general deductions may be made from the run of the isobars drawn on the daily meteorological charts of the northern hemisphere which are now available. Stations in northwestern Europe, Spitsbergen, Iceland, and Greenland show the pressure distribution on one side of the pole (Fig. 9). Stations in Alaska show the conditions on the other side, and interpolation will usually give a fairly accurate outline of the distribution over the polar area. There is, however, in northern Russia and Siberia a wide gap which, it is hoped, will sometime be filled in. Stations exist there, but it is only very occasionally that reports from these stations come to England and France and thence to America.

The weather maps of the winter months show a persistent stream of low areas approaching the northwestern coasts of Canada and Alaska from the Pacific and passing into and perhaps across the continent, and another stream passing from the Gulf of St. Lawrence south of Greenland and to the northwest of Scandinavia (Figs. 10–15). The Polar Regions lie between these two streams; and there is strong evidence that pressure there is normally higher than to the southward, and it may be assumed that the winters are less stormy.

But the meteorologists require further information, there being as yet so many points unexplained. One wonders why it is that in some

[3] On this topic see the preceding paper by Mr. Clayton in the present volume and the references there cited in footnote 6. A recent paper by V. Bjerknes entitled "Die Polarfronttheorie" is published as part of the proceedings of the Nov., 1926, meeting of the International Association for the Exploration of the Arctic by Airship in *Ergänzungsheft No. 191 zu Petermanns Mitt.*, Gotha, 1927, pp. 53–60.—Edit. Note.

winters the cyclonic areas from the Pacific are deep and in other winters shallow, why in some years they are farther north than in others. When they are deep, together with an abnormally northward movement, they force their way into sub-Arctic America, and the normal anticyclonic conditions of the continent do not develop. In other years the Pacific lows enter the continent farther south, and great anticyclones appear over the Polar Regions and enter Arctic America and sweep down over western and central Canada.

These facts indicate much variation in atmospheric circulation, and it seems not improbable that this variation may be largely responsible for the difference in the character of corresponding seasons in different years in northern North America.

Some years ago the Canadian Meteorological Service equipped four of the ships of the Canadian Pacific Steamship Company with thermographs for recording the temperature of the surface water between Vancouver and Yokohama and also had all water temperature records in possession of the company copied out and meaned for the various months and years, and we now possess certain data which may prove valuable in determining to what extent the varying temperature of the Pacific Ocean affects cyclonic development and atmospheric circulation. It is conceivable that a varying solar radiation may so affect the tropics and equatorial regions that the trade winds will vary in strength and affect the strength of ocean currents sufficiently to cause the variation in water temperatures which are recorded in our survey work. The data so far available appear to indicate an intimate relationship between water temperature and the intensity of cyclonic development.

Factors Leading to the Development of Anticyclonic Areas

While some of the factors leading to the development of cyclonic areas seem to be fairly apparent, the causes leading to the development of northern anticyclones are perhaps more obscure. It has been suggested that the high domelike interior of Greenland may be the pole of anticyclonic energy, but in the writer's opinion the weather maps show that this is not the case. The general appearance of the weather map in winter points rather to the poles of greatest refrigeration being located in Siberia and northeastern America, where there is probably as low a temperature as at the high altitudes of Greenland and certainly, being at low altitudes, a much greater mass of air.

A study of the weather charts for the summer of 1926, this being the only summer with reports from Greenland, indicates a prevalence of high pressure within the Arctic Regions with no definite preference for any particular portion of these regions.

It is quite probable that a systematic investigation of radiation at a number of northern stations in Canada would yield results which would throw light on the development of high areas and cold waves, and in addition a few such stations in Greenland especially at high altitudes would be instructive. Meteorological stations reporting by wireless have been placed at several points in Canadian territory within the Arctic Circle and have proved most valuable. An extension of these stations is recommended and hoped for. Stations at Coronation Gulf, Chesterfield Inlet, Ponds Inlet, and Churchill are quite likely to be established in the not distant future, and, were Russia to place stations at the New Siberian Islands and at an intermediate point between these islands and Bering Strait, data would be afforded for a much more accurate knowledge of conditions which lead to the development of Arctic anticyclones.

Dr. Bauer has been the director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington since 1904. He is the author of many papers dealing with that subject and since 1896 has been editor of *Terrestrial Magnetism and Atmospheric Electricity.* Among his works may be mentioned the "Researches of the Department of Terrestrial Magnetism," *Carnegie Instn. Publ. 175 (in collaboration with others, 1912–1926)*; "The Physical Decomposition of the Earth's Permanent Magnetic Field" (*Terrestr. Magnet. and Atmospher. Electr.*, Vols. 4, 6, 8, 9, 1899–1904); "The Physical Theory of the Earth's Magnetic and Electric Phenomena" (*ibid.*, Vols. 15–17, 1910, 1912); "The General Magnetic Survey of the World" (*Bull. Amer. Geogr. Soc.*, Vol. 46, 1914); "The Earth's Magnetism" (*Bedrock*, Vol. 2, 1913; reprinted, after revision, in *Ann. Rept. Smithsonian Instn. for 1913*, Washington, 1914).

UNSOLVED PROBLEMS IN TERRESTRIAL MAGNETISM AND ELECTRICITY IN THE POLAR REGIONS

L. A. Bauer

The accumulation of additional magnetic and electric data in the polar regions is of paramount importance to the definite solution of some of the unsolved problems pertaining to the earth's magnetism and electricity. Increased importance will result also from the fact that the Arctic and the Antarctic differ so greatly as regards physical features. Thus an analysis of the earth's magnetic field for 1922 by the writer clearly indicated effects on the distribution of the earth's magnetism and its secular change related apparently to the distribution of land and water.[1] Since in the Arctic there is a preponderance of water and in the Antarctic a preponderance of land, opportunity will be afforded, if sufficient magnetic data of the required accuracy be obtained, to test this interesting question anew.

Improvement of Magnetic Charts

The following statements will give some idea as to errors in the lines of equal magnetic declination, commonly called by the mariner "lines of equal magnetic variation," in the Arctic regions, for example.

During the Canadian Arctic Expedition of 1913–1918, under the leadership of Mr. Vilhjalmur Stefansson, magnetic declinations were observed in the years 1915–1917 at 26 points with prismatic compasses between the parallels 74° to 80° N. and meridians 98° to 124° W. The differences[2] between the values thus obtained and those scaled from the isogonic chart (No. 2598) published by the British Admiralty for 1922 ranged in the region concerned from −34° to +21°. In consequence, Mr. H. Spencer Jones, then connected with the Greenwich Observatory, undertook the construction of revised lines of equal magnetic declination for the polar regions, epoch 1922, utilizing all the data available to him at the time.[3] The differences between the Canadian Arctic Expedition observations and the values of Jones's revised chart ranged from +12° to −15°.

[1] L. A. Bauer: Chief Results of a Preliminary Analysis of the Earth's Magnetic Field for 1922, *Terrestr. Magnet and Atmospher. Electr.*, Vol. 28, 1922, pp. 1–28; reference on pp. 6–9.

[2] F. A. McDiarmid: Geographical Determinations of the Canadian Arctic Expedition, *Geogr. Journ.*, Vol. 62, 1923, pp. 293–302; reference on pp. 301–302.

[3] H. Spencer Jones: The Magnetic Variation in the Neighbourhood of the North Pole, *Geogr. Journ.*, Vol. 62, 1923, pp. 419–423, with chart, 1:37,000,000.

Since the publication of Mr. Jones's chart considerable additional information in the Arctic has become available. Thus we have now the results of the magnetic observations made by Captain Amundsen's

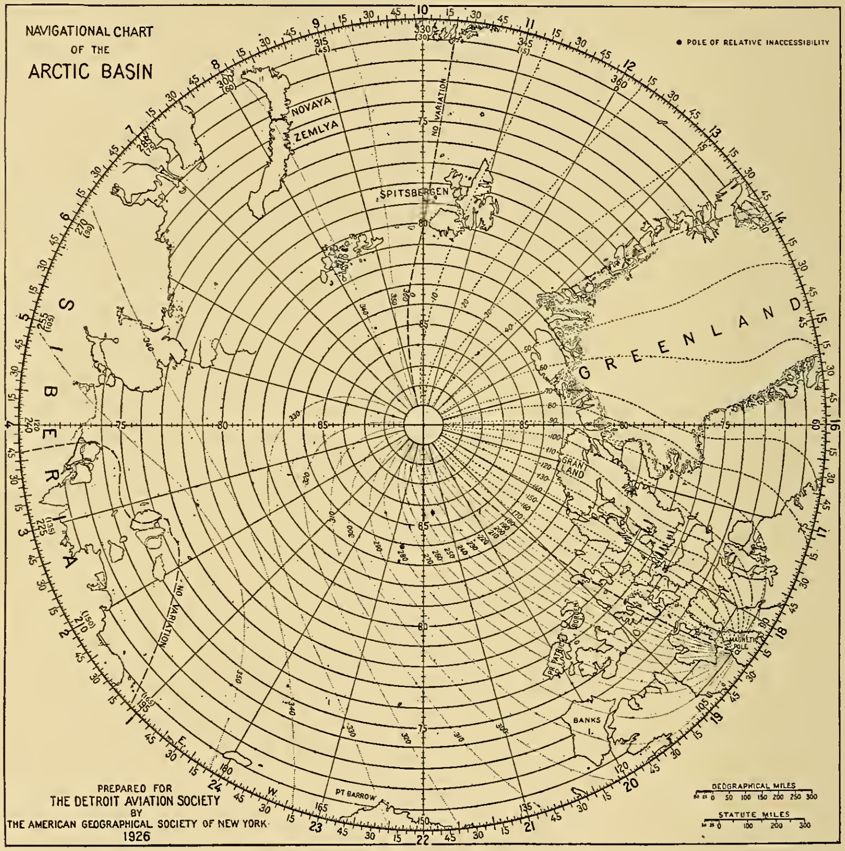

FIG. 1—Air navigational chart of the Arctic Regions north of 70° N. latitude, with approximate lines of equal magnetic declination (variation of the compass) for 1926, revised from data supplied by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. Scale, 1: 40,000,000. See also Fig. 2.

Maud expedition, 1922–1925, for the region between Siberia, Bering Strait, and the New Siberian Islands, and by the three MacMillan expeditions, 1921–1925, to Baffin Island and Greenland.[4] Also, the

[4] The report on the magnetic and electric observations made by the *Maud* expedition will be published by the Carnegie Institution of Washington in a forthcoming volume (Vol. 6) of its Publication No. 175, "Researches of the Department of Terrestrial Magnetism." The magnetic records of the MacMillan expeditions of 1921–1922 to Baffin Island and of 1923–1924 to Northern Greenland are in the files of the Department; the results of the field observations will appear in Vol. 6 of the publication just cited, and the results of the observatory observations will be published in a subsequent volume. The magnetic records of the MacMillan expedition to Greenland, 1925, are in the files of the U. S. Coast and Geodetic Survey; the results have been published in D. L. Hazard: Results of Magnetic Observations Made by the United States Coast and Geodetic Survey in 1925, *U. S. Coast and Geodetic Survey Spec. Publ. No. 125*, Washington, 1926; reference on p. 13.

results of magnetic observations made on Amundsen's Northwest Passage voyage, 1903–1906,[5] and by the Swiss expedition to Greenland, 1912–1913, have been published recently.[6]

These new data, approximately corrected for secular change, show that the British Admiralty chart for 1922, the Jones revised polar chart for 1922, and the United States Hydrographic chart (No. 2406) for 1925 all indicate too large westerly declinations along the northwest coast of Greenland by about 5° to 10°. For stations along Hudson Strait and the southern part of Baffin Island the charts indicate, in general, too small westerly declinations, the difference between observed and chart values reaching at times 10° and averaging about 5°.

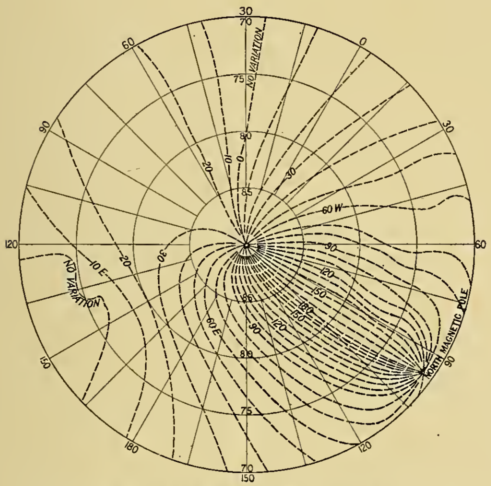

FIG. 2—The lines of equal magnetic declination for 1926 from Fig. 1 without geographical outlines for greater clarity. Scale, 1:75,000,000. The variation is here reckoned 180° east and west, whereas on Fig. 1 it is reckoned 360° continuouslv from west to east.

In the region immediately to the north of the north magnetic pole all charts show too large westerly declinations, on the average about 10°. At Gjöa Harbor, on the southeastern side of King William Island, about 130 miles south of the north magnetic pole, where Amundsen had in operation a magnetic observatory from November, 1903, to May, 1905, the observed magnetic declination was, on the average, 7.4° West. The three charts mentioned all show east magnetic declination, namely 8° (United States Hydrographic Office), 10° (British Admiralty), and 18° (Jones).

On the Arctic drift of the *Maud*, 1922–1925, observations of the three magnetic elements were made at numerous stations on the ice, sufficiently remote from the ship's influence. Isomagnetic lines (magnetic declination, inclination, and horizontal intensity) have been constructed for the epoch 1925.0 by Dr. H. U. Sverdrup, in charge of the scientific work, for the region north of Bering Strait nearly to the parallel of 75° N. and between the New Siberian Islands and

[5] Aage Graarud and Nils Russeltvedt: Die erdmagnetischen Beobachtungen der Gjöa-Expedition, 1903–1906, *Geofys. Publikationer*, Vol. 3, No. 8, Oslo, 1925 (abstracted in *Terrestr. Magnet. and Atmospher. Electr.*, Vol. 31, 1926, pp. 17–21).

[6] Alfred de Quervain and P.-L. Mercanton: Ergebnisse der Schweizerischen Grönlandexpedition 1912–1913, *Neue Denkschr. Schweiz. Naturforsch. Gesell.*, Vol. 53, 1920, Zurich; reference on pp. 180–184 (P.-L. Mercanton: Les observations de magnétisme terrestre, abstracted in *Terrestr. Magnet. and Atmospher. Electr.*, Vol. 31, 1926, pp. 15–16).

northeastern Siberia. His isogonics differ at some places considerably from the published charts. The greatest discrepancy is found in the vicinity of the New Siberian Islands, where according to the *Maud* observations the declination was 2° West, whereas the charts mentioned indicate about 10° East, hence a difference of 12°. Marked local magnetic disturbances were also revealed by the *Maud* observations in regions where the depth of the sea was about 40 to 70 meters.

In the accompanying chart (Fig. 1) a preliminary attempt has been made to perfect Jones's chart in the regions where the additional data, just described, had been obtained.

The recent data as regards magnetic inclination (dip) and intensity of the earth's magnetic field likewise show in crucial regions differences from the published chart values for the Arctic of sufficient amount to be taken into consideration if an analysis of the earth's magnetic field is extended beyond the region of the earth included between the parallels 60° N. and 60° S.

Future polar expeditions should embrace every opportunity to obtain additional magnetic data as regards distribution and secular changes of the magnetic elements, both in the Arctic and the Antarctic.

Magnetic Observatories in High Latitudes

On account of the numerous fluctuations to which the earth's magnetism is continually subject, especially in the polar regions, it is highly desirable whenever conditions permit to conduct a series of continuous observations for as long a period as possible, preferably by photographic means, within the area of the magnetic survey.

Thus Captain Amundsen during his Northwest Passage voyage obtained photographic registration of the continual changes in the magnetic elements from November, 1903, to May, 1905, at his observatory at Gjöa Harbor. For that period the approximate position of the north magnetic pole was determined to be in latitude 70° 30′ N. and longitude 95° 30′ W. of Greenwich.[7] (For comparison it may be stated that the position determined in 1831 by Sir James Clark Ross was 70° 5′ N. and 96° 46′ W.) It would have added greatly to our knowledge of the supposed movements of the magnetic pole if similar series of magnetic-observatory observations could have been obtained simultaneously at several stations surrounding the magnetic pole.

During Captain Amundsen's expeditions on the *Maud*, 1918–1925—the Northeast Passage voyage, 1918–1922, and the drift in the East Siberian Sea, 1922–1925—the scientific personnel, under the direction of Dr. H. U. Sverdrup, obtained valuable continuous records of the changes in the magnetic declination at the winter quarters (77° 33′ N., 105° 40′ E.) near Cape Chelyuskin, Siberia, from October, 1918, to

[7] Graarud and Russeltvedt, *op. cit.*, p. 11.

August, 1919, and again at the winter quarters, Four Pillar Island (70° 43′ N., 162° 25′ E.), from October, 1924, to May, 1925.[8] The latter station exhibited a diurnal range of the magnetic declination about 50 per cent less than what might have been expected according to usual theory, but in full agreement with the results obtained at Nordenskiöld's winter quarters, Pitlekai (67° 5′ N., 173° 30′ W.), January to March, 1879,[9] and at the Russian polar station of 1882–1884, Sagastyr (73° 23′ N., 126° 35′ E.), at the mouth of the Lena River.[10] Cape Chelyuskin, on the other hand, revealed a diurnal variation of the magnetic declination of the expected degree of development for a station in *magnetic* latitude 80.8°.

Continuous registrations of the fluctuations in the magnetic elements were secured by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington in coöperation with the MacMillan Arctic expeditions[11] at Bowdoin Harbor (64° 24′ N., 77° 52′ W.), southwest coast of Baffin Island, 1921–1922, and again at Refuge Harbor (78° 31′ N., 72° 27′ W.), northwest coast of Greenland, 1923–1924.

So also magnetic-observatory work was conducted during Captain Scott's two Antarctic expeditions,[12] by the German Antarctic expedition under the direction of Professor Erich von Drygalski,[13] and by Sir Douglas Mawson's Antarctic expedition.[14]

While our knowledge of the incessant fluctuations in the earth's magnetic condition has been materially advanced, there still remains much to be done before we may perfect present theories of causes. Appreciating this fact, the Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union at the Madrid meeting of October, 1924, passed a number of resolutions recommending the establishment of additional magnetic and electric observatories in high latitudes.[15] Two resolutions of special interest may be quoted here:

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[8] See, above, footnote 4.

[9] A. Wijkander, edit.: Observations magnêtiques, faites pendant l'expédition de la Vega, 1878–80, in: A. E. Nordenskiöld, edit.: Vega-expeditionens vetenskapliga iakttagelser, Vol. 2, pp. 429–504, Stockholm, 1883. The geographical coördinates of Pitlekai are revised values as given in A. E. Nordenskiöld, edit.: Die wissenschaftlichen Ergebnisse der Vega-Expedition, Leipzig, no date [about 1882], p. 282.

[10] V. Fuss, F. Müller, and N. Jürgens: Beobachtungen der russischen Polarstation an der Lenamündung, I. Theil: Astronomische und magnetische Beobachtungen, 1882–1884 (in German and Russian), Russian Geogr. Soc., [St. Petersburg], 1895; reference on pp. 138–139.

[11] See, above, footnote 4.

[12] National Antarctic Expedition, 1901–1904: Magnetic Observations, Royal Society, London. 1909; British (Terra Nova) Antarctic Expedition, 1910–1913: Terrestrial Magnetism, London, 1921,

[13] Erich von Drygalski, edit.: Deutsche Südpolar-Expedition, 1901–1903: Erdmagnetismus in Vols. 5 and 6 and Atlas 2, Berlin and Leipzig, 1906–1925.

[14] Australasian Antarctic Expedition, 1911–14, under the leadership of Sir Douglas Mawson, Scientific Reports: Terrestrial Magnetism in Series B, Vols. 1 and 2, Sydney, 1925.

[15] Transactions of Madrid Meeting, October, 1924, *Sect. of Terrestr. Magnet. and Electr., Internatl. Geodet. and Geophys. Union, Bull. No. 5*, Baltimore, 1925, pp. 27–32.

The Section deems it highly desirable to call attention to the need of additional magnetic and electric observations in high latitudes, especially north of 60° N. and south of 50° S.

The Section recommends the desirability of obtaining magnetic data from high latitudes in years near sunspot maximum to supplement those near sunspot minimum already obtained to some extent by certain Antarctic expeditions and that this matter be brought to the attention of future expeditions.

Likewise the Commission on Solar and Terrestrial Relationships of the International Research Council, at its Brussels meeting of July, 1925, made a number of suggestions and recommendations[16] pertaining to important work in terrestrial magnetism, atmospheric electricity, polar lights, and radiotelegraphy which might be advantageously undertaken in high latitudes, both north and south. For example the Commission makes the following statement:

By means of special expeditions to carry out simultaneous temporary programmes at selected polar stations, as in 1882–1883, the work of the permanent observatories in high magnetic latitudes would be valuably supplemented.

Within the past three years there have been established the following additional magnetic observatories in high northerly latitudes: Matochkin Shar (Novaya Zemlya), by the Russian Government; Godhavn (Greenland), by the Danish Government; and Lerwick (Shetland Islands), by the British Government. There is also in contemplation the establishment of a magnetic observatory in eastern Siberia. Furthermore, the Canadian observatory at Meanook (54° 37′ N., 113° 20′ W.) near Athabaska Landing, the nearest one to the north magnetic pole, is being equipped at present with the required instruments for recording the variations of the horizontal and vertical intensity, instead of as heretofore only those of magnetic declination.

The most southerly magnetic observatory in the southern hemisphere is that maintained by the Argentine Government at the South Orkneys (60° 43′ S., 44° 47′ W.).

Magnetic Storms, Polar Lights, and Electric Disturbances

These subjects have aroused renewed interest during the present period of increased solar activity, as indicated, for example, by increasing sunspottedness. During 1926 we have had notable magnetic storms, brilliant displays of polar lights, interruption of telegraphic transmission owing to induced electric currents flowing within the earth's crust, and even interference in radio transmission for certain wave lengths caused by the entrance in the upper atmosphere of ionizing agencies affecting the so-called Kennelly-Heaviside conduct-

[16] First Report of the Commission [of the International Research Council] Appointed to Further the Study of Solar and Terrestrial Relationships, Paris, 1926 (in English and French).

ing layer. Table I may serve to show how the average monthly state of the sun's activity has varied since the year, 1923, of minimum sunspottedness. The numbers for 1923, 1924, and 1925 are final ones and depend upon the records of sunspots from observatories distributed over the entire globe. Those for 1926 are provisional ones, since they depend only on the records of the observatory at Zurich, Switzerland; on account of cloudy weather a month's record may be incomplete. The expectation is that the period of maximum sunspottedness for the present solar cycle is close at hand.

TABLE I—MONTHLY MEAN SUNSPOT RELATIVE NUMBERS

(according to Prof. A. Wolfer of the Zurich Observatory)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1923	4.5	1.5	3.3	6.1	3.2	9.1	3.5	0.5	13.2	11.6	10.0	2.8	5.8
1924	0.5	5.1	1.8	11.3	20.8	24.0	28.1	19.3	25.1	25.6	22.5	16.5	16.7
1925	5.5	23.2	18.0	31.7	42.8	47.5	38.5	37.9	60.2	69.2	58.6	98.6	44.3
1926	71.6	69.0	63.6	39.1	63.6	71.6	48.3	62.4	60.5	77.7	55.0	66.4	62.4

In spite of numerous observations from polar expeditions the precise relationship between aurora and disturbances in the earth's magnetic state, as shown during periods of magnetic storms, is not yet clearly understood. The results from different expeditions are at times even contradictory. For example, Dr. Sverdrup from auroral and magnetic observations made by the *Maud* expedition at the winter quarters, Four Pillar Island, September, 1924, to the beginning of April, 1925, reached the conclusion[17] that auroral displays are practically always accompanied by a magnetic disturbance whose severity increases, in general, with the intensity and movement of the aurora. He further found that the intensity of the magnetic disturbance increased with increasing altitude of the aurora. At this Arctic station, which was located about 6° south of the zone of maximum auroral frequency, both the maximum of magnetic disturbance and the greatest frequency of aurora occurred around midnight, whereas at the British Antarctic station of 1910–1913, Cape Evans, the middle of the day was most disturbed magnetically and the frequency of the aurora showed a maximum in the night hours.[18] For this Antarctic station Wright found no relation between the altitude of the aurora and the magnetic character at the hour of observation and only a slight relation between the brilliancy of the aurora and the magnetic disturbance.

[17] Dr. Sverdrup's observations and results will be published in the volume cited above in footnote 4.

[18] Chapter 14 of the second work cited above in footnote 12.

Though the *Maud*, during her drift in the Arctic ice from 1922 to 1925, was generally not far from the belt of maximum auroral frequency, Dr. Sverdrup found no relation between the potential gradient of atmospheric electricity and the aurora. Regarding this matter the results from various polar expeditions and observers are again conflicting. Unfortunately the *Maud* did not possess the necessary instrumental equipment for measurements of the electric conductivity of the atmosphere, which would have been of interest also in connection with the question of the relationship between the aurora, atmospheric electricity, and radio reception.

The determination, by the Störmer parallactic photographic method, of the depth of penetration into the atmosphere of polar-light beams in regions near the magnetic poles is an important matter. The many thousand observations made by Störmer, Krogness, and Vegard, in northern Norway have shown that for that region the auroral beams do not come closer to the earth's surface than about 90–100 kilometers. Yet, according to accounts of some explorers, the beams in the Arctic regions have penetrated at times much deeper into the atmosphere. The Department of Terrestrial Magnetism supplied the MacMillan Baffin Island expedition of 1921–1922 with the necessary equipment and instructions for investigations of the height of the aurora, at the winter quarters of the expedition on the southwest coast of Baffin Island; unfortunately, owing to various causes, the expedition was unable to take the desired parallactic photographs. Here, then, remains open an important field of investigation, both in the Arctic and the Antarctic.

The great importance of special radio experiments in the polar regions for elucidating the connection between the aurora and the properties of the conducting layer deserves special mention. Experiments made at the laboratory of the Department of Terrestrial Magnetism at Washington by G. Breit and M. A. Tuve[19] in 1925 showed that it is possible to measure approximately the height of the conducting layer by radio signals. Dr. Breit considers it very desirable that the heights of the aurora and of the conducting layer be ascertained simultaneously at the same station.

Among other important investigations regarding polar lights might be mentioned, for example, those having a bearing on the experiments by Vegard of Oslo and McLennan of Toronto with a view to the explanation of the *spectrum of the aurora*.

Atmospheric Electricity

Under the preceding head some suggestions have already been given regarding investigations in atmospheric electricity open to polar

[19] *Physical Rev.*, Vol. 28, Menasha, Wis., 1926, pp. 554–575.

expeditions. One of the great outstanding questions pertains to the origin and maintenance of the earth's negative electric charge. While the electric conductivity of the atmosphere is extremely small, it is nevertheless sufficiently large to dissipate the earth's entire surface charge in a quarter of an hour if there were no agency operating to replenish that charge. No experiments made in regions remote from the magnetic poles have as yet disclosed that replenishing agency. Special experiments bearing on this matter in regions fairly close to the magnetic poles are therefore highly desirable.

The need for further observations regarding the diurnal and annual variations of atmospheric electricity in high latitudes should be brought to the attention of polar explorers. The accumulated observations from various expeditions indicate that both of these variations follow extremely interesting laws. The diurnal variation of the atmospheric potential gradient progresses in both polar regions according to universal rather than local time; the potential gradient reaches its maximum value about the time when the sun is in the meridian of the north magnetic pole and its minimum value when the sun is in the meridian of the south magnetic pole.

The annual variation of the atmospheric potential gradient seems also to follow the same course during the year in both the Arctic and Antarctic, irrespective of local season. Thus for both polar regions, the potential gradient is on the average greater during the period of the year, October to March, when the earth is nearer to the sun than its mean distance for the year, than during the period, April to September, when the earth is farther from the sun than the mean distance.

The precise laws followed by the variations in the electric conductivity of the atmosphere and of the so-called air-earth current are not definitely known and are of special interest in polar work.

Earth Currents

This is a highly important subject for investigation, particularly in polar regions. The precise relations of these currents with magnetic disturbances, polar lights, and even atmospheric electricity remain to be fully elucidated.

Dr. Coleman, for many years professor of geology in the University of Toronto and now emeritus professor in the same institution, has done much of note in the field of Canadian geology and Pleistocene glaciation. Some of his publications related to the subject matter of the present volume are "The Building of the Torngats" (*Canadian Alpine Journ.*, Vol. 7, 1916); "Northeastern Part of Labrador and New Quebec" (*Canada Geol. Survey Memoir 124*, Ottawa, 1921), "Physiography and Glacial Geology of Gaspé Peninsula, Quebec" (*Canada Geol. Survey Bull. 34*, Ottawa, 1922), and "Ice Ages, Recent and Ancient," New York, 1926. Dr. Coleman has also done field work in Lapland and Spitsbergen.

UNSOLVED GEOLOGICAL PROBLEMS OF ARCTIC AMERICA

A. P. Coleman

FOR more than a century explorers have pushed northwards along the coasts of Greenland or through channels between the islands of the Canadian Arctic Archipelago, and most of the shores of the North American sector of the Arctic Regions have been at least roughly mapped; but many problems of the far north still remain unsolved, and much further work is needed before the geology and geography of these northern lands can be brought into true relation with the better-known areas to the south. Our knowledge of the Arctic lands consists largely of scattered, unrelated facts pieced together from the narratives of men usually untrained as scientific observers and traveling under unfavorable conditions. Many of the older explorers brought back only small contributions to our knowledge of the geology and geography of the regions they had visited.

DEVELOPMENT OF GEOLOGICAL KNOWLEDGE OF ARCTIC AMERICA

The meager results of the earlier observations were brought together in 1887 by G. M. Dawson, who published a map and notes showing what was known of the geology of the northern mainland and of the islands beyond.[1] His map has an appearance of completeness which is deceptive, wide areas of the great islands being geologically colored, though the information on which the coloring was based came mostly from observations and collections made on the coast. When one remembers that the unknown interior of these islands is often hundreds of miles wide it is evident that caution should be exercised in using the map. Dawson's notes show that in many cases the age and distribution of the formations are problematical.

A more trustworthy map was prepared by A. P. Low in 1905.[2] Low was well equipped for the work since he had visited many parts of the region as commander of the cruiser *Neptune*, sent out by the

[1] G. M. Dawson: Notes to Accompany a Geological Map of the Northern Portion of the Dominion of Canada East of the Rocky Mountains, *Ann. Rept. Geol. and Nat. Hist. Survey of Canada*, N. S., Vol. 2 (for 1886), subreport R, Montreal, 1887, with geological map, 1 : 12,700,000, and bibliography. An earlier summary is contained in C. E. De Rance: Arctic Geology, *Nature*, Vol. 11, 1874–1875, pp. 447–449, 467–469, 492–494, 508–509, with geological map, 1 : 17,000,000 (p. 448).

[2] A. P. Low: Report on the Dominion Government Expedition to Hudson Bay and the Arctic Islands on Board the D. G. S. Neptune, 1903–1904, Ottawa, 1906, Chapters 8 and 9 (pp. 183–247), with geological map, 1: 3,168,000.

Canadian Government to patrol the shores of northern Hudson Bay and of the eastern Arctic islands; and he had also landed at some points on the west coast of Greenland. In preparing the map he drew upon the work of Richardson, M'Clintock, Dawson, Bell, and Sverdrup and made use of the paleontological results obtained by Feilden[3] in Ellesmere Island (1875–1876), and of Per Schei,[4] geologist on Sverdrup's expedition in 1898–1902.

It is to be noted that in most parts of Low's map only the coast lines are geologically colored, giving a more correct idea of what is actually known of the million square miles of land comprised in the Arctic Archipelago and Greenland.

J. G. McMillan, geologist of the *Arctic* expedition sent north by the Government of Canada in 1908–1909, has briefly summed up previous work and corrected some statements in regard to the Carboniferous beds of Melville Island.[5]

American, Danish, and Swiss explorers have done excellent work in Greenland, and Arctic Alaska has been largely explored by the U. S. Geological Survey, while Canadian geologists have done reconnaissance work on the western part of the Arctic mainland shore of Canada and in Labrador.

Review of Problems by Geological Periods

It will be convenient to take up the problems of our Arctic sector in historic order, beginning with the oldest formations, advancing through the later ones, and ending with some problems concerning the distribution of living plants and animals.

Special attention will be paid to changes of climate and to features connected with the ice sheets of the past and present.

Pre-Cambrian

Most reports on northern exploration refer to areas of granite and gneiss like the Laurentian of more southern parts of Canada, and there is reason to believe that the Canadian Shield of Suess, with its

[3] H. W. Feilden and C. E. De Rance: Geology of the Coasts of the Arctic Lands Visited by the Late British Expedition under Capt. Sir George Nares, *Quart. Journ. Geol. Soc.*, Vol. 34, 1878, pp. 556–567, with geological map, 1:4,200,000.

C. E. De Rance and H. W. Feilden: On the Geological Structure of the Coasts of Grinnell Land and Hall Basin Visited by the British Arctic Expedition of 1875–6, Appendix 15 to Sir G. S. Nares: Narrative of a Voyage to the Polar Sea, 2 vols., London, 1878.

[4] Per Schei: Summary of Geological Results, *Geogr. Journ.*, Vol. 22, 1903, pp. 56–55; *idem:* Preliminary Account of the Geological Investigations Made During the Second Norwegian Polar Expedition in the "Fram," Appendix 1 to Otto Sverdrup: New Land, 2 vols., New York, 1904.

After Schei's death in 1905 a number of detailed studies were published of the specimens he had brought back. These studies and Schei's own work are summarized in Olaf Holtedahl: Summary of Geological Results, Report of the Second Norwegian Arctic Expedition in the "Fram" 1898–1902, No. 36, Christiania, 1917.

[5] J. G. McMillan: Report of the Geologist of the Arctic Expedition, 1908–09, Appendix No. 10 to J. E. Bernier: Report on the Dominion of Canada Government Expedition to the Arctic Islands and Hudson Strait on Board the D. G. S. Arctic, Ottawa, 1910, with geological map, 1:4,700,000.

peneplained surface, underlies all the later formations; but sedimentary rocks of the early pre-Cambrian are seldom mentioned. Bell describes crystalline limestones like the Grenville series on the south shore of Baffin Island,[6] and the maps give a separate color to the Huronian, but the accompanying descriptions are so brief and vague that the rocks referred to might belong anywhere in the early pre-Cambrian, perhaps in the Timiskaming series, which has proved to be so important in the gold regions of northern Ontario. It would be of much theoretical interest, and perhaps of practical value in opening up the Arctic regions to civilization, if the sediments and basic and acid eruptives of the Keewatin and Timiskaming series, which contain the great ore deposits of Ontario, should be found in Greenland or Baffin Island or Ellesmere Island; and the natural places to look for them would be the parts of those great islands colored as Huronian or Archean on Low's map.

Much more is known of the upper pre-Cambrian (Keweenawan) on the mainland of Arctic Canada, where wide areas of basaltic lavas and of sandstones and conglomerates of that age have attracted attention because they contain native copper, as similar rocks do on the shores of Lake Superior.

The maps of Dawson and Low are unsatisfactory in regard to the Keweenawan, which they include under the same color as the Ordovician and Silurian.

The most promising place for new discoveries of copper ore appears to be about 40 miles northeast of the head of Prince Albert Sound, according to reports of Eskimos to Stefansson and the Canadian Arctic Expedition of 1913–1918.[7] The large masses of native copper reported in this region probably come from outcrops of Keweenawan rocks not yet seen by a white man; and it hardly needs to be pointed out that the development of an important mining region would have far-reaching effects on the exploration of the North American Arctic sector.

Older Paleozoic

The older Paleozoic formations, including the Ordovician, Silurian, and Devonian, usually lie flatly upon the Archean peneplain; and sometimes hard limestones of these ages stand up as tablelands and present lofty cliffs toward the sea. From some of the outcrops many marine fossils have been collected, and it is interesting to note that the fauna is more European than American, suggesting shallow waters

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[6] Robert Bell: Observations on the Geology, Mineralogy, Zoology, and Botany of the Labrador Coast, Hudson's Strait and Bay, *Rept. Geol. and Nat. Hist. Survey of Canada for 1882–83–84*, subreport DD, Montreal, 1884; *idem:* Observations on the Geology, Zoology, and Botany of Hudson's Strait and Bay Made in 1885, *Ann. Rept.* ditto, N. S., Vol. 1 (for 1885), subreport DD, Montreal, 1885.

[7] J. J. O'Neill: The Geology of the Arctic Coast of Canada West of the Kent Peninsula, Report of the Canadian Arctic Expedition, 1913–18, Vol. 11: Geology and Geography, Part A, Ottawa, 1924, p. 54 and map, p. 55.

crossing what are now deep seas. Probably also there were lands joining the New World with the Old in the early Paleozoic.

Some of the Scandinavian geologists have published interesting papers on this subject, but it would lead too far into paleontology to go into details as to their results.

Carboniferous

The Carboniferous rocks which occur on the Parry Islands, Banks Island, and at other points in the Arctic Archipelago present interesting problems as to the distribution and economic importance of the coal seams and also as to climatic conditions at the time of their formation. There are many references to the finding of Carboniferous coal of good quality in the reports of the early explorers, particularly in the Parry Islands; but J. G. McMillan, the latest geologist to visit the region, found little evidence of coal in quantity at some points where earlier reports indicated valuable seams. General conditions are very different from those of the United States and Europe, since only the lower sandstones contain coal beds, while the upper part of the Carboniferous consists of marine limestones.

The indications as to ancient climates are puzzling. On the mainland a tillite found along the Yukon-Alaska border is considered to be of Permo-Carboniferous age and is compared with the tillites of the same age in India and the southern hemisphere;[8] but the few plants reported from the coal-bearing sandstones of the northwestern islands are like those of North American and European coal measures, which are always thought of as belonging to a warm climate. Good collections of the plant remains associated with these Arctic coals should be made to see if they include representatives of the cool-climate *Gangamopteris* flora found with the coals of India, Australia, and South Africa. It is surprising to find warm-climate coal plants ten degrees north of the Arctic Circle while a great ice age was under way in the subtropics of India and the southern continents.

Triassic

Triassic beds are the most widespread of the Mesozoic rocks, forming a broad syncline to the north of the Parry Islands and including Axel Heiberg, the other Sverdrup Islands, and much of the northern part of Ellesmere Island. If the Cape Rawson beds, once considered Cambrian, are Triassic, as is now thought probable, the syncline crosses the north end of Ellesmere Island and touches northern Greenland.

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[8] D. D. Cairnes: The Yukon-Alaska International Boundary Between Porcupine and Yukon Rivers, *Geol. Survey of Canada Memoir 67*, Ottawa, 1914, p. 93.

The fossils obtained from these beds are marine and include ammonites and an ichthyosaurus. It would be of great paleontological interest if land deposits with dinosaur remains should be found, connecting the Mesozoic land reptiles of Europe with those of Alberta in America.

Cretaceous

Cretaceous beds in the Disko region of western Greenland are of terrestrial origin and furnish a group of land plants suggesting warm-temperate conditions in latitudes from 70° to 72°. There are among them genera that include some species which are now tropical or subtropical, such as ferns related to *Gleichenia*, cypresses, magnolias, and even leaves suggesting the breadfruit. The plane tree was very common. The contrast with the present Arctic flora with its low-growing herbs and trailing shrubs is a most startling one.

Seward, in a recent paper on the Cretaceous plant-bearing rocks of western Greenland,[9] suggests that the assemblage of plants indicates a climate like that of southern Europe, and represents Greenland as the region where angiosperms originated. He gives a map showing how they probably migrated to other parts of the northern hemisphere.

There are bewildering problems connected with these rich forests of a warm climate several degrees within the Arctic Circle where polar night prevails for weeks in the winter. The necessary warmth might be provided, perhaps, by a suitably arranged warm current, an enlarged Gulf Stream, impinging on the West Greenland coast, but the winter darkness would imply a very untropical cessation of plant growth for a considerable period every year, perhaps the starting point for the habit acquired by deciduous trees in temperate regions of dropping their leaves in the autumn.

How doubtful many points are in Arctic geology is well shown by the fact that a good paleobotanist like Seward transfers the West Greenland trees to the Cretaceous, though Heer, who first described them and who has been followed in most textbooks of geology, made them Miocene.[10] In the light of Seward's determinations it seems doubtful whether any Tertiary formations occur in our Arctic sector; and probably the so-called Tertiary coal or lignite of Greenland, Ellesmere Island, and Baffin Island is really of Cretaceous age like the coal of Alaska and Alberta. Until more detailed work has been done

[9] A. C. Seward: The Cretaceous Plant-Bearing Rocks of Western Greenland, *Philos. Trans. Royal Soc. of London*, Ser. B, Vol. 215, 1926, pp. 57–175.

[10] Oswald Heer: Om de miocena växter som den svenska expeditionen 1870 hemfört från Grönland, *Öfversigt af K. Svenska Vetenskaps.-Akad. Förh.*, Vol. 30, 1873, No. 10, pp. 5–12; *idem:* Nachträge zur miocänen Flora Grönlands, enthaltend die von der Schwedischen Expedition im Sommer 1870 gesammelten Pflanzen, *K. Svenska Vetenskaps.-Akad. Handl.*, Vol. 13, No. 2, 1874, also in his "Flora fossilis arctica," Vol. 3, Part 3, Zurich, 1874. See also that work, Vols. 6 and 7, 1882–1883, and *Meddelelser om Grönland*, Vol. 5 and Suppl., Copenhagen, 1883.

in the study of these coal-bearing beds, which are quite widely scattered over the Arctic islands, it may, however, be unsafe to assume that all of them are Mesozoic; and it is desirable, in order to determine their age, that collections of fossils should be made from as many of these localities as possible.

Tertiary

While formations containing records of events in our Arctic sector during the Tertiary seem to be lacking, there is one bit of indirect evidence bearing on the subject. Toward the end of the Pliocene and the beginning of the Pleistocene the United States and southern Canada were inhabited by many species of splendid mammals, some of which probably developed in North or South America; but others, including the mammoth and mastodon, a rhinoceros, and some large carnivores, came from Asia or perhaps Africa.[11]

By what route did they reach North America?

One naturally suggests a land connection between Kamchatka and Alaska where the shallow Bering Strait now separates the two continents, and, if there was one, there must also have been a Pliocene climate permitting the growth of sufficient vegetation to support the herbivores. It is to be hoped that remains of these Pliocene migrants will be found somewhere along their line of march to give an idea of the route they followed.

Pleistocene

With the on-coming of the Glacial Period much of the Arctic territory became covered with glaciers, but much remained free from ice, as in the interior of Alaska and the Yukon Territory of Canada, which were not glaciated. The botanist Fernald believes that large parts of the far north were ice-free and that the ancestors of the present Arctic plants survived the intense cold and were ready to colonize the region to the south when the great Keewatin and Labrador ice sheets, which covered most of Canada and part of the Northeastern States, departed.[12]

There is much need for a careful survey of the Arctic glacial deposits to show what parts remained unglaciated when more southern regions of North America were buried under thousands of feet of ice; and one would be glad also to discover the causes which account for such a reversal of present conditions.

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[11] O. P. Hay: The Pleistocene of North America and Its Vertebrated Animals from the States East of the Mississippi River and from the Canadian Provinces East of Longitude 95°, *Carnegie Instn. Publ. No. 322*, Washington, 1923.

[12] M. L. Fernald: Persistence of Plants in Unglaciated Areas of Boreal America, *Memoirs Gray Herbarium of Harvard Univ.*, No. 2, Cambridge, 1925 (also as *Memoirs Amer. Acad. of Arts and Sci.*, Vol. 15, 1925, No. 3, pp. 237–342).

The question of interglacial periods in the Arctic lands demands attention. In the glaciated regions south of the Arctic Circle there is good proof of at least two advances of the ice sheets with a long and mild interglacial time;[13] but in the Arctic sector no interglacial beds have been disclosed. Great oscillations of climate are known to have taken place during the Pleistocene in temperate latitudes; and it is altogether likely that evidence of similar changes will be found north of the Arctic Circle when carefully looked for.

Surviving Ice Caps

There is need, also, for a study of the still surviving ice caps. The great ice cap of Greenland has been crossed by various expeditions, and a good deal is known of its surface slopes and of its meteorology; but as the nearest existing analogue of the Pleistocene ice sheets of Europe and North America it still deserves and is receiving earnest study.[14] Several problems arise in connection with it. Do cyclonic storms ever displace for a time the anticyclone and pile up a heavy snowfall, unlike conditions in Antarctica, where the ice sheet is thin and apparently in process of dilapidation?

Was the Greenland ice cap formed early in the Pleistocene and has it survived ever since? Or is it the last of a series of ice sheets beginning with the Cordilleran, going on to the Keewatin center and then to the Labradorean, and finally developing in Greenland? We know that it was once larger than it is now and covered nearly the whole of the great island. Did this ice cap disappear in the interglacial time, or was it merely diminished in area and thickness?

Information in regard to these points may be difficult to obtain but would be very welcome to the Pleistocene geologist.

In northern Labrador there are among the Torngat Mountains and tablelands some areas of stagnant ice, probably remnants of former ice caps; but only a few small active glaciers survive, and these are of the cirque type and occur only near the coast where drifting snow accumulates.[15] It is probable that the ice caps of Baffin, Bylot, Devon, and Ellesmere Islands include every stage between the tiny snowdrift glaciers of the Torngats and the tremendous ice engine of the Greenland cap. A comparative study of present-day glaciation in the region would certainly give interesting results.

One would expect that the highlands of northeastern Labrador,

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[13] A. P. Coleman: Ice Ages, Recent and Ancient, New York, 1926, pp. 20–31.

[14] See C. F. Brooks: The Ice Sheet of Central Greenland: A Review of the Work of the Swiss Greenland Expedition, *Geogr. Rev.*, Vol. 13, 1923, pp. 445–453 (for the title of the expedition's report, see, above, p. 55, footnote 6).

Lauge Koch: Some New Features in the Physiography and Geology of Greenland, *Journ. of Geol.*, Vol. 31, 1923, pp. 42–65.

[15] A. P. Coleman: Northeastern Part of Labrador and New Quebec, *Geol. Survey of Canada Memoir 124*, Ottawa, 1921.

rising 4000 or 5000 feet above the open Atlantic, with an average temperature of 27.1° F. and a very low maximum in the two summer months (44.6° in July and 46.9° in August at sea level), would be heavily glaciated as compared with Ellesmere Island, which is screened from moisture-bearing winds by Greenland and the floe ice of Baffin Bay; but the reverse is the case.

Problems in Structural Geology

Finally there are interesting but difficult problems to be solved in regard to the origin and relationship of the polar lands and seas.

Why is it that the north pole is situated in a fairly deep ocean almost completely surrounded by the greatest land areas of the globe, while the south pole is on a lofty tableland in the heart of a continent which is surrounded by the world's greatest oceans? The two polar regions are in exact contrast with each other.

Are the three northern Archean shields the blunted corners of an indistinct tetrahedron, and is the Antarctic Continent the fourth, implying an ancient collapse of the earth's primal crust; or are these contrasts accidental?

The structural geologist has reason to ponder over these polar contrasts, which, perhaps, will never be satisfactorily accounted for.

The extraordinary arrangements of land and sea in the European and North American sectors of the Arctic Regions have often aroused the interest of geologists and geographers, and it has been pointed out that the land areas, especially Labrador, the Archipelago, and Greenland, if suitably shifted, would make a compact continental territory, fitting together like the blocks of a puzzle. Is this only apparent, or were these lands once continuous and have they since then drifted apart? Very interesting theories have been proposed to account for these relations.

Taylor in 1909 suggested that the polar lands were once parts of North America, but that the continent began to drift toward the southwest, thrusting up the Cordillera on its way and leaving behind blocks of the crust at various distances.[16]

A few years later Wegener proposed an elaborate theory of the drift of continents, his starting point being an apparent shift of longitude within historic times in Greenland. His speculations cover all the continents and are supported by attempted explanations of glaciation in Permo-Carboniferous and Pleistocene times.[17] From the point of view of the glacialist his conclusions are unacceptable; but

[16] F. B. Taylor: Bearing of the Tertiary Mountain Belt on the Origin of the Earth's Plan, *Bull. Geol. Soc. of Amer.*, Vol. 21, 1910, pp. 179–226.

[17] Alfred Wegener: Die Entstehung der Kontinente und Ozeane, 3rd edit., Brunswick, 1922 (1st edit., 1915; first publication in *idem:* Die Entstehung der Kontinente, *Petermanns Mitt.*, Vol. 58, Part I, 1912, pp. 185–195, 253–256, and 305–309).

many other geologists, notably Daly, support his theory with some modifications.

In a few years a redetermination of the Greenland longitudes by accurate radio methods will probably settle whether that greatest of islands is now moving or not.

There are a number of facts in the distribution of polar plants and animals that strongly suggest former connections between the Arctic lands. The floras of Arctic America and of Arctic Europe include some common species and also many species which are only slightly different from one another on the two sides of the North Atlantic. The plants of Spitsbergen are very like those of Arctic America and Arctic Europe, and all three lands have animals which are closely related. For example the American caribou differs so little from the Spitsbergen and European reindeer that they must have originated in the same area and from the same ancestors.

But the separation of the Arctic lands can be accounted for in other ways than by the drift of continents. De Geer has demonstrated that a great block of the earth's crust has dropped between Scandinavia and Greenland, the sinking mass forcing up basaltic lavas in various places;[18] and Lauge Koch has shown that a continuation of this depression, also accompanied by basic lavas, crosses south-central Greenland.[19]

It may be, therefore, that the northern islands have been separated from one another and from North America by the settling down of slices of the earth's crust, like rift valleys, the sinking going so far as to allow the sea to enter.

It seems improbable, however, that all of the numerous narrow channels between the islands and all of the innumerable fiords have been formed by the dropping of blocks, though De Geer seems to support this view. It is more natural to suppose that the smaller ones were river valleys deeply cut at a time when the land stood higher, scoured out into U shapes by glaciers, and then invaded by the rising sea.

The fact must not be overlooked that in many places the sea once stood 500 or 600 feet higher than now, as shown by marine beaches up to that level. Similar beaches of about the same height along the St. Lawrence are generally accounted for by the rebound of the land after the removal of ice during an interglacial period or at the close of the Ice Age.[20]

It may prove difficult to decide in a given case whether changes of level were due to epeirogenic readjustments of slices of the earth's

[18] Gerard De Geer: Kontinentale Niveauänderungen im Norden Europas, *Compte Rendu XIe Session Congr. Géol. Internatl.* (*Stockholm 1910*), Vol. 2, Stockholm, 1912, pp. 849–860, with map, 1:8,000,000.

[19] *op. cit.*, pp. 59–60.

[20] A. P. Coleman: The Pleistocene of Newfoundland, *Journ. of Geol.*, Vol. 34, 1926, pp. 193–223; reference on p. 208.

crust or to the loading or unloading of a region by the formation or removal of an ice sheet. The whole question of changes of level and the splitting up of what was once a continental mass of land joining Europe and America is one of great interest to the physiographer, and any light thrown upon it will be most welcome to geologists and geographers.

Are There Further Islands in the Arctic Archipelago?

Explorers naturally ask whether Stefansson completed our knowledge of the northern lands a few years ago by his discovery of a new group of islands, north of the long-known Parry Islands, or whether there may not be others still unknown. It seems to the present writer improbable that islands of importance remain undiscovered; but, if there are such, they probably rise from the continental shelf and not from the deep sea toward the pole.

Dr. Tolmachev, former curator of the Geological Museum of the Academy of Sciences, Leningrad, has devoted himself mainly to the geology of Arctic Eurasia. In 1905 he was leader of the Khatanga expedition of the Russian Geographical Society, on which valuable information was obtained regarding the drainage and geology of the Khatanga region (see "Addition to the Geographical and Geological Map in the Region Visited by the Khatanga Expedition in the Year 1905" [in Russian] (*Izv. Imp. Russ. Geogr. Obshchestva*, Vol. 48, 1912, Petrograd, 1915); "New Data on the Geography of Northern Siberia" [in Russian] (*Izv. Imp. Akad. Nauk*, Ser. 6, Vol. 4, St. Petersburg, 1910). In 1909 he led an expedition to explore the Arctic coast of Siberia from the mouth of the Kolyma to Bering Strait. On this expedition he has published "Along the Chukchi Coast of the Arctic Sea: Preliminary Report of the Director of the Expedition for the Exploration of the Coast of the Arctic Sea from the Mouth of the Kolyma to Bering Strait, Organized in 1909 by the Merchant Marine Section of the Ministry of Commerce and Industry" [in Russian], St. Petersburg, 1911. He is also the author of the section on geology in "Aziatskaya Rossiya" [in Russian], St. Petersburg, 1914, and "The Geology of Wrangel and Herald Islands" [in Russian] (*Izv. Imp. Akad. Nauk.*, Sèr. 6, Vol. 6, 1912). From 1914 to 1919 Dr. Tolmachev was secretary of the Permanent Polar Commission of the Russian Academy of Sciences and in 1919 president of a commission for the investigation and practical utilization of the Russian North. He is now on the staff of the Carnegie Museum of Pittsburgh and a member of the faculty of the University of Pittsburgh.

THE GEOLOGY OF ARCTIC EURASIA AND ITS UNSOLVED PROBLEMS[1]

I. P. Tolmachev

The Present Status of Knowledge

ARCTIC Eurasia is one of the least-known parts of the earth's surface whether we consider its geology or its topography. Large sections of it have not been surveyed at all or in sketchy reconnaissance only. Even the Arctic shore line cannot be considered well established, especially in the Asiatic sector, where every new expedition makes important corrections upon the maps. Geologists have been able to examine the rocks only at widely separated localities and often under conditions which severely limited their observations. Many geological data were gathered by explorers without geological training or by uneducated hunters and traders.

Unrelated and sometimes inexact data were often summarized and interpreted by scientists unfamiliar with Arctic geology and influ-

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[1] On the general subject of this paper the reader may also wish to consult W. A. Obrutschew (V. A. Obruchev): Geologie von Sibirien (in series: Fortschritte der Geologie und Palaeontologie, Vol. 15), Berlin, 1926, with references to the literature. Certain aspects of Eurasian geology are discussed in F. B. Taylor: Greater Asia and Isostasy, *Amer. Journ. of Sci.*, Ser. 5, Vol. 12, 1926, pp. 47–67, and Émile Argand: La tectonique de l'Asie, *Compte Rendu de la XIII^e Session du Congrès Géol. Internatl. en Belgique, 1922*, Vol. 1, Liége, 1924, pp. 171–372. R. L. Samoilowitsch (Samoilovich): Geologische Aufgaben der Arktisforschung, in "Internatl. Studiengesell. zur Erforschung der Arktis mit dem Luftschiff: Verhandl. der 1. ordentl. Versammlung in Berlin, 9.–13. Nov. 1926," *Petermanns Mitt. Ergänzungsheft No. 191*, 1927, pp. 30–42, lays special emphasis on Eurasia.

It should be explicitly stated, however, that the greater part of the data and conclusions of the present paper is founded on the personal observations of the writer during his travels in northern Asia and Europe, many of which observations have not yet been published.

Of those that have been published the following may be mentioned, together with two papers by others that deal with an expedition under the leadership of the writer:

I. P. Tolmachev: (The additions to the geographical and geological map in the region visited by the Khatanga Expedition in the year 1905), Petrograd, 1915.

idem: Novyya dannyya po geografii Syevernoi Sibiri (New data on the geography of northern Siberia), *Izvyestiya Imp. Akad. Nauk*, Ser. 6, Vol. 4, St. Petersburg, 1910, pp. 989–998.

M. Kozhevnikov: Marshrutaya semka basseina ryeki Khatangi v 1905 godu (Route survey in the basin of the Khatanga River in the year 1905), *Zapiski Voenno-Topogr. Upravl. Glavn. Upravl. Generaln. Shtaba*, Vol. 64, St. Petersburg, 1910, pp. 77–100, with map in 1:4,200,000.

Helge Backlund: Travaux et résultats de l'expédition de la Khatanga (1905), *La Géographie*, Vol. 17, 1908, pp. 117–124, with map in 1:4,200,000.

I. P. Tolmachev: (Along the Chukchi coast of the Arctic Sea: Preliminary report of the director of the Expedition for the Exploration of the Coast of the Arctic Sea from the mouth of the Kolyma to Bering Strait, organized in 1909 by the Merchant Marine Section of the Ministry of Commerce and Industry), 117 pp., with map in 1:4,200,000, Ministry of Commerce and Industry, St. Petersburg, 1911.

idem: Formy poverkhnosti i stroenie zemnoi kory v predyelakh Zapadnoi Sibiri (Surface configuration and crustal structure within the limits of Western Siberia), Chapter 1, pp. 1–86, of Vol. 16 of "Rossiya: Polnoe geograficheskoe opsisanie nashego otechestva" (Full geographical description of our country), edit. by V. P. Semenov-Tyan Shanski, St. Petersburg, 1907.

idem: Geologicheskoe stroenie (Geological structure). Pp. 104–120 of Vol. 2 of "Aziatskaya Rossiya," 3 text vols. and an atlas, Bureau of Internal Colonization of the Dept. of Land Organization and Agric., St. Petersburg, 1914.—EDIT. NOTE.

enced by the geological conditions of other regions, chiefly Central Europe. Thus the meager and not always exact data on the geology of Arctic Eurasia suffered at times from fundamentally incorrect interpretations.

The Rôle of the Positive and Negative Crustal Elements in the Eurasian Arctic

The Arctic shore of Eurasia belongs to the Atlantic type, i. e. the structural lines of the earth's crust and the trend of the shore are divergent. In general the shore line follows the parallels, and the structural or tectonic lines run with the meridians. In Arctic Europe the structural trend northwest-southeast perhaps is more important than the strictly meridional one. Different geologic formations of Arctic Eurasia, ranging from the Archeozoic and Proterozoic up to Recent, are clearly dependent upon this structure for their geographical distribution.

Arctic Eurasia is composed of seven positive crustal elements of various sizes separated from each other by negative elements of equal geologic importance which in their distribution follow the trend of the structural lines just mentioned (Fig. 1). The positive elements represent what might be called the steadfast regions, those that have persisted throughout the greater part of geological time as more or less firm units. They are in a sense parental elements, composed of Archeozoic and Proterozoic rocks and marine Lower Paleozoic strata not younger than the Upper Silurian. Since that time they have been oldlands; that is, the sea has never again overflowed them though they have been the scene of continental deposition or of basaltic intrusion and overflow. Long periods of still-stand of these oldlands have afforded erosional agencies an opportunity to dissect and degrade their surfaces, giving a certain topographical uniformity to the landscape; and thus its geomorphology is to a high degree dependent upon the work of erosion. All the succeeding stratigraphic history of Arctic Eurasia, that is the history of ancient seas, is recorded in the negative elements of the earth's crust located between the positive elements, or oldlands. Such negative elements are partly geosynclinal in structure and in long succession were overflowed by different ancient seas, beginning with the Devonian. It might be important also to remember that the disturbances that affected the earth's crust during the greater part of geological time had their most marked structural manifestations on the more or less rigid and unyielding borders of the oldlands. These borders were repeatedly the scene of geological changes of a fairly intense type—changes in which the overlapping sedimentaries, originally deposited within geosynclines, were involved, and which produced some of the marginal relief visible today. Thus, unlike the oldlands, the intermediate regions exhibit landforms dependent not only upon erosion, but also upon geological structure. The mutual relations of the positive and negative elements, the resistance produced by the oldlands, are better expressed where the latter are of large dimensions. Smaller oldlands were overlapped and overthrust by the younger elements originating in the geosynclines, even to the extent of being buried beneath or among the newer folds. Their true geological

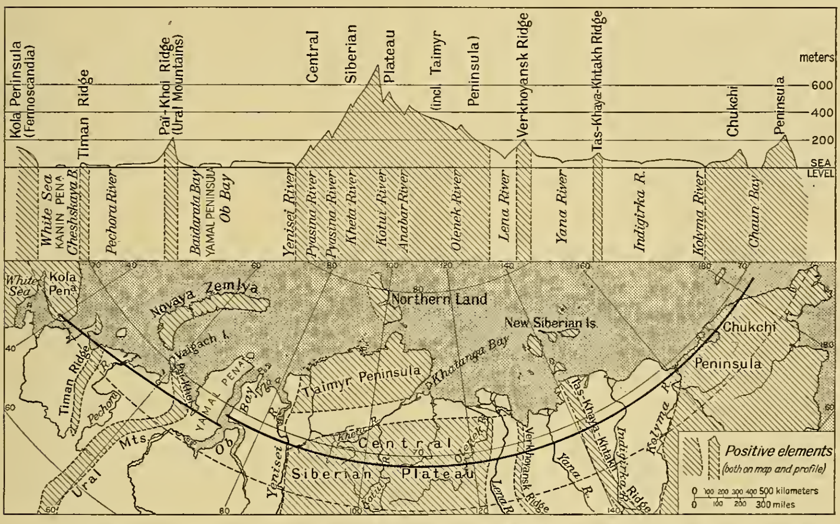

Fig. 1—Sketch profile and map showing the relation of the positive and negative crustal elements in Arctic Eurasia. Horizontal scale of profile and map, 1:54,000,000; vertical exaggeration of profile about 1000 times. In order to make graphic the conceptions here presented, the positive elements are emphasized at the expense of the negative.

nature could be easily overlooked in such a case, especially when the process was repeated. Besides that, owing to their small dimensions such oldlands did not offer sufficient rigidity and resistance to maintain their integrity but gave way under lateral pressure.

The oldlands of continental dimensions cannot be considered absolutely immobile—as uplifted in some geological time and remaining in the same position ever since. They were repeatedly uplifted or depressed, but with the uplifts finally exceeding the depressions as compared with the intermediate (i. e. negative) sections of the earth's crust; hence the appellation, "positive" and "negative" elements. But such uplifts are of a broad regional character and of a totally different class from the detailed and intimate plications, crumplings, overthrusts, and the like, traces of which may be found in old strata within the different parts of the positive elements. Only on the borders of the positive elements were the overlapping and overthrusting of younger folds carried so far as to exceed the oldlands in height, and even this was a rare occurrence.

The deformations of both terrestrial and marine deposits laid down in the depressions between the positive elements reveal much of that long history which was lost through the excessive erosion upon the surfaces of the oldlands, or positive elements. Again and again the sea invaded certain of the negative elements and submerged them. The retreat of the sea at last brought into view the surfaces of the negative elements. This makes it possible now to see both positive and negative elements in their full geographical distribution and structural relationship. It enables us to trace the history of the landscape from one geological age to another and to understand topographic and other relations that are as important geographically as they are geologically, because they give the history of the terrain upon which, in turn, the history of life forms was worked out. They show also the relations of the Arctic islands to the continent, as well as the relations of mountains or plateaus to plains or of coast line to river systems and old geological lines of disturbance.

The Three Major Oldlands, or Positive Elements

The most typical and largest old regions are (1) Fennoscandia (Finland and Scandinavia, in general) at the western end of Arctic Eurasia, (2) the Chukchi Peninsula at the extreme eastern end (between the Kolyma River and Bering Strait), and (3) the Central Siberian Plateau (including the Taimyr Peninsula) located in the middle part of northern Eurasia (Fig. 1).

Fennoscandia is composed of a variety of gneisses, slates, and granites. Since remnants of fossil-bearing Cambrian and Ordovician sediments have been found in some localities partly preserved as structural inliers in the granites, the Lower Paleozoic sediments of which they form a part must be considered as once more extensive. They formed in fact a cover to the older granites, slates, and gneisses which were the old foundation rock, and are now removed from the surface of the Scandinavian Peninsula because of subsequent strong erosion.

The Central Siberian Plateau is composed chiefly of Cambrian, Ordovician, and Silurian strata. Pre-Cambrian rocks, represented by gneisses, granites, and a variety of slates (the slates are widely known on the Taimyr Peninsula), are here more extensively covered by Paleozoic sedimentary slates, and these are usually but little disturbed. Some well-marked but local folds have been produced by intrusions of basalt and are of laccolithic origin. The same basalts, in effusive form, cover many thousands of square miles of the surface of the plateau and form one of the largest known lava fields in the world. Their eruption was going on, probably, during the whole Upper Paleozoic and was continued into the Mesozoic, as coal-bearing Upper

Paleozoic strata, also found on the surface of the plateau, are often traversed by basalt dikes.

The Chukchi Peninsula is built up of a variety of slates, limestones, and igneous rocks. Among the latter, the most important are granite, porphyry, basalt, etc. Because no fossils have yet been discovered on the peninsula, the age of the sedimentary rocks is not positively known, but in the western section of the peninsula they have been considered to be Pre-Devonian, thus corresponding to the Lower Paleozoic deposits of the Central Siberian Plateau. Later investigation may show that the geological structure of the Chukchi Peninsula is more complicated than this description would suggest and that a part of the slates as well as the limestones, especially in the eastern part of the peninsula, may be of younger age and involved in the relatively youthful folds of the Pacific border, piled up or pushed over upon the oldland.

The Four Minor Oldlands

Between these principal oldlands are located others of the same geological structure and origin but of smaller dimensions (Fig. 1).

On the border of Europe and Asia is located the linear belt of the Ural Mountains, the Arctic part of which is known as Paï-Khoi Ridge. It includes a number of oldland masses composed of granites, syenites, and other igneous rocks, as well as gneisses of different origin, together with slates and limestones. As some of the latter probably belong to the Silurian and Cambrian, the geological structure of the Ural Mountains closely corresponds to that of the oldlands, considered above, with this difference, that, owing to the small dimensions of the old masses, as compared with the overlapping and overthrust folds of Devonian, Carboniferous, and Permian strata, it appears more complicated.

Timan Ridge, located in the northern part of European Russia west of the Ural Mountains, has the same geological structure as the oldland just discussed and is usually considered a small northwestern branch of the Ural structural region. It runs in a northwest-southeast direction, or parallel to the Paï-Khoi, and, like the Urals, is reflected in the structure of Novaya Zemlya. The northeastern, or Arctic, shore of the Scandinavian Peninsula trends in the same direction. The triangular area between both ridges is very little known, but a few outcrops of old formations have been found here as well.

A few oldland masses are known near the Arctic shore between the Yana and the Indigirka. Southwards they continue as a large, very little known ridge, Tas-Khaya-Khtakh, with granites and gneisses within its central part.

Still less known is the Verkhoyansk Ridge, situated between the Lena and Yana Rivers. It is composed partly of folded Cretaceous strata and is therefore a mountain of comparatively recent origin, in contrast to the pre-Cambrian and Paleozoic rocks of the oldlands. But since granites and gneisses have been found in the central part of the ridge, and Cambrian and Silurian sedimentaries in its northern part (Khara-Ulakh Mountains), the Verkhoyansk Ridge must be to some extent of ancient origin.

The Formation of These Oldlands

Thus Arctic Eurasia is characterized by the presence of seven oldland masses ranging in size from continental dimensions to comparatively small islands or groups of islands. While they vary in size their geological differences are moderate and secondary. In the larger continental land masses the old geological structure is perfectly clear. Confusion is possible only near the borders, upon which may be piled newer formations, but these borders represent only small outer parts bordering a central oldland. In smaller insular masses sometimes only an insignificant part of the surface remains unaffected by the later border structures. The mountains of this group of smaller oldlands are composed chiefly of younger strata rather than those of the oldland, and their primary origin is often obscure. Such is the case with the Verkhoyansk Ridge and to a smaller extent with the Ural and Timan Ridges. In many cases topographical and geological contrasts among the oldlands have been produced by differential erosion, which, for example, was more extensive in Fennoscandia than on the Central Siberian Plateau. All the oldlands are well reflected in the relief of Arctic Eurasia, as they determine the location and features of the ridges and high plateaus. A remarkable symmetry in their distribution has also to be noticed. They form the projecting peninsulas and related offshore islands, all of which have close geological connection with the mainland and originally were parts of it. The best examples of this connection are: Vaigach and Novaya Zemlya north of the Ural Mountains, Northern Land (Nicholas II Land) north of Taimyr Peninsula, and the New Siberian Islands north of the Tas-Khaya-Khtakh Mountains. Even in the case of the islands that are built up of glacial drift, the drift has probably been deposited around a nucleus of bed rock.

All these masses are parts of the same geological body, of the old Eurasian continent, separated through the sinking of intermediate sections along zones of faulting. The projecting land masses are horsts, or positive elements; the sunken tracts are graben, or negative elements. This is inferred from the distribution of younger strata within graben on the same level or lower than that of the older strata in the oldlands, from the occurrence of old eruptions on the borders of the horsts, and from other evidence.

As no Devonian is known on the top of the horsts, only between them, and as the youngest marine strata on the surface of the horsts are Silurian, the deformative agencies that disintegrated the old continent must be referred to the end of the Silurian, or to early Devonian, more probably to the latter.

The Geological History of the Marine Deposits

Since that time the stratigraphic history of Arctic Eurasia has been recorded chiefly in the seas between the horsts. Different transgressions, although not always known in detail, appear to have followed the direction of the Urals in Europe and probably of Verkhoyansk Ridge in Asia. The communication of corresponding American and Eurasian Upper Paleozoic and Mesozoic seas through the Arctic and the migration of their faunas were guided by these well-expressed geosynclines. These great primary structural features also explain the connection between Arctic and Mediterranean faunas. The Paleozoic strata near the horsts, or positive elements, are always folded, partly owing to the resistance they offered as unmovable masses, partly because of continuing sinking within the graben and especially in the major depressions, or geosynclines.

A strong diastrophism or crustal deformation again took place between the Upper Paleozoic and the Lower Mesozoic, with its maximum at the Upper Jurassic. It is quite possible that the dismembering of old Arctic Eurasia into horsts and grabens referred to above not only had taken place during the Lower Paleozoic but continued in the Mesozoic as well.

The Mesozoic diastrophism separated the present Taimyr Peninsula from the Central Siberian Plateau with a broad sunken strait which existed till the latest post-Pliocene. Mesozoic strata (Triassic, Jurassic, Cretaceous), widely distributed in northern Asia, very distinctly indicate and delineate tracts sunken in the Mesozoic. In the Verkhoyansk Ridge they are folded, but otherwise they are here but little disturbed. Concerning this ridge it is necessary to notice that its folding probably has been continued till very recent time, geologically speaking.

Near the Ural Mountains an extensive Mesozoic transgression, or invasion of the sea, followed a regional depression now marked by Mesozoic deposits. At the eastern end of Arctic Eurasia Mesozoic sediments of the same type are known in the Anadyr region.

The Upper Jurassic faunas of the Arctic belong to the Boreal, or Russian, type, the distinction being dependent, in the opinion of some students, upon climatic differences of the period. The Lower Cretaceous faunas, immediately following the Jurassic, have also a Boreal character.

During the Tertiary (Eocene) period the sea overflowed large areas of Western Siberia along the eastern side of the Ural Mountains, where it probably communicated with the Arctic sea. Another Tertiary (Miocene) sea has left its sediments with marine fauna of Pacific type in the eastern part of Arctic Eurasia, in the Anadvr region.

Geological History of the Continental Deposits

The continental geological history of Arctic Eurasia, where recorded by continental deposits, is not less varied than the marine history. The presence of land during the Lower Paleozoic is suggested by the lithological character of the sedimentary rocks, though the greatest part of old Eurasia was permanently covered with sea. The old horsts, dry land since the Silurian, usually offer very scanty records of their long continental duration. In many cases their surface is composed of the oldest primary bed rock, not always covered even with a thin layer of soil.

Abundant continental deposits are known in Arctic Eurasia, starting from the Upper Paleozoic only. Coal-bearing deposits of that period, discovered in the northern part of the Central Siberian Plateau (on the Yenisei, Khatanga, Anabar, Olenek Rivers), bear witness to a comparatively warm, humid climate favorable to the development of an exuberant flora of Gondwana character, considered by geologists as Upper Carboniferous or Permian. *Glossopteris* is an especially typical plant of this flora, which is therefore often known as *Glossopteris* flora.

The Upper Permian continental deposits of northern Europe record a rather dry and often hot climate corresponding perhaps to that of recent steppes like those of Turkestan today. The Permian strata of northern Europe are widely known on account of a rich and distinctive amphibian and reptilian fauna found within old river deposits. Among reptilians a herbivorous *Pareiasaurus* and carnivorous *Inostranzewia* are the most conspicuous members. Some of these old reptilians had a few characters of organization common with amphibians. Others were related to Triassic reptilians and had even some of the ancestral trends of mammals.

Triassic land must have had a very great extension in Eurasia, but Triassic deposits with a land flora are known only in a few isolated localities on the islands of the Arctic Sea.

Jurassic continental strata with a rich flora, often also containing workable seams of good coal, have been found in many places in Arctic Eurasia. Especially interesting are the localities on the islands of the Arctic Sea—Spitsbergen, Franz Josef Land, the New Siberian Islands, and others. All of them are remnants of a continuous land of immense area which was once connected with corresponding land masses of continental Arctic Eurasia and North America. It was dismembered by a great diastrophic movement, which greatly contributed to the origin of the Arctic Sea in its present outline and form, and isolated masses were mostly destroyed by waves, small islands perhaps being preserved only under special conditions, as, for example, where they enjoyed the protection of a basalt cover. Fossil floras in all these distant localities are very similar to each other and to the corresponding floras of southern latitudes—a usual condition for Middle Jurassic floras, which were surprisingly cosmopolitan. This flora consisted of rushes, herbaceous plants, tree ferns, cycads, gingkoes, and conifers, the descendants of which are now found mainly in southern lands. The cycads were especially abundant and diversified in the Jurassic, the latter being often called the Age of Cycads.

Cretaceous continental deposits are also known on the Arctic islands and on the Arctic shore of Asia. They have a smaller distributional range than the Jurassic, with which they are often immediately connected and from which they are perhaps not always well differentiated. The Cretaceous flora here was similar to the Jurassic flora as well, though more specialized.

Remnants of Tertiary land with fossil floras are known on the New Siberian Islands, on the neighboring coasts of the mainland, and in the Anadyr region. Although they are of early Tertiary (Eocene) age they have been so well preserved at the first locality that the fossil tree trunks for a long time were considered recent driftwood and cliffs were christened "Wood Hills." All these localities, like those of the Jurassic, are disconnected parts of a large land of circumpolar extension, as the same rich fossil flora is known in North America and in Greenland. The dismembering of this Tertiary land concluded, probably, the shaping of the present Arctic Sea, at least in its most essential form.

Post-Tertiary History

In post-Tertiary time Arctic Eurasia suffered great oscillations. The present Arctic shore, from the Scandinavian Peninsula on the west to the Lena River on the east, including offshore islands, is covered with sediments of Boreal transgression with a marine fauna similar to the Recent one of the Arctic Sea. It bears witness to a broad regional subsidence and a succeeding emergence. The latter was more marked in Europe than in Asia, as the elevation at which Boreal shells, *Yoldia*, *Cyprina*, *Tellina*, *Mytilus*, etc., are now found gradually decreases towards the east. On the continent they are not known east of the Lena River but have been found farther east in the New Siberian Islands. In fact near the eastern end of their distribution the sediments of Boreal transgression are confined chiefly to river valleys. In the most eastern isolated localities they are known only in the Anadyr region, where they are of a distinctive Pacific type.

In Europe a Boreal transgression covered old moraines of the Scandinavian ice sheet, and in the Scandinavian region deposits marking the same transgressions are covered by moraines of the last glaciation. Old moraines cover the whole of northern Europe and the northwestern corner of Asia. The northern Ural region was probably an independent glacial center. Old moraines built up Kolguev Island and probably Little Taimyr Island (Tsesarevich Alexei Island). The largest part of Arctic Asia did not have glaciers of a general Ice Age, although in different parts of it there are indisputable records of former local glaciation. The Ice Age phenomena did not acquire the same importance as in Europe chiefly on account of the low relief of northern Asia. The glacial deposits have therefore no importance here, and continental drift is brought out chiefly by rivers, deposited in lakes or more usually in the sea, and accumulated by waves near the shore. Oscillations of the seashore have exposed large tracts of shallow sea bottom with the result that huge areas of Arctic Eurasia are composed of reworked drift.

The time preceding the Boreal transgression, and more or less corresponding to the greatest glaciation in Europe, in Arctic Asia was the time of the highest emergence of the land or the deepest sinking of the sea. During that time the great Siberian rivers had built up huge deltas and accumulated abundant drift along the shore. At that time the Yamal Peninsula probably originated; the New Siberian Islands (then a portion of the mainland) were constructed, completely or partially, of drift; and Bering Strait did not exist at all, northeastern Asia and northwestern North America being joined together. After that emergence a subsidence followed and was accompanied by Boreal transgression. A new emergence has brought marine sediments of Boreal type above the level of the sea.

At the present time most of the shores of Arctic Eurasia are subsiding, but in some sections they are rising and in others standing still. The recent alterations of the shore line are therefore dependent upon the movement of the land itself; they are not an effect of the oscillation of the sea. The subsidence of the shore is proved here by the overflowing of the lower parts of river valleys and the consequent transformation of them into estuaries; by the presence of river channels on the bottom of the sea; by the discovery of rock ice below the sea level; by the separation of islands, composed of drift, from the mainland, a part of which they were but recently.

Frozen Soil and Ground Ice

The ground of Arctic Eurasia is usually frozen many tens and even some hundreds of feet deep. During the summer it thaws only 1 to 3 feet down. Frozen ground gives Arctic Eurasia its typical appearance and in summer turns the tundras into swamps covered with many small lakes. This effect is brought about in spite of the fact that the climate is often very dry. The amount of precipitation in northeastern Asia corresponds, for example, very closely to that of the Transcaspian region with its dry steppes and desolate deserts. The frozen ground in many places contains small lenticles and even large layers of ground ice, called also rock ice. Many theories have been devised to explain this phenomenon. Each one serves to explain some particular case, but none has a universal application. Undoubtedly the origin of rock ice is dependent upon climatic conditions, as the origin of frozen ground itself, and this form of ice can develop only on the land. Present climatic conditions have existed in the country for a long time, therefore rock ice may be very old in some outcrops, comparatively very young in others. For example, some outcrops of ice on the New Siberian Islands are covered with sediments of the Boreal transgression. Frozen ground has attained its greatest development in northeastern Asia, where at Yakutsk it has been discovered, in a pit, extending down 382 feet from the surface. Perhaps it may be brought into connection with the absence of Boreal transgression in eastern Asia as well as with the absence of a glacial cover, as mentioned above. Thus for a long time it had uninterrupted conditions of extremely severe climate as at present.

Mammoth and Other Remains

The frozen ground of northern Siberia is famous on account of the well-preserved corpses of mammoth, rhinoceros, and other extinct animals found within it in quite unusual conditions. Remnants of mammoth are so common in Siberia that there is a regular ivory industry which gives a quite decent income to local hunters and makes an important item of trade and export. The remnants are found in many places in Arctic Eurasia, but real ivory "mines" are worked chiefly on the New Siberian Islands and on the neighboring shores of the mainland. The remnants of other post-Tertiary mammals have also been found there abundantly. Although there has been much speculation as to the conditions in which these animals dwelt on the islands, it appears to be probable that, to a great extent, they were brought there by the same rivers which delivered silt for the building up of the islands themselves. The island localities would be therefore mostly (but certainly not exclusively) secondary, and more of the remnants found on the mainland have been buried on the spot where the animals lived and died.

The Outstanding Unsolved Problems

Having now briefly reviewed the geological history of Arctic Eurasia, the outstanding problems still to be solved in the geology of this region will be pointed out in more or less categorical form.

1. The discovery of new islands in the Asiatic waters of the Arctic should be pushed further. Nearly every one of the last northern expeditions which cruised along the Asiatic coast happened to discover, within the border of the continental shelf, new islands, sometimes of large dimensions, such as Northern Land (Nicholas II Land). There are immense areas in the Arctic not yet crossed by any vessel and not yet visited by any traveler.[2] Among the natives of northern Siberia there are rumors of unknown lands in the ocean, of passage birds going and coming in a direction where nothing is yet known but sea. These rumors are presumably not groundless and should be verified. The sections of the ocean located in front of the old horsts of the mainland are especially important and promising for such a search.

2. Geographical and geological investigation of the little-known Arctic parts of the mainland and islands should be carried out. Only a part of the eastern and southern shores of Northern Land, for example, have been reconnoitered. The configuration of the Arctic shore of the mainland between the Ob and Yenisei Rivers was completely changed by the work of a Russian expedition in 1922. As for the geology of Arctic Eurasia on the geological map of Asiatic Russia in 1:10,500,000 published by the Geological Committee in 1922,[3] Novaya Zemlya, Northern Land, the largest part of Taimyr Peninsula, and the huge area of northeastern Siberia, equal perhaps to half of the surface of Europe, are shown as entirely unknown geologically. Large areas of Arctic Siberia as also of northeastern Europe on the same map are marked with this or that color only as a result of a few reconnaissances and often in a suggestive way only.

3. The scheme of division of Arctic Eurasia into a number of oldlands which are the remnants of an ancient continent, separated by graben-like sections, should be tested by geologists who may visit these regions. Especially the borders of the horsts should be checked, and faults, upon which these borders presumably are dependent, should be proved or disproved.

4. The distribution of Middle and Upper Paleozoic as well as of Mesozoic strata exclusively within the supposed grabens should be checked.

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[2] See the map, Fig. 6, in Dr. Nansen's paper above.—EDIT. NOTE.

[3] Of the fundamental base map of Asiatic Russia in 1:4,200,000 a number of sheets (Nos. 3, 4, 4 bis, 7, 8) have recently been published with geological coloring for areas actually explored.—EDIT. NOTE.

5. The Verkhoyansk and Tas-Khaya-Khtakh Ridges should be investigated geographically and geologically. Of course, these mountains have already been covered in general by Point 2 above, as belonging to the least-known parts of Arctic Eurasia.

6. The geology of the Chukchi Peninsula, especially in its eastern part, should be studied with the object of deciding whether or not it belongs entirely to the old Siberian continent or is composed partly of younger formations connected perhaps with Pacific structures.

7. Special attention should be paid to the examination of the fossil floras of Arctic Eurasia ranging between the Upper Paleozoic (Upper Carboniferous or Permian) and the post-Tertiary. With the Upper Paleozoic flora is connected a much-disputed question concerning Gondwana Land and Angora Land, their connection with, or independence of, each other. Mesozoic floras probably have not always been well differentiated, the Triassic from the Jurassic, and the latter from the Cretaceous. A zonal distribution of different Mesozoic floras and true conclusions on the physico-geographical continental conditions of corresponding periods could be achieved only after such differentiation has been accomplished. The Tertiary flora raises very important and difficult questions on the variations of climatic zones in the Tertiary period. A bold theory on the displacement of the poles has been proposed to explain peculiar circumpolar distributions of Tertiary floras. The study of post-Tertiary floras brings out very important conclusions on the fluctuation of Arctic climate in recent time, geologically speaking, and provides a means of broad correlation.

8. Examination of marks of the Ice Age should be undertaken where they are to be found, or positive proof furnished of their absence. During these investigations it is necessary to keep in mind that the great Siberian rivers in their estuaries produce, by means of river ice, rounded rocks shaped like those carved by glaciers and covered with scratches and grooves. In the same way large masses of drift very similar to moraines may accumulate. All these phenomena have been studied by Russian geologists, for example on the lower Yenisei. There are also known instances when they were erroneously considered as the traces of old glaciers.

9. The study of the present shore line and its oscillations and the connection of the latter with the geological structure of the country should be further pursued. The recent morphology of the Arctic coast of Eurasia and of the continental shield, the relation of islands to the continent, etc., as determined during the last phases of geological history, are other important objects of study.

10. The frozen corpses of extinct animals should receive more attention. Although much has been done in this particular field, much more remains to be done. For different reasons the study has been concentrated chiefly on the remnants of the mammoth, while other

animals, not less important from the theoretical point of view, have received less attention. The vertical and horizontal distribution of different species is particularly important and must be carefully checked.

11. The outcrops of ground ice should be examined and described in detail. Special attention must be paid to the relation of the ice layer to other formations, as well as to the topography of the locality. The question of the origin of ground ice still awaits an acceptable answer.

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THE ICE COVER OF THE ARCTIC SEA, WITH A GENETIC CLASSIFICATION OF SEA ICE*

N. A. Transehe

Classes of Ice Composing the Ice Cover

The ice cover of the Arctic Sea may be considered to consist of three classes of sea ice arranged in two concentric belts around a

Fig. 1—Map of the Arctic Basin showing the distribution of the three classes of ice composing the ice cover of the Arctic Sea (fast-ice, pack ice, and Arctic Pack) during the winter three-quarters of the year, together with some related phenomena (see legend). Scale, 1:53,000,000.

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*In the present discussion the writer's chief inspiration has frankly been Kolchak's "The Ice of the Kara and Siberian Seas" (cited in full at the beginning of the next article and as "Kolchak" throughout the present article). The views and generalizations in that work have seemed to him to merit presentation in a Western European language, for which reason also a whole chapter from that work has been translated in the next article. The present article, however, should not be considered a literal rendering of Kolchak. In addition to containing a classification of sea ice for which the writer is alone responsible, it attempts to present his own views on the background of Kolchak's work and the more recent observations that were not available to Kolchak at the time he wrote (probably 1902–1903).

central mass: fast-ice, pack ice, and the Arctic Pack (Fig. 1). This is the state of the ice cover during the greater part of the year, nine to ten months at least. In summer, however, the fast-ice as such dis-

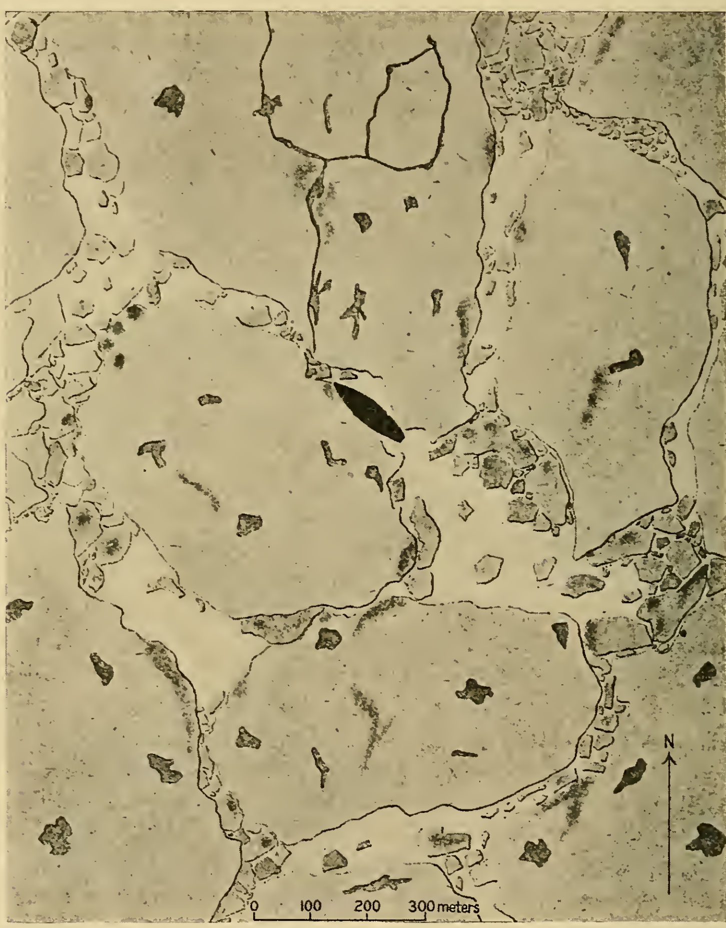

Fig. 2—Actual survey of an area in the outskirts of the Arctic Pack north of Spitsbergen (80° 44′ N. and 9° 5′ E.) on August 19, 1899, by Admiral Makarov showing the ratio of ice cover to open water (here amounting to 100:18). Scale, 1:13,000. (From p. 390 of work cited in footnote 5.)

appears and passes over into the pack ice. Partly it is destroyed as a result of breaking up and melting, partly it forms many-years-old constituents of the pack ice. For two to three months of the year, therefore, the ice cover of the Arctic Sea consists, properly speaking, of pack ice and the Arctic Pack.

Area Occupied by Each Class

The main mass of ice that fills the central and largest part of the Arctic Sea constitutes the Arctic Pack. It occupies about 70 per cent of the whole conventional area of the Arctic Sea.[1] The two other classes occupy concentric belts around the Arctic Pack—the fast-ice, the outer belt, and the pack ice, the belt between the fast-ice and the

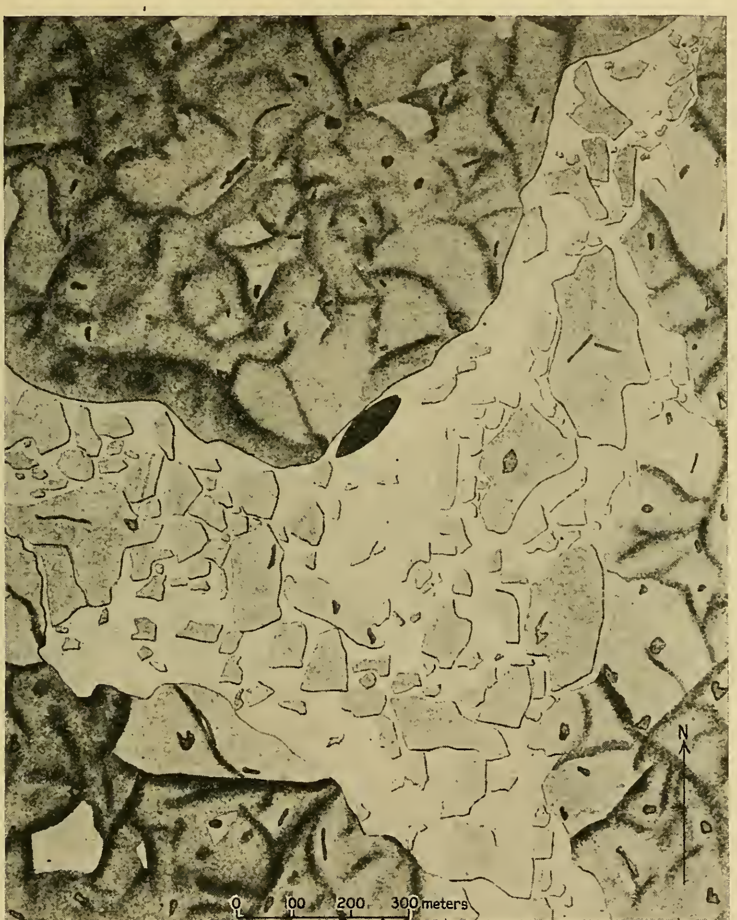

FIG. 3—Similar survey in 81° 22′ N. and 18° 0′ E. on August 27, 1899. Scale, 1:13,000. Ratio of ice cover to open water, 100:28. On the ice in both figures the small, irregular areas represent pools of fresh water mostly, and the shaded streaks, hummocky ridges. Figs. 2 and 3 should be compared with the photographs of the Arctic Pack taken from the air, Figs. 4 and 7. (From p. 391 of work cited in footnote 5.)

Arctic Pack. The pack ice in winter occupies about 25 per cent of the conventional area of the Arctic Sea, and the fast-ice about 5

[1] In dealing with the question of its ice cover the Arctic Sea may possibly be considered as bounded by the northern margin of Spitsbergen, Franz Josef Land, and Northern Land (Nicholas II Land), thence eastward by the Arctic coast of Siberia and Alaska, and finally by the poleward margin of the American Arctic Archipelago and Greenland.

Because of their being shut off from the main bulk of the Arctic Pack and for other reasons, Barents Sea, Kara Sea, the sounds of the American Arctic Archipelago, Baffin Bay, and the western half of Greenland Sea are excluded, but they certainly contain the two other classes of ice.

per cent. As will be explained further, the fast-ice has its greatest width along the Siberian coast and especially opposite the mouth of the Yana River, where it extends outward 270 miles from shore.[2]

What Each Class Consists of

Fast-ice is horizontally immobile young ice attached to the shore. It develops in width outward from the shore from the beginning of the formation of new ice until the end of November or the beginning of

FIG. 4—The Arctic Pack at the north pole on May 12, 1926. Oblique view from the *Norge*. (Photograph from Lincoln Ellsworth.)

December and constantly increases in thickness until May. Consequently it consists of new ice, with parts of pack ice (former fast-ice) embedded in it that remained in the coastal waters until the time of the formation of new ice and have been caught by the new ice at the moment of its formation.

Pack ice in the broad meaning of the term denotes any sea ice "which has drifted from its original position" (Priestley).[3] In the Arctic Sea it represents the movable sea ice consisting partly of remnants of broken fast-ice and partly of newly formed ice among these floating remnants. In summer, when fast-ice does not yet exist as an immovable part of the ice cover of the Arctic Sea, all movable, floating ice between the coast and the Arctic Pack is pack ice. In

[2] The only islands within the bounds of the Arctic Pack are the isolated, outpost islands Bennett, Jeannette, Henrietta, and Zhokhov. In the pack-ice belt lie the northernmost islands of Spitsbergen and Franz Josef Land, Lonely Island, Northern Land, Little Taimyr Island (Tsesarevich Alexei Island), Wrangel Island, and the northwestern edge of the American Arctic Archipelago. Within the fast-ice belt lie the offshore islands of the Kara and Siberian Seas (including in the latter the New Siberian Islands) and the islands along the northern coast of Alaska.

[3] Work by Wright and Priestley cited in the bibliography at the end of this article, especially Chapters 9, 10, and 11 by Priestley.

winter, as has been stated, pack ice occupies the space between the outer limit of the fast-ice and the outer edge of the Arctic Pack. Along this edge all the year round (but mostly in summer) fragments of the Arctic Pack are torn off by winds from its margin and driven into the pack ice, becoming embedded in it.

The Arctic Pack is the ice constantly drifting in a more or less definite direction—"many-years-old, rafted [Russian, *nabivnoi*] ice predominantly in the form of fields, i. e. areas whose limits cannot be seen from a ship's mast. The distinctive characteristics of the

FIG. 5—The Arctic Pack in 87° 44′ N. and about 10° 20′ W. in May, 1925. Note the pressure ridges and, in the left middle background, a level stretch of new ice. (Photograph from Lincoln Ellsworth.)

Arctic Pack are: its tremendous power, greater than that of the pressure-formed ice in the marginal seas of the Arctic Ocean; its solidity, due to the age, of many years' standing, of these rafted ice formations—a solidity that gradually increases to such a degree that the ice masses look like a compact and homogeneous whole; and, finally, the size of the areas of rafted ice, so large that they represent powerful hummocky fields in extent" (Kolchak).

In autumn, with the beginning of frost, freezing of water takes place over the whole area of the Arctic Sea.[4] In the Arctic Pack the only spaces of open water where new ice forms are leads, channels, and lanes among massive, many-years-old fields (and also the water, mostly fresh, in the hollow depressions on the fields). In the pack ice the new ice covers the spaces of open water among the floating pieces of ice, and, notwithstanding its insignificant thickness of a few centimeters only, it strongly impedes their motion.

[4] Strictly speaking, the freezing of sea water and phenomena connected with it may be observed among old floating ice during the whole severe Arctic summer.

The only known measurements determining the ratio of area of open water to continuous ice cover in the Arctic Pack in summer are the topographical surveys made by Admiral Makarov on the *Yermak* in 1899 north of Spitsbergen.[5] Although two such surveys (Figs. 2 and 3), one on August 19 in latitude 80° 44′ N. and longitude 9° 5′ E.

FIG. 6—A lead in the Arctic Pack between Spitsbergen and the pole. Oblique view from the *Norge* from an altitude of about 500 meters. Note the pressure ridges crisscrossing the ice surface. (Photograph from Lincoln Ellsworth.)

and another on August 27 in 81° 22′ N. and 18° 0′ E., gave 18 per cent and 28 per cent of water area respectively (they were made on the outskirts of the Arctic Pack), Makarov estimates that in its normal state the ice of the Arctic Pack in summer has 10 per cent of water area.

[5] S. Makarov: Yermak vo ldakh (The "Yermak" in the Ice), St. Petersburg, 1901.

Annual Life Cycle of the Arctic Sea Ice

THE ARCTIC PACK

The piled-up, telescoped, or hummocked character of the ice of the Arctic Pack develops mainly late in summer and early in autumn,

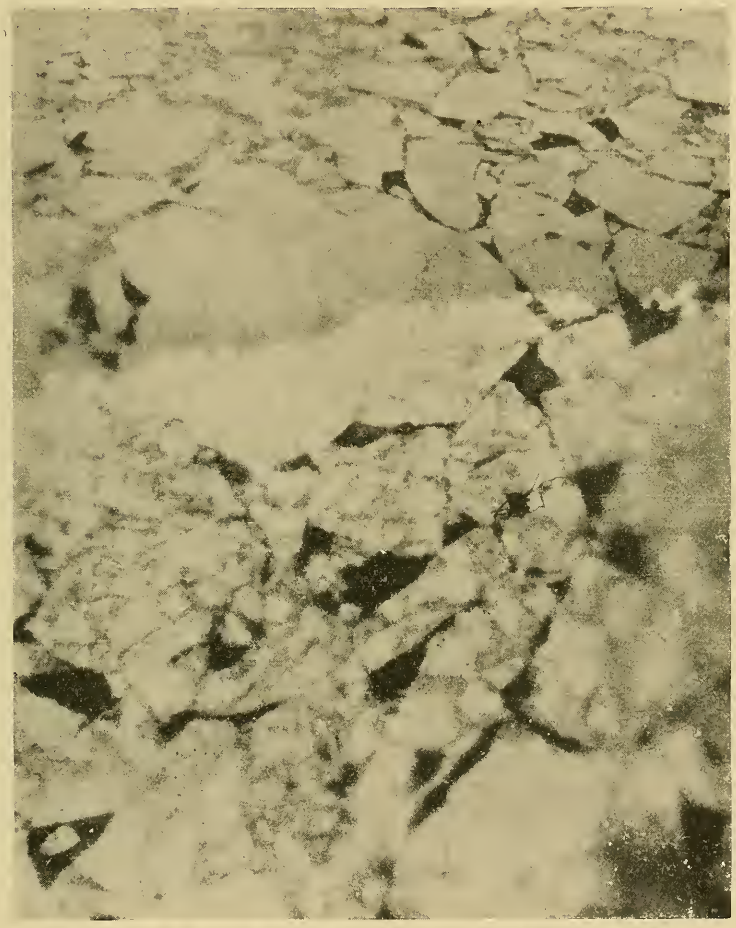

Fig. 7—An area in the Arctic Pack. Slightly oblique air view from the *Norge*. Exact locality not known. So shattered a condition of the Pack was met with only as a rare exception on the transpolar flight. (Photograph from Lincoln Ellsworth.)

when the areas of open water amidst the ice fields and ice floes of which it is composed make possible, under the influence of winds, currents, and tides, a complicated motion of its parts in various directions. The result of this motion is that water areas close up in one place and open up in another. Owing to the inertia of the ice masses in motion, and proportionally to it, this process may be accompanied either by the formation of "pressure ridges" (ridges of hummocks) or of more or less large "pressure areas" (hummocked, piled-up, and telescoped areas).[6] With a change of direction of the motion of parts of the Arctic Pack, pressure ridges are destroyed where they are and are replaced by water areas, and other pressure ridges and pressure areas are formed elsewhere, and so on.

In winter the number, development, and size of areas of open water are considerably less, and therefore the parts of the Arctic Pack, not being so free in their motion as they are in summer, form only cracks and leads, which now shut, now open, or else freeze together with new ice, the rapid growth of which progressively handicaps the motion of these parts. There then takes place the formation of level areas of one-year-old ice amidst the chaotic surface of the Arctic Pack that had been created by the shifting and moving of its parts in the autumn.

The formation of pressure areas in the autumn takes place only among these areas of new ice, while the formation of pressure ridges takes place in winter also, although it is not so widespread as it is in autumn. At the same time, during the whole winter and up to May, the thickening of the ice proceeds by the natural accretion of freezing.

In this manner, late in summer and early in autumn, the area of the Arctic Pack has diminished, but, at the same time, its power, weakened during the period of its thaw, increases in a mechanical way—through hummock formation, telescoping, piling up. During the winter the power of the Arctic Pack increases mainly through accretional freezing; so does its area.

With the beginning of the melting of the snow in June there begins the decay of the winter solidity and compactness of the Arctic Pack and the beginning of its melting and therefore of its decrease in strength and later, after its breaking up, of its decrease in area. The most powerful factor in this process is the thawing of the interstitial snow and ice by whose freezing in the preceding autumn, when they were in a melted form, the blocks of ice were compactly cemented together; this thawing honeycombs and ultimately destroys the hummocks, hummocked fields, and other piled-up ice formations.

In the process of time pools are formed in the hollows and depressions of the ice surface and around the hummocks. This nearly fresh water, freezing in the cracks, widens them; the hummocks themselves no longer present the solid compacted ice masses they did before, and all protuberances on the surface of the ice are rounded (Fig. 16). The hummocks and pressure ridges are finally ready to fall into ruin when favorable conditions develop, i. e. if the wind and tide are of sufficient force to cause a first displacement among the parts of the Arctic Pack. This in turn leads to the destruction of the hummocks and to the formation of channels and leads, which,

[6] The parts of the ice most subjected to this kind of pressure are the areas of the weakest, thin ice.

in their transpositions and alterations, bring about the breaking up of the protruding edges of ice. As a consequence of this the mechanical destruction and partial disappearance of the ice proceeds, and, therefore, the number and size of areas of open water increase. This in turn affords more liberty for the ice to move, helping pressure ridges and pressure areas of larger extent to reform and thus increasing the strength of the Arctic Pack to the point where its annual cycle of life may begin anew.

As to the composition of the ice of the Arctic Pack the measurements and survey by Makarov in 1899, referred to above, gave the following results. Late in June (June 19, in latitude 79° 10′ N. and longitude 9° 5′ E.) the Arctic Pack was composed of the following ice:

Ice of an average thickness of 2 meters . . .	70% of the total area surveyed
Ice of an average thickness of 1.3 meters . .	25% of the total area surveyed
Open water and leads	5% of the total area surveyed

THE PACK ICE

In the pack ice only under conditions of calm water and low temperature of air does the ice finally get so strong that it solidly cements together the separate pieces into more extensive and stable areas. Up to May the ice increases in thickness, until it attains about 2 meters on the average. These areas, however, in their turn undergo breaking up and heaping up throughout the winter and spring, until the breaking up of the sea in summer, i. e. until the breaking up of the fast-ice, whereupon the winter pack ice receives more liberty of motion and consequently is subjected to more frequent and strong shocks and pressure, a circumstance which, together with the process of melting, breaks it into smaller constituents, which partly are destroyed and disappear entirely, forming the larger areas of open water, and partly are left till the time of formation of the ice, supplying the next cycle with pieces of many-years-old ice for insertion into all the three classes of ice that make up the cover of the Arctic Sea.

THE FAST-ICE

The annual life cycle of the fast-ice (Fig. 8) embraces its formation, development, existence, and disappearance as a separate class of the ice cover of the Arctic Sea, which, being destroyed in summer, partly disappears but, once broken up and detached from the shore, passes over into the pack ice and, as a component of the latter, partly disappears, partly passes over into the many-years-old forms.

The factors favorable for the freezing of sea water and the formation of new ice in general are (besides the physico-chemical properties of sea water) the following physico-geographical conditions: lowering

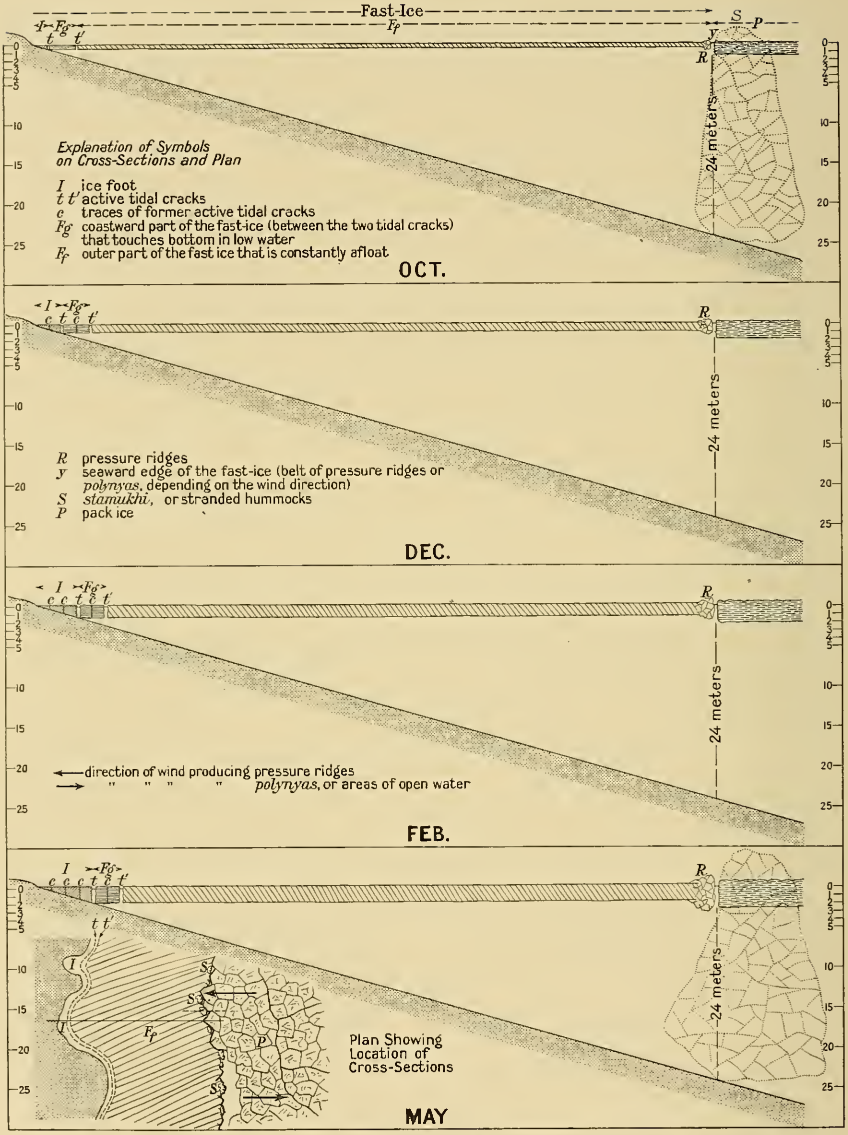

Fig. 8—Cross-sections showing in four consecutive stages the development of the fast-ice. For details, see the explanation of symbols. (The stranded hummocks at the right ends of the October and May cross-sections are shown in dotted outline because they do not necessarily lie in the same plane as these sections; see the short dash line in the plan in the lower left corner. Also, this representation of course does not imply that they occur only during these two months.)

of the temperature of the sea water; increase of freshness or decrease of salinity (its freezing point being thus raised); and hindrance to wave motion or motion of water in general. The decrease in the temperature of the sea water is produced by the decrease of the air temperature and by the quantity of old floating ice masses. Decrease of salinity is produced by the melting of snow and by the discharge of rivers from the land, also partly by the melting of old floating ice. The hindrances to wave motion are well-protected bays and fiords, the presence of floating and grounded old ice and islands, and calm weather.

Therefore, the presence of old floating ice masses plays an important rôle in the process of formation of new ice. With the beginning of frosts the new ice first forms along the shores and among the floating masses of old ice and later in open places of the sea.

Newly formed ice, until the time it reaches a solidity sufficient to resist wave motion and breaking up, is subjected to repeated breaking up and extinction, while with calm weather and a cessation of disturbing reasons "these repeated processes of freezing gain the upper hand, producing the impression of an almost instantaneous phenomenon" (Kolchak). Yet, a quick fall of the air temperature in autumn overcomes all these water-disturbing factors, and under the influence of this energetic process the freezing ice takes on a form which remains stable during the whole period of the Arctic winter.

Except for the places protected from wave motion and currents, the surface of new ice 3 to 4 centimeters in thickness is, in general, uneven, owing to the repeated breaking up that results from the motion of its separate parts.

Having in mind these particulars with regard to the freezing of sea water and disregarding the question of the properties of sea ice itself, we may now describe the formation of fast-ice, its growth, and disappearance.

First of all, fast-ice forms in sheltered bays, gulfs, and fiords, as well as among floating parts of old ice. Developing along the shore and spreading into the sea, it meets with the new ice simultaneously formed and gone forth from islands, grounded hummocks (Russian, *stamukhi*), and floating masses of old ice, and connects with them. Then it is subjected to repeated fracturing, but, with the fall in the temperature of the air, it spreads more and more energetically into the sea, increasing at the same time in thickness, offering more and more resistance to breaking up, and, finally, in December it reaches the maximum of its offshore extension, beyond which limits the region of the pack ice is to be found.

The development of the width of the fast-ice belt depends upon: (1) the configuration of the shore—the more articulated the coast line and the greater the number of islands in its vicinity, the greater is the width of the fast-ice; (2) the relief of the bottom—the more shallow the sea, the less are the possibilities of the existence of strong currents and wave motion; (3) the presence of stamukhi, which owe their formation chiefly to the shallowness—they play a very important rôle in the development of the width of the fast-ice belt, acting, in a way, like skerries on which immovable new ice wedges and creates a bulwark against the breaking up of the fast-ice, a process which is normally caused by the shock of the pack ice.

Kolchak, assuming the average height above water of floating hummocks to be 12 feet and their draft consequently 60–70 feet, sets 12 fathoms, or 24 meters, as the average limit of depth for the free motion of hummocks. In depths shallower than this the floating hummocks become grounded, forming the so-called stamukhi. "Thus the whole area of fast-ice is as though confined between the shore and the rampart of ice heaps that lie approximately along the line of 12 fathoms depth (from the side of the open sea), many of which touch bottom at this depth and most of which in any case are grounded near that depth line" (Kolchak).

The Arctic coast of Eurasia and especially the shore of the East Siberian Sea are distinguished by an extent of shallow water nowhere else found in the Arctic Sea, and this is the reason why the fast-ice attains such great widths in that region, amounting at its widest place off the mouth of the Yana River to 270 miles— a unique phenomenon even for the Arctic Sea.

The outer limit of the fast-ice, which is in touch with the region of pack ice, is subjected to the constant shocks or outward thrusts of the pack-ice masses and is characterized either by ridges of massive hummocks or by *polynyas* (areas of open water; see pp. 117 and 118).

In this condition, increasing, however, its thickness up to May, the fast-ice exists until summer, when its destruction begins—like its formation—first near the shore and then spreading thence into the sea.

The first stage of the decay of the fast-ice is caused by the thawing of the land snow and the flow of melt-water upon the ice, forming the so-called "offshore water." Then follows the melting of snow on the ice, the water from which, filling the open cracks in the ice, freezes quickly in them when it meets the sea water with its temperatures of $-1°$ to $-1.8°$ C. and closes these cracks, thus preventing the water from flowing out under the ice. On the other hand cracks that do not extend all the way through the ice are widened by the expansion of this melt-water freezing in them. This occurs at the end of May or beginning of June. Then, with the rising of the air temperature, the fresh ice in the cracks disintegrates; the cracks break open, and the water, in a layer which is as much as 2 to 3 feet thick, flows under the ice, having furrowed its surface with a net of channels, depressions, hollows, etc., and having widened the cracks.

In a few days all of the water, excepting that which has filled up the hollows, flows under the ice. Then, with the further rise of the air temperature and the help of rains, the ice continues its selfdestruction by melting, a process that is now assisted very much by the river-borne and wind-borne débris from the land.

All this together imparts an exceedingly rough character to the surface of ice. The most rapid destruction of the fast-ice takes place near the mouths of rivers, where polynyas of considerable size are formed by the impact of relatively warm river water and its subsequent overflowing onto the ice.

All these factors contributing to the destruction of the fast-ice create a possibility, especially near and along shore at the end of June or in July, of a local insignificant motion of the fast-ice taking place, its edges breaking up, its chafing against the shore, and so on. All this increases the dimensions of the polynyas and, generally, the ratio of the area of open water to the area of ice and prepares greater space for the movement of the whole fast-ice.

At the same time, out at sea, farther from the shores, these factors play a considerably less important rôle in the destruction of the fast-ice, but there also the melting of the considerable snow hills (Russian, *sugrobi*) around the ice protuberances, hummocks, and stamukhi do their work, i. e. hummocks, stamukhi, and other protuberances thaw off, piled-up pieces become packed, forming more compact masses, and so on, while on the outskirts of the fast-ice the shock of the pack ice assists the process of destruction. Owing to the fact that the fast-ice itself up to the moment of its destruction does not represent a continuous ice cover but is honeycombed with cracks of different kinds (tidal cracks; cracks caused by air temperature changes and by temperature differences in the various layers of the ice; cracks caused by ice pressure) and owing to the formation of open water near and along the shore on the one hand and to the pressure of the pack ice on the other, the parts of the fast-ice first begin to be disconnected among themselves under the influence of winds and currents. Then the increasing number of cracks, channels, and polynyas bring about the motion of the larger areas; with the first strong wind these break into smaller pieces; and finally all the rest of the fast-ice passes over into the pack ice. During the summer part of this former fast-ice disappears entirely owing to the repeated breaking and cracking into pieces due to the collision of separate parts and owing to melting; for the same reasons part of it forms piled-up formations in the zone of the former fast-ice that drift to the north into the region of the winter pack ice, which, in turn, feeds the Arctic Pack.

With the beginning of the new frosts those parts of the fast-ice that have been caught by the newly formed ice in the zone of the fast-ice give rise again to those insertions of old ice into the new which assist in the formation of the new fast-ice, and the cycle is repeated.

This life cycle of the ice cover is caused by processes of heating and changes of water temperature during a period of time that does not last longer than three months.

Summary

Thus, in summary, the main features of the annual cycle of the ice cover of the Arctic Sea are as follows:

a) Fast-ice, as one of the three classes of ice making up the ice cover, disappears in summer, passing over into the pack ice.
b) Pack ice continuously feeds the Arctic Pack, part of which
c) drifts out of the Arctic Basin through its outlets all the year round (the main outlet is the strait between Greenland and Spitsbergen)

In winter the main processes are:

1) Formation, growth, and development in breadth of the fast-ice. This brings with it
2) a decrease of the area of the pack-ice region, which, as well as the Arctic Pack,
3) increases its strength and consolidated areas, thereby decreasing the areas of open water among its parts.

In summer the ice of all classes undergoes:

1) a decrease in thickness through thawing (the most subject to it are the inshore parts of the fast-ice);
2) a breaking up into constituents of lesser size;
3) a decrease in area, which takes place in two ways:
    a) by the piling up or telescoping of the ice, which in turn produces an increased strength of the separate parts of ice;
    b) by the destruction of pieces of ice through crushing and attrition (the most subject to this is the fast-ice).

Variability of the State of the Ice in Consecutive Years

As all these processes are immediately connected with and dependent upon the meteorological elements, which mostly differ from year to year, the degree of development of these processes varies with the years. For this reason, and because of the lack of sufficient systematic observations and data, it is impossible to outline the exact state of the ice over the greater part of the Arctic Sea—a state which it would be very important to know for the purposes of navigation in the pack-ice and fast-ice belts.[7]

[7] For the Kara Sea, for instance, there is available, however, the excellent detailed investigation of this question by E. Leshaft, who, on the basis of a study of the distribution and state of the ice for

But if we accept the area of open water in the Arctic Pack in summer according to Makarov as equal to 10 per cent (see, above, p. 96), we may conclude with confidence that in the pack-ice region in summer, which then occupies the whole space between the coast and the edge of the Arctic Pack (since fast-ice does not exist in summer), this ratio of open water is considerably higher because at the time that the increase in the area of open water takes place in the Arctic Pack mainly as a result of the piling up, hummocking, and telescoping of the ice, in the fast-ice belt it takes place as a result of the disappearance of the one-year-old ice. Yet this ratio varies greatly; just as it depends on the local meteorological conditions for the individual sea, so it depends on its physico-geographical conditions for the separate parts of the sea itself. It is no exaggeration to say that in the coastal belt of Arctic Eurasia, for instance—with the exception of the particularly unfavorable places where ice masses accumulate, as in Long Strait between Wrangel Island and the mainland, Tsesarevich Alexei Strait between Northern Land and Cape Chelyuskin, the region of the Taimyr skerries, and the southern part of the Kara Sea—the water area in summer (August) along the whole distance between Bering Strait and Novaya Zemlya on the average amounts to nearly 50 per cent of the total area.

In the narrow segment along the northern coast of Alaska the area of open water also is near the same figure.

A Genetic Classification of Sea Ice[8]

The following classification is submitted simply as a contribution to the clarification of the existing terminology. It is an outgrowth of the writer's desire to bring into harmony for his own use the numerous and often uncorrelated terms employed in polar literature. To attain this end it has seemed to him possible to organize these terms in their causal relationships, and he has attempted to do this in the accompanying synoptical diagram (Fig. 9) and defini-

the period 1869–1911 and of the prevalence of various wind directions, analyzed all the possible cases of distribution and state of the ice in the Kara Sea. He establishes five type conditions corresponding to the distribution and state of the ice and the accessibility of the Kara Sea by way of one or the other of its entrances (Yugor Strait, Kara Strait, Matochkin Shar, or around the north of Novaya Zemlya). See E. Leshaft: Ldy Karskago Morya i dostupnost ego dlya soobshchenii s Sibiryu (Ice of the Kara Sea and Its Accessibility for Communication with Siberia), *Zapiski po Hidrografii*, Vol. 37, Part II, 1913, pp. 161–260, with 5 maps and 7 tables.

As to the region between Cape Dezhnev and Cape Chelyuskin the most complete and modern Arctic Pilot is K. Neupokoev's work: Materialy po lotsii Sibirskogo Morya (Materials on Sailing Directions in the Siberian Sea), *Zapiski po Hidrografii*, Vol. 46, 1923, Supplement, pp. 1–53, with a chart.

Annual reports entitled "The State of the Ice in the Arctic Seas" are published (in Danish and English) by the Danish Meteorological Institute, Copenhagen, in its *Nautical-Meteorological Annual* (*Nautisk Meteorologisk Aarbog*). These contain excellent monthly maps of the state of the ice for April, May, June, July, and August of the given year, showing graphically the progressive development of open water as the season advances.

[8] This classification relates to sea ice alone. Ice floating on the sea but of land derivation, such as icebergs and shelf ice, is not included.

tions. This genetic aspect is the only justification for putting forward another classification.

In preparing this classification the writer has drawn freely on previous discussions of the subject; these are referred to in the bibliography. He has also been able to draw upon his own experiences in the Eurasian Arctic and familiarity with Russian work in that

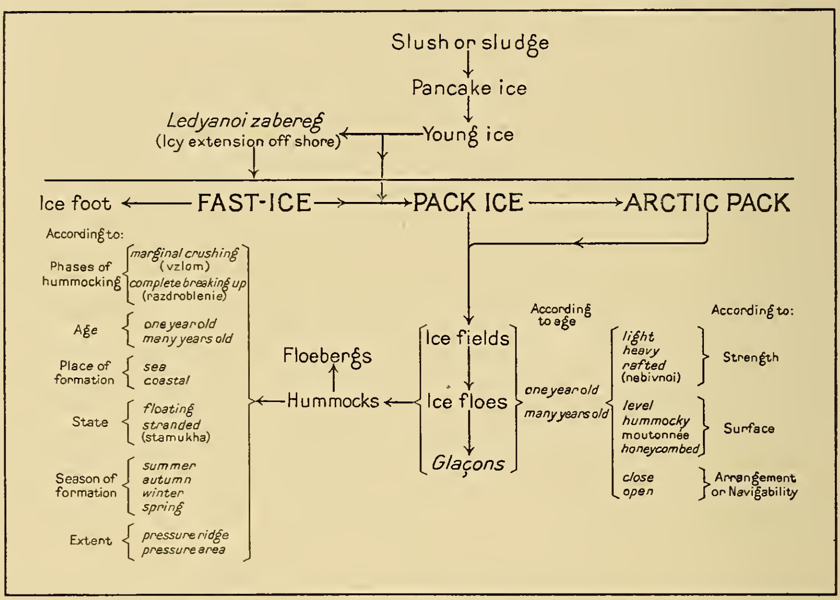

FIG. 9—Synoptical diagram showing the genetic relationship of the various types of sea ice.

region. Whatever the classification may gain from this widening of the range of observation on which it is based is counterbalanced by the fact that English is not his native tongue, a circumstance which he asks the reader to bear in mind and for the consequences of which he bespeaks indulgence.

The two major classes of types of sea ice will first be discussed, and definitions of the different types in the order of their development and other relevant definitions will then be presented.

Types of Ice Resulting from Natural Growth (Accretional Types)

SLUSH OR SLUDGE

The initial stage in the freezing of sea water and its transformation into ice consists of the development of ice crystals in the surface water in the form of spicules and plates (the dimensions of the latter being 2–4 centimeters in length, ½–1 centimeter in width, and ½–1

FIG. 10

FIG. 11

FIG 10—Slush or sludge forming between the open water in the foreground and the young ice in the background. Near Cape Chelyuskin, Siberia. (Photograph from Russian Hydrographical Expedition to the Arctic.)

FIG. 11—Pancake ice, Ross Sea sector of the Antarctic. (Photograph by H. G. Ponting in Wright and Priestley's "Glaciology," Pl. 230.)

millimeter in thickness), which loosely freeze together and form "ice gruel"; the water at that time is of gruelly or souplike consistency, and its surface has the appearance of cooling grease, with a peculiar steel-gray or lead tint. Because of this appearance, this primary stage of the freezing of the sea water has been called *slush,* or *sludge* (Russian, *salo*, grease; Fig. 10).

PANCAKE ICE

"Owing to various disturbing conditions connected with the slight motion in the upper layers of sea water, the freezing together of the ice needles and plates does not proceed equally on the whole surface of the open sea but starts its development as if from a number of centers of freezing, spreading equally in all directions from these centers. Grouping themselves around these centers the crystals or plates of ice form small areas having the appearance of rather regular disks, from 1 to 2 or 3 feet in diameter [maximum, 5–6 feet]" (Kolchak). This phenomenon, called *pancake ice,* is the next stage of ice formation and, like the previous one, develops when the atmosphere and the sea are calm (Fig. 11).

YOUNG ICE

"Gradually growing thicker and stronger, the disks of pancake ice begin to congeal together (thanks to the freezing of crystals in the intervals between the disks) and form more or less large, compact ice areas," which, "starting in motion under the influence of the wind, wave movement, and currents, break up into several pieces; these pieces, colliding with each other, have their edges crumpled up to form narrow rims a few centimeters high; under favorable conditions the pieces freeze together again into new, more extensive areas; gradually they grow thicker and more and more solid; and finally they form compact *young ice* consisting of wet ice, saturated with water, which has a coarse crystalline composition of more or less developed ice crystals. The upper surface of this young ice is smooth or more often slightly rough, while the under surface has a coarse, rough appearance, sometimes like a brush of ice crystals. Underneath the under surface of this ice there is a more or less thick layer (about one foot deep) of water saturated with ice crystals, which gradually makes the newly formed ice thicker and thicker. Such young ice is usually 2 or 3 centimeters thick" (Kolchak); it increases continually during the whole winter and in May reaches its full thickness of about 2 meters on the average (maximum thickness of ice observed by Nansen was 3.65 meters). (See Fig. 10).

FAST-ICE

The three preceding paragraphs describe the process of the freezing of sea water and the formation of new ice in general. But near coasts, at the heads of gulfs and bays, in straits, among islands and icebergs, and generally in localities that are comparatively sheltered, the formation of the ice cover takes place sooner than in the open sea and thence spreads outwards.

This new ice that first forms along shore is called *ledyanoi zabereg* in Russian, which means "icy extension off shore." Its development causes the freezing of gulfs and bays, and its constant spreading along the whole coast and into the open sea creates (from the end of November or beginning of December) a more or less wide zone of immovable ice which bears the name of *fast-ice* (Russian, *beregovoi pripai*, literally meaning "coastal soldering") and which grows in thickness during the whole winter and spring up to May.

That part of the fast-ice immediately close to shore which is not subjected to the rise and fall of the tide is called *ice foot.*

Types of Ice Resulting from Motion (Dynamic Types)

PACK ICE

In distinction to fast-ice any "sea ice which has drifted from its original position" (under the influence of winds, currents, etc.) is called *pack ice* or pack (Priestley).

Therefore the types of sea ice enumerated in the following are derivatives of the pack ice, resulting from its breaking into pieces as a consequence of its motion, or of the fast-ice itself at the first stage of its breaking up. (The types are taken up in decreasing order of size.)

1. The largest areas of the pack ice are called *ice fields*. They are of such extent that their limits cannot be seen from a ship's masthead (Fig. 12).

They in their turn are broken into:

2. *Ice floes*—areas that range in size from about one-third of a nautical mile in diameter to the dimensions of an ice field.
3. The further breaking up of floes (or the direct breaking up of ice fields or of pack ice or fast-ice into pieces smaller than a floe) forms *glaçons*[9] (Russian, *ldini*), areas ranging in

[9] There is no separate term in the existing terminologies for an individual piece of ice forming a subdivision of an ice floe, and while Scoresby, in defining a floe, says "the term (floe), however, is seldom applied to pieces of ice of less diameter than half a mile or a mile," Wordie says "in size a floe may vary from 'pancakes' on the one hand to 'fields' on the other," and he therefore even uses the term "floe" in connection with his definition of "pancake ice" (Priestley also). Such lack of a proper term

size from a cake about 2 to 3 feet in diameter to a floe (Fig. 13). In keeping with Russian Arctic practice glaçons may be further subdivided according to size into small, medium-sized, and large.

Hummocking

When the pack ice, or rather its ice fields or floes, moves, the process of *hummocking* takes place. This process consists of the impingement, shock, and pressure of ice masses upon one another; it results in crushing the edges of fields or floes, breaking them up completely, and piling them up one upon another. The magnitude of hummocking depends upon the size of the colliding masses, their speed, strength, solidity, etc.

There are two distinctive phases of hummocking. The first consists in the marginal crushing of colliding ice masses, the second, in the complete breaking up and piling up of the broken ice.

The chaotic heaps that are the products of the crushing and breaking up of ice masses are called *hummocks* (Russian, *toros*).

Hummocks may be subdivided according to (Fig. 9):

a) Phases of hummocking	hummocks due to marginal crushing (Russian, *vzlom*), which in the pack ice project 2 to 5 meters above the level of the ice
	hummocks due to complete breaking up (Russian, *razdroblenic*), which in the pack ice project 3 to 7 meters above the level of the ice
b) Age	hummocks one year old
	hummocks many years old
c) Place of formation	sea hummocks
	coastal hummocks

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is inconvenient; meanwhile there is the French term *glaçon* which literally means "an individual piece of ice." This term is suitable to designate an individual piece of ice intermediate in size between a cake about 2 to 3 feet in diameter and a floe one-third of a nautical mile in diameter as well as to define the components of "drift ice" and "brash ice."

The term "drift ice" (included in the terminologies and having the meaning of a collective noun) defines, in the main, the character of the ice but not an individual, definite type of ice. In accordance with: (1) the dimensions assigned to a floe by Scoresby (unfortunately omitted in the subsequent terminologies); (2) his definition of drift ice as "consisting of pieces less than a floe in size"; (3) our definition of the term *glaçon*; (4) our definition of the term "brash ice" (p. 117)—one may say that "drift ice" (definition on p. 117) consists of small and medium-sized glaçons and in character represents loose, very open pack in which water preponderates over ice.

Fig. 12

Fig. 13

Fig. 12—Ice fields and ice floes, northeastern part of Kara Sea, August, 1900. (Photograph by F. A. Matisen in Kolchak's "Ice of the Kara and Siberian Seas," Pl. 5, Fig. 2.)

Fig. 13—*Glaçons* in the sea west of Graham Land, Antarctic. (From H. Arctowski's "Glace de mer et banquises," Pl. 1.)

d) State	floating hummocks stranded hummocks (Russian, *stamukhi*), whose height is often 18 to 20 meters above sea level in the Siberian and Kara Seas (Figs. 14–15)
e) Season	summer hummock autumn hummock winter hummock spring hummock
f) Extent	pressure ridges pressure areas

"The formation of the hummocks due to marginal crushing is a primary process at which the hummocking can stop, after the kinetic energy of the colliding ice masses has been spent, or the process may pass into a further form of breaking up and piling up the broken material" (Kolchak).

"Winter and spring hummocks occur in those parts of the sea where the ice is in motion during all the year, and they are not distinguished from the autumn forms except by their greater strength; as for the summer hummock, which forms after the breaking up of the immovable ice of winter, it is distinguished from the autumn hummock not only by its greater strength but also by a difference in its physical properties due to the influence of other temperature conditions, other modes of melting, etc." (Kolchak).

Stranded hummocks (*stamukhi*) are a very important type of hummock, especially in the Russian sector of the Arctic, where the width of the fast-ice depends, among other factors, mainly on the number of *stamukhi* present. In this respect as well as in the initial process of ice formation they play the same rôle as grounded icebergs or groups of small islands.

When the process of hummocking takes place along the outskirts of the pack ice (in the "frontier region of the Arctic Pack," to use Kolchak's expression) the ice masses of the Arctic Pack participate in the formation of pressure areas and pressure ridges. These massive, compact ice masses, or hummocks of the pack ice and Arctic Pack pressed and cemented together, are called *floebergs*.

Small glaçons of hummock origin are called *growlers*.

Subdivisions of Derivatives of the Pack Ice

As to fields, floes, and glaçons, they may be divided as follows according to:

Age[10]	one year old many years old

[10] Strictly speaking, floes and glaçons many years old occur mainly in the pack ice, while, on the contrary, fields occur mainly in the Arctic Pack.

FIG. 14

FIG. 15

FIGS. 14–15—*Stamukhi*, or stranded hummocks, the upper 25 miles off the coast of the easternmost island of the New Siberian group in September, 1903, and the lower off the west coast of Taimyr Peninsula in August, 1900. The upper consisted of many-years-old ice; highest point, 57 feet above the water. The lower was formed during the summer of 1900; height, about 30 feet. (Photographs by F. A. Matisen in Kolchak's "Ice of the Kara and Siberian Seas," Pl. 10, Fig. 2, and Pl. 9, Fig. 1).

Strength	light—up to 2 feet in thickness heavy—more than 2 feet in thickness rafted[11] (telescoped; Russian, *nabivnoi*)
Surface	level (flat) hummocky *moutonnée*[12] honeycombed
Arrangement[13]	close—when they touch each other for the most part open—when they do not touch each other for the most part

The third class of ice covering the Arctic Sea, the Arctic Pack, consists of the same main types of sea ice which are inherent in the pack ice, i. e. fields, floes, hummocks, but they are of much larger dimensions and power, while the products of the further breaking up and disintegration of the sea ice, namely the types glaçons and growlers, are of insignificant importance in the Arctic Pack, being alternately formed and disintegrated in the temporary polynyas, lanes, or cracks, where also takes place the formation of the primary types of sea ice, slush or sludge, and pancake ice.

Sea Ice Definitions

We shall now summarize in the form of specific definitions what has gone before.

Slush, or sludge. The initial state in the freezing of sea water when it is of the consistency of gruel or soup and the surface of the water takes on the appearance of cooling grease with a peculiar steel-gray or lead tint.

Pancake ice. Small cakes of new ice approximately circular and with raised rims. Diameter of cakes is from 1 to 2 or 3 feet; their thickness up to 2 to 4 centimeters; rims are 1 to 2 centimeters high.

Young ice. Compact ice sheet formed from the repeated freezing together and breaking up of pieces of pancake ice. Its initial thickness is 2 to 4 centimeters, which increases during the winter to about 2 meters and as a maximum 3 meters.

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11 The thickness of rafted floes in the Kara and Siberian Seas is from 3 to 10 meters, and near the limits of the Arctic Pack, with the participation of floes of the latter added, it reaches 20 to 25 and even 30 meters.

12 By analogy with *roche moutonnée*, the weathering of the ice producing rounded surface forms (see Fig. 16) similar to those produced by ice action on rock.

13 As to navigability these two forms may be characterized as follows:

close pack—when it is not possible to navigate through it.

open pack—when it is possible to navigate through it but changes in the vessel's course are continually necessary.

Certainly, when the pack ice is composed of *glaçons*, the possibility to navigate through it is greater.

Ledyanoi zabereg (icy extension off shore). The new ice adhering to the shore (in bays, gulfs, and among islands) when it begins to grow outward toward the open sea.

Fast-ice. Fully developed *ledyanoi zabereg.* It forms a more or less wide belt of immovable new ice along the coasts—in other words "sea ice while remaining fast in the position

FIG. 16—An old ice field in summer, with *moutonnée* surface and fresh-water pools in the depressions. Siberian Sea. (Photograph from Russian Hydrographical Expedition to the Arctic.)

of growth" (Priestley). The 12-fathom isobath is approximately the limit of the spread of the fast-ice into the open sea in localities where the configuration of the coast exerts no influence.

Ice foot. The part of the fast-ice immediately close to shore that is not affected by the rise and fall of the tide.

Pack ice. Sea ice which has drifted from its original position.

Ice field. An area of pack ice or Arctic Pack of such extent that its limits cannot be seen from the ship's masthead.

Ice floe. An area of pack ice or Arctic Pack from one-third of a nautical mile in diameter to the size of an ice field.

Glaçon. A piece of pack ice or Arctic Pack ranging in size from a cake about 2 to 3 feet in diameter to a floe.

Hummock. The heaped-up products of the marginal crushing and breaking up of the sea ice as a result of hummocking.

Hummocking. The process of pressure upon sea ice expressed in marginal crushing and breaking up and in the heaping up the products resulting from this pressure.

Floeberg. Massive hummock consisting partly of pack ice, partly of Arctic Pack.

Growler. A small glaçon of hummock origin.

Arctic Pack. Many-years-old rafted ice, mainly in the form of hummocked fields. Its distinctive characteristics are: tremendous power, greater than that of the ice of the marginal seas of the Arctic Sea; solidity, gradually increasing in the course of years; and great size of the fields of rafted ice.

Anchor ice. All submerged ice attached to the bottom irrespective of the nature of its formation.

Descriptive Terms Applicable to All Types of Ice

Besides the above-mentioned terms defining the types of ice of the Arctic Sea—definitions that are based upon certain stages of the life cycle of sea ice (freezing, melting, marginal crushing, and breaking up)—there are in common use a number of terms relating to sea ice in general and not to any given derivative of pack ice or the Arctic Pack. Most of the adjectives constituting these terms have been applied in the preceding classification to define the character of certain types of pack ice and Arctic Pack.

Grouped According to:	*Term*	*Applied to:*
Condition of surface	level	Ice whose surface is flat.
	hummocky	Ice whose surface is hummocked (or jagged).
	rotten	Ice whose surface is honeycombed (or pitted).
Age	young	Ice one year old.
	old	Ice many years old.
Strength	light	One-year-old ice up to 2 feet in thickness.
	heavy	Any ice from 2 feet to 6 feet in thickness.
	rafted (telescoped)	Hummocked, recemented ice with protuberances smoothed by melting (thickness, 6 feet and more).

Arrangement	compact	Continuous, although broken, ice with no signs of water.
	close	Ice with spaces of water, but so close as to hinder navigation.
	open	Ice with spaces of water sufficient for navigation.
	drift ice	An area of small and medium-sized glaçons in which water preponderates over ice.
	brash ice	An area of small glaçons constituting the wreckage of all types of ice.
State	unbroken	Either fast-ice or large ice fields.

Terms for Some Characteristic Phenomena of Sea Ice Not Part of the Genetic Classification

Crack.[14] Any fracture or rift in sea ice (not navigable).

Lead, or lane. A channel of open water in the pack ice or Arctic Pack; it may be navigable in the former (mostly the antithesis of pressure ridges).

Polynya.[15] Any enclosed water area (other than a crack or a lead) among fields, floes, and glaçons of pack ice or Arctic Pack.

Pool. A depression (or hollow) containing fresh water in the fields, floes, or glaçons of sea ice.

Hole. Opening through the ice (as for instance the holes in the rotten ice, honeycombed in the course of melting).

Frost smoke. The foglike clouds of evaporation over newly formed water areas in sea ice.

Ice blink. The whitish glare on the clouds produced by the reflection of large areas of sea ice (the antithesis of water sky).

Water sky. Dark streaks on the clouds due to the reflection of polynyas or the open sea in the neighborhood of large areas of sea ice.

The Polynya as a Major Regional Feature

The definitions in this list relate to certain features considered as general phenomena. A group of these phenomena, however, namely

[14] There are three categories of cracks: (1) tidal, (2) temperature, and (3) shock and pressure cracks. The two cracks of the first category are called "active tidal cracks"; one (inshore) marks the ice foot, and the other (offshore) is the line of demarcation between the coastward part of the fast-ice that touches the bottom in low water and that which is constantly in a floating state (see the diagram, Fig. 8).

[15] For a detailed explanation see the next section.

the polynyas and leads, also occur as large-scale features associated with definite regions, and it is therefore necessary to discuss them briefly in their regional aspect.

POLYNYAS AS A GENERAL PHENOMENON

A few words first, however, with reference to the polynya as a general phenomenon.

The polynya occurs both in the pack ice and the Arctic Pack and depends on the mutual motion of parts (field and floes) of the pack. The motion of these parts depends on the winds, currents, tides, resistance met with (islands, stamukhi, shoals, etc.) and on the various dimensions and forms of the parts participating in the motion. Owing to these factors this motion is very complicated in character. Side by side with the progressive motion of the pack as a whole there goes a rotary motion of its parts, as a result of collision, shock, and pressure among them. Owing to this intricate motion, such a grouping of fields and floes may result as to form an area of open water or an area with fragments of ice (glaçons) in it. This area of open water is called in Russian *polynya*. These polynyas are of a temporary character, and, under the influence of the same combination of factors that cause the motion of parts of the pack, they are closed in one place and reopened again elsewhere, and so on. With a relatively large number of polynyas and with channels connecting them, the pack has the appearance of being more or less favorable for navigation, but it is still tight enough to be called "close pack."

REGIONAL POLYNYAS

Now as to the polynya as a major regional feature.

As such it has been observed in two localities (see Fig. 1), off eastern Siberia from north of the New Siberian Islands at intervals to about Kolyuchin Bay and off Grant Land and northern Greenland.

Great Siberian Polynya

The former, which may be termed the Great Siberian Polynya, is, according to all observations since 1820, permanent in character and of great dimensions. Its observed positions, when plotted, shows it clearly to be associated with the outer edge of the fully developed fast-ice (*beregovoi pripai*) as defined in the present paper. The formation, existence, and extension of this Great Siberian Polynya depend upon those physico-geographical conditions which produce the general motion of the Arctic Pack, or, in other words, they depend in this region on the northwest and west-northwest direction of the drift, i. e. a direction obliquely away from the fast-ice. The width of this polynya depends upon the fluctuations of the outskirts of the

Arctic Pack under the influence of wind, decreasing when it blows toward and increasing when it blows away from the fast-ice.

Further details about this polynya may here be waived as its existence and the causes therefore are well known; also, it is dealt with by Kolchak in the chapter from his report that constitutes the next

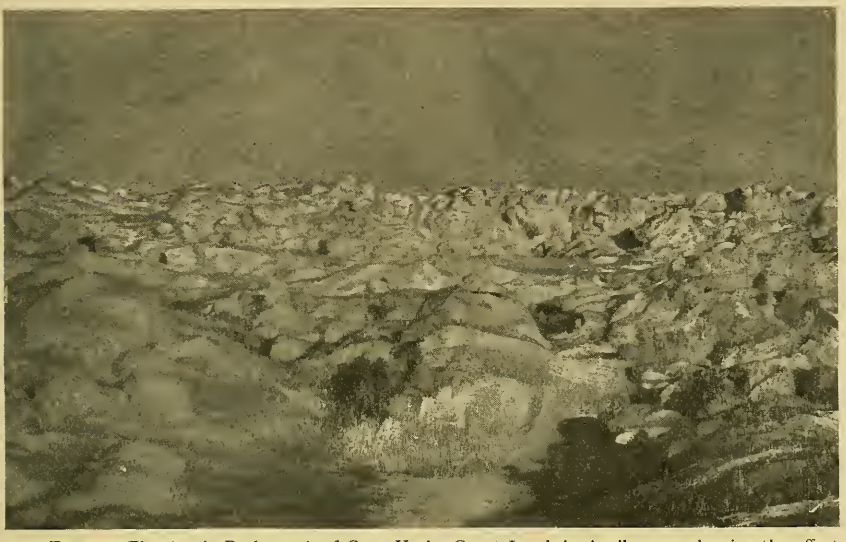

FIG. 17—The Arctic Pack north of Cape Hecla, Grant Land, in April, 1902, showing the effect of the shock and pressure characteristic of this region. (Photograph by R. E. Peary.)

article. With regard to the other polynya it may not be amiss to present a more detailed analysis, as the reasons for its existence have so far been less fully discussed.

Peary's Big Lead

The polynya off Grant Land and northern Greenland might, to employ the two words used to describe it by him to whom we owe our sole knowledge of it, be termed Peary's Big Lead. Based on Peary's repeated observations the following data about this lead are available: (1) Most of it seems to be situated out beyond the continental shelf where the depth of the sea exceeds 1000 meters; (2) its location is between latitudes 84° and 84½° N., and it has been met with on the meridians of 40° and 69° W.; (3) its maximum observed width is about 2 miles, i. e. much less than that of the Great Siberian Polynya.

Besides that there are the following known physico-geographical factors which are inherent in this locality: (1) the great shock and pressure of ice masses upon the northern shores of Greenland and Grant Land; (2) the eastward direction of the drift of the Arctic Pack approximately along the 84th parallel; (3) the southward discharge through Robeson Channel of part of the ice of Lincoln Sea (the enlargement of the Arctic Sea bounded by the coasts of Grant Land and northern Greenland); (4) a westward surface current along the northern shores of Greenland (observed by Lauge Koch).

Analyzing these facts and data we may come to the following conclusions:

The fact itself of the shock and pressure of the Arctic Pack upon the shores points to the difference between the causes respectively producing the Big Lead and the Great Siberian Polynya. In the case of the latter, the main cause governing the formation of the polynya is the general direction of the Arctic Pack motion away from shore. Hence the Big Lead can develop no such width as that of the Great Siberian Polynya.

The fact itself of the shock and pressure of ice masses upon these shores is due to the circumstance that, from the meridian of 90° W. to Cape Bridgman (26° W.), the Arctic Pack probably maintains a constant drift to the east (with a slight tendency to the southeast). This very direction, in connection with the trend and position of the shores of Grant Land and northern Greenland, must produce this shock and pressure of ice masses on these shores (its maximum should be at Cape Bridgman).

The resistance of these shores to the motion of the Arctic Pack, which, as a body, rushes towards its outlet into Greenland Sea, brings it about that Lincoln Sea (which represents a bay, as it were, in relation to this motion of the Arctic Pack) is filled up with ice masses derived from the Arctic Pack about up to the parallel of 84° N. But as the main body of the Arctic Pack seeks an outlet into Greenland Sea, its outskirts slide along this parallel, so to speak, toward the east and make a line of demarcation between the main body of the Arctic Pack, which is drifting to the east to its outlet into Greenland Sea, and those parts of its outskirts with which Lincoln Sea has been filled and which press on the shores under the pressure of the Arctic Pack itself.

This line of demarcation consequently is a place of possible formation of the Big Lead under the influence of sufficiently strong winds and favorable tidal currents.

Owing to this sliding of the Arctic Pack along the parallel of 84° N., its outskirts feed Lincoln Sea with that many-years-old, hummocked, piled-up, and broken ice (the "paleocrystic ice")[16] that, under the influence of this pressure upon the shore, is partly carried out to the south through Robeson Channel.

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[16] This, in agreement with Lauge Koch (Ice Cap and Sea Ice in North Greenland, *Geogr. Rev.*, Vol. 16, 1926, pp. 98–107; references pp. 101–104), and not the iceberg derivation theory of the explorers of the seventies and eighties of the last century, whose deductions were necessarily based on a more limited body of observations than is available today, seems the plausible explanation of the origin of the so-called "paleocrystic ice."

The westward surface current along the northern coast of Greenland observed by Lauge Koch we interpret as a result of the same shock and pressure of the ice masses of the Arctic Pack upon the projecting coast of Peary Land, where, under the influence of ice masses pressing upon the shore a deflection of the current seems to take place along and close to the shore in a westward direction. This current, thus turning down Robeson Channel, carries through that channel part of the ice masses of the outskirts of the Arctic Pack which had already been carried past this meridian on their eastward drift.

As the phenomena of the Big Lead and the shoreward shock and pressure of the ice masses are incompatible for the same moment of time, because one phenomenon is the antithesis of the other, although both are due to the same force, namely winds, but of opposite direction, therefore one may suppose that, when the westward current along the northern coast of Greenland is strong, severe hummocking takes place along the edge of the Arctic Pack in about latitude 84° and, vice versa, that, when the current is weak, hummocking is much reduced or even gives way to the formation of the Big Lead.

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Admiral KOLCHAK was oceanographer on the Russian Polar Expedition under Baron Toll, 1900–1903 (see "Ice in the Kara and Siberian Seas" [in Russian], *Zap. Imp. Akad. Nauk*, Ser. 8, Vol. 26, No. 1, St. Petersburg, 1909; "Preliminary Account of an Expedition to Bennett Island to Help Baron Toll" [in Russian], *Izv. Imp. Akad. Nauk*, Ser. 5, Vol. 20, No. 5, St. Petersburg, 1904; charts Nos. 681 and 712 of the Russian Hydrographic Office; and "Last Expedition to Bennett Island in Search of Baron Toll, Organized by the Academy of Sciences" [in Russian], *Izv. Imp. Russ. Geogr. Obshchestva*, Vol. 42, 1906). He served in the Russo-Japanese War, 1904–1905, and during the World War was appointed Commander of the Black Sea fleet with the rank of rear admiral. He was active in the political life of Russia until his death in 1920.

THE ARCTIC PACK AND THE POLYNYA*

A. Kolchak

Characteristics of the Arctic Pack

By the term "Arctic Pack" I understand the many-years-old ice of the Arctic Ocean, mostly rafted [Russian, *nabivnoi*] and predominantly in the shape of fields, i.e. areas whose limits cannot be seen from a ship's mast. The distinctive characteristics of the Arctic Pack are: its tremendous power, greater than that of the pressure-formed ice in the marginal seas of the Arctic Ocean; its solidity, due to the age, of many years' standing, of these rafted ice formations—a solidity that gradually increases to such a degree that the ice masses look like a compact and homogeneous whole; and, finally, the size of the areas of rafted ice, so large that they represent powerful hummocky ice fields in extent.

The Arctic Pack forms the main mass of the almost continuous ice cover that spreads out over the whole oceanic part of the Arctic Basin. It is in constant slow and complicated motion, as the result of which local shock and pressure of the ice take place on the one hand and, on the other, the formation of polynyas, channels, and cracks.

The ice fields of the Arctic Pack may also consist of areas of many-years-old ice formed by the natural thickening of the ice cover to the extent limited by its conductivity of heat, a limit beyond which the increase of its power must stop. Even in the Arctic seas, as has been mentioned before, the development of extensive intact areas of one-year-old ice is very difficult in the unfrozen part of the sea. The one-year-old ice mostly turns into heaped-up ice, in the course of time changing into many-years-old formations; in summer one can seldom meet with any extensive unbroken areas of one-year-old ice. It is still more difficult to imagine the formation of large areas of ice in the Arctic Pack developing exclusively by natural freezing of the sea water during the period of the predominance of freezing air temperatures. The new ice formed in the polynyas, occasional channels, and cracks throughout the moving powerful ice cover breaks up into pieces under the constant shock, pressure, and squeezing of the old ice, which process produces the heaped-up ice formations that later

* Translation by Messrs. Nicholas George and N. A. Transehe of the American Geographical Society's staff of Chapter 11 of A. Kolchak: Led Karskago i Sibirskago Morei (The Ice of the Kara and Siberian Seas), Résultats scientifiques de l'Expédition Polaire Russe en 1900–1903 sous la direction du Baron E. Toll, Section B: Géographie physique et mathématique, Livraison 1, *Zapiski Imp. Akad. Nauk*, Ser. 8, Phys.-Math. Class, Vol. 26, No. 1, St. Petersburg, 1909.—The last word in the title is also spelled "polynia" in English Arctic literature.

take on many-years-old forms. Thus the greater part of the Arctic Pack consists of heaped-up ice of many years' standing.

The ice fields of the Arctic Pack are usually bordered on their margins by bulwarks and ridges of hummocks formed by the constant collision with similar floating areas. The interior of these fields is covered with piles [*nagromozhdenie*] of ice many years old that has been melted and then reconsolidated, sometimes in the shape of former extensive broken-up areas, sometimes in the shape of shattered bulwarks and hummock ridges. Even and smooth surfaces are met with as exceptions on the fields of the Arctic Pack and usually are associated with the above-mentioned many-years-old formations produced by gradual freezing. In the present work the Arctic Pack is considered only in so far as it influences the ice cover of the Kara and Siberian Seas and the adjacent regions of the Arctic Ocean.

The Limits of the Kara and Siberian Seas

The insufficient exploration of these seas does not yet provide the scientific elements to determine their natural physico-geographical limits, and therefore we have to assume quite conventional lines. For the northern limit of the Kara Sea I take a line drawn from Cape Chelyuskin to Cape Zhelanie, the northern extremity of Novaya Zemlya; this line passes north of Lonely Island and the Nordenskiöld Archipelago.

By the term "Siberian Sea" I understand the water area situated to the east of Taimyr Peninsula, bounded on the south by the coast of Siberia and on the north by a conventional line drawn from Cape Chelyuskin to Cape Anisii, the northern extremity of Kotelny Island. The Lyakhov Islands, together with Kotelny Island, define the eastern limits of this basin. As to the water area situated to the east of the New Siberian and Lyakhov Islands, one may accept as its northern conventional limit a line drawn from Cape Kamennyi, the northeastern extremity of Novaya Sibir Island, to Berry Point or Cape Thomas on Wrangel Island.[1] From the point of view of the formation

[1] Relating to the Siberian Sea, certain geographers have accepted the name "Nordenskiöld Sea" since Nordenskiöld's voyage on the *Vega* in 1878. It is hard to agree with this name, which sometimes appears and then disappears on the maps (on the Russian, British, and American maps it is mostly absent), as there is no sufficient foundation for it, inasmuch as the first navigation in this sea and the skirting of the coast in the same direction as the *Vega* sailed were performed in 1735 and 1736 by Lieutenant Pronchishchev on the sloop *Yakutsk* and the second navigation by Lieutenant Khariton Laptev on the same vessel in 1739 and 1740.

There is no name in geography for the sea to the east of the Lyakhov and New Siberian Islands, and this forces one to give it a separate name. I call it "Yukagir Sea," to commemorate a tribe which, according to tradition, was once very numerous on the shores of this sea and which migrated to some conjectured lands situated to the north of it.

[According to recent Russian official usage the sea between Taimyr Peninsula and the New Siberian Islands is termed Laptev Sea (strictly, Sea of the Brothers Laptev), and the sea between the New Siberian Islands and Bering Strait is termed East Siberian Sea (Kratkiya svyedyeniya po meteorologii i okeanografii Karskago i Sibirskago Morei, i.e. Succinct information on the meteorology and ocean-of the ice cover such limits are quite admissible because, according to all data available, they define a region of the fully developed coastal fast-ice [*beregovoi pripai*], as this does not spread far to the north of Capes Zhelanie and Chelyuskin and the northern coasts of the New Siberian Islands. To the north of the lines mentioned, which conventionally limit the Kara, Siberian, and Yukagir Seas, lies an almost unexplored region, which I call "the frontier region of the Arctic Pack." In this region the Arctic Pack, or more correctly its outskirts, may be met with near the above-mentioned conventional lines and may even pass beyond them to the south. Sometimes the limit of the Arctic Pack moves away to the north of this line, and then the frontier region may be covered with loose mixed ice of marginal-sea and oceanic origin and may even be accessible to navigation.

Region of the Arctic Pack

Before examining the conditions of existence of the ice cover in the frontier region, it is necessary to clear up the approximate limits of the Arctic Pack itself. Where it faces the seas in question the limits are as follows for the following reasons [see map in preceding article].

Opposite Bering Strait the mean limit of the Arctic Pack may be considered as running along the parallel of 71½° N., approximately on a line extending from the northern coast of Wrangel Island to Point Barrow, with considerable fluctuations between 71½° and 73° N.[2] This line was crossed to the north by Kellett in July, 1849, Rodgers in August, 1855, Nye and Soule in 1867, and Berry in September, 1881, who reached nearly 73¾° N. in longitude 171° W. on the schooner *Rodgers*.

Concerning the location of the limit of the pack west of Wrangel Island we have no exact data. However, Lieutenant Wrangel's sledge excursions in 1822 northward from the shores of the Kolyma region, excursions which determined the proportions of the fully developed coastal fast-ice; likewise those of Lieutenant Anjou in 1822 to the east of the New Siberian Islands; as also the *Jeannette's* drift under Lieutenant De Long's command in 1880 in the region of the mobile Arctic Pack—these all give some foundation for supposing that the southern margin of the pack lies to the north of the above-men-

ography of the Kara and Siberian Seas, Hydro-Meteorological Section, Hydrographic Office, Petrograd, 1918, introduction by Y. M. Shokalskii, p. 8).

As to the northeastern boundary of the Kara Sea physical limits may now be substituted for Kolchak's conventional line, namely Northern Land and its possible western termination in lat. 79° N. and long. 82° E. as deduced by Wiese from the drift of the *St. Anna* (see, above, Dr. Nansen's paper, footnote 2, p. 5; on the bathymetric map accompanying that paper the current terminology here discussed is indicated).—Edit. Note.]

[2] Report of Ice and Ice Movements in Bering Sea and the Arctic Basin by Ensign Edward Simpson, U. S. N., U. S. Hydrogr. Office, Washington, 1890. See the map accompanying this report: The Arctic Sea, Wrangel Island to Mackenzie River, showing the northern limit of the southern edge of the ice pack in the years 1879 and 1885–1889.

tioned conventional boundary of the Yukagir Sea, i.e. of the line Berry Point-Cape Kamennyi. Accepting the limit of the Arctic Pack in the longitude of Wrangel Island (approximately 180°) to lie in latitude 72° N., it is possible to assume that on the meridian of 150° E. (near the eastern end of Novaya Sibir Island) it is located in latitude 76° N., passing near Bennett Island. The route of the schooner *Zarya* of the Russian Polar Expedition in 1901 determined the limit of the pack as 10–12 miles to the south of this island, which agrees with the observations of the American expedition on the schooner *Jeannette* in 1881.

Farther to the west the limit of the Arctic Pack bends gradually northward. The position of this limit in 1901, as observed by the *Zarya*, shows that the outskirts of the pack east of Bennett Island gradually bend to the south and, to the west of it, turn to the north, so that it was possible for the *Zarya* to penetrate as far as latitude 77½° N. on the meridian of Faddeev (Thaddeus) Island. In 1893 the Norwegian North Polar Expedition on the *Fram* met the pack in this region in 77¾° N. and passed into it approximately in latitude 78½° N. on the meridian of 138° E. It may be assumed that, as one goes farther west, the limit of the Arctic Pack gradually recedes still more to the north. This limit lies about in latitude 79½° N. on the meridian of Cape Chelyuskin and in 81°–81½° north of Franz Josef Land and Spitsbergen, rising to 82° N. abreast of Greenland and Grant Land. It then descends in a southwestern direction to Beaufort Sea, coming close to the coast [of Prince Patrick Island] of the Parry Islands in latitude 76° N., and then approximately follows the parallel of 72° N. off the northern coast of Alaska.

The limits of this region are defined by the extreme northern points reached by ships on the different meridians. It may be represented schematically, on a map of the Polar Regions, in the form of an elongated ellipse whose major axis corresponds approximately to a line connecting Crown Prince Rudolf Island (Franz Josef Land) with Cape Barrow (north coast of Alaska) and whose minor axis corresponds to a line drawn from Bennett Island to Cape Alfred Ernest (west coast of Grant Land, or Garfield Coast). The point of intersection of these axes lies approximately in longitude 180° and latitude 84° N. The area defined by this ellipse encloses the region permanently covered with the ice fields of the Arctic Pack and inaccessible to navigation.[3] The explorations of Parry, Markham and Parr, Peary, Nansen, Cagni, and especially the drift of the *Jeannette* under Lieu-

[3] It is interesting to note that this is an earlier formulation of the concept which Stefansson later put forth independently as the "pole of relative inaccessibility" (Vilhjalmur Stefansson: The Region of Maximum Inaccessibility in the Arctic, *Geogr. Rev.*, Vol. 10, 1920, pp. 167–172, with map; reprinted as an appendix in his "The Friendly Arctic," New York, 1921). The position which Stefansson assigns to that point, 83° 50′ N. and 160° W., is substantially the same as Kolchak's in expressing the eccentricity of the core of the Arctic toward the Bering Strait side in relation to the mathematical pole.—Edit. Note.

tenant De Long and that of the *Fram* under Sverdrup's command, give a fairly clear conception of the nature and character of the ice in this region. The limits of the Arctic Pack are in general subject to considerable fluctuation, depending upon the configuration of the coasts and the direction of the winds and currents.

There is no doubt that, under the influence of these factors, the area of the pack is considerably expanded to the south, beyond the above-mentioned limits, in which direction its ice masses are continually being driven off. This fringe of ice is what I have called above "the frontier region of the Arctic Pack," which is sometimes accessible to navigation, owing to the more open condition of the ice. The perimeter of the above-mentioned ellipse should be taken rather as the innermost limit of the Arctic Pack, as the ice is constantly descending upon the coasts of the Parry Islands; filling Beaufort Sea in its approach to the coasts of Banks Island and Alaska; projecting into the northern part of the Yukagir Sea; approaching close to the northern shores of the New Siberian Islands; spreading into the Siberian Sea, which is open from the north; coming close to Cape Chelyuskin; attaining the northern limit of the Kara Sea; and going even far south of Franz Josef Land, perhaps as far as Cape Zhelanie in Novaya Zemlya. The ice fields from this region fill the space between Franz Josef Land and Spitsbergen and are carried out by a powerful current into the Greenland Sea, which is the area into which the greater part of the mass of the Arctic Pack discharges.

The Kara and Siberian Seas and other waters contiguous to the Arctic Ocean produce new masses of ice every year, some of which melt away during the summer, while others become telescoped and take on the form of many-years-old ice; to these are added the fragments of the Arctic Pack coming down from the north. This mixed ice is in part carried off again to the north and in part remains where it is, forming the local pack of that part of the sea; and it does not partake in the motion of the body of the Arctic Pack itself but is shifted to and fro by the local winds and currents.

The Motion of the Arctic Pack

There are so few data about the motion of the Arctic Pack that every suggested explanation has the character of an hypothesis, with a greater or less approximation to the truth. Examining the region of the Arctic Pack within the limits of the above-mentioned elliptic curve, we see that, in the part of the ellipse facing the Siberian coast, the drifts of the *Jeannette* and *Fram* would seem to coincide with the direction of its periphery, approximately paralleling it between longitudes 175° W. and 20° E. This parallelism is especially evident in the direction of the *Jeannette* drift in the stretch between Herald Island

and Bennett Island and in the part of the *Fram* drift from its beginning to the meridian of Cape Chelyuskin, beyond which point the *Fram's* course took a more northerly direction.[4] Lieutenant Cagni's explorations in 1900 to the north of Crown Prince Rudolf Island confirm the general western character of the motion of the ice cover.

Observations of the motion of the pack north of Spitsbergen also indicate a western direction, with a tendency to deviate to the south.

North of the coast of Greenland the motion of the pack has a very complicated character. Peary's explorations indicate that the southward-flowing East Greenland Current exerts a great influence. We have still fewer data about the motion of the pack west of Grant Land (75° W.). The same may be said of Beaufort Sea and the region north of the Alaskan coast.[5] The tracks of Franklin's, Collinson's, and McClure's vessels lie in a narrow zone near the shore and give no definite information as to the motion of the ice. There is evidence that the bark *Young Phoenix*, set adrift after she had been abandoned by her crew near Cape Barrow, was carried first to the east almost to the meridian of Return Reef [149° W.], then backwards to the west to Cape Smith [157° W.] near her starting point, and then disappeared in a northwest direction.[6] But the drift of this bark was also limited to the zone near shore.

All existing data give us the right to suppose that the motion of the Arctic Pack between the meridians of Herald and Bennett Islands is directed approximately to the west-by-north and west-northwest and between the meridians of Bennett Island and Franz Josef Land to the west-northwest and that it maintains its western direction still farther west. To state positively what are the causes of this motion, whether permanent currents or winds or both together, is as yet impossible. We have data only about the littoral currents, which generally have the character of tidal currents or are due to the masses of fresh water carried to sea by the rivers.

Two currents seem to proceed out of Bering Strait. One goes along the Siberian coast to Cape Serdtse Kamen and farther to the northwest toward Herald Island. The other is directed along the American coast, and farther on it takes a northwestern direction. The two currents push away the edge of the pack toward the north. The edge projects far to the south between them, making a meeting place for whaling ships cruising near the margin of the pack called Post Office Point.[7]

The powerful flow of the East Greenland Current and the current

[4] Now that our knowledge of Northern Land seems to make it probable that the edge of the Arctic Pack swings backward farther than Kolchak thought (see map in preceding article, Fig. 1,) this parallelism would seem to hold for the whole drift of the *Fram*.—Transl. [N. A. T.'s] Note.

[5] Since this was written, the drifts of the *Karluk*, of Storkerson, and of Wilkins (1927) have thrown light on the currents in this area.—Transl. Note.

[6] Simpson, *op. cit.*, p. 19.

[7] *ibid.*, pp. 12, 14.

moving southward in the straits of western Greenland [Robeson Channel to Smith Sound] has its origin in the region of the Arctic Pack. This region closely approaches the northern coast of Greenland and Grant Land, but it is not known whether these currents are in any way connected with the weak and changeable currents flowing northward out of Bering Strait.

The drift tracks of the *Jeannette* and *Fram* afford no conclusive proof of the existence of a definite current in the region of the Arctic Pack through which they passed. They rather justify the belief that the motion of the ice may be the result of the action of the winds prevailing in that region during a given period. It seems probable that winds are the cause of the general western direction of the motion of the Arctic Pack to the north of the Asiatic continent—a motion that is very irregular and complicated in detail but is maintained in that direction as a result of the winds. The drift of the *Jeannette* and of the *Fram* showed that the speed and direction of this motion change all the time, especially near the border of the pack; and this will probably be the experience, during the first years of their drift, of any ships that get into the pack. As we go from the border into the interior of the pack the motion becomes faster and the direction more definite.

Beginning at a meridian passing to the east of Spitsbergen the motion of the pack shows a tendency to deviate to the south in the direction of the Greenland Sea. North of Greenland according to Peary's explorations the motion of the pack has a southerly tendency, at least up to about latitude 84°, Peary having observed in 1900 a southward motion of the pack in latitude 83° 50′ N. under the influence of the East Greenland Current. To the north of Grant Land, in latitude 84° 17½′ N., Peary speaks in 1902 of an eastward motion of ice fields.[8] Peary's observations of the motion of the pack, however, have the character of separate, occasional observations which in no way exclude the possibility, nay, even the predominance of a westward motion of the pack. We can only say with certainty that off Grant Land and farther to the west the motion of the pack has a southern tendency and that its ice masses approach the shores of the Parry Archipelago and fill up Beaufort Sea, leaving only a free narrow zone close to shore for navigation. This part of the Arctic Ocean seems to have a very indefinite and weak motion, perhaps in the same general westerly direction, and it represents the region of maximum shock and pressure of the ice owing to the direction of the drift toward the shore.

The region of the Arctic Pack is, as above mentioned, divided into two halves by the line Point Barrow-Crown Prince Rudolf Island.

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8 Commander R. E. Peary, U. S. N.: Field Work of the Peary Arctic Club, 1898–1902. [Mimeographed report, New York, 1903; published under the title "Report of R. E. Peary, C. E., U. S. N., on Work Done in the Arctic in 1898–1902" in *Bull. Amer. Geogr. Soc.*, Vol. 35, 1903, pp. 496–534, also as Chapter 15 of Peary's "Nearest the Pole," New York, 1907.]

One half faces the Asiatic continent, and the other for the most part faces the American continent. In the first half the drift of the pack seems to have a northwestern direction away from the coast. In the second half the motion of the ice has been too little studied, and we cannot speak about it definitely. At all events, the motion of the Arctic Pack in this latter region has a clear tendency to movement south towards the shores of the American Arctic Archipelago, while perhaps at the same time maintaining a general western direction.

The motion of the ice on the Asiatic side seems to depend on the winds, being in close connection with the distribution of the atmospheric pressure in Siberia.

During most of the year the great barometric high-pressure area of northeastern Asia is the fundamental factor controlling the atmospheric processes of the adjacent regions. A low-pressure area occurs in the Greenland Sea approximately at the same time. These two areas of high and low pressure determine the direction of the motion of the atmosphere in winter, producing in the northern part of the Asiatic continent and the adjacent region of the Arctic Ocean southern, southeastern, eastern, and finally, north of Spitsbergen, northeastern winds. It is these winds that cause the ice to drift toward the northwest, a direction that gradually changes to west north of Franz Josef Land and southwest north of Spitsbergen. The changes of the wind influence the direction of the drift, which at a given moment may have any direction, but the resultant force of all these partial motions will be a northwestern movement, determined by the flow of air from the area of high pressure to the area of low pressure.

Lieutenant Wrangel's observations in Nizhne-Kolymsk, Jürgens' expedition to the mouth of the Lena River,[9] and also observations of the Russian Polar Expedition of 1900–1903 show the predominance of southeastern winds during autumn and winter.

The decrease of pressure over the Asiatic continent in summer often produces winds from the northern half of the compass near the Siberian coast. These winds fray out the edge of the pack and force the ice masses toward the south into the northern parts of the marginal seas of the Arctic Ocean.[10] North of Greenland the motion of the ice in winter, besides being influenced by north and northeast winds, is affected by the powerful flow of the East Greenland Current. What causes this current is still unknown. There may be some relationship with the Gulf Stream, whose warm water was found by Nansen in the Asiatic region of the Arctic Ocean at great depths, and the East Greenland Current may represent the draining off of the waters

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[9] To establish one of the international circumpolar stations (Sagastyr) sponsored by Russia.—TRANSL. NOTE.

[10] It is worth noting that the *Jeannette* stayed almost in the same position in latitude 74° N. and longitude 180° from April to November, 1880, i.e. approximately during the absence of the area of high pressure in northeastern Asia.

of the Polar Basin supplied by the Gulf Stream, the currents coming from Bering Strait, and the masses of fresh water carried into it by the Siberian and American rivers.

As to the region of the Arctic Ocean washing the coasts of the American Arctic Archipelago and Alaska (Beaufort Sea), it seems to be outside of the influence of definite winds and currents, being situated in a so-called "wind divide" going from Bering Strait to the northern coast of Greenland.[11]

The predominant winds on the northern shores of the Parry Archipelago are mostly northerly. Lieutenant P. H. Ray's observations at Point Barrow[12] also show the predominance of the northerly winds. Probably the Arctic Pack is densely compressed in this region and consequently affords a most favorable condition for the formation of powerful heaped-up ice masses.

Considering in their combination all movements of the Arctic Pack in the different regions it seems probable that a certain rotary motion exists around a center situated somewhere between latitudes 83° and 85° N. and longitudes 170° and 180° W. As I have already mentioned, there is no ground for supposing that this circular motion has a definite speed and direction, but it should rather possibly be considered a motion of ice masses that did not get into the East Greenland Current and were not carried away to the southern marginal seas of the Arctic Ocean and that after a certain period complete the circuit and appear again approximately on the same spot. Consequently the masses of ice are likely to stay in the Arctic Basin for an indefinite time undergoing the changes caused by the character of this basin. There is also no reason to suppose that this motion is general for the whole mass of the Arctic Pack. It probably is different in different regions at the same moment, producing local compacting and loosening of the ice as the case may be, but the resultant of all the forces governing these motions will have a single more or less definite direction. The consideration of the motion of the Arctic Pack also shows that in places where there are obstacles in its way the ice is always compressed and the sea inaccessible to navigation. Such places are, for example, the eastern coast of Franz Josef Land and the northeastern coast of Greenland.

This circumstance is particularly noticeable in comparing the conditions of navigation of the vessel met by the *Tegetthoff* of the

[11] Report on the Scientific Results of the Voyage of H. M. S. Challenger During the Years 1873–76 under the command of Captain George S. Nares R. N., F. R. S., and the late Captain Frank Tourle Thomson, R. N., prepared under the superintendence of the late Sir C. Wyville Thomson and now of John Murray: Physics and Chemistry, Vol. 2, 1889, polar maps of atmospheric circulation [accompanying Alexander Buchan's Report on Atmospheric Circulation, 269 pp., 52 maps]; especially important Map 52: Isobaric lines of the North Polar Regions for the Year.

[The first formulation of the concept of an Arctic wind divide was made by Supan on the basis of Buchan's maps; see Alexander Supan: Die arktische Windscheide und die modernen Polarprojekte, *Petermanns Mitt.*, Vol. 37, 1891, pp. 191–195, with map, Pl. 14.—Edit. Note.]

[12] At the international circumpolar station established by the United States.—Transl. Note.

Austrian Polar Expedition under Weyprecht's command with those experienced by the *Stella Polare* under the Duke of the Abruzzi. The *Tegetthoff* was held fast in the ice and lost the possibility of independent movement, having been caught in the pack in latitude 76½° N., and was finally abandoned by the members of the expedition at the southeastern coast of Franz Josef Land. The *Stella Polare*, going through British Channel on the western side of Zichy Land in the Franz Josef Land archipelago, steamed north beyond 82° N. to a point west of Crown Prince Rudolf Island and found the sea almost free from ice. The same impassableness and inaccessibility for navigation obtain on the outskirts of the Arctic Pack off the American coasts, with its tendency to exert pressure on the shore. The rate of motion of the Arctic Pack is only known in its Asiatic half. The drifts of the *Jeannette* and *Fram* give reason to suppose that it would require about five years for a piece of ice to cover the distance from Herald Island to the longitude of the Greenland Sea, where it can get into the East Greenland Current and be carried out of the Polar Basin into the Atlantic Ocean. Probably only a part of the ice cover of the Arctic Ocean is discharged in this way to the south. The other, possibly greater, part is carried farther to the west and enters the region of constant shock and pressure north of the American continent. As to how long and in what way it continues its motion in this region nothing can be said because of lack of exploration.[13]

Paleocrystic Ice, Floebergs, and Heaped-Up Ice Fields

The only evidence confirmatory of this hypothesis of westward movement is the character of the ice in the region of the Arctic Pack abreast of eastern Asia. De Long, who first penetrated that region,

[13] One more circumstance may influence the direction of the motion of the pack—the deflection caused by the rotary motion of the earth as expressed in Baer's Law. Assuming that a definite northward drift of the ice exists off Siberia, one may suppose that with increasing latitude this drift, deviating to the east, will take on a more northerly direction. Comparing the drift of the *Jeannette* between longitudes 150° E. and 180° with the drift of the *Fram* between 70° and 135° E. we seem to find the said hypothesis confirmed. The drift of the *Jeannette* up to latitude 77° N. generally has a west-northwest direction; the direction of the *Fram* drift between latitudes 79° and 85° N. on the average approximates northwest. In any case, the importance of Baer's Law for the motion of the pack is not great since this motion has no strictly definite character either in its direction or its speed. The Arctic Pack represents a hard and only slightly elastic cover in which through contact, so to speak, the motions produced by local causes, storms, for instance, may be propagated to considerable distances. The motion of the ice masses, having started in some definite place, is transmitted to extensive areas, spending itself partly on the breaking up and piling up of ice, partly on the imparting of speed to the masses of ice. This circumstance undoubtedly much complicates the shifting of the ice fields in the interior of the Arctic Pack.

[The views here expressed should be read in the light of those set forth by Nansen in Chapter 5 of his "The Oceanography of the North Polar Basin" (The Norwegian North Polar Expedition 1893–1896: Scientific Results, Vol. 3, No. 9) Christiania, 1902, especially the sections (c and e) dealing with the effect of the earth's rotation on the drift of the ice and the deflection of currents with increasing depth, to the latter of which subjects, as investigated by Valfrid Ekman, Dr. Nansen briefly refers in his paper above (p. 11). For the standard survey and discussion of the different theories of ocean currents see Otto Krümmel: Handbuch der Ozeanographie (2 vols., Stuttgart, 1907 and 1911), Vol. 2, Ch. 3, Section 3.—Edit. Note.]

draws attention to the power and character of the ice, resembling the formations in the sounds of the American Arctic Archipelago, and calls it paleocrystic.[14] This term, introduced into science by Nares, was intended by him to designate compact ice formations resembling in size and power fragments of inland or glacier ice but, according to Nares's opinion, actually formed by the heaping up of floating masses of ice of sea origin. Greely controverted this opinion of Nares as to the possibility of the existence of paleocrystic ice in the shape of floebergs, considering the latter to be ordinary glacier ice,[15] but I think there are no grounds for denying the existence of the forms of ice described by Nares and confirmed by De Long's observations. During my expedition to Bennett Island in 1903 I observed ice near this island which perfectly corresponded to De Long's descriptions.

Observing the results of shock in the autumn ice of the Siberian Sea in the form of many-years-old grounded hummocks [Russian, *stamukhi*] 60 to 80 feet thick, one may assume that the shock of the ice fields of the pack is capable of producing much greater effects and forming many-years-old heaped-up masses not only out of the thin ice 2 to 3 feet thick but out of old fields 12 to 14 feet thick. A floating mass of ice 30 feet high above sea level, such as reported by Nansen and Weyprecht, may have vertical dimensions up to 200 feet; such a many-years-old formation, being transported to a shallow place, will look like a paleocrystic floeberg. Near the southern coast of Bennett Island I observed quite compact masses of ice of undoubtedly heaped-up formation grounded at depths of 9 to 10 fathoms and having vertical dimensions up to 80 feet over all. Peary (denying, however, the existence of paleocrystic floebergs and considering them to be parts of glaciers) had occasion to observe grounded hummocks up to 100 feet high and more formed by the shock of the pack near Cape Washington at the northern end of Greenland. He also mentions a hill 50 feet high on an old ice field.[16] As to the average thickness of the heaped-up many-years-old fields of the Arctic Pack one may assume it to amount to as much as 100 feet, in keeping with Hall's testimony, who met such fields during the *Polaris* expedition of 1860–1861 near Smith Sound. Simpson[17] mentions a case near the north coast of Alaska where a many-years-old field that projected only a few feet above the water grounded on a shoal and through the pressure of the pack rose up to the height of the foreyard of a near-by bark, i.e. 40 to 45 feet. My measurements and observations showed thick-

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[14] Emma De Long, edit.: The Voyage of the Jeannette: The Ship and Ice Journals of George W. De Long, 2 vols., Boston, 1897, p. 614 (in Vol. 2).

[15] A. W. Greely: Three Years of Arctic Service: An Account of the Lady Franklin Bay Expedition of 1881–84 and the Attainment of the Farthest North, 2 vols., New York, 1886; reference in Vol. 2, Chapter 33 (Polar Ice), pp. 43–60.

[16] Peary, *op. cit.*

[17] Simpson, *op. cit.*, p. 6.

nesses of 30 to 40 feet to be of usual occurrence among fragments of these heaped-up ice fields in the region north of the New Siberian Islands.

The Pack of the Kara Sea As a Local Formation

In considering the ice cover of the Kara and Siberian Seas one cannot help noticing a very sharp distinction between the character of the ice in these two water basins. Observations show that the greater part of the ice of the Kara Sea is formed in that sea itself and that the ice of the Arctic Pack can be met with only in its northern end, whither it is carried as separate fragments, strikingly different in thickness and shape from the local ice. North of the Kara Sea the edge of the Arctic Pack lies considerably to the north, and only seldom during winter does it approach the latitude of Cape Chelyuskin, for this edge in winter is usually pushed back by the predominant southern winds to its northernmost limits. The absence of considerable masses of heavy heaped-up ice leads to less active ice formation during the winter, and in the Kara Sea the process of hummocking generally produces much less effect than in the Siberian Sea, for example. The Kara Sea has greater depths than the Siberian Sea, which do not allow the formation of numerous grounded hummocks, and correspondingly it has a less wide zone of immobile fast-ice near the shore. The conditions of ice formation in the Kara Sea are favorable to the development of extensive smooth areas of ice, some of which, by being cemented together by frost, are transformed into many-years-old formations. Many old fields that I had occasion to measure and that were 5 to 8 feet thick at the end of the period of melting, were quite level and showed no trace of heaped-up ice. The one-year-old ice of the Kara Sea has a thickness from 3 feet to 1 foot at the end of summer, depending on the conditions of melting, and it gradually reaches the limit of thickness of summer ice formed by natural freezing, a limit determined by Weyprecht as 8½ feet at the end of the period of melting. Part of the ice is certainly transformed into heaped-up masses, usually consisting of ice, 1 to 1½ feet thick, from the autumn break-up; their thickness seldom exceeds 12 to 14 feet, although separate hummocks may be as much as 10 to 12 feet high above sea level and 50 to 60 feet thick. Fragments of hummocks grounded at depths of 4 to 5 fathoms are rather usual, and many are found on the 3-fathom line. The ice of the Kara Sea generally has no such distinctive eroded forms as the heavy ice of the Siberian Sea, as it does not rise much above the water; the ice fields and their parts contain smoother areas; in the coastal fast-ice, areas of broken-up hummocks predominate; grounded and floating hummocks are usually gathered at points of the shore that project into the sea, such as capes, inshore islands, etc.; the hummocks of the open sea due to the breaking up of large areas are frequent, whereas the forms due to crushing are found relatively less often than in the Siberian Sea. The difference in the character of ice between the Kara and Siberian Seas is very noticeable near Cape Chelyuskin. Approaching this cape from the west one can observe a sharp change in the floating ice: namely east of the cape one meets more and more frequently thick many-years-old masses of ice that indicate their northern origin and the greater pressure to which they have been subjected. High grounded fragments of various forms alternate with broken fields 18 to 20 feet thick with a very irregular surface covered by hillocks and depressions often filled with clear fresh water. As one approaches the edge of the Arctic Pack, the ice becomes thicker and thicker, until finally one sees extending beyond the horizon compact fields covered with ridges and hills of hummocks and along their margins with piles of fresh broken ice.

The nearness of the edge of the Arctic Pack, which sometimes descends to the northern coast of the New Siberian Islands and detaches masses of its many-years-old heaped-up ice into more southern parts of the Siberian Sea, gives to the ice of this sea an appearance sharply distinct from the ice of the Kara Sea. Many-years-old ice of oceanic origin, taking part in the motion of the ice of local formation, increases its mass and produces greater effects of shock and pressure; this circumstance, in connection with the shallowness of the sea, is mainly expressed in the form of grounded hummocks and prevents the development of large areas of smooth ice, and this in turn produces heaped-up formations that are readily changed into many-years-old forms.

In general one may consider the mass of ice of the Kara Sea that forms the pack of that sea as consisting of the fields of old ice of local origin, whereas the pack of the Siberian Sea is of mixed formation, namely local, almost exclusively heaped-up ice combined with ice brought from the nearest region of the Arctic Pack.

The Phenomenon of Polynya[18]

Beyond the limits of the ice cover, immovable in winter, that forms the fully developed coastal fast-ice, about which we spoke above in Chapter 5[19], the ice is in motion during the whole year. This motion, depending as it does on winds and currents, may be directed either towards the coastal fast-ice or away from it toward the sea. According to which of these two takes place one will meet, at the

[18] Possibly the first presentation in a Western European language of the deductions outlined by Kolchak in this section (without specifically ascribing them to him, however) will be found in J. Schokalsky: La circulation dans les couches superficielles de la Mer Polaire du Nord, *Ann. de Géogr.*, Vol. 33, 1924, pp. 96–104; reference on pp. 102–103 and map.—Transl. Note.

[19] Chapter 5: The Coastal Fast-Ice and Its Development in Its Dependence on the Configuration of the Coast, the Relief of the Bottom, and the Formation of Stranded Hummocks, or *Stamukhi*, pp. 64–77.

edge of the immovable ice cover, either with the phenomenon of ice shock and pressure or else with various degrees of loosening of the floating ice masses up to an entirely open space of water. This last is called *polynya*. Of course, the phenomenon of polynya can be observed wherever there is a floating ice cover capable of motion, while the size of the polynya will depend on the shifting of the margin of floating ice, which shifting is connected with the immediate motion of the ice and also with the phenomenon of hummocking and heaping up of ice masses.

Undoubtedly the Kara Sea offers conditions under which the formation of a more or less considerable polynya will take place on the margin of the coastal fast-ice, but one may assume that such polynyas will be closely related to the direction of the wind and will not be extensive in development. In fact, the phenomena of hummocking and heaping-up of ice, which bear on the size of polynyas according to the observations in the Kara Sea, do not take place on so large a scale in this basin as in the Siberian Sea, the latter being a shallow open gulf of the Arctic Ocean. To our regret all consideration of the polynyas of the Kara Sea must remain in the domain of hypothesis owing to an almost complete lack of observations. Quite different, from this point of view, is the polynya that follows the edge of the coastal fast-ice of the Siberian and Yukagir Seas, in particular north of the New Siberian Islands, which, together with the Lyakhov Islands, lie within a vast area occupied by an immovable ice cover that extends from the Siberian coast. The attempts of the first explorers of the New Siberian Islands, Ustyansk tradesmen, to penetrate beyond them to the north in their search for new lands—attempts which were connected with the monopoly of the trade in mammoth tusks and Arctic fox pelts—met an unsurmountable obstacle in the fact that the open sea begins several miles from the northern coast of the New Siberian Islands.

The explorations of Hedenström, Pshenitsyn, and chiefly of Lieutenant Anjou's expedition in 1820–1824 confirmed this discovery, and the fact of the existence of a polynya in the north of the Siberian Sea became established beyond doubt. Farther to the east sledge journeys on the ice by Kolyma tradesmen and the explorations of Lieutenant Wrangel's expedition in 1820–1824 showed the existence of a polynya beyond the limit of the wide immovable zone of ice off the coast of the Kolyma region.

The recent explorations of the Russian Polar Expedition of 1900–1903 on the *Zarya* and on sledge trips made by myself, Lieutenant Mattisen, and Engineer Brusnev north of the Byelkovski, Kotelny, Faddeevski (Thaddeus), and Novaya Sibir Islands are in complete accord with the information about the existence of a polynya north of the New Siberian Islands based on the reports of Hedenström, Pshenitsyn, and Anjou and give reason to suppose that the polynya in question does not represent an accidental phenomenon but is in close connection with local factors defining the motion of the ice in this region.

The fact that this New Siberian polynya undoubtedly is continuous with the polynya explored by Lieutenant Wrangel that lies farther southeast (which we may call the Kolyma polynya for short) is sufficiently explained if the physico-geographical conditions of the region of the Arctic Ocean where this polynya occurs are taken into consideration.[20]

The New Siberian polynya lies on the border between the fully developed coastal fast ice and that part of the edge of the Arctic Pack that is close to the New Siberian Islands. The average position of the edge of the Arctic Pack passes near Bennett Island (1901), but this edge may come very near to the New Siberian Islands (1902) or move away to beyond the latitude of Bennett Island, e.g. 77° N., as was the case in 1903 during my expedition to this island.

When speaking of the motion of the Arctic Pack, I mentioned above that the exploration of this region of the Arctic Ocean gives reason to suppose that the drift of the ice has a west-northwestern and a northwestern direction, i.e. it moves away from the northern coast of the New Siberian Islands. As a result of this motion an open space of water will be found between the margin of the immovable coastal fast-ice and the moving ice fields of the Arctic Pack, the size of which space will stand in close connection with the position of the edge of the pack. Namely, under continuous northern winds that edge may closely approach the margin of the coastal fast-ice, in which case the polynya will disappear and in its place there will be formed a more or less hummocked, compactly joined ice cover, which, if the wind changes, will again move to the north and be replaced by an area of ice-free water, i.e. a polynya. Such shifting back and forth of the edge of the pack continues during the whole winter, as is indicated by the character of the ice heaps on the margins of the coastal fast-ice which are made up of unusually heavy (up to 2 meters in thickness) broken-up ice dating from April and May—heaps that are paralleled in front by hummocks of ice of varying thickness. These bordering hummocks are usually mixed with fragments of the many-years-old ice, and their dimensions testify to the tremendous shock and pressure that takes place from the side of the Arctic Ocean.

The size of the New Siberian polynya must be greatest in winter, because at that period we may assume that the edge of the Arctic Pack is moved to the north by the winds that result from the distribution of atmospheric pressure over the Asiatic continent, i.e. winds predominantly from the southeast and east in December, January,

[20] A more detailed discussion of the location of this polynya is contained above in Chapter 5, where the development of the coastal fast-ice is dealt with.

and February. Beginning with April we may expect greater fluctuations in the position of the edge of the Arctic Pack and accordingly greater changes in the dimensions and shape of the polynya; this is shown by the fact that the bordering fragments of ice mostly consist of powerful pieces of spring ice. To our regret there have been no winter explorations of the polynya, and all observations of this phenomenon refer to March, April, and May and are not of a systematic nature; therefore we have to base our consideration of the polynya on more or less probable suppositions.

The formation of the polynya is closely related to the position and configuration of the coast in connection with the direction of the motion of the Arctic Pack. Opposite the Siberian coast between longitudes 180° and 130° E., in which stretch the existence of the polynya is completely proved, there is every reason to suppose that the general motion of the pack is directed from the coast to the northwest. As to the other parts of the Arctic Ocean we may mention the following facts. Lieutenant Cagni's sledge trip on the Duke of the Abruzzi's expedition in 1900 north of Franz Josef Land from Crown Prince Rudolf Island to 86° 33′ N. established the fact that the drift of the Arctic Pack is directed to the west along the northern coast, so to speak, of Franz Josef Land. Accordingly Lieutenant Cagni's trip furnishes no evidence of any special shock and pressure of the ice against this shore nor of the existence of a polynya. The eastern coast of Franz Josef Land, however, is subjected to the shock and pressure of ice due to the westward direction of the motion of the Arctic Pack, here also confirmed by Weyprecht and Payer's expedition.

It should be noted that the sledge journeys of Nansen and Cagni indicate a relatively weak pressure and shock of the ice within the Arctic Pack, the motion of which west of the longitude of Franz Josef Land has a western and southwestern direction, a motion which is unimpeded by any obstacles and which is partly directed towards the open Greenland Sea.

Shock and pressure of the ice against the shore are known from the northern coast of Greenland and the coast of Grant Land; they are due to the motion of the Arctic Pack in relation to the position of the coast. The sledge journeys by Markham and Parr of Nares's expedition, by Lockwood and Brainard of the Greely expedition, and the most recent explorations by Peary all point to a tremendous development of hummocking and heaping up of the ice in the adjoining part of the Arctic Ocean. It is true that Peary's explorations report the existence of polynyas beyond 84° N., i.e. within the region of the Arctic Pack itself, but it seems that there are no signs of open water near the coast mentioned.

Under the influence of the southern current passing through Robeson and Kennedy Channels into Kane Sea and farther through

Smith Sound into Baffin Bay, polynyas are formed in these straits and basins during the whole winter, and the deep Kane Sea, in spite of its small dimensions, does not become covered by an immovable ice sheet, these polynyas having an entirely local character. As to the region of the Arctic Ocean situated opposite the American Arctic Archipelago and the coast of Alaska, the masses of the Arctic Pack in this region are solidly crowded together, and the direction of their motion produces shock and pressure of the ice. In connection with the hypothesis here presented one cannot expect to find there anything similar to the Asiatic polynya along the edge of the Arctic Pack with its general offshore motion.

In any case the Asiatic polynya does not appear to be a strictly rigid phenomenon, because it is completely dependent on the shifting of the Arctic Pack, which is generally very irregular and complicated in its direction and rate of motion in different seasons of the year. Thus the polynya may have greater or less breadth and sometimes disappear completely when the edge of the pack moves close to the coastal fast-ice. The conditions in the Asiatic sector are favorable to its development; the opposite is the case in the American sector, where, if the polynya exists, it is only as a temporary, coastal phenomenon produced by local conditions, as for instance by a storm, and where it scarcely even develops to an extent similar to that of the Kolyma and New Siberian polynyas. The problem of the existence of polynyas within the Arctic Pack itself is beyond the limits of the present work. The drifts of the *Jeannette* and of the *Fram* and the Parry, Nansen, Cagni, and Peary expeditions offer material for the basis of a judgment as to the nature of the Arctic Pack in various latitudes from the longitude of Lincoln Sea (60° W.) to the east as far as the longitude of Bering Strait (170° W.). There remains an absolutely unexplored region situated north of the American continent and the American Arctic Archipelago, and final deductions about the nature of the Arctic Pack cannot be drawn until exploration of the ice cover in that region has been made.

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UNSOLVED PROBLEMS IN ARCTIC PLANT GEOGRAPHY

John W. Harshberger

As a phytogeographer, I have been asked the question, What are the unsolved problems of Arctic plant geography which the botanist, ecologist, and phytogeographer who contemplates joining an Arctic expedition might attempt to solve?

Botanical Evidence Bearing on the Viking Landfalls

First, we may consider the problem of the Viking landfalls in America. The botanical evidence has been presented admirably by M. L. Fernald,[1] who, in a study of the distribution of those plants that have been most depended upon to locate Wineland the Good, viz. "vinber," "hveit," and "mosurr" wood, instead of being (1) the grape, (2) maize or wild rice, and (3) the maple (some of which species, by their known distribution, exclude from consideration all coastal regions north of the Maritime Provinces of Canada) has determined that they are in reality respectively (1) the mountain cranberry (*Vaccinium Vitis-Idaea*) or possibly one of the native currants, (2) the strand wheat (*Elymus arenarius*), and (3) the canoe birch (*Betula papyrifera*). This conclusion removes the discrepancies which have been considered to be insurmountable in locating Wineland the Good by the aid of the plants mentioned in the sagas.

There is another line of approach which ought to be considered by botanists, the time for which is now ripe, and that is to study the botanical aspects of the archeological investigations of the ruins, known to their ancestors, which the Eskimos attribute to white men. The remarkable discoveries of costumes in Viking coffins at Herjolfsnes,[2] at the southern extremity of Greenland, with wooden crosses laid on the breasts of the dead, together with the ruins of buildings near which are found the seeds and fruits of plants used by the early followers of Eric the Red, suggest that similar objects may be found among the ruins of the American coast nearest to the early settlements in Greenland. We know that cereals and fruits were carried about in ships of the Viking age from the plant remains found in the Oseberg

[1] M. L. Fernald: Notes on the Plants of Wineland the Good, *Rhodora*, Vol. 12, 1910, pp. 17–38.

[2] Poul Nörlund: Buried Norsemen at Herjolfsnes: An Archaeological and Historical Study, *Meddelelser om Grønland*, Vol. 67, 1924, pp. 1–270; *idem:* The First Scandinavian Settlers in Greenland, *Amer. Scand. Rev.*, Vol. 11, 1923, pp. 547–553. See also William Hovgaard: The Norsemen in Greenland: Recent Discoveries at Herjolfsnes, *Geogr. Rev.*, Vol. 15, 1925, pp. 605–616.

ship[3] now in the museum of Oslo, Norway. One of the unsolved problems of phytogeography would approach solution if expeditions directed to these regions would pay particular attention to the plant remains, if such exist, in the form of wood, fruits, seeds, and other vegetable relics and also to the possible existence of living plants about these ruins whose introduction to the American coast could be traced to the Norse Vikings. On such an expedition a scientific assistant, preferably a trained botanical collector, should gather all the plants within proximity of the ruins to be excavated. The evidence, thus gathered, may be negative, and yet, if the *kvan* (Angelica) were found, it would be evidence of former culture of that plant on these inhospitable coasts.[4] This line of botanical evidence was suggested to William Hovgaard, who has given us the results of his investigation in an interesting volume,[5] and he heartily approved of it. Wherever Norse Vikings landed and had temporary, or permanent, abodes we may expect to find living descendants of the plants, or remains of plants, introduced by the Northmen. After a careful sifting of the evidence and an enumeration of the plants introduced by the Northmen into Greenland, Ostenfeld says:[6] "We may thus reckon, with some degree of probability, that one-eighth (abt. 13 p.c.) of Greenland's 390 species of vascular plants were brought into the country through the old Norse colonisation." There is all the more reason, therefore, for the careful collection of plants where Norse ruins are found to the west of Baffin Bay and Davis Strait and on the Labrador coast.

Means of Dispersal of Circumpolar Plants

There is an important problem as to the means of dispersal of the circumpolar plants which, if we adopt the usually accepted theory, were forced southwards during the Glacial Period and became located in the higher mountains outside of the Arctic Regions.[7] Some of these plants migrated northward when the continental glaciers receded. What were the actual means of migration? Knud Andersen, who studied the contents of the intestines of migratory birds killed by flying against the lights of Danish lighthouses, found them empty, nor were any seeds found adhering to these birds.[8] On the other

[3] A. W. Brögger: The Oseberg Ship, *Amer. Scand. Rev.*, Vol. 9, 1921, pp. 439–447; reference on p. 442.

[4] J. W. Harshberger: The Gardens of the Faeroes, Iceland, and Greenland, *Geogr. Rev.*, Vol. 14, 1924, pp. 404–415.

[5] The Voyages of the Norsemen to America, American Scandinavian Foundation, New York, 1914.

[6] C. H. Ostenfeld: The Flora of Greenland and Its Origin, *K. Danske Videnskab. Selsk. Biol. Meddelelser*, Vol. 6, No. 3, Copenhagen, 1926, p. 17.

[7] Fernald in a recent monograph (see, below, footnote 20) presents evidence for the persistence of plants in unglaciated areas of Arctic America.

[8] Communicated in C. H. Ostenfeld: Phytogeographical Studies Based Upon Observations of Phanerogamae and Pteridophyta, p. 117, in: Botany of the Faeroes Based Upon Danish Investigations, Part I, Copenhagen, 1901.

hand, H. W. Henshaw[9] believes that birds are the most important of nature's seed carriers, for viscid and hooked seeds become attached to their plumage and in mud attached to their feet and feathers. The writer agrees with Professor Henshaw. He has seen robins eat pin-cherry fruits (*Prunus pennsylvanica*) and void the undigested stones. He has seen the tree swallow eat the fruits of the bayberry (*Myrica carolinensis*) and void the fruits, minus the waxy coat; and crows are responsible for the wide distribution of the poison ivy. Simmons[10] recognizes birds as a factor in plant dissemination, and he believes that the ptarmigan, which is non-migratory but roams much about, is responsible for the spread of the Arctic plant species that have edible fruit. He considers the wind, however, as the prime distributing factor, and with this conclusion the recent work of Ostenfeld agrees (see, above, footnote 6)[11]. Of 204 species of plants from the American Arctic Archipelago he found that the majority were wind-distributed, as follows:[12]

Plants Disseminated by Wind			
Having seeds or fruits with flying apparatus	86 species,	i. e.	42%
Having light seeds and achenes	95 "	"	47%
Having spores	8 "	"	4%
	189 species,	i. e.	93%
Plants Disseminated by Other Means			
Having heavy seeds (dispersal by wind possible)	5 species,	i. e.	2%
Having berries and drupes (dispersal by birds, especially ptarmigan)	4 "	"	2%
Dispersal by vegetative propagation alone	6 "	"	3%
	15 species,	i. e.	7%

The whole subject of Arctic plant dispersal needs further study.

Method and Rate of Vegetative Multiplication

The morphology of Arctic plants has been investigated by a number of students (Warming and his colleagues,[13] Holm,[14] Rikli[15]), and

[9] H. W. Henshaw: Our Mid-Pacific Bird Reservation, *Yearbook U. S. Dept. of Agric. for 1911*, Washington, 1912, pp. 155–164; reference on pp. 156–157.

[10] H. G. Simmons: A Survey of the Phytogeography of the Arctic American Archipelago, With Some Notes About Its Exploration, *Lunds Univ. Årsskrift*, N. S., Section 2, Vol. 9, No. 19, Lund, 1913; reference on pp. 145–151.

[11] In the comprehensive work on the action of wind in northern latitudes by Carl Samuelsson (Studien über die Wirkungen des Windes in den kalten und gemässigten Erdteilen, *Bull. Geol. Instn. Univ. of Upsala*, Vol. 20, pp. 57–230, Upsala, 1927) a major section (pp. 118–168) is devoted to the action of wind on vegetation, including the distribution of plants in the Polar Regions and on high mountains.

[12] *ibid.*, p. 148.

[13] Eugenius Warming et al.: The Structure and Biology of Arctic Flowering Plants, *Meddelelser om Grønland*, Vols. 36 and 37, 1912 and 1921.

[14] Theodor Holm: Contributions to the Morphology, Synonymy, and Geographical Distribution of Arctic Plants, Report of the Canadian Arctic Expedition, 1913–18, Vol. 5: Botany, Part B, Ottawa, 1922, with bibliography.

[15] Martin Rikli: Zur Kenntnis der arktischen Zwergstrauchheiden, *Vierteljahrsschr. Naturf. Gesell. in Zürich*, Vol. 61, 1916, pp. 231–248.

little can be added to this satisfactory record; but the method and rate of vegetative multiplication, where, by repeated upward growth and branching of a single-rooted plant, it comes to spread over a very considerable area, should be investigated. When one looks at such a single-plant colony, he is deceived if he is led to believe that the separate, numerous stems, many of them rooted, have had a distinct origin and are independent plants. If he digs down or, better, if near a placer gold mine uses the powerful jet of water used in mining operations and washes away the peat and soil accumulated about the stems, he will discover that he is dealing with one plant which branched repeatedly at different levels representing the different layers of peat; developed, for example, in succession by the upward growth of mosses which enveloped the basis of the plant. This should be investigated in detail for all of the Arctic shrubs and trees. A powerful pump, with attached fire hose and nozzle and mounted on a Ford chassis, would provide the apparatus for such an investigation.

Origin of Tussock Vegetation

A characteristic form of Arctic vegetation are the hammocks, or tussocks. The writer is familiar with these forms from personal observation in Alaska and Sweden on the Arctic Circle. In Alaska these tussocks are locally called "niggerheads." At Kiruna, Sweden, one variety of rick is formed by the growth of various plants that have invaded the tall, conical ant hills until, by the time the ants have finally deserted them, the hills have been completely covered. In Alaska another kind of hassock (rick) is formed by the continuous upgrowth of tussock sedges (probably *Carex lugens* Holm), with runways of water between. Later these hassocks may be invaded by lichens, mosses, and flowering plants. The origin of these tussocks and the succession of plants should be investigated.

Survival of Arctic Plants during the Ice Age

There is another problem about which there has been considerable discussion, namely, the survival of plants in the Arctic Regions during the period of most extensive glaciation. It has been demonstrated that there were ice-free areas and nunataks far north of the border of continental glaciation, and it has been suggested by Warming[16] that these areas harbored a circumpolar flora during the Glacial Epoch. Elsewhere[17] the writer has emphasized the fact that on

[16] Eugenius Warming: Om Grönlands Vegetation, *Meddelelser om Grønland*, Vol. 12, 1888, Ch. 10 (pp. 169–217; with French résumé, pp. 239–245). See also his polemic with Nathorst: Grönlands Natur og Historie: Antikritiske Bemaerkninger til Prof. Nathorst, *Videnskab. Meddel. fra den Naturhist. Foren.*, 1890, Copenhagen, 1891, pp. 265–300.

[17] J. W. Harshberger: Phytogeographic Survey of North America (in series: Die Vegetation der Erde, edit. by A. Engler and O. Drude), Leipzig and New York, 1911, p. 189. See also pp. 11-13 of work by Ostenfeld cited above in footnote 6.

nunataks there was a chance for the survival of arctic plants. Holm,[18] while in the main accepting Nathorst's views[19] on the migration of plants during and after the Ice Age, recognizes the probability of independent centers of origin, chiefly in high mountain regions.

New light has been thrown upon this problem by the investigations of Fernald,[20] who argues for the persistence of plants during the Glacial Period on the alpine tablelands of the Shickshock Mountains of Gaspé Peninsula and of the Long Range of northwestern Newfoundland. These plants are for the most part otherwise known in the Cordillera of western America (in the Rocky Mountains, the Cascades, Sierra Nevada, and Coast Range) or in some cases in Alaska or in the Altai Mountains of Siberia. They are quite unknown in eastern America to the north of the Gulf of St. Lawrence or to the southwest of Gaspé Peninsula. In a few cases western plants occur upon the Magdalen Islands in the middle of the Gulf of St. Lawrence, and in several cases they are found upon the Torngat Mountains, the high, rugged sierras of northern Labrador. Extensive exploration has failed to discover these plants upon the mountains of northern New England and northern New York. Fernald points out that some of these species occur in Novaya Zemlya or on the adjacent smaller islands of Arctic Russia and Arctic Lapland which were uncrossed by at least the last two advances of the European ice sheet. He argues for the greater age of these arctic-alpine plants than 25,000 years, during which postglacial time species have migrated into the glaciated areas, while the arctic-alpine plants have not migrated from the unglaciated regions to the glaciated ones. He points out that the above-mentioned unglaciated areas are now occupied by specialized plants which are, therefore, presumably of great local antiquity and are remnants of a general preglacial flora which survived in the far north in districts not covered during the Pleistocene by continental ice.

The whole problem of plant survival should therefore be thrown into the crucible and an extensive survey made of the areas on which glacial relict plants might have been harbored. Why is the Antarctic flora poor as contrasted with the relatively rich Arctic one? Is it because of the restricted land areas in the south with expansive

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[18] Ch. 2, Geographical Distribution, in work cited in footnote 14, above.

[19] A. G. Nathorst: Polarforskningens bidrag till forntidens växtgeografi, in A. E. Nordenskiöld, edit.: Studier och forskningar föranledda af mina resor i höga norden, Stockholm, 1883–84, pp. 229–301, with 2 maps (German translation: Beiträge der Polarforschung zur Pflanzengeographie der Vorzeit, in A. E. Nordenskiöld, edit.: Studien und Forschungen veranlasst durch meine Reisen im hohen Norden, Leipzig, 1885, pp. 219–288).

See also Nathorst's papers in his polemic with Warming: Kritiska anmärkningar om den grönländska vegetationens historia, *K. Svenska Vetenskap.-Akad. Bihang til Handl.*, Vol. 16, Part 3, No. 6, Stockholm, 1890; Kritische Bemerkungen über die Geschichte der Vegetation Grönlands, *Englers Botan. Jahrb.*, Vol. 14, 1891, pp. 183–220.

[20] M. L. Fernald: Persistence of Plants in Unglaciated Areas of Boreal America, *Memoirs Gray Herbarium of Harvard Univ.*, No. 2, Cambridge, 1925 (also as *Memoirs Amer. Acad. of Arts and Sci.*, Vol. 15, 1925, No. 3, pp. 237–342).

oceans all about, as contrasted with the north, or is it because the north polar regions, being uninterruptedly connected with continental land masses to the south, have been supplied repeatedly by migrants from the south and also in circumpolar directions?

Influence of Slope Exposure

Considerable data have accumulated as to the influence of slope exposure on the distribution of plants in our hilly districts and mountains,[21] but we know relatively little as to the action of this influence in the Arctic Regions. To reach satisfactory conclusions an all-season survey should be instituted where the slope exposures are found facing the different directions of the compass. The mountains of northern Alaska would be suitable for such an investigation.

Plant Succession on Surfaces Exposed through Solifluction

The slipping down of the soil of mountain slopes, or the sliding action of soils on slopes less steep, is known as solifluction. It is not an uncommon phenomenon in the Arctic Regions where the superficial vegetation of mosses, lichens, and shrubs on loose, water-soaked peat will begin to slide down, especially if the front of a given hill has been undermined by the building of a road along its face or by dredging operations in mining gold. As a result of this movement soil entirely denuded of vegetation will be exposed. The succession of plants of such exposed virgin soil is a matter of interest, and of deep concern if the soil movement takes place near mines or established centers of population.

Plant Growth over Frozen Subsoil

Another soil problem, which the writer has investigated in several districts in his recent visit to Central Alaska, is that of the frozen condition of the soil under the superficial layers, which thaw out in summer. Such local observations should be extended to the investigation of similar conditions in all parts of the Arctic realm. The writer learned that on some bench lands the soil may be frozen to a depth of 245 feet; that on well-drained hill slopes, especially those with a southern exposure, the soil is never permanently frozen but thaws out in summer; that in soils which are frozen permanently to a great depth the sinking of a mine shaft may reveal suddenly an unfrozen area, and that this is associated usually with some ancient stream bed which carries subterranean water. The gold miners have learned

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[21] J. W. Harshberger: Slope Exposure and the Distribution of Plants in Eastern Pennsylvania, *Bull. Geogr. Soc. of Philadelphia*, Vol. 17, 1919, pp. 53–61.

A. G. Vestal: Foothills Vegetation in the Colorado Front Range, *Botan. Gazette*, Vol. 64, Chicago, 1917, pp. 353–385.

that the quickest way to thaw out a soil is to run water through it by sinking pipes with openings along their sides into the frozen soil, so that water can be forced into and made to circulate through the frozen strata. This is an important practical matter, for such towns as Valdez, Alaska, are built on alluvial glacial fans under which there is permanent ice. More such studies should be made like the recent investigations of Keränen and Kokkonen in Finland and Högbom in Sweden.[22] Such investigations of frozen soils should be correlated with the fact, which has been known for some time, that large trees will grow on the shallow morainic deposits actually mantling blue, glacial ice. Cooper's field work[23] in Glacier Bay, Alaska, has made known to us in detail this interesting phenomenon. Last summer (1926) the writer photographed and studied plants growing on the green ice covered with morainic material at the foot of Allen Glacier on the Copper River and Northwestern Railway. A detailed investigation of this phenomenon is of importance, as it suggests that plants (even trees) might have existed at the foot of glacial ice during the maximum refrigeration of the continents, for we are beginning to suspect that the Glacial Period did not have such extremely low temperatures but a kind of precipitation which resulted in the general and continental accumulation of snow and glacial ice.

Study of the Tundra As Reindeer Pasture

Stefansson[24] has recently emphasized the importance of the utilization of the "Barren Grounds," or tundra of Canada, in the raising of caribou for the market. The caribou feeds largely on the reindeer lichen and other tundra plants, especially in winter, when it paws away the snow to get the lichens underneath, also using the spadelike downward-projecting front prongs of its antlers to shovel the snow. In these Arctic ranges the mistakes of overcropping which have been made on the prairie plains of the United States should be avoided. Our nation should have learned by bitter experience that scientific study of the vegetation of the open range would have prevented its deterioration. Before we have a repetition of the same economic waste on the tundra, a detailed study of its plants, especially the lichens, should be made and an experimental investigation of the methods of reproduction. The distribution and abundance of the various tundra

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[22] J. Keränen: Über den Bodenfrost in Finnland, *Mitt. Meteorol. Zentralanstalt des Finnischen Staates*, No. 12, Helsingfors, 1923.

P. Kokkonen: Beobachtungen über die Struktur des Bodenfrostes, *Acta Forestalia Fennica*, No. 30, pp. 5–54, Helsingfors, 1926.

Bertil Högbom: Über die geologische Bedeutung des Frostes, *Bull. Geol. Instn. Univ. of Upsala*, Vol. 12, pp. 257–390, Upsala, 1913; *idem:* Beobachtungen aus Nordschweden über den Frost als geologischer Faktor, *ibid.*, Vol. 20, pp. 243–280, 1927.

[23] W. S. Cooper: The Recent Ecological History of Glacier Bay, Alaska, *Ecology*, Vol. 4, Brooklyn, N. Y., 1923, pp. 93–128, 223–246, 355–365.

[24] Vilhjalmur Stefansson: Polar Pastures, *The Forum*, Vol. 75, New York, 1926, pp. 9–20.

species should be investigated by the use of quadrat methods, familiar to all plant ecologists. The data obtained will be valuable in the control of the Arctic ranges. In connection with this detailed phytogeographic survey, the food plants and feeding habits of the caribou should be studied, including the relative attractiveness of different tundra plants, their nutritious qualities, and seasonal use. As an incidental inquiry a study should be made of the controlling factors of the caribou migrations in vast herds across the Arctic tundra.

Arctic Phenology

The long, open summer of 1926 in Central Alaska, when the ice left the Yukon and its tributaries almost a month earlier than usual, was accompanied by an entire upset in the usual phenology of the Alaskan flora. Plants bloomed and matured their fruits much earlier than usual. The occurrence of this unusual season indicates that the seasonal phenomena (phenology) connected with the growth, flowering, and fruiting of Arctic plants would constitute a profitable field of inquiry. Much has been done along these lines in Canada[25] and in Europe, particularly by Finnish and Scandinavian botanists,[26] but not much in this country. The biological station at Abisko, Lapland, Sweden, the United States Agricultural Experiment Stations at Rampart and three miles west of Fairbanks, Alaska, and a Danish Arctic station on Disko Island, Greenland, provide centers where such investigations might be made.[27]

Water Requirements of Arctic Plants

Two Swiss botanists, Brockmann-Jerosch and Rübel, in their classification of deserts have placed the Arctic tundra in their Frigorideserta (Kalteinöden), or frigid deserts.[28] This is recognition of the fact that many of the arctic plants are xerophytes and suffer because of the sterile frozen condition of the soil from physiological dryness.

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[25] See the phenological observations published by A. H. MacKay relating to Canada (*Trans. Nova Scotian Inst. of Sci.*, 1895–1904, and *Proc. and Trans. Royal Soc. of Canada*, 1895–1910) and to Nova Scotia (*Trans. Nova Scotian Inst. of Sci.*, 1901–1904, 1911 to date).

[26] T. C. E. Fries: Oekologische und Phänologische Beobachtungen bei Abisko in den Jahren 1917–1919, *Svenska Växtsociolog. Sällskap. Handl.*, Vol. 5, Upsala, 1925.

[27] Dr. Morten P. Porsild is the resident director of the station at Disko. Its investigations are published in *Meddelelser om Grønland* as "Arbejder fra den Danske Arktiske Station paa Disko." Twelve numbers have been issued since 1910: Nos. 1–5 in Vol. 47 of the *Meddelelser*, No. 6 in Vol. 50, Nos. 7–9 in Vol. 51, Part II, No. 10 in Vol. 56, Nos. 11–12 in Vol. 58. No. 11, by Dr. Porsild, assisted by A. E. Porsild, is entitled "The Flora of Disko Island and the Adjacent Coast of West Greenland from 66° to 71° N. Lat., With Remarks on Phytogeography, Ecology, Flowering, Fructification, and Hibernation."

Mr. G. W. Gasser is in charge of the U. S. Agricultural Experiment Station at Fairbanks, Alaska, and Mr. E. M. Floyd of the station at Rampart. Agricultural bulletins bearing on Alaska are published jointly by the six agricultural stations in Alaska, with headquarters at Sitka, under the supervision of the Office of Experiment Stations, U. S. Department of Agriculture, Washington.

[28] H. Brockmann-Jerosch and E. Rübel: Die Einteilung der Pflanzengesellschaften nach ökologisch-physiognomischen Gesichtspunkten, Leipzig, 1912, p. 55.

The water requirements of arctic plants have not been investigated in a detailed experimental manner by a competent plant physiologist. The scientific conclusions have been based on inference largely, and, if there are detailed pieces of work, they have been done in spots. No comprehensive piece of research investigation on the subject of the source of water and its utilization by arctic plants is in existence. There are many questions that arise in this connection. What is the utilization of rain water by polar species? How do they utilize soil water and what is the source of that water? What is the régime of transpiration or water loss in arctic plants and how is it correlated with internal plant structure and external climatic conditions? What is the temperature range of arctic soils, when underlain by permanently frozen soil? What is the relative age of the stunted spruce trees growing in the bottom lands with permanently frozen soil near the surface, as contrasted with the same species on the slopes, where the soil in which the tree roots are found is not frozen permanently?

Vegetative Growth by Means of Runners

Holm's "Contributions to the Morphology, Synonymy, and Geographical Distribution of Arctic Plants"[29] is full of reference to the north-south migrations of plants as well as the south-north movement of polar-alpine plants. To cite one case: *Saxifraga flagellaris* may be considered to be a true arctic type which originated in the polar regions. It is widely distributed on the Arctic coast of America, including Greenland. It is known from Spitsbergen and Novaya Zemlya and from several stations on the Siberian coast. Farther south it is known from the Rocky Mountains (Colorado), Caucasus, Altai and Baikal mountains, and the Himalayas. It is one of the most interesting species of the genus. This arctic plant is of low stature, the flower-bearing stem reaching a height of only 1½ to 3 centimeters. The shoot bears a number of fleshy leaves, glandular-hairy along the margin, and the leaves form a small rosette. A single flower-bearing stem with a few leaves and one or two flowers terminates the shoot. Long runners are developed on the surface of the ground, consisting of a single internode about 10 centimeters long terminated by a small spherical rosette of green leaves. The main shoot dies off when the fruit matures, and at this time the rosettes on the runners have begun to develop roots and later give rise to independent plants.

The alpine plants from the Rocky Mountains have taller, more leafy flowering stems, and two to three flowers may be developed. The plants are more glandular-hairy. In specimens from James Peak (13,000 feet) the flower-bearing stem reached a height of about 15 centimeters, bearing seven flowers in a unilateral cyme. The flower-

[29] Cited in footnote 14, above.

bearing stems were very leafy, and several of the basal leaves above the rosette subtended runners of the usual structure. The rosette was not as compact as in typical specimens, and, moreover, a subterranean stem portion about 5 centimeters long extended from the rosette to a cluster of secondary roots. This stem portion bore some remnants of withered leaves and consisted thus of more than one internode. Some isolated young rosettes, which grew near the flowering specimens, showed a similar elongated stem beneath the rosette leaves, provided with a corresponding system of secondary roots at the lower end of the stem. A third type of specimens, however, elucidated this singular structure. It consisted of a rosette of leaves with runners, but, instead of being terminated by an inflorescence, the main shoot had continued to grow above the rosette as a vegetative shoot bearing several scattered leaves and terminated by a rosette of a more open structure than in the typical plant. In other words, the alpine *Saxifraga flagellaris* may remain in a purely vegetative stage for several years, but not as a single rosette gradually increasing in size, as in the case of the arctic specimens, but developing an erect, purely vegetative shoot of which the apex assumes the shape of a rosette to produce flowers in the succeeding year and still depending on the same fascicle of secondary roots. The age of such specimens appeared to be not less than four years. The fact that none of the specimens examined by Holm possessed a primary root actually indicates that they owed their existence to rosettes of runners, which undoubtedly is the most common method of reproduction in this species. However, capsules with ripe seeds are to be found frequently in alpine specimens, and even in Novaya Zemlya capsules with seeds are found.

Transplantation Experiments to Discover Effect of Environmental Conditions

The investigation of this plastic species and other suitable alpine-arctic species along the lines followed by the French botanist Gaston Bonnier[30] would yield scientific results of great interest and importance. Bonnier divided perennial lowland plants into several parts and planted these parts in the Pyrenees and the Alpine regions of Switzerland. Similarly he transplanted Pyrenees species to the lowlands and the Alps, and alpine species to the Pyrenees and the lowlands of Paris. He discovered that the changed environment produced certain histological and morphological characteristics of qualitative and quantitative kinds. Similar transplantation experiments should

[30] Gaston Bonnier: (1) Cultures expérimentales dans les Alpes et les Pyrénées, *Rev. Gén. de Botan.*, Vol. 2, 1890, p. 513; (2) Recherches sur l'anatomie expérimentale des végétaux, *Ann. des Sci. Nat.*, Ser. 7: Botan.; Vol. 20, 1895, pp. 218–360; (3) Les plantes arctiques comparées aux mêmes espèces des Alpes et des Pyrénées, *Rev. Gén. de Botan.*, Vol. 6, 1894, p. 505.

be made with alpine plants into the Arctic and with arctic plants into alpine regions. These experiments would discover the effect of the environmental conditions and would make clear the affinities of closely related species, which are considered to be mere geographical forms, such as alpine plants which have migrated to the Arctic Regions, and vice versa, and which are regarded systematically as geographical forms of a common type.

Dr. Stejneger, head curator of biology in the U. S. National Museum, came to this country from Norway in 1881. The following years he went on a natural history expedition to Bering Island and Kamchatka for the U. S. National Museum. He revisited the Commander Islands on several occasions, in 1895 to study the fur seal question, in 1896–1897 as a member of the U. S. Fur Seal Commission, and in 1922 for the Department of Commerce. As a result of these visits he has contributed a number of papers on the biota of the North Pacific region to the publications of the U. S. National Museum. He is also the author of "Eine Umsegelung der Berings-Insel, Herbst 1882" (*Deutsche Geogr. Blätter*, Vol. 8, 1885); "The Russian Fur Seal Islands" (*Bull. U. S. Fish Commission*, Vol. 16, 1890); "The Asiatic Fur-Seal Islands and Fur-Seal Industry" (in D. S. Jordan's "The Fur Seals and Fur-Seal Islands of the North Pacific Ocean," Vol. 4, Washington, 1898), and translator of "Steller's Journal of the Sea Voyage from Kamchatka to America and Return on the Second Expedition 1741–1742," constituting Vol. 2 of "Berings Voyages" (*Amer. Geogr. Soc. Research Series No. 2*, New York, 1925). As a zoölogist Dr. Stejneger has specialized in the taxonomy and geographic distribution of the vertebrates, chiefly birds and reptiles, on which he has published more than 300 titles, among them the greater portion of the bird volume of the "Standard Natural History," a volume on the birds of Kamchatka, one on the herpetology of Japan, etc.

UNSOLVED PROBLEMS IN ARCTIC ZOÖGEOGRAPHY

Leonhard Stejneger

Theory of a North Polar Continent As a Zoögeographical Center

About sixty years ago, after the discovery of coal in Spitsbergen and of warm-temperate fossil plants in Greenland and coincident with the agitation by Dr. Petermann for his celebrated theory of the existence of a north polar continent, there appeared a paper by Dr. G. Jäger, director of the zoölogical garden at Vienna, on the north pole as a zoögeographical center.[1] On the map accompanying this paper is outlined Dr. Petermann's polar continent or, as he expressed it, the greatest island on earth, extending from Cape Farewell, the south end of Greenland, to the neighborhood of Bering Strait, "as great as Europe from Gibraltar to Novaya Zemlya or from North Cape to Mursuk in the interior of Africa." Dr. Jäger, however, did not assume that this land covered the north pole itself; on the contrary, he postulated a sea basin "which must have been surrounded by land like the Mediterranean Sea at the present day, nay, without doubt, even much more narrowly enclosed. However, there must have been somewhere a communication with the ocean," and this outlet, he thinks, was through Bering Strait, which "played the same rôle for the Arctic Sea as the Strait of Gibraltar now does for the Mediterranean." He emphasized vigorously his refusal to accept the theory that "the bridge across which the faunas of the Old and New Worlds mixed" was to be found in the Bering Strait region. On the contrary, he says, "in my opinion the Arctic Sea at that time was separated from the Atlantic Ocean by a broad bridge of land on the opposite side, where today an enormous gap yawns between Greenland and Norway. This bridge extended from Iceland and the Faeroes to the north edge of Spitsbergen, and these islands, as well as Jan Mayen and Bear Island, form the remnants of it." Similarly, Davis Strait, Baffin Bay, and the other narrow waterways between Greenland and the American continent were at that time undoubtedly dry land according to his hypothesis. This ring of land, narrowly surrounding the north pole, was supposedly blessed by a congenial climate, and the fauna which originated here radiated from this center southward to the adjacent American, Asiatic, and European continents.

[1] Der Nordpol, ein thiergeographisches Centrum, *Ergänzungsheft No. 16 zu Petermanns Mitt.*, 1865, pp. 67–70 and map, Pl. 3.

This view of the north pole as a zoögeographical center was later taken up and elaborated by others, and some years afterwards there appeared two papers, one by Wilhelm Haacke,[2] the other by Canon H. B. Tristram.[3] Haacke's idea was that all the larger groups of animals originated on the polar continent. He argued more particularly from the distribution of the struthious birds, the monotremes, marsupials, lemurs, edentates, and insectivores, the older forms being supposed to have been pushed southwards in widening circles by the forms evolved subsequently. Hence, he concluded, we find at the present time the ancient types crowded farthest off to the south end of the continental masses, while the more modern ones occur nearer the north pole. He did not touch upon the rôle of the Glacial Period, nor did he discuss the presence or the absence of land bridges between the Old and the New Worlds, for the simple reason that he was willing to concede the possibility of the 1000-fathom line having formed the original coast line, which of course—according to the knowledge of that time—would outline a solid circumpolar continent of tremendous proportions. Tristram's hypothesis is in many ways similar, but he goes into more detail and attributes the southward push from the pole to the gradual advance of the Glacial Period. "The polar continent continued to cool, the accumulation of snow and ice over its whole surface became so enormous from the precipitation of frozen vapour as to equal the present deposits on the southern polar continent."[4] This enormous accumulation of ice finally depressed the continent to such an extent that when the ice melted the oceanic waters of the Atlantic and Pacific gained access to the more deeply depressed portions of the area.

This idea of a once elevated polar continent depressed into a shallow sea between Eurasia and America by the weight of the ice cap was finally disposed of by Nansen's drift in the *Fram* and his demonstration of the fact that the Arctic Basin is of truly oceanic nature. From this time on the discussion of the north polar area as a center of zoögeographical distribution assumed a somewhat different aspect.

The Arctic Not a Faunal Center of Origin

It is not the place here to discuss the distribution of land and water in the circumpolar area during geological periods previous to the origin of the present polar fauna or all the theories which have been advanced since the demolition of the hypothesis of a central polar continent with a subsequent enormous ice cap, but it is the intention

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[2] Der Nordpol als Schöpfungszentrum der Landfauna, *Biol. Centralblatt*, Vol. 6, 1886, pp. 363–370.

[3] The Polar Origin of Life in Its Bearing on the Distribution and Migration of Birds, *Ibis*, Ser. 5, Vol. 5, 1887, pp. 236–242; and Vol. 6, 1888, pp. 204–216.

[4] *op. cit.*, Vol. 6, p. 206.

to look into some of the more important recent theories especially as they bear on the present fauna of the whole polar region.

It is generally admitted that the true polar land fauna, that is, broadly speaking, the animals inhabiting the circumpolar belt north of the limit of trees, has a rather uniform aspect. In most places we find the polar fox, stoat, polar hare, ptarmigans, lemmings, snow buntings, polar bears, seals, walrus, reindeer, some auks, gulls, and waders, and—not to be forgotten—the mosquitoes. We might even with some propriety include in this category a fish, viz. the char, or brook trout (*Salvelinus*). Others are more local at present, such as the musk ox, certain ducks and geese; and here we might with equal propriety include another fish, the Alaska blackfish (*Dallia pectoralis*). Looking more closely into details, however, we find that there are certain inequalities in the distribution of these animals which require explanation. Thus in Spitsbergen we miss certain strictly Arctic vertebrates which in other localities we are used to associate with polar conditions, such as the hare, the lemming, the stoat, while a reindeer and a ptarmigan are abundant. Then again we notice that certain kinds of animals are represented in different parts of the region by somewhat different, though evidently quite closely related, species. Thus the walrus on the Pacific side (*Odobenus divergens*) has been separated by zoölogists from the one on the Atlantic side (*O. rosmarus*); the Spitsbergen reindeer and ptarmigan are plainly different from the Greenland species. Moreover, the reindeer and the ptarmigans inhabiting the Arctic portions of Siberia and North America have recently been split up by specialists into a large number of forms or subspecies. Even the polar foxes and the polar bears, though apparently less confined to definite localities, have been similarly subdivided.

Plainly, the problem of the north pole as a center of origin is entirely different from that of the north pole as a center of distribution. Probably no zoölogist in this generation is naïve enough to hold that the typical Arctic animals are indigenous to the polar central area. Every one of the inhabitants of the frozen zone is closely allied to some species originated in or still living in the adjacent southern regions. Even the polar bear, which most zoölogical taxonomists recognize as the type of a separate genus (*Thalarctos*) distinct from that of the brown bears (*Ursus*), possesses no characters different enough to obscure its close relationship to them. The difference is most pronounced in the dentition, inasmuch as "the cheek-teeth are relatively small" while "the incisors and canines are enlarged and unusually prehensive in character" as compared with the ordinary bears of the boreal zone. It is easily seen that this modification of the teeth is an adaptation to the peculiar necessities of the feeding habits of the polar bear. The white color may be due to a similar adaptation, though for all we know the possibly originally white color of the ancestral species may have facilitated the adoption of semi-marine and polar habits. It may be well in this connection to call attention to the occurrence in British Columbia of a white form of the black bear genus (*Euarctos kermodei*) which externally is astonishingly like a polar bear, though this reference should not be taken as suggestion of a direct relationship between them.

The Arctic Not a Faunal Center of Distribution

Evidently the present inhabitants of the polar area are the modified descendants of ancestors living to the south of it, which have become adapted in structure and habits to the rigorous conditions of the polar climate. The polar region therefore cannot by any stretch of the term be considered a center of origin of the fauna. But neither is it in any sense a center of faunal distribution. It is unfortunately true that the animals composing this fauna have not all been studied sufficiently from this particular viewpoint. In some of the cases, however, we already know enough to support the above statement. Let us examine that of the collared lemmings (genus *Dicrostonyx*) for instance. Taking the latest revision of these strictly Arctic animals,[5] we find them arranged as follows:

1 *Dicrostonyx torquatus*
  1a. *D. t. torquatus:* Old World from eastern shore of White Sea; eastward limits unknown; New Siberian Islands.
  1b. *D. t. ungulatus:* Novaya Zemlya.
2 *Dicrostonyx chionopaes:* Nizhne Kolymsk, northeastern Siberia.
3 *Dicrostonyx rubricatus*
  3a. *D. r. rubricatus:* Alaska Peninsula; lower and middle Yukon Valley; Seward Peninsula; Arctic coast of Alaska and of the Mackenzie District eastwards to Coronation Gulf.
  3b. *D. r. richardsoni:* From the western shore of Hudson Bay westwards through Arctic America, meeting and intergrading with 3a in the neighborhood of Coronation Gulf.
  3c. *D. r. unalascensis:* Island of Unalaska, Alaska.
4 *Dicrostonyx exsul:* St. Lawrence Island, Bering Sea.
5 *Dicrostonyx groenlandicus:* Maritime districts of northern and eastern Greenland; also Grant Land, Grinnell Land, Ellesmere Land, and Baffin Island.
6 *Dicrostonyx hudsonius:* Barren Ground area of the Labrador Peninsula.

In analyzing this table, we may at once eliminate from our present consideration the forms *D. hudsonius*, *D. exsul*, and *D. rubricatus unalascensis* as of only local interest on account of their isolated ranges. *Dicrostonyx chionopaes* may also be left out as it is known only from a single specimen of somewhat obscure characteristics. With regard to the remaining forms, Hinton, in 1926, has to confess that the material

[5] M. A. C. Hinton: Monograph of the Voles and Lemmings, Vol. 1, British Museum, London, 1926.

at his command (collections of British Museum, etc.) is "totally inadequate" for the purpose of determining the characters of the Eurasian *D. torquatus* and its exact kinship with the American *D. rubricatus*, to which it is "undoubtedly very closely related." On the other hand, he admits that, as G. M. Allen has suggested, *D. rubricatus richardsoni* and *D. groenlandicus* may intergrade somewhere to the north of Hudson Bay. However, from his treatment of the case and the data submitted it is concluded that the Novaya Zemlya subspecies is descended from the Siberian *D. torquatus*, and the eastern American *D. r. richardsoni* from the Alaskan *D. rubricatus*; and that, further, the Old World *D. torquatus* and the New World *D. rubricatus* in their turn are descended one from the other or both from a common ancestor. The plain inference is that it would be illogical to speak of the polar area as a center of distribution of the collared lemmings, especially as fossil remains of at least two species of *Dicrostonyx*, one apparently more nearly related to *D. torquatus*, the other to *D. hudsonius*, are common in Pleistocene deposits of Great Britain, Ireland, France, and Germany.

Other polar subspecies show similar indications of closer relationships toward their congeners occupying adjacent territory to the south than to the corresponding polar forms inhabiting other parts of the Arctic area, but in no case has there been any recent scientific investigation like that of the lemmings. It is not the place here to go into the matter further, but an additional reason for giving the above example in such detail was to show how defective our knowledge of the geographical distribution is even when dealing with the larger and better known animals of the Arctic. A large amount of material has been gathered, though by no means enough, but it is scattered among a dozen large museums and there has been no concerted effort to have it brought together in one place and studied by a single mind capable of realizing the ultimate problems involved and at the same time qualified to treat the taxonomic questions according to modern conceptions and requirements. And yet, only in this way will it be possible to unravel within a reasonable time the intricate questions connected with the origin, evolution, and present geographical distribution of the polar fauna.

Theory of Latitudinal Dispersal in the Arctic Faunal Realm

The early hypotheses of the north pole as a center of origin or of zoögeographical distribution did not only, or even mainly, have reference to what is now the strictly polar fauna. They were chiefly concerned with the boreal, or perhaps rather arctogean, animals in general and tried to explain how it happened that this category of animals had spread to such widely divergent regions as Africa, India, and America. With the relegation of the hypothesis of a polar continent to limbo, the center of origin had to be shifted to some place or places on the continental ring surrounding the deep oceanic Polar Basin. About the same time it became generally accepted that the animals now inhabiting the continent of Europe, northern Asia, and northern America are so closely allied that they are properly considered to form a continuous holarctic zoögeographic province or realm. Obviously, then, the movement, which under the earlier conceptions was thought to have been along radiating north-south meridians, assumed under the new hypothesis an east-west or west-east direction. Even Dr. Jäger had realized that the Polar Sea had to have an outlet and argued against a land connection between Eurasia and America across the Bering Strait region, holding that the interchange of faunas within comparatively recent geological time had been across a broad land uniting Europe to Greenland and the rest of North America. Such also was and still is the contention of various prominent zoögeographers. Thus Scharff[6] assumed this connection to have been by way of Spitsbergen, but, on the present writer[7] having successfully argued against this supposition, Scharff, in his later works, chose the other alternative of a Greenland-Iceland-Scotland land bridge.

It is not the intention in this article to argue pro or con any of the various hypotheses which have been proposed to explain the present distribution of the holarctic animals or even to mention all of them. Only the more representative views can here be set forth briefly. The hypothesis that some of the constituents of the present boreal faunas have had their origin, and that others have had their secondary center of distribution, in the high lands of the interior of Asia, which constitute one of those never submerged continental areas which physiographers call "shields," or "bosses," or "Scheitels," has gradually gained almost universal acceptance, and, as a corollary, the opinion that the Bering Strait or Bering Sea land connection has been the principal route by which the exchange of the faunas between Eurasia and America took place. As an illustration of this view I need only cite W. D. Matthew's discussion in his excellent, though obscurely entitled article "Climate and Evolution,"[8] in which he demonstrates that it is unnecessary, at least for an explanation of the present distribution of the placental mammals, to postulate any other intercontinental land bridge than that of Beringia, as the Bering land bridge has been named by Sushkin. Of course, the hypothesis of the former existence of a land connection in this region is an old conception.

[6] R. F. Scharff: The History of the European Fauna, London, 1899.

[7] Leonhard Stejneger: Scharff's History of the European Fauna [a review], *Amer. Naturalist*, Vol. 35, 1901, pp. 87–116; reference on pp. 103–104.

[8] *Annals New York Acad. of Sci.*, Vol. 24, 1914 (published Feb., 1915), pp. 171–318.

As a matter of fact there has been more controversy over its extent, and over the question whether there has been more than one such connection within recent geologic times, than over its having existed at all. Gradually a route over the Aleutian chain, as at present constituted, has been eliminated, but, on the other hand, a possible connection to the north of Bering Strait is still awaiting a thorough investigation. As for the possibility of several openings and closings of the gap between the two continents and the mingling of the waters of the Arctic Basin with those of the Pacific, the deciding arguments must come from the minute study of the distribution, past and present, of the marine invertebrates.

The Alaska Blackfish as Evidence of a Bering Land Bridge

That there has been a rather early continuity of land is almost beyond dispute if we consider the occurrence of the so-called "Alaska blackfish" (*Dallia pectoralis*), named after one of the earliest and most celebrated students of the problem, the late Dr. W. H. Dall. This is a truly Arctic fresh-water fish and for this reason deserves a more extended mention in this connection. It was first described under the above name in 1879 by T. H. Bean[9] from specimens collected at St. Michael, Alaska. Two years later Smitt,[10] in Stockholm, described the same species from specimens collected by Nordenskiöld's *Vega* expedition near the wintering station at Pitlekai, on the north coast of the Chukchi Peninsula, under the name *Umbra delicatissima*. In "The Voyage of the Vega"[11] Baron Nordenskiöld gives the following account of this fish:

"In the fresh-water lagoon at Yinretlen . . . we caught by hundreds a sort of fish altogether new to us, of a type which we should rather have expected to find in the marshes of the Equatorial regions than up here in the north. The fish were transported in a dog sledge to the vessel, where part of them was placed in spirits for the zoologists and the rest fried, not without a protest from our old cook, who thought that the black slimy fish looked remarkably nasty and ugly. But the Chukches were right: it was a veritable delicacy, in taste somewhat resembling eel, but finer and more fleshy. These fish were besides as tough to kill as eels, for after lying an hour and a half in the air they swam, if replaced in the water, about as fast as before. How this species of fish passes the winter is still more enigmatical than the

[9] T. H. Bean: Description of Some Genera and Species of Alaskan Fishes, *Proc. U. S. Natl. Museum*, Vol. 2, 1879, pp. 353–359; reference on pp. 358–359.

[10] F. A. Smitt, *Öfversigt af Svenska Vetenskapsakad. Förhandl.*, Vol. 38, 1881, No. 5, p. 1 and Pl. 5, Fig. 1.

[11] Amer. edit., New York, 1882, pp. 442–444; British edit., 2 vols., London, 1881, reference in Vol. 2, p. 58.

winter life of the insects. For the lagoon has no outlet and appears to freeze completely to the bottom."

Lucien M. Turner, who had ample opportunity to study this extraordinary fish on the American side at St. Michael, Alaska, says[12] that "it is found in all the small streams of the low grounds, in the wet morasses and sphagnum-covered areas, which are soaked with water and which at times seem to contain but sufficient water to more than moisten the skin of the fish. In the low grounds or tundra are many—countless thousands—small ponds of very slight depth, connected with each other by small streams of variable width, of few feet to those so narrow as to be hidden by the overlapping sedges or sphagnum moss. . . . These narrower outlets of the ponds are at certain seasons so full of these fish that they completely block them up. . . . In such situations they collect in such numbers that figures fail to express an adequate idea of their numbers. They are to be measured by the yard. Their mass is deep according to the nature of the retreat. If it is a pond overgrown with sedges and mosses which by their non-conductivity of heat allows only a slight depth to be thawed out in the short Arctic summer, the fish mass will completely fill it up." "Here the fish are partially protected from the great cold of winter by the covering of moss and grass." "They form the principal food of the natives living between the Yukon Delta and the Kuskokvim River and as far interior as the bases of the higher hills. North of the Yukon Delta they are also abundant. . . . When taken from the traps [by the natives] the fish are immediately put into . . . baskets and taken to the village, where [they] are placed on stages . . . out of the way of the dogs. Here the fish are exposed to the severe temperature and cold winds." Under such circumstances the mass of fish is frozen in a few minutes, and, when needed for food for man or dogs, they have to be chopped out with ax or club. Turner proceeds: "The vitality of these fish is astonishing. They will remain in those grass-baskets for weeks, and when brought into the house and thawed out they will be as lively as ever." He also mentions a case where he saw a dog which had swallowed a frozen fish vomit it up alive, thawed out by the heat of the stomach! It having been made probable on other grounds that the Bering Strait region has never been covered by a solid ice sheet, we are quite prepared to believe that this fish in its present habitat may have survived the entire Glacial Period. Knowing, moreover, that it belongs to a very ancient group of fishes, in Dr. Gill's classification[13] occupying a separate "order," Xenomi, by itself, we must also concede that it offers no proof of a

[12] L. M. Turner: Contributions to the Natural History of Alaska (Arctic Series of Publications Issued in Connection with the Signal Service, U. S. Army, No. 2), Washington, 1886 [publ. 1888], p. 101.

[13] Theodore Gill: An Important Arctic Fish (in "Record of Scientific Progress for 1883: Zoölogy"), *Ann. Rept. Smithsonian Instn. for 1883*, Washington, 1885, pp. 727–728.

very recent land continuity and that it probably long antedates the period when the bears, the deer, and the related fauna migrated from the Old to the New World.

Circumpolar Land Connections and the Taylor-Wegener Hypothesis

The problem of the circumpolar land connections has of late years entered into a new phase by the appearance of the Taylor-Wegener hypothesis[14] of the lateral migration of the continental land masses and the origin of the Arctic-Atlantic Ocean through a gradual drifting apart of the American and Eurasian continental blocks. It implies within comparatively recent times a practical continuity of northwestern Europe and northeastern North America and thus conforms startlingly to the theoretical land connection postulated by Jäger in 1867. But, contrary to the latter, the Wegener conception would seem to imply an originally much wider gap between the continents in the Bering Strait region, since, with the separation of Greenland from Norway and the gradual widening of the gap between them by the westerly drift of the American continent, an approach of northwestern America to northeastern Asia would seem to be a necessary corollary. However, while the assumption of the Norway-Greenland continuity might find favor with some zoögeographers as explaining certain distributional facts, the doing away with the Beringian land bridge, on the other hand, is certain to arouse a greater opposition.

Need for Correlation and Unification of Observations in Arctic Zoögeography

It will thus be seen that the very latest aspect of the case brings us back practically where we stood sixty years ago. It is true that the innumerable polar exploration expeditions have vastly increased our knowledge of the structure, distribution, and habits of the animals peculiar to the Arctic Regions; the nesting places and eggs of nearly all the polar species of birds unknown sixty years ago have been found and described; and many equally curious and interesting observations have been made in the interval. A list of all the literature on these and related subjects would fill a good-sized volume. Hundreds and thousands of specimens collected during these years fill the shelves of many museums. But, unfortunately, all this mass of information remains scattered and uncorrelated. Moreover, it should be emphasized that the aims and methods of zoögeography have undergone a refinement during recent years which makes the earlier accumulations of

[14] F. B. Taylor: Bearing of the Tertiary Mountain Belt in the Origin of the Earth's Plan, *Bull. Geol. Soc. of Amer.*, Vol. 21, 1910, pp. 179–226; Alfred Wegener: Die Entstehung der Kontinente und Ozeane, 3rd edit., Brunswick, 1922 (first publication in *Petermanns Mitt.*, Vol. 58, Part I, 1912).

literary and museological material to a great extent obsolete. This condition is in full harmony with that set forth by Nansen as one of the main reasons for undertaking a duplication of his drift in the *Fram* across the Arctic Sea, viz. that newly invented instruments and methods necessitate a regathering of observations and specimens for the verification or the correction of the old data. In addition, the older material is defective because collected by disconnected expeditions having other and, for the time at least, more important business to attend to.

If the zoögeographical problems are to be solved within a reasonable time so as to be available as arguments in the discussion now going on, they must be attacked according to a methodical and unified plan somewhat on the order of the palearctic biological survey proposed to the Carnegie Institution by Gerrit S. Miller and the present writer more than twenty years ago.[15] In conjunction with the U. S. Biological Survey such a plan, if carried out, would by this time have resulted in an adequate circumpolar zoögeographical investigation. There would have been gathered in one place under one head a body of material from all the important localities surrounding the pole that would have been sufficient for the purpose. As a matter of fact, what conditions does the circumpolar zoögeographer face today? First, a fairly good representation here in Washington of the American material necessary for such a survey and, second, a considerable number of miscellaneous specimens distributed among a dozen or more European and American museums—material which, even if it could be brought together in one place, would undoubtedly be found to require additional collections to be of real use. I have already alluded (p. 158) to the unsatisfactory status of the best of these cases, that of the banded lemming (*Dicrostonyx*). For the sake of further illustration let me cite the case of a conspicuous polar bird, the ptarmigan (*Lagopus mutus*). Just as the earlier mammalian zoögraphers had only one or two forms of the banded lemming to deal with, the earlier ornithologists recognized at most four forms of Arctic ptarmigans.

The latest general account of these arctic-alpine birds enumerates no less than 19 named forms or subspecies.[16] Since then several new forms have been described, so that at present at least two dozen geographic modifications of *Lagopus mutus* have to be dealt with by the next monographer. The material of these birds now in existence is scattered among more than a dozen museums in the United States, England, Denmark, Sweden, Germany, Switzerland, Russia, Japan, etc. Moreover, it is safe to say that if all the specimens in all the museums were brought together, the material, which should consist

[15] Leonhard Stejneger and G. S. Miller, Jr.: Plan for a Biological Survey of the Palearctic Region, *Carnegie Instn. Year Book No. 1 for 1902*, Washington, 1903, pp. 240–266.

[16] Ernest Hartert: Die Vögel der Paläarktischen Fauna: Systematische Übersicht der in Europa, Nord-Asien und der Mittelmeerregion vorkommenden Vögel, Vol. 3, Berlin, 1921.

of series of males and females in the various seasonal plumages from all the critical localities, would be utterly inadequate for a conclusive study of the zoögeographical problems involved. Even while this was being penned, a Russian ornithologist, P. Serebrovski, after examining 205 ptarmigans from America and Eurasia (except Scotland!) in the Leningrad Museum, came to the conclusion that the material was utterly inadequate[17]. Nevertheless, he described and named four new subspecies from various parts of Siberia (the type of one in a private collection) and indicated two more as possibly distinct, one from Kamchatka and the other from Korovi Island at the entrance to Taui Bay on the northern shore of the Sea of Okhotsk, the material at hand being insufficient to decide.

It goes without saying that all the Arctic zoögeographical problems need not be attacked simultaneously, if only their interrelation be kept in mind. As will be understood from the above, much material must yet be collected, and the accumulation of a sufficient quantity may take time, but it is necessary that the collecting campaigns should be so conducted that the separate efforts may supplement one another and have a concerted bearing on the problems in their totality.

Study of the Bering Strait Region of Immediate Promise

The whole Arctic zoögeographical problem naturally falls into several subordinate problems of greater or lesser importance and urgency. Of these the most immediately promising one would be a very detailed biological survey of both sides of Bering Strait and adjacent regions, carried out in an advanced spirit of problem investigation as indicated above and for a series of years in succession until finished. A standard for similar and coördinated work in the other parts of the Arctic area might thus be established, justifying the hope that in this way one of the more momentous zoögeographical investigations may reach a satisfying conclusion within a reasonable time.

[17] P. Sserebrowsky (P. Serebrovski): Übersicht der in Russland vorkommenden Formen von *Lagopus mutus* Montin, *Journ. für Ornithol.* Vol. 74, 1926, pp. 691–698.

Mr. Jenness, chief of the Division of Anthropology in the National Museum of Canada at Ottawa, is a graduate both of the University of New Zealand and Oxford University. His first anthropological field work was undertaken in New Guinea, as part of the results of which he has published (with A. Ballantyne) "The Northern D'Entrecasteaux," Oxford, 1920; the remainder is now being printed as a memoir of the Polynesian Society under the title "Language, Anthropology, and Songs of Northern D'Entrecasteaux." As ethnologist of the Southern Party of the Canadian Arctic Expedition, 1913–1916, he was able to study at first hand the Eskimos of Alaska, the Mackenzie Delta, and Coronation Gulf. Among the results of his work on this expedition the following reports have been published in the Reports of the Canadian Arctic Expedition, 1913–1918, Ottawa: "The Life of the Copper Eskimos" (Vol. 12, Part A, 1922); "Physical Characteristics of the Copper Eskimos" (Vol. 12, Part B, 1923); "Eskimo Folk-lore" (Vol. 13, Part A, 1924); "Eskimo String Figures" (Vol. 13, Part B, 1924); "Eskimo Songs: Songs of the Copper Eskimos" (with H. H. Roberts; Vol. 14, Part A, 1925). A "Comparative Vocabulary of the Western Eskimo Dialects" (Vol. 15, Part A) is in press; likewise a popular account of his experiences among the Arctic Eskimos entitled "The People of the Twilight." Mr. Jenness has contributed a number of articles to the *Geographical Review.*

ETHNOLOGICAL PROBLEMS OF ARCTIC AMERICA*

Diamond Jenness

ALTHOUGH, from the days of Frobisher and Davis down to the present generation, every explorer of the American Arctic has filled the pages of his journal with descriptions of the Eskimos, yet until the last six years we knew very little of the early history of this strange people that has elected to dwell amid almost perpetual ice and snow. Older ethnologists regarded them as a single tribe who, migrating from some hypothetical home in northern Asia, in Alaska, or in central Canada, to the Arctic shores of America, gradually spread over the whole coast line and attained to their present condition by slow and rather uneventful modifications that permeated from one tribe to another. This conception still holds good in the main, but in detail it requires considerable revision to meet the demands of recent discoveries. We still believe that the Eskimos are fundamentally a single people, that they had their origin in a homeland not yet determined; but we have learned that they reached their present condition through a series of complex changes and migrations, the outlines of which we have hardly begun to decipher.

EARLY ESKIMO CULTURES: THE THULE CULTURE

It was archeological research that here, as in other parts of the world, produced the revolution in our ideas. From Bering Strait to the south of Baffin Island, through the Parry Archipelago to northwest Greenland, stretch the ruined dwellings of ancient tribes that have only recently become the object of careful investigation. Mathiassen, the Danish archeologist, discovered in 1922 that they held the remains of a culture very different from that which now prevails east of the Mackenzie River delta, although it was not unlike the culture of the Eskimos in northern Alaska just prior to European exploration and resembled still more closely that of an earlier period in the same region. To this ancient culture in the eastern Arctic he gave the name of Thule culture, from the site of its first discovery in northwest Greenland. There were no written records, of course, to indicate its antiquity or to show how long it had prevailed along these shores; but from the location of the ruins he concluded that some of them dated from a time when the land was

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8 to 13 meters below its present level, while others, containing the same culture slightly modified, were a little younger, belonging to a period when the land was only 4 to 8 meters lower. It is certain that the shores of Hudson Bay have risen 600 feet since the ice cap disappeared from Canada. But even though we may accept Mathiassen's conclusions, we cannot translate his changes of level into terms of years, because the uplift was probably both uneven and frequently interrupted. We can merely guess, in the absence of more accurate criteria for determining their age, that the oldest ruins of the Thule culture in Hudson Bay may date back 1000 or 1500 years, and the youngest perhaps 500. After that time, or it may be a little earlier, it was superseded by a simpler culture brought to the coast by inland tribes, who gradually spread over the whole region from Coronation Gulf to Baffin Island and even beyond.

The antiquity of the Thule culture in northern Alaska cannot be estimated by the same method, for the coast line seems to have changed but little since the Glacial Period and no invasion swamped the ancient inhabitants. Instead, their culture slowly changed, passing through stages that appear to have followed each other in regular succession at every place along the coast. The last stage, the one that immediately preceded the European discovery of Alaska, can be dated with approximate accuracy from the Russian penetration of northeastern Siberia; for the Rus-

FIG. 1—Objects representing three culture stages.

UPPER: Harpoon heads from Cape Dorset, of bone and ivory; *a*, *b*, modern forms with closed sockets; *c*, *d*, *e*, Thule forms with open sockets; *f–k*, new forms with narrow, rectilinear sockets probably representing the Cape Dorset culture (see also Fig. 2).

LOWER: Bone, ivory, and antler objects from Cape Dorset, deeply patinated; *a*, *k*, *l*, uses unknown; *b–j*, darts of various kinds (*d*, though deeply patinated, is hardly weathered and has a more modern appearance than the other darts: it may be an ancient implement remodeled in more recent times); *m*, *n*, perhaps foreshafts of harpoons; *o*, *p*, perhaps butts of harpoons; *q*, portion of snow knife. Three-eighths natural size.

sians introduced a flood of European beads among the Chukchis, who in turn traded them on to the Eskimos. By using the ruins of this last period as a datum line and measuring the amount of soil that has since accumulated on top of them, we may be able to estimate, within a century or two, the ages of still older ruins found in the same localities under similar conditions of topography and soil.

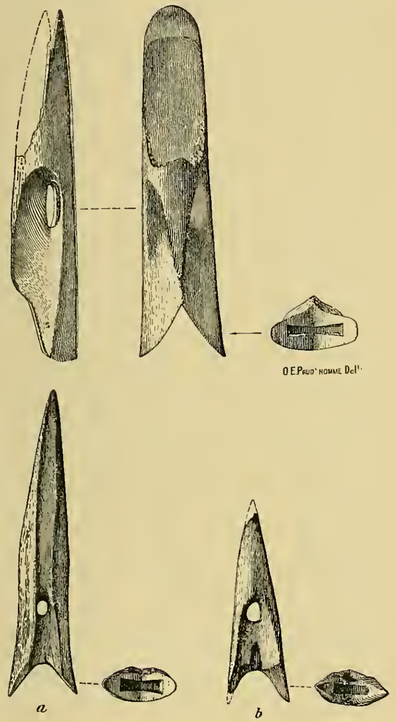


Fig. 2—Bone harpoon heads from Coats Island (lower, *a*, and upper) and Southampton Island (lower, *b*), with narrow, rectilinear sockets, probably representing the Cape Dorset culture. Half natural size.

The discovery of the Thule culture raises other problems besides that of its antiquity. Do all the ruins that have been recorded from the now uninhabited northern archipelago by the Franklin search parties and later explorers date from this Thule period, or are many of them later and a few, perhaps, earlier? As yet almost no archeological work has been done in the vast region that stretches from the Alaska-Canada boundary to the magnetic pole. Again, were the Eskimo migrations of the tenth and eleventh centuries that brought about the destruction of the old Norse colonies in Greenland directly connected with the disappearance of the Thule culture in Hudson Bay? In what region did the Thule culture first arise, and was it carried from west to east or from east to west by migrating tribes, or did it slowly permeate from one district to the next? Finally, did it extend to the southward—to the Yukon delta and the Siberian coast on the one side and round the shores of the Labrador Peninsula on the other?

The Cape Dorset Culture

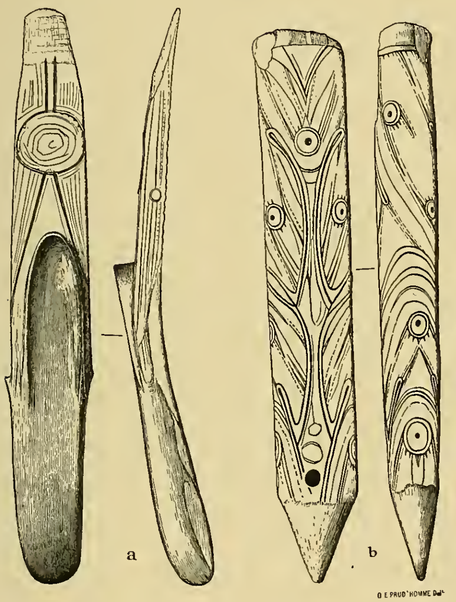
Now, in both these regions, in Hudson Strait and in Bering Sea, other ancient cultures have recently been unearthed. At Cape Dorset in the south of Baffin Island, and on Coats, Mansel, and Southampton Islands at the entrance to Hudson Bay, the ruined stone houses contain remains, not only of the Thule culture but of another very different that shows strong marks of Indian influence. The center of this "Cape Dorset" culture, as it has been tentatively named, seems to have lain around Hudson Strait, perhaps in the Labrador Peninsula; but it had offshoots in the north end of Baffin Island, possibly even on King William Island near the magnetic pole. Unlike the Thule, however, it never made its home in Alaska or influenced to any extent the Eskimos of the western Arctic. Was it then earlier, contemporary, or later than the Thule? The writer, studying specimens gathered by others, thought that at Cape Dorset it was the earlier; but Mathiassen, who himself excavated some of its remains on Southampton Island, concluded that in that place at least it was later. Possibly the two were contemporary, since doubtless they both lasted many centuries; and one might therefore be earlier in one district, the other in another. This question, and the mutual influence of the two cultures, can only be settled by further excavations, for which the most promising regions seem to be the south coast of Baffin Island and the north and west shores of the Labrador Peninsula. One interesting side issue enters here. Dr. Birket-Smith, the Danish ethnologist, has suggested that the Eskimos who left the Thule remains in Hudson Bay should be identified with the Tunnit, a half-mythical people celebrated in Eskimo legend from Coronation Gulf to Greenland and down to southern Labrador; but a hasty scanning of these legends leaves it open to doubt whether they were not rather the people with the Cape Dorset culture, who have likewise scattered their remains around Hudson Bay.

The Bering Sea Culture

The evidence for the third ancient culture, that in Bering Sea, rests on a mere handful of specimens collected by the writer in the summer of 1926. They came from Little Diomede Island, but several of similar type were obtained by Dr. Hrdlička, of the Smithsonian Institution, from St. Lawrence Island to the south, and many more, according to the Eskimos, have been found in other places around Bering Sea. They differ from the usual Eskimo specimens in the wealth and style of their ornamentation, which consists entirely of scrolls, circles, and wavy lines, skillfully etched on hard ivory. Some of the designs recall the wood carving of the Pacific Coast tribes of Canada and southwest Alaska, others the well-known scrollwork of Melanesia. With the latter, at least, they surely have no connection; the true source of the art lies more probably in northeastern Asia. However this may be, the border of Bering Sea, more perhaps than any other region in the Arctic, calls for archeological work to untangle its early history. The writer may hazard an opinion, based, it is true, on evidence not altogether sufficient, that there were Eskimos living south of Bering Strait before the Thule culture established itself in Arctic Alaska whose culture attained a level as high as, or higher than, any known today and whose influence reached as far to the north as Point Barrow.

Need for Archeological Excavation

We cannot hope to determine the antiquity of all these early cultures, their relationship to each other, or their subsequent developments and changes down to the present time until we have a much fuller knowledge of the elements of each and a more extensive collection of the implements and utensils it has left behind. For the



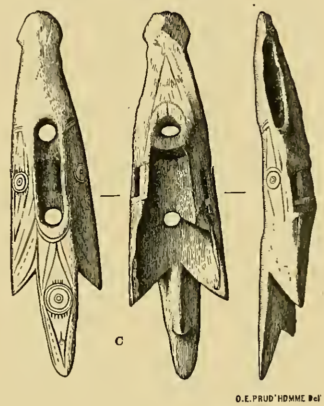


Fig. 3—Objects representing the early Bering Sea culture: *a*, ivory handle of a skin scraper; *b*, decorated harpoon foreshaft; *c*, ivory harpoon head with multiple terminal barbs and slots in the fore end for flint blades. Objects *a* and *b* are three-eighths, *c* is three-fifths natural size.

moment our most pressing need in the Arctic is the excavation of the ancient ruins, not in the haphazard, uncritical manner only too common in past years, when Eskimos were paid for the number of "curios" they could recover, without regard to their origin or age—this will only confuse the problems—; but by rigid, scientific methods that will take into account the geological and botanical conditions, the locations of the sites, the depths of the remains beneath the soil, and all the other factors that are relevant to the inquiry. A little such work has already been done in Alaska, the Hudson Bay region, and Greenland; but much more is required. Travelers who have no time to excavate can render good service by noting the locations, condition, and apparent ages of all the ruined dwellings they encounter and recording, especially in the central region from the Mackenzie River delta to Hudson Bay, the materials that entered into their construction, whether wood, stone, or bones of whale.

Camping places, indicated by circles of stones that have held down the margins of the tents, should be carefully distinguished from permanent houses; the former yield little or nothing to the investigator, the latter are frequently prolific in remains.

Seat of the First Eskimo Culture

The elucidation of the three cultures mentioned above is by no means the only result that we may hope from archeological work in the Arctic. Somewhere or other there must surely be an earlier, more primitive culture than any of them, for we can hardly believe that they sprang, full-grown, as it were, from the minds of the first people who adopted the hunting of seals, whales, and walruses for a livelihood. We do not know, indeed, in what region the Eskimos first settled on the coast and abandoned the interior life preserved, up to the end of the last century, by some tribes in the basin of the Colville River in northern Alaska and still maintained by the Caribou Eskimos inland from Hudson Bay. Steensby, it is true, has conjectured that their earliest seaboard settlements lay somewhere between Coronation Gulf and the magnetic pole; but the archeology of this region, so far as we know it today, fails to support his theory. Their first littoral home may well have been in Alaska or even on the Siberian shore; or they may have occupied more than one stretch of coast line simultaneously and developed different cultures that later coalesced. This is pure theory. Nevertheless, somewhere along the shores of the Arctic, we may be sure, the primitive littoral culture of some "proto-Eskimo" tribe awaits discovery.

Migrations in the Bering Strait Region

In Alaska even richer prospects are open to future archeologists. If America was peopled from Asia about the close of the Ice Age, as most ethnologists believe, and the immigrants came across Bering Strait from East Cape to Cape Prince of Wales, some traces of their passage should be discernible in this region. East Cape itself, and the Diomede Islands that lie like stepping-stones in the middle of the strait, consist largely of broken-down masses of granitic rock and are therefore less promising hunting grounds than the mainland of Alaska. Geological and geographical considerations favor a search in the delta and valley of the Yukon River, for not only is this the only highway into the interior of the continent, but the climate offers fewer obstacles to archeological work than either Bering Strait or the coast line farther north. Migrations from Asia, it may be objected, must have ceased so long ago that the discovery of their traces hinges on chance rather than on systematic search. Even if this be true, there is still another possibility. The resemblances between the Chukchis, Koryaks, and neighboring tribes of northeastern Asia and the Indians of British Columbia and southwestern Alaska have led certain authorities to believe that the former have drifted back from America to Asia—that they are really American tribes that have returned to the mother continent. Now a return migration of this kind, compared with the original migrations into America, must have been relatively recent, and its remains should be less deeply concealed. So the archeologist has a twofold chance of making significant discoveries along the Yukon River or around Bering Sea, in addition to what he may unearth of the less ancient remains.

I may add here one other Arctic problem that can hardly be settled without the aid of archeology, namely, the relationship of the Aleut to the Eskimos proper. Dr. Waldemar Jochelson has recently published a valuable account of his excavations on the Aleutian Islands,[1] but his work will never be complete until the old ruins on the mainland to the north and northeast have been similarly excavated and the specimens from the two regions carefully compared.

Need for Archeological Work in Labrador

I may mention also, perhaps, the need for archeological work along the Labrador coast. For in Labrador there are three interesting problems still unsettled. First, how ancient has been the Eskimo occupation of the coast? Second, are there any Norse remains left by Leif or his successors between 990 A.D. and the fourteenth century? And, third, were the Eskimo visits to Newfoundland and their battles with the Indians on the north shore of the Gulf of St. Lawrence part of a general movement southward that was arrested by the coming of Europeans, or were they rather the rear-guard actions in a retreat to the north under the pressure of advancing Algonquian tribes?

Ethnological Problems

The reader must not imagine, on account of the emphasis here laid on the archeological problems awaiting solution in the Arctic, that the day for strictly ethnological work has ended. It is true that the various expeditions of the last twenty years have greatly lightened the darkness that enveloped the long stretch of coast line between the Mackenzie River delta and Hudson Bay, but even yet we have only a limited knowledge of the Eskimos living along Back River and in the vicinity of the magnetic pole. No one has adequately described the ancient mode of life, the old customs and traditions,

[1] Archaeological Investigations in the Aleutian Islands, *Carnegie Instn. Publ. No. 367*, Washington, 1925.

of the tribes in the Mackenzie River delta or on the east coast of Hudson Bay. Even in Alaska the folklorist, the sociologist, and the student of primitive religions will find mines of fabulous richness that such veteran ethnologists as Murdoch and Nelson hardly did more than sample. Of all these regions the east coast of Hudson Bay has perhaps the first claim to investigation, because it may throw much-needed light on the religious beliefs and mythology of the Labrador Eskimos and on the depth to which they were affected by their contact with the Indians. On the other hand, philologists who are attempting to reconstruct the ancient stem forms of Eskimo words, in order to compare them with the ancient stem forms in various Asiatic languages, require more than all else phonetically accurate vocabularies of the dialects in western Arctic America. The writer has, indeed, compiled extensive vocabularies from two places in that region, Point Barrow and Cape Prince of Wales; and he has smaller vocabularies from Nunivak Island, East Cape in Siberia, and one or two other districts. In collecting them he discovered that the dialects of the Siberian coast and of the Yukon and Kuskokwim deltas diverged more widely from those spoken north of Norton Sound than the latter from the dialects of far-distant Greenland and Labrador. This has undoubtedly an important bearing on the early history of the Eskimos, although its full import is not yet clear. One fact is evident, however; we must have more complete information concerning the dialects spoken around Bering Sea before we can formulate the main phonetic rules that have brought into existence the different varieties of the Eskimo tongue. To attempt to correlate, as some writers have done, a modern Eskimo dialect with a modern European or Asiatic dialect, without taking into account their separate histories, seems as difficult an undertaking as to compare modern English with modern Hindustani without a knowledge of Sanskrit.

Problems in Physical Anthropology

Turning now from archeology and ethnology to physical anthropology, the first question that confronts us is the effect of Arctic life on the anatomy of the Eskimos. We know that their skin color is lighter than that of most Mongoloid peoples, that the nasal aperture is the smallest in the world, and that the head and face have certain marked peculiarities. Most authorities ascribe these changes to the combined effect of climate and food—to the diminished intensity of the sun's rays, the low temperature combined with great humidity, and the unvaried diet of meat and fish, eaten raw, frozen, or imperfectly cooked. But we really know very little concerning the result of a diet that excludes practically all vegetable products, the physiological result, that is, as well as the purely mechanical, such as the increased strain on the temporal muscles. And no one has studied the Eskimos at different periods of the year to discover whether there is any seasonal variation in glandular or nervous activity. Even if we are certain that climate and food (aided perhaps by inbreeding) could produce the specialized Eskimo type, it would be exceedingly interesting to know how long a period nature has required to bring about this result. Do the crania in the most ancient ruins reproduce faithfully the peculiar characteristics of the modern Eskimo? This question involves still another. Are the differences that we know exist between the Eskimos of different regions to be ascribed very largely to varied admixture with Indian and Asiatic tribes, or are they also caused, in the main, by slight differences in the environment?

Eskimo Peopling of Greenland; Endemism of Eskimo Culture

A few problems have been purposely omitted from this discussion. One relates specifically to Greenland. Certain writers hold that this island continent was peopled in two waves; that the first body of immigrants traveled by sled through the northern archipelago, up the west coast of Ellesmere Island, across the north end of Greenland, and down its east coast, giving rise to the present tribe at Angmagssalik; and that the second, starting at a later period, skirted in boats the coast of Baffin Bay and settled along the western shore of Greenland. This theory will probably stand or fall according to the discoveries that result from the geological and topographical survey of the entire coast of Greenland now being planned by the Danish government. Another problem, how much of the culture of the Eskimos is their own invention, how much they have borrowed from tribes immediately adjacent to them, whether in America or Asia, and how much is a heritage from a far-distant past common to all or most of the aborigines of North America, can be investigated in libraries and museums more easily than by the worker in the field. In this paper I have tried to present only those problems that depend for their solution on further explorations in the American Arctic.

For many years Dr. RASMUSSEN has studied the life of the Eskimo and explored northern lands. He has made many visits to Greenland and has been the leader of four of the five "Thule" expeditions, named after the Thule trading station he established in North Star Bay, Wolstenholme Sound, Greenland. In the first of these in 1912 he twice crossed northern Greenland over the inland ice and explored the region at the head of Danmark and Independence Fiords, thus establishing a link between the explorations of the ill-fated Mylius Erichsen, 1906–1908, and of Peary, 1892 (see "Report of the First Thule Expedition, 1912," *Meddelelser om Grönland*, Vol. 51, 1915, and "Min Rejsedagbog," Copenhagen, 1915). On the second Thule expedition the remaining unexplored fiords on the northern coast were surveyed, and our knowledge of the precise outline of Greenland thus practically completed (see "Greenland by the Polar Sea," London, 1921; "The Second Thule Expedition to Northern Greenland, 1916–1918: Narrative of the Expedition," *Geogr. Rev.*, Vol. 8, 1919; and "Scientific Results of the Second Thule Expedition to Northern Greenland, 1916–1918," *ibid.*, Vol. 8, 1919). On the fourth Thule expedition, 1919, he studied folklore among the Angmagssalik Eskimos in eastern Greenland. On the fifth Thule expedition (1921–1924) he went from Greenland across Arctic America to the Pacific for the purpose of studying the native tribes (see "Across Arctic America," New York, 1927). He is also the author of "The People of the Polar North," Philadelphia, 1908, "Eskimo Folk-Tales," London, 1921, and "Myter og sagn fra Grønland," 2 vols., Copenhagen, 1921–1925.

TASKS FOR FUTURE RESEARCH IN ESKIMO CULTURE*

Knud Rasmussen

EVERY scientist who has had occasion to occupy himself with the Eskimos must soon have realized that there is hardly a primitive people in the world whose history is so interesting and so complex. Scattered about throughout half the Arctic circumference of the globe, the Eskimos have, under the most widely different conditions, managed to adapt themselves to the requirements of nature and have carried on their struggle for existence in regions which one would hardly believe could offer any possibility of maintaining human life. But it is just this resistance, the opposition encountered in their surroundings, that has hardened and developed their minds, until we find among them what is relatively a surprisingly high degree of culture, material and spiritual alike.

The Eskimos are like no other people in the world; and, despite the fact that they have been studied now for over two hundred years, despite the fact that expeditions with up-to-date equipment, in Greenland, Canada, and Alaska, have specialized in that study, there are still many problems awaiting the ethnographer. The more we learn the more we desire to know about them, and each new expedition, achieving new aims, seems to leave in its wake a series of fresh problems to be solved.

Here, then, despite the voluminous works already written about this people, there seems to be a gold mine for those who will undertake the search; and it may console the younger generation of scientists, now ready and waiting to take a hand, thus to be assured that there is work for them enough and to spare.

STUDY OF BARREN GROUNDS INLAND ESKIMO CULTURE AS POSSIBLE SURVIVAL

On the Fifth Thule Expedition, from Greenland to the Pacific, where we succeeded in visiting all the Eskimo tribes with the exception of those living south of the Yukon on the shores of Bristol Bay, our main object was to procure material illustrating the origin of the Eskimos, their routes of migration between Siberia, Alaska, Canada, and Greenland, and, finally, to collect folklore from as

*Translated by W. Worster, Worthing, Sussex, England, from the Danish original written for the present volume.

many tribes as possible. The scientific results of the expedition are still in process of compilation, and the only fairly comprehensive survey hitherto published is that which appeared in the *Geographical Review*[1]. The article in question describes how Birket-Smith and I encountered, on the shores of Lake Yathkyed in the Barren Grounds (in the Kazan River basin, 63° N. and 98° W.), an Eskimo tribe, the most primitive of all those we met throughout the whole of the expedition, that seemed to represent in many ways the remains of the aboriginal Eskimo culture. The Danish professor H. P. Steensby had already, some years before, put forward[2] the theory that the origins of the Eskimo culture were to be sought by the great lakes and rivers of northern Canada. The Eskimos were thus, to begin with, an inland people but later made their way down to the coast, either voluntarily, in pursuit of the reindeer on their way to the coast regions, or driven out themselves by hostile Indian tribes. And on the shores of the Arctic they gradually developed that form of culture which at the present day is regarded as typical of the Eskimos generally, based on the capture of marine animals.

The tribes we met in the Barren Grounds had no recollection of ever having lived by the sea, and there was nothing whatever in the form of their implements to suggest that they had ever done so. Furthermore, their religion was of a pronounced inland type, devoid of the numerous taboo rules which are so characteristic of the coast dwellers. This and many other observations made it seem likely that we had here come upon a survival of an ancient aboriginal culture, and it would be supremely interesting to follow it up along its presumed route down towards the coastal regions. The best means of doing so would be by archeological investigation, but this we were unable to undertake during our stay inland, and it would in any case be extremely difficult in the Barren Grounds. The Eskimos of these regions have no permanent winter dwellings where refuse accumulates, providing the material for archeological "finds"; they live throughout the winter in snow huts, and, as these are constantly being rebuilt on different sites, kitchen middens have no time to form. Even did such exist, it would be extremely difficult to trace them, for we have not here, as on the coast, ruins of the houses themselves to indicate the site. Precisely the same difficulty is encountered by the archeologist in the case of the tent rings, which are indications

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[1] Knud Rasmussen: The Danish Ethnographic and Geographic Expedition to Arctic America: Preliminary Report of the Fifth Thule Expedition, *Geogr. Rev.*, Vol. 15, 1925, pp. 521–562. With sections on Folklore by Knud Rasmussen; Physical Anthropology, Linguistics, and Material Culture, by Kaj Birket-Smith; The Archeology of the Central Eskimos, by Therkel Mathiassen; Contributions to the Physical Geography of the Region North of Hudson Bay, by Peter Freuchen and Therkel Mathiassen; and a map in 1:4,000,000.

[2] In his: Om Eskimokulturens Oprindelse: En etnografisk og antropogeografisk Studie, Copenhagen, 1905; revised English transl. as: An Anthropogeographical Study of the Origin of the Eskimo Culture, *Meddelelser om Grønland*, Vol. 53, No. 2, Copenhagen, 1916.

of merely temporary dwellings. The whole of the summer is generally passed in one continued pursuit of game and fish; and to look for old implements or similar archeological remains in the Barren Grounds would be worse than looking for a needle in a haystack.

Study of Coastal Culture Along the Northwest Passage Straits

Again, we have the same difficulty, from the archeological point of view, down on the coast, both at Hudson Bay and the straits along the Northwest Passage, where the first Eskimo emigrants doubtless used only snow huts, just as do the present inhabitants of these tracts. All these coast dwellers do in reality resemble the inland tribes very closely, both in their material and spiritual culture, and appear to have settled on the coast only in comparatively recent times. All the ruins now found on the coast date from an altogether different period, and the implements there found are very much like the Alaskan type, the result of many generations' adaptation to the sea as a source of livelihood.

It would be most interesting, then, if archeological finds could be made on the coast—especially in the region of the Northwest Passage—of such a character as to support and link up with the material procured by the Fifth Thule Expedition, all of which points to the Barren Grounds of Canada as the earliest home of the aboriginal Eskimos.

Archeology the Tool for the Study of Cultures

There is no denying that the surest means of ascertaining the origin of Eskimo culture is that of archeological investigation. And it is the more gratifying, then, to note that interest in such investigations seems to have increased considerably of recent years, in the United States and Canada as well as in Denmark.

The investigations of Therkel Mathiassen on the Fifth Thule Expedition showed that it is just in the field of archeological research that important results can be obtained; for he demonstrated by his excavations the existence of a widespread ancient form of culture, the Thule type,[3] in places which, at the time of their occupation, lay several meters lower than at the present day. Some of the implement types here found were previously known from the northeast coast of Greenland, and their kinship with finds from Southampton Island had already been established, e.g. by Professor Franz Boas. On the west coast of Greenland, also, similar types have been found; here, however, the conditions under which they were found afforded no means of determining their chronological relation to other finds.

[3] *Geogr. Rev.*, Vol. 15, 1925, pp. 547–549.

Greenland As a Field for Archeological Study: Northern Part of East Coast

It is natural that I, as a Dane, should call attention to Greenland as one of the countries where there are still many problems awaiting solution. Strange as it may seem, we know more as to archeological conditions on the uninhabited northern part of the east coast of Greenland than we do of the inhabited and colonized regions on the west coast. This is explained by the fact that investigators have naturally turned chiefly towards those fields where all was yet untouched and where there was most to do and dare.

Even here, however, there is of course still much to be done. Unfortunately, it is rarely that expeditions have numbered among their members any scientifically trained archeologist; and on sledge journeys, where time is precious, it is natural to devote oneself chiefly to such ruins as show up plainly in the landscape and seem to promise the richest yield; this means, however, that the oldest and most valuable ruins escape notice. Bendix Thostrup, who was with Mylius-Erichsen on the Danmark Expedition in 1906–1908 to the northeast coast of Greenland, has already called attention to this point; and later excavations, carried out on the occasion of the recent establishment of a Danish colony at Scoresby Sound, seem to show that he is right in supposing that an older form of culture than we at present know still remains to be found.

So much for the northern part of the east coast.

Southern Part of East Coast

There is far more need, however, of investigations on the west coast and the southern part of the east coast as far north as Angmagssalik. Such researches as have hitherto been carried out here have not succeeded in establishing any cultural connection between northeast Greenland and Angmagssalik; and, as matters stand at present, the results seem to suggest that the Angmagssalik district must have been populated from the south, by people coming down along the west coast and going on again to the east.

This, however, cannot be regarded as a certainty as long as we have so few archeological finds from the southern part of the east coast and no systematic excavations whatever have been made. To form definite conclusions by comparison of archeological material from northeast Greenland with modern implements from Angmagssalik is out of the question; there is, for instance, the possibility that the original inhabitants of Angmagssalik came from the north and that this older form of culture remained hidden in ruins that have never been excavated, while a later group of immigrants from the south gave the inhabitants their present form of culture.

The Problem of Migration Routes

In this connection it may be well to point out that all finds in ruined dwellings on the northernmost part of the east coast lie so near finds made on the northern part of the west coast that we may, not least on account of the slight distance via the north coast between the sites, be warranted in supposing that the east coast, at any rate as regards its northern parts, was first inhabited by immigrants coming round the north of Greenland. Most archeologists hold this view; I myself, however, find it very hard to accept. In the course of the Second Thule Expedition I traversed and very carefully explored the entire north coast of Greenland from Humboldt Glacier up to De Long Fiord. North and northeast of Cape Sumner on Polaris Promontory we found no indication of previous occupation, though we went up into all the fiords and were particularly on the alert for any such indications all the way up to our northernmost point. The polar sea ice piles its enormous pressure ridges up close in to shore, while on the landward side the inland ice leaves hardly anything in the shape of clear, snow-free coast right up to Peary Land. The pursuit of game is so difficult here that an expedition with modern equipment is hard put to it to get through, and it is hardly possible to suppose that the Eskimos, with implements of the Stone Age type, on the march with their women and children, would venture to choose the northern route through a waste of tumbled ice devoid of game, when by going south along the west coast they would be moving over excellent ice towards regions in which game grew ever more plentiful as they advanced. That the climate, and thus also the state of the ice generally, should at that time have been different from what we find today is, to my mind, out of the question.

Lauge Koch, who has been in these regions since I was there, is of the opinion that certain features in the northernmost part of the east coast might suggest that the Eskimos had moved from west to east through Peary Land. His arguments, however, have not convinced me, and I can still see no practicable route for a primitive people migrating round the north of Greenland. The question is, however, an interesting and important one, and it is to be hoped that it may one day be definitively settled.

The Eskimos coming from the west, first from Canada and later from Alaska, evidently must have moved, some through Ellesmere Land, others through Grant Land via Lake Hazen; and, if we keep to the west coast, where, in the Cape York district and also farther south, in Melville Bay, house ruins of various types and ages abound, it is plain to see that several different streams of culture must have flowed along the west coast of Greenland; and that the Thule culture was one of them we may say with certainty. Where these different

FIG. 1—(Based on maps by Grant, *7th Ann. Repl. New York Zool. Soc., 1902*, following p. 196, and by Steensby, *Meddelelser om Grønland*, Vol. 34, 1910, p. 401.)

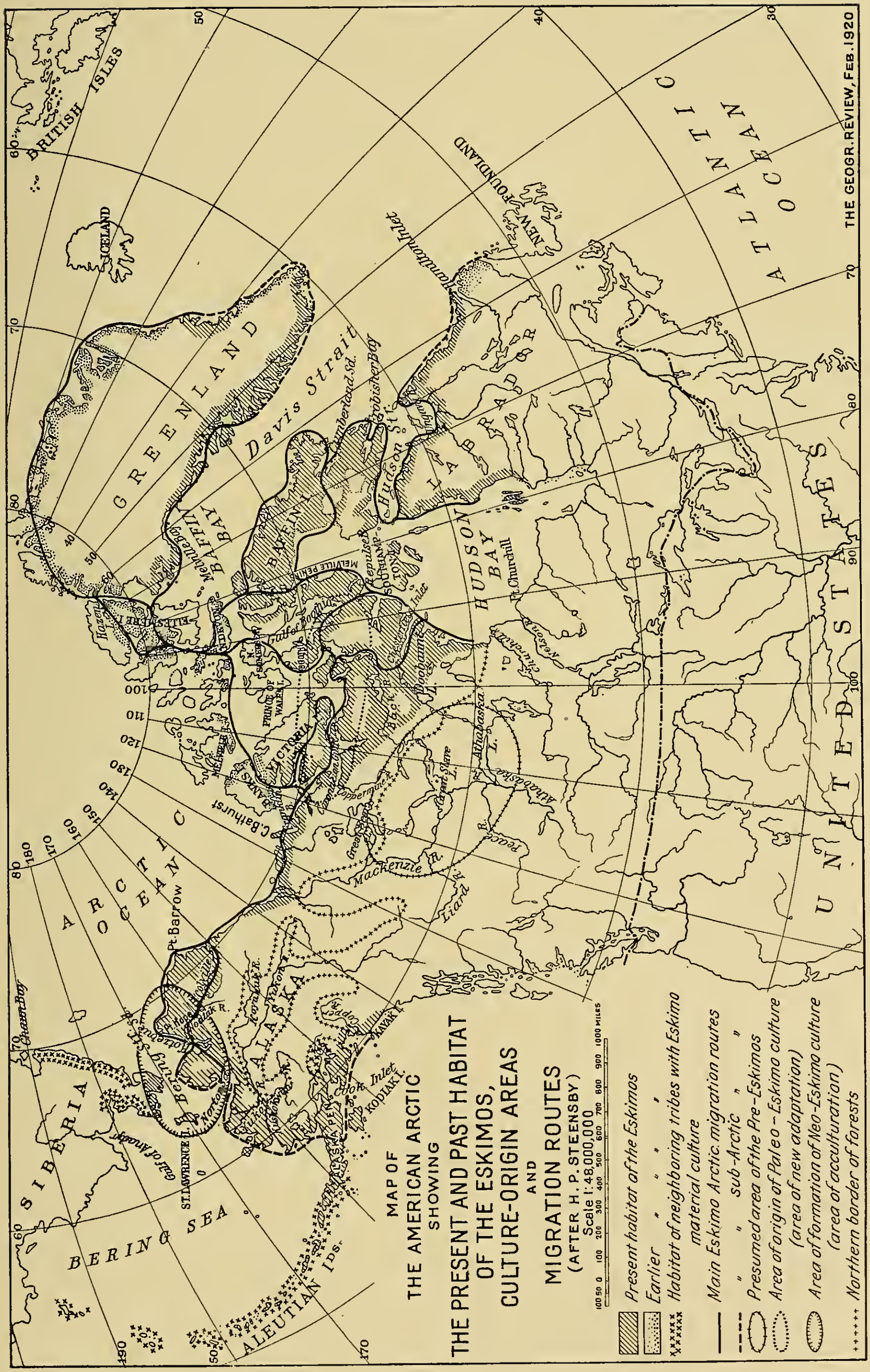

FIG. 2—(Based on map by Steensby, *Meddelelser om Grønland*, Vol. 53, Article 2, separate plate, 1917.)

streams originated, however, and how far southward one or another may have reached, are questions of considerable scope still awaiting further investigation.

Mixture and Superposition of Cultures

Greenland is of course the extreme eastern limit of the Eskimo migrations, forming a cul-de-sac where further progress becomes impossible. Here, then, as under similar conditions in India, we find a mingling and superposition of the cultures of many different immigrant tribes, which renders study of the question difficult but at the same time more interesting.

On the west coast, where we have what is by Eskimo standards a densely populated region and where Europeans have traveled and traded and had their dwellings for centuries past, it is high time that the question should be taken under consideration, before its solution is rendered impossible by the greatest danger of all, to wit, the interference of untrained hands hunting for antiques.

It is most fortunate, then, that plans are now under consideration in Denmark for systematic research in this field. The Cape York district in particular would be a most important site, that is to say the area between Cape York and Humboldt Glacier, which forms, as it were, the entrance into Greenland.

Apart from the Eskimos, we have in Greenland also the problem of the ancient Northmen and their fate and the question of possible reciprocal influence between their form of culture and that of the Eskimos; then, again, there is the possibility of Eskimo immigration to the east coast prior to the arrival of the Northmen, who, as we know, saw little of it in the earlier times but found traces of previous occupation.

The leading problem in Greenland, and one of essential importance to the Eskimo question as a whole, is at what stage of culture the earliest immigrants were when they arrived and which were the tribes that reached so far to the east. The question as to the actual origin of Eskimo culture itself, however, is one that must be studied in regions farther west.

Up to now the Thule culture is the oldest form of Eskimo culture of which we have any detailed knowledge and which has been geologically determined as to date; the position of the Cape Dorset culture is still vague; there is perhaps no great difference in point of time between the two. The Thule culture, however, is based to a marked degree on the capture of marine animals and has its origin in the west.

The question as to the development of the Eskimo coast culture is also one of importance on the Pacific shores of Alaska, and parallels in point of culture between tribes in the Vancouver and Amur regions carry the problem farther beyond the actual Eskimo territory. Kamchatka would here be a good field of investigation, and we might also point to the north coast of Siberia, at the spot where the Swedish *Vega* expedition discovered the so-called Onkilon ruins, the finds from which are now in the museum at Stockholm.

The position of the Aleuts in relation to Eskimo culture also calls for further study. In this question, too, archeological methods have already proved fruitful and, in the hands of experts, will continue to yield valuable results. These methods should be accompanied by the requisite observations as to geological and other features of interest. Where a deposit left by previous occupation is of such thickness as to indicate considerable length of time it is most essential that the investigation should be carried out by strata. To determine the exact chronological sequence of the types found, from the lowest layers to those above, is very necessary indeed.

Nor should we here omit to note that archeological investigations on what is now Indian territory might help to throw light on the question as to the previous southern limit of Eskimo occupation.

Among the Eskimos of the present day accurate investigations are needed in several quarters, as for instance, on the west, among the tribes of the Yukon and Bristol Bay and, on the east, of the east coast of Hudson Bay and the shores of Hudson Strait. Both in Alaska and Labrador there is also a lack of anthropological measurements and physiological investigations.

So much, then, for archeology, which from its very nature is and must be the main source of the information we are seeking as to the Eskimos and their past in fields associated with the origin of their culture, their life, and the route followed in their migrations.

Importance of Folklore Studies

An altogether different field of work, which, however, likewise offers most valuable information, is that of folklore—the unwritten history of the Eskimos, handed down by oral tradition from generation to generation throughout centuries. I am aware that some caution is always needed when dealing with material procured in this way; on the other hand, when we have proofs of the reliability with which a tradition has been preserved for a thousand years, so that one finds the same story told word for word in Greenland precisely as in Alaska, it is hardly too much to say that folklore also may be regarded as a source of the very greatest importance.

Folk tales from all regions should be written down, with carefully formulated specimens of the language and dialect. As regards the Greenland Eskimos, there are already most exhaustive collections.

On the Fifth Thule Expedition I endeavored, wherever I went, to procure as much material as possible, writing it all down in the original; and, despite the great amount of time occupied in journeying from place to place, I managed nevertheless to obtain exhaustive collections from the Hudson Bay regions, the Barren Grounds, King William Island, Bathurst Inlet, the Mackenzie delta, and the Colville River, Alaska. Obviously, however, much still remains to be done in this field of work.

The Eskimo folk tales are altogether unique and unlike the folklore of other primitive peoples. We find here graphic imagination and simple narrative skill combined with the greatest respect for historical fact, and endless information may be gleaned from these stories as to the relations of one tribe with another, their life, and their religious ideas.

It would be highly desirable to obtain collections from East Cape, Siberia, and the Yukon region with Bristol Bay, as the material at present available from these important localities—and also, by the way, from the islands in Bering Strait—is still very inadequate. And it is a matter which will not admit of delay. There is still a wealth of varied material waiting for those who take up the work now; but, before many years have passed, the advance of civilization will have introduced white men's ways and customs everywhere, and it will then be too late. The material will be lost beyond recall.

Ethnographical Collections in Museums

The same applies to the collection of ordinary ethnographical, as distinct from archeological, objects throwing light on the present-day culture of the Eskimos as regards their implements, now disappearing. Here also white men's gear has almost everywhere ousted the simple yet most ingenious inventions of the Eskimos themselves. It is still possible, however, to make collections in the more isolated districts.

It is fortunate, then, that various museums already possess rich and instructive collections. As regards the Old World, by far the greater part of Eskimo material is found in Northern Europe. The most comprehensive collection is that of the National Museum in Copenhagen; and as regards Greenland and the Central Eskimos it is doubtless the most important. The Western Eskimos, who are less thoroughly represented here, will be found together with the Northwest Indians in a rich collection in the Ethnographical Museum in Berlin, mainly acquired from the travels of Adrian Jacobsen.

Copenhagen is a leading center of Eskimo archeology; the archeology of Greenland is also well represented in Stockholm. At Oslo there is the rich collection brought home by the *Gjöa* expedition from the neighborhood of the north magnetic pole. In the British Museum in London, and also in Edinburgh, there is the important, though not very extensive, material from the Northwest Passage expeditions, while the peoples of northern Asia, who have some connection with the Eskimos, may be studied in representative collections at Leningrad and Helsingfors.

Need for International Coöperation

The most important sphere of operations for the furtherance of our knowledge of the Eskimos and especially for the solution of the last and by no means negligible questions is, as I said at first, that of archeological research. At a time when the present Eskimo settlements are being modernized and all individuality is being effaced, we turn to the ruins of ancient dwellings now leveled to the ground, where archeology finds its material untouched by time and subsequent development.

This is one reason why it is so vitally important to have all old sites of Eskimo occupation properly protected. In Greenland it is already assured; no amateurs are allowed to undertake excavations. May it soon be the same in Canada, Alaska, and Siberia!

But, while we thus recognize that the work of the future must lie to a very essential degree among the ancient dwelling places, it would be most valuable to have these sites themselves marked off on suitable maps. There are already several maps with sites of occupation, old and more recent; the maps are too small, however, for precise determination of locality.

It would therefore be most advantageous if we could collect at some convenient center all that is known as to Eskimo occupation and indicate it on large-scale maps. This would also be the best way of showing distinctly what is lacking.

Work of this sort, however, calls for regular international cöoperation. And cöoperation is the one thing most needed at the present stage in our study of the Eskimos.

Mr. Bogoras has spent much time in the Kolymsk district of the Yakutsk Province of Siberia, where, as one of a group of political exiles, he devoted himself to the study of the region. In 1897–1898 he was coworker with Mr. Waldemar Jochelson on the Sibiryakov Expedition of the Russian Geographical Society around Nizhne Kolymsk. As the result of this expedition he published "A Brief Account of the Investigation of the Chukchis of the Kolyma District" (*Bull. of the East Siberian Division of the Imp. Russian Geogr. Soc.*, Vol. 30, 1899, in Russian); "Materials for the Study of the Chukchi Language and Folklore Collected in the Kolyma District" (Imp. Russian Acad. of Sci., St. Petersburg, 1900, in Russian); and "The Lamuts" (*Zemlevedenye*, Vol. 7, 1900, in Russian). In 1900–1901 he was engaged, again with Jochelson, in anthropological researches for the Jesup North Pacific Expedition of the American Museum of Natural History. On this expedition his work was for the most part among the Chukchis, on which he has published "The Chukchee" (Amer. Museum of Nat. Hist. Jesup North Pacific Expedition Memoirs, 1904–1910). He is also author of the article "Chuckchee" in the "Handbook of American Indian Languages" published by the Bureau of American Ethnology, Washington (*Bull. 40*, Part II, 1922); "Early Migrations of the Eskimos Between Asia and America" (*Compte-Rendu Congrès Internatl. des Américanistes, 21st Session, 1925*); and of the two papers related to the following article there referred to in the asterisk footnote.

ETHNOGRAPHIC PROBLEMS OF THE EURASIAN ARCTIC*

Waldemar Bogoras

The recent successes of scientific ethnography are due to a wide application of the comparative method. Instead of a description of separate tribes, a connected study of whole tribal groups and ethnographical regions in many parts of the world has brought new and unexpected results.

Russian ethnographical science now aims to locate and explore more carefully the ethnographical regions within the wide circle of Russian nationalities. One of the most important and clean-cut problems in that field is the problem of the extensive Russian polar regions, that is, properly speaking, of the whole Eurasian Arctic. This belt, geographically and ethnographically, is closely related to the polar regions of America. In discussing its ethnographic problems we will first deal with the native and then with the Russian populations.

The Native Population

Unity and Origin of the Polar Culture

The Arctic Sea is the common mediterranean sea for the whole polar region, and along its shores, in spite of the severity of the climate, mutual reaction of cultures has taken place, so that there is a special polar culture, quite original and in many respects different from the culture of more southern latitudes, expressing itself in physical conditions, in industries, dwellings, clothing, in religious ideas, folklore, and art.

This polar culture originated in the Arctic region and was accepted and assimilated by peoples coming from the south. Whether it had one or several centers of origin is unknown; but it is natural to assume that this culture originated in one area and thence spread throughout the polar world.

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*Condensed translation by Mr. Nicholas George of the American Geographical Society's staff of V. G. Bogoraz: Novye zadachi Rossiiskoi etnografii v polyarnykh oblastyakh (New problems of Russian ethnography in the Polar Regions), Trudy Severnoi Nauchno-Promyslovoi Ekspeditsii (Publications of the Northern Scientific-Practical Expedition), No. 9, Petrograd, 1921. An English version of the section on the native population was later published by the author under the title "New Problems of Ethnographical Research in Polar Countries" in *Proc. 21st Internatl. Congr. of Americanists, First Part, Held at The Hague, Aug. 12–16, 1924,* The Hague, 1924, pp. 226–246.

On Siberian ethnography and anthropology in general the reader may wish to consult M. A. Czaplicka: Aboriginal Siberia: A Study in Social Anthropology, Oxford, 1914, which, for one, has made accessible to the English reader the results of Russian research in this field.—Edit. Note.

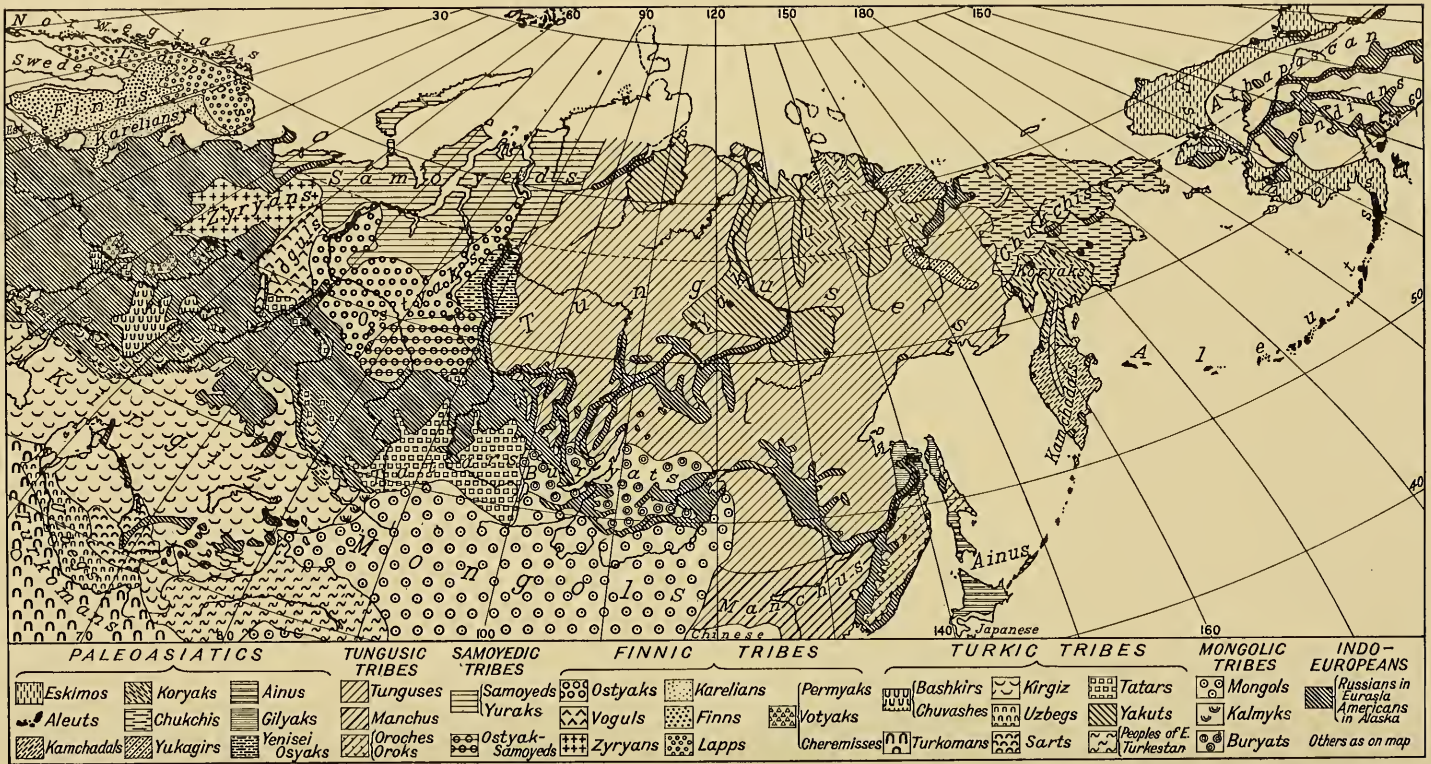

FIG. 1—Ethnographic map of northern Eurasia. Scale, 1:53,000,000. The distribution of tribes is based mainly on the "Atlas of Asiatic Russia," Bur. of Internal Coloniza. of the Dept. of Land Organization and Agric., St. Petersburg, 1914, Pl. 25, and on the ethnographic articles in Vol. 2 of the accompanying text volumes (I. P. Poddubnyi: Ethnography, pp. 93–178; V. K. Kuznetsov: Original Russian Settlers in Siberia and Central Asia, pp. 178–188; New Immigrants in Siberia, pp. 188–199).

Even in the present state of our knowledge the paths along which certain cultural influences have spread are apparent; these influences have mostly traveled in an eastward direction, seldom in a westward.

We may assume that the polar culture had its origin in a more southern latitude at the end of the Glacial Period and only later moved to the north with the retreating of the glaciers. In this way we may bring it into connection with the culture of European Paleolithic man and, for instance, assume that the domestication of the northern reindeer is immediately related to the reindeer hunting so much practiced in the Paleolithic epoch. We have, however, no data referring to this connection.

On the other hand we may suppose that the unity of the polar culture is based, at least in part, on the common origin of a considerable number of Arctic tribes. These include, among Paleoasiatics, the Yenisei Ostyaks, the Yukagirs, Chukchis, Koryaks, Kamchadals, and, in southeastern and southwestern Siberia respectively, the Pacific coast tribes as far south as the Amur River and Sakhalin Island and certain now mostly extinct tribes on the upper Ob and Yenisei Rivers. To the east the northern tier of tribes is continued by other Paleoasiatics, the Asiatic and American Eskimos, to the west by Uralo-Altaic tribes, the Samoyeds and Lapps, the last, however, modified by Finnish influences. Even the Ostyaks and the Voguls, who are true Finnish tribes and therefore Uralo-Altaics, stand apart from the other Finns and in several ways are more closely related to their Paleoasiatic neighbors. (For distribution of tribes, see Fig. 1.)

The Bering Sea Region and Its Relation to the Eskimo Problem

The problem of the origin of the polar culture is closely connected with another no less important problem, namely that of the origin of the population of the New World, because in the Bering Sea region is situated the only known bridge from the Old World to the New. In this connection there is also the special problem as to the origin of the Eskimos, who live now almost exclusively in polar America, but a few bands of whom still cling, as it were, to the extreme northeastern promontories of Siberia and the influence of whose culture is still felt in Asia.

Thus the study of the particular culture developed in the Arctic regions is closely related to the study of the lands encircling Bering Sea. Only with the aid of this study can we fill the gaps that remain open, especially in the northernmost part of the Bering Sea region, as, for instance, the problem of the Eskimo wedge. This Eskimo wedge, it now seems established, entered the region from the north, from Bering Strait, and cut into two parts the continuous chain of

Americanoid tribes, forcing them back to the west and to the east. However, the links of this chain still remain, from the Kamchadals in Asia to the Tlingits and Haidas in America. For some time this Eskimo wedge expanded within the Bering Sea region and moved southward, then again it was compressed and driven back northward. There is no answer as yet to the question whence, originally, came this wedge, whether from the west or from the east, and whether the Asiatic Eskimos are primitive inhabitants of Asia or only a colony that came from America. Only the study of the polar ethnographical region in its whole extension can shed light on these tangled and complicated intertribal relations.

Physical Types and Abilities of the Eurasian Arctic Tribes

We shall begin our survey of polar ethnographical problems by way of physical anthropology and then discuss somewhat more fully questions of material and spiritual culture.

The physical type of the polar peoples shows three main variants, often found together in the same tribe and often intermixed: (1) Mongoloid, (2) Turkoid, and (3) Finnoid. These terms, however, are purely conventional and do not imply the intermixing of the Arctic tribes with Mongols and Turks. Only intermixture with Finns, as has been said above, has really taken place. As to the Mongoloid and Turkoid types we may assume that they are the fundamental human types for all Northern and Central Asia and partly also for Europe and Arctic and sub-Arctic America and that the formation of these types preceded the racial subdivisions of the present.

The Arctic tribes, as would be expected, show quite an unexampled endurance as regards cold, hunger, tiredness, and sleeplessness—the last especially in summer, "when the sun doesn't sleep." It is difficult to tell who are superior in these respects, the western or the eastern tribes, coastal seal hunters or nomadic reindeer breeders of the tundra. Even the sub-Arctic Yakuts are able to sleep in winter at a temperature of −50° C. near a wood fire under the open sky. They strip quite naked and, having no sleeping bags, simply cover themselves with their clothes instead of a blanket. Snow falls on the bare body and melts without causing them noticeable inconvenience.

At the same time the polar tribes are extremely susceptible to contagious diseases brought by the Russians, such as syphilis, smallpox, grippe, scarlet fever, and even measles. In the far northeast the same epidemics devastate Russian villages and native camps, often carrying away a third of the scanty population.

Further, we have to note a special polar hysteria, common to many (but not all) polar tribes and particularly to Russians also, especially in extreme northeastern Siberia. Polar hysteria attacks mostly women, sometimes the whole female population, being associated like other hysteria with the function of sex. In its weaker forms it is somewhat similar to that of the Russian *klikusha* (a woman possessed of the devil). More serious forms are similar to epilepsy and not seldom result in temporary insanity.

Temperament

As to the temperament and mood of the Arctic tribes, pushed off into the far northern latitudes, living under hard conditions in tragically bare surroundings, one might expect to find a certain melancholy. However, such an expectation is not confirmed by the facts. Thus the Eskimos, as has been commonly reported by explorers, are as much given to merriment and laughter as are the primitive tribes of southern and tropical countries. In their folklore a prominent place is occupied by ironical songs composed for a given occasion and sung by young men and girls. Such ironical songs are also met with among the Chukchis and Lapps as well as among the Russian immigrants on the lower Kolyma and Anadyr. The Chukchis have always been distinguished by an indomitable character, and in the defense of their independence they have been not less persistent than the New Zealand Maoris and the Chilean Araucanians. Only such tribes as the Ostyaks and tundra Yukagirs, oppressed and facing extinction, exhibit a sad or melancholy mood.

For artistic genius the Arctic tribes, as is shown by their embroidery, drawings, sculpture, and carving, can well sustain comparison with the tribes living in the south.

Material Culture: The Rôle of the Reindeer and Dog

Turning now to a discussion of material culture, we shall take up in order the rôle of the reindeer and the dog in that culture, hunting, clothing, food, housing, and tools and weapons.

In the sphere of animal domestication, the polar culture is characterized by the breeding of reindeer and dogs. These are hardly found elsewhere than in Arctic and sub-Arctic latitudes—reindeer breeding in the Old World only, dog breeding in the Old as well as in the New World.

There are three types of reindeer breeding, two of them connected with sled driving and the third with deerback riding. The two types connected with sled driving are practiced on the coast of the Arctic Sea, the Yenisei River being the boundary between them. The western of these two types is characterized by the use of a shepherd dog to guard the herds, this usage being evidence of a higher degree of culture. In the eastern type the reindeer, badly tamed, are watched by the shepherds themselves without the help of dogs.

To the first type belong the Lapps, Samoyeds, Zyryans, and some of the Ostyaks; to the second the Chukchis, Koryaks, Yukagirs, Tunguses, and some of the Yakuts. The backriding type is practiced in the sub-Arctic regions, its representatives being mainly the Tunguses (Lamuts).

Reindeer breeding apparently has slowly spread from west to east and is beginning to envelop the Asiatic Eskimos living near Bering Strait, but, as an autochthonous institution, it apparently has not yet had time to cross Bering Strait into polar America, although the American caribou is not less useful for domestication than the Asiatic reindeer. (The introduction of the domesticated reindeer into Alaska by the United States government during the latter part of the nineteenth century is, from the ethnographical viewpoint, of course, an artificial importation.)

Dog breeding and dog driving are more ancient than reindeer breeding, as the dog is the earliest domestic animal. But only in the North, besides being used for hunting and guarding, is the dog a draft animal, like the horse, reindeer, and ox.

Dog driving also originated apparently in Arctic Asia, but it has had time to cross to America. As to the method of harnessing the dogs there are two main types, the fan type and the chain type. The fan type is earlier, and it is this type that crossed to America. In Asia dog breeding, like reindeer breeding, spread along the Pacific coast to the mouth of the Amur and Sakhalin Island, within the area occupied by the Tunguses and Tungusicized Paleoasiatic tribes.

A problem for the future to explain is the mutual relation of the reindeer-breeding and dog-breeding tribes.[1] In this, special importance attaches to the study of frontier spaces and influences. For instance, east of the Yenisei River lives a reindeer-breeding tribe of Tungus origin (with admixture of Yakut elements), the Dolgans, who combine the practice of the second and third reindeer-breeding types and may represent an intermediate link.

The Yenisei River in general is a dividing line between the western and eastern divisions of the Eurasian polar regions, the eastern region having many cultural relations with America.

Hunting and Trapping

As in the whole circumference of the Arctic belt we find an almost identical fauna on sea and land, the types of hunting and trapping

[1] In the paper in *Proc. 21st Internatl. Congr. of Americanists* referred to above the author discusses this problem at some length (pp. 237–240) and presents a reconstruction of the ancient ethnography of the polar zone in relation to the use of the reindeer and the dog.—Edit. Note.

are marked by uniformity. For instance, the Eskimo and Samoyed ways of crawling up on seals lying near their air holes in the ice are completely similar.

Ethnography has ahead of it, however, a considerable undertaking in distinguishing the types of implements—fishing rods and nets, floats and weights, creels and scoops, bows and arrows, darts and traps. It must indicate the variants of these types and make a comparative study of the entire extensive region.

Clothing

In the whole polar zone of the Old World fur clothes of reindeer skin are commonly used. Kinds of skin and methods of tanning are almost everywhere identical. The footwear everywhere is made of *kamus*, i.e. the skin of reindeer legs. *Kamus* has a short dense hair, growing downwards, to which the snow does not stick. This footwear is universally made with a soft sole and without heels and fitted with an inner sole of grass; but with this general similarity there exists the special peculiarity that every tribe makes its inner grass soles in a definite way that distinguishes it from all other tribes.

Such definiteness in small details seems to indicate that the formation of the polar culture must have occupied a long time.

The fur shirts of the Chukchis are made so wide that, if desired, it is possible for the wearer to take out his arms from the sleeves without removing the shirt and without effort turn around in his shirt as if in a small tent. The same fashion of shirt is found among the Samoyeds of the Yamal Peninsula.

It is curious to note the similarity of various small articles of wear. For example, eye shades, worn in springtime for the protection of the eyes from the intolerable glare of the snow, are quite identical in the whole circumpolar zone. The same is true of a special form of needle case, bone or leather thimbles, a girdle pouch for minor articles, and embroidery patterns.

Food and Cooking

The same similarity, almost identity, is noted in the ways of preparing and using food. Meat and fish are used as food either raw or cooked. In cooking, the meat is boiled a little and remains bloody and hard, and the manner itself of eating the meat, raw or boiled, is the same, from the European Samoyeds to the American Eskimos. A piece of meat is taken with the teeth and held with the left hand. The right hand uses the knife and cuts the meat, almost at the lips, by a characteristic upward stroke, somewhat slanting in order not to hit the nose.

Dwellings and Household Utensils

Dwellings show more diversity. In the polar zone there are various types—the regular tent and the tent with a double chamber (Chukchis and Koryaks), both covered with skins of reindeer or seal or with birch bark; the hut of sticks and poles covered with branches and bark; the dirt hut, half underground or entirely underground; and huts made of turf, of poles, and of standing boards; and finally a kind of timber cottage.

The Chukchi-Koryak double tent with a special sleeping chamber and the Eskimo dirt hut with an analogous chamber probably have the same origin. They solve in the same way a difficult problem, how to build a warm dwelling with no hearth, heated only by a lamp and the warmth of the human body. They characterize the whole American part of the polar zone and also the adjoining part of eastern Asia.

In the Eurasian half of the polar zone there appears in some places a better type of dwelling, the timber cottage with a flat roof covered with bark and leaves under a thick layer of dirt, with a fireplace of a peculiar form made of rocks or clay or of thin poles smeared with clay. We find this form of cottage and hearth among the Lapps and Ostyaks, the Yakuts on the Lena (hearth only), and the northern Russians beyond the Lena up to the Kolyma and Anadyr.

Household furniture and utensils, tools, and the methods of various industries offer the same general similarity in the whole polar zone. In regard to these things there arise a series of questions which not only have not been solved but have not been even raised: questions, for example, about the earthenware which is found in excavations in various places but whose manufacture has now almost entirely disappeared; about the implements of the Stone Age type in their inexhaustible diversity—like the bow drill, the adze, the small curved planing knife, the scraper for hides—which, although long out of use in the materials of that period, are now reproduced in iron and copper in exactly the same shape and for the same purposes.

Weapons

Everywhere, in Europe, Asia, and America, the so-called complex bow is used, composed of two or more strips of wood of different species glued together and covered with thin birch bark, often wound around with cords and strips of reindeer sinew. The same sorts of arrows are used everywhere—arrows with a blunt wooden tip for small game, with a forked iron tip for larger prey. To protect the hand from being hit when releasing the bowstring a bent piece of bone is used; and as far as can be judged from pictures and museum collections it is of identical character, for instance, among the Ostyaks and the Eskimos. The self-acting bow is everywhere set on game trails.

Spiritual Culture: Folklore and Religious Ideas

In the domain of spiritual culture, owing to the lack of material, it is much more difficult to establish similarity and uniformity. We may, however, point out the similarity of Lapp drawings in "Muittalus Samid Birra" (Book of Lapp Life) by the Swedish Lapp, Johan Turi, with drawings of the Chukchis and Eskimos to be found in various publications.

The same similarity can be noted also in the realm of folklore, in the fairy tales of the Samoyeds and the Chukchis and Koryaks. For instance, the Samoyed story about the reindeer owner Vilka related by Zhitkov is quite similar to Chukchi stories in character and style. The hero starts to search for unknown lands and visits various countries, described realistically and at the same time fantastically. The manner of description itself and the main details are similar.

We may note, too, the similarity of ideas and tales about spirits, apparently relating to the same degree of animism. There are many coincidences even in the scarce material known to us. Thus with the Lapps and Chukchis the constellation Orion is a powerful hunter, and Cassiope is the reindeer which he pursues. Rites connected with bear hunting coincide among the Lapps with those of the Tunguses, Yukagirs, and Gilyaks. With the Lapps the bear is a powerful, mysterious being. In the center of the Lapp bear rites is the festival of the resurrection of the killed bear. Similar animal resurrection festivals are practiced by the above-mentioned tribes of northeastern Asia and by the Chukchis, Koryaks, and Eskimos.

Shamanism

The same similarity may be traced in the ideas connected with shamanism. The Lapp tales, for instance, about deceased shamans who rise from the dead and attack living persons and strive to lacerate them with their iron teeth are similar to the tales of the Russianized natives in the Kolyma and Anadyr regions about the heretics with iron teeth, i.e. wizards who rise from the dead. Here perhaps we have some Finnish religious elements carried over by the Russians from the west to the east.

Social Organization

It is probable that in ancient times before the advent of the conquerors from the south the northern tribes were living in small separate groups. Tribal connections were comparatively weak. Even family connections were not particularly strong and were broken easily. The fundamental unit was really the individual. As the fairy tales have it, "There lived in the tundra a man without family or tribe. He grew in loneliness, hunted, ate, seeing no men." Boundaries between tribes often consisted of uninhabited spaces. The members of a tribe considered as real men only themselves and gave their tribe this name, "real men." They considered their language the "real language" and their faces and appearance the "real appearance." In case of necessity, for instance a great war, all the members of the tribe united with surprising celerity.

On this primitive social condition a new organization was superimposed after the advent of the Russians. Special cantons were established, with councils, aldermen, and mayors; and at the present time it is almost impossible to distinguish in this organization the earlier fundamental element.

Among interesting social problems, for instance, are the questions as to which line of descent is considered generally more influential and important, maternal or paternal; the question as to marriages between close relatives; the question whether with the purchase of a wife there is also involved service to the father-in-law in payment for the wife; the questions of grouped marriages and their character, of blood feud, and of ransom for bloodshed.

Problems of Trade and Social Relationships

A series of no less interesting problems in the realm of commerce remains to be solved. (1) Are there traditions about silent trade, and to what extent are they general? We find hints of this form of barter in the Novgorod chronicles relating to the Ugrians, i.e. to the Ostyaks and Voguls, and also in the Chukchi and Eskimo traditions and legends. (2) Is there a commercial exchange between neighboring tribes of the same cultural level, e.g. between fishermen and reindeer breeders? What is the object of exchange, and how are the relative values of wares computed? (3) Were there in the north ancient commercial routes from Asia to Europe and in Asia from the Ob to the Yenisei and from the Yenisei to the Lena?

Regarding the social culture of the reindeer-breeding tribes a series of problems of more special character may be stated. For instance, does the influence of the higher economic level of the reindeer breeders show itself in intertribal relations? How is the fundamental economic unit of the reindeer mode of living—the nomad camp—organized? Is there an owner, with dependent people? Do his hangers-on consist of relatives or of persons from outside? What are the mutual relations among the unequal elements of the nomad camp?

The Russian Population

Such in brief are some of the elements of the first and main problem of ethnography in the Eurasian polar regions—that of the natives.

In addition to this problem there is another, not so broad, but in no way less important for Russian ethnographers. It is the problem of the Russian population in the polar regions.

Its Derivation

In the north of Russia and Siberia, along the whole distance from Kola Peninsula to the Kolyma River and Kamchatka, non-indigenous villages are scattered—the last outposts of Russian colonization. The common center from which this emigration proceeded is the Dvina region, inhabited by Novgorodians many centuries ago. Eastwards from the Dvina River Russian villages become fewer in the polar belt. They are scattered in islands and separate groups or occur singly along the middle and lower courses of the chief rivers discharging into the Arctic Sea and into Bering and Okhotsk Seas.

This population is generally of mixed origin. In its composition are two fundamental elements—the first of Russian Slav origin, the second of native origin. The Russians are the descendants of the first colonizers and various later newcomers from Russia. East of the Urals the most important part of the Russian population is made up of the descendants of the Cossacks, the conquerors of Siberia. With the Cossacks came the *promyshlennyi*, who on the one hand took part in the strife with the natives and on the other hand were collectors of sable and other furs, organizing trade with the tribes that had just been conquered and even with those that had not yet been conquered. On the Pechora were descendants of the fugitives who fled from religious oppression or from punishment.

Together with these fugitives and strange people were also other immigrants, serfs, and convicts of various kinds: peasants banished by the government, criminal convicts exiled instead of executed, Little Russian cossacks, strelitzes, heretical priests, and even prominent statesmen in disgrace.

Into the farthest villages of northeastern Siberia all these categories of immigrants were continuously flowing until recent times.

The Russianized Natives

The second element of the population of Russian villages is of native origin. First it was principally women, as Russian women were few and Russian immigrants began to marry local women, purchased or made prisoners. Later, the native women began to be joined by the native men—individuals in some way caught by the Russian wave, deserters, prisoners, half enslaved laborers, fragments of families and tribes. In the contact with the Russians they became gradually Russianized, materially, socially, and spiritually; on the other hand they contributed many native qualities, giving a particular and characteristic stamp to the Russian life of the region.

These native elements were of course of different origin. In one place these were Ostyaks, in another Tunguses, in a third Yukagirs and Chuvantses. But the above-mentioned uniformity of the polar culture made their influence on the local Russian life generally uniform.

General Uniformity of Russian Arctic Population With Increasing Native Influence Eastward

As a result we have a Russian population of the same type from the Pechora to the Kolyma and Kamchatka, though in the extreme east this native admixture is more marked. For instance, in Kamchatka the remnants of pure Kamchadals, at present completely Russianized, in spite of an enormous decrease in number still are predominant over the mixed Russian-Kamchadal population.

On the other hand a cultural difference between the western and eastern villages is noted. The western villages, especially those situated within the limits of European Russia, beginning from the second half of the nineteenth century experienced new influences from places of higher culture and finally underwent a considerable material and spiritual change.

At the same time the eastern villages of polar Asiatic Russia have preserved entirely untouched their seventeenth- and eighteenth-century characteristics. That is why we have the curious coincidence that the Russian inhabitants of the Kolyma and Anadyr regions live in the same sort of huts as the Kola Lapps and Ob Ostyaks, while the Russians of identical origin on the lower Ob have established more comfortable dwellings.

Fusion of Russian and Native Elements Based on Similarity of Pursuits

Generally, however, the whole mode of life of this Russian and Russianized population, at least for Siberia, can be characterized as twofold. It is an intermixture of two elements, Russians and natives, who during two centuries have melted into an indivisible whole. The fact that it was possible for this fusion to be accomplished in a comparatively short period is due to a certain spiritual affinity of the first Russian newcomers with the native tribes conquered by them.

The early Russian inhabitants of the Pechora and Dvina forests were animal hunters not inferior to the natives. The Russian coast dwellers were also fishers and hunters of sea beasts from ancient time. Later the descendants of these hunters and fishers conquered Siberia from the Ob to Kamchatka. The conquerors of northern Siberia came from the Archangel and Olonets districts, the Pechora and Kama forests, from the Murman Coast and the Kola Peninsula, from the Mezen, from Kargopol, from Kholmogori, as had been indicated in the earlier Cossack reports to the chiefs. The Cossack conquerors were hunting for ready furs, for valuable sable tribute (*yasak*). The fellow travelers of the Cossacks, the *promyshlennyi*, hunted fur animals, live sables, and foxes.

These white Russian hunters from ancient times had worked out their own hunting and fishing experience on the basis of the methods of their grandfathers and great-grandfathers, the experience which later fused into one with the similar experience of the dark-faced inhabitants of native origin.

In European Russia, however, the Russians tried to extend to the north as far as possible the principles of agriculture and domestic cattle breeding.

In northern Siberia, especially in its eastern half, the Russians have abandoned all agricultural habits even where the climate would permit them. Russian peasants transplanted by the government in the eighteenth century to Kamchatka have discarded all their former modes of living and become ichthyophagi like the native Kamchadals. In the Russian village of Milkovo half a century later only a single plow remained, and that was kept in the church as an ancestral memorial.

Instead, the Russian hunters of Arctic Siberia boast that they are "fired by a look at a living animal," i.e. that their hunting passions are extraordinarily roused at the first sight of live running prey.

Three Physical Types of the Russian Population

From the anthropological viewpoint two fundamental types of Russian population can be distinguished: one, with more prominent signs of Russian Slav origin, is characterized by taller size, blue or gray eyes, and light-colored hair; the other is marked by a browner skin, large black or dark brown eyes, black hair, often wavy or even curly, short stature and lean body—a type which, although it approaches the southern Caucasian type, must be considered the product of the fusion of Russian Slav and local native blood.

There is also a third type, subordinate to the others, having mixed but infused characteristics, such as the broad Mongolian cheek bones (which the inhabitants of the Kolyma region speak of ironically as "a face like an oven door") combined in the same individual with blond hair, or blue eyes combined with oblique slits or even the Mongoloid fold.

Gradual Deterioration in Initiative of the Descendants of the Cossack Conquerors

In many spiritual qualities the Russian population closely approaches the natives. The change in this direction was already noticeable even in the eighteenth century.

The first Russian colonists were stubborn people, hardy, not inclined to yield either to the authorities or to the severity of their environment. They subjugated the natives with an almost lightning-like swiftness. For instance, the conquest of the enormous territory in the extreme northeast was accomplished within some eighteen years, from 1632 to 1650.

The Cossack conquerors were men of quite indomitable courage and of a certain elemental initiative. Like the Spanish *conquistadores*, they advanced irresistibly in their search for the sable that was not less valuable than American gold. They moved in small companies, covered with rusty mail and armed with "fire fight," unseen and terrifying for the natives, conquering and destroying village after village, tribe after tribe.

They moved mostly by land, passing from one river system to another; but some of them reached the northern sea and became navigators. The sea campaigns of the Cossacks are almost fabulous. They "went it blind," with no compass, no charts, no navigating experience, on clumsy, roughly constructed *kochas* as if predestined for shipwreck. However, on such *kochas* Dezhnev and Alekseev rounded the Asiatic continent long before Bering.

Nevertheless, several scores of years later the character of the Cossack conquerors began to change. The naval campaigns were finished as unexpectedly as they were begun. At the end of the seventeenth century we find indications of this in the Cossack reports, "Our ships are weak, and the sails are small; and we don't know how to build large ships as formerly." At that time all the Russian population passed from a state of fusion into immobility, as if crystallized. Initiative and activity disappeared, and boldness evaporated into timidity.

At the beginning of the second half of the eighteenth century this change was already quite marked. It coincided with the failure of the Cossack campaigns against the Chukchis, which ended in a catastrophe and the destruction of Shestakov and Pavlutski. After that, in the nineteenth century, the descendants of the Cossack conquerors became government serfs, slaves of every government official sent north in punishment for faults of office. In fact, in many villages the Russian population has become quite degraded and spiritually abject, regarding officials, as the natives do, with panicky terror and resigned obedience. In addition to this, it has become subject to nervous diseases, fits, and polar hysteria.

Russian Contributions to and Adaptations of Native Culture

However, even in this spiritually debased state the Russian population in the loneliest places still appears to a certain extent as the bearer and spreader of culture; and in every branch of material life the effect can be noted of the more advanced culture brought from the west and to a certain extent individually developed in its new home.

First the Russians brought with them iron, which speedily spread among the northern tribes and almost completely replaced stone and bone implements. Iron articles first were sold at a high price. For instance, a hatchet bought as many sables as could be drawn through the opening in its head. But later iron implements became more common. An iron belt knife sufficiently strong and long became with both Russians and natives a necessary adjunct of a man's equipment.

The other adjunct of a man, not less indispensable, is an iron ax. Gradually this is ground off up to the head and in time turns into a hatchet. Of all implements of the Stone Age the stone axes are the least adapted to their work, and therefore the natives especially valued the iron axes. Subsequently the Russians taught blacksmithing to the natives and in various regions have continued as blacksmiths to the present day.

Furthermore, the Russians brought that "fire fight" itself which had helped the Cossack conquerors to subjugate the native tribes so quickly and easily. The gun of the polar zone has remained till now, within the limits of Russian influence, mainly a flint one. On the other hand, in the farthest regions of the eastern country even the Russians themselves have not yet lost the art of using the bow.

The Russians brought the material for manufacturing fishing nets, viz. hemp, linen, flax thread, which supplanted such native materials as willow and nettles.

Of branches of local material culture adopted and at the same time improved by the Russians we may note, for instance, that of dog breeding. Russian sledge dogs, the Russian *narta* and harness, the Russian way of driving are considered the best and are imitated by all native tribes.

Contrary to this, the Russian newcomers absolutely nowhere showed any inclination to reindeer breeding. With all their mobility and modesty in living requirements the Russians were devoted to a settled and permanent life, to daily rest in warm and dry quarters under a strongly built roof. They had no wish to become nomads; all the allurements of reindeer breeding were ineffective; most of them joined the fishermen along the lower courses of the great rivers who were tied to their habitat by the abundance of fish coming from the sea and by a relative ease of existence.

Fused with the native fishing tribes, the Arctic Russians east of the Yenisei have gone backward culturally and economically and even become dependent on neighboring opulent nomad reindeer breeders.

The native cut of the fur clothes, highly practical and well adapted to northern conditions, was also somewhat improved by the Russians. They sewed the belt part to the Chukchi trousers and fitted a tightening *ochkur* to the fur hood of the *kukhlyanka*, so as to permit narrowing or widening at will. They joined the Ostyak slit to the Chukchi fur glove, which permits working in the cold without exposing the hands.

Through the Russians rye flour, salt (for fish salting), tea (mainly brick), and tobacco (mainly leaf) came into use in the eastern region. The trade with the natives is carried on almost solely with tea and tobacco for money. Tobacco or tea famine is considered as more terrible than food famine.

However, together with these, the Russians brought alcohol, which has greatly contributed to the degeneration of the natives as well as the Russians themselves.

Russian Trade

Besides hunting and fishing the most important occupation of the Russians in the polar region is trade; indeed, trade was the first incentive to the Russian movement into these regions, preceding their conquest by many years. The Novgorodians as early as the eleventh century had carried on a silent trade with the half mythical Ugrians and with Siberia through the "little window" cut in the wall of the Urals.

In later times, despite the celerity of the Cossack movement, traders always overtook the most advanced companies, and the search for commercial prey has always preceded the search for military prey and the collection of "state tribute." In still later times, when the conquest of the region was completed and the Russian population had become settled, the collection of tribute passed from the Cossack to the government officials and the Cossacks themselves became dependent.

Trade was centered, however, in the hands of a few merchants, and the general Russian population were, like the natives, reduced to a position of dependent buyers. Such a state of things prevailed everywhere from the Pechora to the Kolyma and Anadyr. However, the commercial instincts of the Russian population could not be completely smothered, and many changed from being traders to being small middlemen, thus as a group becoming the willing and unpaid agents for the several merchants and making as it were a commercial compact directed against the natives.

The mutual relations of the Russians among themselves in the most remote and lonely corners are also based on trade. Every mutual service is computed in rubels and kopeks. Everything is sold, everything is bought. This is one of the hard sides of Russian life in the remote polar regions.

Spiritual Culture of the Arctic Regions: Folklore

The spiritual culture of the polar Russians also shows the same involved character.

In the realm of folklore the Russian Arctic in its whole extent, including even the element of the Russianized natives, is the only part of the Russian domain that has preserved the most ancient epics, the *stariny* of the Kiev cycle. The most eastern collection of these epics is that made by myself in the Kolyma region in 1890–1898. It is singular that these tales of Kiev heroes of the feudal period and the southern steppes should be preserved only in the north, in virgin forests and in snowy tundras. Especially striking are the story-tellers of the far northeast who repeat in their peculiar sweet lisping tones but with the precision of a phonograph a long chain of verses incomprehensible to themselves about an old and unknown culture. Not less striking are the Pechora Zyryans who sing the same epics of the Kiev cycle, not in Zyryan but in broken Russian.

North Russian folklore is also especially rich in a great variety of songs, fairy tales, conundrums, and sayings. No less considerable and important is the native deposit in this folklore. It consists mainly of fairy tales, curious, rich, breathing the spirit of the north, of the hard, stubborn fight against the cold of nature. Some of these Russian fairy tales are simple translations from native languages, somewhat polished and adapted to the Russian understanding. In some places there appear attempts to fuse into one the Russian and the native folklore and create a harmonious whole. The most important of these attempts are the *andyshchiny*, half improvised love songs and dialogues of youths and girls that are sung on the Kolyma and Anadyr Rivers in Russian by the Russian and Russianized population. The word itself is of Yukagir origin, from *adyl*, youth. The *andyshchina* is sung in a drawling way, with unexpected changes of tone, endless repetitions, and digressions, the general character of the tune being somewhat reminiscent of the Tyrolese yodel and the text composed with the same liberty as the tune.

Language

The language spoken in the Russian Arctic belongs to the North Russian dialects and is marked by some very curious properties.

The vocabulary, as may be judged by notes and collections, possesses a considerable unity in its Slav-Russian part.

Mingled with Slavic words occur words of native origin, different in each region. For instance the word for lasso on the Ob and Pechora is *tyndzyan*, from the Samoyed; on the Kolyma *chaut*, from the Chukchi. Besides these native words of different local origin there is a whole series of words, of rather obscure character, common to all Russian but borrowed from some foreign source. Such, for instance, are *narta*, sled; *rovduga*, chamois leather; *kamas* or *kamus*, skin of reindeer legs; *torbos* or *torbas*, soft winter boot; *yukola*, dried fish; *vazhenka*, reindeer doe; *pyzhik*, reindeer calf; and many others. These words came into use very early, being found, for instance, in Cossack reports of the middle of the seventeenth century. Their origin is perhaps Finnish. It is probable that the greater part of these words came from that little-known Finnish tribe exterminated by the Russians in the very beginning of their colonization. However, some of them have a Turkish root, such as *alyk*, harness; *balyk*, smoked fish back; *chuval*, wooden fireplace.

The grammar and phonetics of the polar dialects are rather varied. Some of them have preserved their Russian form and character almost intact; others, on the contrary, have changed, especially in the far northeast, where, for example, they have assumed a soft, thick, lisping pronunciation.

Religion

In regard to religion the polar Russians are of course Greek-Orthodox Christians. We may, however, note a considerable admixture of beliefs of more primitive character and a mixture of Slav-Russian and native elements. Thus, the Slav-Russian conceptions of spirits of forest, river, and house are fused into one with the related native conceptions. The forest and river spirits according to Russian tales have wives and family. The forest spirits carry on an atrocious war with the river spirits. The forest spirits are great lovers of card games and play with one another all night long, the animal species of corresponding localities being the stake. In this way the polar inhabitants explain the constant migrations of animals.

As to shamanism, there are no real shamans with costume, drum, and rites among the northern Russians or even Russianized natives. It is true there are witches, wizards, sorcerers, and simply "knowing people." However, in a lonely locality of the Kolyma region I met a Russianized Yukagir who was said to be a shaman. After many requests this disguised shaman consented to arrange for me a little séance. He called in the aid of spirits in the dark with the help of ventriloquism, although the latter was not so clear and sharp as it is, for example, with the Chukchi shamans. The spirits spoke an unknown language, and in order to explain to us their speeches a spirit translator also appeared who knew the demonic as well as the Russian language.

Having no shamans of their own, the Russians treat the shamans of their native neighbors with special reverence, whether Lapp, Samoyed, Ostyak, Chukchi, or Yakut. In northeastern Siberia I used to meet priests who at one and the same time subjected the native shamans to persecution and, in the case of illness, besought them for the help of their demonic art.

Social Organization

In regard to social culture the polar Russians are distinguished by the same evidence of two contributing elements and by the same uniformity throughout its whole expanse. All social organization is extremely backward, in fact has not emerged from eighteenth-century conditions. The officials sent from the south bring with them the nineteenth-century pre-reform epoch of Gogol. But toward the east we find, together with eighteenth-century customs, those of the seventeenth century and the primitive conditions of the epoch when the country was first peopled. In the courts very effective though not severe tortures are still used. In regions of sparse population, when, under the former régime, the governor unexpectedly passed by, Russian women and girls fled into the tundra the same as the natives.

Russian marriage customs have fused with the native customs. On the lower Kolyma almost all Russian families are tied by the chains of group marriage with the neighboring reindeer Chukchis. Woman's purity is not appreciated and, in fact, may be said not to exist at all in the whole extent of the Russian Arctic.

Conclusion

Such, briefly, are the new ethnographical problems in the polar regions both regarding polar culture in general and regarding the conditions of life in polar Eurasia.

Only an attentive study of the enormous material scattered throughout the extensive polar regions, studied according to a general plan systematically worked out by the comparative method, can give scientific answers to the most important questions, many of which have only just been raised.

Mr. STEFANSSON'S Arctic explorations were carried out mainly on three expeditions to the American Arctic Archipelago and adjacent regions: the first in 1906–1907 to the Mackenzie delta; the second in 1908–1912, on which the "blond" Eskimos were studied in Victoria Island, Dolphin and Union Strait, and Coronation Gulf; the third as commander of the Canadian Arctic Expedition in 1913–1918, as a result of which much light was shed on the constitution of the western margin of the Archipelago, by extensive sledge journeys over unexplored ocean between Alaska and Banks Island, where deep soundings were taken and the continental shelf determined, and by the discovery of Brock, Borden, Meighen, and Lougheed Islands. He used the method of "living off the country" extensively on his Arctic explorations and was the first to apply this method on the deep Arctic Sea far from land. He is an advocate of the utilization of the resources of the Arctic for the production and marketing of reindeer meat and of the domestication of the musk-ox for its wool as well as its meat. Among his books are "My Life With the Eskimo," New York, 1913, "The Friendly Arctic," New York, 1921, "The Northward Course of Empire," New York, 1922. See also his "Misconceptions About Life in the Arctic" (*Bull. Amer. Geogr. Soc.*, Vol. 45, 1913), "Some Erroneous Ideas of Arctic Geography" (*Geogr. Rev.*, Vol. 12, 1922), and the article "Arctic Resources" in the 1926 supplement to the Encyclopaedia Britannica.

THE RESOURCES OF THE ARCTIC AND THE PROBLEM OF THEIR UTILIZATION

Vilhjalmur Stefansson

THE value of the Arctic to civilization will depend on two chief factors, its intrinsic qualities and its position in relation to the inhabited lands. We shall first briefly discuss the latter and then turn to some of its intrinsic values, namely the wealth of the sea and the mineral and grazing resources.

Positional Values

The Arctic lies in the central part of a circular region enclosed for the most part by northerly extensions of rich and densely populated modern countries. Therefore, by the logic of position, it should be one of the great crossroads of the world. It has instead been till now without any roads at all, or any thoroughfare, by land or sea. The conditions which determined this are, however, passing rapidly. The lands themselves may long remain pathless and the seas permanently, but we are about to realize that the northern air is a potential highway. This realization will bring into play the Arctic's advantage of central position, especially as flying conditions for crossing it are not unfavorable.

With our unfortunate habit of looking too frequently at Mercator charts, we have visualized the northward spread of civilization as a march from centers near the equator to an extremity or a sort of jumping-off place in the Arctic. But if we look instead at a globe, which represents the earth truly because it is shaped like it, or at a map of the northern hemisphere that has the equator for circumference (and especially if we represent civilization on successive historical maps as it advanced by millenniums), then we see it instead gradually crowding in towards a center. That central region is the Arctic.

Such a picture of civilization crowding in towards a central Arctic region may have been more vivid in the mind of Europe during Elizabethan times than it has been recently. At any rate, the men of that day were more alive than we have been since to the commercial importance of the geographic fact that the nearest ways from many of our world centers of commerce to the markets of China and Japan lie northward across the Arctic. But no one found a practicable Northeast or Northwest Passage route, and not any route at all was found leading more directly north to China. This made it seem for a time immaterial whether the Arctic was at the center of the inhabited lands or not. But now that fact has suddenly become important through the development of flying.

If conditions of air navigation are favorable, or even tolerable, the importance of the Arctic as a flying crossroads will steadily increase as commercial cities develop farther and farther north in Siberia and Canada, making the undeveloped polar center of the world ever smaller and smaller. But even now Arctic routes are important, as shown by the following table contrasting the mileage of transarctic air lines between certain centers with the mileage by steamer and rail as now in ordinary use.

Comparative Table of Shortest Distances Between Places in the Northern Hemisphere by Steamship-and-Railroad Routes and by Air

Distances in Statute Miles

Route	By Steamship and Railroad		By Air
New York–Pekin	via Seattle,	9342	6850
New York–Tomsk	via Seattle,	10594	5625
	via Hamburg,	7958	
Edmonton–Tomsk	via Vancouver,	7266	4775
London–Tokyo	via Montreal,	11553	5940
	via Trans-Siberian Railway,	8142	
Seattle–Leningrad	via New York and Hamburg,	8276	4865

Resources of the Sea

However we define the Arctic the larger part of the inscribed area is water. Some of this, in the North Atlantic, is never covered by ice; some, like a portion of Bering Sea, has ice in winter but none in summer; some, like the waters between the Mackenzie and Banks Island, has moving ice every winter and is without ice for a while most summers. And then there is the "inaccessible" area in the center of the Arctic Sea, which is covered with floating ice at all seasons in quantity that prevents navigation by ordinary ships.

Fisheries (in the Elizabethan sense, which includes even whales) are immemorially the chief resource of the sea. Floating ice may be either their friend or enemy. It is friendly in that the quantity of animal life in the ocean per cubic unit of volume increases towards the Arctic and Antarctic,[1] until it is very great when you come to the ice frontier. Our chief food fishes, the cod, haddock, herring, and halibut, have northerly ranges.

[1] Sir John Murray: The Ocean: A General Account of the Science of the Sea (in series: Home University Library of Modern Knowledge, No. 76), New York and London, [1913?], pp. 162–164.

The Theory of the "Lifeless Frozen North"

During the times before kerosene and gas, it was of prime importance to both Europe and America that blubber from incredible numbers of seals, walruses, and whales could be secured, for instance, in the Spitsbergen fishery. Even now certain Norwegian companies are paying dividends on blubber secured from corresponding animals in the Antarctic, while more or less polar ventures both for fish proper and for sea mammals continue to flourish in the northern hemisphere.

There has been from ancient times a theory of a "lifeless frozen North," just as there used to be a theory of a boiling sea and a burning land in the middle tropics. The boiling tropics were finally abolished by Prince Henry the Navigator and his successors many centuries ago. The abolition of the lifeless frozen Arctic may be considered to have been started sooner, but it has been completed only within the last decade. In fact, it is only partially completed even now; for a few men of eminence still maintain that there really is a considerable area in the Arctic Sea where animal life is wholly absent (according to some) or present in quantities so small (according to others) that it cannot have commercial value. A few declare outright that there is not enough life in the larger part of the Arctic Sea to support even one or two hunters, no matter how skillful they may be.

The "lifeless frozen North" theory seems to have had it once that no plant or animal would be found north of the north tip of Scotland. Pytheas would have dealt that creed a fatal blow more than two thousand years ago but for the curious fact that his travel story, which is now considered a marvel of accuracy, was disbelieved by most ancient authorities.[2] For then, even more than now, facts had a way of sounding incredible when checked against a firm and ancient belief.

The next great blow against the "lifeless polar regions" was struck by the Irish when they discovered Iceland sometime before 800 A. D. It appears that they followed the discovery almost immediately by colonization, and certainly they were there when the Norsemen, who had probably heard in Ireland about Iceland, went there first to reconnoiter, shortly after the middle of the ninth century, and later to settle.

The mythical dead region continued to shrink not only beyond Scotland but also beyond Iceland. For in 1194 the Icelanders discovered Svalbard, which scholars agree must have been one of three places: Spitsbergen, Jan Mayen Island, or the Scoresby Sound district of Greenland. In all three the lifelessness of the sea has been found equally mythical.

If we consider length and inclemency of winter the Greenland colony (on the southwest coast) was a real inroad into the lifeless North, though it does not seem so by the conventional latitude degrees.

[2] See Fridtjof Nansen: In Northern Mists: Arctic Exploration in Early Times, 2 vols., New York, 1911; reference in Vol. 2, pp. 43 ff.

In 982 Eric the Red began the exploration of West Greenland, and in 985 or 986 he began the colonization which eventually amounted to sixteen churches, two monasteries, 280 farms, a republic politically independent but dominated ecclesiastically by Rome and subject to its bookkeeping and other records. This colony maintained itself certainly for four hundred years, and newer researches are beginning to make it seem as if it lasted into the post-Columbian era of revived exploration.[3]

The further course of history continued the advance of knowledge and the retreat of the lifeless polar regions, although the tragic death of most of the earlier post-Columbian explorers who tried to winter in the Arctic at first seemed to confirm the old view that human life, at any rate, could not flourish there. Willoughby in 1554 lost his entire expedition of 66 in an unintentional wintering on the Kola Peninsula. Barents, wintering intentionally in 1597 on Novaya Zemlya, lost his own life, and several of his companions died with him. But gradually it developed that Arctic wintering did not make death inevitable, nor even necessarily probable.

What destroyed the early explorers seems to have been chiefly their own imagination, with its direct and indirect results. The pioneers were not literally frightened to death, but their fears probably affected their digestion and their mental processes directly. It kept them indoors, too, with many evil results. It was believed the winter "darkness" would produce melancholia, and this belief it was rather than the absence of the sun that did produce the expected mental gloom.[4] And so on with things that make for suffering, disaster, and death.

When the winterings gradually became safer and safer, it was at first by superior housing, better hygiene, and devices for entertainment, such as the local publication of newspapers and magazines, the writing and acting of plays, careful indulgence in supervised games, teaching by the officers and learning by the men, and other mitigants of a winter life that was not very different from hibernation.

In this stage of Arctic exploration the cold months were endured that work might be accomplished in the warmer spring. But gradually the winter, too, began to be a working season. Many deserve smaller shares of the credit which M'Clintock gets in large part for having broken away from the fear of cold to do active sledging as soon as the spring daylight allowed, paying no attention to the thermometer. To apportion the credit properly for this development would require a special and extensive study, but I would suggest here that Kennedy and other little-heralded captains of the Franklin search made their

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[3] See especially *Meddelelser om Grønland*, Vol. 67.

[4] See Vilhjalmur Stefansson: The Friendly Arctic, New York, 1921, pp 22–24.

original contributions about the same time as M'Clintock, without having thus far shared with him adequately in the glory.

Every advance of knowledge compelled a further retreat of the lifeless polar regions, and still each traveler seems to have thought, whatever his turning point, that he was beginning his retreat about at the dividing line between the life he had observed in the district traversed and the death which he knew must be ahead. This is well stated in the "Life of Admiral Sir Leopold McClintock," published in 1909, by Sir Clements Markham, a former President of the Royal Geographical Society, a distinguished explorer himself, and the personal friend and recipient of the confidences of most of the great explorers of his time, where he says of Prince Patrick Island that: "It forms the boundary between the Arctic paradise of Melville Island and the polar ocean without life" (p. 172).

There were, of course, other travelers who imagined themselves to have penetrated into and later escaped from a realm of lifelessness.

Recent Areal Reduction in the Application of the Theory

Within the last few decades the lifeless region, apart from mountain tops and such ice caps as that of Greenland, has been supposed to consist exclusively of a part of the Arctic Sea and possibly of some hitherto undiscovered islands within it. The extreme boundaries were seldom put down exactly, even for a segment of the circumference, yet there was an approximate agreement on the size and limits of the dead patch. In part the bounds were set to conform with the opinion of local Eskimos or other natives who were accepted by travelers, and in turn by scientific men, as authorities on the limits of sea life.

On the basis of many careful discussions with the Eskimos of the north coast of Alaska east of Point Barrow, I concluded that they believed animal life to go something like ten or fifteen miles beyond the coast. Apparently the American whalers in Alaska had adopted a modification of that view, supposing a considerable abundance of seals might go about as far north as the navigable waters in favorable seasons, which would be, say, fifty miles from the coast.

I judge that scientific men may have given some weight also to the depth of the ocean, apparently considering life less probable beyond the continental shelf. At any rate, the opinions given to the Canadian Government, as well as many others expressed by polar authorities during the time when Storker Storkerson, Ole Andreasen, and myself were supposed to be dead (from about May, 1914, to September, 1915), based the confirmation of our death on the view that we had traveled north from Alaska into a region containing no game and could, therefore, not possibly have lived by hunting, as we had announced we expected to do.[5] None of these authorities is known to me to have stated a 50-mile limit in so many words, or to have placed it exactly at the edge of the continental shelf, but some such idea was clearly in all their minds.

As with our expeditions in Alaska and western Arctic Canada, Peary and his men were told by the Eskimos of northwest Greenland that animal life did not go far from land. He stated it in just those terms to me verbally and is not otherwise definitely on record as to mileage from shore or as to ocean depth. But the tenor of his writings would indicate that, following Eskimo information and ancient theory alike, he considered the limit beyond which a skillful man could not live by hunting to be, say, twenty to fifty miles from land (at any rate in the region north of Greenland or Grant Land).

It used to be agreed that Eskimo belief and the inherited "scientific" theory coincided. But they really did not, the difficulty being that the explorers who thought they found agreement were misunderstanding the language of the Eskimos. They had pointed and asked some Eskimo, "What is your name for that direction?" Whereupon the Eskimo had replied with a word which was taken to mean the equivalent of one of our cardinal points. But a comparison shows that what is said to mean north in the record of one traveler means east, west, or south in the records of others. Intrepreting these words in terms of the map, each in the district where it was picked up by the traveler, you discover that instead of meaning north, south, east, and west, they mean "up the coast," "down the coast," "inland," and "out to sea," for the Eskimo tongue, which is one from Greenland to Siberia, has no word for north or any other of our cardinal points.

Peary, then, standing on the north coast of Greenland or Grant Land, or a whaling captain looking north from Alaska, was being told by the native that animal life did not exist far out to sea, a view with which these travelers would not have agreed had they so understood the statement. But, being predisposed to think that there was a northern limit to animal life somewhere not far beyond Alaska and Greenland, they accepted the Eskimo dictum as confirming that view. It was probably the discovery of this linguistic confusion which first led me to suspect that the European belief in a lifelessness beyond a

[5] The Government of Canada, represented by the Department of the Naval Service, quite rightly refused to send out a rescue expedition in 1915 when we had gone by sledges into the Beaufort Sea area and not been heard from for a year. The active head of the Department, G. J. Desbarats, its Deputy Minister, based his refusal on two points: (1) If I were right in what I had told him, verbally and in writing, before I left, then my party were in no danger; but if (2) the polar authorities were right in thinking the Beaufort Sea to be without life, then my companions and I were dead of hunger long ago and the rescue expedition, therefore, as such, without point.

But we made our Arctic journeys in fact so easily over the previously "lifeless polar sea," both that year and succeeding years, and have reported them to have been so easy, that the number of people who now think that they previously thought we would be able to do it has increased far beyond the number who actually expressed that opinion. As said above, no opinion by any oceanographic or exploration authority is known to be on record from any date before 1914 to the effect that such a journey was possible, while there is an abundance of recorded opinion as to its impossibility.

certain distance from the equator was no more reliable than the Eskimo belief in a lifelessness beyond a certain distance from land.

It would take too long to explain here why early travelers did not observe life and considered themselves to have observed the absence of it in regions which we now know to be well supplied. But I have dealt with this fully elsewhere.[6]

Up to fifteen years ago, as indicated by the quotation from Markham, *ante,* Beaufort Sea was considered practically or wholly devoid of living things. It had been defined as the peculiar home of the massive ice known as paleocrystic. No part of the Arctic Sea seemed, in 1912, more dead and forbidding. We have come to realize since then that the center of the floating Arctic ice, now called the pole of inaccessibility, does not coincide with the north pole, as was previously assumed, but is really near latitude 84° N. and longitude 160° W., therefore nearer to Beaufort Sea than was formerly supposed. Had that been understood in 1912,[7] the presumption for the lifelessness of that sea would have been further increased.

The Theory Challenged

But it is from the reported actual abundance of life in Beaufort Sea that the ancient view of the lifelessness of every part of the Arctic has been challenged recently. We must therefore consider why Beaufort Sea used to be "known to be" lifeless; therein we have a key to the supposed general lifelessness of the central Arctic waters.

Since it had been observed both that the abundance of ocean life generally increases as you go northward from the equator and that life is tremendously abundant at the edges of the ice, the problem was to reconcile these observations with the theoretical scarcity or absence under the ice.

The long-known abundance of whales at the edge of the ice presupposed a corresponding abundance there of the tiny living things upon which whales feed. This had been independently observed, too; so there was no room for argument. Plankton would be carried under the ice by any current in whatever direction that current was tending and at a rate approximately set by the current itself.

If able to, the larger animals would follow this feed. So you accounted for the assumed absence of the food things farther north either by denying that there were currents to carry them or else by explaining how they died and sank to the bottom. You had to sink them as well as kill them, for if they floated after death they might

[6] See "The Friendly Arctic," where the subject is dealt with incidentally throughout the narrative and particularly in Chapters 12 and 13.

[7] For Kolchak's formulation of that conception as published in Russian in 1909, of which Mr. Stefansson was not aware until recently, see the text passage at footnote 3 in the translation from Kolchak on "The Arctic Pack and the Polynya" presented above. See also footnote 3 there.—Edit. Note.

feed the larger animals. In which case you would need a separate explanation of the agreed-upon absence of, for instance, fish and seals in the "dead" area.

The farther you went into the explanation of the lifelessness, the harder your task became. For it was already known, for instance in the case of the Labrador and Newfoundland fisheries, that cold waters were particularly favorable to an abundant animal life. It was also known that the waters of the Arctic do not usually go below 28° F., or 27°. There was accordingly no reason to think that the mere chill of the water would have a determining influence upon every species, both big and little, unless you assumed that the drop to 28° was critical for all of them. And this would have to be a pure assumption.

The Question of the Stifling of Life under the Sea Ice

At this stage of the argument it became necessary, since you could not rely on the mere cold, to assume that the lifeless area was lifeless because the animals would stifle under the ice. Examining that hypothesis, we had to consider what the ice conditions were or would probably be where the life was supposed to be absent and to compare these with similar conditions, if they could be found, where it was known from observation whether life exists or not.

It is agreed on all hands that the floating ice on the Arctic Sea is more or less broken even in midwinter, though estimates vary as to the abundance and extent of these breaks. The accounts of expeditions such as Wrangel's, Nansen's, Cagni's, Peary's, or ours, show that you may be traveling over extensive, continuous ice but finding everywhere proof that a week or two ago these now continuous fields were a conglomeration of cakes with open water between them. Similarly you are stopped by open water one year at a locality where the ice was continuous the year before. Accordingly, most authorities would agree that in any parts of the ocean so far traversed by men and sledges, floes more than fifty miles in diameter that maintain their integrity for several weeks at a time are extremely rare, if they occur at all.

Then, if it be assumed that, in the Arctic Sea, life disappears because of stifling and that this happens because a solid roofing prevents oxygen from penetrating down from the air through the ice and through the water, we turn to known places of similar condition to see if life be possible. We get our most conclusive answer from the great lakes that are roofed with ice in winter.

Take, for instance, Lake Winnipeg, which is in places more than 50 miles in diameter. The lowest winter temperatures there come down to 55° F. below zero, or about the equal of Arctic winter temperatures at sea. As such, the coldness of the air, however, makes no difference to life underneath the ice, for the lake water, like the sea water, is approximately at the same temperature throughout the winter. The only thing that varies with the cold is the thickness of the ice. Fresh-water ice forms more rapidly than salt-water ice, chiefly because it tends to remain glare, so that the snow does not cover it with the uniformity that is found on the rougher and more sticky salt surfaces. Accordingly, although the Manitoba winter may be two or three months shorter than in parts of the Arctic, thicker ice is formed on Lake Winnipeg than is produced in one season anywhere on the Arctic Sea.

The sea cakes, too, float along as well as break up, so that a 50-mile field is not above the same water in March that it was in January. It may instead be over an area that, in January, was covered by small and broken cakes with plenty of open water, whereas the waters which in January were stifled (if there was any stifling) by the big cake are having their relief in March. Furthermore, the Arctic cake, no matter how big, has margins of broken ice and open water here and there. But the Lake Winnipeg ice hugs the shore of every bay and promontory, plugging the lake as if it were a corked bottle. There are, it is true, lake ice cracks caused by expansion and contraction, but these are never wide like the ocean cracks that are caused by winds or currents; they are frozen over much more quickly and leave in any case large areas of unbroken surface running snug up against the shore.

If fish stifled under sea ice, they would for a greater reason stifle under the ice of such a lake as Winnipeg. But they are instead prosperous, fat, and lively until caught by the fishermen through holes in the lake's practically air-tight and continuous roof.

If we conclude that fish do not stifle under such ice as that of the Arctic Sea but still want to hold a theory which permits the lake animals to live but compels the sea animals to die, we must accept one of four explanations—at least I have seen no others in print. (1) Lake ice is more glare than sea ice and admits more sunlight, making living conditions underneath more favorable. (2) Lake water is at 32° F. while the sea water is four degrees colder at 28°, and this margin is important in the lives of the animals. (3) Lake water has a greater ability than sea water for absorbing and storing oxygen, this difference being assumed to be critical for living creatures. (4) Fresh-water life forms have superior adaptability.

I think it will appear on scrutiny that these are merely working hypotheses to account for the assumed truth of the absence or rarity of Arctic animal life and are not deductions from sufficient observation. You are really only accounting for one hypothesis by another if you assume that a slightly increased cold explains a lessened or banished Arctic life. Equally hypothetical, as we have seen, is the argument that fish would stifle or suffer in any way from such an ice roofing as we have on the Arctic Sea. It is the same if you assume that lake animals and plants get enough light through fresh ice but that sea life does not get enough through salt ice, and so on with the less formidable arguments, which we have not space to consider here though I have dealt with them elsewhere, chiefly incidentally, in the course of travel narratives describing how we have lived an aggregate of years by hunting the animals that live in the "lifeless polar sea."

The Views of Explorers on the "Lifeless Polar Sea"

Although the facts are apparently against it now, the universal belief that the Arctic lifelessness existed was formerly supported also by extensive "proof" from the experience of explorers.

As said before, we cannot here undertake to explain why such travelers as Peary did not observe any animal life under the ice in places where I at least believe it to be abundant, because the subject has been thoroughly covered in my published books. But it is pertinent to say that Peary himself was one of the first to express a doubt that there was anywhere a lifeless polar sea, in the sense in which that view has been generally held and in the sense in which he himself had held it up to the publication of his last book. Confirmation of this is found in his speech delivered at the January, 1919, meeting of the National Geographic Society, quoted in the April, 1920, issue of the *National Geographic Magazine.*

It has been said that Peary contradicted his books in that speech. But he was in reality merely saying that new evidence had appeared which justified a new opinion. He had himself overthrown several conclusions previously held by explorers and scientific men, and he saw no reason why some of his own earlier conclusions, or rather some assumptions which he had never tested or questioned, should not be similarly overthrown. In 1909 he had considered the seal which he met near latitude 86° N. as a rare visitor to that region, but by 1919 he had come to wonder whether he himself instead of the seal had not been the surprising stranger there.

Nobody who understands the habits of seals and the hunting methods of polar bears looks upon the absence of bears as any indication of the presence or absence of seals in places where there is little or no open water. And so with all the other stock arguments about sea life.[8]

Nansen's Views

But there remains to be seriously considered the testimony in favor of the old view given by Fridtjof Nansen in his well-known books and apparently still held by him, to judge from an article in the

[8] For detailed analysis of this, see "The Friendly Arctic," especially Chapter 13.

recent three-volume addition to the Encyclopaedia Britannica.[9] Evidently he has either not gone into the evidence which converted Admiral Peary or else that evidence has seemed to him either unsound or insufficient.

Nansen's is no roundabout argument based on complicated reasoning, for he made direct attempts to determine and measure the presence and abundance of undersea life on the long drift of the *Fram*. Moreover, he is a scientist of the highest standing in general and a leader of oceanography in particular.

It seems to me that Nansen attached too much importance to his failure to observe much animal life during the years when the *Fram* was drifting embedded in the ice. I gather that he took the fewness of animals on the entire strip marked out on the map by his line of drift to mean approximately the same as if he had sailed along that line in a free ocean. He does point out here and there that the water in many cases drifted with the ice, but he is nevertheless commonly assumed to have studied an ocean surface the area of which is the product of the length of drift (disregarding back tracks), multiplied by the width of the area he could superficially observe either from his masthead or by walking from the ship at right angles to the course. However, this is really not much more true than if we were to assume—if such a thing were possible—that a person has a knowledge of a belt 5 miles wide and 19,000 miles long just because he had hovered in an airplane not far above the ground near Springfield, Illinois, for twenty-four hours and observed a prairie meticulously while the earth revolved underneath him.

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[9] Fridtjof Nansen: The Oceanography of the North Polar Basin, The Norwegian North Polar Expedition, 1893–1896: Scientific Results, Vol. 3, Memoir No. 9, Christiania, etc., 1902; reference in section "The Biological Conditions of the North Polar Basin," pp. 422–427.

Section on "Biological Problems," in article "Polar Exploration " Encyclopaedia Britannica; The Three New Supplementary Volumes Constituting with the Volumes of the Later Standard Edition the Thirteenth Edition, 3 vols., London and New York, 1926; reference in Vol. 3, p. 178. This reference reads:

"The North Polar Sea, covered in its interior by an almost continuous layer of thick ice, is extremely poor in plant as well as animal life. The sunlight is absorbed by the thick ice, and extremely little light penetrates to the water underneath. Hardly any plant life can therefore be developed in this water; there is only just a little—chiefly in the water lanes between the floes in the summer; and without plant life, no animal life. The interior, continuously ice-covered North Polar Sea may therefore be considered as a desert in the ocean, where the *Fram* expedition (1893–1896) 'found comparatively many species of small crustaceans, but the fauna was so extremely poor in number of specimens that the tow-nets might hang out for several days and, although we drifted along at a good speed there was extremely little in them when we hauled them up.' These conditions have a peculiar effect. The substances in the sea water generally used to sustain the plant and animal life of the sea are thus used only to an extremely small extent in the ice-covered North Polar Sea, and the result obviously is that these substances are to a great extent stored in the sea water of that region. But as soon as this water with these accumulated riches is freed of the ice, near the outskirts of the Polar Sea, and is exposed to the sunlight in the spring and summer, an unusually rich plant and animal life (plankton) is developed and flourishes. It would certainly be of great importance for the understanding of the biology of the ocean in general to study in detail the biological conditions in the North Polar Regions."

Another statement will be found in the section "Organic Life" at the end of Dr. Nansen's paper in the present volume.

On this general topic see also A. H. Clark: The Biological Relationships of the Land, the Sea, and Man, *Science*, March 11, 1927, pp. 241–245; especially pp. 243–244.—Edit. Note.

For Nansen's ship was embedded in the drifting ice almost as securely as a boulder is embedded in the surface of the rotating earth. If there were seals in his vicinity, they were prisoners, too, not fettered quite motionless but, in effect, tethered. We must remember, too, that the way seals live under the ice and how they can be found is not necessarily known to an Arctic explorer or even to every Eskimo who makes his living by sealing. I knew, for instance, an American whaling captain of twenty years' experience in the Arctic who had Eskimos aboard that had been brought up in Alaska sealing methods and who was wintering in Walker Bay, Victoria Island, without any suspicion either on the part of whites or Eskimos that any seals could be secured, or indeed that any existed, within ten to thirty miles. And yet when skillful seal hunters visited the ship who believed seals to be present and knew a technique unknown to the ship's Eskimos, a dozen were captured within a mile from the ship.[10]

There is not in Nansen's books, so far as I have been able to see, any indication that he was at the time of the *Fram* expedition familiar with the particular technique here involved. Certainly if he had applied it in a search for seals he would have mentioned it somewhere. We can take it as proved, then, unless he makes a statement hereafter to the contrary, that no search of a nature that would have revealed seals, had there been any within the radius of observation from the ship, was ever made by himself or his companions. Their negative testimony, therefore, means no more than Benjamin Franklin's failure to commercialize oil in Pennsylvania.

The ice areas visible from the masthead of the *Fram* were always practically the same from the beginning of the drift to the end. It was as if a farm had been drifting intact across an ocean, somewhat in the manner imagined by Jules Verne in his famous account of the drifting away of the tip of Cape Bathurst. It may have happened that no seals were in this floe at the beginning of the drift, in which case there would be none at the end. But if there were one or more at the start, they would have remained confined to their excavated homes under the ice, with breathing apertures an inch in diameter hidden by inches or feet of snow, unable permanently to abandon these to go far on pain of stifling but able to leave them for ten or fifteen-minute intervals to get shrimps, fish, or other food—if the food was there—which, of course, is the question here at issue.

On our Arctic Sea journeys when we have been living by hunting in some cases hundreds of miles away from land over an ocean thousands of feet deep, we have opened the stomachs of nearly all the seals we have killed and have found that most of them were feeding on shrimps and other crustacea, the presence of fish fragments in their

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[10] MS. account of the wintering of the *Olga* in 1907–1908, by W. J. Baur, of which a photostat copy is deposited with the American Geographical Society.

stomachs being rare. This rareness of fish may have been due either to their scarcity, or, as I believe, to the fact that the shrimps were easier to catch and equally agreeable to the seals, who were always in as good condition as any seals; in fact, so far as we could judge from their buoyancy in water, they are inclined to be fatter the farther from land you go and the farther they are within the area formerly said to be "devoid of animal life."

When an extensive field of ice, such as that in which the *Fram* was embedded, is floating over a deep ocean far from land, the water immediately under is generally moving with it, although not always at the same speed, so that a suspended net would have little sweeping motion with reference to floating things and could not be expected to catch many even if there were many. This should, I believe, have more weight than Nansen gives it in explaining how little plankton he captured. Fish, however, swim about, and an ordinary net lowered to the right depth would seem, at first blush, to have a chance to catch them. But I know from actual experience that many varieties of fish are caught in considerable numbers by a given net in the dark of night that cannot be caught in a similar net during daylight, even under the heaviest snow-covered winter ice. Since Nansen did much of his experimenting with nets during the perpetual light of spring, or else lowered and raised them during one period of daylight, I feel his negative conclusions are again considerably weakened.

Even so, Nansen did observe more animal life than he apparently expected and, more strikingly, a greater variety than he had expected. He was accordingly finding less confirmation than he expected both of decreasing quantity and decreasing variety in going from warmer to colder waters.

Of course, the great variety were caught because many kinds of animals were present; but may it not be that the principal explanation of why small quantities of each were caught lay in methods that were inadequate, for the reasons above given, and others? I for one am inclined to believe that had there been some way of accurately gauging the amount of life per cubic unit, this would have surprised Nansen as much as did the variety. In any case his observation of a little life contradicted the old theory of the total absence of life.

Marine Deserts in the Arctic Sea

There is great difficulty in stating a novel view without overstating it, or at least creating too strong an impression in the reader's mind. I realized this early and therefore in 1912 and 1913, when I was gathering money and men (in part) to test out the view that skillful hunters could live indefinitely anywhere on the floating ocean ice, I found people either flatly incredulous or, if converted, then too sanguine and expecting to find a game paradise everywhere.

The enthusiasm of the over-converts can best be checked by presenting an analogy with overland expeditions such as those of Lewis and Clark across the North American continent a century ago. As they proceeded west, they found less game and more game and then less game again. But when their advance was showing a gradual decrease of game, there was no sound reason to think that they were coming to the western limit of animal life; nor when they found a gradual increase of game as they marched was there any reason to jump to the conclusion that game would continue to increase steadily no matter how far they went. If they found themselves in an area where game was absent, that gave them no logical cause to fear that the gamelessness would extend all the way to the Pacific.

Similarly, when you have once begun to doubt that life is bound to decrease as the latitude increases, then an observed decrease in animals as you travel north becomes exactly the same type of evidence that a similar decrease was to Lewis and Clark when they were traveling west.

In the narrative of my book "The Friendly Arctic" and earlier still in an article in the *Geographical Review*[11] entitled "The Region of Maximum Inaccessibility in the Arctic," I make it clear that we more than once staked our lives on the theory that we could find food wherever we went; and I make it equally clear that we expected to find regions where life would be scarce if not wanting altogether. When we came to such an area it was to us only as if we had come to a desert in exploring an unknown continent. We then merely had to decide whether to turn back, attempt to skirt the "desert," or try to march rapidly across it. We really had this all thought out before starting, the plan being to treat a dash across as one of the legitimate risks of polar exploration. However, each time animals seemed to be getting scarcer we used to discuss the case. These discussions never resulted in our turning back but only in a more careful search for game and a more penurious husbanding of whatever food we happened to have on the sledges.

The only time we turned back in an area of little game was when two out of four in our party developed a serious illness.[12] The invalids were not in favor of retreating, thinking that we should be able to get across the "sea desert" to a game district on the other (north) side. I decided against trying it because I thought their disease to be progressive and expected our traveling speed, therefore, to lessen from day to day. This turned out to be so.

It is, of course, possible to say that the desert where we turned back might have proved the real beginning of the "lifeless polar sea." By analogy with other oceans it may indeed have been an extensive

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[11] Vol. 10, 1920, pp. 167–172; reference on pp. 171–172.

[12] The Friendly Arctic, p. 615.

desert. That area, like every other, should of course be studied—but why in the medieval attitude of a search for a lifeless North? Rather should we do our work there as elsewhere with suspended judgment, refraining from further assertions that lifelessness is going to be found because of latitude, cold, opacity of ice, thickness of ice, or any set of conditions whose real effect on life is as yet unknown. Why be mystical about the Arctic when we are scientific about all the other oceans?

If we must make a forecast on the basis of our present knowledge, perhaps we may arrive at a reasonable picture by a comparison between the Arctic seas and those of lower latitudes. The work of successive dredging expeditions has shown that there is not only a great horizontal variation in the distribution of ocean life but a great vertical variation as well. Take the ocean southwest of the Galápagos Islands. For various reasons we have there what may be called a sea desert by analogy with the arid lands where life is sparse and specialized. The oceans as a whole have not been studied thoroughly from this standpoint nor the areas most deficient in life mapped out. We know of the existence of such marine deserts in the frequented oceans; we do not know their extent. Naturally, therefore, no one can say what extent they may have in the Arctic. It may be that a marine desert or several of them may be located in the Arctic Basin. Only intensive oceanographical collecting will disclose the true state of affairs. Pending such study, we can only say that no one has yet definitely located such an area in the Arctic. For even in districts where my expedition, for instance, discovered little animal life, there may well be an abundance another year—and there may even have been an abundance when we were there, only we failed to see it.

Our living by hunting many months in the previously "lifeless" Beaufort Sea has not proved, of course, that life is as abundant in the Arctic as in any ocean. We have established, however, a presumption to that effect, and (pending further studies) the burden of proof will lie upon those who desire to cling to the old theories.

Between the larger marine deserts just referred to and the areas that I had in mind when writing the *Geographical Review* article and "The Friendly Arctic" there is a substantial difference, however. Marine deserts are of a much greater magnitude. The smaller areas that I had in mind may be caused by local or temporary conditions, such as an unusual amount of pack ice, etc. The smaller areas of deficient life may therefore shift in position. They may be crossed with only a modern degree of difficulty. On the other hand, the larger areas, if they exist, may offer much more substantial obstacles.

The outstanding object in research on the possible marine deserts of the Arctic should be the search or discovery, along positive lines, of facts regarding the existence and distribution of such life as occurs.

This is better than taking a negative position that there are large areas without life and that we are searching for the limits of those areas.

Inadequacy of Observation from the Air to Settle Question of Existence of Life in the Arctic Sea

We shall close this section on a lighter note. Reporters, editors, and even scientific men of some standing in other fields have lately been discussing in the newspapers the bearing of observations from an airplane or dirigible upon the question of life or lifelessness under the floating Arctic ice. Several commentators think it now at last settled that there is no life in certain vast areas, because Amundsen, Byrd, and Wilkins have reported none observed from the air. Apparently these commentators were not trying to be funny.

Obviously an unfrozen ocean presents a better field of study from the air than one which is partly frozen. Yet none of the fishing companies thought of going out of business just because codfish were not reported on the Newfoundland Banks by Hawker or Alcock and Brown as they flew eastward across the Atlantic. Nor did Byrd report any more fish in the Atlantic when he flew to France than he did in the Arctic when he flew to the north pole. Why should anyone think that air observations have any sort of bearing on whether there is life under the Arctic Sea ice? For no reason at all, except that the newspaper public is willing to take anything as confirmatory evidence if it does not contradict what they already believe.

Problems of Arctic Fishing Technique

If the time ever comes when scarcity of food in the rest of the world, or some other reason, inclines fishermen to attempt commercializing the Arctic, they will be met by several new problems of method. But in view of the difficulties that have been solved already with regard to earth and sea and air, there is no reason to doubt that suitable technique for Arctic fishing will be developed before the need of it has been pressing on the world for many years. However, in listing unsolved problems we must set down as a major one the development of a procedure that will enable us to capitalize the life under the mobile ice of the sea as we now do the life in the waters that are either free or covered with stationary ice, for such methods as explorers have used to support themselves on Arctic expeditions are suited only for securing seals and for maintaining a hunting rather than a commercial population.

Mineral Resources

The Arctic has been so little prospected for minerals that if we attempt to estimate the eventual discoveries by some addition to or multiplication of the known resources we shall doubtless go farther wrong than if we make the simple assumption that thorough exploitation will probably develop about as many and valuable minerals in the Arctic as the terrestrial average for areas of similar size.

Coal and Oil

There used to be theories against the probability of Arctic minerals, but they are weakening year by year. For instance, it was formerly believed that coal would be less likely to be found the farther north you went. But now it is well known that Spitsbergen coal is both abundant and good, some of it 800 miles north of the Arctic Circle. It was supposed that oil would not be found far north, but there are now flowing wells hard by the Arctic Circle on the Mackenzie in Canada, and the United States Government has set aside an oil reserve in Alaska, with the northern tip of the reserve at Point Barrow, the northernmost cape of the territory. Indeed, the general prospect on which the reservation was based is a "pitch lake" about 300 miles north of the circle, back of Cape Simpson near Point Barrow, that had been frequently reported even before I first heard of it in 1906 and first visited Cape Simpson in 1908. In Melville Island we have oil in association with coal at Cape Grassy, more than 600 miles north of the Arctic Circle. Coal has been found on more than two-thirds of the Canadian islands, irrespective of latitude, and there is no known reason to think that if other lands should be discovered there would not be coal and oil upon them.

But coal and oil are the only important minerals that have ever been supposed to be limited by latitude. That appears to leave the field clear (pending careful exploration) for the law of chances as the best determinant of the probable Arctic mineral wealth.

Special Conditions of Exploitation

But even if the minerals be there, they may be less valuable because more difficult to work. That is undoubtedly the case for the moment, since most Arctic localities are at present far removed from population centers. Settlements are, however, crowding north in Alaska, Canada, and Siberia, making smaller and smaller the uninhabited Arctic patch that lies towards the center of the inhabited world.

It is said that the earliest discoveries of coal in the mountains of what is now West Virginia were considered only of academic interest by the Virginians of the time, their view being that coal mines so located were too remote ever to be of value. Similar opinions were later expressed about copper in Montana and, indeed, are constantly being expressed about minerals in every part of the earth, always to become less true each year as railways cross deserts and settlements spread over plain and through jungle.

But even if the land be permanently settled, the Arctic mineral deposits might still be expensive to work because of climatic difficulties. Just how much force there is in that objection we do not know. In some cases there will be advantages to compensate for the disadvantages. Spitsbergen coal mines, for instance, have air temperatures within shafts and tunnels suitable for miners to work at maximum physical energy and cold enough to freeze water and therefore eliminate pumping and drainage problems. On the other hand, the cold prevents the dampening of the air in the shafts by steam and thus removes the chief protection used in more southerly mines against dust explosions. Accordingly, mining is to that extent more dangerous in Spitsbergen, so to remain till a new safety method is developed against coal dust.

Any mining done through mud in southerly countries requires not only pumping but heavy timbering. But Arctic mud, being solidified, can be cut like ice, the difficulty of working it being in some cases more than compensated for by the ability of the walls to stand without reinforcement.

Among the unsolved problems of the Arctic is, then, the invention and development of special mining methods. However, it cannot always be taken for granted that a method suitable in the temperate zone is unsuitable in the Arctic. Take, for instance, hydraulic gold mining. It had been assumed, even by Yukoners themselves, that this could be used around Dawson only in summer, and it was something like twenty years before it was finally tried in the midwinter period, when temperatures run below −50° F. and even −60°, or about as low as they ever get anywhere near the ocean in the Arctic, and almost as low as even the extreme temperatures of the Siberian lowlands. The attempt was an engineering success, but no information is at hand to say if it paid financially.

With fishing and mining methods, as with all Arctic problems in general, we must remember that the ingenuity of the European mind has been face to face with them only occasionally and only during the last few centuries. Besides, the explorers who have "braved" the Arctic have, in many cases, been either plain sailors or typical sportsmen rather than scientists or inventors, and it is not surprising that they have usually concerned themselves with describing difficulties rather than with solving them. Practical men, with careers to make through the success of the industries they develop, are little represented in the Far North even yet, except by scouts and prospectors. In view of that, their successes to date (in gold mining, coal mining, etc.) are more remarkable than their failures.

Grazing Resources

Since human life depends on plants and animals and all animals depend directly or indirectly on plants, it would seem that the fundamental study most needed in the Arctic would be the study of the relation of the climate and country to the life and growth of plants. This is doubtless true, but it may turn out that one of the customary divisions of this study does not exist in the Arctic, that of the annual or regional variation of plant life with reference to drought.

Relation of Precipitation to Plant Growth in the Arctic

Assume the maximum Arctic snowfall and you have the ground covered at all times, crowding out all vegetation except bacteria and similar growths in the snow itself. This condition is found nowhere on lowland, except near mountains—unless it be true that there are places in northeastern Siberia where snow does stay on lowland through every month of every year.

Next below the stage of permanent snow would be a deposit so heavy that it takes the sun most of the year to remove it. This will shorten the growing season of plants. Snow, then, is a powerful influence upon them, but not in any way closely analogous to that of excessive rainfall in lower latitudes.

But it really makes little difference as regards the length of the growing season how much snow falls in the cold winter. The winds sweep most of it into lees and ravines, where it may persist in comparatively small drifts far into the summer and in rare cases throughout the year, but on the remaining 80 per cent or 90 per cent of the land the quantity of dry winter snow that sticks depends on the grass or similar things that can hold it, and, as we shall show later on, the quantity of this grass does not depend, in any important sense, on the amount of precipitation. This little snow that clings in the grass disappears like magic in the early summer, but this is not the case with the sticky snow of spring, which largely remains where it falls until it is melted—thus affecting the length of the growing season.

Apart from the spring snows, then, the flat lands in districts of heavy snowfall start under the same conditions in the spring as those of light snowfall. But the rains of summer may make more difference. Assume it rains one year twice the normal for a given district. The skies then would be unusually overcast, and plant growth would perhaps be thereby somewhat affected. Studies have not yet been made, so far as I am aware, to determine which would produce a deeper thawing of the ground, the falling of rain from warm clouds or the direct impact of the sun's light. The one producing the deeper thawing would doubtless be the more favorable influence.

Some writers on Arctic climate and vegetation have discussed certain districts as being deficient in vegetation because lacking in rain. They seem to be analogizing from the tropic and temperate lands which they know and assuming the vegetation to be suffering thirst because the rainfall measures small in centimeters. But it is doubtful whether such thirst can befall anywhere in the Arctic. I have frequently dug into the ground in the Canadian sections where the books say that the vegetation is suffering from lack of water and have never failed to find, a few inches or a foot down and well within reach of the plant roots, a frozen earth which, when thawed, became mud or was at least extremely damp. Imagine, then, a plant growing here in soil that ordinarily thaws five inches by August. Assume a particularly dry season with constant glaring sunshine and the warmest winds possible in that district. Conceivably this might double the thaw to ten inches, whereupon the extra five inches thawed would become mud from which the plants could draw moisture. Thus they certainly would not suffer from thirst that year; more likely it would be a favorable year for them.

But it seems *a priori* that a succession of such extremely dry seasons would exhaust the water supply farther and farther down.[13] The simplest reply (and one sufficient until definite observation contradicts it) is that of all the places examined by us through many years in the supposedly too-dry areas, none was found that showed the assumed desiccation.

Study of Proper Grazing Methods

One of the outstanding climatic features of the Arctic, then, is that drought, as understood elsewhere, does not exist. This is important for the grazing wild animals and for domestic herds that have been or may be introduced. For if you use husbandry methods analogous to those that prevent overgrazing elsewhere, then you can in the Arctic rely on the same amount of vegetation per year every year forever. A square mile that supports twenty-five reindeer in Alaska this year will, if that limit has been set by a competent student of grazing, support twenty-five reindeer indefinitely.

This does not say that a study of climatic conditions affecting possible variation in Arctic vegetation is not necessary. Rather it points out that such study will have a special interest, for the chief cause of variation elsewhere (droughts) is either eliminated or so changed in local application that a new set of conclusions will have to be drawn.

Arctic grazing problems have already been attacked by the U. S. Biological Survey. The quantity figures for one year serve roughly

[13] For a discussion of how the cultivation of fields may change the natural situation see the writer's "The Northward Course of Empire," New York, 1922, p. 212.

for any other, for the only expected fluctuations are for length and warmth of the growing season. Indeed, the most recent studies tend to show that even the warmth is less important than we had supposed, the length of the light period being the main factor. And this is nearly constant.

Having determined the amount of vegetation for one year in terms of how many animals of a certain kind can be supported, the grazing expert has next to consider overgrazing—will the beasts trample out and kill some of the vegetation; and will some that is eaten this year fail to appear next year because it has been pulled out by the roots or because it requires several years to grow?

Potential Meat Production of the Arctic

With the reindeer for the standard animal, the U. S. Biological Survey has estimated the permanent supporting power of the Alaska ranges at from 20 to 25 head per square mile. In meat production this would fall somewhat between three and seven head of cattle, according to the breed of reindeer and of cattle. All the lowlands north of the heavy forest are grazing territory; for, as we have seen, the permanent snow is found only in mountains or on other high land. We estimate the average Arctic and sub-Arctic grazing value at half the Alaska figures, although there is no reason for doing so except the preference many have for erring by an equal amount rather below a mark than above it. We then have the following figures for the major divisions of the continental and insular lowlands north of the wheat belt (prairies and sparse forest).

Alaska	will support	2,000,000	reindeer	on	200,000	square	miles
Canada	" "	10,000,000	"	"	1,000,000	"	"
Eurasia	" "	20,000,000	"	"	2,000,000	"	"

In this estimate we consider 90 per cent of Greenland covered with ice, which is probably not far from right; 75 per cent of Spitsbergen; 50 per cent of Ellesmere, Devon, and Heiberg Islands, and 10 per cent of Baffin Island. We ignore Franz Josef Land, Northern Land, and Meighen Island, for their interiors are too little known, though doubtless heavily iced. All others we consider free of land ice; for, if there be little ravine snowdrifts in some of them (such as the Ringnes Islands or Melville Island), these are inconsiderable when compared with the areas of Arctic lands that are covered with lakes—such aggregate snowdrifts must be far less than 10 per cent of the lake area.

Cattle are now raised on arid lands that support less than one head per square mile. The Arctic, then, with 10 reindeer per square mile, is potentially more productive than the poorest cattle lands, especially if you remember that the real estimates of the grazing experts run to twice the reindeer figure we are using here.

The grazing resources of the Arctic have long been used by primitive men but are only recently coming into the domain of commerce. Chinese records show reindeer in northern China (or north of China) in the fourth century of our era, and King Alfred in England knew about their being in northern Norway in the ninth century. Some of the larger North European cities, such as Stockholm, have had reindeer meat on their markets regularly for several decades, with prices usually a little above mutton or beef. At the urging of a Presbyterian missionary, Dr. Sheldon Jackson, the United States Government introduced a few domestic reindeer from Siberia into Alaska in 1892; these were followed by successive small shipments, until, by 1902, 1280 had been imported. Every three years without fail they have more than doubled in number, and now (1927) there are more than 650,000 in Alaska, although more than 200,000 have been butchered for local use. Export to the United States began a few years ago on a small scale in a sporadic way not easy to trace accurately. In 1926, 4000 carcasses, weighing about 125 pounds each, were shipped from the vicinity of Nome to the larger American cities by one firm, and about 3000 were shipped by various other firms and by the U. S. Bureau of Education. The meat has been selling at from two to three times the price of beef, although the production costs in Alaska are very low and the shipping costs only moderate, the price being regulated by the willingness of consumers to pay for a favored and rare article. The price will doubtless come down to that of beef eventually but is unlikely ever to go lower because, in America as in the European cities where reindeer is now a standard meat, a number of people sufficient to keep the price up will doubtless consider it as good as or better than beef.

The Reindeer and Musk Ox as Sources of Meat Supply

We have, then, in connection with this new meat industry, a whole series of economic problems. The most general one is to decide which of the Arctic climates are best for reindeer. The tentative answer, which needs checking, is that the reindeer is a northern animal and, generally speaking, the farther north it goes the more it prospers. This we deduce chiefly from what is known of the caribou, which is the same animal under a different name. Arctic expeditions have usually found them fattest and most prosperous in the most northerly islands, whence they never migrate. That must be because the vegetation and climate there are at least equally agreeable to them as farther south, and they escape certain insect pests, especially the mosquito and the botfly, which are a great trial to them around the Arctic Circle and for some hundreds of miles north of it.

There is less snow the farther north you go, generally speaking, but this seems to mean little to reindeer, for they will often avoid patches that are nearly bare and by apparent preference wade into a snowdrift where they dig several feet down for their feed.

Reindeer breeders have a seasonal problem to control the calving; for, if it is too early, hard weather may kill numbers of the newborn animals—although the death rate of reindeer calves in Alaska is not as high as that of cattle calves in Texas. But the most serious climatic problems of the reindeer ranchers, so far as we know, are about winter rains and thaws which produce what is called a glitter—an ice covering over the grass which makes it difficult or impossible for the animals to feed. This is more likely to happen near seacoasts than inland, and the more likely the warmer the winter—another reason why reindeer are safer the farther north they go, the winters, generally speaking, being more uniformly cold.

The chief grazing problem of the Arctic ranchers is not directly climatic but rather botanical. Reindeer, although they do not live exclusively on mosses and lichens as was formerly supposed, nevertheless are particular in their choice of feed, leaving perhaps three-quarters of the vegetation unused. It happens that there is a wild animal, the ovibos (musk ox), which eats exactly the foods untouched by reindeer and which is as well if not better adapted to the Arctic climate as the reindeer. Neither of them needs a barn for shelter, nor does either need artificial winter feeding. Both may lose some of their calves if there is a spell of particularly bad weather at the calving season, but otherwise they are immune to cold or blizzard.

They differ in many things, however. The reindeer flees from its enemies and only with comparative success; large numbers would, therefore, be killed by wolves, except for the protection of herdsmen. The ovibos does not flee from wolves but has a successful defense; so that, whether in the wild or domestic state, wolves would cause only small losses, chiefly among newborn calves. Reindeer travel easily and rapidly like horses and can therefore be driven hundreds and even thousands of miles from the home ranges to a seaport market. But the ovibos is slow and clumsy, perhaps impossible to drive and certainly difficult, so that one would have to have a transportation system for marketing, except where the ranches are near a coast. Reindeer meat, while preferred to beef by many, is nevertheless different from beef. There is, accordingly, a certain small problem in introducing it. Man, like most animals, is conservative about changing foods. We are already partly liberalized about vegetables—we have hundreds, we are used to meeting new ones, and are therefore always ready to welcome one more. But we have only a half a dozen meats, most of us have seldom and some of us have never learned to eat a new meat, and so we are suspicious of any proposed addition to our chops and steaks. But there would be no newness about the ovibos, unless each steak were labeled, for its meat is identical with beef in flavor, texture, color, and odor.[14]

Both reindeer and ovibos have valuable hides. The chief use for reindeer hides will doubtless be as furs for aviators and for everyday wear in cold winter climates; with the ovibos the hide will be used for leather and the wool for the weaving of cloth. Reindeer milk is now used by certain nomads but has not been much used in Alaska and will probably not be used under commercial domestication because it is small in quantity, although agreeable in taste. However, reindeer milk differs from cow's milk in flavor, but ovibos milk is like cow's milk except that it is richer or more creamy. The ovibos gives three or four times as much milk as the reindeer, and it is therefore possible, although unlikely, that it will become a dairy animal.

It is reasonably certain that any attempt to domesticate the ovibos, if made with average common sense, would succeed. But it would cost from $100,000 to $200,000 to do it in a practicable way, and this money is very difficult to secure. It cannot be had from governments, for they are largely influenced by farm opinion. The farmers feel that they are getting too little money for their domestic meats now and that it would be to their disadvantage to encourage more competition. They are already jealous of the reindeer; they would have more cause for jealousy against the ovibos.

But if, wishing to be both truthful and conciliatory, you say to the farmer, or the politician controlled by farm opinion, that ovibos meat would not come on the markets in appreciable quantities for forty or fifty years (it being slow work to develop an animal from the first few head domesticated to the millions that are required for a world commodity), you immediately step beyond their range of vision, for not many can take any interest in a thing that is going to happen fifty years from now when they are either dead or old. Similarly with the capitalist, who is usually vain enough to want credit for a thing accomplished during his lifetime, or else so "practical" that he wants immediate results. Furthermore, capitalists are like sheep (or like the rest of humanity): they all follow one another around. Many capitalists have already built schools, and therefore many others want to; but no animal has been domesticated during historic times, so it will probably be difficult to find a capitalist of originality enough to do it. Since there is no known precedent he would, for one thing, fear to seem eccentric.

Let us hope, nevertheless, that some philanthropist or someone who merely wants to do a remarkable thing will give $100,000 to add

[14] For discussion of this and many other points not fully developed here, see "New Land: Four Years in the Arctic Regions" by Otto Sverdrup (2 vols., London, 1904), Vol. 1, pp. 35 and 48. Also see index of "The Friendly Arctic" and Chapter 6, "The Northward Course of Empire," especially pp. 142 ff.

this animal to the equipment of our civilization. That done, the meat-producing power of the Arctic lands will be multiplied by three. You will have three pounds of ovibos meat for one of reindeer.

Pending the actual domestication, it is interesting, of course, although temporarily only academic, to make a study also of any other animal, such as perhaps the yak, which could conceivably capitalize the northern grasslands, or certain parts of them.

Conclusion

When we turn away, then, from the layman's conception of the Arctic as a frozen but glorious proving ground for heroes, we come first to that realm of the pure scientist which we all believe in cultivating and whose problems have been set forth by many contributors to this symposium. Beyond it, smaller, but important in the economic view of the day, lies the realm of science applied to transportation and to direct development. We have, in this article on resources, touched on only a few of the more obvious lines of research.

Mr. Miller is a specialist in international law. He was associated with the "Inquiry," a group of experts organized to gather and prepare information for use at the Peace Conference, and was attached as legal adviser to Colonel House's Mission in Paris in 1918, subsequently becoming legal adviser to the American Commission to Negotiate Peace. With Sir Cecil Hurst of the British Foreign Office he drew up the final draft of the Covenant of the League of Nations. In 1921 he was counsel to the German Government on Upper Silesian questions. Among his many publications may be noted: "The International Régime of Ports, Waterways, and Railways" (*Amer. Journ. of Internatl. Law*, Vol. 13, 1919); "Reservations to Treaties, Their Effect, and Their Procedure in Regard Thereto," 1919; "International Relations of Labor," New York, 1921; "Opinion on the Question of Upper Silesia Written at the Request of the Government of Germany," New York, 1921; "The Geneva Protocol," New York, 1925; "Political Rights in the Arctic" (*Foreign Affairs*, Vol. 4, 1925), of which the first part of the present article is a modified reprint.

POLITICAL RIGHTS IN THE POLAR REGIONS*

By David Hunter Miller

The Arctic

UNTRAVELED air routes and undeveloped resources in the Arctic are now being thought of as valuable for the future, even the near future. For this, Mr. Stefansson is perhaps more responsible than any other one individual. That the French, in 1763, gave up Canada rather than Guadeloupe to the British, who accepted the former instead of the latter with hesitating reluctance, and that the judgment of Seward regarding Alaska had to wait a generation or so for its vindication, have been some of the effective historical arguments of the practical explorer, who is so often deemed merely a prejudiced dreamer.

The known land area within the physical limit of the Arctic Regions as defined in the present work (mean isotherm of 10° C. for July) comprises over 2,000,000 square miles. What states have sovereignty over this vast region? To what countries are we to assign the known and the unknown?

Let us think of the Arctic as in part known land, in part known sea, and in part unexplored, and thus let us look at it on the accompanying map (Fig. 1). We see that the countries now having important possessions within the Arctic Regions are Canada, the United States, Russia, Denmark, and Norway.

DANISH SOVEREIGNTY

Denmark's Arctic possession is the island of Greenland, with its enormous area of over 800,000 square miles. There are some settlements at various points along the coasts of Greenland. But the interior is uninhabited, partly unexplored, and the island has been crossed from one side to the other only six or seven times by explorers such as Nansen and Peary and more recently by Rasmussen and Koch. With an area thrice the size of Texas, the population is not more than 15,000, mostly Eskimo. The island is under Danish administration, and the title of Denmark, in part at least, is ancient and is now unquestioned. (Norwegian rights on portions of the east coast were adjusted by the Convention of 1924.[1]) The world generally,

*Reprinted by permission, with modifications, from *Foreign Affairs*, New York, Vol. 4, 1925–26, pp. 47–60, and Vol. 5, 1926–27, pp. 508–510.

[1] "In 1921 Denmark issued an official circular closing all of the country to other nationals. Subsequently Norway protested against this action, and by treaty of July 28, 1924, Denmark opened East Greenland to Norwegian traders, sealers, and whalers and agreed to postpone final decision 20 years, during which time the two nations would enjoy equal opportunity of establishing commercial influence

and the United States in particular, recognize that Greenland is a Danish land. In 1916 our Government formally declared, in connection with the Convention[2] for the cession of the Virgin Islands, that it "will not object to the Danish Government extending their political and economic interests to the whole of Greenland."

Norwegian Sovereignty and Claims

Spitsbergen (including Bear Island), with its valuable coal and other mineral deposits, is Norwegian. The history of this archipelago is instructive. Discovered as far back as 1596, the subject of many conflicting claims and much diplomatic correspondence in the seventeenth century, it came to be recognized as *terra nullius* and was formally so described in the Protocol of 1912 drawn up by representatives of Norway, Sweden, and Russia. Still more formally, Norwegian sovereignty was recognized by the Treaty of 1920,[3] a treaty which the United States ratified in 1924. While Russia is not yet a party to that treaty, the Norwegian Government is in effective occupation of the region, and there can be almost no doubt that her title is perfect to "all the islands situated between 10° and 35° longitude east of Greenwich and between 74° and 81° latitude north." It is reported that Norway, in a note to Canada, has made some claim to Axel Heiberg Island (and perhaps one or two other islands) based on the discoveries of Sverdrup. Now Axel Heiberg, while unoccupied by any one, is within the region claimed by Canada. Its northern tip, Cape Thomas Hubbard, was chosen for the airplane base of the MacMillan expedition of 1925, although finally, because of remoteness, it could not be established there. The possibility of Norwegian title to land in this region becoming a reality is highly remote.

The island of Jan Mayen in the Greenland Sea (71° N. and 9° W.) is considered by Norway as falling within the Norwegian sphere of interest. This declaration[4] was made in the Storting on May 4, 1927, by Minister of State Lykke; he added that the foreign Powers concerned had been notified to that effect. Actually the island has been occupied since 1921 by the Norwegian Meteorological Institute, a

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in that part of the country. Exception was made of Angmagssalik and of a tract about Scoresby Sound provided it be populated by Greenlanders. Steps towards such occupation have already been taken. A preliminary voyage was undertaken by Ejnar Mikkelsen in 1924, and colonists were carried thither in 1925. A concession similar to that for Norway was made to Great Britain in 1925" (*Geogr. Rev.*, Vol. 16, 1926, p. 146; see also Ejnar Mikkelsen: The Colonization of Eastern Greenland: Eskimo Settlement on Scoresby Sound, *ibid.*, Vol. 17, 1927, pp. 207–225, especially p. 210 and p. 214). The text of the Convention of 1924 is printed in League of Nations Treaty Series, Vol. 27, pp. 204–212, Geneva, 1924.

[2] Convention for the Cession to the United States of the Danish West Indies, Signed at New York, August 4, 1916, in: Treaties, Conventions, International Acts, Protocols, and Agreements Between the United States of America and Other Powers, 1776–1923 (3 vols., Senate Doc., Washington, 1910–23), Vol. 3, pp. 2558–2566; reference on p. 2564.

[3] League of Nations Treaty Series, Vol. 2, pp. 8–19, Geneva, 1920.

[4] *Morgenbladet* (Oslo newspaper), May 5, 1927, and personal communication from the Norwegian Legation in Washington.

government bureau which has made daily observations of the weather elements there since September of that year.

Canadian Claims

Future territorial expansion in the Arctic seems to be open only to the Canadians, the Russians, and ourselves. All three governments at this time are showing active interest in the situation.

The Government of Canada in recent years, particularly since 1919, has been devoting much attention to its northern lands and to

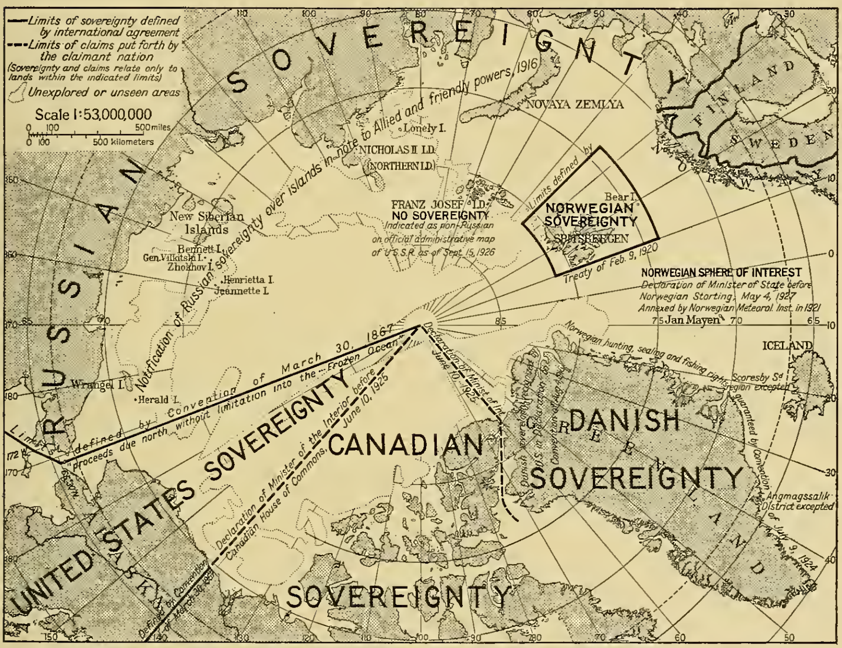

FIG. 1—Map showing the limits of political sovereignty and claims in the Arctic. Scale, 1:53,000,000. The basis for a given sovereignty or claim is stated on the map in accordance with the treaties, conventions, or other agreements cited in the text. Unexplored areas are bounded by a dotted line. (Compiled by the American Geographical Society.)

the possibilities that lie still farther north. The Canadian budget item for the "government of the North West Territories" was less than $4000 in 1920; it was over $300,000 in 1924; and it doubtless will continue to increase. In 1920 there were elaborate official investigations conducted by the so-called Reindeer and Musk-ox Commission. In 1922, a Canadian expedition on the ship *Arctic* established a police post, post office, and customhouse at Craig Harbor on Ellesmere Island, with a personnel of seven men headed by an inspector of police. This post is in latitude 76° 10′ N. and longitude 81° 20′ W. It is interesting to note that the 1922 expedition selected near the post "a site sufficiently level and smooth for an aerodrome." In

1926 an even more northerly post was established on Ellesmere Island, on Flagler Fiord, Bache Peninsula, in 79° 4′ N. and 76° 18′ W. This is one of the most northerly official stations in the world, being only about 750 miles from the pole.

Indeed, Canada has now established a periodic ship patrol of Ellesmere Island and neighboring lands. In the summer of 1924 a building was erected on the west shore of Rice Strait, near Kane Basin, north of Craig Harbor, in latitude 78° 46′. The intention is that the police at Craig Harbor shall make a patrol to Kane Basin during the winter. A second permanent post was opened on Devon Island, and there is also one at Ponds Inlet on the north coast of Baffin Island, where the Hudson's Bay Company has a station. In 1925 the annual voyage of the ship *Arctic* commenced about July 1 as usual, and still other posts are to be established in this region. Melville and Bathurst Islands are mentioned as possibilities. A glance at the map will show that Ellesmere Island and Devon Island, with Baffin Island and Bylot Island to the south, form the eastern fringe of the Arctic Islands of Canada.

The Canadian Government has also been careful to preserve its rights in the matter of explorations, both positively and negatively. The Stefansson expedition of 1913 received instructions to reaffirm any British rights at points which the expedition might touch. Both Rasmussen and the Danish Government were formally notified by Canada in 1921 that any discovery of Rasmussen would not affect Canadian claims.

No relevant diplomatic correspondence between the United States Government and the Canadian Government has been published. However, the Prime Minister of Canada said in the Canadian House of Commons on May 11, 1925, when asked for the papers about Wrangel Island, that some of the correspondence might be regarded as confidential by the Government of the United States, indicating that on that question at least there had been some correspondence; and on June 10, 1925, in speaking of the Canadian claims in the Arctic generally, Mr. Charles Stewart, Minister of the Interior, said: "A dispatch dealing with the subject was sent to Washington, to which we have had no reply."[5]

The Canadian claims[6] in the Arctic deserve special attention. They were definitely and officially stated by Mr. Stewart, on June 10, 1925, in speaking before the Canadian House of Commons and are outlined on a map he laid on the table of the House. They include everything, known and unknown, west of the Davis Strait-Baffin Bay-Smith Sound-Robeson Channel-60th meridian (W.) axis, east

[5] p. 4238 of reference cited in next footnote.

[6] House of Commons Debates: Official Report, Unrevised Edition, Vol. 60, No. 84, June 10, 1925, Ottawa, pp. 4253 and 4238. These claims were foreshadowed almost in their present terms in the Canadian Senate in 1907.

of the meridian which divides Alaska from Canada (141° W.), and north of the Canadian mainland up to the pole.

What is to be said as to the Canadian title to the islands now on the map within these lines, islands having an area of say 500,000 square miles? There is of course no doubt of the perfect jurisdiction of Canada over these lands under Canadian law. Statutes and Orders in Council include within the Dominion all of these territories; the national act and the national assumption of jurisdiction are complete; but we are thinking of their status internationally.

Baffin Island, the largest of all, with 200,000 square miles, is as certainly Canadian as is Ontario; and we may take for granted Canadian ownership of the other islands directly adjacent to the mainland. As Halleck says: "The ownership and occupation of the mainland includes the adjacent islands, even though no positive acts of ownership may have been exercised over them."

As to the rest, there are various shades of doubt—the doubt increasing generally with the latitude. We have seen that Ellesmere Island and Devon Island have each at least one officially established and maintained police post; that is actual, even if it is to be deemed only partial, possession. The other islands north of 74° are unoccupied, are generally uninhabited, and indeed have rarely—and some of them never—been seen or visited except by explorers of various nationalities. The very existence of the more remote of them was unknown a generation ago.

On the other hand, whereas Canada makes a precise and definite claim of sovereignty, no other country (aside from the rather shadowy "discovery" rights of Norway to one or two islands) has announced any claim whatever. Furthermore, the appearance of these islands on the map as a seeming northern extension of the Canadian mainland is a visible sign of an important reality—namely, that many of them are quite inaccessible except from or over some Canadian base. With her claim of sovereignty before the world, Canada is gradually extending her actual rule and occupation over the entire area.

It has been suggested that the Monroe Doctrine has a bearing upon lands in the Arctic. Speaking very generally, this is no doubt true. Historically, the Monroe Doctrine at its original enunciation was aimed in part against the extension of territorial claims by Russia in the north. It is well to remember, however, that the geographical extent of the Monroe Doctrine has never been precisely delimited. Monroe spoke of "the American Continents" or, in other words, North and South America. Does this wholly exclude Antarctica, and if not, what part of that region is included? Furthermore, what are the precise northern boundaries of the continent of North America?

It is also frequently said that the Monroe Doctrine applies to "the Western Hemisphere." Now whatever this expression means in this connection it certainly does not mean half the sphere. It must rather mean something roughly equivalent to "the American Continents." Geographically, the western hemisphere is usually mapped as commencing at about 20° longitude west of Greenwich and extending to 160° E. This corresponds to the idea of a "western" half, because if the western hemisphere commenced any farther east it would take in part of Africa. But this western half of the globe, as any one may see by looking at an atlas, includes not only the Cape Verde Islands and the Azores and Iceland on the east, but on the west includes all of New Zealand and a considerable expanse of the Pacific beyond the Fiji Islands. Of course what all this means is that the word "hemisphere" is frequently used very loosely, as meaning not the western "half" but a large western "portion" of the globe, and it is in this sense only that it is to be connected with the Monroe Doctrine.

Assuming, however, that the Monroe Doctrine may be invoked in relation to Arctic islands, may it, or should it, be invoked as against Canadian claims east of 141° west longitude?

In answering this question we should think of realities. The Monroe Doctrine is a national policy established primarily for the benefit of the United States. It doubtless will remain unlimited by any precise geographical formula and undefined by any particular form of words. In more than one sense, Ottawa is very near to Washington. The international frontier between the two countries means more a tariff than it does anything else. To interpret the Monroe Doctrine as meaning that Canada could not extend her domains to the north would be to say that acquisition by Mexico of Axel Heiberg Island would be regarded by the United States with complaisance and Canadian sovereignty thereover with opposition. The absurdity of the conclusion demonstrates the falsity of the premises.

As to the islands now known and lying north of the Canadian mainland, the average American would have no objection to the Canadian title. Certainly we would prefer Canadian ownership to any other ownership. We do not regard Canada as a "European Power" despite her membership in the British Empire—a much looser tie to London than it was even a generation ago. The only other possibilities would be something in the nature of *terra nullius*, an unsatisfactory sort of ownership by everybody, or else ownership by the United States. No public sentiment here would favor either, as against Canada.

So while it cannot be asserted that Canada's title to *all* these islands is legally perfect under international law, we may say that as to almost all of them it is not now questioned and that it seems in a fair way to become complete and admitted.

The undiscovered lands are another story. We can make up our minds about them when we know what they are.

Russian Claims

Russian claims in the Arctic have not been so precisely set forth. However, in 1916 Russia notified the Governments of Great Britain, France, the United States and doubtless other countries that it considered various islands near the Arctic coast of the Empire as forming an integral part thereof.[7] These included Nicholas II Land and the adjoining smaller islands, Lonely Island, Henrietta Island, Jeannette Island, Novopashennii (Zhokhov) Island, General Vilkitski Island, Bennett Island, the New Siberian Islands, and also, of particular interest in view of recent history, Wrangel Island and Herald Island. It is clear that the British Government now makes no objection to any of these claims. The attempt by Mr. Stefansson to make Wrangel Island British did not receive official support in London; the British have obviously decided to claim no Arctic lands west of 141°. The Russians took active steps to end a more recent settlement on Wrangel Island, and since 1926 it has been occupied by a Russian colony.

Wrangel Island lies about 80 miles from the Siberian coast and is perhaps of some value and habitable. Its early history is summed up by a leading authority as follows: "A Russian heard of it in 1824 but never saw it; an Englishman saw it in 1849 but never landed on it; an American landed on it in 1881 and claimed it for the United States." Except for Herald Island, which is a few square miles of barren rock, Wrangel Island is much nearer Alaska than any other island in the Russian Arctic; the United States may be interested in the future of Wrangel Island; but probably no country is concerned with the other Russian claims north of the mainland of Russia and Siberia, so far as they have been disclosed; they are to be thought of chiefly in their bearing on future air routes.

Recent dispatches indicate that the present Russian Government is pursuing its rights. It seems that the Soviet Government is making plans for a polar expedition by air to explore the areas directly north of Russian territory, in accordance with a program drafted by Dr. Nansen; and also that an expedition is to be sent to Nicholas II Land (Northern Land), on the 80th parallel and at about 100° east longitude.

Franz Josef Land

The only known land in the Arctic which is not now the subject of a positive claim by some government seems to be Franz Josef Land[8], a group of islands—uninhabited and of unknown value—lying just

[7] The text of the note as delivered in December, 1916, by the Russian Ambassador in Paris to the French Minister of Foreign Affairs is printed in full in *La Géographie*, Vol. 31, 1916–17, p. 393. Excerpts of the note as delivered in London are published in the *Geogr. Journ.*, Vol. 62, 1923, pp. 442–443.

[8] Before the World War, because of "discovery," it would have been necessary to think of Austria-Hungary as a possible sovereign, but not now.

north of 80° and, generally speaking, east of Spitsbergen and north of Novaya Zemlya. From their location they might be considered as falling within the sphere of influence of Russia, for they are in about the same latitudes as the Russian claims some 300 miles to the east. It appears that, as a war measure, a Russian expedition in 1914 landed on the archipelago and hoisted the Russian flag.[9]

Sovereignty over Unknown Lands

We cannot say that the sovereignty of all the known lands in the Arctic is definitely settled internationally. We can say, however, that the sovereignty of substantially all of these territories is now either definitely known or definitely claimed. The next few years will bring some sort of occupation of most lands hitherto unvisited except by occasional explorers. And the probability is that few of the claims thus far made to lands hitherto discovered will be questioned.

More doubtful, of course, is the status of the unknown.

The United States has never officially made any claim to any known Arctic lands outside of our well-recognized territory. The sole declaration we have made regarding Arctic regions is the renunciation of any possible rights based on discovery or otherwise in Greenland. As to the unknown territories, there likewise is no official statement; but there is significant action.

The MacMillan expedition of 1925 must be regarded as in effect an official expedition of our Government. True, it was largely financed by the National Geographic Society; but it was mostly composed of Navy personnel, it was supplied with Navy airplanes and with Navy wireless, and it was as indubitably governed by instructions from the Secretary of the Navy as it was formally bidden Godspeed by his representative. Nothing was lacking to give the party official character, national duties, and international rights.

The announced purpose of the MacMillan expedition was to explore the unknown area of the Arctic, the "white spot" on the map; and there can be no doubt that behind all this preparation and action will be found a national policy, to be announced publicly in due course. This great unexplored region of the Arctic lies, generally speaking, north, northwest, and northeast of Alaska. The area of this "white spot" on the map, prior to its bisection by the Amundsen-Ellsworth-Nobile transpolar flight of 1926, was something more than 1,000,000 square miles—more than the area of Greenland.

This is another way of saying that the Arctic Continent, long believed in and long sought, does not exist. Even if all this unknown

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[9] Evidence of a sort that the present Russian Government lays no claim to this group is furnished by two recent official maps (Map of Ways of Communication of U. S. S. R., 1:6,300,000, 1923; Map of Economic Regions of U. S. S. R., 1:6,000,000, 1926) on which Franz Josef Land is not colored as Russian territory.

area were land, it would not be a continent; at the utmost it would be a large island or islands. But, though unexplored, it would be going too far to say that this area is totally unknown; and inferences regarding it, based on known facts, almost forbid the idea that it is all land. The pole and its immediate surroundings are water and not land; and soundings made in that vicinity show that the water is very deep water, suggesting that no very large land area is adjacent. On the other hand, data from observations of the currents, the tides and the ice lead some scientists to think it unlikely that there is no land in this region. It may well be that islands exist there.

If the methods of exploration previously used were the only ones available, it would perhaps be some generations before such a vast surface could be even approximately charted; but with the airplane or the dirigible (and perhaps the submarine) the possibility is quite otherwise. The question is now more one of expense than anything else. With proper preparation and flight bases, the difficulties involved in obtaining the necessary information—and these difficulties are still great—could be overcome in the course of a few years.

If the political situation in the unknown Arctic finally results in agreement among the British Empire (Canada), Russia, and the United States, the legal aspects of the problem will become unimportant. In the meantime, however, they are very interesting and in some of their features novel.

Legal Aspects of the Problem

In early days, the discovery of unknown lands was regarded as the primary source of national title. But the impossibility that discovery, without anything more, should constitute a continuing basis of sovereignty soon became obvious, and "effective occupation" or "settlement" became a requisite. In recent years a third element of title has come to be thought of internationally as almost necessary, and that is what Lord Stowell called "notification of the fact," usually by an express communication to other Powers.

Of course, no formula or statement yet devised has solved or can solve all the difficulties connected with sovereignty over newly discovered lands. If effective occupation or settlement is to be deemed the real test, certainly "settlement" in the Arctic Regions can hardly be regarded as precisely synonymous with settlement elsewhere. Greenland is admittedly Danish, but I do not suppose that any one would say that the whole of Greenland is settled at this time. But clearly (if sufficient money is available) there may be effective occupation of an enormous Arctic area by the establishment of a few posts, here and there, with airplane and radio communications, without there being much "settlement" in the ordinary sense of that word.

In speaking of "the occupation which is sufficient to give a State title to territory" Mr. Olney, as Secretary of State, wrote in 1896: "The only possession required is such as is reasonable under all the circumstances—in view of the extent of the territory claimed, its nature, and the uses to which it is adapted and is put, while mere constructive occupation is kept within bounds by the doctrine of contiguity." While these words were not written about the Arctic, they seem very applicable to that region, where—doubtless for some time to come—no possession will be more than "reasonable" and occupation will be very largely "constructive."

In thinking of these three elements of title we are apt to conceive that their order in time is naturally, first, discovery, then occupation or settlement, and finally notice. Obviously, occupation cannot precede discovery *by some one;* and it seems generally to have been considered, as by the Institute of International Law, that the international notice required was a notice of possession. But the official Canadian claim, so far as it relates to the unknown, is in the nature of a notice before discovery and before occupation. What Canada says is that if Arctic lands be found—found by any one—east of 141° W. and west of 60° W. and Davis Strait, they are Canadian or will be.

It cannot be said, however, that such a claim as this is wholly without foundation or precedent. It bears some analogy to the "back country" or "hinterland" theory regarding territory stretching away from the coast. More accurately, it may be said to rest partly on the notion of "territorial propinquity" which the United States on one famous occasion recognized as creating "special relations between countries." Claims to unoccupied territory on the ground of contiguity are not unknown, although it cannot be said that there is any well-defined or clearly settled principle to support them.

Very naturally, Canada thinks of the islands now on the map north of her mainland as contiguous territory, natural geographical extensions of the country. Discovered, to a great extent (not wholly) by British explorers, separated from the more southern area and from each other by comparatively narrow straits, though largely unoccupied in any sense, these lands seem to the Canadians a geographical entity and clearly parts of one domain, their own. To project this sentiment still farther north, perhaps across a considerable extent of Arctic sea or ice, is less logical but seems equally natural.

Legal Theory Underlying Canada's Arctic Extension of the 141st Meridian Boundary

However, assuming, as we must, that the Canadian claim even to the unknown rests partly on the principle of contiguity, there is another feature of the Arctic map, as Canada would draw it, which is of peculiar interest to us. A definite western line to the pole is fixed, so far as Canada can fix it, and that line is the 141st west meridian. Of course, to claim up to that meridian is to renounce anything beyond it. In other words, the British now say that they *now* admit the rights of the United States to all unknown lands north of Alaska. This proposed line of division certainly does not rest entirely on any principle of contiguity; however that principle may be described or limited, it does not favor any one point of the compass as against any other; northwest or northeast may be as well "contiguous" as north. Nor does the line rest on any agreement between Ottawa and Washington, or we should know of it. It may accordingly be supposed that the suggestion of this line has as its foundation some legal theory, and that it is not merely an arbitrary continuation of the Alaskan boundary north from Demarcation Point to the pole.

It appears probable that the Canadian theory of the line of the 141st meridian up to the pole is based somewhat on the history and the provisions of former treaties. Going back a century, to about 1820, the various territorial pretensions of Russia, Great Britain, and the United States in the vast Northwest were not accurately defined and to some extent were overlapping. In 1821 a famous ukase was issued by Russia. This asserted sovereign rights over the waters of Bering Sea and a large portion of the North Pacific and also claimed land on the west coast as far south as 51°. Protests against the terms of this ukase were promptly made by both Great Britain and the United States.

Following these protests the United States and Russia signed a treaty, in 1824, by which Russia substantially abandoned any claim to sovereignty over "any part of the Great Ocean" (although this was by no means the last heard of such a claim). The two countries reciprocally agreed that their citizens should not form "any establishment" to the north and south of 54° 40′, Russia renouncing to the south and the United States to the north of that subsequently famous line. It may be said that the effect of this was to leave territorial questions north of 54° 40′ to Russia and Great Britain, and south thereof to Great Britain and the United States.

The Treaty of 1825 between Great Britain and Russia followed. We now know that the British cared comparatively little about the boundary; they were thinking of navigation and fishing and trade in the Pacific. The frontier clauses were the excuse and the mask for the rest of the treaty. Indeed, the British, if pressed, would have conceded 135° west longitude as the eastern boundary of Russian America, a concession which, if made, would have left all the Canadian Klondike within the United States some generations later. But the 141st meridian was agreed to, and, in describing the boundary between the possessions of the two countries, "sur la côte du Continent et les Iles de l'Amérique Nord-Ouest," the provisions of the treaty here material, in its original text, read thus: "La même ligne méridienne du 141me degré formera, dans son prolongement jusqu'à la Mer Glaciale, la limite entre les Possessions Russes et Britanniques sur le Continent de l'Amérique Nord-Ouest."

It is to be remembered not only that in 1825, when this treaty was written, the northern part (at least) of the boundary fixed was a matter of little concern to the parties or to any one else, but also that the two countries were dealing to some extent with the unknown. A considerable length of the northern mainland coast, both east and west of what is now Demarcation Point, was unexplored in 1825 and was put down on the maps of that time by guess. Bering Strait and its vicinity had been charted for half a century; but Point Barrow was not reached till 1826.

In 1867, by our treaty with Russia,[10] we purchased Alaska for $7,200,000 and succeeded to the rights of Russia under the Treaty of 1825. The expression above quoted from the Treaty of 1825 was incorporated in the French text of our Treaty of 1867; and in the English text it is imperfectly translated as "the said meridian line of the 141st degree, in its prolongation as far as the Frozen Ocean."

How far is "as far as the Frozen Ocean," or "la Mer Glaciale" of the Treaty of 1825? That the "Frozen Ocean" meant what came to be called the "Arctic Ocean" may be assumed; in the negotiations the words "Polar Sea" were used at least once; but this does not answer our question as to the extent of the line. What lands, if any, lay between the northern coast and the north pole was not known in 1825, for it is not known now. Certainly if there had been islands adjacent to that coast they too, although then unknown, would have been subject to the same line. We now know that there are no such adjacent islands; there may be islands to the north, but if so they are some hundreds of miles toward the pole. Indeed, the expression "as far as the Frozen Ocean" is vague enough (taking into account the previous Treaty of 1824) to make it at least arguable that the line runs as far as the 141st meridian itself runs, and that means to the north pole (for the continuation of that line beyond the pole is not the 141st but the 39th meridian).

It is also of interest here to notice what the Russian Treaty of 1867 says about our boundary to the west. The treaty ceded "all the territory and dominion now possessed by his said Majesty (the Emperor of All the Russias) on the Continent of America and in the adjacent islands, the same being contained within the geographical limits herein set forth"; and the western limit subsequently set forth in the text runs from a point in Bering Strait on the meridian (ap-

[10] Treaties and Conventions Concluded Between the United States of America and Other Powers Since July 4, 1776, revised edit., State Dept., Washington, 1873, pp. 741–743.

proximately 169°) which passes midway between certain named islands "and proceeds north without limitation, into the same Frozen Ocean." (The treaty French of this phrase is also worth quoting—"et remonte en ligne directe, sans limitation, vers le Nord, jusqu'à ce qu'elle se perde dans la Mer Glaciale.") These words "without limitation" are pretty strong words. They come very near to fixing the territorial rights of Russia and the United States, so far as those two countries could then fix them, up to the pole.

So I think we may say that the Canadian theory is, in part at least, based on the history of these treaties. It comes to this: the areas round the north pole, whatever they may be, form three or four great sectors—the Canadian sector from 60° W. to 141° W.; the United States sector from 141° W. to 169° W.; and the great Russian sector running from 169° W. to some undefined line in the neighborhood of 30° or 40° east longitude. The remainder of the circle, from say 40° E. to 60° W., would, so far as this theory goes, be unassigned, but, very fittingly, that remainder seems to contain no land at all north of Spitsbergen and Greenland. Possibly a few islands close to the north Greenland coast are exceptions to this statement.

Whatever may be said by way of argument against this Canadian theory, it is certainly a highly convenient one. All unknown territory in the Arctic is appropriated by three Great Powers and divided among them on the basis of the more southerly status quo. Certainly if these three Powers are satisfied with such a partition, the rest of the world will have to be.

Looking at the matter from another point of view, the Canadian theory would give the United States (if we wanted it) a very large portion of the present unknown area. What this would mean in terms of territory we cannot now say; perhaps nothing; perhaps a frozen empire. We shall know more about it very soon.

The Antarctic

British Claims

The recent Imperial Conference which met in London in October and November, 1926, gave some consideration—at the instance primarily of Australia—to the question of British policy in the Antarctic. Political rights in the Antarctic (see Fig. 2) are much less complicated and much less important than those in the Arctic, which were dealt with in the preceding section. At London vast areas were mentioned "to which a British title already exists by virtue of discovery," namely: the outlying part of Coats Land (viz., the portion not comprised within the Falkland Islands Dependencies), Enderby Land, Kemp Land, Queen Mary Land, Wilkes Land, King George V Land, and Oates Land. These are in addition to earlier British claims to the Falkland Islands Dependencies (20° W. to 80° W.; Letters Patent of July 21, 1908, and March 28, 1917), and to the Ross Dependency of New Zealand (160° E. to 150° W.; Order in Council of July 30, 1923).

It may be assumed that each "Land," while not capable of precise delimitation and perhaps referring primarily to the coast, is intended to include the sector to the south as far as the pole, the hinterland or "hinter-ice," so to speak. Taken all together, with the Ross Dependency and the Falkland Islands Dependencies, they would include nearly all of the Antarctic Continent.

French Claims

The seeming exception is the region known as Adélie Land in the neighborhood of 140° E., 66° S., which the French claim by reason of the discoveries of D'Urville in 1840. No precise statement of the limits of this region has been made. Publication of the claim was made in the *Journal Officiel* of March 29, 1924; but it seems to have been notified to the British and perhaps to other Governments as early as 1912, when the region was spoken of as "that portion of Wilkes Land known as Adélie Land." Terminology here may cause some confusion; in the report of the United States Geographic Board, Wilkes Land is described as the region between 155° E. and 96° E.; the British list above speaks of Wilkes Land as the area *west* of Adélie Land; while the French decree of 1924 says "Adélie or Wilkes Land."

Later French decrees (November 21 and December 30, 1924) indicate increasing interest of the French Government in the whale and other fisheries. Kerguelen Island and the Crozet group, as well as Saint Paul and Amsterdam Islands, lonely and remote points in that vast stretch of ocean between South Africa and Australia, are placed under the Fisheries Regulations with special provisions made for conservation of animal life; and all of them, with Adélie Land, are attached to the Government of Madagascar. The phraseology of the British White Paper indicates that the French claim to Adélie Land is not contested by London, although it seems that Australian sentiment would be quite reluctant to admit it. However, as yet there has been no express international recognition of the French and British claims.

No Other Claims

No other claim to sovereignty in the Antarctic has been made public, though there are various other countries that might conceivably rest on the exploration of their nationals. However, any German rights were renounced in the general language of Article 118 of the Treaty of Versailles; and there are similar clauses in the Treaties of Peace with Austria and with Hungary.

Attitude of the United States

Our Department of State has never acquiesced in various suggestions made that this country should claim sovereignty over Wilkes Land because of the discoveries of the Wilkes Expedition (1840),

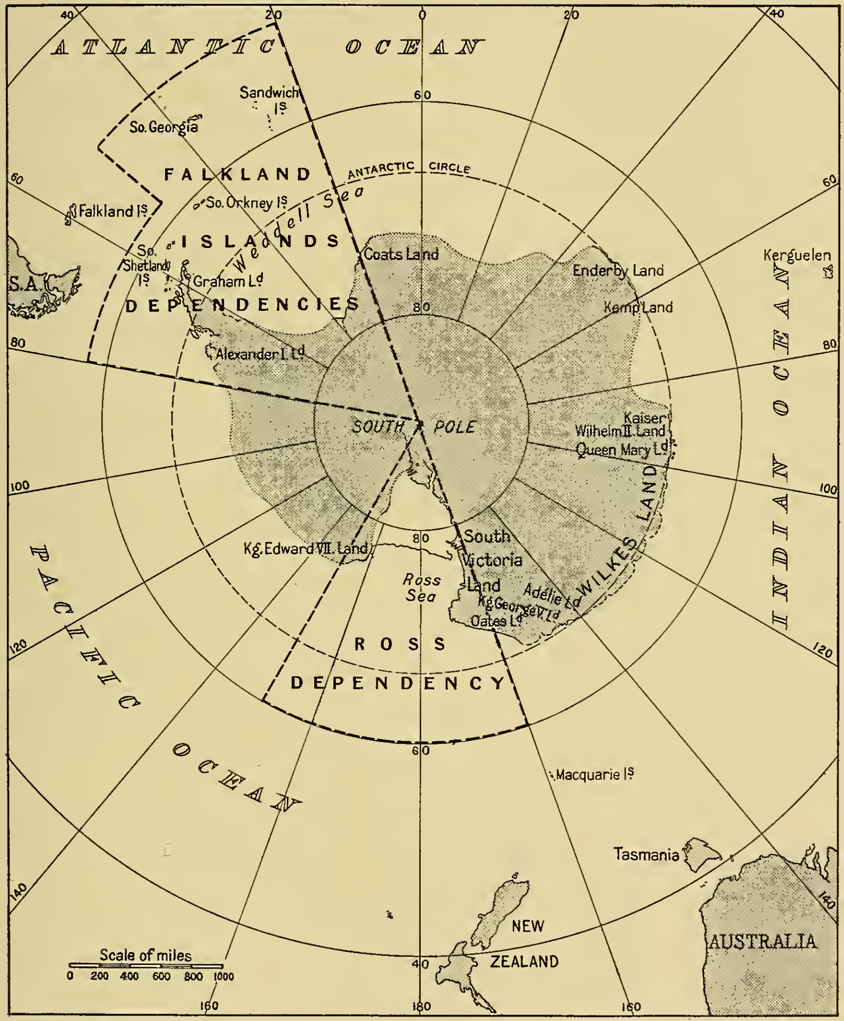

Fig. 2—Map showing the present status of political sovereignty in the Antarctic. Scale, 1:80,000,000. (Reprinted, with modifications, from *Foreign Affairs*, Vol. 4.)

which was official in the strict sense, having been authorized by Act of Congress of May 18, 1836. As recently as 1924 Secretary of State Hughes wrote to an inquiring citizen as follows: "It is the opinion of the Department that the discovery of lands unknown to civilization, even when coupled with a formal taking of possession, does not support a valid claim of sovereignty unless the discovery is followed by an actual settlement of the discovered country. In the absence of an act of Congress assertative in a domestic sense of dominion over Wilkes Land this Department would be reluctant to declare that the United States possessed a right of sovereignty over that territory."

Knowledge of this Antarctic Continent and its surroundings is as yet very incomplete. Commander Byrd has expressed the opinion that exploration by air, while difficult, would not be impossible; but such voyages as those of the *Discovery*, which sailed in September, 1925, on a three years' expedition under the auspices of the Government of the Falkland Islands, are more likely to be of scientific value.

The Antarctic region is of present importance only in connection with sea life; there is no question of future air transit, as in the Arctic; any form of mineral wealth is no more than a remote possibility of the unknown; nor can we today visualize any settlement or occupation, in the ordinary sense, of any part of the Antarctic Continent. National territorial jurisdiction, if exercised, could seemingly touch only those visitors engaged in whaling or sealing or in exploration.

Such diplomatic discussion of the Antarctic as may have taken place is unpublished and doubtless not important; perhaps because of the fact that there has been no attempt at a rigid administration of any system of control of the fisheries. However, if certain marine species are not to become extinct, international discussion and agreement, which will include the Antarctic region generally, are a necessity. Various valuable forms of sea life are in question; but in particular, because of whaling in the southern waters, a highly profitable and very active industry, the whale seems destined to extinction within a brief period. The very learned and interesting report made to the League of Nations Committee of Experts by M. Suárez in December, 1925,[11] tentatively estimates the remaining number of whales at not over 12,000, with at least 1500 killed in the Antarctic every year.

In no part of the globe are claims to sovereignty over land areas of as little apparent consequence as in the Antarctic; but the waters of the Antarctic, which seem to be a natural refuge for the whale and other habitants of the sea, are now the scene of a ruthless and reckless slaughter of those creatures of the deep whose protection from extermination is a matter of interest to mankind generally. From this point of view alone the Antarctic is a part of the problem of international coöperation.

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[11] J. L. Suárez: Report on the Exploitation of the Products of the Sea, *Publs. League of Nations, V: Legal, 1926, V. 6: C. P. D. I. (Codification Progressive du Droit International) 28, revised,* Geneva, 1926.

Sir Douglas Mawson is professor of geology and mineralogy in the University of Adelaide. In 1903 he visited the New Hebrides, publishing a preliminary note on the geology of that group (*Rept. Australasian Assn. for the Advancement of Sci.*, Vol. 10, 1904). Later he was appointed to the scientific staff of the British Antarctic Expedition, 1907–1909, led by Sir Ernest Shackleton. On this expedition he reached the south magnetic pole with Sir T. W. Edgeworth David and A. F. Mackay and was one of the members of the party to climb Mt. Erebus. He subsequently became the leader of the Australasian Antarctic Expedition, 1911–1914. To the scientific reports of this expedition he has contributed "Records of the Aurora Polaris" and has also published the general narrative entitled "The Home of the Blizzard," London, 1915. Prior to the expedition he had discussed in an article in the *Geographical Journal* (Vol. 37, 1911) various hypotheses as to the structure of the Antarctic Continent, and after its return he summarized the scientific results in the same periodical (Vol. 44, 1914).

UNSOLVED PROBLEMS OF ANTARCTIC EXPLORATION AND RESEARCH

Sir Douglas Mawson

GEOGRAPHICAL knowledge concerning the Antarctic is yet exceedingly fragmentary—far more so than those unfamiliar with the subject are likely to realize. This impression of geographical accomplishment and of geographical exploration and achievement around the south pole has resulted from the publication during recent years of maps incorporating not only the limited extent of known coast line but actually outlining a hypothetical continent. The latter has been arrived at by joining up the already discovered isolated areas by a somewhat indefinite boundary where in the opinion of the particular author the margin of the land is likely to be situated.

The charting of the coast line of the south polar lands has now been accomplished through less than 150 degrees of longitude. But much of this is, as yet, only roughly located on the map. Therefore, the land still remains to be outlined through considerably more than half the circumference of the globe in those latitudes.

The completion of this work, merely in a broad and general fashion, must be of prime importance in the further unraveling of the problems of the Antarctic. In the achievement of this fundamental proposition the labors of many successive expeditions will be required.

PROBABLE CONTINENTALITY OF ANTARCTIC LAND MASS

By degrees, the probable existence in that region of a land of continental proportions, largely overridden by ice, has come to be fairly generally recognized by geographers. This agreement did not exist some few years ago when I published[1] sketches suggesting the existence of a continuous mass of land and land ice in the polar area. For, in private communications, several leading geographers of the time held that, on the contrary, the area would be more likely to prove an archipelago of islands, separated by arms of the sea, as is the case in the North American sector of the Arctic. Such ideas, based on the scrappy distribution of coast line on the map as known at that date, were readily entertained by those whose polar experience had been

[1] Douglas Mawson: The Australasian Antarctic Expedition, *Geogr. Journ.*, Vol. 37, 1911, pp. 609–620, with two maps: (1) South Polar regions, with the Antarctic Continent drawn to illustrate the probable topography as deduced from present available data, 1: 40,000,000, facing p. 700; (2) Supposed Antarctic Continent: Alternative configuration to that shown on the general map, 1: 50,000,000, on p. 613.

gained in the Arctic. But, for one who had suffered a land campaign in the Antarctic, the extreme severity of the climate points to the conclusion that, even if the rocky crust of the earth thereabouts only rises above sea level in scattered patches, with potential waterways between, the whole is nevertheless likely to be buried beneath and welded together by a great ice cap extending far from the pole in all directions.

Subsequent exploration has substantiated this latter contention and has given further confidence in the existence of a great Antarctic Continent the outline of which is probably very much as shown on the maps in this volume.

Present Status of Knowledge of Antarctic Coasts

In the Ross Sea region, that part of the coast line extending from King Edward VII Land to the west is now thoroughly well known and most of it accurately charted to beyond North Cape (165° E.), which is a considerable distance to the west of Cape Adare. This is the result of the labors of many British expeditions, principally those of Ross, Scott, and Shackleton.[2]

Between Cape North and King George V Land is a section which has not yet been charted, but in which the location of the coast is approximately known. This is made more definite owing to the sighting by the last Scott expedition of a stretch of low shore in the middle of the area. This they named Oates Land.

King George V Land was charted by the Australasian Antarctic Expedition, which also revised and extended to the east and to the west the coast line of Adélie Land as placed on the map by Admirals Dumont d'Urville and Wilkes. The formerly charted Clarie Land was found to have no existence. It is assumed that what was mapped was either a gigantic iceberg or an ice tongue extending from the land existing farther to the south. To the south and west of that locality the Australasian Antarctic Expedition found high land which was placed on the map under the title of Wilkes Land,[3] in honor of Admiral Wilkes who, long prior to that time, had reported distant land at intervals in the Australasian sector.

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[2] For details refer to H. R. Mill: The Siege of the South Pole, London, 1905.

[3] In this sense Wilkes Land extends through about four degrees of longitude (131°–135° E.). This contrasts with the use of the term as applying to a stretch of coast extending through about sixty-five degrees of longitude (95°–160° E.) and comprising the range of discoveries of (then) Lieutenant Charles Wilkes, U. S. N., in 1840, which he himself interpreted and announced as constituting the margin of the Antarctic Continent. Although some of his landfalls, especially toward the east, have proved to be non-existent and although it is probable that he sometimes mistook for land the northern edge of the shelf ice and the solid pack with icebergs embedded in it, it is indisputable that he first outlined in their continuity, and recognized as such, the phenomena of a continental margin for a distance of 1800 miles.

On the nomenclature controversy see, *inter alia*, E. S. Balch: Antarctica, Philadelphia, 1902, Ch. 2; *idem:* Wilkes Land, *Bull. Amer. Geogr. Soc.*, Vol. 38, 1906, pp. 30–32; A. W. Greely: American Discoverers of the Antarctic Continent, *Natl. Geogr. Mag.*, Vol. 23, 1912, pp. 298–312; J. E. Pillsbury: Wilkes' and D'Urville's Discoveries in Wilkes Land, *ibid.*, Vol. 21, 1910, pp. 171–173.—Edit. Note.

Between this Wilkes Land and Queen Mary Land several landfalls were reported during the first half of last century. However, doubt has been cast on most of these by the fact that the vessel *Aurora* of the Australasian Antarctic Expedition did not find land in certain of the reported locations. Nevertheless the soundings suggest that, were the pack-ice conditions to allow of navigation to the south, land would probably be met at no great distance from the locations assigned. Consequently it is not likely that the margin of the continent recedes far from the Antarctic Circle in this region.

The evidence vaguely recorded by Wilkes for the existence of his Knox Land was substantiated by the Australasian Antarctic Expedition, so that its existence can now no longer be doubted.

Queen Mary Land was charted by the Australasian Antarctic Expedition, as also was Kaiser Wilhelm II Land as far as Gaussberg. Prior to that Drygalski's *Gauss* expedition had discovered and mapped the immediate locality of Gaussberg.

Between Gaussberg and Enderby Land a southerly sweeping indentation of the margin of the continent is strongly suggested by the distribution of the pack ice and soundings as noted by the *Challenger*, the *Gauss*, and the *Aurora*.

A vague report of land by a whaling captain almost a hundred years ago led to the appearance on the map of Kemp Land. But its existence has never been verified and is therefore in question. Enderby Land was seen by Biscoe in the year 1831. Perusal of Biscoe's report[4] leaves no doubt as to the existence of land thereabouts. Judging by the continuous high offshore winds experienced by Biscoe, this land will in all probability be found to lead south to a high ice-plateau region.

To the westward of Enderby Land is a great area concerning which we are entirely ignorant. The chances are that it is similar to the Coats Land coast.

We now arrive at a section that has been charted by the labors of the expeditions of Bruce, Filchner, and Shackleton. Here, in Coats Land and Prince Luitpold Land, an ice sheet on a rocky base descends to the sea, but no solid rock formation is visible above the ice.

As regards the western margin of the southerly extension of the Weddell Sea, its location and its nature are still unknown.

This brings us to the long, narrow peninsula which extends from the Antarctic unknown up towards South America. This is now well charted as the result of a deal of careful mapping principally by the expeditions of Bellingshausen, Dumont d'Urville, Ross, Gerlache, Larsen, Nordenskjöld, and Charcot.

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[4] J. K. Davis: Future Exploration: The African Quadrant of Antarctica, *Rept. 16th Meeting Australasian Assn. for the Advancement of Sci., Wellington Meeting, 1923*, Wellington, 1924, pp. 488–492; extracts from Biscoe's journal on pp. 490–492.

Charcot carried his discoveries well south on the Pacific Ocean side to Charcot Land. From the latter to King Edward VII Land is the greatest blank space on the map. In this region the soundings made by Gerlache and Charcot show that land surely exists in the ice-clad region south of the limits to which they penetrated. There seems no reason to doubt that it continues till it joins with King Edward VII Land. It is notable that in the vicinity of about 107° W. longitude Cook reached to beyond 71° S. latitude in open sea, and this performance was repeated about 135 years later by the *Pourquoi-Pas?* expedition. The existence of open water as a permanent feature of that locality suggests high land to the south and southeast, for thereby would be furnished a wind shed which would clear the neighboring seas of pack ice.

The unknown region lying north and northeast of King Edward VII Land is likely to be an area either of land or of heavy pack or shelf ice held together by scattered islands or bergs aground in shoal water.

Before leaving this brief review of what is known and what is not known of the margin of the Antarctic Continent reference should be made to a statement written by Captain Benjamin Morrell of Stonington, Conn., who was connected with sealing ventures early in the last century. On February 1, 1823, he gives his ship's position as 64° 52′ S. latitude and 118° 27′ E. longitude.[5] He reports that the ship was then steered west and to the southward until "*we crossed the antarctic circle* [italics are Morrell's] and were in lat. 69° 11′ S., long. 48° 15′ E." In this location he reports no field ice and very few "ice-islands" in sight. He then intimates that he sailed west on that latitude until well into the Weddell Sea. Though Morrell's veracity has long been in question, it was not until the examination by the Australasian Antarctic Expedition of the segment between the 118th degree of east longitude and Gaussberg that very definite proof was forthcoming of the impossibility of Morrell's statement. Judging by the latter his ability as a navigator must have been of a very unusual order, for, according to the course run on that westerly voyage, he passed unhindered over shelf-ice formations and high land. This is mentioned to explain why Morrell's reports have not been taken into account in the preceding summary.

Possible Existence of Undiscovered Sub-Antarctic Islands

Apart from the undertaking thus far considered, namely the charting of the coast line of the Antarctic continental mass and neighboring off-lying islands of continental character, there is still the possibility of the existence and discovery of additional oceanic islands in the more

[5] Benjamin Morrell, Jr.: A Narrative of Four Voyages to the South Sea, North and South Pacific Ocean, Chinese Sea, Ethiopic and Southern Atlantic Ocean, Indian and Antarctic Ocean, from the Year 1822 to 1831, New York, 1832, p. 65.

southerly zone of the sub-Antarctic regions and in the pack-ice belt. There are still considerable stretches of ocean in those latitudes thus far untraversed by any ship's keel so far as indicated by available records. On the other hand, those seas may have been more thoroughly searched over than is today realized; for in the old fur-sealing days of the southern seas many voyages in search of new seal islands were conducted in secret, and no record remains.

Reports from such sources led to the inclusion on the map, from time to time, of a number of islands whose existence in the charted localities has since been disproved. As examples amongst such may be mentioned Emerald Island (alleged location, 57⅓° S. and 163° E.), Dougherty Island (59⅓° S., 120° W.), the Nimrod Islands (56⅓° S., 158½° W.), and the Royal Company's Islands (50° S., 142° E.). If any of these do actually exist they must be far from the localities reported, for searches made in recent years have failed to confirm the presence of land where indicated. But before finally dismissing these reports as myths, it is to be recalled that Bouvet Island after its first report was later thought to have no existence because subsequent ships failed to find it where charted. However, it was eventually relocated, the trouble having arisen from the original inaccurate determination of its latitude and longitude.

Our Australasian Antarctic Expedition, whilst traversing the seas south of Australia between 60° and 65° S. latitude, passed on occasions quantities of floating kelp of a kind not met with along the shores of the Antarctic mainland. Also the bird population in those seas is very unequally distributed, as if the ship were at times distant from and at other times near to their nesting places. Such phenomena, suggesting the possibility of islets in those seas, is further supported by the visit of a sea elephant at Cape Denison (67° S. and 142⅔° E.) in Adélie Land and reports in the records of one of the older expeditions of sea elephants on the pack ice near the Balleny Islands. The sea elephant does not inhabit the coast of the Antarctic mainland, but adopts as a sanctuary and breeding ground the sub-Antarctic islands of the cold seas outside the pack-ice zone. Unless unknown islands do exist thereabouts, these elephants must have been far from their nearest known rendezvous of Macquarie Island and Heard Island.

Systematic Soundings As an Aid in Their Discovery

Of all methods of clearing up such doubts, the systematic delineation of the sea floor by soundings will be the most conclusive. Where, in the ordinary way, a vessel may pass close to an oceanic island without noting its proximity, there would be furnished a hint of its existence in the contour of the sea floor obtained by systematic close soundings. Such clue being followed up would lead directly to the discovery of the island. The very complete method of ascertaining the depths of the sea now supplied by echo sounding instruments such as the sonic depth finder will furnish future expeditions with a powerful aid in their search for such minute specks in the wide oceans.

Delineation of the Antarctic Continental Shelf

This leads on to the consideration of the invaluable work that only sounding can accomplish, namely the delineation of the limit of the continental shelf of the Antarctic crustal bulge. Whether the rocky basement under the polar ice dome is continuously above sea level over almost its entire area or whether it exists merely as a number of isolated, island-like units, we are certain, from the nature of the sediments composing those portions already examined and the story unfolded in the strata, that we are dealing with a convexity of the earth's crust of continental proportions, which, in the vicissitudes of time, has been at some periods above and at others below the sea. Such soundings as are available thus far further support this contention, for they indicate a general shoaling of the oceans in proximity to the present known and conjectured coast line. Thus it is that we are satisfied that there does exist an Antarctic continental bulge of the crust. Hence, more basic than the question as to how much at this epoch lies above sea level—the actual charting of the coast line—is the delineation of the continental shelf, a geographic feature of fundamental importance.

In the conduct of all these operations at sea the distribution and movements of the pack ice should be carefully noted. With the accumulation of such information in time, communication with the continent will eventually be much simplified.

Form of Antarctic Land Relief under the Ice and Structural Contrast between West and East Antarctica

From what has already been said of the possible disposition of the rock basement of the icy continent, it will be appreciated that it is of the greatest possible interest and value to ascertain the true nature of such foundation. Is it one continuous rocky land above sea level, merely veneered by ice? Is it a number of isolated epicontinental islands which have been overwhelmed and united by a flood of glacier ice and between which the sea would flow were the ice to melt? In the latter case, are the inter-island channels choked to the very bottom with glacier ice so that the ice rides on a rock bottom below sea level? Or does the sea water, in some at least of these, maintain a through-flow deep down under the capping ice so that the inter-island ice caps, though very thick and of land origin, are yet afloat on sea water?

When inquiring into the possibilities along these lines we are arrested by a fact, long ago emphasized by Nordenskjöld[6] and others, to the effect that the geology, including both lithology and tectonics, of that prolongation of Antarctica lying southward of Cape Horn—the Graham Land peninsula—is totally unlike that prevailing in the lofty land mass lying to the south of Australia, typified by South Victoria Land.

Nordenskjöld refers to the former as West Antarctica and to the latter as East Antarctica. These are useful terms for the purpose of the present review. Much has been written[7] regarding the unity on the one hand and the individuality on the other hand of these two land masses.

The labors of Nordenskjöld's Swedish expedition and of Charcot's French expeditions in West Antarctica have shown a relationship in rock types and in tectonic features of that region with those of the southern tip of South America. The presence of Andean granodiorites is especially remarked, and there is evidenced true Andean folding.

Suess long ago held that the Andean fold chain swung around to the east in the neighborhood of Tierra del Fuego and could be traced beneath the sea in a great sweeping curve reappearing at intervals in the islands of South Georgia, the South Orkneys, South Shetlands, and finally extending into Graham Land. But Nordenskjöld has clearly indicated[8] that the connection is more apparent than real in a geological sense, for those island groups referred to are structurally older than the period of Andean orogeny. In no case, however, is there any question as to the good evidence of the recurrence in West Antarctica of Andean characteristics. How far this condition of things continues to the south and southwest beyond Charcot Land is a first-class problem of outstanding interest.

The build of East Antarctica is in direct contrast to the foregoing. Here we have a great elevated land mass which, so far as yet explored, is a region of block uplifts on a grand scale and has in its tectonics nothing corresponding to the folding in late geological times evidenced in West Antarctica and the Andean cordillera. It has long been recognized that in its structure South Victoria Land closely corresponds with that of Australia, whereas the tectonic features of West Antarctica are akin to those of New Zealand.

Now, the question that has been long before us is whether or not an arm of the sea separates East Antarctica from West Antarctica.

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[6] Otto Nordenskjöld: Antarctic Nature, Illustrated by a Description of North-West Antarctica, *Geogr. Journ.*, Vol. 38, 1911, pp. 278–289; reference on p. 278.

[7] British Antarctic Expedition, 1907–9, Reports on the Scientific Investigations: Geology, Vol. I: Glaciology, Physiography, Stratigraphy and Tectonic Geology of South Victoria Land, by T. W. Edgeworth David and R. E. Priestley, London, 1914, especially Chs. 1 and 20. See also the publications cited above in footnotes 1 and 6.

[8] Nordenskjöld, *op. cit.*, pp. 280–281. See also Franz Kühn: Der sogenannte "Südantillen Bogen" und seine Beziehungen, *Zeitschr. Gesell. für Erdkunde zu Berlin*, 1920, pp. 249–262.

Their want of correspondence, structurally and geologically, is favorable to the existence of such a channel. Also, arms of the oceans, represented by Weddell Sea on the one side and Ross Sea on the other, do extend from either hemisphere into the Antarctic unknown in just such locations as support the contention of a dividing channel. The Ross Sea depression is well known to be a downfaulted area, referred to by David and Priestley as a *senkungsfeld*. Does this *senkungsfeld* extend right through to the Weddell Sea?

Analysis of tidal data obtained from stations in the southern Ross Sea led Darwin[9] to conclude that a through passage from the head of Ross Sea under the ice to the Atlantic Ocean was probable.

The advocates of the separate identity of an East and a West Antarctica look to King Edward VII Land as the prolongation to the southwest of Graham Land, which may then be considered to pass beneath the ocean and to reappear in the folded mass of New Zealand. Unfortunately little is yet known of the structure and the rocks of King Edward VII Land. So far as the available geological evidence from the latter area is concerned, Nordenskjöld reports,[10] after examination of rocks brought by the Amundsen expedition, that the result is inconclusive. Amongst the suite of igneous rocks examined were granodioritic rocks chemically like the Andean types but different microscopically. They have an older facies, which, he remarks, is rather suggestive that they are related to the older formations of South Victoria Land. So we find that the very interesting question as to the structural type to which King Edward VII Land belongs is still unsettled.

Though Filchner found the head of Weddell Sea to pass under a great shelf ice (floating land ice) formation, just as in the case of Ross Sea, yet it does not seem likely that a sea water channel extends through under the shelf ice all the way. Discounting the probability of a through channel also is the fact that Amundsen, on his journey to the south pole along a route passing down the east side of the Ross Sea depression, reported the appearance of rising ice slopes to the east of his trail. This implies elevated ground over at least some part of the area between the head of Ross Sea and that of Weddell Sea, thus rendering unlikely the existence of a through passage of sea water below the ice.

As, however, the ice capping the Antarctic land reaches to enormous thicknesses, it may be that the rising ice slopes—obviously ice riding on a rocky bottom—seen by Amundsen to the east of the Ross Sea shelf ice were resting on a basement still actually below sea level.

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[9] Sir George Darwin: The Tidal Observations of the British Antarctic Expedition, 1907, *Proc. Royal Soc. of London, Ser. A: Math. and Phys. Sci.*, Vol. 84, 1910–11, pp. 403–422; reference on pp. 420–422.

[10] Otto Nordenskjöld: Antarktis (Handbuch der Regionalen Geologie, Vol. 8, No. 6), Heidelberg, 1913, p. 16.

In this case, were the Antarctic ice cap to melt and disappear, a shallow sea channel situated to the south of King Edward VII Land might connect the Pacific and Atlantic Oceans.

However, so little is known of the area that, instead, there may be quite elevated ice-capped land extending from Graham Land to King Edward VII Land and south to the Queen Maud Range seen by Amundsen. Against this, the chances of much elevated land to the southeast of Amundsen's winter quarters at Framheim (78⅔° S. and 165° W.) at the edge of the ice barrier are discounted by the fact that unusually calm conditions were found to prevail there, whereas highlands in that direction would surely have started a strong outward wind flow.

What little we yet know of the tectonic features of Antarctica suggests to me as most probable that the Andean structures will be found to skirt around the borders of the Pacific Ocean to the neighborhood of King Edward VII Land; that the boundary of the plateau block of East Antarctica extends along the west side of Ross Sea and then straight across to Prince Luitpold Land on the east side of Weddell Sea; sandwiched in between these two belts and extending between Ross Sea and Weddell Sea there may be, crumpled against the massif of East Antarctica, undulating and but moderately elevated land composed of newer geological formations with igneous contributions. But this is, of course, pure speculation, and the solution awaits the explorer.

As regards the great mass of East Antarctica, there appear to be good grounds for suspecting that the major portion of it, at least, exists as ice upon a rock base standing above sea level.

Determination of the Profile of the Ice Cap

From what has already been stated it will be observed that, though a great and elevated continent of ice resting upon a rock foundation surely exists around the south pole, still we have as yet no knowledge as to how much of this is ice and how much is rock. Sledging journeys inland in the neighborhood of the pole and in the region between Adélie Land and Ross Sea have demonstrated the existence of a vast ice plateau to the west of the rocky ranges that constitute the scarp face overlooking the great downsunken area of Ross Sea. Further, what is known of the continental margin elsewhere, such as at Prince Luitpold Land, Coats Land, Kaiser Wilhelm II Land, Queen Mary Land, and Wilkes Land, is strongly indicative of a continental ice cap extending over the remainder of the area. The domed plateau usually rises to elevations of 3000 feet within sight of the coast, and there is little reason to doubt that by far the larger portion of it stands above 6000 feet. Around the pole itself the plateau surface is uniformly over 10,000 feet above sea level.

In its accumulation the ice has piled up on the land to a height which represents, for the time being, equilibrium between precipitation and wastage—the latter effected both by surface ablation and slow glacier flow of the ice to the periphery of the continent. Under the régime of an ice age such as that prevailing in Antarctica today there is no knowing how high the heaping up of the ice over the land may extend. Possibly at some spot eccentric to the pole the ice dome may exceed the 10,000 feet registered at the pole. This is rendered the more probable on account of the pole itself being eccentrically placed in relation to the general build of the land. But counteracting the effect of this eccentricity is the fact that the rocky ranges along the fault scarp, between the pole and the Ross Sea depression, are reported to reach elevations up to 15,000 feet. They therefore must be effective in damming back the ice of the plateau in the neighborhood of the pole.

The determination of the contour of the ice cap is not merely of interest to the geographer and glaciologist but is of very considerable importance to the meteorologist.[11] The latter finds in it a prime factor in the determination of the flow of local surface winds, which, in turn, are responsible for currents in the neighboring seas and the movements of the pack ice.

Determination of the Thickness of the Ice Cap and Delineation of the Underlying Rock Floor

Having determined the contour of the surface of the inland ice sheet, there is next the problem as to the thickness of this ice cap and the delineation of the underlying rock floor. Here is a problem of the greatest possible interest and importance. We want to determine the topographical features of the buried rocky land, to ascertain what valleys, what mountain peaks—in short, what physiographic relief is smothered under the ice. Once this is outlined, we shall be in possession of a wealth of information relating to the preglacial history of that land; also, we shall know more about the modifying effects of ice-cap erosion and shall have secured the long-sought data as to the thickness attained by such continental ice caps; finally, the question will be answered as to whether there is a rocky continent or merely an island archipelago underlying the ice carapace.

Such an undertaking is certainly an ambitious project but should be well within the realm of possible accomplishment. What is required is that some method be devised to sound the depths of the ice. Several years ago when echo-recording instruments had been perfected in

[11] W. H. Hobbs: The Glacial Anticyclones: The Poles of the Atmospheric Circulation, *Univ. of Michigan Studies: Sci. Ser.*, Vol. 4, New York, 1926.

connection with anti-submarine warfare, I suggested[12] that a modification of the same device might be employed in the determination of the thickness of glacier ice. The difference in elasticity between ice and rock should be sufficient to allow of the application of this method.

Since that time the principle has been developed and perfected in the sonic depth finder for sounding the ocean. It now remains only to extend this further to deal with ice. No doubt there will be certain inherent difficulties, on account of the rigidity of the ice and also on account of the variability of entrapped air in glacier ice, but these should not be insuperable. Other methods of attack that suggest themselves are the employment either of the principle of electrical permeability or of the differential specific gravity between the ice and the rock floor. Instruments based on these principles are already employed in the field as ore finders.

When an instrument capable of such measurements has been perfected, it can also be employed to ascertain the thickness of the shelf-ice formations and the depth of the underlying sea water. Then will there be cleared up many of the outstanding problems of the Antarctic, and, in addition, the study of glaciology as a whole will benefit immensely.

Other Desirable Studies Relating to the Ice Cap

Other studies relative to the land ice of interest to the general geographer may be mentioned. Determinations as to its rate of movement are required. To assist in accurately gauging this for the margin of the ice sheet, very detailed and accurate charts of short stretches of the ice-cliff face, each related to some fixed datum point, should be made at intervals along the coast line and resurveyed by later expeditions.

Also, any information as to the alimentation of the ice cap and its ablation will supply a great need in arriving at conclusions regarding the factors operative in determining the present domed contour of the inland ice sheet. Such information can be got only by journeys over the ice cap. To obtain such data, and as an indispensable feature of a meteorological program, stations should be established on the inland ice plateau and continuously occupied for considerable periods.

The Problem of Previous Glaciations

Careful soundings taken on the continental shelf will serve a useful purpose in defining submarine moraines and overdeepened rock-floored valleys respectively deposited and carved out during the climax of the

[12] Douglas Mawson: A Discussion on the Antarctic Ice-Cap and Its Borders, Nov. 6, 1918, *Quart. Journ. Geol. Soc. of London*, Vol. 75, 1919, pp. i-vii; reference on p. vi. Though the method suggested at that meeting for sounding the depth of the ice was verbally explained, the reference to such invention was necessarily left vague in the printed proceedings.

Pleistocene glaciation, when Antarctica supported an even greater ice capping than is the case at present. In the same department of inquiry observations are wanted as to the height above sea level to which the rocks of the mountains have been eroded by the ice.

A quite remarkable and significant feature of Antarctica is that, though so severely glaciated in Pleistocene and Recent times, no record of previous glacial conditions has yet been observed in its rocky strata. A very careful search should be made for such at all times in the sedimentary strata wherever occurring. Any evidence shedding light upon the past climate of Antarctica is most desirable and will help to clear up the present enigma of a polar land with no previous glaciations, whereas Australia, in a temperate to tropical situation, exhibits in its strata repeated striking evidence of glaciation on a grand scale.

Life in the Sea Below the Shelf Ice

The great extent of shelf ice is one of the unique features of the Antarctic. Such formations range from a few hundred to perhaps some two thousand feet in thickness and completely deck over the sea, excluding light and limiting circulation and aeration of the sea water below. The underlying waters will, of course, be difficult to investigate on account of inaccessibility, but any information relating thereto, and especially in regard to organic life there existent, would be a novel contribution. A general absence of living plant life is to be expected, which circumstance must greatly limit the possibilities for animal life. Preliminary studies of some value in this respect could be readily made in the case of waters of currents issuing from beneath the shelf-ice formations such as the Ross Barrier.

Evidences of Changes of Level

Careful watch should be maintained along Antarctic shores for evidences of change of level of the land relative to the sea. It is generally accepted that a waning of the Antarctic ice cap is in progress. In accordance with the theory of isostasy this unloading of the area should be followed by a general uplift of the land. The determination of the amount of uplift to date and the establishment of datum marks for future observation are wanted.

Gravity, Magnetic, and Auroral Observations

With a view to obtaining an accurate knowledge of the figure of the earth, gravity determinations by pendulum observations are needed both on the sub-Antarctic islands and at numerous bases on the Antarctic Continent itself.

Likewise in the elucidation of the problem of terrestrial magnetism, the determination of the magnetic elements is required at chains of stations around and across the Antarctic regions. Also, the reoccupation of former stations is particularly desirable.

In the matter of the aurora australis careful and detailed observation of the manifestations is anxiously awaited. This is the more desirable, for in the Antarctic regions the displays appear to exhibit more clearly than in the Arctic certain fundamental features which may assist in arriving at a satisfactory explanation of that remarkable phenomenon. In this regard, however, merely picturesque descriptions should be avoided and the observer should concentrate on observations as to the trend of auroral curtains, the direction of motion of the luminous impulses, etc. As an example for those unacquainted with this branch of observation some of the features that might profitably be observed are to be found in a recently published report of the manifestations seen in Adélie Land.[13]

Volcanism

The Antarctic is not without its share of volcanoes. Though much has been gleaned concerning the active cone of Mt. Erebus, of several less important extinct volcanic centers in the Ross Sea region, of Gaussberg in Kaiser Wilhelm II Land, and of certain not long extinct centers in West Antarctica, there still remains much to be studied. The Balleny Islands are an active volcanic group, as yet unexplored. Other submarine and subaerial volcanoes extinct or dormant may yet be found along the trend lines of crustal weakness already known.

Condition of the Air

The Antarctic Continent is so isolated from other lands and so universally covered by ice that dust particles in the atmosphere are reduced to a minimum. The remarkable purity of the air in this regard is quite striking. Observations as to the quantity of dust motes and bacteria in the air are, therefore, of special interest. Further, the attrition of the snow particles flying at high velocities in the blizzard winds at very low temperatures causes unusual electrification of the atmosphere. As a result there is much silent electrical discharge—St. Elmo's fire—in areas of prevailing strong winds. This state of affairs is conducive to the production of a high ozone content in the atmosphere. Consequently estimations of the ozone content are likely to prove interesting.

On account of the existence of a continent around the south pole and the consequent intense cold that prevails throughout—far lower

[13] Douglas Mawson: Records of the Aurora Polaris (Australasian Antarctic Expedition, Scientific Reports, Ser. B, Vol. 2: Terrestr. Magnetism and Related Observations, Part 1), Sydney, 1925.

temperatures on the average than in the Arctic regions—the atmosphere is singularly free from water vapor. This condition of minimum water vapor and dust motes should leave the atmosphere much more transparent to the blue end of the spectrum. In clear weather the sunlight is certainly remarkably actinic towards photographic plates. This fact and the freedom of the coastal waters from land sediment, the latter giving the sea also greater transparency to the sun's rays, may be the explanation of the observation that plant life in those seas has been found to continue down to greater depths than usual. Observations to confirm these indications would be useful.

Economic Possibilities

It may be remarked that many of these inquiries are of direct benefit only to pure science, but it cannot be gainsaid that pure science is the foundation of all invention and economic advance.

On the other hand there is much in Antarctica that may be of direct economic value. No one knows what the future has in store for that region; but whaling is already a settled industry in those waters. For many years now whaling companies have operated from the island of South Georgia with very satisfactory financial results. The conduct of this whaling industry is directly under the surveillance of the British Government operating under control of the Falkland Islands and Dependencies. The killing of whales is so regulated that it is hoped to avert extinction of the species. Similar operations are now being conducted annually from New Zealand in the Ross Sea region. The penguin and seal life of the Antarctic coasts and pack-ice zone also offers opportunities for future economic exploitation.

A certain amount of coal, of late Paleozoic age, is known to exist over a large area between King George V Land and Ross Sea. Ores of many of the metallic elements have been met with in small quantities, and there is always the prospect of explorers stumbling upon economically valuable deposits. Finally, the Antarctic Continent may have a future as a source of power by harnessing the phenomenal winds which in some areas sweep down as a steady torrent from the cold ice plateau to the sea. There is some possibility, therefore, of the eventual establishment of a sparse and strictly limited population on Antarctic shores. The prospects are yet, however, somewhat remote.

Dr. VON DRYGALSKI has long been professor of geography in the University of Munich. His early work dealt chiefly with glaciology (Die Geoiddeformationen der Eiszeit, *Zeitschr. Gesell. für Erdkunde zu Berlin*, Vol. 22, 1887). His next major contribution to the subject related to the structure of the Greenland inland ice and its significance in the theory of glacier movement—material gathered while leader of the Greenland Expedition of the Berlin Geographical Society, 1891–1893 (see "Grönland-Expedition der Gesellschaft für Erdkunde zu Berlin, 1891–1893," 2 vols., Berlin, 1897; "Über die Struktur des Grönländischen Inlandeises und ihre Bedeutung für die Theorie der Gletscherbewegung," *Neues Jahrbuch für Mineral., Geol. und Paläontol.*, 1900). In 1900–1903 he was leader of the German Antarctic expedition on the *Gauss*. The reports of this expedition, published in a series of monographs entitled "Deutsche Südpolar-Expedition, 1901–03" (18 vols., Berlin, 1905 to date) are of exceptional value for their comprehensiveness and thoroughness. Among reports contributed by Dr. von Drygalski himself are "Das Eis der Antarktis und der subantarktischen Meere" (Vol. 1, No. 4, 1921) and "Ozean und Antarktis" (Vol. 7, No. 5, 1926). The popular account of the expedition by its leader is entitled "Zum Kontinent des eisigen Südens," Berlin, 1904. Dr. von Drygalski has also made valuable contributions to general geography in such publications as "Der Einfluss der Landesnatur auf die Entwicklung der Völker," Berlin, 1922. In the Memorial Volume of the Transcontinental Excursion of 1912 of the American Geographical Society, in which he was a participant, he has written "Talübertiefung im Grand Cañon des Colorado," New York, 1915.

THE OCEANOGRAPHICAL PROBLEMS OF THE ANTARCTIC*

Erich von Drygalski

AMONG the many Antarctic problems awaiting solution, those bearing on oceanography have especially been the subject of active discussion. This has been the case not only because the ocean surrounds the whole Antarctic Continent as an uninterrupted ring of waters and is in contact with all parts of that continent in practically the same latitudes and under ice conditions that do not substantially vary, but also chiefly because the influence of the Antarctic on the ocean waters was known to extend northward far beyond the equator. The former circumstance brings it about that the individual phenomena of all three oceans, i. e. their temperature, salinity, and gas content, as well as their organic life, are influenced by the Antarctic in all longitudes practically in the same way; and the second circumstance showed that this influence is so potent that it must still be taken into consideration in the case of regions far distant from the Antarctic in order to understand the character of other lands and seas. For in this matter oceanographic phenomena are by no means the only ones that have to be considered. As the sea surface is, according to Hermann Wagner, 2.42 times as great as the whole land surface of the earth, the sea has a correspondingly greater influence on the atmosphere and on its thermal régime and other forms of energy. This determines indirectly not only the phenomena of the atmosphere but the inorganic and organic development of the lands. Thus the ocean is the great power reservoir of the earth—indeed, some of the Ionic natural philosophers interpreted it as the source of everything; and, as the ocean receives part of its energy from the Antarctic, it is important to examine the power sources of that area.

INFLUENCE OF THE ANTARCTIC ON LOWER LATITUDES

Because of the uniformity of the water masses of the ocean and the ready mobility of their parts, temperature and salinity and plant and animal life would develop in the same way if they were everywhere subjected to the same external conditions. The different intensity of sunshine in different latitudes as well as the different reflection of this warmth by coasts of many varying forms disturb

*Translated by the editor from the German original written for the present volume. The translation has profited from a revision kindly undertaken by Mr. H. A. Marmer.

this equilibrium. Thus arise waves and currents; they strive to reëstablish this balance, without, however, ever attaining that result. In addition the ocean is affected by the gravitational power of moon and sun, not only on its surface but down to its depths, and thus is involved in a rhythmical to-and-fro movement which we must always bear in mind, although quantitatively it is inferior to the movements induced by warmth and coastal form. At all events the heat of the sun is the main agency by which the movements of the ocean are influenced; and the effect of this agency of course differs most at the two extreme regions, the equator and the poles, so that the strongest equalizing tendency of the oceans occurs between these two regions. As the Arctic, however, is surrounded by connected land masses through which narrow passages exist in Bering Strait and west of Greenland, and somewhat wider ones on both sides of Spitsbergen—which, however, are again barricaded farther south by the Faroe-Iceland submarine ridge—it is comprehensible that the high north can exert only a slight influence on the oceans and that the aforementioned equalizing tendency is developed most between the Antarctic and the tropics.

The interchange of water which results from this takes place partly on the surface, partly in the depths. In the warm latitudes the surface water is much warmed from above, and at the edge of the Antarctic Continent it is cooled off; in the former region its temperature rises to 27° C. and more, whereas in the latter it drops to $-1.8°$ and $-1.9°$, so that there is a temperature difference between the two areas of almost 30°. In the tropics these influences do not go far down, as, for example, can be seen from the rapid downward decrease of the water temperatures there. The effective range of these influences, according to the fundamental plankton researches of H. Lohmann[1], seems to extend to depths of 300 or 400 meters. The cooling influences of the Antarctic Continent are of a somewhat different nature, as they emanate partly from the wall-like termination of the inland ice toward the sea, partly from the surface. Both are jointly effective, but their combined effect is much less powerful than are the warming influences in the tropical zone, inasmuch as these relate to an area ten times as large, if the area of the two regions be estimated according to Hermann Wagner's values for the distribution of land and water in the different zones.[2] The effective lower limit of the cooling influences of the Antarctic may, like that of the warming influences in the tropics, be taken to lie at 300 or 400 meters, as was determined on the *Gauss* expedition to be the case in the shallow shelf sea off the

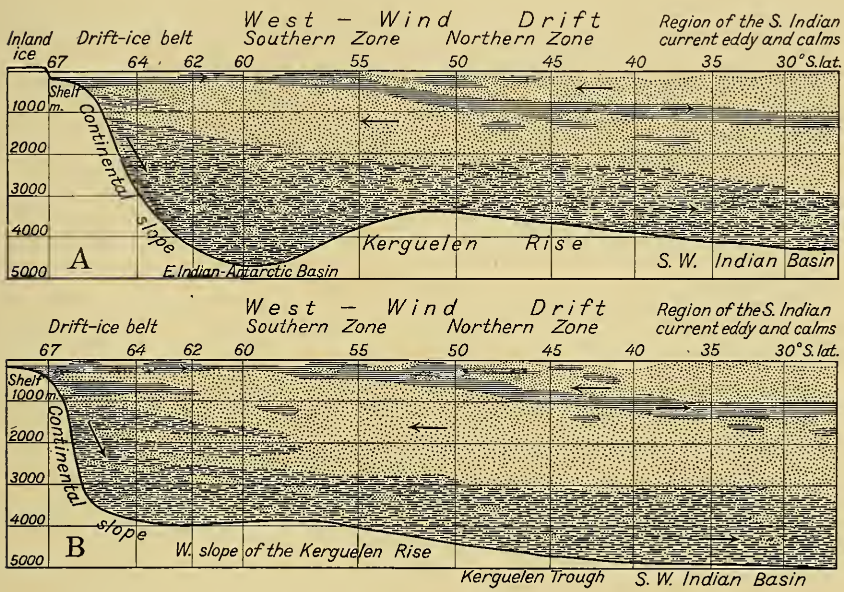
[1] H. Lohmann: Die Bevölkerung des Ozeans mit Plankton, nach den Ergebnissen der Zentrifugenfänge während der Ausreise der "Deutschland" 1911, *Archiv für Biontologie, herausg. von der Gesell. Naturf. Freunde zu Berlin,* Vol. 4, No. 3, Berlin, 1920, especially pp. 255–285 and Pl. 13.

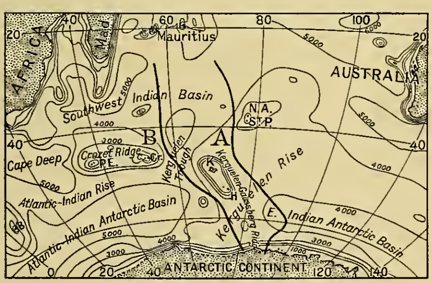
[2] Hermann Wagner: Lehrbuch der Geographie (10th edit., Hanover, 1922), Vol. 1, Part II, p. 269.

coast of Kaiser Wilhelm II Land. For this reason the thrusts of warm water that emanate from the tropics must be much greater than the thrusts of cold water that are caused by the inland ice of the Antarctic.

The Mesothermic Condition of the Polar Seas

As a consequence of the action of these warming and cooling influences on the ocean waters there is produced in the polar regions, as





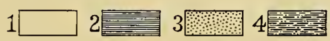


Fig. 1—Two sections across the southern Indian Ocean northwards from the Antarctic Continent to show the stratification of water. 1, surface water; 2, polar water; 3, tropical water; 4, bottom water. The location of the sections is shown on the inset map. On the sections the parallels of latitude are spaced as on Mercator's projection. On the basis of the distortion that this involves the vertical exaggeration is 200 times. (From Pl. 8 of work cited in footnote 4.)

has long been known, a stratification of warm and cold water—a condition to which the term "mesothermic" has been applied. For, whereas in the "anothermic" condition of the warm seas the temperature of the water generally decreases downwards, at first rapidly, then slowly—with the slight exception that at a depth of about 1000 meters a brief inversion takes places as a result of a flat and soon disappearing minimum (caused by a thrust of Antarctic water), which, however, hardly is expressed in the temperature[3] but only in the salinity—the polar and subpolar seas have cold water above and below and warmer water in a massive intermediate layer. From the magnitude of this polar mesothermy in comparison with the slight inversion at 1000 meters in the warmer seas, it is evident how much more potent the influence of the tropics is than that of the Antarctic. Mesothermy also takes place in the Arctic Sea and is there due to the Gulf Stream,

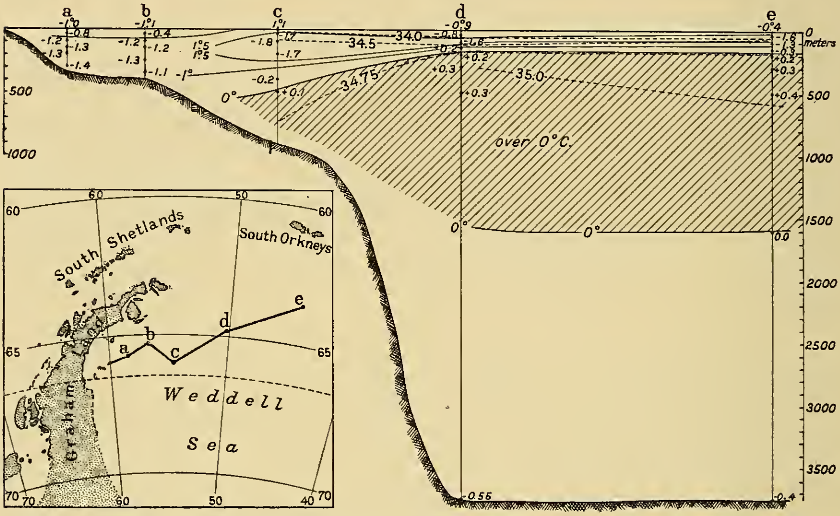


FIG. 2—Section showing temperature of the water in the southernmost part of the Atlantic Ocean, at the northern end of Weddell Sea. Isothermals (temperature in C.) are shown as full lines, isohalines (salinity in thousandths) as broken lines. The mesothermic layer is ruled. Vertical exaggeration, 125 times. The location of the vertical temperature series a, b, c, d, and e is shown on the inset map. (From Pl. 2 of work cited in footnote 5.)

as the warmer water of this current pushes in between the cold masses on the surface and on the bottom. The cold reaction which corresponds to that inversion is, on the other hand, to be found only in a restricted area south of Lightning Channel, which cuts through the Faeroe-Iceland submarine ridge. Thus even in the north the influence of the tropics predominates.

In the accompanying figures, I have represented the mesothermic stratification as it has been found so far in the vicinity of the Antarctic. Figure 1, for the southern Indian Ocean, is based on the observations of the *Gauss* expedition;[4] Figure 2, of the southernmost South At-

[3] G. Wüst: Zweiter Bericht über die ozeanographischen Untersuchungen [der Deutschen Atlantischen Expedition], *Zeitschr. Gesell. für Erdkunde zu Berlin*, 1926, pp. 231–250; reference on p. 249.

[4] Erich von Drygalski: Ozean und Antarktis: Meereskundliche Forschungen und Ergebnisse der Deutschen Südpolar-Expedition 1901–1903 (Deutsche Südpolar-Expedition 1901–1903, herausg. von Erich von Drygalski, Vol. 7, Part V, pp. 387–556), Berlin and Leipzig, 1926, pp. 473 ff. and Pl. 8.

lantic, on those of O. Nordenskjöld[5] and W. Brennecke;[6] and Figure 3, of the extreme southeastern Pacific Ocean, on the observations of H. Arctowski on the *Belgica*.[7] All three figures show to what great extent the warm water pushes forward between two cold layers as far as the Antarctic Circle and even beyond. From the southwestern

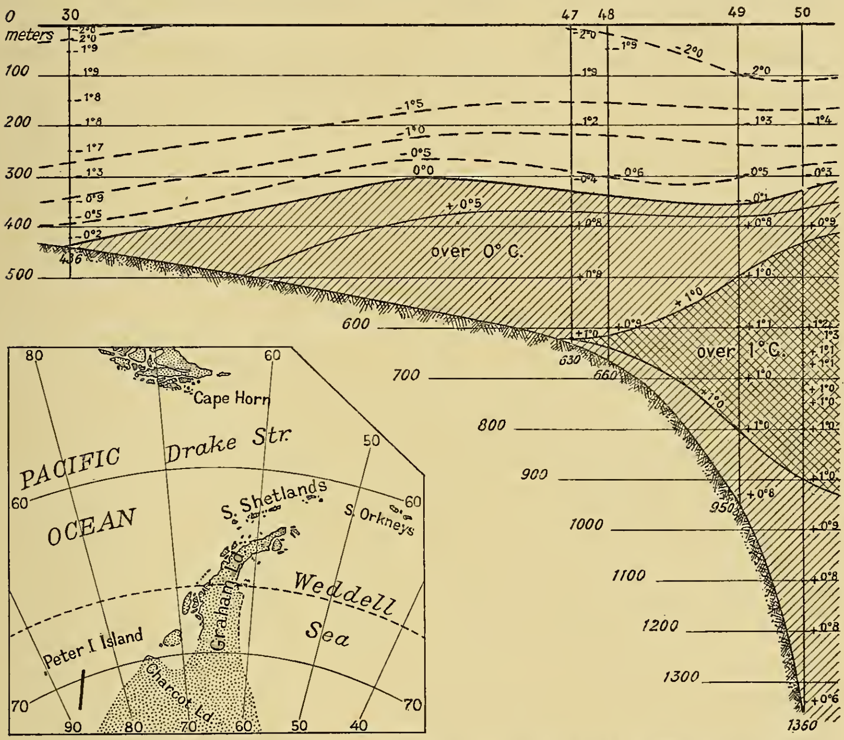


Fig. 3—Section showing temperature of the water in the extreme southeastern Pacific Ocean, west of Graham Land. Water over 0° C. ruled, over 1.0° C. cross-ruled. Vertical exaggeration, 125 times. Location of the section is shown by the short bold line in the southwestern corner of the inset map. (From Pl. 3 of work cited in footnote 7.)

Pacific region, i. e. south of Australia, no detailed observations are available to me,[8] but a short series of observations by L. Kohl[9] and

[5] Otto Nordenskjöld: Die ozeanographischen Ergebnisse (Wissenschaftliche Ergebnisse der Schwedischen Südpolar-Expedition 1901–1903, herausg. von Otto Nordenskjöld, Vol. 1, No. 2), Stockholm, 1917, Pl. 2.

[6] Wilhelm Brennecke: Die ozeanographischen Arbeiten der Deutschen Antarktischen Expedition 1911–1912, *Aus dem Archiv der Deutschen Seewarte*, Vol. 39, 1921, pp. 1–216 and Pls. 4 and 5.

[7] Henryk Arctowski and H. R. Mill: Relations thermiques: Rapport sur les observations thermométriques faites aux stations de sondages (Expédition Antarctique Belge: Résultats du Voyage du S. Y. Belgica en 1897, 1898, 1899 sous le commandement de A. de Gerlache de Gomery: Rapports scientifiques, Vol. 5, Part II), Antwerp, 1908, Pl. 3.

[8] Temperature observations were made in this region on the Australasian Antarctic Expedition, 1911–1914, under Sir Douglas Mawson. The results, not yet published, will appear in that expedition's Scientific Reports, Ser. A, Vol. 2, Part N. A short vertical series from 0 to 200 fathoms (366 meters) for a locality in 50° 30′ S. and 148° 2′ E. is published in J. K. Davis: With the "Aurora" in the Antarctic, 1911–1914, London, 1919, p. 110.—Edit. Note.

[9] Ludwig Kohl: Zur grossen Eismauer des Südpols: Eine Fahrt mit norwegischen Walfischfängern, Stuttgart, 1926, p. 136.

Sten Vallin on the whaling cruise of Captain C. A. Larsen in Ross Sea in 1923–1924 shows that conditions are the same there. The condition of mesothermy may therefore be assumed to exist in the sub-Antarctic and Antarctic seas throughout the whole circuit of the South Polar regions. The cooling influence of the inland ice is thus resisted from the far tropics and to a certain extent overcome.

Position and Origin of the Intermediate, or Tropical, Water

The southern end of this warmer intermediate water lies at the edge of the Antarctic continental shelf or on its outer parts. It does not reach to the outer wall of the inland ice, as the above figures unanimously show. From observations in the region of the Gaussberg of an extraordinary development of plankton in February it was evident that this warm intermediate water increases in thickness during the southern summer and then sends forth weak thrusts of warm water farther into the shelf sea. On such occasions the shelf-ice masses in front of the inland-ice walls, such as the Ross Barrier and the "West Ice" of the *Gauss* expedition, are reached in places by its southernmost projections.

That this intermediate water originates in lower latitudes may be assumed, on the one hand, because of its warmer temperature; on the edge of the continental shelf it differs by 2° to 3° C. from the water lying above and below it. Its higher salinity also points to the fact that it comes from warmer seas in the north. For this reason it may also be observed that on the southern side of islands, i. e. on the lee side of its movement, it is separated. For example, considerable differences in the temperature of the deep water occur on both sides of the Kerguelen-Gaussberg ridge (Fig. 4), and from this the conclusion may be drawn that this intermediate warmer water flows southward in greater volume on its western side than on its eastern side.[10] Similar conditions were found by Arctowski in the extreme southeastern Pacific region on both sides of Peter I Island.[11] In addition W. Brennecke,[12] from his observations during the *Deutschland* expedition, and A. Merz and G. Wüst[13] from the older material

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[10] Drygalski, Ozean und Antarktis, pp. 406, 499 ff.

idem: Der Kerguelen-Gaussberg-Rücken, eine submarine, vulkanische Höhenzone im Indisch-Antarktischen Gebiet, *Sitzungsber. Bayer. Akad. der Wiss., Math.-naturw. Abteil.*, Munich, 1924, pp. 157–164.

[11] Expédition Antarctique Belge: Rapports Scientifiques, Vol. 5, Part II, pp. 23 ff.; also J. Rouch: Océanographie physique (Deuxième Expédition Antarctique Française 1908–1910, commandée par le Dr. Jean Charcot: Sciences physiques, Documents scientifiques), Paris, 1913, p. 31. Cf. also Nordenskjöld, *op. cit.*, Vol. 1, No. 2, p. 18 and Pls. 3 and 4.

[12] Brennecke, *op. cit.*, pp. 137 ff.

[13] A. Merz and G. Wüst: Die atlantische Vertikalzirkulation, *Zeitschr. Gesell. für Erdkunde zu Berlin*, 1922, pp. 1–35; 1923, pp. 132–144.

W. Brennecke and G. Schott: "Die atlantische Vertikalzirkulation": Eine Entgegnung auf die Abhandlungen von A. Merz und G. Wüst, *ibid.*, 1922, pp. 277–288.

A. Merz: Temperaturschichtung und Vertikalzirkulation im Südatlantischen Ozean nach den "Challenger"- und "Gazelle"-Beobachtungen, *ibid.*, 1922, pp. 288–300.

of the *Challenger* and the *Gazelle*, hitherto not thus interpreted, have been able to prove that a subsurface current from the North Atlantic subtropics carries warm water to the south. This current we may take to be a feeder of the Antarctic intermediate water and may assume a similar origin in the other oceans, as its occurrence is the

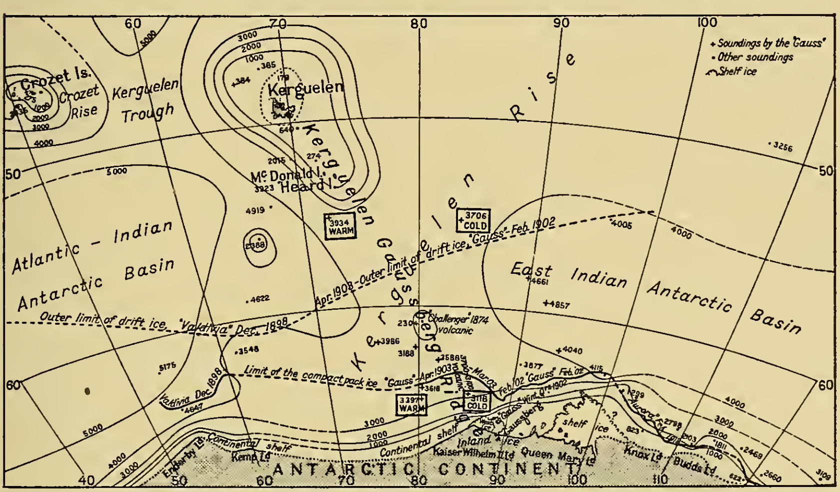

FIG. 4—Bathymetric map of the southernmost Indian Ocean, north of the Antarctic Continent. Scale, 1:44,000,000. Depths in meters. The map is also intended to illustrate the probable separation of the southward-flowing tropical water by the Kerguelen-Gaussberg submarine ridge, the observations of the *Gauss* expedition having shown that the temperatures of this layer on the western side of the ridge were higher than on the eastern side. The vertical temperature series at the four stations occupied (indicated on the map by soundings 3934 and 3397 on the west and 3705 and 3118 on the east) are published in the second paper cited in footnote 10, from which also the present map is taken.

same throughout the whole circuit of the Antarctic. I should like to designate this intermediate water "tropical water," because it comes from the tropics or subtropics.

Origin and Movement of the Polar Water

This warmer water in the higher southern latitudes lies between two colder layers. This constitutes the mesothermy referred to, which is partly connected with mesosalinity, as the salt content of the warm intermediate water is higher than that of the water above and in places higher than that of the water below. The water above is of Antarctic origin, as could be observed in the Gaussberg region as well as in Weddell Sea. It originates when the walls of the inland ice disintegrate in the flat shelf sea in front of it, and throughout its whole depth it has nearly uniform salinity and temperature, both considerably lower than those of the intermediate water farther north. For the former we found in the Gaussberg region $t = -1.85°$, $S = 34.4‰$, and both practically constant down to a depth of 400 meters. Similar conditions have been reported by W. Brennecke, O. Nordenskjöld, and R. C. Mossman from Weddell Sea, by H. Arctowski from the *Belgica* drift in the southeastern Pacific, and by C. S. Wright[14] and L. Kohl and Sten Vallin from Ross Sea. The variations in salinity and temperature occurring among these observations are slight and seem to have been caused by the different forms of the shelf sea bottom.

This typical "polar water" of the shelf seas, as I should like to call it, is caught by currents and carried northward. It is to be found in the drift-ice belt and in the west-wind drift northwards to the 50th parallel of south latitude close to or immediately below the surface (Fig. 1). Above it lies, frequently in the drift-ice belt but rarely in the west-wind drift, a layer of water which is generally very thin but whose salinity and temperature vary greatly. Both circumstances are due to the disintegration of the drifting floes and icebergs, so that this layer may properly be termed "ice-melted water." This water is differentiated by its fluctuating characteristics from the polar water underneath, with its constant characteristics. During the *Gauss* expedition the polar water in the southern Indian Ocean had a thickness of 100 to 300 meters and rested with an undulating contact surface on the tropical or intermediate water below. North of latitude 50° S. the polar water submerges and then flows at a depth of about 1000 meters to beyond the equator. The *Gauss* expedition was able to observe its distribution in the Indian Ocean to the Tropic of Capricorn and in the Atlantic to the Tropic of Cancer, the latter observations having also been made by the *Deutschland* expedition. It forms an important horizon for the subdivision of the deep sea, as its temperature increases northwards only gradually and slowly and its salinity changes very little. For the Pacific region no corresponding observations are yet available.

Westward-Flowing Current Along the Antarctic Continent

Movement is imparted to the current of polar water, and to the melted water above it, by the wind; its direction is determined by the wind, by the earth's rotation, by the coasts, and by the border of the shelf ice. At the *Gauss* station we were able to recognize a purely superficial drift, caused by the wind, which flowed to the south and consequently toward the coast, as a result namely of the deflection of the east-west wind direction to the left.[15] Below this surface drift we found a gradient current [Windstaustrom] in the sense of V. W.

[14] C. S. Wright: The Ross Barrier and the Mechanism of Ice Movement, *Geogr. Journ.*, Vol. 65, 1925, pp. 198–220; reference on p. 219.

[15] Drygalski, Ozean und Antarktis, pp. 512 ff.

K. Hessen: Gezeiten- und Strombeobachtungen auf der Winterstation des "Gauss" 1902–03 (Deutsche Südpolar Expedition 1901–1903, herausg. von Erich von Drygalski, Vol. 7, Part V, pp. 557–602), Berlin and Leipzig, 1926, pp. 587 ff.

Ekman, which flowed parallel to the coast and to the edge of the shelf ice and affected nearly the whole thickness of the polar water. The dependence of both the drift and the current on the direction of the wind has been demonstrated conclusively by W. Brennecke[16] for Weddell Sea also. J. M. Wordie[17] also emphasizes their dependence on the winds and the direction of the coast line and makes this deduction from a comparison of the drifts of the *Belgica*, *Deutschland*, *Endurance*, and *Aurora*, the first in the South Pacific, the second and third in Weddell Sea, and the last in Ross Sea. Thus we now know that, below the superficial drifts, there is a strong westward-flowing current system completely encircling the Antarctic Continent, a system which owes its existence to the predominant winds and flows parallel to the coast and to the inland-ice and shelf-ice walls. Its thickness is variously estimated. Where I observed it it was 100 meters to over 300 meters. This current system under the influence of the earth's rotation tends toward the left, i. e. toward the coast, and it holds the drift ice together. Over it lie those purely surface and fluctuating currents due to variable winds which carry the drift ice hither and thither and project irregularly but not far into the west-wind drift.

The Cold Bottom Water and Its Origin

Under the intermediate, or tropical, water lies the cold bottom water which, as has long been known, is characterized by great uniformity and occupies the bottom of all the oceans to beyond the equator. Inasmuch as the Arctic Sea is segregated from the oceans, whereas the Antarctic waters everywhere connect with them, as furthermore the cold bottom water slowly increases in warmth towards the north, and as a number of deep-sea basins which are closed to the south seem to be cut off thermically from this bottom water, it has long been assumed that this bottom water comes from the Antarctic. The Antarctic expeditions of the last three decades have confirmed this view. It was in addition possible both in the Gauss region and in Weddell Sea to show that the bottom water arises through mixture of the shelf-sea water, or polar water, and the intermediate, or tropical, water. The former is brought to the latter by the above-mentioned flow (Fig. 1); where they meet, undulation and mixing take place which create the bottom water. This is a mixture because its temperature lies between those of the two constituent waters. Its mass, however, is primarily derived from the tropical water because this is quantitatively greater at the shelf edge than the polar water and because its salinity is exactly or almost exactly the same as that of

[16] Brennecke, *op. cit.*, Pl. 15.

[17] J. M. Wordie: The Ross Sea Drift of the "Aurora" in 1915–1916, *Geogr. Journ.*, Vol. 58, 1921, pp. 219–224; reference on pp. 223–224.

the bottom water. We may assume that the tropical water at the edge of the continental shelf is cooled through its contact with the polar water—occasionally also through climatic influences—and that therefore it becomes heavier and sinks to the bottom. Its flowing over the bottom of the oceans is then due to its specific gravity. We may therefore characterize the influence of the Antarctic on the oceans, first, as bringing about the distribution of pure polar water on the surface and later at a depth of 1000 meters, and, second, as creating the bottom water through the cooling of the tropical water at the edge of the shelf. The warm zones, however, are of greater influence, for they call forth the vast mass of tropical water and drive it as the intermediate layer up to the shelf edge, whence, cooled, it returns along the bottom to the tropics.

Methods of Investigation to Determine Different Kinds of Water

These currents may be ascertained directly by current measurements in different depths and indirectly by the observation of the physical and biological properties of the different kinds of water and their distribution. Temperature and salinity measurements are the most important. These show that as a rule salinity is the property most generally constant in the different kinds of water, whereas temperatures become equalized more readily. Salinity is therefore more important to help trace spatial distribution. Of importance, furthermore, are observations on the gas content of the water, especially in oxygen, nitrogen, and carbon dioxide; as, for example, the amount of nitrate plus nitrite nitrogen remains quite constant in spite of the wide distribution of the polar water. Related to the gas content is the bacterial and plankton life; biological observations thus should supplement the physical observations. Not infrequently plankton studies may yield evidence as to the origin of a given type of water, if it cannot be determined by its salinity and temperature.[18] Thus the summer development of plankton in the Gaussberg region showed that the warmth of the tropical water penetrated into the shelf sea in February, although this fact could not be established thermically. It would lead too far, however, to discuss here more fully the methods of investigation.

Other Problems

The preceding discussion in no way exhausts the oceanographical problems of the Antarctic, although most of them are connected with the phenomenon of currents, so that the study of currents leads indirectly also to an understanding of other phenomena. Nevertheless a number of other problems may here be touched upon.

[18] Lohmann, *op. cit.*, p. 422.

Tides

On tides there are relatively few observations, a circumstance which is probably due to difficulties arising from the ice. Otto Nordenskjöld[19] reports a number of observations from Weddell Sea, without, however, being able to deduce definite results. More important is the work of G. H. Darwin[20] on the tidal observations of the *Scotia* expedition on Laurie Island in the South Orkneys and of the *Discovery* expedition in Ross Sea. R. E. Godfroy[21] has communicated the observations of the second French expedition under Charcot at Cape Horn, at the South Orkneys, the South Shetlands, and on the west side of Graham Land; A. T. Doodson[22] those of the *Terra Nova* at Cape Evans in Ross Sea; and K. Hessen[23] those of the German Antarctic Expedition in the shelf sea north of Gaussberg. The observations of this last expedition have been characterized as the most complete and the least affected by disturbing influences. In the working up of the *Scotia* observations G. H. Darwin at his two stations finds a good correspondence with the equilibrium theory; K. Hessen, however, at the *Gauss* station finds a marked spring-tide lag as well as a constantly increasing preponderance of the diurnal tides poleward. This last Darwin had also been able to establish for Ross Island. Of course, further observations are greatly to be desired, especially as we now know that tidal currents affect the sea at all depths and thus interfere with the current system previously discussed. For the *Gauss* station K. Hessen has been able to separate the tidal currents from the wind-driven surface currents.

Bottom Deposits

All Antarctic expeditions have reported on bottom sediments and concur in the statement that the Antarctic land mass is everywhere surrounded by deposits of a continental character, as Sir John Murray had already declared after the return of the *Challenger* expedition. From this fact he had concluded that the land of the Antarctic is a continent and not an archipelago. These deposits, how-

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[19] Nordenskjöld, *op. cit.*, pp. 27–28.

[20] G. H. Darwin: Tidal Observations Made During the Voyage of the Scotia, 1902–1904 (Scottish National Antarctic Expedition: Report on the Scientific Results of the Voyage of S. Y. "Scotia" During the Years 1902, 1903, and 1904, under the Leadership of William S. Bruce, 6 vols., The Scottish Oceanographical Laboratory, Edinburgh, 1907–1920), Vol. 2: Physics, pp. 321–324.

idem: Tidal Observations of the "Discovery," in: National Antarctic Expedition 1901–1904: Physical Observations with Discussions by Various Authors, Prepared under the Superintendence of the Royal Society, London, 1908, pp. 3–12.

F. J. Selby, J. de Graaff Hunter, and G. H. Darwin: Tidal Observations of the "Scotia," 1902–1904, *ibid.*, pp. 13–16.

[21] R. E. Godfroy: Étude sur les marées (Deuxième Expédition Antarctique Française 1908–1910, commandée par le Dr. Jean Charcot: Sciences physiques, Documents scientifiques), Paris, 1912.

[22] British (Terra Nova) Antarctic Expedition 1910–1913, Miscellaneous Data, compiled by H. G. Lyons, London, 1924, pp. 68–73.

[23] Hessen, work cited above in footnote 15.

ever, consist not only of the blue mud that surrounds the other continents but also of much terrigenous matter of a glacial character, making appropriate E. Philippi's[24] designation of these sediments as glacio-marine for the whole circuit of the Antarctic.

Thus such sediments were found on Sir Douglas Mawson's[25] expedition between Adélie Land and the Gaussberg northwards to latitude 64° S.; on the *Gauss* expedition in the adjoining area between longitudes 80° and 95° E., likewise northwards to latitude 64° S.; on Shackleton's *Quest* expedition[26] between longitudes 17° E. and 46° W. along the Antarctic Circle; furthermore, on the tracks of the *Scotia*, *Antarctic*, *Deutschland*, and *Endurance* throughout Weddell Sea and, according to R. G. Mossman,[27] in a tonguelike northward projection toward Bouvet Island; and finally on the *Belgica* expedition west of Graham Land between longitudes 70° and 100° W. along the 70th parallel.[28] North of this zone of glacio-marine sediments everywhere comes the diatom and then the globigerina ooze. This distribution is related to the currents and to the ice. For the glacio-marine sediments extend as far as the ice drifts, and the diatom ooze extends farther northwards into the area of the cold currents which come from the ice, although it is found only rarely in the drift-ice belt itself. As diatoms are particularly abundant on the surface of this belt, their absence on the bottom is noteworthy. This absence, however, can be explained by the fact that the glacio-marine sediments cover them, as well as by the fact that the outward-flowing currents of polar water carry these light organisms out of the ice towards the north. The distribution of globigerina ooze corresponds with the area of warm currents; therefore it lies north of the diatom ooze, but warm branch currents have, in the Kerguelen region as well as in the southeastern Pacific, carried it here and there southward along the bottom of the drift-ice belt. Thus the distribution of the bottom sediments can furnish evidence of the development of the present and former currents. The stratification of the bottom sediments found by the *Gauss* expedition has already been interpreted in this manner; this interpretation has been related to the former greater extension of the ice.[29]

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[24] E. Philippi: Die Grundproben der Deutschen Südpolar-Expedition 1901–1903 (Deutsche Südpolar-Expedition 1901–1903, herausg. von Erich von Drygalski, Vol. 2, Part VI), Berlin, 1910, p. 578.

[25] Frederick Chapman: Sea-Floor Deposits from Soundings (Australasian Antarctic Expedition 1911–14 under the Leadership of Sir Douglas Mawson, Scientific Reports, Ser. A, Vol. 2, Oceanography, Part I), Sydney, 1922, pp. 58–59.

[26] F. A. Worsley: The Voyage of the "Quest": The Hydrographic Work, *Geogr. Journ.*, Vol. 61, 1923, pp. 97–103; reference on p. 101.

[27] R. G. Mossman: The Physical Conditions of the Weddell Sea, *Geogr. Journ.*, Vol. 48, 1916, pp. 479–500; reference on p. 497.

[28] Henryk Arctowski: Géographie physique de la région antarctique visitée par l'Expédition de la "Belgica," *Bull. Soc. Royal Belge de Géogr.*, Vol. 24, 1900, pp. 93–175; reference on p. 139.

[29] Philippi, *op. cit.*, pp. 591 ff.

Ice, Especially Shelf Ice

Antarctic glaciation need not be discussed in detail in this oceanographical paper. It is known that the masses of ice drifting in the sea consist of icebergs and ice floes, the former representing land ice, the latter sea ice. Of importance oceanographically is the fact that the floes through freezing attain a thickness of only 2 or 3 meters and that their further growth is dependent on the fall of snow and its turning into ice. Therefore the floes for the most part have an origin like that of the land ice and are thus free from salt; they differ from the land ice, however, in their lack of all those structural forms which the flowing movement brings about in the land ice.[30] In the sea the movement of the floes as well as of the icebergs is of course passive; the floes are moved by the purely surface drifts, and icebergs, which project much farther downwards, by the permanent currents, i. e. essentially by the current of polar water. The outer margin of the drift ice is described by most observers as being compact and as being frayed out only by the winds blowing at a given time. I have already mentioned that the unbroken front of this edge and the rapid compacting of the drift ice behind the margin is caused by the dominant east winds and the currents resulting therefrom which encircle the continent in a westerly direction, inasmuch as these currents are deflected to the left by the earth's rotation, i. e. toward the coast. It thus follows that the belt of drift ice substantially follows the coast and that from its position one may draw inferences as to the position of the coast line behind it.

Of great importance is the shelf ice, as that ice formation is called which surrounds the coast in the shallow shelf seas and which has been found by all expeditions wherever their advances lay. It is an intermediate form between the inland ice and the drift ice, as, like the latter, it floats but, like the former, stays in place or moves only very slowly within its limits. The best-known occurrence of this type is in Ross Sea, where it ends in that wall or barrier first described by James Clark Ross, which gave to the ice behind it the designation "barrier ice."[31] It is comprehensible on historical grounds if in England all similar formations in the Antarctic are being termed barrier ice;[32] objectively, however, the term "shelf ice" is better because the shallow shelf sea with its banks and shoals is the necessary foundation for the origin and character of this ice formation. Both its origin and

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[30] Erich von Drygalski: Das Eis der Antarktis und der subantarktischen Meere (Deutsche Südpolar-Expedition 1901–1903, herausg. von Erich von Drygalski, Vol. 1, Part IV), Berlin and Leipzig, 1921, pp. 517 ff., 626 ff.

[31] Griffith Taylor: Physiography and Glacial Geology of East Antarctica, *Geogr. Journ.*, Vol. 44, 1914, pp. 365–382, 452–467, 553–571; reference on p. 378.

[32] In their fundamental report "Glaciology" (British (Terra Nova) Antarctic Expedition, 1910–1913), London, 1922, which is now the leading discussion in English of the topics with which it deals, C. S. Wright and R. E. Priestley adopt the term "shelf ice" for the formation in question (see pp. 161–169 and 205–222; on terminology, pp. 162–163).—Edit. Note.

nature have recently been much discussed,[33] especially the question whether the shelf ice develops through the joining of land-ice tongues or through the thickening of sea ice. Views on this question are tending to converge, to the effect that both processes take place, as Griffith Taylor[34] and C. S. Wright[35] have reported concerning the Ross shelf ice, Sir Douglas Mawson[36], together with Frank Wild and J. K. Davis, concerning the Shackleton ice, and I[37] concerning the Gaussberg shelf ice (West Ice). According to these reports the masses of shelf ice are complex formations. They develop through the overriding of shallow seas by land ice and through the freezing of sea water itself; this holds true whether these ice masses are developing at present or are survivals of former greater glaciation, which latter is generally the case in the Antarctic. Today the shelf ice forms an outer coast line which lies beyond the inner coast line. The latter is formed by the terminal wall of the inland ice, by solid rock, and sometimes by islands.[38] It is an important problem to clarify the relation of these two coasts to each other and to the compact edge of the drift ice farther out.

Need of Investigation of the Depth of the Shelf Sea

In this the precise investigation of the depth of the shelf sea is necessary because, as has been said, the shallower seas are the bases on which individual parts of the shelf ice become fixed and thus hold together the floating pieces. From the whole circuit of the Antarctic we now know that the depths of the shelf sea vary greatly and also that quite generally they are considerably greater than they are about the other continents. For around these continents the shelf seas are generally limited outwards by the 100-fathom line, whereas the shelf seas of the Antarctic go down to 1000 meters. Explanations have been sought for this. E. Philippi thinks the great depths are due to ice erosion, J. M. Wordie[39] to faults and folds on the sea bottom, Otto Nordenskjöld[40] to isostatic sinking under the pressure of continental glaciation. None of these explanations satisfies. To ascribe the

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[33] T. W. Edgeworth David: Antarctica and Some of Its Problems, *Geogr. Journ.*, Vol. 43, 1914 pp. 605–630; reference on pp. 620 and 629.

R. F. Scott: The Great Ice Barrier and the Inland Ice, *ibid.*, Vol. 46, 1915, pp. 436–447; reference on pp. 436 and 441.

G. C. Simpson: Captain Scott in the Great Ice Barrier, *ibid.*, Vol. 47, 1916, pp. 226–227.

C. S. Wright: The Ross Barrier and the Mechanism of Ice Movement, *ibid.*, Vol. 65, 1925, pp. 198–220; reference on pp. 204 ff.

[34] Taylor, *op. cit.*, p. 378.

[35] Wright, *op. cit.*, p. 204.

[36] Sir Douglas Mawson: Australasian Antarctic Expedition, 1911–1914, *Geogr. Journ.*, Vol. 44, 1914, pp. 257–286; reference on pp. 266–267.

[37] Drygalski, Das Eis der Antarktis, pp. 443 ff.

[38] According to Stillwell; see Mawson, *op. cit.*, pp. 270–271.

[39] J. M. Wordie: Shackleton Antarctic Expedition, 1914–1917: Depths and Deposits of the Weddell Sea, *Trans. Royal Soc. of Edinburgh*, Vol. 52, 1921, pp. 781–793 (= Part IV, No. 30).

[40] Nordenskjöld, *op. cit.*, pp. 7 ff.

great depths to ice erosion is to overestimate the effect of this agency, which surely cannot exert such an influence under water, because ice in the sea is buoyed up by the water and its pressure on the ground is thus diminished. Wordie's explanation possibly meets the conditions in Weddell Sea but not the general distribution of the great shelf-sea depths. This Nordenskjöld's explanation tries to do, but it suffers from the fact that the widespread Antarctic shelves still persist in their deep-lying position today, although they have been freed from the pressure of the inland ice. It is also of importance to note that the shelves of the Antarctic are very wide throughout; a narrow shelf is reported only from the west coast of Coats Land.[41] The depth and width of these shelves must first be investigated more thoroughly in order to find a satisfactory explanation for their peculiarities. At all events, in the sea, too, Antarctic nature proper ends at the outer edge of these shelves, as well with respect to temperature and salinity as with respect to many organic phenomena. Therefore it is justifiable to regard the Antarctic Continent as extending to the outer edge of the shelf and to restrict the term "The Antarctic" to this area, as the drift-ice belt over the continental slope beyond is of an entirely different nature—sub-Antarctic, indeed, in character. Therefore the somewhat infelicitous name "Antarctica" for the continent is unnecessary, as according to natural conditions only the continent with its shelf should be called "The Antarctic."

Conclusion

I cannot further discuss in this short paper the oceanographical problems of the Antarctic, although many details remain to be considered, and must refer the reader to the published works of the various expeditions. I have emphasized the most important matters and shown how uniform is oceanic nature throughout the whole circuit of the Antarctic and how in all its details it can be explained through the conflict between the inland ice and the warmth of the tropical seas. In this conflict the warmth, because of its greater areal distribution, is much the stronger, the inland ice being able only to modify and divide the oceanic influences of the tropics.

[41] R. N. Rudmose Brown: The Weddell Sea, *Geogr. Journ.*, Vol. 61, 1923, pp. 133–135.

The work of Dr. TAYLOR, professor of geography at the University of Sydney, is unusually varied in its scope. Formerly physiographer in the Commonwealth of Australia Bureau of Meteorology, Melbourne, he distinguished himself by his fruitful application of climatology to the problems of settlement and human adaptation to environment in general. He was acting Commonwealth geologist at Canberra, and as senior geologist he accompanied Scott on his last expedition, also serving on this expedition as leader of the western parties. A few of his many publications are: "The Australian Environment, Especially as Controlled by Rainfall," (*Commonwealth Advisory Council of Science and Industry Memoir No. 1*, Melbourne, 1918); "Australia in Its Physiographic and Economic Aspects," 4th edit., London, 1925; "The Frontiers of Settlement in Australia" (*Geogr. Rev.*, Vol. 16, 1926); "The Climate and Weather of Australia" (with H. A. Hunt and E. T. Quayle), Melbourne, 1913; "The Climatic Control of Australian Production" (*Commonwealth Bur. of Meteorol. Bull. No. 11*, 1915); "Geographical Factors Controlling the Settlement of Tropical Australia" (*Queensland Geogr. Journ.*, Vol. 32–33, 1918); "Australian Meteorology," London, 1920; "Climatic Cycles and Evolution" (*Geogr. Rev.*, Vol. 8, 1919); "The Evolution and Distribution of Race, Culture, and Language" (*Geogr. Rev.*, Vol. 11, 1921); "The Distribution of Future White Settlement" (*Geogr. Rev.*, Vol. 12, 1922); "Environment and Race," London, 1927; "With Scott: The Silver Lining," London, 1916; "The Physiography of the McMurdo Sound and Granite Harbour Region" (British Antarctic Expedition, 1910–1913, Reports, London, 1922); "Scientific Travel in Antarctica" (in H. A. Brouwer, edit.: Practical Hints to Scientific Travellers, Vol. 4, The Hague, 1926).

CLIMATIC RELATIONS BETWEEN ANTARCTICA AND AUSTRALIA

Griffith Taylor

In this brief study of some of the more important of the climatic problems concerning both Antarctica and the adjacent continents I shall discuss the Australian sector almost entirely, partly because by far the greater amount of Antarctic meteorological research has been done in this region, partly because the adjacent Australian data are readily obtainable, and partly because my own personal knowledge is confined to this sector.

Australia

LOCATIONAL RELATIONS OF ANTARCTICA

The continent of Antarctica occupies a large portion of the area comprised within the Antarctic Circle (66½° S.), which indeed limits it on the Australian side. On this side (to northward) a belt of ocean 26° of latitude wide (about 1800 miles) separates Antarctica from the south coast of Australia. On the South American side the long peninsula of Graham Land in Antarctica projects towards the still longer peninsula of South America, and the two continents are only about 850 miles apart (see Fig. 1). South Africa is about 35° of latitude (i. e. about 2400 miles) from the hypothetical position of the Antarctic coast nearest to it. From these figures it is probable that the broad southern coast of Australia, being opposed to a lengthy parallel coast in Antarctica, is better situated to exhibit climatic relations with Antarctica than are the narrow coasts of South America or the more distant lands of Africa.

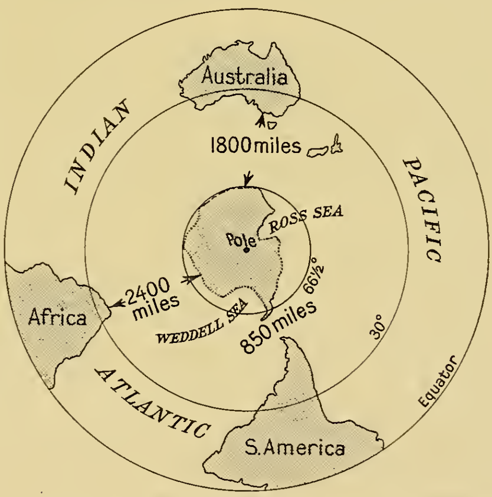

Fig. 1—The position and size of Antarctica with respect to the surrounding continents.

AUSTRALIAN CLIMATE AND WEATHER

We may first of all consider the salient features of the Australian climate and weather. Australia is the continent that is marked by the simplest topography of all. It has a very low general elevation and has a very simple coast line, so that it lies like an oval "blackboard" ready to assist in the elucidation of climatic problems. The essential features in the climate can be grasped from a consideration of the construction shown in Figure 2. Here the two belts of depressions (lows, or rainstorms) are labeled monsoonal (or tropical) and Antarctic rains respectively. Between them is the dry region of the anticyclone "centers" (in the south) and the dry region in the belt of trade winds (in the north). Thus the climatic sequence is (1) tropical rains, (2) trade winds arid belt, (3) anticyclone arid belt, and (4) Antarctic rain belt.

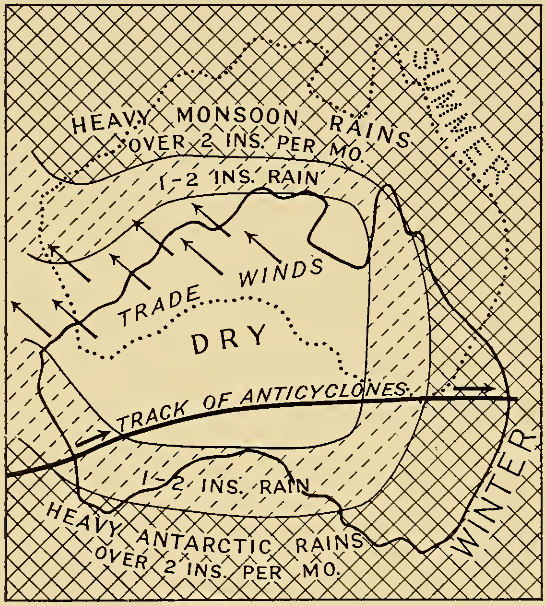

FIG. 2—Seasonal changes in Australia. The continent is supposed to move from the summer position to the winter position under the atmospheric belts. (After frontispiece in the writer's "Australian Meteorology," Oxford, 1920.)

If we now imagine that these climatic belts remain more or less anchored to a stationary sun and imagine further that the continent of Australia (beneath the climatic belts) swings north and south in accord with the tilt of the earth's axis, then the actual changes in climate and rainfall are very near to those indicated in our figure. In summer Australia has a position to the north right under the sun. It falls under the influence of the tropical rainstorms in the north, the trade winds in the center, and the dry anticyclone belt in the south. In winter we may picture the tilt of the axis swinging Australia south to the position noted. In winter the trade winds occupy most of the north of Australia, the anticyclones cross the center, and the heavy Antarctic rains affect the south coast.

Such, then, are the salient climatic controls in Australia. The winds blowing along the northern margins of the anticyclones are easterlies and are in accord with the trade winds. Both are drying winds over all the continent (except the actual east coast). Hence arise the permanently arid center of the continent and the arid northern winter and the arid southern summer.

The weather of Australia—as opposed to the climate—depends on the passage of the atmospheric eddies of high and low pressure. They occur in three belts as already mentioned. The tropical lows, or depressions, are very much more numerous (25 per cent) in the hot months (see Fig. 3), and more than half of them move to the south-east across West Australia. In the colder months occur about 16 per cent of these tropicals, almost wholly down the eastern half of Australia. The Antarctic lows are very numerous (41 per cent of the whole) in winter and affect the south coast strongly. In the hot months the tracks of the Antarctic storms lie far to the south and can only be approximately indicated in the daily charts. Moreover, in summer only the northern margins of cyclones to about half the number of winter Antarctic lows (i. e. 22 per cent) affect Australia in this season.

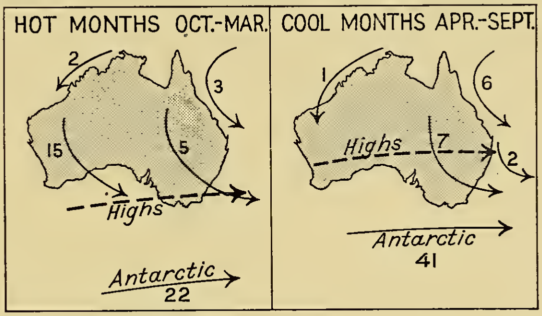

FIG. 3—Percentage in year of lows along the tracks indicated. (N.B. About 30 highs also cross Australia in each six months.)

It is in regard to these Antarctic low-pressure eddies that we come closest into touch with conditions in the Antarctic Continent. Before considering other aspects of the Australian climate we may properly discuss the form of these Antarctic lows so far as we know them. The Australasian Antarctic Expedition of 1911–1914 was of particular importance in this connection, because it maintained a meteorological station upon Macquarie Island. This lies about halfway between New Zealand and Antarctica, and the station was in charge of Mr. Ainsworth, an officer of the Commonwealth Weather Bureau. In Figure 4 (taken from Mawson's "The Home of the Blizzard") we see the isobars as plotted from stations in Tasmania (latitude 41°), New Zealand (46°), Macquarie Island (54°), and Adélie Land (Mawson's base at 66° S.). An intense cyclone is centered just to the southwest of Macquarie Island, which registered a reading of 28.34 inches, with strong northeast winds. The Commonwealth meteorologist states that the barometer on the island fell from 29.49 at 9 A. M. on April 11 to 27.91 at 6 P. M. on April 12. At Adélie Land the barometer rose from 28.70 to 28.90 as the cyclone passed (eastward) to the north.

In the course of the years 1912 and 1913 a number of lows of

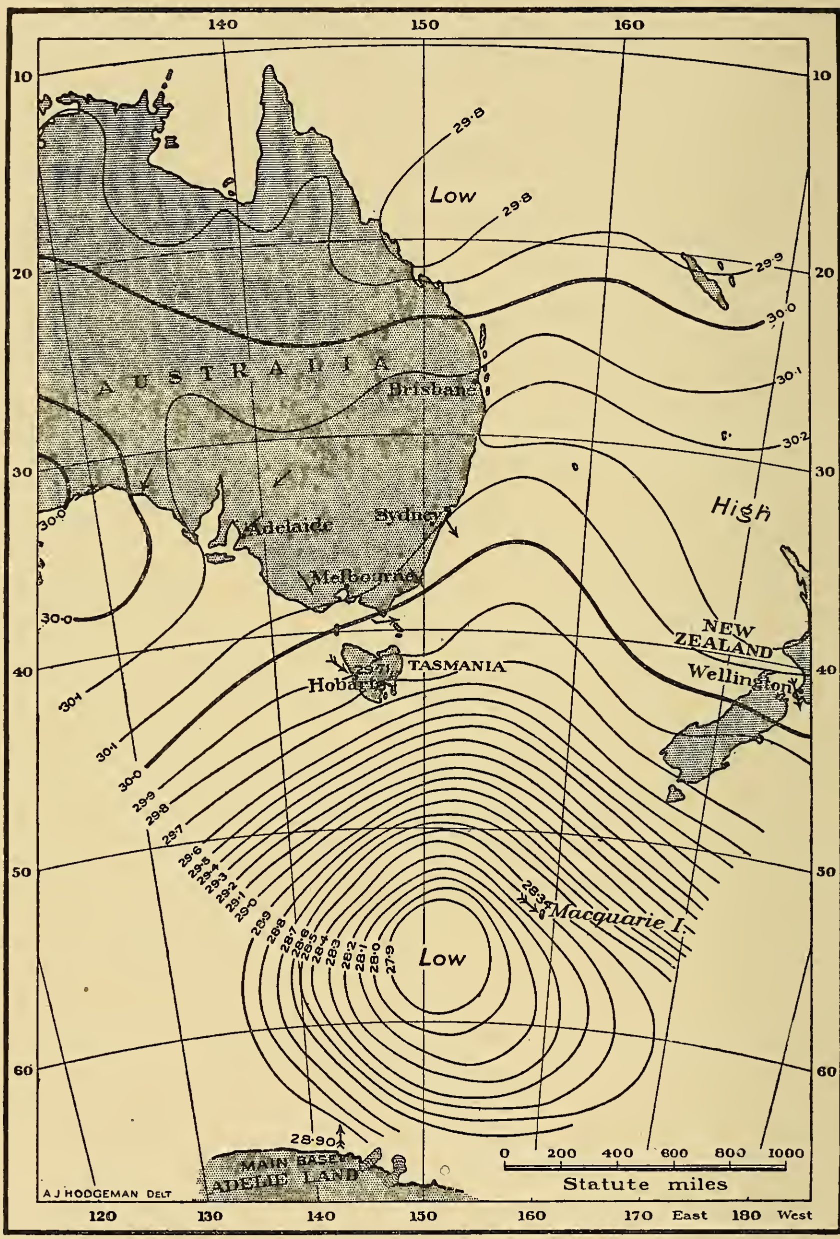

FIG. 4—A complete Antarctic cyclone from a chart by the Commonwealth Meteorological Bureau for April 12, 1913. (From Sir Douglas Mawson's "The Home of the Blizzard," London, [1915], Vol. 2, p. 142.)

somewhat similar type were charted, showing that the larger Antarctic cyclones move to the east about latitude 60° and are so large at times that they extend from Tasmania to Antarctica. The normal weather chart for Australia of course shows only the upper limb (or margin) of these widespread storms, and the meteorologist is quite unable to estimate where the center lies, especially as very few vessels usually sail in the seas south of Tasmania.

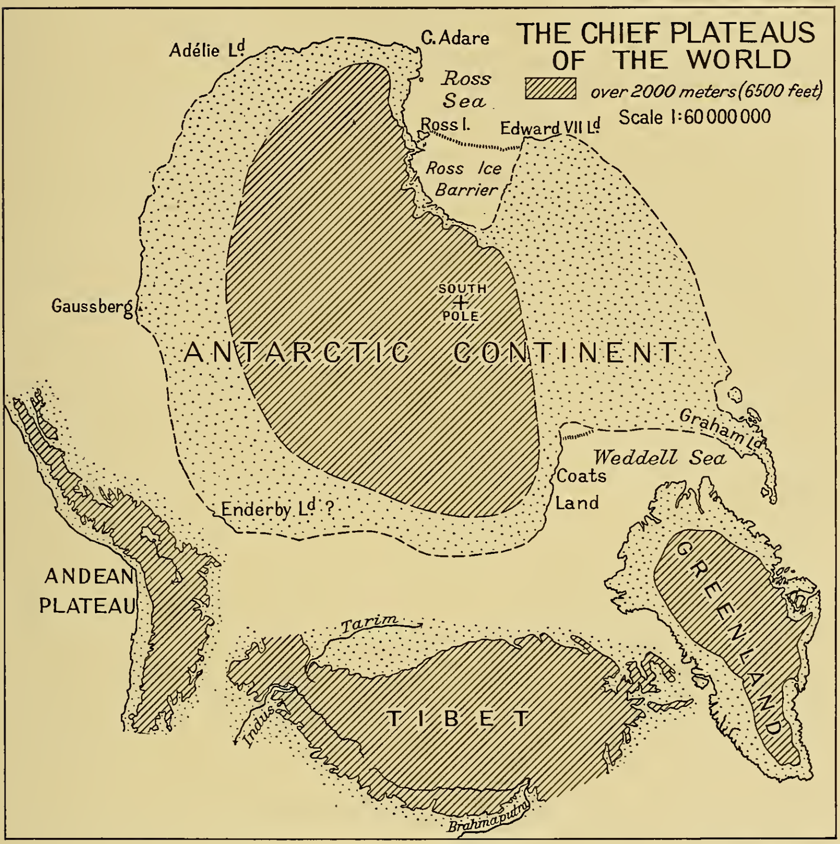

FIG. 5—The Antarctic Continent and other chief plateaus of the world drawn to the same scale.

ANTARCTICA

CLIMATE AND WEATHER OF ANTARCTICA

We may now turn to the general condition governing the climate and weather in Antarctica. For these there are the results of a number of expeditions, notably those of Scott (1902–1904) in the Ross Sea area, of Drygalski (1902–1903) south of the Indian Ocean, of Bruce (1903) in Weddell Sea, of Shackleton (1908) in Ross Sea, of Scott (1911–1913) in the Ross Sea area, and of Mawson (1912–1913) in the region south of Australia. Of all these the records of the two Scott expeditions and of the German (Drygalski) expedition have been most thoroughly examined and used to formulate general conclusions. The most important research is without doubt that of Dr. G. C. Simpson (now head of the British Meteorological Office), who was in charge of the meteorological research in the Antarctic on Scott's last expedition[1] and who has produced three large volumes of data based on observations made in the Antarctic.

Since only the Australian and American sectors of the great Antarctic Continent are at all adequately mapped, it is of course impossible to give more than a very incomplete description of the land near the south pole. The edge of the great Ross Ice Barrier and the west coasts of Ross Sea to Cape Adare are known. Much is known from Cape Adare to the Gaussberg (see Fig. 5). From the latter right round to Coats Land is totally unknown, save for doubtful coasts such as Enderby Land. Weddell Sea and Graham Land are charted, and then all is conjectural until we reach King Edward VII Land again. From inland journeys it seems probable that a great deal of the continent exceeds 6000 feet in elevation. This is true of the lands to the southwest of Ross Sea, while the pole itself is at a height of over 9000 feet. In Figure 5 it is seen that the Tibetan Plateau is the only one which can compare in area and height with the (probable) Antarctic Plateau. Greenland and the Andean Plateau are much smaller.

THE ANTARCTIC ANTICYCLONE

It is the presence of this extremely high plateau which determines the chief characteristics of the Antarctic climate and weather. As pointed out by W. H. Hobbs and others, the control of the meteorology of the North Polar Regions is maintained by the permanent anticyclone over Greenland. The center of the latter is some 20° of latitude away from the geographic north pole. Much more should we expect the more pronounced topographic conditions of the Antarctic Continent to take charge of Antarctic meteorology.

The temperature changes as we move southward are indicated in Figure 6, where the monthly temperatures are given for Sydney, Hobart, Dunedin, Cape Adare, McMurdo Sound (Ross Island), and the Ross Barrier (some little distance south of Ross Island). For comparison with the latter is given also the mean monthly temperature of the parallel of 78° N. It is seen that the Antarctic is much colder—from 10° to 20° F.—during the summer, autumn, and winter, though there is not so much difference in spring. At headquarters on Cape Evans (Ross Island) the sun sets on April 24 and returns on August 21. It does not set between October 24 and February 17 in this latitude (77° 38′).

[1] The writer of this article was senior geologist on this expedition but was in charge of the meteorological station when Dr. Simpson was engaged sledging. Dr. Simpson's research is published in the scientific results of the British Antarctic Expedition, 1910–1912, Meteorology (Vol. 1: Discussion, in which see especially Ch. 7, "The General Air Circulation Over the Antarctic"; Vol. 2: Weather Maps and Pressure Curves; Vol. 3: Tables), Calcutta, 1919 (Vols. 1 and 2) and London, 1924 (Vol. 3).

It was soon realized by mariners that the mean isobars fell in value as the Antarctic Continent was approached. But as the result of comparatively recent researches it has been found that this only holds good down to about 60° S. Thereafter the isobaric values increase in general towards the pole. Fricker in 1893 perhaps first discussed the meaning of the prevalence of easterly winds around the Antarctic Continent. Later (as Simpson states) "The Gauss expedition during her stay of eleven months in 66° S. latitude had easterly winds, often extremely strong, during 73 per cent of the total time." The research of Hepworth,[2] Lockyer,[3] and Meinardus[4] (all writing about 1910) showed that over the Southern Ocean there was a constant succession of true cyclonic depressions passing from west to east. These cyclones have westerly winds (the roaring forties) on their northern sides and easterly winds on their southern sides.

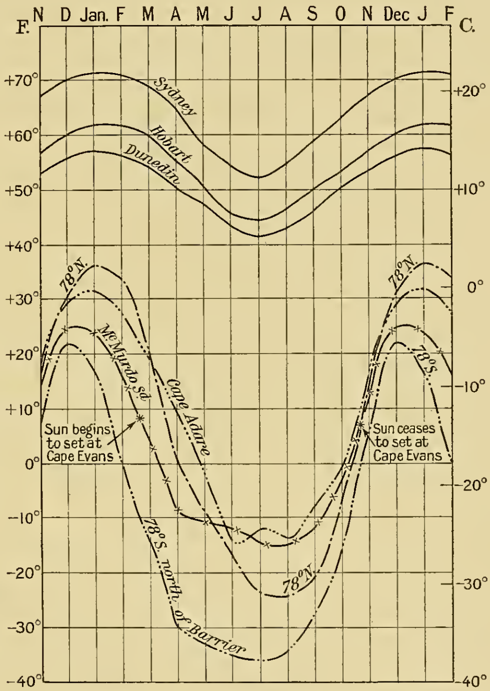

Fig. 6—Mean monthly temperatures at certain Australian and Antarctic stations. For comparison the mean monthly temperature in 78° N. is also given. (Antarctic and Arctic values from Vol. 1, pp. 84–85, of report by G. C. Simpson cited in footnote 1.)

Lockyer postulates some eight of these cyclones more or less continuously wandering round the Southern Ocean, and each very much like that depicted on the weather chart for April 11, 1913 (Fig. 4). Over the continent itself he placed a permanent anticyclone centered more or less over the geographic pole.

Meinardus differs from Lockyer in that his Antarctic cyclones are often centered over the Gaussberg (66° S.) rather than in latitude

[2] M. W. C. Hepworth: Climatology of South Victoria Land and the Neighbouring Seas (National Antarctic Expedition, 1901–1904, Meteolorogy, Part I, pp. 417–452), Royal Soc., London, 1908.

[3] W. J. S. Lockyer: Southern Hemisphere Surface-Air Circulation: Being a Study of the Mean Monthly Pressure Amplitudes, the Tracks of the Anticylcones and Cyclones, and the Meteorological Records of Several Antarctic Expeditions, Solar Physics Committee, London, 1910.

[4] Wilhelm Meinardus: Meteorologische Ergebnisse der Winterstation des "Gauss" 1902–1903 (Deutsche Südpolar-Expedition, 1901–1903, Vol. 3: Meteorology, Part I, pp. 1–339; see especially section D: Betrachtungen über die allgemeine Zirkulation der Atmosphäre im Bereich des Südpolargebiets, pp. 323–339), Berlin, 1909–1911.

60°, as Lockyer shows them. Furthermore, Meinardus realizes the great difficulty of postulating a normal anticyclone over Antarctica, for this kind of eddy is essentially accompanied by dry conditions. We know that large glaciers are being given off all round the Antarctic Continent. These presuppose a constant accretion of snow or ice in the interior, to keep up the supply, or one would imagine that the central plateau would long since have been denuded of its icy carapace. Indeed so marked is the outflowing character of the winds that Hobbs talks of the general circulation as constituting an Antarctic "broom."[5] He considers that the anticyclone winds continually sweep large quantities of snow and ice from the center toward the periphery.

It is not necessary in this article to criticize the various theories set forth to explain the origin of the snow. Hobbs believes that the cirrus clouds furnish much of the precipitation. Meinardus places a cyclone *over* the anticyclone, giving the indraft and cooling which would seem to be essential.

Simpson shows that an inversion of the circulation is clearly demonstrated (above 5000 feet) by the cloud movements over Ross Island. He follows Meinardus as regards the method of precipitation but raises the "snow-supplying cyclone" well above the plateau. He thinks that the plateau itself is everywhere controlled by a shallow *surface* anticyclone. There is therefore not very much difference, so far, between the views of Meinardus, Simpson, and Hobbs.

ANTARCTIC PRESSURE WAVES

When the local variations in pressure in Antarctica are investigated it is found that they are usually not accompanied by changes of wind direction, as in lower latitudes. Thus the passage of a low-pressure wave from west to east in southern Australia over a given place is accompanied by a rather sharp wind shift from north to south at that place. Simpson finds that a series of pressure waves moves across the Ross Sea area, affecting first the southern plateau and Framheim, then Ross Island, and lastly Cape Adare (see Fig. 7). The mean length of such a wave is 150 hours, and the mean variation amounts to 0.572 inches. These waves take twelve hours to pass from the south pole plateau to Framheim (which indicates that their velocity is about 40 miles per hour). The normal pressure conditions near Ross Island consist of a more or less permanent low over the warm Ross Sea and the permanent high over the continent. Owing to the Ferrel effect the resulting winds are deflected to the west. They are "pent in" by the funnel of the great western scarp and so rush past Cape Evans as southerly winds. Simpson believes that the

[5] W. H. Hobbs: The Glacial Anticyclones: The Poles of the Atmospheric Circulation, *Univ. of Michigan Studies: Sci. Ser.*, Vol. 4, New York, 1926.

pressure waves mentioned above modify the usual pressure conditions. When they intensify these normal conditions a furious blizzard results, when they counteract them calms or northerly winds result at Cape Evans.

No adequate explanation is available as to these pressure waves or surges. They seem to rise in the hypothetical lower portion of East Antarctica and radiate outwards therefrom, but Dr. Simpson leaves their further elucidation to the future. He thinks they are of permanent importance all through Antarctica. They largely account for the phenomena at the Gaussberg. They are dominant at Cape Adare, but the normal west-to-east cyclone conditions are superposed on them at this latter locality. Traces of these pressure waves are apparent as far north as Kerguelen, where many pressure changes without corresponding changes in the wind direction are apparent. There is, however, little if any evidence of them in New Zealand or in the south of Australia, where the weather is entirely dominated by traveling cyclones and anticyclones.

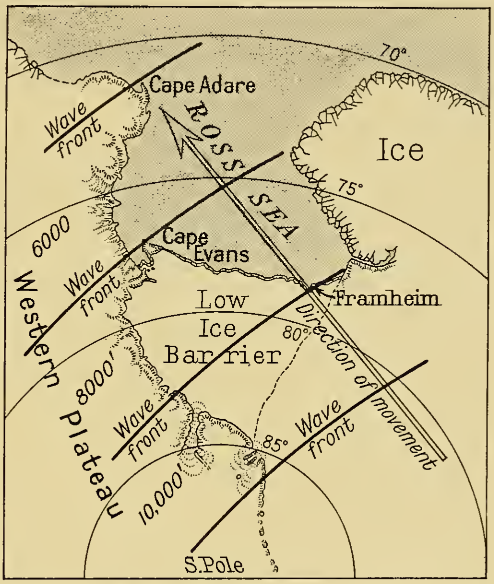

Fig. 7—Pressure waves moving over Antarctica to the northwest. (After G. C. Simpson, *ibid.*, p. 216.)

Australia and Antarctica

METEOROLOGICAL CORRELATIONS

A consideration of the foregoing data makes it appear probable that there is no very close connection between minor weather conditions in the Antarctic and in Australia (or other similarly situated inhabited lands). However, this does not destroy our interest in certain larger meteorological correlations. The writer in 1914 indicated some of these in an earlier publication in the following words:[6]

"The isobars apparently exhibit a tendency to lie parallel to the great Antarctic mountains bounding the Ice Plateau. On many

[6] Antarctica, The British Sector, Ch. 16 in: Oxford Survey of the British Empire, edited by A. J. Herbertson and O. J. R. Howarth, Vol. 5, Oxford, 1914, pp. 537-538.

occasions almost identical readings were taken at Cape Evans and Cape Adare, though the latter is 450 miles north. . . . Pressures decrease to the east of the mountains—the large area of warmish water in the Ross Sea undoubtedly tending to this result. . . . Sometimes, however, when a 'low' lies over New Zealand, a 'high' covers Cape Adare, as shown on December 23, 1911.

Cape Evans [77° S.]	Pressure 29.955
Cape Adare	Pressure 30.004
Terra Nova 500 miles NE. of Cape Adare	Pressure 30.01

"This leads to the inference of breaks in the great low-pressure belt of the Southern Ocean.

"During the voyage of the *Terra Nova* to and from Antarctica, it was possible to trace the relation of Australasian and Antarctic pressure curves. From December 1, 1910, until December 23, 1910, the ship was proceeding south from the Auckland Isles [lat. 50°] to lat. 60° 31′. In general it may be stated that there was a distinct resemblance in the barometric variations of the station at the Bluff, N. Z. [46½°], and those at the ship until latitude 67° was reached. On the return voyage correlation was again possible only between these latitudes. The second voyage gave similar results. These graphs showed a great similarity in the barographs at Cape Adare and Cape Evans. . . . The Cape Adare (71°) and Cape Evans (77¾°) barographs are almost totally opposed to those obtained at the Bluff. The *Terra Nova* graph of course starts in unison with the Bluff and ends in unison with Antarctica. It apparently passes through the region of maximum amplitude about 60° S. Summarizing, we may state that Australasian weather does not reach to Cape Adare (71°) but may extend south beyond the Antarctic Circle (66°)."

Simpson has shown the same sort of relation more accurately in the accompanying chart (Fig. 8). Here he has compared pressure changes in Australia and America with those at Cape Evans (which he thinks may be taken as fairly typical of Antarctica).

Figure 8 shows that encircling the Antarctic is a region in which all the correlation coefficients are negative. This zone lies approximately along latitude 40° S. There appears to be a seesaw of pressure between the Antarctic and the belt of anticyclones. In other words a month of high pressure over the Antarctic is accompanied by a month of low pressure over latitude 40° S. To the north of Australia is a belt where the pressure changes take place in the same sense as the changes over the Antarctic. This belt was strongly developed in 1902–1903.

Thus the Antarctic is one of the great "centers of action" of the world. Changes here affect all the southern hemisphere.

THE PROBLEM OF RAINFALL FLUCTUATION IN AUSTRALIA

One of the great problems in south temperate lands is the forecasting of drought years. In Figure 9 (dealing with Australia) the period 1908–1925 is analyzed as regards areas receiving annual rainfall above and below the average. If the chart for 1912 be examined the dotted area shows where all the agriculture occurs and where a very large majority of the sheep and cattle are pastured. Rainfall

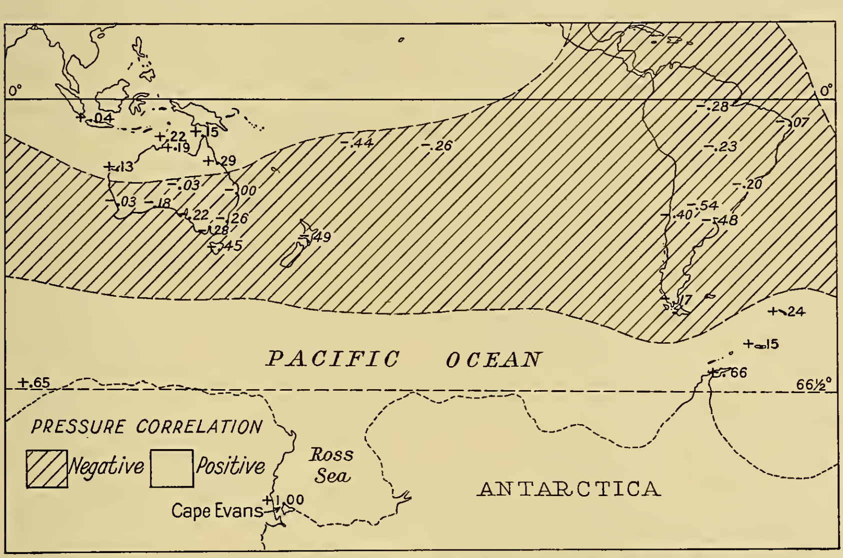

FIG. 8—Correlation of Antarctic pressures with those of south temperate lands. (After G. C. Simpson, *ibid.*, p. 204.)

in the rest of Australia is of much less direct importance in Australian production. We see, then, that 1910–1911, 1916–1917, 1920–1921, and 1924 have been years of good rainfall in the vital regions of the Commonwealth.

On the other hand 1912, 1914, 1919, and 1922 have been drought years over much of Australia, though 1914 was the worst period discussed. There is some indication of a recurrence of "rain distributions," as may be seen by examining the three following five-year periods.

	Dry in All Important Regions	Rain Chiefly in West	Good Year; Especially in Center and East	Good Year; Especially in East	Poor Year
A	1908	1909	1910	1911	1912
B	1914	1915	1916	1917	(1918)
C	1918	1919	1920	1921	1922

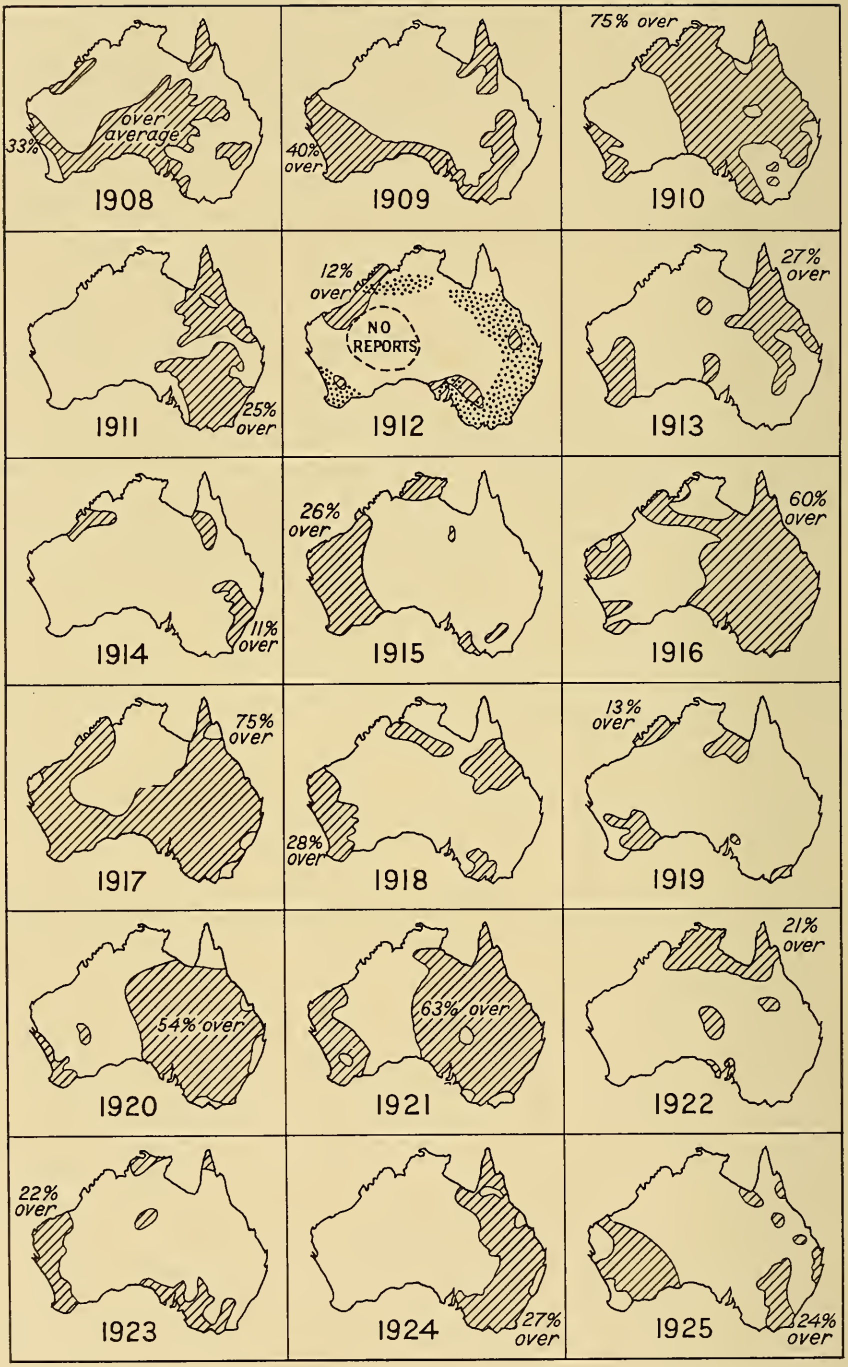

FIG. 9—Rainfall areas in Australia above and below the average for the period 1908–1925 (from the official records). The chief agricultural and pastoral areas are shown by stippling on the map for 1912 only, but they are the same for all the other years as well.

All such attempts to show regular cycles have failed, probably because the areas are too large. But in 1922 the writer pointed out how closely the drought periods in the Darling River area (i. e. Bourke) agreed with variations in solar energy. Captain E. Kidson has shown in his recent study of Australian rainfall[7] that there are alternate zones in the continent, which are differently affected by solar energy (see Fig. 10). In times of strong solar energy the southern coasts, north coast, and inland Queensland and New South Wales have more than average rainfall. The correlation rises as high as +0.7 or +0.8 at certain stations in these two areas. In years of low solar energy, the arid center and the coast of New South Wales benefit. Here again correlations are often of the same high order, such as −0.7 or −0.8. It is probable that along these lines of investigation a real progress in drought forecasting may be made in the future. It may be mentioned that Dr. Pigot is in charge of a solar-radiation station near Sydney where variations in solar energy will soon be recorded continuously.

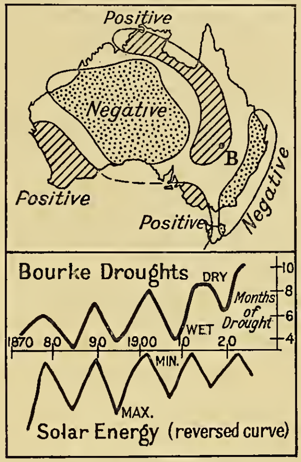

FIG. 10—(above) Correlation of rainfall with solar energy. (After Kidson, work cited in footnote 7.) B = Bourke.
(below) Correlation of Bourke droughts with solar energy. (From the writer's "Environment and Race," Oxford, 1927, Fig. 75.)

One factor connecting the Antarctic weather with that of Australia

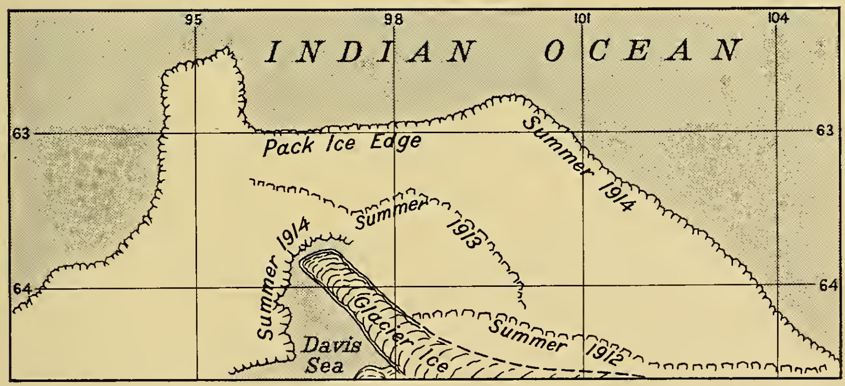

FIG. 11—The Antarctic coast near Mawson's West Base showing the variation in the width of the pack ice during the years 1912, 1913, and 1914. (After J. K. Davis's "With the 'Aurora' in the Antarctic, 1911–1914," London, 1919, p. 152.)

is the drifting pack ice. In the *Terra Nova* about Christmas, 1910, we passed through a belt of pack ice nearly 500 miles wide between lati-

[7] Edward Kidson: Some Periods in Australian Weather, *Commonwealth of Australia Bur. of Meteorol. Bull. No. 17*, Melbourne, 1925, pp. 5–33.

tudes 64½° S. and 71½° S.[8] In other years this "moving refrigerator" is only 200 miles wide about the same period. If we refer to the rain map for Australia for 1911 (Fig. 9) we find that it was a very good year in eastern Australia. Perhaps the extra cooling led to greater rains than usual. Turning now to the charts made by Captain J. K. Davis of the pack ice along the north coast of the Antarctic Continent (Fig. 11) we see that in 1914 the pack ice remained attached to the fixed glacier ice of the continent in a remarkable fashion. It was 60 or 70 miles wider than in the year 1912. Presumably in 1914 Australian conditions were therefore not affected by the usual approach of large areas of pack ice, and this in part probably accounted for the abnormal character of the rainfall of 1914 in Australia—for it was almost the lowest on record.

APPLICATION OF POLAR FRONT THEORY TO THE SOUTHERN HEMISPHERE

In conclusion attention may be drawn to an interesting application of Bjerknes' theory of the polar front to Antarctic conditions. This appears in an address by Captain Kidson given in Wellington, N. Z.[9] His diagram (Fig. 12) seems to link up many lines of evidence. The permanent anticyclone at the pole is indicated, and also a belt of anticyclones revolving around the pole at about latitude 40°. The low-pressure belt is traversed by "families" of cyclones of varying intensities and at varying latitudes but chiefly around latitude 60°. Fluctuating tongues of warm air from the tropics are depicted as forming warm wave fronts which

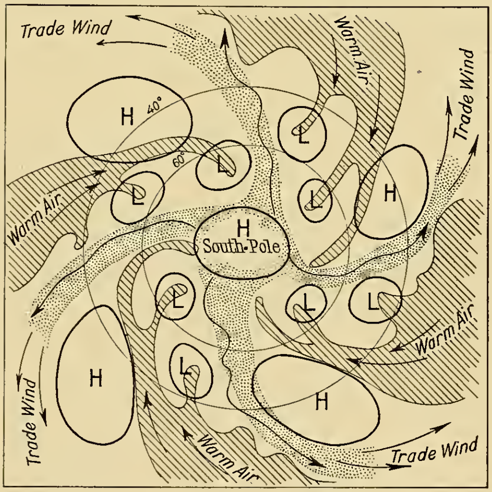

FIG. 12—Atmospheric circulation in the southern hemisphere south of the trade wind belt according to the polar front theory showing the belt of lows (L) surrounding the Antarctic anticyclone (H). (Slightly modified from E. Kidson, paper cited in footnote 6.)

[8] See the map in the writer's book "With Scott: The Silver Lining," London, 1916, p. 77.

[9] Edward Kidson: The Theory of the Polar Front (President's Address, Section A), *Rept. 16th Meeting Australasian Assn. for the Advancement of Sci., Wellington Meeting, 1923*, Wellington, 1924, pp. 140–153; reference on p. 151. [A paper on the same topic was presented at the first meeting of the International Association for the Exploration of the Arctic by Airship held in Berlin in November, 1926, and has appeared in its proceedings, viz. P. Wehrlé and P. Schereschewsky (Shereshevski): Sur le front polaire austral, *Ergänzungsheft No. 191 zu Petermanns Mitt.*, 1927, pp. 77–84. In a footnote the authors raise the question of priority. As a matter of fact Captain Kidson's presentation at the Wellington Meeting took place in January, 1923.—EDIT. NOTE.]

alternate with northward-moving currents of cold Antarctic air. The belts of cyclones are developed where these two dissimilar currents come into contact.

CONCLUSION

In this résumé of recent meteorological work the writer has tried to draw attention to the most promising fields of research, but it seems obvious that not much progress can be made until a number of permanent stations can be established around the Antarctic Continent, so that synoptic charts of the whole southern hemisphere will be available for scientific study.

Captain ROUCH, at one time head of the Service Météorologique des Armées et de la Marine, is at present a commander in the French navy. He was meteorologist on the Second French Antarctic Expedition, led by Charcot, 1908–1910. To the scientific results of this expedition he has contributed "Observations météorologiques," Paris, 1911; "Électricité atmosphérique," Paris, 1913; and "Océanographie physique," Paris, 1913. A number of his publications deal specifically with the polar regions; "Le pôle nord: Histoire des voyages arctiques," Paris, 1923; "Le pôle sud: Histoire des voyages antarctiques," Paris, 1921; "L'Antarctide: Voyage du 'Pourquoi-Pas?,'" Paris, 1926; and "Les régions polaires," Paris, 1927, a regional geography.

THE METEOROLOGY OF THE AMERICAN QUADRANT OF THE ANTARCTIC*

Jules Rouch

The Meteorological Investigation of the American Quadrant of the Antarctic

Of all the Antarctic the lands situated south of Cape Horn offer the most fruitful field for meteorological investigation. Seven major scientific exploring expeditions have visited this region.

In 1898–1899 the Belgian expedition under de Gerlache on the *Belgica* traced the main outlines of the western side of Graham Land and spent a year in the pack ice west of Alexander I Land in the sea that is now termed by geographers Bellingshausen Sea. The *Belgica*, in longitude 87° 33′ W., reached 71° 36′ S., a latitude which has not been surpassed in this area by any subsequent expedition.

In 1902 the Swedish scientist Otto Nordenskjöld explored the eastern side of Graham Land and wintered at Snow Hill Island in latitude 64° 21′ S. The vessel of the expedition, the *Antarctica*, was shipwrecked on the voyage back to fetch the explorers. The ship's party wintered on Paulet Island, whereas Nordenskjöld and his associates continued their observations for another year until an Argentine vessel was able to effect their rescue.

In 1903 a Scottish expedition under the command of Dr. W. S. Bruce explored Weddell Sea. This expedition was not able to make as great a southing as Weddell, who had attained latitude 74° 15′ in 1823 in waters practically ice-free, but the discovery was made in 74° 1′ S. and 20° W. of a new land, which was named Coats Land. The expedition spent the winter on the South Orkneys in latitude 60° 44′.

In 1904 Dr. Charcot on the *Français* visited the lands explored by the *Belgica* and wintered on Wandel Island in 65° 3′.

In 1908 Dr. Charcot undertook a new expedition, which reëxplored the western side of Graham Land and the vicinity of Alexander I Land, discovered new lands in this region, wintered on his vessel, the *Pourquoi Pas?*, on Petermann Island in latitude 65° 10′ S., spent more than a month on the South Shetland Islands, and crossed Bellingshausen Sea approximately along the 70th parallel.

In 1912 a German expedition under Dr. Filchner on the *Deutschland* explored Weddell Sea, exceeded by a wide margin all preceding records in this region, and discovered Luitpold Land in 77° 49′ S.

* Translated by the editor from the French original written for the present volume.

and 36° 31′ W. The *Deutschland*, held fast by the ice, drifted for eight months in Weddell Sea.

Finally, in 1915, Shackleton in an unsuccessful attempt to cross the Antarctic Continent, reached latitude 76° 30′ in Weddell Sea, lost his vessel, the *Endurance*, through ice pressure, and drifted for more than a year on a floe before reaching the open sea in the vicinity of the South Shetlands.

Each of these expeditions, with the exception of Shackleton's, has published extensive reports on its meteorological observations, accompanied by discussions of great interest. The meteorologists on these expeditions were: Arctowski on the *Belgica*, Bodman on the Swedish Antarctic expedition, Mossman on the Scottish Antarctic expedition, Rey on the *Français*, Rouch on the *Pourquoi Pas?*, and Barkow on the *Deutschland*.

But these reports are not the only ones from which meteorologists can draw information. On the return of Dr. Bruce's expedition the Argentine Government, impressed with the important bearing of the meteorological phenomena of the Antarctic on the climate of Argentina, decided to continue the observations made on the South Orkneys and to establish a permanent observatory there.

On South Georgia continuous meteorological observations are also made. Official observatories exist on Staten Island, at Point Dungeness at the eastern entrance to the Strait of Magellan, and on the Falkland Islands.

Finally, in order to complete this review of the meteorological source material for this sector of the Antarctic, there are also the very complete observations made at Orange Bay near Cape Horn by the Mission Française du Cap Horn in 1882–1883, the records which the Chilean Government has had made since 1901 by the keepers of the lighthouse on the Evangelist Islands at the western entrance to the Strait of Magellan, and the very important series of observations of the Salesian Fathers at Punta Arenas, who have been in charge of a meteorological observatory of the first rank since 1888.

General Aspect of West Antarctica

Like the southern end of the New World, West Antarctica is a mountainous country with peaks more than 3000 meters high. It consists of a folded chain on the western side and a tabular region on the eastern side. Physiographically West Antarctica has a fiord-and-channel coast like Patagonia. Apparently the long island garland designated by Suess the Southern Antilles, consisting of South Georgia, the Sandwich Islands, and the South Orkneys, forms a direct continuation of the Andes. South Georgia, however, although in the same latitude as Cape Horn, is much more desolate in appearance. The

South Orkneys and the South Shetlands already are polar islands almost completely covered by ice and snow. As for Graham Land and the lands that continue it towards the south, Adelaide Island, Fallières Land, Alexander I Land, and Charcot Land, a conception of their general aspect can be gained if one envisages what would happen to any mountainous country bordering the sea with steep-sloped mountains of 2000 to 3000 meters elevation were it covered by a sheet of ice several tens of meters thick. Toward the south glaciation is still more intense, and all relief is drowned under an immense ice cap from which project only the steep summits of individual peaks. The underlying rock appears only in places where the walls are too steep for snow to hold.

Atmospheric Pressure

In the following general summary of the meteorology of the American quadrant of the Antarctic we will consider only the three principal elements of climate, viz. atmospheric pressure, temperature, and wind movement.

MEAN ATMOSPHERIC PRESSURE

The mean values of atmospheric pressure decrease rapidly with increasing latitude. In Argentina in latitude 40° S. the mean atmospheric pressure reduced to sea level is 760 millimeters; in latitude 45° it is only 757 millimeters; in 50°, 753 millimeters; in 55°, 748 millimeters. The mean value of atmospheric pressure at Punta Arenas in latitude 53° 10′ S., as deduced from a long series of observations, is 751.3 millimeters. Over Tierra del Fuego as over Patagonia the mean isobars follow the direction of the parallels.

But as one proceeds eastward into the Atlantic the isobars curve slightly toward the north. Thus the mean atmospheric pressure in South Georgia, situated in latitude 54° 20′, is 746.7 millimeters, or 4.6 millimeters lower than the mean at Punta Arenas. If only the years are considered during which simultaneous records were made at both stations, the difference between Punta Arenas and South Georgia becomes 5 millimeters. The mean barometric pressure is practically the same at the Falkland Islands in 51° 30′ and at Punta Arenas in 53° 10′.

As we proceed south the pressure decreases. Again taking the value at Punta Arenas as a starting point, we find that the atmospheric pressure in the South Orkneys in latitude 60° 44′ is 7.8 millimeters lower than at Punta Arenas. We thus have seen that between latitudes 50° and 55° pressure diminishes by 5 millimeters, i. e. by one millimeter per degree of latitude. This rate of decrease continues to latitude 60°.

Between the South Orkneys and Snow Hill, whose latitude is 64° 22′, the difference in pressure is 0.7 millimeter. The decrease in pressure thus becomes less rapid south of the South Orkneys, inasmuch as here there is one millimeter change for every 3° of latitude.

The observations at the two adjoining islands, Wandel and Petermann, differ much from one another, although they were made almost at the same place. The mean of the two years' observations gives a difference of 2.4 millimeters between the South Orkneys and these stations in a difference of latitude of 4° 20′.

South of Petermann Island there have been no fixed stations. The only long-series observations are those of the *Belgica* to the west in Bellingshausen Sea and those of the *Deutschland* to the east in Weddell Sea.

The difference between the observations of the *Belgica*, in an average latitude of 70° 35′, and Punta Arenas was −9.2 millimeters in a latitude difference of 17°. Between the South Orkneys and the *Belgica* the difference in pressure would therefore be only 1.4 millimeters for about 10° difference in latitude. The pressure would be about 1 millimeter higher in latitude 70° in Bellingshausen Sea than at Petermann Island in latitude 65°.

The observations of the *Deutschland* expedition grouped according to belts of latitude give the following differences with the atmospheric pressure at the South Orkneys:

60°–65°	−2.8 millimeters
65°–70°	−3.9 "
70°–75°	−2.8 "
S. of 75°	+3.0 " *

* Two months of observation in summer.

These results do not clearly prove that pressure increases with increasing nearness to the south pole, in other words that there exists an Antarctic anticyclone, but they prove in any case—in so far as one may draw conclusions from a relatively restricted number of observations—that the atmospheric pressure which decreases about 1 millimeter per degree of latitude down to the 60th parallel decreases much more slowly farther south and probably increases beyond the 70th parallel.

ANNUAL VARIATION OF ATMOSPHERIC PRESSURE

The annual march of atmospheric pressure over the southern part of South America differs according to the elevation and the latitude of the observing station.

In latitude 35° (Buenos Aires) the annual curve shows a minimum in December-January (summer) and a maximum in June-July (winter). The mean annual amplitude is 7 millimeters.

In the high-altitude stations of the Andes the annual variation is reversed: the summer pressure is greater by 2 to 3 millimeters than the winter pressure.

As one approaches the southern tip of South America the annual variation of atmospheric pressure becomes less regular. At Punta Arenas and in Tierra del Fuego the pressure is 3 to 4 millimeters greater in winter than in summer. At the Falkland Islands the variation is in the same sense, but its amplitude does not exceed 2 millimeters. The same annual variation obtains also at South Georgia and the South Orkneys. Elsewhere in the Antarctic the series of observations are too short to allow of any definite deductions. Certain observations, like those made at Petermann Island, indicate greater pressure in summer than in winter, and the march of their annual variation is similar to that of high-altitude stations.

DIURNAL VARIATION OF ATMOSPHERIC PRESSURE

Diurnal variation of atmospheric pressure depends on latitude, altitude, and to a less degree on the moisture content of the air. Broadly, the principal maximum of the day takes place at 9 A. M. and the principal minimum between 3 and 5 P. M. A secondary maximum occurs between 10 P. M. and midnight, and a secondary minimum between 3 and 5 A. M.

This general habitus is illustrated in the subtropical region of South America. There days are very rare on which the barometric curve fails to indicate the diurnal variation, and in the majority of cases the maxima and minima are so marked and regular that the trace of the curve can serve as an indicator of time.

As one goes southward in latitude the amplitude of the daily variation decreases, as illustrated in the following table:

Stations	Latitude	Amplitude of Diurnal Variation
Asunción (Paraguay) . . .	25°	2.4 mm.
Córdoba	31°	2.3 mm.
Buenos Aires	35°	1.6 mm.
Patagones	41°	1.4 mm.
Ushuaia	55°	0.7 mm.
South Orkneys	61°	0.4 mm.

In high latitudes the daily variation of barometric pressure is no longer regular; in order to make it evident it is necessary to take the mean of a number of years' observation.

Also, the principal maximum takes place in the afternoon instead of in the morning. The morning maximum is often hardly noticeable, and the mean daily variation thus becomes a single-period curve with a maximum in the afternoon. The short series of observations at Wandel Island, at Petermann Island, and at Snow Hill Island yielded analogous daily variations.

It is interesting to note that the curves thus obtained resemble those resulting from the observations of stations in intermediate altitudes in the temperate zone (Berne, for example).

In the Antarctic the influence of cloudiness on diurnal atmospheric pressure is very clearly evident. In the South Orkneys and at Snow Hill, when the sky was clear, the barometric curve was very regular and comprised a single period having a maximum at about noon and a minimum at about midnight. The amplitude was 1 millimeter at the South Orkneys and 0.7 millimeter at Snow Hill.

When the sky was covered the curve was reversed: the maximum occurred at midnight and the minimum at noon. The total amplitude was 0.5 millimeter.

CASUAL VARIATIONS OF ATMOSPHERIC PRESSURE

With increasing latitude the casual variations of the pressure become more frequent and stronger. The monthly amplitude, i. e. the difference between the greatest and the smallest figure for pressure in a given month, affords a good criterion of these accidental variations. This monthly amplitude is as follows:

Stations	Latitude	Monthly Amplitude
Buenos Aires	35°	18 mm.
Bahía Blanca	39°	21 mm.
Santa Cruz	50°	31 mm.
Punta Arenas	53°	30 mm.
Staten Island	54°	32 mm.
South Orkneys	61°	38 mm.
Wandel Island	65°	32 mm.
Snow Hill Island	64°	36 mm.
Petermann Island	65°	34 mm.
Belgica	70°	35 mm.

At Buenos Aires the barometer rarely goes below 740 millimeters. At Tierra del Fuego it often goes down to 720 millimeters. In the Antarctic pressures less than 710 millimeters are observed every year. On the first of April, 1912, at the South Orkneys the pressure at sea level fell to 698.2 millimeters.

Temperature of the Air

A mean isothermal map of South America shows that between latitudes 22° and 56° the temperature ranges between +24° and +5° C., i. e. decreases by 19° for an increase of latitude of 34°.

The mean value of the temperature at the Falkland Islands is nearly a degree less than the temperature at stations situated in the same latitude on the continent. This lowering of the temperature is due to a cold current coming from the Antarctic which continues into this latitude, the northward-flowing current from Weddell Sea, whose existence has been proved by the drift of the *Deutschland* and the *Endurance* better than by any oceanographical reasoning.

Similarly South Georgia, although on the same parallel, has a lower temperature than Tierra del Fuego by 3° to 4°. There the influence of this Antarctic current is still more evident. South Georgia is a truly polar land, surrounded by ice for several months a year.

If we pass on to stations of strictly Antarctic character we get the following mean annual values:

Stations	Latitude	Mean Annual Temperature
South Orkneys	60.7°	− 4.8°C.
Snow Hill Island	64.2°	−11.8°
Wandel Island	65.0°	− 5.4°
Petermann Island	65.2°	− 2.8°
Belgica	70.6°	− 9.6°

Temperature, then, does not decrease regularly according to latitude. The position of each station with relation to the neighboring ocean is of considerable importance and, in a large measure, modifies the temperature mean. The observations in 1909 at Petermann Island, which is almost completely surrounded by water, and in 1903–1904 at Snow Hill, which is continually surrounded by ice, show this clearly.

The wind regimen must also have some bearing. The stations on the western coast of Graham Land, where north winds are frequent, enjoy milder temperatures than the Weddell Sea stations, where as a rule south winds prevail.

The temperature variations differ so much from year to year that in order to obtain a more exact idea of mean temperatures it is necessary to select for comparison stations where the observations were simultaneous. From this comparison, taking Punta Arenas as a base, there result the following deductions:

(1) Punta Arenas compared with the neighboring coast stations exhibits a clearly continental character (higher temperatures in summer, lower temperatures in winter). At the Falkland Islands the temperature in summer is 2° or 3° less than the temperature at Punta Arenas, and in winter 1° to 2° more.

(2) At South Georgia, which is all the year round subjected to the influence of the polar current, the temperature is always colder than at Punta Arenas, by 4° in summer and by 2° to 3° in winter.

(3) As regards the Antarctic stations the differences from Punta Arenas are much greater in winter than in summer. These stations thus exhibit a much more pronounced continental character than Punta Arenas.

(4) In summer the differences among the various Antarctic stations are slight, the mean temperature ranging between –2° to 1°. But in winter the differences are much greater. The condition of the ice and the wind régime, different at each station, are the reasons for these variations. From one year to another for the same reasons the summer temperatures do not differ much, whereas the winter temperatures may vary as much as 10° or more.

As a first approximation the following mean summer and winter temperatures may be assumed:

Stations	Summer	Winter
Punta Arenas	11°C.	2°C.
Falkland Islands	9.5°	3.5°
South Georgia	6°	–1°
South Orkneys	1°	–9.5°
Deception Island (So. Shetlands)	2°	–9.5°
Paulet Island	0°	–14°
Snow Hill Island	–2°	–18°
Wandel-Petermann Islands . .	1°	– 8°
Belgica (latitude 70½°)	–1°	–20°
Deutschland	–3° (latitude 72°)	–27° (latitude 70°)

DIURNAL VARIATION OF TEMPERATURE

Theoretically the amplitude of the diurnal variation of the temperature, zero at the south pole, should increase regularly to the equator. This amplitude, which amounts to 8° at Buenos Aires, is only 2° at Staten Island and 1° to 2° at the Antarctic stations.

The study of the diurnal variations of temperature during the winter days in the Antarctic, when the sun is constantly below the horizon, is of special interest. Even if only clear days be taken into account in order to eliminate as much as possible the causes of corollary variations, a rise in temperature is observed during the hours which correspond to night. It is hard to offer a satisfactory explanation of this rise, whose amplitude may be as much as 2°.

The diurnal variation of the temperature obtained by taking the means of 24 observations a day gives only a rather inaccurate picture of the variation of the temperature during the course of the day. One would have a very incorrect idea of the climate of the Antarctic if one supposed that the temperature in winter does not vary more than 1°

every day. The difference between the maximum and minimum of each day, which is sometimes called the diurnal amplitude and should not be confused with the amplitude of the diurnal variations, attains a mean value of 7° to 8° at the stations in the American quadrant of the Antarctic. At Snow Hill there was observed an amplitude of 33.9° one day in July, and in two years 16 days were counted on which the daily amplitude was more than 20°. At the South Orkneys the highest observed daily amplitude was 27°, and amplitudes greater than 20° are observed every year. At Petermann Island the greatest daily amplitude was 18.6° in July, and only nine times did the amplitude exceed 15°.

In the Antarctic, temperature changes of more than 20° in an hour are occasionally observed; for example at Snow Hill on May 8, 1903, the thermometer fell from −0.8° to −21.5° between 6:45 and 7:45 P. M.

VARIABILITY OF THE TEMPERATURE

Another datum which serves as a criterion for an evaluation of the climate is the variability of the temperature, i. e. the difference between the mean temperatures of two successive days. Temperature variability is less at maritime stations than at continental stations. It varies inversely with the moisture of the air. An important factor to consider is the position of the station with regard to the pathways of atmospheric lows, as the variability depends in a large measure on changes in the wind direction.

The mean variability of temperature is as follows in the American quadrant of the Antarctic:

Stations	Mean Variability of Temperature
Ushuaia	1.9°C.
Orange Bay	1.7°
Falkland Islands	1.2°
South Georgia	2.1°
South Orkneys	3.0°
Snow Hill	3.1°
Belgica	3.3°

Whereas the maximum variability at the Falkland Islands is 6°, it is 12° at South Georgia, 19° at the South Orkneys, 22° at Snow Hill, 15° at Wandel Island, 14° at Petermann Island, and 21° in the region where the drift of the *Belgica* took place.

In comparison it may be said that at Verkhoyansk in Siberia, the continental-climate station *par excellence*, the mean variability is 4.8°, with a maximum of 29°.

EXTREME TEMPERATURES

The minimum temperature may be as low as −20° in Tierra del Fuego.

At the South Orkneys and at the Weddell Sea stations minima of −41° have been attained.

On the western coast of Graham Land the temperatures are not so low. The minimum at Wandel Island is −34°, and at Petermann Island in 1909 the thermometer did not go below −23.9°, which is remarkable for a polar station.

The minimum of the *Belgica* was −43.1°.

All these temperatures are not extraordinarily low—in the Arctic as well as in the Antarctic temperatures of −60° have been observed. The open sea, which is never far away in the American quadrant of the Antarctic, exercises a noticeable tempering influence on the climate of the region.

The Wind

DIRECTION OF THE WIND

In general, although it is always rather arbitrary to try to summarize the character of the winds in regions where they are so changeable, it may be said that the stations at Tierra del Fuego, the Falkland Islands, and South Georgia are included in the general westward wind drift.

In the Antarctic proper the winds differ from one station to another: at the South Orkneys the predominating winds blow from the west; at Snow Hill from the southwest; at Wandel and Petermann Islands from the northeast; in the region traversed by the *Belgica* on her drift, from easterly directions in summer and westerly in winter; in the region where the *Deutschland* drifted, from south and southeast in latitudes lower than 70° and rather definitely from the east in summer in latitudes higher than 70°.

As is well known, mean isobars run very nearly parallel to the mean direction of the wind. The direction of the winds along the drift routes of the *Belgica* and the *Deutschland* in the summer show that there are two areas of relatively low pressure over Weddell Sea and Bellingshausen Sea respectively and that the Antarctic anticyclone is met with in about latitude 70°, as is indicated directly by the observations of atmospheric pressure themselves. But in winter the distribution of pressure seems more complex. In Weddell Sea, as far as latitude 69°, there is no evidence that pressure increases with latitude. The observed winds on the contrary show that the low pressures are always situated to the south, producing southwest winds at Snow Hill, west-southwest at the South Orkneys, northwest at South Georgia, and southeast on board the *Deutschland* in latitude 69°.

Over Bellingshausen Sea the direction of the winds from the west in winter on board the *Belgica* seems also to indicate higher pressure to the north of the 70th parallel than to the south.

WIND VELOCITY

In the vicinity of Tierra del Fuego the velocity of the wind is greater in summer than in winter. At Orange Bay, near Cape Horn, the mean annual velocity is 6.6 meters per second, 7.8 meters in summer, 6.0 meters in winter.

In summer on the average the wind attains a velocity of 15 meters per second every day. Every month of summer has a mean of 50 hours of strong gales (velocity greater than 18 meters per second), whereas there are 23 hours of such winds every month in the winter. Of each 100 strong gales 47 blow from the west and 44 from the southwest. These strong gales occur during a rise in the barometer. During the fall preceding the rise there are only changeable winds of varying strength, accompanied by rain; a west and southwest gale sets in as soon as the barometer has begun to climb again. This special circumstance is certainly due to topographic conditions, Orange Bay being situated east of Tierra del Fuego and protected from the north and northwest winds which should occur on the arrival of a low-pressure area.

The lows almost always pass by to the south of Cape Horn. They succeed each other without interruption, and the barometric curve is nothing but a series of more or less long and more or less deep fluctuations. The annual variation of gale frequency shows that the depressions pass near Cape Horn more frequently in summer than in winter.

At the Falkland Islands and South Georgia southwest and west gales also predominate but not as exclusively as at Orange Bay. Gales from the north and northwest are rather frequent.

At the South Orkneys the mean velocity of the wind is considerably less in summer than during other seasons, but the greatest mean velocity is observed in spring and autumn. Gales are a little less frequent than at Cape Horn. In April and September 50 hours of winds whose velocities are greater than 18 meters per second were observed, whereas during each month of summer only 12 hours of such winds were observed. Northwest and southeast winds between them include practically all of these strong gales. Generally the barometer falls with winds from the northwest and rises with winds from the southeast.

At Snow Hill, on the east coast of Graham Land, summer is also the season when the velocity of the wind is least. The gales blow almost exclusively from the southwest with a rising barometer. During the fall of the barometer the winds are relatively weak and from the northeast. The storm of longest duration during two years of observation lasted no less than 164 hours, with 77 hours of winds of greater velocity than 21 meters per second.

At Wandel and at Petermann Islands, on the western coast of Graham Land, the velocity of the wind, as at the South Orkneys and at Snow Hill, is less in summer than in winter, contrary to the case in Tierra del Fuego. The greatest monthly mean, 8.2 meters per second, is much lower than the highest monthly mean at Snow Hill, which was 13.65 meters, but it is of the same degree as at the South Orkneys. The maximum velocity observed in 1909 at Petermann Island was 33 meters per second, whereas during the same year the wind at the South Orkneys did not exceed 23.50 meters. At Petermann Island 19 hours out of 100 hours were characterized by winds of greater velocity than 18 meters per second, whereas at Snow Hill there were only 12 such hours out of 100.

The gales at Petermann Island all come from the northeast, with a falling barometer. The difference between the gales at Snow Hill, all from the southwest with a rising barometer, and those at Petermann Island, all from the northeast with a falling barometer, although the two stations are very close to each other, is evidently due to the steep pressure ridge that separates them. This difference in direction of the high winds has very important consequences for the climate of the two stations: at Petermann Island the gales, which there come from the north, raise the temperature, whereas at Snow Hill, where they come from the south, they lower it. It is a well-known fact that low temperatures are all the harder to support when the wind is high.

TRAJECTORY OF THE DEPRESSIONS

If the mean monthly values of atmospheric pressure at Punta Arenas and in the Antarctic are compared it will be seen that for certain sequences of months these curves resemble each other, whereas for other months they are reversed. It therefore seems that at times Tierra del Fuego and the Antarctic are under the influence of the same center of atmospheric action and at times under the influence of different centers having a seesaw movement in the opposite sense. Although the climate of Patagonia is entirely different from that of the American quadrant of the Antarctic the climates of these two regions are seen to be often only the different manifestations of the same cause, provided that one accepts barometrical variations as the determining causes of meteorological phenomena.

An examination of the hourly values of the pressure shows that in a general way the barometric variations transplant themselves from west to east and that they take from 24 to 48 hours to go from the 65th to the 35th degree of west longitude.

As for the depressions themselves, the rather sketchy pressure maps that it is possible to construct with the small number of simultaneous observations available show that they are generally closed depressions and that they follow a trajectory broadly moving from west to east between Tierra del Fuego and the South Shetland Islands. Sometimes they pass to the north, sometimes to the south of the South Orkneys. When, on coming from Bellingshausen Sea, they strike against the high mountains of Graham Land, they seem to stop and sometimes to turn on their tracks as if to look for a direct passage. This they finally find either to the north through Drake Strait or perhaps to the south through some still unknown lowland or other depression in that region.

These trajectories of the atmospheric cyclones, in the Antarctic as in the temperate regions, are very complex and doubtless often describe pronounced curves or even loops, influenced as they are by the always changing distribution of ice cover and open sea.

Mr. PRIESTLEY, now on the faculty of Cambridge University, was a member of the scientific staff of the British Antarctic Expeditions under Shackleton (1907–1909) and Scott (1910–1913), serving as geologist. As a result of the investigations made on these expeditions he has published, in collaboration with C. S. Wright, the report on "Glaciology" in the scientific results of the British Antarctic Expedition of 1910–1913, London, 1922, now the most authoritative treatment in English of the subjects with which it deals. He has also published a general narrative, "Antarctic Adventure: Scott's Northern Party," London, 1914; "Physiography of the Robertson Bay and Terra Nova Bay Regions" (British Antarctic Expedition, 1910–1913, Reports, London, 1923); and a "Syllabus of a Course of Lectures on the History and Science of Polar Exploration," Cambridge University. With Sir T. W. Edgeworth David he prepared the report on "Glaciology, Physiography, Stratigraphy, and Tectonic Geology of South Victoria Land" (British Antarctic Expedition, 1907–1909: Reports of the Scientific Investigations: Geology, Vol. 1, London, 1914) in which the chapters "Physiographic Introduction" and "Notes on the General Geological Relations of Antarctica to Other Parts of the World" are of special geographical interest.

Dr. TILLEY, demonstrator in petrology at Cambridge University, formerly held a similar position in geology and mineralogy at the University of Sydney. He has published a number of papers on the petrology and geology of South Australia and has contributed "The Metamorphic Limestones of Commonwealth Bay, Adélie Land" to the scientific reports of the Australasian Antarctic Expedition, 1911–14 (Series A, Vol. 3: Geology, Part II, Sydney, 1923.)

GEOLOGICAL PROBLEMS OF ANTARCTICA

R. E. Priestley and C. E. Tilley

Present Status of Geological Knowledge of Antarctica

Isolated from the other great land masses of the globe, the Antarctic Continent is almost completely encompassed by a broad girdle of deep ocean. Considered as a single unit, it is estimated to possess an area of roughly 5,000,000 square miles, of which the greater part is a plateau covered by ice of great thickness. Of its coast line, only that portion comprised within the Australian Quadrant[1] and a small arc of the American Quadrant can be said to be moderately well known. The coasts of the African and Pacific Quadrants are almost completely unknown. Of the interior, beyond the field of view opened up by the traverses to the south magnetic pole and a western traverse from McMurdo Sound by Scott in 1903, only the region in the immediate vicinity of the converging lines of the Shackleton, Scott, and Amundsen routes to the pole has been under direct observation.

Unusual Depth of Antarctic Continental Shelf

The available bathymetrical surveys of the waters fringing the ice barrier indicate that Antarctica is singular among the continents in the depth of its continental shelf, which is approximately 200 fathoms below sea level. This can be well illustrated by the following soundings taken by various expeditions.

	Sounding on Shelf (fathoms)	Sounding in Deep Water (fathoms)	Distance Apart in Sea Miles	Slope
Belgica	279	1476	25	1 in 21
Gauss	209	1267	18	1 in 17
Scotia	159	1950	45	1 in 25
Deutschland . .	305	820	18	1 in 35
Endurance . . .	185	1146	Not comparable because oblique	

It is possible, as Nordenskjöld and others have pointed out, that the chief factor in determining this abnormal submergence of the

[1] Antarctica may be conveniently considered as divided into four quadrants commencing from the meridian of Greenwich, each quadrant being named after the lands or sea to the north; thus: the African Quadrant, the Australian Quadrant, the Pacific Quadrant, and the American Quadrant.

Antarctic continental shelf is the existence upon the land of a great sheet of continental ice, but, as will be indicated later in this paper, in Weddell Sea there is evidence that faulting also has probably played its part.

Paucity of Rock Exposures for Geological Evidence

The great central plateau (8000–11,000 feet) is covered with ice to an unknown depth and is known to descend more or less gradually to low levels in the Adélie Land sector of the continent. It is perhaps a reasonable assumption that similar conditions hold for the rest of the western portion of the Australian Quadrant and the quadrant facing Africa. Only a very small proportion of the land surface is exposed to view. Where the glaciers have cut deep troughs through the coastal ranges or horst, steep rock cliffs, often several thousands of feet in height, stand on either side with their feet buried in mighty screes of débris lying at or about the angle of repose. The peaks of the higher mountain ridges project above the sheets of continental ice, or highland ice, and often have steep slopes on which snow and ice can obtain no hold. Here and there along the coast line comparatively new areas of dark volcanic rock are kept clear by the combined action of insolation and the blizzard winds. All these are, however, exceptions almost negligible as regards extent, though of supreme importance to the geologist and the explorer. Geological data are fortunately, however, not limited to the evidence acquired from the scant areas thus laid bare to direct observation. Much priceless information has been gleaned from transported morainic débris drawn from wide areas, to appear in time at the surface of ice sheet or glacier.

As in the past, so in the future, the evidence which, when pieced together, provides the solution of many of the geological problems of Antarctica must inevitably be in large measure won from erratic material of this kind.

Australian Quadrant

Of the quadrants, that facing Australia is by far the best known, both geographically and geologically. This sector of the continent is bounded on the east by Ross Sea and extends westward to Queen Mary Land. A belt of mountainous country forms the western rim of Ross Sea and extends from Cape Adare to the southeastern limit of the quadrant (in 85° S.) where the chain is continued in the Queen Maud Range. The mountains rise abruptly from the sheet of shelf ice known as the Ross Barrier, or from the sea, to heights ranging from 8000 to 15,000 feet and thus form a containing buttress to the vast snow plateau of the hinterland. The eastern edge of this range is situated on a meridional zone of stupendous fractures with a displacement probably amounting to not less than 5000–6000 feet. The ice of the hinterland is discharged to Ross Sea through a comparatively small number of mighty glacier channels—ranging from 5 to 15 miles in width and up to 100 miles in length—which breach the ranges at intervals of many miles.

This broad stretch from 50 to 100 miles wide, extending probably for nearly 1000 miles in this quadrant and bounded on the east by Ross Sea, has been appropriately named the Antarctic horst of South Victoria Land. Whether the western rim where it descends to the snow plateau is a zone of meridional fracture is still uncertain. The occurrence of down-faulted blocks measuring many miles from north to south along its eastern border has been inferred from the physiography, while the presence of inclusions both of Beacon sandstone and of quartz dolerite in a parasitic cone on Ross Island suggests that Ross Sea itself is underlain by the same formation. As these rocks in the main horst in this latitude lie several thousand feet above sea level, faulting on a very large scale with tremendous throw is implied. The horst fractures are indicated by a volcanic zone extending from Cape Adare at least to the region of 78° S., where the active volcano Mt. Erebus (13,300 ft.) forms the dominating feature of a cluster of mountains which rise from the sea in front of the range.

The explorations of the Mawson expedition have yielded much information as to the nature of the outer arc of the Australian Quadrant west of South Victoria Land. The region along the Antarctic Circle westward to 90° E. is now shown to be continuous land and forms King George V Land, Adélie Land, Wilkes Land,[2] and Queen Mary Land.

Adélie Land takes shape as a huge ice-covered plateau rising rather steeply from the coast and reaching a height of 6000 feet at a distance of 300 miles inland. The nature of the basement rocks of this portion of the quadrant shows that the region is geologically similar to South Victoria Land, both forming integral parts of a single tectonic unit.

Owing to the work of numerous British expeditions, the geology of the Australian Quadrant can now be said to be moderately well known. This geological structure is summarized in the synoptic statement which follows.

Lower pre-Cambrian

Paragneisses, schists, crystalline limestones, calc-silicate rocks.
Orthogneisses, granite gneisses, charnockites, amphibolites.

Upper pre-Cambrian (or Lower Paleozoic)

Slate-graywacke formation of Robertson Bay.
Younger granites, sphene-bearing diorites, lamprophyres, porphyries, etc.

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[2] See (editorial) footnote 3 to Sir Douglas Mawson's paper above.—Edit. Note.

Cambrian

Limestone fragments in breccia of Beardmore Glacier with *Archaeocyathus*, *Protopharetra*, and *Epiphyton*.

Devonian

Shales (? estuarine) of Granite Harbour containing fish plates and probably forming the base of the Beacon sandstone.

Permo-Carboniferous to Rhetic

Beacon sandstone (5000 feet) with wood fragments, coal seams, *Glossopteris indica*, *Rhexoxylon priestleyi*, *Vertebraria*, etc.

? Upper Jurassic or Cretaceous

Quartz dolerites in sills (and dikes), intruding younger granites, and Beacon sandstone. Thickness up to 2000 feet.

Late Tertiary

Palagonite tuffs, limburgites, kenytes, trachytes, phonolites, etc., Mt. Erebus, Mt. Discovery, Mt. Melbourne, Possession Island, Cape Adare, etc.

Recent

Low-level and high-level moraines, raised beaches, kenyte lavas of Erebus.

The structure of the horst region of South Victoria Land is revealed in a basement of the pre-Cambrian complex, surmounted by a great thickness of horizontal or slightly inclined Beacon sandstones, intruded by thick sills of quartz dolerite.

Uncertainty about the chronological position of the Robertson Bay slate-graywacke series and the younger granites still exists. The former series are shown by Priestley to be folded along northeast-southwest axes, with more intense folding towards the east. The younger granites have been seen only in relation to the older pre-Cambrian rocks and, for all evidence to the contrary, may themselves be of pre-Cambrian age. Cambrian rocks are known only through the evidence of *Archaeocyathus* limestone forming portion of a limestone breccia found as erratics on Beardmore Glacier. The location of the source of the Cambrian limestone, its structural character, and its relations to the granites of the Beardmore Glacier mountains will shed new and important light on the hiatus now existing in the stratigraphy and tectonics of Lower Paleozoic time in this quarter.

The fundamental rocks of Adélie Land and Queen Mary Land are metamorphic sediments and igneous gneisses found both *in situ* on the coastal nunataks and islets and profusely in moraines. The wide extent of the Beacon sandstone and of the quartz dolerite sills which intrude it is clearly indicated by their discovery in King George V Land. In the vicinity of Horn Bluff (150° E.) a sweep of coast line bounded by rocky cliffs 1000 feet high is built up of red sandstones containing coal and carbonaceous shales. These outcrop at a height of several hundred feet and are capped by an immense thickness of dolerite sills. In the moraines of Adélie Land (at Mawson's winter quarters) the abundance of red sandstones is indicative of the fact that the Beacon sandstone formation extends through Adélie Land but is now hidden by the ice cap. Thus, this great formation of horizontally bedded sediments, apparently lying mainly upon a peneplain of pre-Cambrian metamorphic rocks and the granite which has intruded them, may extend throughout the whole extent of the Australian sector, at least so far as the periphery of the continent is concerned.

African Quadrant

The African Quadrant is bounded on the east by Kaiser Wilhelm II Land and is almost wholly unknown. The only investigated solid rock outcrops are those of the Gaussberg, a rocky eminence rising 1148 feet above the sea in latitude 67° S., at the eastern end of the quadrant. This extinct volcano is built of leucite basalt containing fragments of pyroxene-bearing gneiss as well as cognate xenoliths carrying picotite, olivine, bronzite, and augite. The nature of the basement rock of the region is, however, indicated by morainic rocks. These, according to Reinisch, include both metamorphosed sediments, paragneisses carrying garnet, sillimanite or cordierite, and igneous gneisses and microcline granites. In addition, metamorphic amphibolites, quartzites, crystalline limestones, and sandstones are known. These assemblages closely correspond with those known from the Australian Quadrant to occur farther east, and it is at least probable that, tectonically speaking, the two quadrants form one unit. Of the remaining region of the quadrant the only known data are provided by the discoveries of the whaling captains of the firm of Enderby Brothers. Enderby Land was discovered by Biscoe in 1831, the promontory of Cape Ann being sighted when he was in longitude 49° 18′ E. Two years later Kemp reported the discovery of land approximately 10° east of Enderby Land, in 66° S. and 60° E.

The *Valdivia* expedition dredging off Enderby Land recovered, at a depth of 4600 meters, an assemblage of rocks which, again, are distinctly reminiscent of the pre-Cambrian basement of Adélie Land. They include paragneisses with garnet, sillimanite, and cordierite; and also igneous and metamorphosed igneous rocks, including biotite, muscovite, and hornblende granites, gabbro, dolerite, and amphibolite. Sediments include sandstones (one large mass of red sandstone weighing 5 cwt.) of similar type to the Beacon sandstone of Adélie Land.

Pacific Quadrant

The western border of this quadrant is formed by Ross Sea, and the only known rock exposures in the outer arc are provided by King Edward VII Land, at the eastern end of Ross Sea. Here, in the Alexandra Mountains (77° S.), which are a low ice-swathed range trending northeast, Prestrud collected from Scott's Nunataks (1700 feet) a series of rocks determined by Schetelig as white granite, granodiorite, hornblende and biotite-quartz diorites and quartz-diorite schists. This assemblage, as Schetelig points out, can be compared with the pre-Cambrian rocks of the horst west of Ross Sea. The interior of the Pacific Quadrant has been traversed by Amundsen on his journey to the pole. The ranges of Carmen Land discovered by him commence at a point 86° S. and 160° W. and trend in an east-to-northeast direction at least as far as 84° S. Though wisely refraining from inserting on the map a range in the region intervening between Carmen Land and the high bare land apparently trending northeast, situate between 81° and 82° S. in 157° W., Amundsen states "what we have seen apparently justifies us in concluding that Carmen Land extends from 86° S. to this position, about 81° 30′ S., and possibly farther to the northeast." The Shiraze Japanese expedition traveling southeast from the Bay of Whales reached at 150 miles an elevation of 1300 feet, and though no rock was visible it was confidently believed that land was present. It is, therefore, likely that the Ross Barrier is bounded along its eastern border by one continuous range extending from Amundsen's point of entry to the plateau to King Edward VII Land and beyond. From the point of view of Antarctic tectonics this is one of the crucial areas and problems and would well repay detailed investigation by the scientific sledge parties of future expeditions.

The great ranges of South Victoria Land extend beyond Beardmore Glacier to 86° S. and 160° W., where they join up with those of Carmen Land to form the Queen Maud Range, which, with heights rising to over 15,000 feet (Mt. Nilsen, 15,500 feet), stretch southeastwards until they disappear below the horizon, as seen from Amundsen's poleward route. Seen from a point in 88° S. and 170° W., this mighty range could be observed to extend southeastward beyond the range of vision of the pole-seekers, and Amundsen concludes that the chain traverses the Antarctic Continent to where, if their trend remains unaltered, they would reach the encircling ocean in the neighborhood of Weddell Sea.

On the ice plateau, beyond the Queen Maud Range, on the route to the pole, Amundsen discovered an ice divide near 87° 40′ S. (in 170° W.), and it is probable that Shackleton reached, and Scott traversed, a continuation of this parting near Shackleton's farthest south in 88° 23′.

Shackleton		
lat. 85° 55′ S.	height of ice plateau	7,865 feet.
lat. 88° 23′ S.	" " " "	10,050 feet.
Amundsen		
lat. 87° 40′ S.	" " " "	11,075 feet.
south pole	" " " "	10,260 feet.

A similar divide was crossed by David, Mawson, and Mackay on the route to the magnetic pole, 180 miles inland from the coast. This, however, is probably a meteorological rather than a geological feature, and will be remarked upon in the next paper.

The splendid achievement of Amundsen in reaching the south pole by a new route pioneered by himself is an outstanding example of the genius for organization and for polar travel possessed by one who is undoubtedly the foremost of the present generation of polar travelers. His contributions to Antarctic science, however, are far less complete. One most serious shortcoming of the great journey was his failure to spend easily spared time in making at least a general survey of the geology of that most interesting portion of Antarctica it was his good fortune and privilege to discover and traverse. In spite of having "time to burn"—so much so that the hours of marching were voluntarily restricted and the hours spent in the tent extended until they became burdensome—little attempt to survey the country was made. The only specimens collected were a few pieces of muscovite-biotite granite, granite gneiss, garnet aplite, and mica schist from Mt. Betty (1000 ft.) in 85° 8′ S. From the photographic evidence of Mt. Fridtjof Nansen (15,000 feet) and our knowledge of the structure of the coterminous Beardmore Glacier mountains it is a reasonable conjecture that the summit of this mountain is partly composed of Beacon sandstone, but there is unfortunately no direct evidence of this.

There is no more important object lesson to the geological party of the future than that afforded by the contrast between the geological harvest of the Scott and the Amundsen southern parties. On the one hand we see debilitated men, buffeted by nature in her worst moods, suffering under manifold disabilities due in part to ill fortune, in part to their leader's errors, in part to a mistaken tradition as regards modes of polar transport inherited from their predecessors in the Arctic, destined in the event to leave their bodies as a mute witness at the same time to the greatness of their spirit and the inadequacy of the means they had employed. In a cairn within a few miles of their last resting place their comrades later found a priceless bag of specimens, collected, many of them, after the direness of the emergency must have been realized. By their side lay the notebooks containing the detailed notes, lacking which the specimens would have been deprived of half their value. On the other hand, a few hundred miles away and two months earlier, another party, secure in the attainment of their dominant ideal, safe beyond any reasonable doubt from failure, made a hurried traverse of a region more interesting because less well known, returning to their base unwearied and ahead of scheduled time, bearing with them a few fragments of rock from one or two only of the many rock exposures on whose surfaces their eyes had been the first to rest.

If the geology and the glaciology of the continent is to be elucidated, the example of Scott and his devoted companions must be emulated in the future as it has been paralleled in the past by many parties whose fate has been less tragic. It is in one sense fortunate for Antarctic science that the poles have been removed from the sphere of the unknown and, therefore, to a great extent, from among the major objectives of the explorer of the future.

American Quadrant

Beyond 70° S. in the west and 78° S. in the east, the whole inner portion of this quadrant is unknown.

The Weddell Sea area and Coats Land form the easternmost explored region of the quadrant. From east to west the fringing zone of this land may be referred to as the Bruce, Caird, and Luitpold Coasts. Of the structure of Coats Land there is still no direct evidence. The Filchner expedition has shown that Weddell Sea does not extend south of latitude 78° S., and several nunataks have been sighted (but not visited) by Filchner in 77° 55′ S. and 34° 30′ W. The investigations of the *Endurance* expedition have also shown that Morrell Land (or New South Greenland) does not exist.[3] It would appear that the continental shelf of Coats Land is comparatively narrow, and a large number of soundings taken from the *Endurance* during her forced detention in the pack have thrown a flood of light on the structure and nature of that portion of it which forms the floor of Weddell Sea. The shelf is here shown to consist of a series of stepped terraces (180–190 fathoms, 250–260 fathoms, respectively) having northeast-southwest boundaries, running at right angles apparently to the presumed coast line farther to the southwest, but probably parallel to the known fringe of the Luitpold and Caird Coasts of Coats Land. The most probable explanation of these terraces, as J. M. Wordie has pointed out, is that they are due to faulting. The deep sounded by Ross in 1843 does not enter Weddell Sea.

Though Coats Land is now completely ice-covered (except for the nunataks seen in 78° S.), the mountainous nature of the snow surface beyond the long line of barrier cliffs is certain indication of the presence of land, and, in the far distance, ice-clad mountains rise apparently to great heights.

The geology of the region is partially revealed in the numerous erratic blocks dredged from the Weddell Sea floor. Most commonly these rocks are grits, quartzites, and gray granite, some of the sedi-

[3] It may be stated in this connection that it has been pointed out (A. W. Greely: Handbook of Polar Discoveries, 5th edit., New York, 1910, p. 306, and J. M. Wordie, *Geogr. Journ.*, Vol. 51, 1918, pp. 227–228) that Morrell may have skirted the eastern coast of Graham Land and that the non-existent positions he gives of his landfalls may have been due to incorrect longitudes (his latitudes are substantially correct).—Edit. Note.

ments recalling the Beacon sandstone formation. In 76° 27′ S. and 38° 43′ W. a red grit boulder of over 70 pounds was recovered as well as fossiliferous limestone, but unfortunately these specimens were lost with the *Endurance* later in the expedition. Other rocks collected were dolerite, hornblende granite, shale, and metamorphic rocks, including garnetiferous gneiss and mica schist. Owing to the clockwise motion of the Weddell Sea ice, there is good reason to believe that the transported material had its source to the east. An important find was the recovery of a fragment of *Archaeocyathus* limestone by the *Scotia* expedition in 62° 10′ S. and 41° 20′ W., at a depth of 1775 fathoms.

The Graham Land sector of the American Quadrant is better known. Morphologically Graham Land stands as a mirror image of Patagonia across the deep water of Drake Strait. The festoon of islands of western Patagonia is reflected in the island archipelago of its western border. This symmetry is furthermore revealed in geological architecture, for the geological structure of Patagonia is repeated in the Graham Land peninsula. The region forms an ice-covered highland with eminences rising to a height of 6000–8000 feet. Of this highland the western zone consists for the most part of great plutonic intrusions, the outer rim partly submerged in an archipelago with recent volcanic outpourings, while the eastern tract is capped by horizontal Cretaceous and Tertiary strata covered by basic volcanic rocks. On the northwest coast the highest latitude reached by Charcot was 70° 30′ S., and the land (Charcot Land) was seen to continue to the southwest of Alexander I Land. The western zone of Graham Land and its outlying archipelago is believed to consist largely of a calc-alkaline series of granodiorites, adamellites, diorites, gabbros, and serpentine. A folded series of mudstones, slates, andesites, and porphyry breccias, tentatively referred to the Mesozoic (? Jurassic), is intruded by quartz diorites and gabbro. Probably an older basement series is seen in a group of metamorphosed sediments and gneisses not yet clearly differentiated. According to Nordenskjöld, the plutonic series forming the dominant rocks of the region shows marked chemical and petrographical similarity to the plutonic massifs of the South American Cordillera.

At Hope Bay at the extreme northeastern end of Graham Land Jurassic graywackes and plant-bearing shales with a rich flora, including *Otozamites*, *Thinnfeldia*, *Sphenopteris*, etc., and covered by porphyry and porphyry tuffs, are folded and metamorphosed. They occur in close proximity to the plutonic rocks, but the conglomerates of the Jurassic series are free from pebbles of these intrusions. It is probable, though not actually proved, that, like the Patagonian plutonic series, the granite-gabbro series is of post-Jurassic age. The Tertiary lavas on either side of the Graham Land ridge at James

Ross Island, Paulet Island, and the Robben (Seal) Nunataks on the east, and King George Island, Deception Island, etc., on the west, are essentially calc-alkaline. They comprise olivine basalts and glassy pyroxene andesites.

While there is much that is still obscure in the geology of Graham Land—the interior is still practically unknown—there is every reason to believe that the peninsula forms tectonically and petrographically a continuation of the Andean chain of Patagonia. The ridge has been appropriately referred to by Arctowski as the Antarctandes.

With the paleontological aspect of these rocks there is no space in the present paper to deal. Something on this subject will be said in the next paper, under the heading of glaciological and paleoclimatological problems. In Graham Land, however, occur the most interesting Antarctic geological floras and faunas yet discovered, with the possible exception of the *Glossopteris* flora of the Beardmore Glacier region. Much material has been brought back by expeditions fortunate enough to make their headquarters in close proximity to fossiliferous sediments, but much remains to be done. From this point of view there are few regions of the continent likely to repay detailed investigation to the same extent as certain known areas of the American sector. Detailed work at permanent or semi-permanent winter quarters would go hand in hand well with the extended meteorological observations which are necessary if climatological generalizations, fit to be applied to weather forecasting or the elucidation of meteorological problems of major importance, are to be made possible.

Antarctic Geological Problems To Be Solved

Such is a bare outline of Antarctic geology as at present known, and, at best, our present knowledge of the continent is not sufficient to provide more than the barest outline of its geological and paleontological history and the barest hint of its geological constitution.

The problem of the future is the filling in of these outlines and the verification or the shattering of the hypotheses which have been built upon the slender evidence provided by the expeditions whose chief objectives have been the poles and whose activities have been restricted in large measure by that fact.

Relation of the Two Structural Areas of the Continent

First of all, the geologist is faced with the question: "Am I dealing with one continent or with two? Do the Antarctandes of Graham Land stretch across the continent to South Victoria Land? Alternatively, is the Ross Barrier continued across Antarctica as a great ice strait?" The balance of evidence summarized in the preceding pages suggests to the present writers that neither is the case. The apparent occurrence of fault blocks upon the floor of Weddell Sea, the finding of Archaeocyathidae limestones as erratic blocks still farther north in the same sector, the trend of the mountains seen by Amundsen, the extension of the Beacon sandstone to King George V Land, the occurrence of similar sandstone erratics in the seas off Kemp and Enderby Lands—all suggest that the major portion of the continent is one tectonic unit forming a great shield against which the Antarctandes of Graham Land are folded as a continuation of the long South American and sub-Antarctic ridge. Graham Land south of 68° S. latitude is geologically a *terra incognita*. Does the Andean chain die out against the Antarctic shield or are the trend lines swung westward towards the Pacific?

It would seem that one of these alternatives is the solution to this problem of the Antarctandes, and to that end the investigation of southern Graham Land and the land sighted by Charcot in the region west of Alexander I Land would do much to clear present obscurity. That the Antarctandes link up across the continent with the Queen Maud Range (and South Victoria Land), as has frequently been suggested, seems geologically improbable. We have noted above that the trend of the Queen Maud Range as last seen by Amundsen from 88° S., if projected, would strike the Weddell Sea area.

Field Work in Critical Areas and the Use of Aircraft

It is unfortunate that nothing definite is known of the geological constitution of these mountains (apart from Mt. Betty and the suggested presence of Beacon sandstone on Mt. Fridtjof Nansen), though it may reasonably be expected that they are similarly constituted to those through which Beardmore Glacier cuts. For the clearing up of the main problem a transcontinental journey similar to that projected by Shackleton would be invaluable, but much light could be thrown upon the problem by less ambitious programs in critical areas, such as that between King Edward VII Land and Graham Land, which unfortunately is of all areas of the coast line the most difficult to approach. The time-honored methods of the past generation have failed before the barrier of pack ice which is here particularly difficult to penetrate. The expedition of the future may, however, be in a position to renew the attack either by airplane from bases on the flanks, by seaplane from the pools within the outer portion of the pack ice itself, or by dirigible from the continents to the north. Reconnaissance, the conveyance of sledge parties to suitable points of attack, and supply of the necessary stores to enable the attack to be kept up, are all part and parcel of the rôle likely to be played by aircraft in the polar exploration of the immediate future. Until they are employed there is little likelihood that the blank white spaces of the map which indicate pack-infested seas and the hypothetical coast lines which are dotted across them will be filled in or sketched in accurately, as is essential before we can claim anything but a very approximate knowledge of the continent.

Meanwhile, for parties whose resources are not equal to the attack upon a major problem such as this, there is much useful work which can be carried out at less expense and with far less material, money, and personnel.

The more sections that can be made through the coastal ranges, the more chance there will be of making broad generalizations which are likely to hold good. The importance of the collection of paleoclimatological evidence cannot be too much emphasized. The location, *in situ*, of the formations whose presence has already been indicated by erratic blocks, is of the utmost importance, since without this knowledge the relations of these rocks to others already examined in place cannot even be guessed. Further collection from spots which have already yielded the evidence on which our knowledge of Antarctic paleontology is based is wanted and will probably be more productive in the immediate future than the search for fossils in regions elsewhere, though this also is essential if progress is to be made. The steep walls of the Antarctic glacier valleys, completely bare of vegetation as they are, are ideal hunting grounds for the geologist, and in Antarctica under present conditions the more mountainous the country the greater the results he is likely to obtain. Among historical localities which need immediate attention, the Beardmore Glacier region, the Terra Nova and Wood Bays area (on the South Victoria Land coast in 75° S.), and Graham Land, generally, would well repay further detailed investigation. In the first-mentioned area are centered some of the most intriguing of all problems. It has been traversed by four sledge units, not a single one of which included a geologist or was able to spare more than a few hours for geological investigation. With an airplane available to concentrate men and stores on the Barrier immediately to the north, both sides of Beardmore Glacier might be roughly surveyed in a single season and priceless material collected. Parties could work across the horst farther to the north by way of the various outlet glaciers which intersect it, and in a comparatively short time the main outstanding problems of the Australian Quadrant might be solved. The geology of the less accessible portions of the coast is likely to remain obscure for longer periods, though systematic echo sounding and further dredging on a large scale might add considerably to the available evidence.

Paleogeographical Problems

Exigencies of space do not permit more than brief reference to the highly interesting but speculative problem of the past relations of Antarctica to the continental masses lying to the north.

A consensus of scientific opinion insists upon the direct connection of Graham Land to Patagonia which is so clearly revealed in the similarity of geological architecture of the two regions. The course of the intervening bridge is more in dispute. The contention of Reiter and Arctowski of an arcuate trend line from Patagonia through South Georgia, the South Sandwich Islands, and the South Orkneys to Graham Land is supported by Suess in his interpretation of the Southern Antilles as a Pacific structure advancing for the second time into the Atlantic region.

On the interpretation adopted, Coats Land is comparable to the Brazilian foreland. The principal difficulty that has since been urged against this conception is the supposed Paleozoic structure of South Georgia. Despite much recent research on this island, its geology is very unsatisfactorily determined; the most reliable evidence, however, suggests that folded Mesozoic rocks are present, though no Tertiary lavas have been recorded. Apart from the further geological data required, an accurate bathymetrical survey of the floor between the islands is much to be desired, and here, again, echo sounding may prove a potent weapon.

Returning to the Pacific region, more speculative biologic evidence, revealed in the close affinity of the Cretaceous fauna of New Zealand, Patagonia, and Graham Land, suggests that these regions lay at the close of Cretaceous time on the southern coast of the Pacific Ocean, involving the existence of a circum-Pacific land connection which was severed in Tertiary times. This conception is clearly not disharmonious with the views already stated with regard to the possible continuation of the Andean chain of Graham Land westward to the Pacific. This brings us face to face with the problem of Gondwana Land, of which East Antarctica, through the discovery of a *Glossopteris* flora as far south as 85° S., is now commonly considered a component part. Any adequate discussion of this problem with reference to Antarctica would lead us far afield into paleobotanical and paleoclimatological evidence of an admittedly speculative kind. On the botanical side we can do no better than quote from Professor A. C. Seward:

> The origin of the higher plants is still an unsolved problem, but knowledge acquired since 1881 . . . renders it difficult to escape from the conclusion that the ancient continent of Gondwana extended to within a short distance of the South Pole or even to the Pole itself, whether as a continuous continent or as an archipelago of islands cannot be determined. Meagre as it is, the material collected by the Polar Party calls up a picture of an Antarctic land on which it is reasonable to believe

were evolved the elements of a new flora that spread in diverging lines over a Palaeozoic continent, the *disjuncta membra* of which have long been added to other landmasses where are preserved both the relics of the southern flora and of that which had its birth in the north.[4]

To that may be added the striking tectonic similarity between South Victoria Land and Tasmania, lying far to the north in the same quadrant.

The great plateau formation of the Beacon sandstone is represented in the Permo-Carboniferous coal measure formation of the island, and the dolerite sills of the Antarctic horst and King George V Land have their counterpart in the Tier dolerites which have flooded large areas of central and southeastern Tasmania.

The geological evidence in itself is not sufficient to prove the existence of a land connection between the two regions, though it may legitimately be used to supplement the biologic evidence which suggests—and demands for its reasonable explanation—the existence of such a bridge.

All these problems become very simple to the ardent advocates of Wegener's hypothesis of continental drift, but to the writers of the present article the paleoclimatological evidence from this particular continent presents an insuperable obstacle to the acceptance of this most fascinating and all-embracing theory of modern geology.

[4] A. C. Seward: Antarctic Fossil Plants (British Antarctic (Terra Nova) Expedition 1910: Natural History Report: Geology, Vol. 1, No. 1, p. 42), British Museum, London, 1914.

Mr. Priestley, now on the faculty of Cambridge University, was a member of the scientific staff of the British Antarctic Expeditions under Shackleton (1907–1909) and Scott (1910–1913), serving as geologist. As a result of the investigations made on these expeditions he has published, in collaboration with C. S. Wright, the report on "Glaciology" in the scientific results of the British Antarctic Expedition of 1910–1913, London, 1922, now the most authoritative treatment in English of the subjects with which it deals. He has also published a general narrative, "Antarctic Adventure: Scott's Northern Party," London, 1914; "Physiography of the Robertson Bay and Terra Nova Bay Regions," (British Antarctic Expedition, 1910–1913, Reports, London, 1923); and a "Syllabus of a Course of Lectures on the History and Science of Polar Exploration," Cambridge University. With Sir T. W. Edgeworth David he prepared the report on "Glaciology, Physiography, Stratigraphy, and Tectonic Geology of South Victoria Land" (British Antarctic Expedition, 1907–1909: Reports of the Scientific Investigations: Geology, Vol. 1, London, 1914) in which the chapters "Physiographic Introduction" and "Notes on the General Geological Relations of Antarctica to Other Parts of the World" are of special geographical interest.

Mr. Wright, at present on the faculty of Cambridge University, was one of the members of the British Antarctic (Terra Nova) Expedition, 1910–1913, serving in the capacity of physicist. As one of the publications of this expedition he has written jointly with Mr. Priestley, the fundamental work "Glaciology," London, 1922. Other reports of the expedition which he has prepared are "The Physiography of the Beardmore Glacier Region," London, 1923; "Determinations of Gravity," 1921; and "Observations on the Aurora," 1921. He has also published "The Ross Barrier and the Mechanism of Ice Movement," *Geogr. Journ.*, Vol. 65, 1925, and (jointly with G. C. Simpson) "Atmospheric Electricity Over the Ocean," *Proc. Royal Soc. London*, Series A, Vol. 85, 1911.

SOME ICE PROBLEMS OF ANTARCTICA

R. E. Priestley and C. S. Wright

Summary of Antarctic Paleoclimatology

No problems having reference to the Antarctic regions are more difficult of solution than those that are concerned with their past climatic history, and no speculations are more enthralling than those that can be based upon the somewhat slender evidence which is all that is available on this subject. Sufficient is known, however, to suggest strongly that glacial conditions about the south pole have been the exception rather than the rule. Positive evidence of possible warmer climates is first found in Cambrian deposits, where an *Archaeocyathus* limestone, certainly of considerable extent, probable underlying the pole itself and stretching northward on either side through many degrees of latitude into East and West Antarctica respectively, is a witness to what were more likely temperate than frigid seas. One might argue more strongly in favor of a genial climate from the evidence provided by these common ancestors of sponges and corals were it not that the forms are stunted and possess indurated skeletons suggestive of existence under conditions somewhat unpropitious for their full development.

From Cambrian times on, the paleontological record is almost lacking, until in the Permo-Carboniferous period we find far more conclusive evidence of warmer conditions than now exist. That Antarctica was the home of the ancestors of the *Glossopteris* flora many paleobotanists assert. Whether this is the case or not, it is certain that in East Antarctica a flourishing land flora, with strongly developed trees and with swamp or forest vegetation capable of forming beds of coal, some of them several feet in thickness, found a congenial home well south of latitude 80° S., probably, indeed, across the pole. Judging from the paleobotanical evidence in South Victoria Land, similar climatic conditions may have existed well into Rhetic times, while in West Antarctica we have conclusive evidence that the widespread warm-temperate or subtropical climate of the Jurassic period embraced Antarctica, as, indeed, it did also Greenland, Spitsbergen, and other Arctic lands. If one imagines a Yorkshire considerably warmer than that of the present day, in all probability with no appreciable winter, and then realizes that West Antarctic contemporaneous vegetation was exactly similar in type, a good idea can be obtained of the all-embracing scope of the Jurassic non-zonal climate, which, so far as the paleobotanical record can be relied upon, may have included the entire earth in one salubrious whole.

In Cretaceous times, again, there is clear indication of a temperate to warm-temperate climate in West Antarctica, and it is not until the close of this age that the first evidence of local refrigeration is found. Then followed a regional cooling which was to usher in one of the world's greatest glacial episodes, giving birth, after some set-backs, to immense ice floods. These today, in the Antarctic and in Greenland, remain the only parallel to the American and European ice sheets of the Pleistocene, which were of vital importance in the evolution of man and still are of the greatest interest.

Remains of dicotyledonous trees, including beech leaves, from Graham Land bear eloquent testimony to the fact that this great cooling took place, as appears always to have been the case, in a series of great pulsations. Evidence of several such gigantic pulses with ebb and flow of the ice floods is clearly seen both in East and West Antarctica, the pendulum swings culminating in a continental ice sheet a thousand and more feet thicker than that of the present day. Today the ice sheets are steadily receding; and we do not know why. It is possible that the phenomenon may be caused—as was first suggested by Captain Scott—by the very severity of the Antarctic climate itself, causing starvation at the center of the anticyclone and the development of a steepened temperature gradient at its periphery, with enhancement of the outward-blowing hurricanes laden with drift from the coastal valleys and the interior.

This is only one of the manifold problems of polar glaciology which require for their solution the development of polar meteorology on a scale far transcending that attempted up to date.

Expedition after expedition has reported bare slopes where ice-swathed contours ruled in the times of its immediate predecessors. Ice-bound peninsulas have become islands in a very few years. Controversies between generations of polar surveyors are a witness not necessarily to the ignorance or lack of precision of the preceding generation but often to the steady retreat of the coastal ice. One of the problems of the future explorer will be to keep track of this continuous, though jerky, recession; one of his difficulties, to resist the tendency to attribute visible changes to the inefficiency of his predecessors (sometimes, alas, justified) rather than to a natural process of which evidence is steadily accumulating. It is not enough to make a single survey of lands inundated by ice. Their contour and outline are ever changing. Constant attention to such detail, combined with the careful recording of every factor, large and small, of the environment in which the ice forms exist, will, in the long run, render it possible to make the generalizations which are so fascinating but which the present generation of explorers should avoid.

Need on Future Expeditions of Detailed Paleoclimatological Observations

The most pertinent example of such dangerous generalization the authors can cite is perhaps the preceding account of Antarctic paleoclimatology. It is, however, strictly necessary from the present point of view. To gain a general view of the situation as it appears from evidence at present available, some such summary is essential. Its truth is not so certain. All that can be said is that expedition after expedition has traversed the great outlet valleys of the East Antarctic horst or the glaciers of the Graham Land area where the best rock sections are exposed. Here, in one place or another, complete sections through the sedimentary rocks down to the basal Archean complex have been seen and examined. Sometimes the examination has been made by geologists, sometimes not. In all cases, however, intelligent men—often specialists studying other branches of polar science—have accompanied the sledge parties, and much of the preceding winter has been spent learning the elements of the recognition of rocks and other geological signs. Glacial remains, moreover, whether in the form of striated pebbles, *roches moutonnées* with their grooved surfaces, boulder clays or their older equivalents, the tills, or even the varve clays which invariably mark the closing stages of a glacial or the course of an interglacial period, are comparatively easily recognizable and could hardly have been consistently overlooked. The amount of negative evidence is thus considerable, in addition to the positive evidence provided by the floras and faunas to which reference has already been made. The two together are by no means sufficient to make certain that no pre-Eocene glacial period has existed in the area about the south pole, but the presumption that ice has been the exception is a reasonable one.

It remains a presumption, however; and one of the chief tasks of future parties will be to accumulate further evidence, whether it upholds or rebuts the view set forth above. Every member of each sledge party in the future should know the elements of this branch of geology and should be instructed to pay particular attention to the collection of paleoclimatological evidence of any sort. Every exposure should be closely examined with this end in view. The collection and labeling of specimens should be a duty common to all but directed by the member of the party most suited to the task. The history of past parties as regards the collection of geological evidence would be unbelievable were it not so well attested. Strong sledge parties have traversed whole mountain ranges without taking a specimen either from moraine or cliff. The whole paleontological evidence of a major expedition has come by sheer chance from a small specimen collected as a souvenir by a sailor, jealously hidden from the responsible authorities but fortunately revealed to a scientist friend and traded for a "pretty" piece of rock. Education of the rank and file of a sledge party is essential and one of the most needed polar reforms. No man should be taken south who has not wide interests and a capacity for taking up others. Every man should be an enthusiast in his own subject and eager to add his quota to that of each of his companions. If this fact is realized half the battle in making the most of the available time and team is won. In this question of paleoclimatology especially, constant, accurate, and detailed observation is the essence of success. It is often argued that the old methods of exploration have become obsolete, but this generalization is not true and is to be avoided. It is correct to say that airplanes, snow tractors, and other means of transport can be employed with great advantage by the explorer in the Antarctic regions as elsewhere, but the old-fashioned dog-hauled, even man-hauled, sledge parties will still be required for detailed scientific work. Survey from the air can only be approximate at best; in the polar regions there are factors which will necessarily make this method even less accurate than elsewhere. Just as in war, in spite of the great development of the technical services, the infantryman with all his disadvantages is still requisite if captured ground is to be held, so in polar exploration detailed work can be carried out only by ground parties who must still work very much under the conditions that have hampered their efforts in the past.

Paleontological Significance of the Ice Ages

The chief interest which Antarctic ice conditions will have for man must naturally spring from their relation to the factors that have produced mankind and have strictly delimited the conditions of his life. While Antarctica has passed apparently from a uniform-temperate to a frigid climate, the remainder of the world—now one continent, now another—has been aperiodically visited by glacial incidents which have profoundly modified the course of life. But for the Permo-Carboniferous glaciation of India, Australia, South America, and Africa, with the accompanying cooling of the remainder of the earth, gigantic insects might have dominated the world. But for the cooling of Cretaceous and Eocene times, it appears quite likely that mammals might yet be insignificant tribes, leading a precarious existence at the mercy of descendants of the Jurassic horde of reptiles. Refrigeration has again and again involved extinction of specialized races and vivification of more generalized and newer types. Insects gave place to reptiles, reptiles to mammals, and—to bring the history up to date—the dominance of man coincides remarkably with the coming of the great cooling of the Pleistocene, the effect of which upon the climates of the world is still apparent.

Bearing of the Present Antarctic Ice Cap on the Pleistocene Ice Sheets

It is through its relation to the Pleistocene ice sheets, and the comparisons which its existence makes possible, that the Antarctic continental ice has a more than purely scientific interest. There are many questions to which the answer must be sought in Antarctica. Modern theories of ice action can be tested only in the one region where ice sheets of continental extent still maintain almost their fullest development. It is in Antarctica alone that all the main types of land ice are met with today. Three of these, in particular, the largest and the smallest, the continental ice, the shelf-ice sheets of the coast, and the tiny scooplike and cuplike drifts and cwms, present problems which are of particular interest both in themselves and as representatives of similar conditions elsewhere in the world.

A sheet of continental ice comparable in size with the European and North American Pleistocene ice sheets is found in Greenland as well as in Antarctica today, but it is the latter alone which not only occupies the continent on which it is based to its uttermost limits (if we except a few wind-swept promontories mostly of recent volcanic origin) but spreads out into the sea, adding some hundreds of thousands of square miles to the effective "land" area. In one respect both the Greenland and the Antarctic ice sheet are better compared with the Pleistocene continental ice of Europe than with that of America, for the latter spread out and thinned out mainly over lowlands, while the former ended abruptly, on one side at least, in the sea, as also do its modern rivals. Only in the Antarctic—indeed, so far as we know, only in the Ross Sea sector of the Antarctic—is there anywhere a true parallel, in importance and extent, to the ice sheet that formerly filled the North Sea and deposited its load of boulders, including the unique "rhomb porphyry" from Scandinavia, across the lowlands of East Anglia and even pushed them up the slopes of the uplands of the Lincolnshire and Yorkshire coast.

Study of Ice Erosion

It is unfortunate for our study of glacial erosion that the continent of Antarctica is so symmetrical in shape. The ice sheets everywhere push out and persist until they float upon the sea, and the accumulated débris of the erosion of the Ice Age is deposited beneath the water and thus successfully hidden from the gaze of man. The tendency of the Antarctic explorer has thus been to adopt a very conservative estimate of the power of ice to erode. There are, however, hints that a systematic survey of the deposits of the sea bottom would give us a much truer view of the eroding power of the ice sheets at their maximum, when the outward flow of the glaciers must have been of an entirely different order from the few feet or yards per year which is today the rate of advance of the majority. Such a survey is one of the important tasks of the expeditions of the future, which should, incidentally, glean much further valuable information, if only in general terms, about the constitution of the lands from which the débris has been reft. Valuable petrological and paleontological evidence has already been brought to light by the biologist's dredge, notably the nest of iceberg-borne boulders brought up by the dredge of the *Scotia*, which more than doubled our knowledge of the *Archaeocyathus* limestones of Antarctica and proved their occurrence on the opposite side of the continental divide from where they were first collected by Shackleton's sledge team. Even the contents of the stomachs of sea-living animals cannot be neglected from this point of view, valuable hauls having been obtained from both seals and penguins off portions of the coast line where no exposed rock exists.

At the same time the glaciologist should use every other possible opportunity for obtaining evidence of the erosive powers of ice. Many further measurements of the speed of different types of glaciers are required, and evidence of signs of former stream erosion should be looked for everywhere. If the great through valleys of the South Victoria Land horst owe their inception and deepening entirely to the abrasive and plucking work of ice, that fact alone should go far to prove the potency of an ice stream as an eroding agent.

Internal Ice Investigations and the Methods To Be Pursued

Knowledge of the interior of Antarctica, and therefore of its continental ice, is very scanty indeed. Of all the expeditions that have landed on its shores only five have penetrated more than a couple of hundred miles inland, and all but one of these have been based on the Ross Sea sector of the continent, whence sledge parties have made hasty, almost furtive, journeys across the plateau in midsummer in the attempt to reach their geographical objective, the south, or south magnetic, pole. Nevertheless, we know that practically the whole continent is covered with ice, the surface of most of which lies at a great elevation. Most of the sledge parties concerned have traveled across an ice divide which lies close to the steep coastal range of South Victoria Land. We cannot feel sure that this forms the main ice divide or that the slopes on the other side are for this reason uniformly less steep than in the area traversed, though the evidence as yet to hand suggests that such is the case. The thickness of the continental ice is entirely unknown, though in some places evidence exists that it is underlain for many miles beyond the most southerly visible peak by submerged ranges which cause its surface to break in swirls and chasms of colossal size. Boring has been suggested as a possible means of investigation of the interior layers, but internal movement would render this method impracticable. The sides of crevasses should afford to the more leisured parties of the future information as to temperature and temperature gradients within the ice. Its depth might be measured by the application of the principles of echo-sounding, which are rapidly revolutionizing our ideas as to the contour of the sea bottom. The loose nature of the upper snow layers makes the problem a difficult one, but the ice of the outlet glaciers may afford satisfactory ground for preliminary experiments.

Such work, however, and the equally necessary meteorological investigations required to afford information about the alimentation of the Antarctic ice involve the maintenance of inland winter stations. Such a feat of organization has never been within the power of expeditions whose scientific program has been subordinated to the more spectacular geographical achievements upon the success of which their financial prosperity ultimately depended. Now that the poles have been discovered, polar exploration must wait upon the support of more enlightened patrons valuing science for itself. Once such patrons have been found, there should be no difficulty in vastly increasing the scientific programs. Parties armed with modern equipment and modern means of transport, attacking the problems from a number of suitable bases on the periphery of the continent, should rapidly accumulate facts inaccessible to their predecessors of the expeditions of the period just past, scattered and sporadic as their efforts have necessarily been. Indeed, one of the features of an adequate scientific attack on the secrets of the polar regions should be international coöperation on the grandest scale. The features of the polar environment, and consequently the climate of polar lands, vary from place to place and from year to year in the most amazing manner. No generalizations can be made with safety unless they can be based on facts collected at many stations throughout several years at least.

Alimentation and Ablation; The Glacial Anticyclone

The amount of permanent addition to or loss from the ice of the Antarctic Continent is conditioned, as in other snow-bound countries, by the balance between the snowfall on the one hand and evaporation, melting on the surface and movement of ice to lower levels, snow drift carried by outward-moving winds, and melting of the terminations of the glaciers on the other. These latter, in a special degree in the Antarctic, reach sea level and push out floating masses of ice to distances up to several hundred miles. In the Antarctic the ice covering is maintained in spite of the meager snowfall of a desert climate, because of the smallness of the denudational and distributive forces operating to clear the continent of ice. Surface melting seems to be unknown except in the immediate neighborhood of rock, and the rate of movement of the glaciers whose movement has been measured is far less than in Greenland, for example. The tendency to form floating extensions to the ice covering of the land results partly from the low rate of melting in the cold waters that bathe the seaward terminations of the glaciers and partly from the fact that the snowfall added annually to their surface is probably often greater than that lost through evaporation. One of the most difficult of the problems awaiting the future scientist-explorer is the measurement of the rate of melting of such floating ice tongues in water and the evaluation of the factors which control their denudation. The importance of a complete knowledge of these various factors for our present purpose lies in the possibility of determining whether the greater extension of ice on this continent in the past was associated with greater or less wind velocity and snowfall and with a higher or lower temperature. On these points we have no reliable information; nor are there many useful data regarding absolute or relative humidity, which, together with wind velocity and temperature, determine the rate of evaporation of the snow and ice surfaces. There are no accurate data regarding either snowfall or radiation to and from the earth. It is this last factor, radiation, that must, in the main, determine the activity of the glacial anticyclone or outflow of air cooled by contact with the snow surface. To what extent this outflow is controlled by the snow slopes and to what extent by the contrasting meteorological conditions at the boundary of the continental ice remains uncertain. Still another factor of unknown degree of importance in shaping the glacial anticyclone is the contrast of conditions across the boundary which separates a loosely coherent snow surface from a compact icy surface. For the greater part of the year this boundary lies outside the Antarctic Continent, but it is possible that it penetrates inland to some extent in summer and in some areas.

To appreciate the importance of the type of snow surface it is necessary to refer to the fact that the cooling of the air above the surface takes place by contact with the snow. Where the surface consists of loose snow, it cools rapidly through the small heat capacity and low heat conductivity of the snow, whenever outward-directed radiation exceeds that directed inwards. As it ages, the snow surface becomes more coherent by the slow growth in the mean size of individual crystals, until finally it becomes a compact and dense mass of interlocking grains. The absence of fresh snowfall or drift may thus modify the surface so as to prevent a close correspondence between air temperature and exchange of radiation to and from the earth. When outward-directed radiation is in excess, as is usually the case, the intensity of the glacial anticyclone may be expected to decrease when the area of the loose snow surface is at a minimum. The conditions are rendered more complicated by the important effect of the downward-blowing winds in sweeping the loose snow surface towards the edge of the continent and in "packing" the snow during its passage. Nothing definite is known, either, of the relation between evaporation and the intensity of the glacial anticyclone, though there is good reason to expect that evaporation will be greatest when the intensity is greatest, in otherwise similar conditions. Sufficient has been said to emphasize the importance of a more complete knowledge of the meteorological and physical conditions associated with the glacial anticyclone. To some extent we may say the chief importance of such knowledge will lie in the help it will afford towards determining to what extent the glacial anticyclone which must have been associated with any large ice mass in the past may have carried with it conditions that tended to limit or control the dimensions of the ice mass to which it owed its origin.

Small-Scale Ice Erosion: Cwms and Snowdrift Hollows

A problem on a smaller scale, but one that has exercised much thought and caused much controversy in the past, is that concerning the mode of growth of the smallest of the permanent ice formations of the land. How do the permanent or semi-permanent snowdrifts of glacierized lands deepen the hollows in which they lie until the latter can be dignified by the title of cwms? What, again, are the processes by which these cwms become deepened to such an extent as to give rise to glaciers capable of eroding their beds in the normal manner? For the latter, movement is required, and it seems certain that several hundred feet of ice must accumulate before movement at any pace can take place. Nivation and bergschrund erosion as explained in papers and textbooks are certainly not sufficient to account for these phenomena in Antarctica today. What, then, is the truth? Are the present Antarctic snowdrift hollows and cwms relics of former different climatic conditions but now the containers of stagnant masses of ice that exert a wholly conservative influence? If so, many of them should be gradually disappearing through the action of subaërial erosion, which is active on all exposed land masses in Antarctica today. Such truncated cwms have been described from more than one region of the continent. Bergschrunds do exist; nivation does operate in summer around the edges of the snowdrifts which nestle in the lee of all exposed rock faces. Nevertheless, it seems certain that in the normal Antarctic summer no melting at all takes place on the under side of the thicker drifts; equally is it true that temperature changes must be practically damped out throughout even the short Antarctic summer at the bottom of any deep crevasse. Certainly there can be no oscillation of the temperature about the freezing point of water such as is postulated to account for bergschrund action in milder climates. No expedition has yet had means or leisure to inquire into these things carefully enough. All energies have been directed towards the more generalized peripatetic investigations of the pioneer. Here, however, is work and to spare for the trained glaciologists of the more leisured parties of the future.

Sea Ice: The Antarctic Pack-Ice Belt

If we turn our attention to sea ice, we find at once that the Antarctic pack has attracted far less attention than its rival in the north. The broad features of the meteorology of the southern hemisphere, with its more symmetrical disposition of land and sea, have combined with the earlier and greater development of civilization in the north to make this true. The ice driven north from the shores of the Antarctic Continent by southeasterly gales is closely packed between those winds and the northwesterlies of the middle latitudes. There it hangs sullenly as a barrier to southern navigation, but normally well south of the main traffic routes between the ports of southern civilizations. Only occasionally, driven by deep-water currents, do the mighty southern icebergs force their way irresistibly through the sea ice perhaps to strand and form a nine days' wonder—sometimes a source of unexpected income—on southward-reaching temperate shores. Normally the Antarctic pack is out of sight of the seafarer in these days of steam, and out of sight is usually out of mind. Not until the twentieth century have the fresh incursions of the whalers into ice-laden seas in search of finback whales reminded the northern peoples of the existence of the southern sea-ice belt. Nevertheless, its study is of interest, and in this respect much has already been achieved. We know, for instance, of its westerly drift, of certain weak places in the belt which are easily penetrated, and of others where danger is likely to be encountered even in normal years. From the observation of past expeditions it has become clear that access to the thousands of miles of coast yet unexplored is most likely to be achieved along the western shores of northward-reaching land promontories or ice tongues. Conversely, the danger of approaching the coast on the eastward side of such prominences has been upheld in theory and demonstrated in practice more than once. The fact remains that large stretches of the coast line have remained inaccessible to man even when armed with the combined resources of steam and sail.

Conclusion

The time has come when new technique or better equipment will have to be evolved. Further progress may take place in any one of several ways. The use of the seaplane as the eyes of the polar navigator or as an instrument of extended survey may open up new tracts. The calm pools and leads of the outer pack will lend themselves well as taking-off or landing places for such work, while the seaplane carrier may lie safely and easily within the same natural breakwater, secure from damage by storm or pressure. The value of the airplane working from a land base has already been demonstrated in the Arctic. Dirigibles may be used from bases in south temperate lands so far as the Antarctic blizzards will permit. Advances by more orthodox and old-fashioned polar methods may follow upon the improvement of the technique of living off the produce of polar lands and seas, which Stefansson has done so much to elevate into a science in the north. Ice breakers of improved construction may well make navigation amidst pack of the Antarctic type a less hazardous and less dilatory affair. Bound up with the extension of the polar explorer's radius of action which the exploitation of new methods will assure will be a thousand fresh responsibilities and possibilities for attack on the problems of polar science.

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ANTARCTIC AND SUB-ANTARCTIC PLANT LIFE AND SOME OF ITS PROBLEMS[1]

R. N. Rudmose Brown

PLANT life in the Antarctic is necessarily confined to the edges of the continent, the lofty mountain ranges, and the islands that lie near the coast. The great ice sheet that covers the greater part of Antarctica is a complete desert devoid of any form of animal or plant life. The regions that experience true Antarctic climatic conditions lie approximately south of latitude 60° S.[2] To the north of this parallel lie the regions which may, for want of a better term, be called sub-Antarctic, including numerous islands and island groups, South Georgia, the South Sandwich Islands, the Crozets, Kerguelen, and others. The South Shetlands, the South Orkneys, the Balleny Islands, and the islands of the Ross Sea are all within the Antarctic region.

Poverty of Antarctic Flora as Compared With That of the Arctic

The Antarctic flora, thus defined, has been explored in various places, and its general aspect is well known, although subsequent exploration will undoubtedly add a few species of cryptogams to the list. Its poverty, compared with the flora of the same latitudes in the North Polar Regions, is striking. The Arctic Regions support some four hundred species of flowering plants, many of which flourish luxuriantly even in the north of Greenland: the Antarctic Regions support only two, both of which maintain a precarious hold and are apparently at the extreme limit of their range. These species are a grass (*Deschampsia antarctica*) and a small caryophyllaceous plant (*Colobanthus crassifolius*). The grass was discovered over a century ago at the South Shetlands and was rediscovered this century on the west of Graham Land between latitudes 65° and 68°. The other plant was found along with the grass in several localities. Both grow sparingly in dwarfed specimens and appear to have only vegetative

[1] On the topic of the present paper see also the writer's: Problems of Antarctic Plant Life (Scottish National Antarctic Expedition: Report on the Scientific Results of the Voyage of S. Y. "Scotia" . . . 1902–1904, under the Leadership of W. S. Bruce, Vol. 3: Botany, pp. 3–20), Edinburgh, 1912 (expanded from an earlier paper: Antarctic Botany: Its Present State and Future Problems, *Scottish Geogr. Mag.*, Vol. 22, 1906, pp. 473–484) and Chapter 12 (Polar Vegetation) of his "The Polar Regions: A Physical and Economic Geography of the Arctic and Antarctic" (Methuen's Geographical Series), London, 1927.

[2] Carl Skottsberg: Some Remarks Upon the Geographical Distribution of Vegetation in the Colder Southern Hemisphere, *Ymer*, Vol. 25, 1905, pp. 402–427, with map, here reproduced as Fig. 1. This paper contains a useful bibliography of Antarctic and sub-Antarctic botany.

reproduction. They are more at home in Fuegia, the Falklands, and South Georgia.

Antarctic Mosses and Lichens[3]

There are no ferns, but mosses are numerous and are in fact one of the chief constituents of Antarctic plant life, in individuals if not in species. Over fifty species have now been described, of which the majority come from the more favored Graham Land and neighboring islands. Many specimens show vigorous and even luxuriant growth, but those from the southern coasts of South Victoria Land in latitude 78° are often stunted and puny compared with specimens from Graham Land, fifteen degrees farther north. All Antarctic mosses are frozen solid for a period ranging from eight to eleven months a year, but this does not seem to impair their vitality. They grow in favorable places in small colonies of several species, and occasionally a small tundra of moss and lichen may form a close covering over half an acre or more of ground. The luxuriance of growth in these places is generally due to bird guano supplying nitrogenous matter. Fruiting specimens are rare, and only some six species have been recorded as showing this form of reproduction. Even in the South Orkneys, where moss growth is luxuriant, only one species has been found with any well-developed fruits.

Hepatics and liverworts are rare. The few that have been found grew in the shelter of moss colonies, mainly in Graham Land. Lichens are numerous, both in species and individuals, and form the predominant feature of plant life on Antarctic land. Many cliffs, even in midwinter, appear gray or orange with thick coverings of *Usnea*, *Placodium*, and other lichens, while in summer there is scarcely a bare rock to be seen that has not some growth. Over a hundred species have been recorded, and no doubt more will be found.

Climatic Causes of Poverty of Antarctic Flora

The meagerness of Antarctic vegetation and the poverty of its flora compared with those of the Arctic is mainly due to climatic causes, of which the principal is the shortness of the Antarctic summer and its remarkably low temperature. There is no real summer as far as temperature is concerned, for no month has a mean above freezing point. Thus in South Victoria Land in about latitude 78° the mean

[3] Jules Cardot: La flore bryologique des Terres magellaniques, de la Géorgie du Sud et de l'Antarctide (Wissenschaftliche Ergebnisse der Schwedischen Südpolar-Expedition 1901–1903, herausg. von Otto Nordenskjöld, Vol. 4: Botany, Part II, No. 8), Stockholm, 1921.

idem: Les mousses de l'Expédition Nationale Antarctique Écossaise (Scottish Natl. Antarctic Exped. Sci. Res., Vol. 3: Botany, pp. 55–69), Edinburgh, 1912.

O. V. Darbishire: The Lichens of the Swedish Antarctic Expedition (Wiss. Ergebn. Schwed. Südpolar-Exped., Vol. 4: Botany, Part II, No. 11), Stockholm, 1921.

idem: Lichens (British Antarctic ("Terra Nova") Expedition, 1910, Nat. Hist. Repts.: Botany, Part III), London, 1923.

of the warmest month is only about −4° C.; at Cape Adare, some seven degrees farther north, it is −0.3°; at Snow Hill in Graham Land it is −0.9°; and even at the South Orkneys, in about latitude 61°, it is not half a degree above freezing point. The three summer months, December, January, and February, in the true Antarctic climate,

FIG. 1—Map of the plant geographical provinces of the Antarctic and sub-Antarctic regions according to Skottsberg (paper cited above in footnote 2). Scale, about 1:120,000,000.

I, Antarctic vegetation province (within the 60th parallel). II, sub-Antarctic vegetation province, subdivided into (1) sub-Antarctic South America, consisting of (A) South Chilean-Fuegian province and (B) Magellanian-Falklandian province; (2) South Georgia district; (3) Kerguelen district; (4) New Zealand district, consisting of (A) the sub-Antarctic part of South Island, (B) Bounty-Antipodes-Auckland province, and (C) Macquarie province. III, dominion of Australia. IV, dominion of Tristan da Cunha, St. Paul, and New Amsterdam Islands. ᴧᴧᴧᴧᴧ, extreme outer limit of drifting pack ice.

invariably have a combined mean below freezing point. As a result, the snow lies late on the ground, and December is well advanced before the sun's rays lay bare what little soil occurs in a few places. By early February the snow again begins to accumulate.[4] Only for four

[4] These conditions may be compared with the Arctic, where the warmest month always has a mean above the freezing point, and the combined mean of the three summer months is nearly always above that point. The summer, though short, is a real summer in the Arctic.

to six weeks is the vegetation, except lichens on cliff faces, exposed to sunlight. The ground thaws to a depth of a few inches only on a few cloudless days about midsummer and even then is saturated with ice-cold water in which the root hairs of plants are physiologically inactive.

These influences are detrimental to plant life and make it practically impossible for higher plants to complete their life cycles. A plant would be unlikely to reach the flowering state and would have no chance of maturing its seeds. Even in the Arctic summer, with its eight to ten weeks' growing season, plants have to "rush" their life cycle, often flowering before the snow is off the ground and even then finding the summer too short for sexual reproduction. The low means of the Antarctic winter, which fall as low as –35° C. on some coasts, are probably no more detrimental to plant life than means of zero. Antarctic mosses which are frozen solid for ten or eleven months grow vigorously for the rest of the year.

Other Causes

In addition to these principal causes there are contributory factors in the poverty of Antarctic plant life. The chief sites for plant growth are small islets and rocky coasts. In such places winds help to clear the snow, but they are chiefly cold, dry winds blowing out of the Antarctic anticyclone and are detrimental to plant growth by their active promotion of transpiration.[5] Lack of soil has been suggested as an adverse influence, but it cannot be of first importance, since many places that are devoid of vegetation have several inches of soil well impregnated with bird guano. On comparable sites in the Arctic vegetation would be luxuriant. A few samples of soil from South Victoria Land proved on analysis to be alkaline owing to the accumulation of carbonates and zeolites and the absence of organic acids, but they were not valueless for plant growth. In several of the samples wheat was grown in Australia and showed rapid germination and unusual vigor.

Apart from climatic influences the greatest enemy of plant life is found in the penguin. In spring and summer myriads of these sea birds occupy every site which is at all favorable to plants. Nothing escapes their insatiable curiosity or fails to prove attractive to their beaks. Any plant which had gained a footing on a penguin rookery would stand a poor chance of survival.

[5] Carl Skottsberg: On the Zonal Distribution of South Atlantic and Antarctic Vegetation, *Geogr. Journ.*, Vol. 24, 1904, pp. 655–663.

Algae

Fresh-water algae[6] are comparatively abundant in the Antarctic. In the South Orkneys alone about seventy species have been recorded.[7] The most interesting are those that color snow. Red snow is the commonest and, as in the Arctic and elsewhere, is generally caused by *Sphaerella* but occasionally, as in the Alps, by red rotifers. Yellow snow is rare and may be due to a remarkable association of many algae and fungi or, when it occurs on sea ice, to diatoms. Some scanty deposits of a peatlike material that have been found in fresh-water lakes are composed of algae which have been compressed but have not undergone the partial decomposition characteristic of peat. In fact, putrefactive organisms, where they have been searched for, are no more abundant in Antarctic than in Arctic soils, while examination of the air has proved it to be sterile, except where contaminated by contact with soil or animal life.

Marine algae,[8] both unicellular and multicellular, are very abundant in the Antarctic seas. The scouring action of drifting ice prevents much growth except of encrusted calcareous algae, between tide marks and for some feet below; and where glaciers reach the sea, of course, no littoral vegetation can exist. Strange to say, algae grow at times in pools that are frozen solid every winter. Luxuriant species, like *Laminaria* and *Macrocystis*, flourish only on sub-Antarctic coasts which remain open throughout the year and are little exposed to drifting pack. Below the influence of ice, within range of the penetration of light, the larger algae flourish in the Antarctic seas and seldom have to contend with the low salinity of the water which is a deterrent influence to alga growth on certain Arctic coasts.

Most remarkable, however, is the wealth of diatom life in the Antarctic seas,[9] a phenomenon that has long been noted in the Arctic seas. A few minutes' haul is enough to fill a silk townet with a gelatinous mass of these unicellular plants. Various reasons have been given in explanation of this abundance of phytoplankton in cold seas by contrast with its scarcity in warm seas. The most important features are probably the scarcity and decreased activity of denitrifying bacteria in cold seas; the tendency for surface layers of water to sink and be

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[6] W. West and G. S. West: Freshwater Algae (British Antarctic Expedition 1907–9, Reports on the Scientific Investigations, Botany, Vol. 1, Part VII), London, 1911.

G. W. F. Carlson: Süsswasseralgen aus der Antarktis, Südgeorgien und den Falkland Inseln (Wiss. Ergebn. Schwed. Südpolar-Exped., Vol. 4: Botany, Part II, No. 14), Stockholm, 1921.

F. E. Fritsch: Freshwater Algae (British Antarctic ("Terra Nova") Expedition, 1910, Nat., Hist. Repts.: Botany, Part I, pp. 1–16), London, 1917.

[7] *idem:* Freshwater Algae of the South Orkneys (Scottish Natl. Antarctic Exped. Sci. Res., Vol. 3: Botany, pp. 95–134), Edinburgh, 1912.

[8] Carl Skottsberg, H. Kylin, D. E. Hylmö: Zur Kenntnis der subantarktischen und antarktischen Meeresalgen (Wiss. Ergebn. Schwed. Südpolar-Exped., Vol. 4: Botany, Parts I and II, Nos. 6, 15, 16), Stockholm, 1908 and 1921.

[9] L. Mangin: Phytoplancton antarctique, *Mémoires Acad. des Sci. de l'Inst. de France*, Vol. 57, 1922.

replaced by deeper layers richer in nitrates, thus renewing the food supply of the diatoms; and the abundance of silica in polar seas owing to the low temperature of the water and the great quantities of glacier-swept waste from the land.

Origin of the Antarctic Land Flora

An analysis of the scanty land flora of the Antarctic shows three elements, endemic, Arctic, and Fuegian. The high proportions of endemic species, particularly among mosses, can be explained by long isolation and peculiar conditions of environment. Two explanations of the Arctic element have been suggested. Carriage of spores and soredia on the feet and plumage of birds like Wilson's petrel and the Arctic tern, which wander through 150° of latitude, might account for some species, but it is difficult to find in this suggestion[10] an adequate explanation of the occurrence of half the Antarctic lichens and 30 per cent of the mosses in the Arctic. A more credible explanation is either that the species in question are cosmopolitan and have not yet been found in low latitudes or that they have been crowded out by stress of competition in low latitudes where happier conditions lead to more rivalry for location.

The Fuegian element,[11] or, it may be said, the Fuegian relationship, of most species shows that the present flora has reached the Antarctic Continent and islands by the prevailing northwesterly winds from South America, birds no doubt playing a part.[12] Ice transport can be ruled out altogether. There is direct evidence of transport from South America in the pollen grains of a Chilean conifer, *Podocarpus*, which were found among red snow at the South Orkneys.[13] Probably the present flora first reached Graham Land and adjacent islands, where it shows its richest form, and then spread eastward round the rim of the continent. The migration must have been slow, for it could occur effectively only during a few weeks at midsummer when mosses and lichens "fruit" and there is bare ground for the wind-blown spores to

[10] Jules Cardot: Note sur la flore de l'Antarctide, *Compte Rendu Assn. Française pour l'Avancement des Sci., 36e Session, Reims, 1907*, Paris, 1908, pp. 452–460.

[11] On the plant life of Fuegia see, among others:

Carl Skottsberg: (a) Feuerländische Blüten; (b) Zur Flora des Feuerlandes; (c) Pflanzenphysiognomie des Feuerlandes; (d) Das Pflanzenleben der Falklandinseln (Wiss. Ergebn. Schwed. Südpolar-Exped., Vol. 4: Botany, Parts I and II, Nos. 2, 4, 9, and 10 respectively), Stockholm, 1908 and 1921.

Carl Skottsberg, F. Stephani, and T. G. Halle: Botanische Ergebnisse der Schwedischen Expedition nach Patagonien und dem Feuerlande 1907–1909 (five separate monographs), *Svenska Vetenskaps.-Akad. Handl.*, Vol. 46, two numbers, 1910 and 1911; Vol. 50, No. 3, 1913; Vol. 51, No. 3, 1913; Vol. 56, No. 5, 1916.

P. Dusén: (a) Die Gefässpflanzen der Magellansländer, nebst einem Beitrag zur Flora der Ostküste von Patagonien; (b) Die Pflanzenvereine der Magellansländer nebst einem Beitrage zur Ökologie der magellanischen Vegetation (Wissenschaftliche Ergebnisse der Schwedischen Expedition nach den Magellansländern 1895–1897 unter Leitung von Dr. Otto Nordenskjöld, Vol. 3: Botany, Nos. 5 and 10, pp. 77–266 and 351–523 respectively), Stockholm, 1905.

[12] Carl Skottsberg: Die Gefässpflanzen Südgeorgiens (Wiss. Ergebn. Schwed. Südpolar-Exped., Vol. 4: Botany, Part I, No. 3), Stockholm, 1905.

[13] Fritsch, Freshwater Algae of the South Orkneys, p. 119.

lodge on. Moreover, only at that season does the Antarctic anticyclone retreat sufficiently to allow the westerly winds to touch at times the rim of the continent. No doubt sub-Antarctic islands like the South Sandwich Islands, Kerguelen, and the Heard Islands helped in the process by acting as sources of supply for the continually migrating flora, which lodged on these islands in its passage.

Former land connections cannot be held responsible for the present Antarctic flora, since there is abundant evidence that they disappeared before the last great extension of glacialism in the Antarctic which must have effectiveiy destroyed every vestige of vegetation. It is of interest to note that the phytoplankton of the Antarctic seas is almost wholly distinctive from that of the Arctic seas in spite of the prevalence of diatoms in both and the great similarity of physical conditions. Even in various parts of the Antarctic seas considerable differences have been found.

Sub-Antarctic Vegetation[14]

The vegetation of South Georgia, the Crozets, Heard, Kerguelen, Macquarie, and other sub-Antarctic islands is a form of poor tundra more closely covering the lower ground than in the Arctic islands but much poorer in species. Mosses and peat bogs are numerous, while, owing to the low temperature and high winds, there are no trees. Among higher plants tufted species flourish best, no doubt owing to their power to resist the cooling influence of winds. On many islands tussock grass grows high and luxuriant, giving an impression of rich vegetation. The term "sub-Antarctic" is justified rather by proximity to the Antarctic than by any real approximation to Antarctic conditions. The true Antarctic climate is typically continental in contrast to the climate of these sub-Antarctic islands, which is essentially oceanic and in most aspects cool-temperate rather than polar. In fact, were it not for the prevailing strong winds, the vegetation would probably be much richer than it is.

The flora of these islands must be wholly, or at least, almost wholly, postglacial, which accounts for the poverty of species. South Georgia has 18, Kerguelen 30, and Macquarie Island 34 vascular plants. Many of these species are circumpolar in distribution, and most are of Fuegian origin. Some in Macquarie Island are found in New Zealand but not in Fuegia. There can be little doubt that the postglacial

[14] Carl Skottsberg: The Vegetation in South Georgia (Wiss. Ergebn. Schwed. Südpolar-Exped., Vol. 4: Botany, Part II, No. 12), Stockholm, 1921.

idem: Die Gefässpflanzen Südgeorgiens (*ibid.*, Part I, No. 3), Stockholm, 1905.

R. N. Rudmose Brown, C. H. Wright, and O. V. Darbishire: The Botany of Gough Island (Scottish Natl. Antarctic Exped. Sci. Res., Vol. 3; Botany, pp. 33–34), Edinburgh, 1912.

T. F. Cheeseman: The Vascular Flora of Macquarie Island (Australasian Antarctic Expedition 1911–1914, Scientific Repts., Ser. C.: Zoölogy and Botany, Vol. 7, Part III), Sydney, 1919.

C. Chilton: Biological Relations of the Subantarctic Islands of New Zealand: Summary and Bibliography, Wellington, 1909.

species of these islands were brought by birds and winds from the west, and to Macquarie Island also from the northeast. The poor and uncertain means of transport, the inclement weather conditions, and the ravages of penguins account for the poverty of the flora. The fossil trees of Kerguelen, sometimes dignified by the name of coal or lignite, must be relics of a preglacial flora. They are found in Tertiary basalt flows which no doubt were largely instrumental in destroying the forests of what were then more extensive land areas, before the Ice Age set in.

Some Problems of Antarctic Plant Life

LABORATORY WORK

The adaptations of the various species to their environments, a study particularly important in the case of cosmopolitan species, promises most valuable results but is more likely to be undertaken seriously when the systematic and geographical interests of the flora have been more fully worked out. It is, moreover, extremely desirable that such physiological and morphological questions should be studied on the spot; indeed, the impracticability of satisfactory investigation in any other circumstances is most obvious. The difficulty of laboratory accommodation in the isolated Antarctic Regions is naturally great but not nearly so great as is generally supposed. Various expeditions which have recently wintered in the south have shown that the climatic conditions, though not exactly as favorable as in the north, offer no serious inconvenience to a person endowed with an ordinary robust constitution and cheerful disposition. And, furthermore, it should be remembered that there are at the present time several habitable dwellings within the regions of south polar ice which have been erected by one or other of the expeditions of this century. Of these the house at Scotia Bay, South Orkneys, is permanently inhabited as an Argentine meteorological observatory. The Falkland Islands government has a marine station on South Georgia in connection with the scientific researches on the whaling industry. Most of the Antarctic stations available, it may be remarked, are not very far south; but that is a distinct advantage, for while all are within the true polar regions and experience the real Antarctic climate, they escape in very large measure the long night and its attendant drawbacks, and, most important consideration of all, they are readily accessible, so that a relieving ship should experience little difficulty in gaining all or any of them every summer. The Danes have now established in the Arctic Regions, on Disko Island, a fully equipped biological laboratory; and the extreme desirability of a similar station in the Antarctic need not be further urged. If such a station should be instituted, it would be a matter of extreme interest to attempt to cultivate on certain of the mossy oases various species of hardy Arctic plants, such as *Papaver radicatum*, *Ranunculus sulphureus*, *Cerastium alpinum*, *Saxifraga oppositifolia*, etc., which all prosper and produce seed in Spitsbergen.[15]

COLLECTING

In addition to laboratory work, much still needs to be done in the way of collecting. Further collections are much to be desired, especially from the Pacific and Indian sides, little known except by the various collections from Graham Land and South Victoria Land. Among the Antarctic lands from which no plants are known are Coats Land, Enderby and Kemp Lands, Queen Mary Land, Oates Land, Wilkes Land, Charcot Land, and Alexander I Island, though it is quite to be expected that their flora is very scanty since they are more or less covered with ice and little bare rock appears.

THE SUB-ANTARCTIC ISLANDS AS A FIELD FOR BOTANICAL EXPLORATION

Turning now from the true Antarctic Regions to the sub-Antarctic islands, it must be said that it is here that the most fruitful botanical collections of future expeditions will probably be made. Although a number of them have been studied botanically all would be worth the attention of a careful explorer, especially as regards the lower forms of plant life. Bouvet Island is altogether unknown from a botanical or almost any other standpoint. According to the *Valdivia's* reports, it is entirely covered with ice and is devoid of vegetation: moreover it offers no landing place. On the other hand, previous voyagers have given the island a slightly better reputation, Bouvet (1739) and Lindsay (1808) both reporting trees and shrubs (? tussock grass), and Morrell (1823) speaking of small spots of vegetation. Whatever may be the case it well merits a visit, and in view of its probable accessibility at all times of the year, even in a steel vessel, it is to be hoped it will not be long before we have some definite knowledge of the natural history of the island and its surrounding waters. Gough Island, I can assure any intending botanical explorer, will more than repay a visit, and it is not difficult of access, though landing may be a little troublesome.[16] Many important botanical discoveries could be relied on.

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[15] On my return from the Antarctic in 1904 I attempted to make such an experiment by sending to the Argentine meteorological station at the South Orkneys a supply of seeds of 22 Arctic species of phanerogams, with a request to have them planted in a certain spot which I chose as suitable during my stay at Scotia Bay in 1903. I understand that all the seeds that were planted failed to sprout, but the absence of a biologist on the spot may have militated against the success of the experiment.

[16] R. N. Rudmose Brown: Diego Alvarez, or Gough Island, *Scottish Geogr. Mag.*, Vol. 21, 1905, pp. 430–440; *idem:* The Botany of Gough Island (Scottish Natl. Antarctic Exped. Sci. Res., Vol. 3: Botany, pp. 33–44), Edinburgh, 1912.

The six islands lying in the extreme South Atlantic, which were discovered and named by Cook in 1775 the South Sandwich group, are probably the most neglected spot in all sub-Antarctic regions, and no scientific expedition since that of Bellingshausen in 1820, with the ships *Vostok* and *Mirny*, has visited them, though several sealers and whalers report that they are quite accessible and contain some harbors. Forster, the German naturalist who accompanied Cook, says no vegetation was to be seen, though Cook himself mentions that he observed vegetation to the north end of Saunders Island. Morrell in his somewhat doubtful voyage of 1823, speaking of the islands, says they are "entirely barren." The *Scotia* expedition of 1903–1904 was unable to visit them. The *Deutschland* in 1911 could not make a landing on account of heavy sea, but in 1908 Captain C. A. Larsen landed on two of the group.[17] The islands should be botanically explored. Probably it will be found that they are not entirely barren of vegetation, while their extreme interest from a botanical point of view lies in their position intermediate between the Antarctic and sub-Antarctic zones, the islands approximating to Antarctic conditions, though doubtless not quite so rigorous. The floral statistics should also prove of great interest and may throw some light on the vexed question of the origin of southern floras and former land connections. The flora will probably show a distinct South Georgian and consequently South American relationship, but the point of extreme interest to be looked for is whether it will show near relationships to the flora of the Crozets on the one hand, or to that of the Tristan da Cunha group on the other; and it will be interesting to find out how far this Sandwich group flora has evolved and whether any new and distinct species have originated.

[17] An account of some zoölogical collections made at the Sandwich group by Captain Larsen and Dr. F. Lahille of Buenos Aires is contained in two papers by E. Chevreux: (a) Sur quelques amphipodes des îles Sandwich du sud; (b) Algunos animales marinos de los islos Sandwich, *Anal. Museo Nacl. de Hist. Nat. de Buenos Aires*, Ser. 3, Vol. 14, pp. 403–407 and 409–412 respectively.

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ANTARCTIC ZOÖGEOGRAPHY AND SOME OF ITS PROBLEMS

Robert Cushman Murphy

In considering problems of Antarctic distribution the chief circumstance to be appreciated is the extreme isolation of the land areas and littoral waters. At all points the Antarctic Continent is separated from other parts of the world by five hundred or more miles of practically oceanic depths. Because of the permanent westerly winds which characterize the sub-Antarctic zone, there are, moreover, few compensating interchanges between the warm and cold air and water of the south temperate and polar belts, respectively. No land mass interferes with the fixed meteorological circulation between the latitudes of 55° and 65° S.; while the parallel of 60° S., which serves in many respects as a convenient demarcation between the sub-Antarctic and the truly Antarctic regions, encircles an oceanic waste without touching any islet or other land whatsoever.

Recent expeditions have established the fact that the south polar climate renders terrestrial life conditions more severe than those of any other part of the world. Not only is the winter no less cold at high latitudes than in corresponding regions of the north, but the summer is very much colder, and temperature varies far less in relation to latitude. At the South Orkneys, which lie well outside the circle, the mean temperature of the atmosphere for the three warmest months barely passes the freezing point, and yet at 77° S. the average of the warmest month is only slightly colder (30° F.). The annual means of high southern latitudes, as determined by Meinardus, are as follows: 30° F. in 60° S., 25° F. in 70° S., 18° F. in 80° S., and 15° F. in 90° S.

Even more important than the conditions mentioned is the highly unfavorable combination of low temperature with high winds. For duration, intensity, and frequency of storms the Antarctic has no counterpart, and when we still further take into account the relatively low humidity and a general deficiency of sunlight, we reach a climax in the way of an inhospitable environment. South of the westerly belt of the southern oceans the prevailing winds are easterly, flowing down from the higher parts of the ice-clad continent toward the peripheral barometric lows. That the blizzards of Adélie Land are of this nature, rather than anticyclonic phenomena, is indicated by the manner in which these terrific outrushes of air, chilled by the intense cold of the great plateau, the average altitude of which is estimated at

6000 feet, pour down the slopes under the pull of gravity. Conversely, the still greater cold of favorably placed localities at sea level, such as the Bay of Whales, from which Amundsen began his polar journey, is usually accompanied by calm atmosphere.

The Sub-Antarctic Zone

Situated within or closely outside the pack-ice zone, or at least in similar relation to the outer limit of icebergs, are the fifteen or more islands and small archipelagoes which make up the sub-Antarctic chain. With the exception of the Tristan da Cunha group and St. Paul and Amsterdam, these are beyond the sinuate limit of tree growth. Most of them lie within the belt of westerly winds, many are still actively glaciated, all are characterized by cool summers and slight yearly temperature amplitudes, and all consequently suffer from the inhibiting effect of the controlling oceanic climate which results in a paucity of land fauna and flora far more marked than anything to be found in corresponding latitudes of the northern hemisphere. Few of the typically sub-Antarctic members, such as South Georgia, Kerguelen, and Macquarie, have a mean annual temperature which rises much above freezing, but the extent of an ice-cap depends largely upon the height of the land. Thus Macquarie is almost but not quite glacial, while lofty South Georgia has a permanent névé and great consolidation of ice in the valleys. Islands farther southward, such as the South Shetlands and South Orkneys, are essentially Antarctic in all their climatic and biotic features.

The sub-Antarctic islands form a natural transition zone between south temperate and polar life. Here we find, for example, the handful of southernmost flowering plants (except for two species which barely reach the Antarctic Continent), the southernmost insects save for lowly organized Collembola and wingless flies, the southernmost earthworms, land birds, and waterfowl of northern affinities (e. g. ducks). Here also a large proportion of such sea birds as albatrosses and diversified types of petrels, which range widely in the southern hemisphere, penetrating even as far southward as the pack ice, find their sole nesting grounds. In like manner many of these islands provide the beaches of nativity for typically sub-Antarctic seals, such as the sea elephant (*Mirounga leonina*) and the southern fur seals (*Arctocephalus*), species which like some of the birds are widely dispersed beyond the temperate seas and which also extend their ranges far northward via the paths of cool currents. South of the surface isotherm of 6° C., however, they are replaced by other species of distinctly Antarctic type.

In the present consideration of Antarctic zoögeography it seems advisable to treat the Antarctic and sub-Antarctic zones as a unit, emphasizing the transitions, sometimes gradual and again sharp, which the marine flora and fauna reveal.

Former Land Connections

Some aspects of distribution have been interpreted as supporting theories of early land bridges, which would connect the old Antarctic Continent with South America, Australia, and perhaps with Africa. In fact, the reconstructions which cause certain maps of distribution to resemble seventeenth-century charts of the Terra Australis are based more often upon the inferred migration routes of plants and animals than upon any accepted geological evidence. As recent an investigator as Benham,[1] however, believes that he has exhausted all the possibilities under existing geographic conditions without accounting for the distribution and relationships of oligochaets, insects, spiders, and terrestrial crustaceans at the sub-Antarctic islands. He maintains that the facts demand either land bridges during early Cenozoic time or such a juxtaposition of Antarctica with Australia and South America as is postulated by the Taylor-Wegener hypothesis.

In favor of certain less extensive land connections there is, indeed, evidence from many sources. It is more than probable, for example, that during the early Tertiary Antarctica may have been linked up with Fuegia by closely spaced islands over the route which passes through South Georgia, the South Sandwich group, and the South Orkneys. But as regards major continental offshoots across the present deep-water areas by way of "Gondwana Land" or otherwise, the zoölogical evidence seems to be inconclusive when not actually unfavorable.

Regan[2] denies that the southern fishes show any indication of land bridges and concludes that the Antarctic Continent has been washed for a long time, perhaps throughout the greater part of the Tertiary, by an ocean of extremely low temperature. Much has been made, this author notes, of the distribution of the eel gudgeons (Galaxiidae), the supposed fresh-water fishes of South Australia, Tasmania, New Zealand, and the southern parts of South America. *Galaxias attenuatus*, for example, is a species common to all these regions; but it has now been demonstrated that the fishes of this family breed in the sea and that they are salmonoids of marine origin. The evidence from the distribution of mammals has also been reviewed by Regan, who agrees with many earlier workers regarding the lack of true relationship between the Tasmanian "wolf" (*Thylacinus*) and the Patagonian Miocene marsupials known as Borhyaenidae.

[1] W. B. Benham: Oligochaeta of Macquarie Island (Australasian Antarctic Expedition 1911–1914, Scientific Repts., Ser. C.: Zoölogy and Botany, Vol. 6, Part IV, pp. 1–38), Sydney, 1922.

[2] C. T. Regan: Fishes (British Antarctic ("Terra Nova") Expedition 1910, Nat. Hist. Repts.: Zoölogy, Vol. 1, pp. 1–54), London, 1914.

On the last point, however, Wood[3] has since reached the opposite conclusion.

During the last few years several Australians have attacked the question of earlier distribution, with rather full discussion of the literature. Jones[4] and Anderson[5] support in general the hypothesis of immigration from paleo-Arctic centers, without actually denying the possibility of effective Antarctic land connections. Harrison,[6] on the other hand, flatly espouses the cause of a southern route for the pre-Tertiary constituents of the flora and fauna. In building his bridges, however, this author postulates an elevation which would come near to draining the permanent ocean basins. He seems to ignore the fact that, one after another, many of the resemblances between varied elements of the South American and Australasian faunas have proved illusory, and that more and more the testimony is reduced to groups of animals of whose past history we still know nothing. Indeed, as Anderson holds, the more closely the zoölogical props of Antarctic land-bridge theories are examined, the weaker they appear, while similarity of floras, by analogy from present conditions, affords but poor evidence.

The real proof, or at least the data to shift the burden, would be forthcoming only through the discovery of marsupials or other pertinent material in fossiliferous beds of Antarctica. Here, beyond doubt, lies one of the most fascinating and important opportunities for south polar investigation, as pointed out by the paleontological finds of the Swedish expedition. The mere fact that all or parts of Antarctica once enjoyed a mild climate, a diversified rain forest, etc., does not, as Harrison seems to believe, imply the presence of a mammalian fauna; the region may even then have possessed some proportion of its modern geographic isolation, without terrestrial vertebrates other than birds.

Contrasts Between Arctic and Antarctic Life

The striking contrasts between conditions in the Arctic and Antarctic Regions have been well expressed in many aspects but perhaps never more simply and clearly than by Darwin in his journal of the cruise of the *Beagle*, where, in a section devoted to the climate and productions of the Antarctic islands, he writes:

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[3] H. E. Wood: The Position of the "Sparassodonts," With Notes on the Relationships and History of the Marsupialia, *Bull. Amer. Museum of Nat. Hist.*, Vol. 51, 1924, pp. 77–101.

[4] F. W. Jones: The Mammals of South Australia, Part I: The Monotremes and the Carnivorous Marsupials (Handbooks of the Flora and Fauna of South Australia), British Science Guild, South Australian Branch, Adelaide, 1923; reference on pp. 20–28.

[5] Charles Anderson: The Australian Fauna, *Journ. and Proc. Royal Soc. of New South Wales*, Vol. 59, 1925, pp. 15–34.

[6] L. Harrison: The Migration Route of the Australian Marsupial Fauna, *Austral. Zoölogist* (Royal Zoöl. Soc. of New South Wales), Vol. 3, Part V, 1923, pp. 247–263.

On the northern continents, the winter is rendered excessively cold by the radiation from a large area of land into a clear sky, nor is it moderated by the warmth-bringing currents of the sea; the short summer, on the other hand, is hot. In the Southern Ocean the winter is not so excessively cold, but the summer is far less hot, for the clouded sky seldom allows the sun to warm the ocean, itself a bad absorbent of heat; and hence the mean temperature of the year, which regulates the zone of perpetually congealed under-soil, is low.[7]

From this characterization and the preceding sketch of climatic environment, it will be seen that there is nothing in the south to compare with the highly diversified terrestrial flora and fauna of the north polar regions. Lacking are the equivalents of the Arctic tundra plants, the flowers which bespangle moist, snow-free meadows during the short but warm summer. Lacking, too, are the myriads of ephemeral insects, the land birds, the reindeer, musk oxen, polar carnivora and rodents, which penetrate to the northernmost land projections of the globe.

Another contrast is apparent in the relationships of the respective higher faunas of the two areas. In the Arctic most elements of the vertebrate life are, as might be expected, closely related to forms found within the adjacent temperate belt; but the greater proportion of the higher animal life in the far south gives the impression of strong endemism. The penguins, which have no counterpart in northern regions, the four extremely well-marked genera of truly Antarctic seals, the one genus, and perhaps more species, of cetaceans which are said to be peculiar, well exemplify this distinctive character.

Theory of Bipolarity

Any consideration of Antarctic zoögeography could hardly omit at least a brief review of the time-honored theory of bipolarity, originally suggested by Théel in discussing some of the deep-sea invertebrates of the *Challenger* expedition. The hypothesis was restricted to the marine faunas of extratropical regions and particularly to those of the Arctic and Antarctic. It took into account not so much an admitted general resemblance between the two polar faunas as an alleged identity involving large numbers of marine organisms occurring in both polar areas and not found in the intervening tropics, even though in deep water the temperature conditions remain the same.

Pfeffer,[8] who with Sir John Murray,[9] strongly advocated the essential truth of the theory, interpreted the evidence to mean that numerous species occurring in the higher latitudes of both hemi-

[7] Charles Darwin: Journal of Researches into the Natural History and Geology of the Countries Visited During the Voyage of H. M. S. Beagle round the World, London, 1860, p. 249.

[8] Georg Pfeffer: Über die gegenseitigen Beziehungen der arktischen und antarktischen Fauna, *Verhandl. Deutsch. Zoöl. Gesell.*, Vol. 9, 1899, pp. 266–287.

[9] John Murray: On the Deep and Shallow-Water Marine Fauna of the Kerguelen Region of the Great Southern Ocean, *Trans. Royal Soc. of Edinburgh*, Vol. 38, 1896, pp. 343–500.

spheres and absent from the tropics represented hardy coeval survivors of an almost universally distributed Mesozoic or early Tertiary fauna which had withstood a subsequent cooling of the seas. Under the latter influence a process of separating out and selection had taken place, and the similarity of the causes had resulted in the same components of the old fauna remaining behind in both the north and the south. In this manner, according to these supporters, arose the still well-marked similarity of two faunas of completely discontinuous range.

The theory was promptly combated by Thompson,[10] Ortmann,[11] and other investigators. Thompson showed that the evidence advanced by Murray was inconclusive, much of it being based upon doubtful cases of identity due to poor material or to insufficiently critical taxonomy. He held the distributional facts to be proved only in the case of certain demersal organisms and a few others which inhabit the surface in higher latitudes but also the deeper and colder waters of tropical seas. Further search in temperate and warm oceans would reveal, he believed, the presence of many other "bipolar" species in intermediate zones.

Chun[12] also regarded the known facts as sufficiently accounted for by the continuous distribution of "bipolar" forms via the deeper water, of which he cited examples among the plankton.

The testimony of more recent students has been variously pro and con. Pratt[13] pointed out 32 cases of alleged bipolarity among crustaceans, annelids, and other littoral invertebrates. None of these species, according to the author, has been found within the tropics in either deep or shallow water, and only two of them in temperate seas. In only two instances is there any evidence of passage of these forms along the prevailingly cool western coast of America, while evidence of similar interchange by way of the west coast of Africa is entirely lacking.

Still more recently Meisenheimer[14] has recorded practical identity in two or more species of northern and sub-Antarctic pteropods. He calls attention to the fact that one of the northern species which he cites has broken up into several varieties, whereas the respective Antarctic representative exists as a single circumpolar form. Meisenheimer suggests the tropical origin of the pteropods and their pelagic

[10] D'A. W. Thompson: On a Supposed Resemblance Between the Marine Faunas of the Arctic and Antarctic Regions, *Proc. Royal Soc. of Edinburgh*, Vol. 22, 1897–99, pp. 311–349 (read in 1898).

[11] A. E. Ortmann: On New Facts Lately Presented in Opposition to the Hypothesis of Bipolarity of Marine Faunas, *Amer. Naturalist*, Vol. 33, 1899, pp. 583–591.

[12] Carl Chun: Die Beziehungen zwischen dem arktischen und antarktischen Plankton, Stuttgart, 1897.

[13] E. M. Pratt: Some Notes on the Bipolar Theory of the Distribution of Marine Organisms, *Memoirs and Proc. Manchester Lit. and Philos. Soc.*, Vol. 45, 1901, No. 14, pp. 1–21.

[14] Johannes Meisenheimer: Die Pteropoden der Deutschen Südpolar Expedition (Deutsche Südpolar Expedition 1901–1903, herausg. von Erich von Drygalski, Vol. 9: Zoölogy, Part I, pp. 93–153), Berlin, 1906.

expansion into cold-water areas. He also rightly regards the absence of connectants through the warmer regions as of more importance than absolute identity of the bipolar forms. It should be noted by way of caution, however, that Meisenheimer deals for the most part with rather widely distributed north temperate, rather than with truly Arctic or sub-Arctic pteropods.

Pelseneer,[15] Dollo,[16] and Regan[17] have, on the other hand, strengthened the objections of Thompson. Dollo, for example, states that evidence drawn from the fishes, birds, mammals, tunicates, crustaceans, mollusks, worms, echinoderms, coelenterates, sponges, and plants, is all against bipolarity. He holds that the polar faunas are independent adaptations and in no sense the relics of a universal fauna spreading toward the poles from tropical shallow water or mud line. The existence of certain identical and non-cosmopolitan organisms in both polar areas is not impossible, he admits, but is aside from the problem. The real point concerns the question as to whether the characteristics of the present polar faunas are due to a direct common origin and whether they have remained unchanged because of the maintenance of polar climates.

Gran,[18] in a work by Murray himself, mentions two species of oceanic diatoms which are "the two most characteristic forms along both the polar boundaries of the Atlantic." He adds, however, that these forms have both been found within the tropics and that there is no similar agreement between the Arctic and Antarctic waters when we consider the neritic diatoms.

Berry[19] states that the cephalopod fauna of Antarctic shores shows no relation to that of the Arctic save a superficial facies due, no doubt, to the similarity of physical environment. There is not a single bipolar species.

Ortmann[20] stresses the peculiar character of much of the south polar fauna. He believes that little if any of it is derived from the tropics but that it is rather a remnant of the Pacific Mesozoic fauna which had its original home on the shore of the Antarctic Continent. A rather extensive and striking element which he finds among the littoral ensemble at the southern extremities of the great continents

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[15] Paul Pelseneer: Mollusques (Expédition Antarctique Belge: Résultats du Voyage du S. Y. Belgica en 1897, 1898, 1899 sous le commandement de A. de Gerlache de Gomery: Rapports Scientifiques, Vol. 7–9: Zoologie, Part 50–51, p. 58), Antwerp, 1903.

[16] Louis Dollo: Poissons, *ibid.*, Vol. 7–9, Zoologie, Part 53, Paris, 1902, section on "Bipolarité," pp. 191–207.

[17] C. T. Regan: The Antarctic Fishes . . . (Scottish National Antarctic Expedition: Report on the Scientific Results of the Voyage of S. Y. "Scotia" . . . 1902–1904, under the leadership of W. S. Bruce, Vol. 4: Zoology, pp. 311–374), Edinburgh, 1913.

[18] H. H. Gran: Pelagic Plant Life, in: Murray and Hjort's "The Depths of the Ocean," London, 1912, pp. 307–386; reference on p. 352.

[19] S. S. Berry: Cephalopoda (Australasian Antarctic Expedition 1911–1914, Scientific Repts., Ser. C.: Zoölogy and Botany, Vol. 4, Part II, pp. 1–38), Sydney, 1917.

[20] A. E. Ortmann: Origin of the Deep-Sea Fauna, *Rept. 8th Internatl. Geogr. Congr., Held in the United States, 1904*, Washington, 1905, pp. 618–620.

differs entirely from anything in the Arctic. For the progenitors of this, he holds, we must look to the Tertiary Antarctic fauna and to the pre-Tertiary Pacific.

However, the bipolarity problem may not be allowed to rest here, for as often as the theory is "discredited," it seems certain to be resurrected in one phase or another. Théel,[21] in a careful review, points out the indubitable bipolarity of certain priapulids, shallow-water wormlike organisms quite incapable of distant transportation in either the adult or larval stages and unknown, in the case of the bipolar species, from regions intervening between the two polar oceans. Such a phenomenon, he maintains, cannot be due to convergence and is one of a number of examples of true bipolarity which fully meet the requirements laid down by Thompson and which demand a specific interpretation. The one which Théel offers uncompromisingly harks back to the original idea that such organisms are "relicta, that their progenitors had a world-wide distribution, and that they are in possession of a remarkable power of resistance."

Still more recently, Benham[22] reports the discovery of another Arctic species of this same vermiform group (*Phascolosoma eremita*) at a depth of 318 fathoms in Commonwealth Bay, Adélie Land. The species is widespread in Arctic seas, and Benham believes that its addition to the list of bipolar species strengthens Théel's views.

The whole subject, as Thompson has said, needs argument less than investigation. The importance of a group of animals in relation to any problem of distribution depends, first, upon the thoroughness of the collecting throughout the entire range and, then, upon the extent to which classification has been correctly worked out. Further elucidation of bipolarity, which can evidently no longer be accepted in its broad and naïve sense, rests especially upon scrupulous systematic work. Murray tells us that the greatest difficulties encountered during the classification of the *Challenger* collections were due to the extraordinary number of species and genera of marine invertebrates found to possess reduplicated names. Possibly he was not even wrong in assuming that the northern and southern seas would now show many more common or closely allied species but for the fact that systematists are often prone to regard discontinuity as sufficient reason for making the most of very slight differences.

The inherent weakness in the bipolar hypothesis is touched by the question "What has now become of the tropical representatives of the formerly universal fauna?" The inference seems to be that, owing to the higher rate of metabolism in warm water, the primordial or-

[21] Hjalmar Théel: Priapulids and Sipunculids Dredged by the Swedish Antarctic Expedition, 1901–1903, and the Phenomenon of Bipolarity, *K. Svenska Vetenskaps.-Akad. Handl.*, Vol. 47, 1911, No. 1, pp. 1–36.

[22] W. B. Benham: Gephyrea Inermia (Australasian Antarctic Expedition 1911–1914, Scientific Repts., Ser. C.: Zoölogy and Botany, Vol. 6, Part V), Sydney, 1922, pp. 1–22.

ganisms have disappeared from intertropical regions through evolutional transformation rather than extinction, but neither Théel nor other recent workers discuss this point. Until it has been squarely met, however, may not the data serve equally well to support the converse theory of a universal *cold sea* in earlier geologic times, with subsequent elimination of certain types from the intervening areas as they became warm?

In considering bipolarity in its historical aspect, care must be taken to distinguish the original restricted meaning of the term from various usages which have given it distinct though related significance. Heintze[23], for instance, explains the "bipolarity" of many species of plants through entozoic carriage of seeds by shore birds (Limicolae) at the culmination of the last Ice Age. Similar methods of approach might conceivably give a clue to some of the existing problems in the sea.

Terrestrial Biota

The fauna and flora of the true Antarctic and adjacent regions being mostly littoral or oceanic, with a minimum of terrestrial elements, it will be advisable to begin our discussion with the latter.

PLANTS

On one part of the continent only, and on islands near by, there are two kinds of flowering plants, namely a grass and a *Colobanthus*, both Fuegian species. North of the Arctic Circle, it should be remembered by way of comparison, some four hundred species of vascular plants grow. On the very restricted exposed land surfaces of the Antarctic Continent there are patches of cryptogamic vegetation comprising mosses, lichens, and fungi. These, with a few fresh-water algae and certain microphytes which flourish only in snow and ice, make up the entire flora. Among the 63 south polar mosses, 27 species, or 43 per cent, including one genus, are found nowhere else—a high percentage of endemism. The present paucity of vegetation is doubtless postglacial. At any rate, a rich flora which resembled in many respects that of modern New Zealand, Australia, and southern South America once flourished. Fossil floras of both Jurassic and late Cretaceous or early Tertiary age, and including such trees as *Sequoia*, *Araucaria*, and *Fagus*, are known from West Antarctica. It has been suggested that from this region as a center many plants and animals once extended their ranges into more northerly zones.

Schenck[24] emphasizes the fact that Antarctic plants can vegetate

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[23] A. Heintze: Om bipolara växter och deras vandringar, *Fauna och Flora*, Vol. 13, 1918, pp. 145–161.

[24] Heinrich Schenck: Vergleichende Darstellung der Pflanzengeographie der subantarktischen Inseln (Wissenschaftliche Ergebnisse Deutsch. Tiefsee-Expedition, Vol. 2, Part 1, pp. 1–178), Berlin, 1905; Flora der Antarktis, pp. 169–178.

during only a few days of the summer, when solar radiation may be very high, with a correlated rapidity of growth and reproduction. Plants, as Darwin has said, exist not where they can, but only where they *must*, and the wonder is, in view of the unparalleled severity of the environment, the absence of any warm period, and the presence of vast numbers of penguins, which, as Rudmose Brown[25] has shown, render much of the bare surface unsuitable for vegetation, that post-glacial plants have contrived to gain even the slight foothold to which they now cling.

Skottsberg considers the plant life of Palmer Land (by some called Graham Land), the South Shetlands, and South Orkneys as essentially Antarctic. The sub-Antarctic vegetation which occurs on most of the other surrounding islands, in part north of the tree limit at Gough and Amsterdam Islands, offers a marked contrast with the truly polar flora. While the vascular plants are still relatively limited, we do find local species of widely distributed northern genera, such as *Carex*, *Poa*, and *Ranunculus*, together with Alpine types of south temperate genera. The "Kerguelen cabbage" (*Pringlea antiscorbutica*) has no near relative in the southern hemisphere but is closely related to the northern *Cochlearia*.

As Skottsberg[26] lists the vegetation of South Georgia, a typically sub-Antarctic island, it comprises 214 species, of which 19 are vascular plants, 99 mosses, 36 hepatics, and 58 lichens. Spitsbergen, which extends to latitude 80° N., has 120 species of vascular plants. The most conspicuous and generally distributed element in the South Georgian flora is the tussock grass (*Poa flabellata*), which is found at nearly every southern island. Macquarie Island, on about the same parallel as South Georgia, has 34 vascular plants.

INSECTS

On the Antarctic Continent there is almost no land fauna away from the penguin rookeries, in the vicinity of which are found mites, such lowly organized insects as Collembola, and a wingless Chironomid fly, together with a few rotifers, a tardigrade (well named *Macrobiotus antarcticus*), and two or three protozoans in the moss. Members of several of these groups, like the vegetation, are characterized by enormously specialized viability. They awaken for at most a few days in summer in order to carry on their active life processes, and they are capable of existing for months, perhaps for years, in a frozen

[25] R. N. Rudmose Brown: The Life and Habits of Penguins (Scottish National Antarctic Expedition: Report on the Scientific Results of the Voyage of S. Y. "Scotia" . . . 1902–1904, under the leadership of W. S. Bruce, Vol. 4: Zoölogy, pp. 249–253), Edinburgh, 1915.

[26] Carl Skottsberg: Die Gefässpflanzen Südgeorgiens (Wissenschaftliche Ergebnisse der Schwedischen Südpolar-Expedition 1901–1903, herausg. von Otto Nordenskjöld, Vol. 4, Part III, pp. 1–12), Stockholm, 1905.

state. According to Enderlein, the only species of insects with a wide distribution in the Antarctic are parasites of seals.

The insect population of the sub-Antarctic islands is naturally somewhat richer. At South Georgia, for example, we find 5 species of beetles, 4 of Diptera, and 5 of Collembola, not counting parasitic forms. Enderlein[27] remarked that the insect fauna of South Georgia is so well known that new forms can hardly be looked for, but the fact that several have since been added is indicative of the possibilities of future collecting. The richest part of the sub-Antarctic zone, so far as insects are concerned, is what Enderlein calls the "Heard-Marion region," comprising the groups of islands lying between these two as extremes. We might expect such relative profusion to be associated with the more diversified vegetation of the Indian Ocean islands. Kerguelen has 54 species of insects, including about 7 which have been introduced. The native fauna, however, represents no less than 9 orders, including Coleoptera, Lepidoptera, Hymenoptera (an ant, *Camponotus*), and Diptera, in addition to Collembola, Thysanura, etc. The presence of ants on Kerguelen, as well as the Crozet group, is especially interesting because these insects occur at none of the other sub-Antarctic islands nor at the Falklands. Among beetles, the following families are found at one or another of the sub-Antarctic islands: Tenebrionidae (meal worm beetles), Curculionidae (weevils), Staphylinidae (rove beetles), Dytiscidae (carnivorous water beetles), Carabidae (carnivorous ground beetles). Macquarie has a Crambine moth, and a locustid reaches the Antipodes Islands.

LAND BIRDS

The land birds of the sub-Antarctic isles are notable for their small number when contrasted with the varied bird population of even much higher latitudes in the north, but they present few geographic problems. The southern outliers of New Zealand have endemic snipe, rails, or parrot-like forms, all of obvious affinities. The native pipit of South Georgia is related to species in South America, directly to windward, as is also the native teal. The pintail duck of Kerguelen and the Crozets is of holarctic relationship, and its presence is more puzzling. The sheathbill (*Vaginalis*) is an aberrant and very peculiar Limicoline, which has penetrated from southern South America to the polar continent by way of the islands and the Palmer Land peninsula. A related genus occupies the islands of the Indian Ocean, but the group has gone no farther along a circumpolar track. It would be exceedingly interesting to learn which form of sheathbill, if any, inhabits Bouvet Island.

[27] Günther Enderlein: Die Insekten des Antarktischen Gebietes (Deutsche Südpolar Expedition 1901–1903, herausg. von Erich von Drygalski, Vol. 10: Zoölogy, Part II, pp. 361–528), Berlin, 1909.

MAMMALS INTRODUCED BY MAN

No fresh-water fishes are found on any island south of 55° S., and neither the Antarctic Continent nor any of the sub-Antarctic islands have native land mammals. The nearest approach to a sub-Antarctic insular mammal was the now extinct Falkland Island fox. That the absence of mammals is due to isolation, rather than to rigorous climate or scanty food supply, is shown by the fact that rats, reindeer, and horses, introduced by man, thrive in a feral state at South Georgia. The rats have existed at this island for well over a century, feeding both upon vegetation, such as the tussock grass, and upon burrowing petrels and their eggs. To some of the native birds they have apparently become a serious menace. During their three hundred or more generations of residence at the island, the rats, according to Lönnberg,[28] have evolved a longer and denser coat of fur than that characteristic of their northern progenitors. This, together with certain other peculiarities, justifies, he believes, the description of the South Georgia rat as a new subspecies,[29] although, with the persistent yet groundless legend of Darwin's Porto Santo rabbit as a warning, the matter needs further inquiry.[30] In contrast with the ability of the adaptable rat and the naturally acclimated reindeer to survive, it has been found that neither rabbits nor sheep can endure the heavy snowfall and the unvarying even though seldom extreme cold of South Georgia. At Macquarie Island, on the contrary, both rabbits and sheep can flourish.

Richness of the Marine Life, and Its Basis

Whatever wealth of land life is wanting in the region under discussion is amply compensated for by the profusion of life in the sea. These austral waters make up the coldest marine area on the globe according to Andersson,[31] with depth temperatures a degree or more below the centigrade zero, and yet they are so teeming with life that no expedition has failed to obtain many new species at all depths in which collecting has been undertaken.

The food substances of all forms of life in the ocean comprise carbonic acid, nitrites and nitrates of calcium and magnesium, etc., phosphates, silica, and salts containing a few other elements. These all exist in very small quantities, at most in the proportion of a few

[28] Einar Lönnberg: Contributions to the Fauna of South Georgia, I: Taxonomic and Biological Notes on Vertebrates, *K. Svenksa Vetenskaps-Akad. Handl.*, Vol. 40, 1906, No. 5; reference on pp. 21–23.

[29] R. C. Murphy: Faunal Conditions in South Georgia, *Science*, Vol. 46, 1917, pp. 112–113.

[30] G. S. Miller: Catalogue of the Mammals of Western Europe (Europe exclusive of Russia), in the Collection of the British Museum, London, 1912, p. 494.

[31] K. A. Andersson: Das höhere Tierleben im antarktischen Gebiete (Wissenschaftliche Ergebnisse der Schwedischen Südpolar-Expedition 1901–1903, herausg. von Otto Nordenskjöld, Vol. 5 (Zoölogy, I), No. 2, pp. 1–58), Stockholm, 1905.

parts per million of water. The vast quantity of living substance in the ocean is therefore built up from materials present in exceedingly dilute solution, and the solution is dilute just because organisms are incessantly using up the materials. But sea waters of low temperature are favorable to a high gaseous content and are, moreover, richer in the mineral nitrogenous compounds (ammonia, nitrites, and nitrates) than are temperate or tropical waters. The waters of the Antarctic, for example, contain on the average 0.5 per million of nitrogen in the above forms, as compared with an average content of 0.15 per million in the North Atlantic and 0.10 in equatorial seas. The plankton, and especially the phytoplankton, is therefore far more abundant in polar than in warm oceans, and especially so in shallow coastal waters of relatively low salinity. Owing to the angle of incidence of a low sun and the dense screen of plankton, the photic zone is thin. Growth is mostly restricted to the upper hundred fathoms, with much reduced reproduction in the lower strata. The microscopic plant forms, obtaining their food substances directly from mineral sources, combine the simple nitrogenous salts with carbohydrate resulting from the synthesis of water and carbonic acid under the action of sunlight and produce proteids. This protophytic type of growth is the basis of the existence of all animal organisms, from tiny copepods to whales.

But the abundance of nutritive substance in cold sea water, which has been so greatly stressed by oceanographers, does not alone account for the abundance of life. The crux of the matter lies in the vastly larger number of coexisting generations. Loeb's[32] illuminating experiments upon larval sea urchins demonstrate that the temperature coefficient of duration of life differs enormously from the temperature coefficient of development. From this he concludes that the chemical processes which determine development are altogether different from those which cause old age and natural death. According to the formula deduced by Loeb, if the longevity of an echinoderm larva at T° C. is equal to D, its length of life at a temperature of T-n degrees will equal 2^n D. In other words, a lowering of the temperature n° C. multiplies the length of life by 2^n. When the temperature coefficient of longevity at 10° C. equaled 1000, Loeb found the coefficient of development to be only 2.8. With regard to the extraordinarily rich plant and animal life in the surface waters of the cooler seas, he applied the principle as follows: Within the range of the experiments, reduction in temperature of 10° C. increases longevity a thousandfold; reduction of 20° C. increases longevity a millionfold; but the corresponding periods of development are multiplied by only about three and nine, respectively. From this it follows that at

[32] Jacques Loeb: Über den Temperaturkoeffizienten für die Lebensdauer kaltblütiger Thiere und über die Ursache des natürlichen Todes, *Pflügers Archiv für die Gesammte Physiol.*, Vol. 124, 1908, pp. 411–426.

0° C. many more successive generations of the same species must exist contemporaneously than at 10° or 20°.

Such generalizations are based upon very limited but undoubtedly sound data. Their extension offers a peculiarly fruitful field for research of a type which might be readily conducted in the ship or shore laboratories of a modern polar expedition.

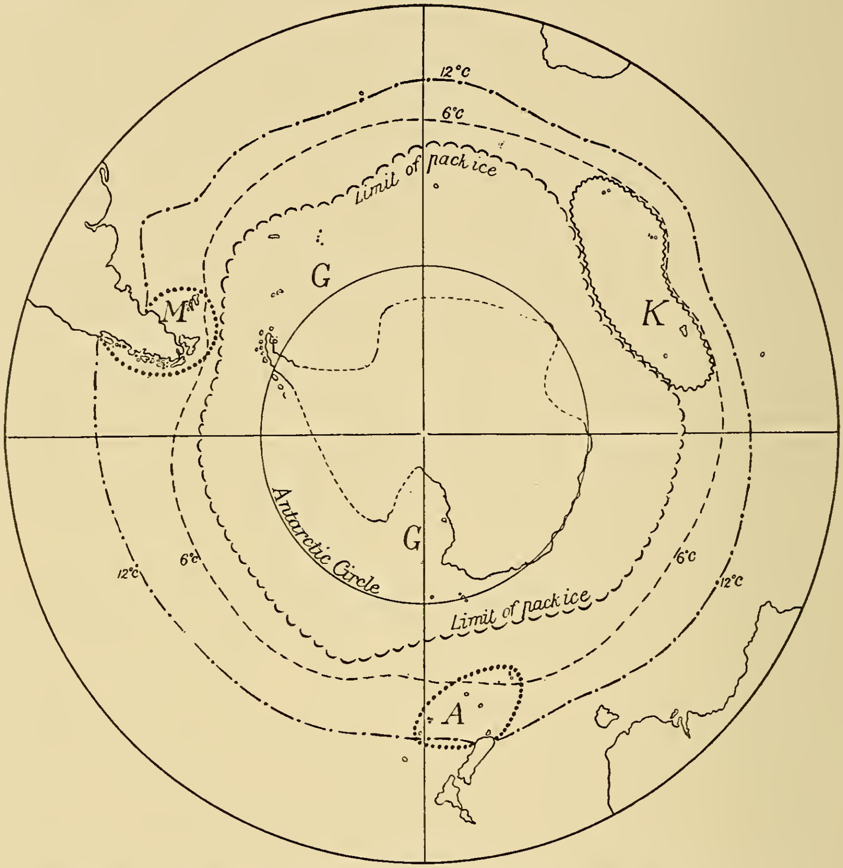

Fig. 1—Map of the fish regions of Antarctic and sub-Antarctic waters, after Regan (paper cited above in footnote 2). Scale, about 1:120,000,000.

The mean annual surface isotherms of 6° C. (– – – –) and 12° C. (— · — ·) as calculated by G. Schott respectively represent the northern limits of the Antarctic and sub-Antarctic zones. The Antarctic zone includes the Glacial district (G), whose northern boundary is the extreme limit of pack ice (⌒ ⌒ ⌒ ⌒), and the Kerguelen district (K), comprising, in addition to Kerguelen, the Marion, Crozet, and Heard island groups. The sub-Antarctic zone includes the Magellan (M) and Antipodes (A) districts.

In tropical seas the predominating groups of marine invertebrates are those which secrete large quantities of calcium carbonate, comprising such forms as corals, macrura, brachyura, anomura, lamellibranchs, gasteropods, etc. In the Antarctic seas these are largely replaced by organisms containing little lime, among which may be mentioned tunicates, hydroids, holothurians, annelids, amphipods, and schizopods. Among the last, the Euphausiids, or opossum shrimps, which have a non-calcareous carapace, exist in inconceivable myriads and furnish food for vast numbers of vertebrates. The secretion of calcium carbonate is determined mainly by temperature. We see an effect of the cold environment in the feeble development of large molluscan shells or limy skeletons either in Antarctic waters or in the deep sea. Even the shelled pteropods of warm oceans tend to be replaced to southward by naked forms.

The invertebrates do not divide geographically so as to indicate a definitely Antarctic group, but many specializations similar to the foregoing illustrate adaptations to Antarctic life conditions. The richness of life in the southern oceans is indicated by figures which Murray[33] records of collections made in the vicinity of Kerguelen Island during the *Challenger* expedition. The number of species of metazoa obtained at eight stations in depths exceeding 126 fathoms was 272. More remarkable is the fact that *not one species among these* proved common to all eight stations, and not more than 40 of them were common to any two stations. From such data Murray inferred that further dredgings in the deep water toward the Antarctic would yield a large number of new species, a prophecy which has been abundantly fulfilled. He called attention, furthermore, to the fact that the vicinity of the mud line, at a depth of about a hundred fathoms, is especially rich and that the change in the nature of bottom deposits which occurs beneath the border of the pack ice is responsible also for a transformation in the benthic fauna. Another general condition seems to be substantiated by the southern marine invertebrates, as well as by fishes and higher organisms, namely, that while short distances may reveal well-marked faunal changes in the sub-Antarctic zone, the greater proportion of the truly Antarctic fauna is characterized by circumpolarity. Pelseneer,[34] for instance, notes many circumpolar species among truly Antarctic mollusks, while among sub-Antarctic forms he finds specific change within small distances to be the rule.

The Austral Fishes

According to Regan,[35] all of the fishes native to waters beyond the south temperate regions may be assigned (Fig. 1) to either the sub-Antarctic zone, with two districts which he designates by the names Magellan and Antipodes, or to the Antarctic zone, which is likewise divided into two districts, a Glacial and a peri-Glacial. The annual surface isotherms of 6° C. and 12° C. mark, respectively, the

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[33] Work cited in footnote 9, above.

[34] Work cited in footnote 15, above.

[35] Work cited in footnote 2, above.

northern boundaries of the Antarctic and sub-Antarctic zones. Regan further divides the fauna into coastal and oceanic assemblages, including in the former not only the littoral fishes but also those which occur not far from the coast, in waters down to a depth of 300 fathoms, and which are not pelagic or bathypelagic.

The Antarctic zone includes therefore the coasts of the polar continent and all islands which lie to the southward of the isotherm of 6° C., "with the probable exception of Macquarie." In this zone we find an absence of south temperate types, a high percentage of peculiar genera, and few species which range beyond the limits of the zone. In the division which Regan terms the Glacial district, 90 per cent of the fishes are Nototheniiformes, a Percoid group confined to waters of the far south and somewhat analogous to the cod group of the northern hemisphere, although in appearance many of them rather resemble sculpins. Most of the other fishes of the Glacial district are eelpouts (Zoarcidae), many of the species of which are circumpolar. The Zoarcidae also have sub-Antarctic representatives, of which *Lycenchelys* and *Melanostigma* represent northern deep-water genera which have no species in the south temperate zone.

The Kerguelen, or peri-Glacial district, which includes the Crozet Islands and others lying south of the limit of pack ice, is a small and somewhat impoverished branch of the Antarctic zone, but with well-marked characters of its own.

The sub-Antarctic zone, covering generally the regions between the surface isotherms of 6° and 12° C., is penetrated by a number of south temperate types. Galaxiidae are characteristic; most of the Nototheniiformes belong to the genus *Notothenia*, and there are several peculiar Zoarcidae.

The Nototheniiformes as a group extend northward to the continents of South America, Africa, and Australia, to New Zealand, Juan Fernandez, Tristan da Cunha, St. Paul, and Amsterdam. They are divided into four distinct families and their present variety indicates, according to Regan, the existence of a large cold southern ocean throughout a great period of time. *Bovichthys* is the most northerly genus, and *Trematomus* the most southerly. It is interesting and true to form to note that no *Bovichthys* is of circumpolar distribution, a distinct species being found in each of the sub-Antarctic areas. In *Trematomus*, on the other hand, most of the known species are circumpolar. The condition harmonizes, incidentally, with what is known of the circumpolar distribution of fishes in the Arctic.

Zoögeographic Relationships of the Mammals and Birds

So far as the orders and families of birds and mammals are concerned, the Antarctic by no means forms a distinct province. Among birds the penguins and sheathbills are both southern hemisphere groups, though the former have an extensive distribution in temperate and even in equatorial latitudes. Several genera of sea mammals, including four seals and the pygmy right whale (*Neobalaena*), are peculiar to the waters of the far south and have been made the criteria of a distinct marine area, the Notapelagia of Sclater.[36] On the whole, however, the Antarctic birds and mammals are characterized rather by high specialization of structure and habits than by fundamental remoteness from more northerly stocks. At least two representatives among birds, namely the species complex of the skua gulls (*Catharacta*) and the silver-gray fulmar (*Priocella antarctica*), might almost be regarded as bipolar, for closely related forms of these birds inhabit high latitudes in each hemisphere. The genus name *Priocella* perhaps unjustifiably obscures the very close relationship of this southern petrel with *Fulmarus*. There seems to be no common meeting ground of the northern and southern skuas and fulmars, respectively, in tropical and temperate seas. These sea fowl therefore fulfill the requirement of completely discontinuous range demanded by the bipolar hypothesis, though we should scarcely be justified in applying the original interpretation to such mobile creatures as sea birds.

Distribution of Antarctic Birds

As indicated above, only a handful of true land birds reach the sub-Antarctic islands, and beyond the 55th parallel or thereabouts there is not a single species. The only Antarctic birds, indeed, which take even a portion of their food from anywhere except the ocean, are the skua, the sheathbill, and the giant petrel (*Macronectes*). All the others are apparently incapable of even recognizing food substances except in their watery element. According to Gain,[37] only about 32 species of birds penetrate beyond latitude 60° S., and most of these are sub-Antarctic wanderers rather than polar species.

But three species of birds can be considered exclusively Antarctic, namely the south polar skua (*Catharacta maccormicki*), the Adélie penguin (*Pygoscelis adeliae*), and the emperor penguin (*Aptenodytes orsteri*); and, as might be expected, these three are fully circumpolar. The emperor penguin has been taken as far south as 78° S. Even during the non-breeding period it clings to the northern border of the fast-ice which fringes the Antarctic Continent. Apparently it avoids for the most part the northwardly projecting peninsula of

[36] *Berardius*, another cetacean which Sclater placed in this group, has since been discovered in the Arctic, so that the genus may be called bipolar.

[37] L. Gain: Oiseaux antarctiques (Deuxième Expédition Antarctique Française, 1908–1910, commandée par le Dr. Jean Charcot: Sciences naturelles, Documents scientifiques, Vol. 2, pp. 1–200), Paris, 1913.

West Antarctica, though a few examples have been noted as far north as the South Orkneys. Its breeding habits are most extraordinarily specialized, for the incubation of the egg takes place in the dead of winter. The probable origin of its almost "marsupial" mode of brooding the egg and young, a habit shared by its congener, the sub-Antarctic king penguin (*Aptenodytes patagonica*), has interesting geographic significance. It may well be reminiscent of a period of such extensive glaciation that ice-free terrane, upon which an egg might be deposited and hatched, was totally lacking throughout the range of the genus.

The Adélie penguin, which breeds upon more or less snow-free headlands of the continent and outlying islands, reaches the northern limit of its residential range at the South Orkneys. Upon the approach of the austral winter this species takes to the northern edge of the pack ice, where the birds lead a pelagic life. Its return across the fast-ice to its nesting grounds during October is the Antarctic signal of spring. At any one locality this occurrence, which has been dramatically described by several visitors to the far south, falls on practically the same date each year.

The entirely predaceous polar skua probably earns the distinction of being the southernmost bird on the globe. Amundsen[38] encountered two at the inner edge of Ross Barrier, latitude 84° 26′ S., on January 9, 1912; and, in December of the same year, Mawson[39] observed one, which flew off in the direction of the pole, when he was more than 125 miles from the sea, and at an altitude of 3600 feet, in Adélie Land.

The second circumpolar group of Antarctic birds is made up of two species of Tubinares, the snow petrel (*Pagodroma nivea*) and the so-called Antarctic petrel (*Thalassoica antarctica*), which, however, extend their wanderings to the sub-Antarctic islands, at least in the American quadrant. Apparently the range of the snow petrel does not extend north of the limit of the pack ice. Indeed the bird is seldom seen away from the vicinity of the pack, though it is not uncommon at South Georgia even during the summer. Wilson[40] has called attention to the development of whiteness, or light coloration, among the Antarctic vertebrates. Although far less general than in the Arctic, it is exemplified perfectly by the snow petrel and in lesser degree by the crab-eater seal, the polar skua, the young of the emperor penguin (which differs in color from that of the closely related king penguin), and the giant petrel. The last-named, highly variable bird even suggests a definite correlation between latitude and pigmentation, for

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[38] Roald Amundsen: The South Pole, 2 vols., London, 1913; reference in Vol. 2, p. 164.

[39] Douglas Mawson: The Home of the Blizzard, 2 vols., London and Philadelphia, 1915; reference in Vol. 1, p. 289.

[40] E. A. Wilson: Mammalia (National Antarctic Expedition 1901–04, Natural History, Vol. 2; Zoölogy, pp. 1–69), 1907.

white examples are proportionately more numerous at the Antarctic limit of the breeding range than in the sub-Antarctic islands.

A third Antarctic group, likewise made up entirely of petrels, is circumpolar throughout both the Antarctic and the sub-Antarctic. It comprises the giant petrel, a storm petrel (*Oceanites oceanicus*), the silver-gray fulmar, and the Cape pigeon (*Daption capensis*). The first of these breeds even at the Falkland Islands. All four species are famous oceanic wanderers, the *Oceanites* regularly migrating to high latitudes in the North Atlantic during the northern summer and the other three approaching or crossing the equator by way of the cool littoral of western South America.

A fourth group of somewhat heterogeneous composition is circumpolar in the sub-Antarctic belt but extends into the Antarctic proper only via the South Orkney-South Shetland-Palmer Land approach. The birds of this group are the gentoo penguin (*Pygoscelis papua*), the macaroni penguin (*Eudyptes chrysolophus*),[41] the kelp gull (*Larus dominicanus*), the sub-Antarctic skua (*Catharacta antarctica*), which is a very different bird from the south polar skua, the blue petrel (*Halobaena*), and a storm petrel (*Fregetta tropica*).

Finally, the last aggregation which can be called Antarctic is made up of certain species characteristic of southern South America, the Falklands, South Georgia, or the islands to the southward, which penetrate into the adjacent parts of the south polar mainland. These are the ringed penguin (*Pygoscelis antarctica*), a tern (*Sterna hirundinacea*), the sheathbill, and a shag (*Phalacrocorax atriceps*). The zoögeographic importance of the Palmer Land peninsula and its outliers as a connection with South America is evident. By this route no less than ten species of birds have gained a local foothold on the polar continent. Mere proximity does not wholly account for this, for the extension of the great land projection toward the milder winds of the belt of westerlies endows it with generally favorable life conditions. It is probably the richest part of Antarctica, and Drygalski has likened the region to the west coast of Spitsbergen.

The foregoing geographical grouping of Antarctic birds has been adapted from Andersson,[42] who has also applied the same plan to a discussion of the seals. Although based upon altogether insufficient collecting, it may serve as a skeleton to be clothed with further observations.

Many other species of penguins, Tubinares, etc., are exclusively sub-Antarctic in their breeding ranges and are unknown south of the northerly parts of the pack-ice region. The king penguin, several albatrosses (*Diomedea*, *Phoebetria*, *Thalassarche*), the prions, or whale

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[41] In the literature the crested penguin of West Antarctica has been incorrectly reported as another species, *Eudyptes chrysocome*.

[42] Work cited in footnote 31, above.

birds (*Pachyptila*), the diving petrels (*Pelecanoides*), and a number of closely related cormorants are examples.

Some of the penguins are south temperate in range, and at least two species are exclusively tropical, if latitude rather than temperature of the sea water be made the test. No penguin of the genus *Spheniscus* reaches sub-Antarctic shores, the often repeated record of *S. magellanicus* at South Georgia being due to a misinterpretation of the vernacular name "jackass penguin" which Weddell applied to *Pygoscelis papua*.

In keeping with the general features of the biota of cold oceans, the austral marine bird life is relatively poor in species but enormously rich in individuals. The flocks of several kinds of sub-Antarctic petrels beggar description. Rudmose Brown[43] mentions a rookery of a million Adélie penguins on Graptolite Island, South Orkneys, and one of two hundred thousand ringed penguins at Route Point. Mawson[44] speaks of a colony of royal penguins covering 16½ acres at Macquarie Island and comprising about three-quarters of a million birds. He refers also to the *legalized* destruction by oil hunters of three hundred thousand penguins per annum at the same island.

Need for More Extensive Ornithological Data

Our ultimate understanding of the distribution of birds in the circumpolar oceanic area is bound up with far more extensive collecting, with broad taxonomic work such as only satisfactory collections can make possible, and with bringing to bear an "oceanographic" point of view in considering the reactions of the living birds. The terrestrial life of these creatures, as is sometimes forgotten, is reduced to a minimum; their ranges appear to be circumscribed, in the main, by the same set of factors which control other pelagic organisms, and detailed study of their marine ecological relationships promises fruitful outcome.

As regards collecting, it is certain that no adequate series of Antarctic or sub-Antarctic specimens, representing forms from the entire breeding range of a single genus, have yet been brought together. Taxonomic studies, especially those pertaining to species and races of the sub-Antarctic islands, have thus far been made at random, a fact which we realize today far more than was realized a few decades ago, when the famous Catalogue of Birds of the British Museum and subsequent monographs were published. From year to year since that time new material has seeped in little by little to museums in a score of countries, and piecemeal systematic studies have revealed intricate diversity among the species or lesser units of certain

[43] Work cited in footnote 25, above.

[44] Douglas Mawson: Macquarie Island, *Proc. Royal Geogr. Soc. of Australasia: South Australian Branch*, Vol. 20, 1921, pp. 71–85.

groups, while others seem to spread over very large areas without exhibiting geographic variation—contrasting states which impress us with the nonconformity of nature. A sound classification of the birds found between the roaring forties and the Antarctic Continent is still a long way in the future. The mere fact that so much recent ornithological writing has degenerated into a game of juggling localities and subspecific names should not, however, obscure the truth that taxonomy must be worked out to its practical limit before we can interpret the subtler points of distribution. Up to the present, no single museum in the world possesses an even moderately good representation of birds from the Antarctic and the sub-Antarctic islands as a whole. If all existing collections were combined, they would still be insufficient, especially since no specimens whatsoever are known from the South Sandwich group, Bouvet Island, and other isolated and important stations.

Fossil Birds and Their Significance

Little is known of the Antarctic Continent as an original center of dispersal for some of the groups of birds which have undergone so great a structural radiation in the southern oceans. It would be natural to infer that the penguins are of Antarctic or at least austral origin; in favor of this view, indeed, we have paleontological support. Fossil remains taken by the Swedish expedition at Seymour Island, West Antarctica, were associated with bones of primitive whales (zeuglodonts) and are assigned by Wiman[45] to Eocene age. The Seymour Island fossil penguins comprise not fewer than six forms, which have all been generically distinguished. The largest was apparently a much taller bird than the modern emperor penguin. Together with four or five Patagonian middle or late Tertiary species and two New Zealand species, these fossils bring the known number of extinct penguins up to twelve or more.

Wiman concludes that the early Tertiary penguins were nearer the carinate stem of birds than the existing, more highly specialized members of the order. He refers to the "walking" type of tarsometatarsus characteristic of the fossil species, which suggests, remotely perhaps, that the penguins may well have evolved from a tribe of terrestrial birds, inhabitants of the Antarctic Continent during the long period of mild climate indicated by the fossil vegetation. In the absence of traces of mammalian enemies, we may think of the ancestral penguins as flightless, somewhat "dodo-like" birds, which took to the sea before the gradual progress of glaciation. The picture is, of course, pure speculation, but for reasons of analogy it is by no

[45] Carl Wiman: Die alttertiären Vertebraten der Seymourinsel (Wissenschaftliche Ergebnisse der Schwedischen Südpolar-Expedition 1901–1903, herausg. von Otto Nordenskjöld, Vol. 3, Part I, pp. 1–37), Stockholm, 1905.

means fantastic, nor is it out of harmony with what we know of the geographic history of the far south. As a theory it is worth presenting, moreover, because evaluation is possible in two ways, first, through further paleontological discovery, and, second, through the application of morphological methods such as Bensley[46] followed in his classic reconstruction of the checkered evolutionary history of the tree kangaroos (*Dendrolagus*).

Distribution and Ecology of the Southern Seals

To return to the mammals, the southernmost waters are inhabited by four species of typical or phocid seals, which are remarkable in that they exhibit diverse structural peculiarities correlated with no less distinctive habits (Barrett-Hamilton).[47] Each one represents a well-marked genus which fills its own niche in the general ecological system of the region, the four forms practically avoiding mutual competition. They are as follows:

Crab-eater, or white, seal (*Lobodon carcinophagus*)
Weddell seal (*Leptonychotes weddelli*)
Sea leopard (*Hydrurga leptonyx*)
Ross, or singing, seal (*Ommatophoca rossi*).

The first to be encountered by voyagers from the north is the crab-eater seal, which lives among the ice packs during the winter and summer, chiefly in pairs or small bands. It subsists on Euphausiids and other pelagic crustaceans. Its pronged, antero-posteriorly lengthened cheek teeth alternate in the opposing jaws, the curious dentition thus functioning as a sieve or strainer, just as the baleen of whales or the gill-rakers of certain fishes serve a like end.

The Weddell seal is more southern in distribution, confining its range mostly to the fast-ice throughout the year, although stragglers sometimes reach South Georgia and other sub-Antarctic localities. Its presence may usually be taken as an indication of the proximity of land. It is the only one of the truly Antarctic seals to be found ordinarily in large herds. Its food consists mainly of fishes, with a certain admixture of bottom crustaceans, holothurians, etc. Its incisor and canine teeth are protuberant and strongly developed to serve not only as organs of prehension but also for use as a veritable "circular saw" with which breathing and sounding holes are cut through heavy ice.

Wilson[48] has made an interesting comparison between the two

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[46] B. A. Bensley: On the Evolution of the Australian Marsupialia, with Remarks on the Relationships of the Marsupials in General, *Trans. Linnean Soc. of London*, Ser. 2, Zoölogy, Vol. 9, Part III, 1903, pp. 83–217.

[47] G. E. H. Barrett-Hamilton: Seals, in "Antarctic Manual," Royal Geogr. Soc., London, 1901, pp. 209–224.

[48] Work cited in footnote 40, above.

foregoing species of seals and the two essentially Antarctic species of penguins. On the one hand the Adélie penguin and the crab-eater seal select the same pelagic environment, keeping in touch with raft and floe ice and feeding upon plankton crustaceans; on the other the emperor penguin and the Weddell seal are littoral and non-migratory, always remaining as far south as the existence of ice seams or leads of open water will permit. The food of both is fish. Their choice of habitat protects them from enemies, the Weddell seal being as free from the attacks of the killer whale as the emperor penguin is from the depredations of the skua.

The sea leopard, which is more or less of a hermit seal, has an exceedingly broad latitudinal range, being found from the shores of the Antarctic Continent northward even to parts of the temperate zone. Fish, cephalopods, young seals of other species, diving petrels, and cormorants have been found within the stomachs of sea leopards, but the primary food of the creature throughout its range is penguins. In its amazingly formidable dentition, in speed and ferocity, and in certain unique specializations of its internal anatomy[49] it is built as an impressive engine of destruction to the birds which form its prey.

Finally the Ross seal, the rarest of the quartet, is confined to southerly parts of the area, being unknown to the northward of the pack ice. Its dentition is feeble, the cheek teeth being degenerate, but the incisors and canines have curved needle-like points with which this seal seizes the soft cephalopods that form its food.

In the geographic arrangement of Andersson,[50] referred to above, the Antarctic and sub-Antarctic seals and sea bears are grouped as follows, except for one slight modification here made:

1. Circumpolar and exclusively Antarctic—Ross seal.

2. Circumpolar in the Antarctic but occasionally reaching sub-Antarctic latitudes in the American quadrant—Weddell seal and crab-eater seal.

3. Circumpolar throughout both the Antarctic and sub-Antarctic—sea leopard.

4. Circumpolar in the sub-Antarctic and penetrating into the Antarctic by way of the South Shetland-South Orkney-Palmer Land route—sea elephant (*Mirounga leonina*) and fur seal (*Arctocephalus australis*) and perhaps other closely related species or races.

Sea elephants and fur seals have been observed but rarely in the pack ice. Both were formerly exceedingly abundant upon the whole chain of sub-Antarctic islands, extending southward at least oc-

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[49] R. C. Murphy: The Trachea of Ogmorhinus, With Notes on Other Soft Parts, *Bull. Amer. Museum of Nat. Hist.*, Vol. 32, 1913, pp. 505–506.

[50] Work cited in footnote 31, above.

casionally to the South Shetlands. In nearly all parts of its old range the fur seal has been exterminated.

The American southern sea lion (*Otaria byronia*) is found only north of the zone of floating ice and nowhere at a great distance from the coasts of South America. Together with many other Magellanic marine organisms it ranges northward in the Humboldt Current region to Cape Blanco, Peru (4° 16′ S.). A related sea lion occupies a corresponding area, outside the extreme limit of floating bergs, at islands south of New Zealand. The distribution of the species and genera exhibits nothing approaching bipolarity. The present representatives of southern pinnipeds in the northern hemisphere, such as a sea elephant, and a fur seal not of the Alaskan genus, on the west coast of North America, have evidently pierced the warm-water barrier at points vulnerable because of current conditions. Or, as is not out of the question, the transequatorial migration may have originally proceeded in the opposite direction. Far more must be learned of the history of the several groups, and far more of the factors which still so rigidly control distribution, before such problems can be solved.

Antarctic and Sub-Antarctic Cetaceans

There remain among vertebrates only the whales and smaller cetaceans which probably exist in greater abundance in the rich southern waters than anywhere else, but about whose life history and seasonal movements all too little is yet known. One or more genera of the lesser whales are perhaps endemic. The majority of the larger cetaceans are types identical with, or closely related to, species of world-wide distribution, which reduces their zoögeographic value. The tradition of plentiful right whales (*Balaena*) in Antarctic seas is apparently traceable to erroneous identification by Sir James Clark Ross. Sperm whales (*Physeter*) likewise tend to avoid the colder waters, and examples have been captured only rarely by whaling steamers from the stations at South Georgia. But humpback whales (*Megaptera*), several species of fin whales (*Balaenoptera*), and killers (*Orca*) are found in numbers which apparently increase with the latitude to the very foot of the Great Barrier. Shoals of destructive killer whales remain throughout the year as far south as open water can be found; indeed these creatures sometimes break up heavy sea ice with the apparent object of precipitating their prey into the water. Crab-eater seals are said to be the most frequent victims owing to their liking for the pack ice, while the Weddell seals, as noted heretofore, are protected by their shore-haunting proclivities.

Unfortunately, human concern with the great southern cetaceans, such as the humpback, finback, and blue whale, has been chiefly commercial. After the exhaustion of many whaling grounds in the northern hemisphere, the center of the industry, which is mainly under Norwegian control, shifted to sub-Antarctic waters. The output of Norwegian whale oil from seas south of the equator increased from 4200 barrels in 1906 to 306,000 barrels in 1911. By the end of 1915 a total of more than 100,000 whale carcasses had passed through the reduction plants of stations between the Falkland Islands, South Georgia, and the South Shetlands. This figure takes no account of the toll of whaling in South Africa, the Indian Ocean, New Zealand, and Ross Sea.

Data on the distribution of the southern whales are scattered and still relatively slight. In addition to investigations on seasonal migration, breeding, embryology, and other phases of the life history detailed in the reports of the various national Antarctic expeditions, preliminary information of great value is contained in two publications of the British Colonial Office.[51]

An increase of knowledge regarding the southern whales is of inestimable scientific and economic importance. Fortunately steps toward this end are now being made, for in October, 1925, the Colonial Office sent out an expedition in Commander Scott's old Antarctic vessel, the *Discovery*, equipped for an investigation of whales and whaling in the far south, which returned to England in September, 1927. Among the apparatus used were bronze markers, already proved practicable, which are discharged from a gun and planted firmly in the blubbery surface of living whales.

Investigations at sea are to be supplemented by continuous work of a laboratory at South Georgia. From the consummation of such boldly conceived plans we should eventually derive information more precise and comprehensive than anything learned in the past.

[51] Report of the Interdepartmental Committee on Research and Development in the Dependencies of the Falkland Islands, with Appendixes, Maps, etc. 164 pp. Cmd. 657, H. M. Stationery Office, London, 1920.

M. A. C. Hinton: Reports on Papers Left by the Late Major G. E. H. Barrett-Hamilton Relating to the Whales of South Georgia, pp. 55–209. Crown Agents for the Colonies, London, 1925.

Commander BYRD of the United States Navy has done much that is notable in the field of air navigation. He accompanied D. B. MacMillan on his Arctic expedition to Ellesmere Island in 1925 as commanding officer of the naval aviation unit, flying almost 6000 miles on this expedition (see "Flying over the Arctic," *Natl. Geogr. Mag.*, Vol. 48, 1925). On May 9, 1926, he made the first successful flight to the north pole, flying from Kings Bay, Spitsbergen, to the pole and back ("The First Flight to the North Pole," *Natl. Geogr. Mag.*, Vol. 50, 1926.) In June, 1927, he flew across the Atlantic from New York to Ver-sur-Mer, France ("Our Transatlantic Flight," *Natl. Geogr. Mag.*, Vol. 52, 1927). He is also the author of "Flying over the Polar Sea" (*U. S. Naval Inst. Proc.*, Vol. 51, 1925). Prior to his own flights he had charge of navigational preparations for the transatlantic flight of the Navy NC boats in 1919, the proposed transatlantic flight of the airship ZR-2 from England to the United States, and the flight of the airship C-5 from Long Island to St. John's, Newfoundland.

POLAR EXPLORATION BY AIRCRAFT

Richard E. Byrd

What a thrill the aviator-explorer gets flying over Arctic regions at the rate of a mile and a half or two miles a minute! He looks down on snow-covered land and ice where the dog-team traveler would take months to cover what he can traverse in a day. The foot traveler would undergo hardships and privations, while he is skimming along comfortably, easily.

But the aviator-explorer has staked a great deal, possibly his life, on his engines; throughout much of his flight a forced landing would mean a crash in a region where a safe return to base, even if he were uninjured, would be uncertain. This risk, of course, will become less and less as engines become more reliable.

Though aircraft afford a quick means of covering large areas, there are only certain times of the year when flying in the polar regions is practicable. It is more hazardous than foot travel, even with the best flying conditions. At the present stage of aviation development it would seem that the principal function of aviation in exploration in the Arctic is to locate regions desirable for scientific investigation and to leave to the dog-team user the gathering of local scientific data, for the scientific information that can be obtained with aircraft is limited.

Structural Features Adapting an Airplane to Arctic Flying

Let us consider the airplane as an instrument alone. It is, of course, not so easy to operate in extremely cold weather as it is in warmer temperatures, but it is nevertheless feasible and practicable to do so. The mechanic must know his business, and great attention must be given to mechanical details.

The air-cooled motor seems preferable for Arctic use. If this type of cooling is used, there is no danger of a forced landing from a water leak in the radiator and there is no water to freeze or to drain from the engine at the end of each flight. In case of a forced landing on snow in the spring on account of engine trouble that could not be repaired immediately (if the plane is not "cracked up") the water would have to be drained. There would then arise the difficulty of melting the snow or ice to refill the radiator, with the consequent expenditure of precious fuel and time. Bad weather might set in during the delay, with possibly tragical results.

An air-cooled engine can be so cowled in that after it is once started it can be kept at any desired temperature regardless of the outside conditions, and the number of cooling fins on the engine cylinders can be regulated by the manufacturer for the work in hand.

STARTING ENGINES IN LOW TEMPERATURES

The starting of engines appears to many a bugaboo in Arctic flying, but that need not be troublesome. Fireproof canvas hoods can be made to cover the motor. A cylinder of this canvas can be led down from the bottom of the hood to a pressure gasoline stove (similar to a Primus stove, only larger) on the ground, and the engine can be heated to any desired temperature (Fig. 1). Then, with proper priming and the use of a little ether (though ether is seldom necessary), the engine can be started instantly, even with a hand crank.

This method of starting the engines in low temperatures has several advantages, besides being simple and effective. The pre-warming of the engines expands the metal parts gradually, whereas when the motor is started stone-cold there is a quick change in the temperature of the metal parts from the low atmospheric surroundings to the high operating temperature. There is danger in this latter procedure from the unduly rapid expansion of the engine parts.

PROPER LUBRICATION

The oil for the motors has to be carefully selected. The first inclination would be to use a very light oil on account of the low temperatures. But the consumption of such oil would be great and would cut down the cruising radius, and when the motor gets warm on a long flight it lacks the necessary qualities to protect the engine's working parts. Its advantages would be that it would enable the motors to be turned over more easily and (in the low temperatures) would flow more readily from the cans. But these advantages disappear when the oil and motors are pre-heated.

Dashboard and other delicate instruments that require grease for operation are likely to get sluggish from the cold, and it is necessary to treat them with graphite instead of grease. It may also be advisable to insulate rather heavily certain leads in the engine that may not be protected sufficiently by the cowling from cold streams of air.

SKIS AS LANDING GEAR

There are no mechanical difficulties, then, in the airplane itself that necessarily prevent its successful operation in the Arctic. Skis

(Fig. 1) can be used to fly from the snow, wheels from land or smooth snow-covered ice, and pontoons or boats from the water.

Of course, there is a great deal yet to be learned about flying with skis from the snow. In making turns in the snow the strain on the skis and landing gear is tremendous, and it is advisable to allow in their design a big factor of safety. The strain on the landing gear is more from the side than from dead ahead. It would seem that the skis should be constructed with a bow in them similar to the curve of

Fig. 1—The airplane used by the writer in the May 9, 1926, flight to the north pole showing, on the left, the fireproof canvas cylinder with pressure gasoline stove below used to heat the engine. On the right may be seen one of the skis used as landing gear. (Photograph copyrighted by Pathé News.)

foot skis, so that the total weight of the plane does not fall on a few square feet in the middle of the skis, which not only decreases the factor of safety but makes the initial start more difficult. It is not so easy to start a large heavily loaded plane on the snow. To facilitate the start it is important, too, to treat the bottom of the runners with a mixture of tar and resin to prevent the snow from sticking to them.

Turning a large ski-equipped plane by hand power is difficult to accomplish without straining or breaking the landing gear. It is necessary to use blocks and tackle secured to the hub of both skis and to pull both lines simultaneously and with the same force. It is advisable to assist the pivoting of the plane by hammering the skis with large wooden mallets in order to break them loose from the snow.

Take-Off and Landing Fields

It is difficult to find long, level stretches of snow on land in the Arctic, from which a plane can take off with a heavy load, without first leveling and packing the snow. The take-off field should be at least a mile long. The smoothest places are frequently wavy and bumpy. The "bumps" slow up the plane and render it difficult to attain flying speed. For a plane with a light load, the snow, if it is ordinarily firm, need not be packed.

Landings, however, can be made on the smoother stretches of unprepared snow. They should not be made on rolling soft snow, for this tends to stop the plane in a short distance. In the case of taking off with a heavy load, it is sometimes advisable to ice the snow immediately in front of the skis for the initial start.

Best Season for Arctic Flying

Of course, weather conditions vary from year to year locally as well as for places in the same latitudinal climatic belt; but, generally speaking, the best flying conditions in the Arctic seem to prevail during the months of April and May. During these months there is plenty of firm snow covering the land and ice that is suitable for a take-off with skis. If the season in the locality in question is far advanced, the snow will probably begin to soften in the latter part of May, and that condition will, of course, cut down the load that the plane can take off the snow with skis. Generally speaking, of course, the farther from the pole the earlier the snow will become soft. In 1925, in Spitsbergen, the snow on the land and ice was firm as late as May 24, whereas in 1926 the snow had begun to soften by May 14. In Alaska in 1926 the snow began to soften during the first part of May.

There is another great advantage of flying in April and May, namely, the freedom from fog—the airplane's great enemy. Of course, fog conditions vary from year to year and are not the same throughout a given latitude, but generally fogs are worse during the summer months than during the spring months. For example, fog is rare at Etah and Spitsbergen the first two weeks in May. After that there may be fog at both places, but more at Spitsbergen—due to the influence of the Gulf Stream. Fog is likely to be a handicap in Alaska beginning the latter part of May.

It is not generally practicable to use skis in the autumn because there is not sufficient snow. However, if the explorer decides to fly from the snow with skis in the spring, starting anywhere north of latitude 78°, he must winter in the Arctic, unless he chooses Spitsbergen, which is generally opened up in spring by the Gulf Stream. Etah, North Greenland, or Point Barrow, Alaska, cannot be reached by steamer until July or August.

With expert meteorological advice it is possible to fly in the Arctic during the summer, in spite of unfavorable weather conditions. For example, though there is fog in the summer in the region covered by Peary's explorations, it is, from time to time, possible to start out there with a reasonable assurance that the weather will remain good for twenty-four hours; yet, even when fog is encountered, it is frequently in spots, and the navigator can soon learn the peculiarities of this kind of fog and fly in spite of it. The "spottiness" of this fog would be far more apparent to the flier than it would be to the foot traveler.

Take-Offs and Landings in the Arctic in Summer

In most parts of the Arctic in summer it seems preferable to fly from the water, with flying boats or pontooned planes. The land is generally too rough to fly from, and, though a field for take-offs might

Fig. 2—Character of ice-cap surface of Greenland suitable for landing of planes (after Peary).

be cleared, a forced landing away from home would very likely find the pilot with no landing place below him, and a wrecked plane would be the result.

When flying in the summer, north of where the ice begins, there are occasional open spaces of water where landings can be made. Over the Arctic Sea open leads seem to occur with varying frequency, depending on the location, and over land-locked harbors, bays, and fiords there is sometimes open water at the foot of glaciers, for there is a tendency for the wind to blow down the glacier and so to force the ice away from its foot. The tide and winds, of course, make occasional leads in harbor and bay ice, but these may close up with great rapidity.

It is not possible to land on the summer ice because the snow is largely melted, leaving the old ice rough. It looks smooth from a few hundred feet, as do the rolling fields of snow. Indeed, it is sometimes almost impossible to see from the air the rough or rolling spots in a snow field that might cause a plane to crash on landing. Rough spots frequently appear smooth. Snow is most deceptive from an altitude.

If landings are to be made in the water for scientific work on the land it touches, it is advisable to use the amphibian plane that has, in addition to its pontoon or boat, wheels that can be let down so that the plane can be beached. Even if there is an ice foot around the bay or fiord, it is generally possible to find an opening in the ice foot.

In the summer the snow high up on the glaciers or high land is firm enough to land on with skis or a boat. With the exception of its soft stretches of snow, there are many places on the Greenland ice cap suitable for landings (Fig. 2).

Of course, a multi-motored plane that will fly with one motor dead is preferable to the one-engined plane because of the greater factor of safety from forced landings.

There is no reason why the Arctic navigator should not fly at any altitude he desires up to 10,000 feet. He can use shutters to regulate the air that gets to his motors and so keep them at any desired temperature. For any but long flights, he need not be caught in storms, with an efficient aërologist to call upon for weather prognostications.

Flying Conditions in the Antarctic

Apparently there would be more hazard from storms in the Antarctic regions than in the Arctic, because the spring and summer storms there sometimes reach great intensity, and not only would it be very dangerous to fly in them, but there would be a likelihood of the airplane being blown about by the winds when on the ground. Skis would have to be used when flying inland even in the summer, because snow seems to cover a large part of the Antarctic Continent, and the land is probably too rough anyhow for landing with wheels. On the routes that may be flown across the Antarctic Continent there would probably be many places where planes could land.

It would therefore seem inadvisable to make long flights in the Antarctic, it being more practicable, if possible of accomplishment, to advance by bases—say, one base every 200 miles. That would decrease the hazard. In view of the absence of life in the interior of the Antarctic Continent, it would be impossible to live off the country, and, in case of a forced landing 500 miles or more from the base, it probably would be likewise impossible for two or three men to pull on a sledge enough food and other equipment necessary to get back safely.

For flying around the edge of the Antarctic Continent an amphibian type of plane would be desirable.

Relative Functions of Arctic Exploration by Aircraft and by Sledge

Temperatures of areas distant from the base can be obtained by the airplane, but these can only be taken when meteorological conditions permit flying, and so the scientist could not so obtain his complete temperature data. For example, temperatures over the Greenland ice cap could be procured during the flying months with comparative ease, over areas that would take great and long effort on the part of the foot traveler. The foot traveler's hardships might be severe, but his data would be more complete.

Many scientists think that there is land yet to be found in the Arctic Sea. All agree that if unknown land is there it cannot be of any great size. If land be there it will probably be located by means of aircraft. The location of the land certainly seems to be the function of aircraft. Then if the expedition commander is an enthusiastic explorer, as well as being an aviator, he will attempt to map and investigate scientifically the new land. He would probably have to spend the winter at his main base and start out early in the spring for the new land. It would be possible to form an advanced base by airplane there for scientific investigation, and the scientists could be taken by air to the base. But this might be extremely hazardous with our present knowledge of landing in the Arctic, and it would seem wiser to leave the major part of the scientific work to the explorer who uses dog teams.[1]

I believe that for exploration work in the Arctic an expedition that combined dog teams and aircraft would be most effective. If there are no landing places at the advanced dog-team base, food could be dropped from the aircraft without landing. With a few flights of a large plane, enough food could be left to last the sledging party many months. The sledging parties could then travel faster, as they need carry only light loads.

In the case of finding and exploring an island in the Arctic, the airplanes could act as scouts—fly out in the summer months and locate the island, and then the sledging parties, assisted by the airplanes, could start out in the early spring for the thorough investigation of the land. It would be an easy matter to spend the winter with the food and equipment that could be supplied by the airplanes.

Upon arrival at the island, the sledging party could select a suitable landing place, and mapping could then be done from the plane with the automatic mapping camera.

Relative Merits of Airships and Airplanes for Arctic Exploration

The airship could, of course, be used, but it would appear to be practicable to use it only during the months that are free from strong

[1] Several important accounts of scientific exploration in the various parts of the Arctic and Antarctic by the methods hitherto used have been published in the series "Practical Hints to Scientific Travellers" edited by H. A. Brouwer (W. Werenskiold on the polar regions in general, A. Hoel on Spitsbergen, O. Holtedahl on Novaya Zemlya, O. B. Bøggild on Greenland, in Vol. 2, The Hague, 1925; Griffith Taylor on Antarctica in Vol. 4, The Hague, 1926).—Edit. Note.

winds. Not only does the airship have a difficult time getting through areas with strong and sudden upward and downward currents of air, but its speed is not sufficient for safety against a forty-knot wind. On the other hand, an airship is better able to cope with fog than is an airplane, because an engine failure does not result in an immediate forced landing. The airship can hover and possibly wait for the fog to lift, whereas the airplane must keep up a certain speed to stay aloft and, of course, is using up the precious gasoline. It is difficult to get an airship into the Arctic unless it is flown there, and that would always be uncertain and hazardous with the airships in use today.

An airship, however, twice the size of the *Los Angeles* (England is building two such airships) would have a tremendous cruising radius and would be large enough to cope with any storms but those of very great violence. These ships could make a non-stop flight from England to any place in the Arctic Sea and return. They could hover for hours over a spot for investigation. Congress has authorized two airships of this size for the Navy, but has not yet appropriated the funds for building them.

Bases for Exploration of the Arctic from the Air

If Nansen's conception of a deep polar basin is true, then new lands will most likely be found on the continental shelf. The border of that shelf is not everywhere known. It is possible that at some point it may have considerable extension toward the pole, and such an extension may have islands on it. At any rate, it seems likely that bases established on known outpost lands on the continental shelf offer the best chance to discover new land.

There are a number of locations which may be used for main bases, the more advantageous of which appear to be Etah, North Greenland, or vicinity; Point Barrow or vicinity; Wrangel Island; the New Siberian Islands; Northern Land (Nicholas II Land); Franz Josef Land; and Spitsbergen.

From Etah unexplored regions north and west of Grant Land and Axel Heiberg Island would be within striking distance of aircraft and dog teams. The surface ship could reach Etah in the summer and possibly explore by hydro-airplane before autumn sets in. If land is located, it could, with the help of the planes, be reached by dog team the following spring. The explorer could, of course, wait until spring to begin his flight, using skis instead of pontoons. The plane should either be amphibious or should be constructed, as are many of our navy planes, so that floats or skis and wheels can be used interchangeably. It would also be possible to reach in the same way the unexplored areas of the Arctic Sea north of Greenland.

This area could also readily be reached by aircraft from Spitsbergen, but dog teams would be of no use there because of the difficulty and hazard of traveling on the rapidly moving ice between Spitsbergen and Greenland. An advanced base might be established by airplane on Peary Land from Kings Bay, Spitsbergen, but to keep the plane there for the time necessary to investigate any newly found land would be, at this stage of airplane development and knowledge, too hazardous for practical consideration.

Some unexplored parts of the continental shelf are within striking distance by aircraft from Point Barrow and vicinity. The situation here is somewhat similar to that at Etah. The surface ship, with dog team and aircraft, should reach Point Barrow in July or August and winter there for thorough, effective work.

Wrangel Island would be a splendid place for a main base. Of course, an experienced ice captain would be necessary, as there would be hazard to the steamer from the ice. Here, too, it would be advisable to spend the winter. It would appear to be generally true that no detailed work can be done in the Arctic Sea without spending at least one winter at a main base.

If the flights of the exploring aircraft are too far away from its base, any land that is found may be beyond the range of dog teams; therefore, for sane and thorough work it is thought to be more practicable to keep the aircraft flights down to a reasonable limit. Of course, if the object is merely to locate the land, spectacular flights would be in order for anyone willing to take the hazard.

Proceeding around to the westward, main bases could be formed with advantage at the New Siberian Islands, Northern Land, and Franz Josef Land. If there is difficulty in locating a base on Northern Land on account of the ice, a base could be established in the vicinity of Cape Chelyuskin, Taimyr Peninsula. Incidentally, Northern Land is only incompletely surveyed, the location of its western coast being totally unknown, and an excellent and quick method of completing our knowledge of this land would be to explore it with a long-distance airplane and a mapping camera.

The southern limit of the ice pack during the summer seems to vary from year to year, and for different longitudes. Nansen, on his famous drift across the Arctic Sea, froze in during September in approximately latitude 78° N. This was farther north than the southern limit of the New Siberian Islands and in the same latitude as the southern coast of Northern Land.

So little of the Antarctic is known, that a base established anywhere on its border would, for the air explorer, be at the threshold of unknown regions. A combination of airplanes and dog teams would be preferable in the Antarctic also. Airships would be of little use on account of the strong winds. So far as we know, Amundsen's winter base at the edge of the ice barrier would be the best location for the main base.

Air Navigation in the Arctic[2]

Where navigation is to be done, it is very desirable for the plane to have a closed-in cabin, accessible to the pilot's seat, so that the navigator will have a chance to navigate out of the wind stream and from time to time relieve the pilot. Air navigating in a cold wind stream, or any wind stream, is a difficult matter.

Aviation will have to make considerable advance before it will be practicable to fly in the Arctic during the months of total darkness. On the other hand, for long flights, the twenty-four-hour daylight of the spring, summer, and autumn months is a great advantage, as there is no dark zone through which to fly, as would be the case south of the land of the midnight sun. A forced landing in darkness where there are no lights is almost certain to end in disaster. It is also more difficult to navigate at night, and under some conditions (such as a cloudy night) impossible, at the present stage of development of air navigation.

USE OF THE MAGNETIC COMPASS AND SUN COMPASS

The navigation of aircraft in many of the Arctic areas presents some difficulties that do not exist in areas generally frequented by seacraft and aircraft. The compass needle not only may be sluggish, but the variation of the compass may be unknown and very large at the same time, amounting, in some areas near the line joining the north and magnetic poles, to the maximum of variation of 180°[3].

It is sometimes difficult in any locality to compensate the compass of an aircraft. It should always be done under actual flying conditions, because the angle of the airplane to the horizontal, the speed of the motor, and the location of the equipment carried may affect the compass needle. Five-gallon cans of gasoline, carried as extra fuel for long flights, repair tools, etc., may exert a magnetic influence.

In those Arctic regions where the horizontal directive force of the earth's magnetism is comparatively small, this deviation, caused by the magnetism of the plane, is naturally more troublesome and sometimes very large. Some aviators exploring in the Arctic who had planes with much metal about them have found it impossible to compensate their compasses on the ground, no matter how closely they strove to simulate flying conditions. Then, if on top of this the navigator does not know his variation (a theoretical variation may easily be in error as much as 10°), he is very likely to get lost.

[2] On this topic see also Mr. O. M. Miller's paper below.—Edit. Note.

[3] See Figures 1 and 2 in Dr. Bauer's paper, above.—Edit. Note.

The difficulty can be met by using a sun compass (Fig. 3), provided the explorer starts out with the sun showing. He can compare the sun compass with the magnetic compass and procure at once the error of the compass for the particular course he is on. This error is the sum of the variation and the deviation of the compass. But since the deviation changes with changes of headings of the plane, the air navigator cannot apply this error to his return course (the opposite course to the one he is flying away from his base).

If the air navigator wants to get back to his base, he should circle at intervals, head the plane on the return course, and take the error of the compass—the combined variation and deviation. If he is cutting across magnetic meridians, the error will change by the amount of the change in variation, which, in some localities, is a disconcertingly rapid one.

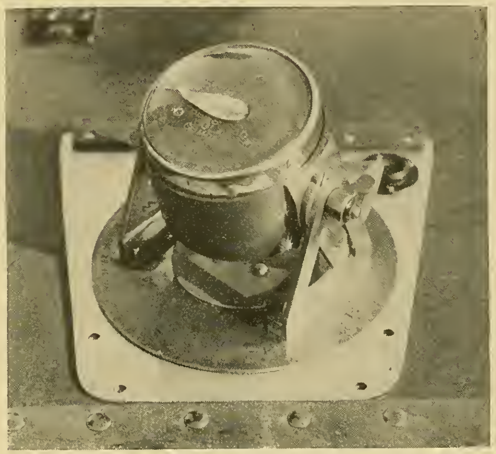

Fig. 3—A sun compass (Bumstead model) of the type used by the writer on the north polar flight. Note the shadow of the shadow pin on the pear-shaped hand of the 24-hour clock.

If the air navigator, then, is conservative and turns back in case the sun goes behind a cloud, he can get back to his base unless he gets over fog. Then he will be taken off his course by the amount of the drift of the wind, for no instrument has yet been developed that will give the drift of a plane when flying above fog.

It is sometimes possible, and certainly it is highly desirable, to select a spot in the plane where the compass has no deviation—where there is no local magnetism.

This was done in the case of the transatlantic flight of the N. C. flying boats and the polar flight of the *Josephine Ford*. This is easy of accomplishment where an earth-induction compass is used. The coil of the compass that cuts the magnetic line of force can be placed in the stern of the fuselage, or out at the end of a wing, where there is little metal.

Where there is no deviation, the application of the variation alone to the "return-to-base course" will give accurate results, and time need not be lost circling for the return compass error. It is a good rule to use as large a compass as possible. Cutting down on weight in an airplane by taking a smaller compass seems to be poor economy where long-distance navigation flights are to be made. Though it is admitted that the magnetic compass is comparatively sluggish in parts of the Arctic, it is generally possible, with a good pilot and moderately smooth air, to steer by it.

The most difficult dead-reckoning navigation occurs in flying at right angles to the lines of variation when using the magnetic compass, or at right angles to the meridians of longitude when using a sun compass.

In the former case, the change in variation must be allowed for at regular periods, depending upon the accuracy desired by the navigator; in the latter (when using the sun compass), it is accurate enough for practical purposes to set the compass to the latitude and time of the position of the mid-point of the line to be flown.

For example, in flying from Point Barrow direct to Etah, the lines of variation would be cut almost at right angles throughout the flight, and the variation of the compass would range from about 95° at Etah to 330° at Point Barrow. Frequent changes of steering course would have to be made to make good a straight course. When 200 miles from Axel Heiberg Island the variation would change approximately a degree for a minute of flying time, and, on top of this, the value of the variation is only theoretical. If the navigator happens to be in error as to the distance he has traveled, then of course he applies the wrong variation and gets into trouble. Therefore, in using the magnetic compass alone, a flight of this kind would be difficult.

If practicable, two sun compasses should be carried so that the shadow from the wings at certain angles of the sun may not render the compass useless. It is advantageous to have good-sized windows in the navigating cabin and to have the passageway open forward to the pilots' seats—forward of the leading edge of the wing—and aft to a trap door, just abaft the trailing edge of the wing.

DETERMINATION OF DRIFT, SPEED, AND DIRECTION

The air navigator in the Arctic, as elsewhere, must allow frequently and carefully for the drift caused by the wind. The drift indicator used by the United States Navy is a simple and accurate instrument. A wire is stretched taut in a frame, and the object below—an ice hummock, a blotch on the snow, an irregular place in a lead, or a smoke bomb which can be dropped—is simply made to follow the wire by screwing the wire to the proper angle to the course. Not only the angle of drift but the approximate speed over the ground can be procured very quickly, by using a stop watch and a table.

The speed of the craft through the air can be obtained from air-speed meter. Then, knowing the angle of drift of the craft and its speed over the ground, it is a simple matter to calculate the speed and direction of the wind at the altitude flown, which may be quite different, of course, from the direction of the wind at the surface.

There is an instrument called the course-and-distance indicator that will quickly and automatically solve the triangles of velocity and direction. The parts of this instrument consist of a disk upon which a movable disk, squared with parallel lines, is superimposed. The length of the side of each square on the disk represents, let us say, 5 nautical miles. Two movable arms, graduated to scale, radiate from the common center of the two disks. The two arms are graduated to the same scale as the disks and are marked every 5′, from 5′ to 100′. On each arm is placed a rider, enabling the user to indicate a particular graduation. The solution of problems on the instrument is similar in every respect to the graphical method, except that no lines need be drawn.

The Arctic air navigator should equip his plane with a turn indicator for use in fog to enable the pilot to tell instantly when he is turning. He can then steer a straighter compass course.

POSITION FINDING

For long flights, dead-reckoning navigation is not sufficient. The navigator must obtain lines of position from some celestial body or bodies. The usual method of forming an artificial horizon by means of mercury seems too cumbersome to use in an airplane, therefore some form of artificial-horizon sextant should be used. The sun does not get very high in the Arctic, and it is generally possible so to maneuver the aircraft that the sight of the celestial body can be taken through the open window of the cabin, with the observer comfortably seated, since he does not need to see the horizon. It is necessary for him to get his position line quickly on account of the great speed of travel.

Suppose an altitude of the sun is taken. The sun can be bisected by the horizon line in the sextant, and if this sextant has no error (as it should not have when properly regulated) the true altitude can be obtained by applying only the parallax and refraction. This makes for rapidity of work.

Some short method of obtaining the position line must be used. There are a number of different methods which are equally satisfactory.

The air over the Arctic Sea seems generally to be without "bumps" and so affords a steady platform for the observer. This is not the case in flying over the rugged land of the Arctic. The air there is sometimes very rough. But in that case the navigator may be aided by landmarks in determining his position, unless the land is entirely unknown.

Photography From Aircraft

Photography from aircraft in the Arctic is not without value to science. It would seem that the aircraft mapping camera affords a very rapid and excellent method of surveying any unknown Arctic areas. It would not be difficult to survey Baffin Island with amphibian airplanes, and there are many other places in the Arctic and Antarctic waiting to be mapped in this way.

There are some rugged regions in Ellesmere Island that it has not been practicable for the foot traveler to traverse. Indeed this is true of many of the more magnificent formations of that ice-chiseled land. Does it not seem reasonable that motion pictures of these areas taken from aircraft will be interesting from a scientific as well as an artistic viewpoint? The same is true of some other parts of the polar regions. It must be remembered that the foot traveler has, as a general rule, followed routes most easily traversed by dog teams. May not aircraft bring back a new idea of some of the more rugged of the Arctic and Antarctic areas?

Conclusion

Enough flying has been done in the Arctic to lead us to conclude that aviation has supplied a new and valuable method of polar exploration. As it develops and we learn more and more about flying in the Arctic, the scientific data that can be brought back by aircraft will be less and less limited.

Captain WILKINS is an experienced traveler both in the Arctic and Antarctic. In the Canadian Arctic Expedition, 1913–1918, he was second in command of Stefansson's party (see Canadian Arctic Expedition, Vol. 3: Report on Topographical and Geographical Work, Ottawa, 1917). He was also second in command of the British Imperial Antarctic Expedition, 1920–1921, and naturalist on Shackleton's last expedition, 1921–1922. The following years (1923–1925) he was leader of the Wilkins Australia and Islands Expedition for the British Museum (Natural History). During 1926–1927, as commander of the Detroit Arctic Expedition, by his airplane reconnaissance he made valuable additions to the knowledge of hitherto unknown Alaskan regions, especially the Brooks Range between the Yukon and the Arctic Coast. On March 29, 1927, he made the important sounding of 5440 meters in 77° 45′ N. and 175° W., or about 330 miles north of Wrangel Island, making the probability greater that the deep basin established by the soundings of the *Fram* extends continuously across the Arctic Sea to the Alaskan shore.

POLAR EXPLORATION BY AIRPLANE

George H. Wilkins

Plans for polar exploration by aircraft must necessarily depend on the type of exploration undertaken. An expedition may be confined to reconnaissance or it may undertake more detailed work—in surveying (by means of aërial photography and the use of fixed positions on the ground), oceanography, geology, and meteorology. The type of equipment used will depend on the class of work to be done.

Flying Conditions in Different Parts of the Polar Regions

Long-distance flying in the Arctic is not more hazardous than long-distance flying in other regions. Under certain conditions, such as over the extensive swamps and large jungle areas of the tropics, over deserts, mountains, and among inhospitable people, the hazards are greater than in the Arctic.

There is a wide difference between Arctic and Antarctic conditions. An airplane expedition to the known sections of the Antarctic would meet with winds of prolonged high velocity that may set in without warning. There is, however, one section of the Antarctic coast, as yet unexplored, where only normal winds may be expected. This section lies between King Edward VII Land and Graham Land. The few soundings taken in this vicinity point to the possibility of a low coast and therefore an absence of the turbulent winds that rush down to the sea from the edge of the high polar plateau in the known portions of the Antarctic Continent.

There are atmospheric disturbances in the Arctic, but they occur more frequently about the Arctic Circle than nearer the pole. There are, judging from records collected, no smoother air conditions in the world than those over the Arctic Sea during the late winter and spring. During summer and autumn, when the Arctic ice pack is much broken and the atmosphere laden with moisture, meteorological obstacles may be met. The greatest obstacle that faces an aviator in any latitude is low visibility as the result of low clouds and fog. The difficulty with fog would probably be less in the Arctic than elsewhere because all available records show that the layer of fog covering the Arctic ice during summer is thinner than that usually met in lower latitudes. Also, in flying over the sea ice, where there are no elevated points to avoid, it would be possible to fly low enough to see the ground and yet to have a sufficiently extended horizon of visibility.

The best months for aircraft exploration in the Arctic are March and April. For flying in the Antarctic December and January would probably be the most suitable, although during this period the explorer might be subject to some delay because of the weather. In the Antarctic the weather, with the possible exception of the region noted, is always more or less erratic, but inland summer conditions are likely to be dependable.

During winter flights over the Arctic the difficulty experienced because of darkness is the same sort of difficulty experienced at night in any other latitude and may be overcome in the same way. As to temperature there is generally less diurnal change in the Polar Regions than elsewhere, and it has been proved that polar flying is subject to temperatures not lower than those met with at altitudes necessarily maintained on several established air-mail routes and to temperature ranges much smaller than those experienced by the planes on these routes when the warmer temperatures they pass through in their low-altitude flying are taken into account. The difficulties because of temperature are therefore less in high Arctic latitudes than those contended with daily on mail routes across various other parts of the world.

Type of Aircraft To Be Used in Polar Exploration

The cruising radius of airplanes depends in a measure on the fatigue of metals and men. The continuous daylight and exhilarating atmosphere in high latitudes are advantages to the men, and the low temperatures experienced have, so far as we know, no deteriorating effect on the materials used in modern aircraft. Temperature may effect one's comfort and convenience in serving the machines, but on expeditions or established air routes, this service—filling with gasoline and oil and minor adjustments—could be performed at base headquarters, where the necessary conveniences, such as warmed hangars, oil-heating arrangements, etc., may be easily provided.

In a cabin of correct design the pilot and navigator can be warm and comfortable. Heat for warming any part of the plane can be taken from around the exhaust pipe of the engine without interfering with its power or adding much to the weight. A well-lighted cabin will enable the navigator to read his instruments without the eyestrain that would be incurred by looking from points of observation on the brilliant sunlit snow back into a dark cabin.

In choosing the type of machine for work confined to reconnaissance, consideration must be given to the maximum non-stop distance to be covered. If airplanes are to be used, a multiple-engine machine might give a greater factor of safety because it can fly with a light load on a small part of its total power or it can fly with its maximum wing load on less than the available power; on the other hand, if the machine is loaded to the capacity of its engines, the certainty of carrying out the full flight is not as great as with a single-power unit. Failure of any one of the several engines would, with a maximum load, mean either a forced landing or the dumping of some of the load, thereby curtailing the flight. Where, as in the Arctic, safe forced landings are possible and where there is a possibility of finding sustenance on the ice during a forced return march, a single-power unit offers several advantages if the maximum wing load is to be carried at the start of the flight. With a single-power unit there is a great economy in initial expense and in upkeep and personnel required. Because of its lighter weight it has greater maneuverability on the ground. However, if economy in initial expense need not be considered and sufficient personnel is available, multiple-engine machines with normal loads are more suitable for the work.

Airplanes constructed almost entirely of wood afford fewer chances for petty annoyances and inconvenience in extremely low temperatures than all-metal craft, which could not be handled or even accidentally touched with bare fingers without injury. Wooden planes also overcome some of the difficulty experienced with compass deviation in steel-frame machines. All hinges and moving parts of a plane for use in the Polar Regions should be free and lubricated with some form of dry lubrication.

For exploration limited to reconnaissance or for detailed surveying by means of aërial photography the airplane has many advantages over the airship. These advantages are high speed, maneuverability in the air and on the ground, economy in material and expense, and flexibility in arrangement of plans. Airplanes are more suitable for mapping than airships, since the essentials for that work are high speed, constant speed, and constant height and direction. Airships may be used successfully in the Arctic if expense need not be considered, but they would not be serviceable in the Antarctic, where offshore winds of great velocity are frequent.

Air-Cooled Versus Water-Cooled Engines

The power units in a machine for polar work may be either air cooled or water cooled. Air-cooled engines have an advantage in inherent lightness per H. P., ease of maintenance, and freedom from trouble due to failure of the cooling system. Light, convenient and controllable heaters for warming the air before it enters the carburettors can be attached, without reducing the power of the engine. Available water-cooled engines have in the past been more reliable than air-cooled, but they are at a disadvantage because of additional weight per H. P., possible failure of the cooling system, and expensive maintenance. This disadvantage is no greater in the Polar Regions than elsewhere.

In order that the temperature of the engines may be controlled, both air-cooled and water-cooled engines should be fitted with variable cowling. In water-cooled engines a radiator mixture of 33 per cent alcohol, 2 per cent glycerine, and the rest water has been found to be satisfactory in temperatures between $-48°$ and $0°$ C.; but in the writer's experience it proved more satisfactory to use unadulterated water and keep the engine, the oil, and the water in the radiator above the freezing point at all times. If alcohol and glycerine are used in the radiator, an extra tank of radiator mixture should be carried in order to replace the loss by evaporation. This tank should be directly connected to the radiator and accessible to the pilot or navigator in order that an anti-leak solution may be injected with the mixture if necessary.

All temperature difficulties with power units are minimized by the fact that it is possible to keep the engine always above the freezing point. This can be done by covering the power unit with temporary insulation, such as a tent or hood made of fireproof material (Fig. 2), and keeping it warm by any one of several convenient methods. Two ordinary hurricane lanterns slung beneath an engine (such as a Liberty or a Wright Whirlwind) well housed in a canvas cover will keep the engine warm even when the general temperature is extremely low. More heat from an oil stove or other contrivance may be applied to warm the engine thoroughly before starting.

Hangars for an Airplane Expedition

Little expense or preliminary preparation except depositing supplies is necessary in order to accommodate the airplanes and personnel ofan airplane expedition to the Arctic.

Any hangars or fixed buildings constructed in high latitudes will become more or less covered with snowdrift during the winter. The drifts obstruct the exits and entrances, and it causes much trouble to keep them free from snow. The difficulty of snowdrifts about hangars may be overcome by putting the hangar beneath the ground and having the roof level with the general surface. The snow then drifts past without accumulation. The planes can be run in and out over a ramp, as was done at the underground hangars during the World War. Underground, or rather under-ice, hangars might easily and economically be constructed under the ice conditions prevailing in the Antarctic, but greater difficulty would be met in constructing an underground hangar in the frozen ground on the Arctic coast. If planes are to be

FIG. 1

FIG. 2

FIG. 1—The airplane used by the writer on his Arctic flights taking off from the runway at Fairbanks, Alaska, for its first trip to Point Barrow.

FIG. 2—The same airplane on the frozen lagoon back of Point Barrow showing its engine protected against the cold by a close-fitting fireproof canvas cover.

idly wintered in the Arctic it would be better to dismantle and house them in small hangars, assembling them outside just before starting work for the season. They might thereafter be left in the open. During the writer's experience in Alaska snowdrifts did not form beside or behind the high-wing monoplane used, but a drift formed several feet in front of it. About the biplanes drifts formed as high as the lower wing and over the fuselage and tail.

At the suitable time of the year any machine practicable for reconnaissance work in the Arctic could be flown from points in civilization to an Arctic base of supplies, the expedition thus avoiding not only the expense of wintering in the Arctic but also the possible demoralizing effect that wintering might have on the personnel. An expedition to the Antarctic would carry the planes and the supplies to be used in a vessel to the edge of the continent during early summer and complete the season's work in time to escape the winter conditions.

Landing Gear for Polar Airplanes: Wheels and Skis

The design of landing gear for use with airplanes in the Arctic will depend on the area to be visited and the type of work to be done. On the Alaskan, Canadian, and Siberian coasts, where large lagoons and long stretches of level ice, thinly covered with snow, are to be found, and if long out-and-back flights are contemplated, wheels may be used to advantage because they are not so susceptible to damage and afford a speedier take-off. In the writer's Arctic experience it was found safe to land with wheels in snow twelve inches deep, and, while it might be possible to take off with a light load from snow as deep as that, it is better—and little trouble—to clear runways or gutters, just as wide as the tires on the wheels, to a depth that reaches the smooth ice below the snow. When the wheels are placed in the gutters, the machine cannot change direction and, running over the smooth ice, takes off in excellent fashion.

Where the snow is deep, as in the neighborhood of Greenland and Spitsbergen, it would not be possible to use wheels. When suitable landing gear designed especially for use with skis is available and when suitable skis weighing not more and offering not more head resistance than wheels are obtainable, then skis will offer advantages over wheels for Arctic flying.

Much investigation is necessary before satisfactory ski equipment will be available. The many variable conditions encountered in snow-covered countries—differences in snow texture, density, temperature, and surfaces—demand special equipment designed for the particular district and season involved.

Snow temperature and texture materially influence the coefficient of friction between the snow and ski surfaces. Friction varies with the various materials from which skis may be made. For extremely low temperatures, on hard, wind-driven, granular snow, which acts more or less like hard, dry sand, skis shod with soft metal such as fine brass or duralumin or bottomed with soft wood offer little resistance. For soft, dry snow and very wet snow, the treatment of the wood surfaces with a mixture of Stockholm tar, resin, and tallow ironed into the wood with a hot iron or burned in with a blowtorch gives a very good result. For damp snow, metal surfaces are unsuitable. Probably, for all-round service, a duralumin ski would give the best results, but unless metal skis are of a most expensive design they lack the resiliency and consequent factor of safety offered in a supple ski made of hickory or some other form of hard wood.

Ski surface area to be used is another consideration that will depend on conditions to be met, and, because the conditions during late winter and spring in the Arctic change rapidly, it is best to adopt a ski of a surface area and material suitable for general conditions.

The shape of the ski bottom is important. The writer found that a ski 9 inches wide, 9 feet long—of which one foot is turned up in front and 3 inches are curved at the back—with the bottom hollowed by a longitudinal curved groove 6 inches wide and ¾ inch deep, leaving on each side, a flat runner 1½ inches wide, proved most satisfactory in the Arctic when carrying a plane the total load of which ranged from 2000 to 4750 pounds over a variety of surfaces. The skis used were made of second-growth hickory, treated with the mixture mentioned. The greatest thickness of the skis was 2 inches, and they were tapered to ¾ inch at the ends. Metal standards were used to fit them to the axles, and the axles were set above the ski at a point fixed by a ratio of 5 to 3, the longer section being toward the front of the machine.

Snow-surface conditions do not occur in such variety in the Antarctic as in the Arctic, owing in part to a lesser range of seasonal temperature. In the Antarctic wheels would probably not be suitable, but skis could be used all the year round. For coastal exploration in the Antarctic and summer flying in the Arctic flying boats or machines fitted with pontoons may be used, but the use of any type of machine built for alighting only on water is hazardous both in the Arctic and Antarctic.

Landing Conditions

Even in water that may appear from a boat's deck to be entirely free from ice there may be small lumps of ice almost submerged and difficult to see from the air when flying at high speed. A blow from one of these "growlers" might wreck the machine. Another consideration is that the polar sea ice is, in summer, nearly always in motion and that the areas of open water change shape and size continually. An area that afforded a good landing place might in a few minutes be covered with rough pack-ice that would either crush the machine or hold it fast for an indefinite period. Landing on the Arctic tundra during summer would be extremely dangerous owing to the swampy condition of the surface and to the growth of large clumps of tufted grass, known in Alaska as "niggerheads." Accumulated driftwood and other obstructions would make forced landings on the Arctic beaches hazardous but would not be so dangerous as landing on the tundra. High, offshore winds are a source of danger to water craft in the Antarctic, and the steep ice-cliff coast lines of the Antarctic Continent afford few sheltered harbors in the event of an onshore drift.

If the purpose of the expedition is to take limited ground observations at many points in the Arctic, the airship offers advantages. Under normal conditions personnel can be landed from an airship for an hour or so and picked up again when their observations have been made, the airship hovering in sight during that time. Because of the greater numbers carried in airships the results of observations can be worked out quickly and in greater comfort, and further observations can be taken in the vicinity if necessary. From the writer's experience in making three airplane landings far from shore on the Arctic pack ice and from observations taken during 2000 miles of flying over the Arctic Sea there seems to be a possibility of finding many safe landing fields on the Arctic pack ice, both for airplanes and for men from an airship.

Although perhaps 90 per cent of the pack-ice surface is too rough for safe landings and a forced landing there might lead to disaster, there are many stretches of level ice on which a plane might be landed with safety. The essential knowledge to make landing on the Arctic pack-ice a safe procedure can be gained only by actual experience in travel on foot over a variety of ice surfaces and long experience in observing from an airplane. Various colorings and shades indicate various thicknesses of ice, but the colorings and shades differ under different conditions of light, and only long personal experience on the ice and in the air in the Polar Regions will give an aviator the necessary qualifications for sound judgment in this respect.

Other necessary qualifications for safe landings on the ice are experience of pack-ice movement and the ability to interpret meteorological conditions skillfully. The navigator or pilot should be able to determine whether it is safe to remain on an ice floe for even an hour or whether there is danger from ice fracture or pressure.

Wireless Communication Between Base and Plane

With modern wireless apparatus it is now possible to maintain communication between an airplane in flight and its base of supplies.

In the event of a forced landing, or if the machine had been landed and used as temporary base, even if the pack were drifting it could remain in touch with the rest of the expedition, and a rescue effected if necessary. It has been definitely demonstrated that short-wave communication can be maintained throughout the year from the Arctic to latitudes as far south as the equator, and, once sufficient Arctic wireless stations are established, it will be possible to use radio directional apparatus and to receive weather reports that would make Arctic travel as safe as elsewhere.

Air Navigation in the Polar Regions[1]

The instruments required for aërial navigation in high latitudes are the same as those used for aërial navigation in other latitudes, but in high latitudes additional advantage may be gained by using the sun compass and quick methods of computation not practicable in low latitudes. The sun compass is virtually a twenty-four-hour clock used as a sun dial on which the hour hand is the shadow pin. It is useful in cross-latitude flying, but it is of the greatest advantage when the track follows a meridian. Stereographic circumpolar charts, prepared curves, and a revised Sumner method of determining position facilitate aërial navigation in the Polar Regions.

Except for the great changes in magnetic declination, aërial navigation over the Arctic ice offers less difficulty than in any other part of the globe. Corrections for drift and ground speed depend on altitude, air speed, and time passed in reaching an observation point. A navigator, when flying over some kinds of low terrane and over the ocean, may not be able to find points on which to observe and, when flying over mountainous or hilly tracts, may not know the exact height above sea level of the point observed. (The altimeter carried in the airplane registers only the altitude of the observer above sea level.) On the Arctic ice there are numerous points on which to fix for observation, and these points are known to be at or near sea level. Correct altimeter reading applied to the drift indicator gives the necessary base line for the computation of wind drift and ground speed. The drift and ground speed in low latitudes is generally determined through a series of observations by trial and error, whereas, if three elements of the problem, correct air speed, height, and time of travel, are known—as they might be when flying over the Arctic ice—it is possible by means of instruments now available to work out rapidly the correct ground speed, wind velocity, and direction and so determine the necessary compass correction for any given course.

The functioning of the magnetic compass in high latitudes depends greatly on the longitude of the area visited. If the area is near the

[1] On this topic see also Mr. O. M. Miller's paper below.—Edit. Note.

magnetic pole the problem of navigation by means of the magnetic compass is difficult, not only because of rapid changes in declination but also on account of the sluggishness of the horizontal needle with which the ordinary compass is fitted. Compasses for high-latitude work should have exceptionally large clearances for vertical movement. Special care must be taken to eliminate deviation. A compass that somewhat eliminates that difficulty is the earth inductor compass, which may be installed in the plane far from the interference of engine ignition and which can be remotely controlled by the pilot or navigator. The earth inductor compass dial can be set at any convenient point and not necessarily near the directional mechanism. Like other compasses it was found in high latitudes to be less positive in its action and therefore less reliable.

Astronomical observations and the use of prepared charts and tables are a means of checking position, but position-finding by means of bubble-sextant observations taken from the cabin of a fast-moving airplane, when the sun is low in the heavens and refraction at high elevations in high latitudes an unknown factor, is likely to be inaccurate.

The Arctic especially offers many aids for piloting, i. e. keeping a course by the observation of surface conditions. The ability to "line up" on points of ice, careful observation of the direction of snowdrifts, the lighting on the ice pack during periods of sunshine, the azimuth of the sun, visible for twenty-four hours a day during summer, the direction of open leads of water or the surface condition of recently frozen leads, which give an indication of past, present, and future air currents (the ice movement is often an indication of wind direction long before and long after the actual wind has passed a given point)—are all aids to a navigator in the Arctic that may not be found in lower latitudes.

Even flying through fog conditions over the Arctic pack ice offers less danger than flying in fog in other latitudes, as was pointed out before. There are few obstructions as high as a hundred feet on the Arctic sea ice, and this enables the pilot to fly low at a constant, known height. With a visibility of less than 300 feet, we discovered from actual experience in 1926 that it was possible to get some idea of the rough ice horizon and keep our airplane on an even keel. The pilot had, under those circumstances, little to occupy his attention except the direction of flight. In fog over the sea ice there is little turbulence in the air, and low flying is comparatively safe.

Observations To Be Made

It is as easy to carry out a detailed survey by means of aërial photography in the Polar Regions as it is in other latitudes. Prolonged

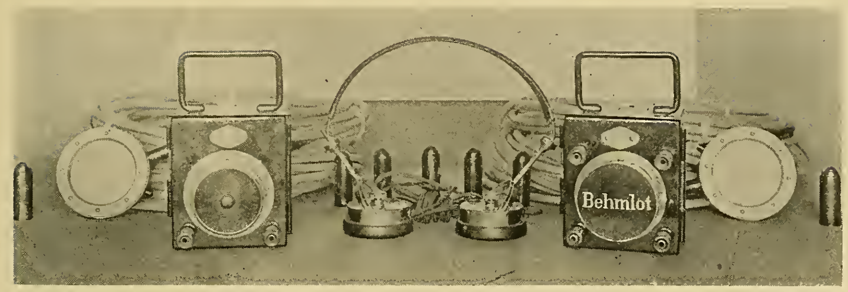

FIG. 3

FIG. 4

FIG. 3—The echo sounding apparatus (Behm model) of the type used in making the sounding of 5440 meters in the deep basin of the Arctic Sea in latitude 77° 45′ N. and longitude 175° W., on April 14, 1927, during the writer's flight to that point.

The square objects to the left and right are batteries for the transmitter and receiver, respectively. In the center is the head set, in the background are two coils of cable, on the sides two receiving microphones and in the center detonating cartridges.

FIG. 4—Riiser-Larsen making the sounding of 3750 meters in the Arctic Sea, May 28, 1925, in latitude 87° 32′ N. and longitude 10° 54′ E., with an apparatus of the same model as shown in Fig. 3. (Figs. 3 and 4 from Behm Echolot Gesellschaft.)

daylight and continuous clear weather during certain seasons when the sun is low and shadows are long bring about a condition ideal for mapping from the air.

For general observation close to a base an airplane offers the advantage of being easy to handle on the ice by a limited personnel. After landing, the plane can be anchored to the ice without difficulty, turned in a small area, and moved in any direction. It will take off and land in a small space, and it can be used for housing the party during a long period of observation with less risk than with a ship fast in the ice pack.

The capacity of the airplane and the distance of the desired point of observation from the base would determine the extent of the work and the amount of scientific equipment that could profitably be carried. With machines available today light enough to be handled by two men it should be possible, in the Arctic, to reach a point about 800 miles from a base, carrying a sonic depth finding apparatus (Figs. 3 and 4), sufficient equipment for manual soundings to 5000 meters, for collecting bottom samples, sea and air temperatures, and water samples. This is work that might be done quickly, the time depending on the convenience of penetrating the ice floe or of sounding through an ice crack or a lane of open water. The observations might be taken without moving far from the plane, and little extra equipment is required to keep the engine warm while the observations are being taken.[2] The number of landings and observations taken on one journey would be governed by the number of suitable landing fields and the range of the machine. From observations taken in the neighborhood of Point Barrow and the Beaufort Sea it seems likely that in the late winter suitable landing fields on the Arctic sea ice might be found within a radius of twenty miles from any given point. Absolute accuracy could not be expected on a hurried reconnaissance, but many useful data could be collected.

For prolonged oceanographical and meteorological observations airplanes could be used—either from a land headquarters or from a vessel that might be moving under its own power or drifting with the ice—to transport personnel and equipment to outlying bases established for such studies. In the Antarctic, where there is much geographical work, both along the coast and inland, to be done, modern aërial photographic equipment and the usual navigation instruments for fixing base lines would be desirable. To make geological observations from the air and from the ground would require very little equipment, and samples equal to the weight of the gasoline expended could be brought back.

Equipment To Be Carried

Fur clothing, suitable for foot travel in case of necessity, is satisfactory for use in aircraft, and a considerable amount of concentrated emergency rations can be conveniently carried. Apart from concentrated food, matches, and fuel, the equipment recommended by the writer to be carried on Arctic flights of exploration is as follows: high-power rifle; ammunition; hunting knife; large knife and saw (for cutting snow blocks for snow houses); Primus stove; aluminum cooking pot; enamel cups; plates; spoons; a convenient animal-oil

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[2] Since writing this Captain Wilkins in March, 1927, carried out the program here outlined to the extent of making a sounding in the deep part of the Arctic Sea (see above, pp. 396, 407 (Fig. 3), and Pl. I). As the instrument used was an echo sounding device, no bottom or water samples were taken.—Edit. Note.

burning stove (such a stove is not on the market, but the writer contrived a most satisfactory one that would burn seal oil and bear fat without constant attention and with economy in fuel); an alpine ax; a length of fish net, hooks and line (used for catching small birds near cliffs as well as for fishing); ice pick, attached to a handle the opposite end of which is part of the apparatus for spearing seals through the ice; a detachable spearhead attached to a thong for use with the seal spear; an apparatus for retrieving dead seals from the water; small, light snowshoes; sealskin pokes (whole seal skins which can be inflated for rafts or used for food in emergency); a light tent that can be used as a shelter during warm weather and as a lining for snow houses; fur sleeping bag, with blanket attached so that it can be drawn about the shoulders; a strip of reindeer skin to put beneath the sleeping bags; spare boots and clothing; some satisfactory form of pack for carrying loads on the back; first-aid medical outfit; surgical outfit; ophthalmic outfit; some form of concentrated stimulant or narcotic (to be used only in an emergency). The total weight of this equipment need not exceed 75 pounds.

For a number of years Mr. ELLSWORTH was connected with the exploratory survey party sent out by the Grand Trunk Pacific Railway to explore a route for a transcontinental railway line across Canada. His interest in surveying led him to spend a winter in the School of Surveying of the Royal Geographical Society, London. In 1924 he took part in a geological expedition from Johns Hopkins University under the leadership of Dr. Joseph T. Singewald, Jr., to study the Peruvian Andes. His interest in Arctic exploration was evinced by his support and participation as joint leader with Roald Amundsen in the Amundsen-Ellsworth North Polar airplane flight of 1925, and the Amundsen-Ellsworth-Nobile transpolar flight of 1926. He has written, together with Amundsen, "First Crossing of the Polar Sea," New York, 1927; "Our Polar Flight," New York, 1925.

ARCTIC FLYING EXPERIENCES BY AIRPLANE AND AIRSHIP*

Lincoln Ellsworth

THE AIRPLANE FLIGHT OF 1925

THE story of our flight from Spitsbergen in 1925 with two airplanes out over the Arctic Sea to within 136 miles of the north pole has already been told.[1] After a flight of eight hours, the time estimated to bring us to the pole, we came down into the first open lead

FIG. 1—The airplane N-24 after having landed on the pack ice of the Arctic Sea in 87° 44′ N. and about 10° 20′ W. on the flight of May, 1925. (Figs. 1–4 photographs from the author.)

big enough for our planes to land in to take an observation as to our exact whereabouts, for we had been heavily drifted to the westward by a strong northeast wind, and our fuel was half consumed. We found ourselves to be in latitude 87° 44′ N. and longitude 10° 20′ W. Thus, while we had flown 600 miles—the exact location of the pole from Spitsbergen—our drift of 50 miles off our course was responsible for our loss in latitude and the fuel necessary to carry us to the pole. Before we could get out, the lead closed up, and it required twenty-five days at hard labor to free our imprisoned planes. This, in short, is the history of the flight itself. The scientific results, from an expedition that cost $150,000, consisted in viewing 120,000 square miles of hitherto unknown territory and the taking of two soundings with a Behm echo sounding machine which showed the depth of the polar

* The manuscript of which this article is a part was kindly made available by Mr. Ellsworth for publication in the present volume. It has since been published in full under the title of "At the North Pole" in the *Yale Review* for July, 1927 (Vol. 16, pp. 739–749).

[1] Roald Amundsen and Lincoln Ellsworth: Our Polar Flight, New York, 1925.

basin at that point to be 3750 meters (12,300 feet), thus precluding the likelihood of any land in the sector between the north pole and Greenland-Spitsbergen. In addition the flight had shown that the meteorological conditions prevailing over the Arctic Basin offered no hindrance to its successful exploration by the proper kind of aircraft.

There were two things that most impressed me during our long sojourn so near the pole. First was the stability of the meteorological conditions in that isolated area—the winds blowing from the same direction day after day, with a velocity just sufficient to keep our Norwegian flag fully extended. The mean average temperature during the first two weeks of our stay was 14° Fahrenheit (−10° C.), but on June 2, with the onset of Arctic summer, the fogs descended on us and the thermometer rose to freezing and did not vary more than 4° F. during all the rest of our stay. Although the sun at that latitude—so close to the pole—maintained practically the same altitude above the horizon during the entire twenty-four hours, there was always a drop of a few degrees during the night period. The second thing that impressed me most was the manner in which we maintained our strength to do hard manual labor on a diet consisting of liquid food only—the equivalent of one half pound per day per man of nourishment—a mug of weak chocolate morning and night, accompanied by three small oat wafers, and a mug of pemmican soup at noon.

The mournful sound of the wind blowing through the rigging of our plane made us quick to seek shelter in its interior after our day's labor of clearing. Although our four-walled compartment was of metal and heavily coated with hoarfrost, it shut out the damp, fog-bound waste in which we were but mites, a colorless waste that seemed to reach into infinity. The scanty heat from the Primus stove, together with that given out by our bodies, was sufficient to raise the temperature above freezing. Nothing could dampen our spirits. Spitsbergen was but eight hours away; maybe tomorrow we should be on the way! Thus passed twenty-four days, but on the twenty-fifth—the day we had actually set, two weeks previously, to start on foot for the Greenland coast, 400 miles away, but which we knew we could not reach—our efforts were rewarded, and one plane, with six men in it, rose and left that prison forever.

The Transpolar Flight of 1926 by Airship[2]

But our work was not yet finished. Beyond, to the northward, between the pole and Alaska, still stretched the unknown—an area twice the size of the United States east of the Mississippi River.

For our next venture we decided to try an airship. A dirigible was available in Italy that appeared to fit both our needs and the size

[2] Roald Amundsen and Lincoln Ellsworth: First Crossing of the Polar Sea, New York, 1927, with map showing route, 1:17,500,000, facing p. 138.

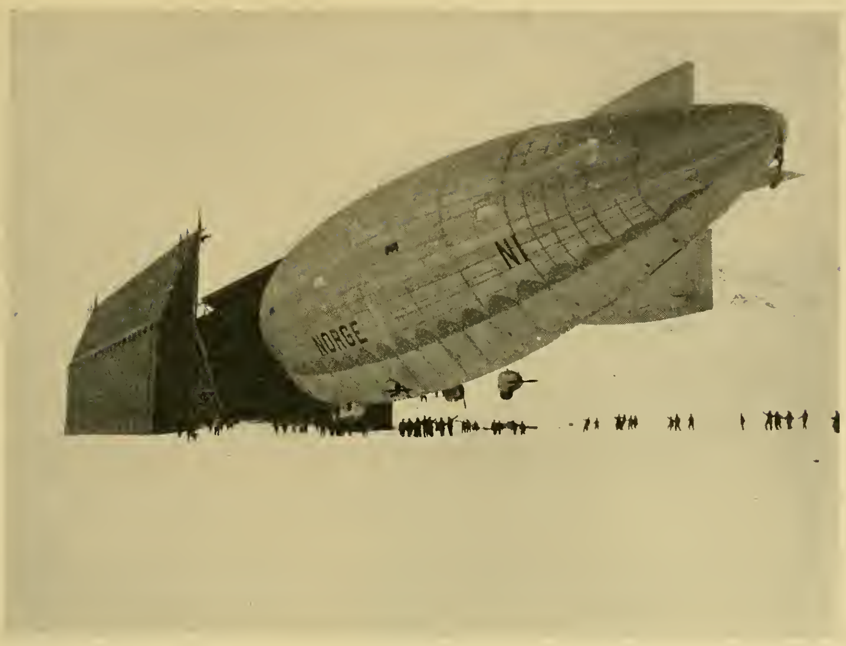

Fig. 2

Fig. 3

Fig. 2—The *Norge* arriving at her hangar, Kings Bay, Spitsbergen, preparatory to her transpolar flight.

Fig. 3—The *Norge* leaving Kings Bay, May 11, 1926, on the transpolar flight.

of our purse, and so we bought it. The *N1* built to the designs of Colonel (now General) Umberto Nobile in the Italian state airship factory and christened by us the *Norge*, was of semi-rigid construction, 348 feet long, with a displacement of twenty tons. Her fuel capacity of seven tons, with which to run her three 250 horse-power Maybach motors, gave her a range of 3500 miles, or about 70 hours at a speed of 50 miles per hour. Her gas capacity was 660,000 cubic feet. The *Norge* was equipped with a Marconi wireless direction finder, the tuning circuit for which was designed to cover a wide band of wave lengths: those used ranged from 900 to 1400 meters. The energy for the specially constructed valve transmitter was delivered from a windmill-driven generator supplying 3000 volts.

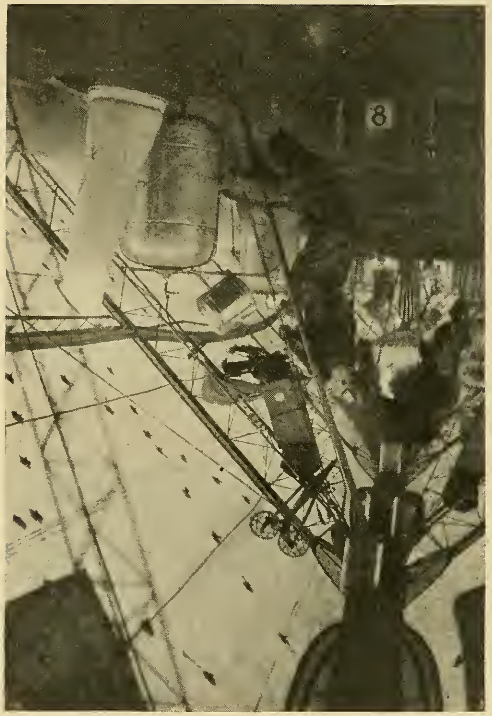

FIG. 4—View along the canvas-covered keel of the *Norge*, showing oil tanks, the runway, etc.

There was a delay of several days after the long flight from Italy to Spitsbergen before the *Norge* was able to proceed on her journey across the Arctic Sea. Favorable weather conditions were essential. We needed a clear sky with good visibility and a favorable wind; also high barometric pressure and a low temperature. These last two elements influenced greatly the lifting capacity of the dirigible. For each degree Fahrenheit that the temperature went down the airship gained 80 pounds in lifting capacity, which was increased by 140 pounds for each tenth of an inch added to the barometric pressure.

The keel of the *Norge* looked like a flying storehouse when all was ready for the start at 8.55 on the morning of May 11, 1926. The equipment included tents, sleeping bags, skis, snowshoes for those who could not ski, rifles, shotguns, ammunition, a hand sledge made by Oskar Wisting on the *Maud*—a fine piece of workmanship—and a big canvas boat. Two men among the personnel, Amundsen and Wisting, had the distinction of having been at the south pole, and now both were en route for the north pole. Provisions consisted of pemmican, chocolate, oat biscuits, and dry milk, sufficient to last sixteen men two months with a daily ration of 500 grams for each man.

Two hours after leaving Kings Bay found us over the pack ice. What weather! The sun shone brilliantly out of a sky of pure turquoise, and the whalelike shadow that our airship cast beneath us trailed monotonously across a glittering snow field, unbroken save where wind and tide had riven the icy surface into cracks and leads of open water. Three white whales darted under the protecting shelf of an ice floe, and a number of polar bears, diving into the sheltering leads, sent up columns of spray that reflected the bright sunshine, frightened at the sight and noise of the weird monster that took to the air instead of the sea. As we approached latitude 83½° the snow-crowned peaks of Spitsbergen merged into the deepening blue of the southern sky, losing their identity, and all signs of life vanished. Intermittent light fogs hid the ice from our view, rolling beneath us like a great woolen ocean. Approaching latitude 88° we had to rise from 1800 feet to more than 3000 in order to get over it. At this point, in latitude 87° 44′, we crossed, fifty miles to the eastward, the parallel that we had reached the previous year. Three hours more, and we were nearing the pole. The fog had completely cleared away, and the sun shone brightly; there was no wind. The navigator, who had been on his knees at one of the starboard windows since 1.10 A. M. (May 12) with his sextant set at the altitude the sun should have at the pole corresponding to the given date, suddenly announced, "Here we are!", as the sun's image started to cover his sextant bubble. We were over the north pole! With motors throttled and heads uncovered, we descended to within 300 feet of the ice and dropped the flags of Norway, the United States, and Italy.

THE FLIGHT ACROSS THE UNKNOWN AREA BEYOND THE POLE

With full speed ahead we settled down to the monotony of routine again, heading southward instead of north, with the sun compass settled for Point Barrow, Alaska, 1500 miles away. Ahead lay the unexplored area two-thirds the size of the United States. What would it reveal? Hour after hour passed, but only the same glittering surface riven by wind and tide into cracks and leads of open water, here, as before, crossing our route in a west-east direction. We reached the ice pole at 7 A. M., 5½ hours later. This "ice pole," so called because it is the center of the Arctic pack and therefore the most difficult spot in the Arctic regions to reach,[3] lies about in latitude 86° N. and longitude 157° W. But its inaccessibility was now broken, and the sixteen men that looked down upon the chaos of broken ice fields and pressure ridges of upturned ice blocks, as though giants

[3] On the origin of this conception see, above, footnote 3 to Kolchak's paper.—EDIT. NOTE.

had waged war with the polar ice, agreed as to its accessibility by means of aircraft only. At latitude 86° we had covered one-half the distance between Kings Bay and Point Barrow. Of the seven tons of fuel the ship carried, only about two tons had been consumed. Here we picked up the first sign of life since leaving 83½° (almost 700 miles)—one lone polar bear that could plainly be seen crossing a larger ice floe.

We now ran into fog, wind, and sleet. Ice coated the aërial wire and froze the windmill driver of our generator, which supplied the electrical energy to operate the radio transmitter and charge the storage batteries, and all efforts to establish communication with Alaska were of no avail. The last weather report from Alaska, before the wireless ceased to work, indicated that there was a low-pressure area over Bering Sea that seemed to be stationary. Ice crust formed on the bow of the ship, which was alarming, not only because it loaded her down but also because it spoiled her trimming. We tried to counteract the effect by moving the fuel from the bow tanks and sending the crew aft. Needless to say, our greatest danger lay in the ice that was torn loose from the sides of the ship by the whirling propellers and thrown against the gas bags. An ice block of the most fantastic shape settled on the sun compass, which stopped the clockwork and put it out of action for the rest of the flight. It was a surprise, therefore, to find by observation at 4 A. M., on May 13, that we were on a north-south line striking the Alaskan coast only 21 nautical miles west of Point Barrow, because it had been nearly twelve hours since the last longitude observation.

THE LAST LAP ALONG THE ALASKAN COAST TO TELLER

At 6.45 A. M. land was sighted ahead on the port bow, and at 7.25, after a voyage lasting 48 hours, we reached the coast. Flat and snow-covered, it was the most desolate looking coast line imaginable, but it was land and that was enough. As we followed the coast line the fog became denser and denser, obliging us to go lower and lower in order to be able to see far enough ahead so as not to run against obstacles. At last, abreast of Cape Beaufort, where the coast swings from a southwest direction to straight west, it became impossible to see any longer, and we rose through fog and cloud into bright sunshine. Heavy layers of fog drifted beneath us, and only now and then through openings in it could we glimpse the barren peaks of the De Long Mountains, the western extremity of the Brooks Range, over which we were passing, but we could see far too little to enable us to make out our exact whereabouts. When we believed ourselves as far south as we should go, we tried to get down underneath the fog and do our best to find the way. We had to nose down to an elevation of only 300 feet before we could see what lay underneath. We were over drift ice again. Where were we? To our surprise our wireless seemed to recover at this moment and picked up a strong signal which we thought might be Nome, but we could not tell for certain, because it was a communication with another station and we could not get the signature. But it gave us a position north of Diomede Island and enabled us to set a course for Cape Prince of Wales. Very soon we were over open water, which aroused our suspicions, for we might just as well have been on the southern side of Bering Strait, which, with our course, would have led us toward the Aleutian Islands. Getting into sunshine again we were obliged to take our observations from the top of the ship as the sun at this latitude was so high that it was hidden by the envelope in whichever direction the ship pointed. The observation gave our latitude as 67° 30′. We then went down through the clouds and found ourselves over land, having passed over the whole of Kotzebue Sound, driven by a northerly gale of more than 70 miles per hour. Heading west to get to the sea, again we heard the Nome wireless, which, together with the identification of the coast line, gave us our exact position. At 3.30 on the morning of May 14 we rounded Cape Prince of Wales and, tired but happy, brought our airship, coated with a ton of ice, safely to rest at the little trading post of Teller, 91 miles northwest of Nome, after a journey of 3393 miles, lasting 72 hours, across the Arctic Sea from Europe to America.

General NOBILE has been engaged in airship work since his entrance into the Italian army. He designed the dirigible *Norge* used in the Amundsen-Ellsworth-Nobile transpolar flight of 1926, on which he acted as pilot. On this expedition he has written "Navigating the *Norge* from Rome to the North Pole and Beyond" (*Natl. Geogr. Mag.*, Vol. 52, 1927) and two newspaper articles in the *Corriere della Sera*, Milan, June 24 and September 9, 1926.

THE DIRIGIBLE AND POLAR EXPLORATION

Umberto Nobile

AVIATION, which is bringing about profound innovations in every human activity, has opened a new era in the history of polar exploration.

Nobody can doubt the superiority of aircraft—airplanes or dirigibles—as a means of exploring the unknown regions of the earth. We can truly say that aviation has produced a revolution in this field. In a few hours it is possible now to make a journey that in the past required months and years of travel with ships and sledges. From Spitsbergen we reached the north pole in the *Norge* in sixteen hours, while Nansen in one year and eight months reached only latitude 86° 14′; and in only thirty hours we traversed the unexplored area between the pole and Alaska for a distance of 2000 kilometers.

One radical change that has taken place in the matter of polar exploration is this: experts who know how to travel on the ice are no longer needed, and men who know how to navigate the air take their place. In addition, it is no longer necessary that the scientists of an expedition be men strong enough to support long journeys on the ice and trained in making them. Edison could be a member of an expedition of this kind and read his own instruments himself.

Certainly there is no field of human activity so well suited as polar exploration to impart a realization of the great contribution that aërial transportation is bound to make to human knowledge: in one year it is possible to reveal what has been sought for centuries.

AIRSHIP VERSUS AIRPLANE IN POLAR EXPLORATION

There is no doubt that aircraft are now the best means of exploration: the problem is to decide between the heavier and the lighter-than-air machines. Two cases should be considered: as to whether the aircraft is to be used as a means of exploration while flying, or whether it is only to be used to carry the explorers and their equipment to the place to be explored.

In the latter case the airplane is preferable because of the lower cost, the greater freedom from dependence on atmospheric conditions, and the greater facility with which both machine and stations can be made ready. At all events the airplane can be used in many cases as a subsidiary means of transportation and exploration.

But when we speak of a long trip of exploration the lighter-than-air craft is without doubt the best. There is nothing new in the use of the dirigible for exploration.[1] During the World War it was used by the Germans for long flights, including one to East Africa, and by the Italians, in coöperation with the navy, especially in the defense against submarines. The main reason for the superiority of the dirigible over the airplane as a means of observation lies in the fact that, while the latter can stay in the air only dynamically, the former stays in the air by its buoyancy.

The dirigible can reduce its own speed without being obliged to land; it can also reduce its speed until it comes to a complete stop; and, provided the atmosphere is calm enough, it can stand still at a certain height above the ground through the use of a landing ballast buoy.

The airplane has not the same freedom. It is obliged to keep itself in movement to get the lift from its speed; and this speed cannot vary very much. Nor can the airplane stand still in the air.

It is a fact that when there is the possibility of reducing the speed at one's pleasure the observation and exploration of the ground underneath are much easier. It is easier, also, to explore the depth of the sea from a dirigible than from an airplane.

As to scientific observations, the conditions for the instruments and for the personnel are much more favorable on a dirigible than on an airplane. This is true not only because of the possibility of carrying more weight, which is one of the advantages of the lighter over the heavier-than-air machines, but also because the perturbation of the instruments caused by the motion of the aircraft can be reduced to a minimum or entirely eliminated by reducing the speed of the motors or by stopping them.

It has been said that one of the advantages of the airplane is the possibility of landing for scientific observation. That is true. But landing in an unknown place is frequently impossible, and very often it is not safe. A dirigible can stand at anchor, provided the atmospheric conditions are favorable, and it is then possible to land personnel and materials in perfect safety. A mechanism for this purpose has been studied and perfected by us, but we had no opportunity to use it on our transpolar flight.

Finally, there is another attribute of the dirigible: its capacity to carry a useful load much greater than that of any airplane or hydroplane, and as a rule for greater distances on a non-stop flight. So far as our present knowledge goes, it would be possible to build an

[1] On the use of the airship in Arctic exploration see also especially:

Das Luftschiff als Forschungsmittel in der Arktis: Eine Denkschrift, Internatl. Studiengesell. zur Erforschung der Arktis mit dem Luftschiff, Berlin, 1924.

Walther Bruns: Praktische Wege für den Einsatz des Luftschiffs grossen Typs zu ausgedehnter wissenschaftlicher Erforschung und ständiger Überwachung der Arktis, in "Internatl. Studiengesell. zur Erforschung der Arktis mit dem Luftschiff: Verhandl. der 1. Ordentl. Versammlung in Berlin, 9.–13. Nov. 1926," *Ergänzungsheft No. 191 zu Petermanns Mitt.*, Gotha, 1927, pp. 19–25.

W. Bleistein: Das Starrluftschiff und seine Entwicklungsmöglichkeit für Weltverkehr und Forschungsarbeit, *ibid.*, pp. 89–102.—Edit. Note.

airship able to fly on a non-stop flight of ten days at an average speed of 80 to 100 kilometers an hour. In other words with such a ship it would be possible to explore a zone from 19,000 to 24,000 kilometers long. Because of the greater load capacity it would be possible to carry on board a complete scientific laboratory with all the instruments and personnel necessary for a thorough investigation of the area to be explored.

The feasibility of establishing scientific observation stations in the Arctic has often been discussed. Such establishment is possible. The type of large dirigible just referred to could deposit the materials and the personnel, and the station could then keep itself in contact with the rest of the world by means of radio communication or through airplanes.

Meteorological Conditions for Arctic Flying

All the advantages of the dirigible hold equally for any region to be explored, be it the Arctic or the Antarctic, innermost Africa or Australia. But with particular reference to polar exploration it is necessary to add something about the meteorological conditions of the regions through which one must fly.

As far as the Arctic is concerned the general conditions cannot be regarded as unfavorable. It is true that all around the north polar area, and especially over Barents Sea and Bering Strait, low-pressure cyclones with very strong winds are frequent; but it is also true that meteorological conditions over the central polar area itself are generally good. This fact had already been observed in the past by Nansen and the Duke of the Abruzzi. In that area there is no record of storms and, what is more important, of electrical storms, which indeed constitute the real danger of aërial navigation, especially for dirigibles.

Another favorable condition for Arctic flying is the continuous daylight of the summer months. The darkness of night is not favorable for observation and is also a depressive moral factor. Even so, I do not believe it is impossible to fly in the Arctic during the polar night.

FOG

The real danger of summer flying in the Arctic is the fog. According to our experience it is the fog that makes flying dangerous and makes impossible any work of observation and exploration. This was the case in our 46-hour flight from Kings Bay to the northern coast of Alaska, during which time we flew in or over the fog for about 16 hours. Happily the fog was low, never over 3000 feet, and it was generally possible to fly over it and avoid the danger of ice incrustations. But according to our experience I believe that in many cases it is possible to fly under the fog when it consists only of a thin layer near the ground. We flew in this way during the last part of our polar flight near the coast of Alaska. However, navigation under such conditions is of course dangerous and difficult.

Our flight took place during May (May 11–14, 1926). The lowest temperature was −12.6° C., with a maximum of −10°. Future flights, I therefore believe, it would be advisable to carry out one month earlier. In April the fog is not so intense, and yet the temperature is not excessively low. On the other hand we must bear in mind that low temperatures, provided the ship and personnel can stand them, have the advantage of making possible a heavier useful load.

During our polar flight we found the atmosphere very calm, with the exception of the first stretch, from Spitsbergen to the pole, when we had a wind that sometimes reached a velocity of 25 kilometers an hour. The ship was hardly ever subject to pitching and rolling. For the rest of the way over the central polar area the airship did not pitch or roll, and it would have been possible to land without outside help. These conditions, however, were completely reversed in the flight over Bering Strait, where we encountered a severe storm.

For an airplane flying in foggy weather the danger would certainly have been greater, especially in case of a forced landing, whereas a dirigible is able to reduce its speed and consequently its fuel consumption and wait for clearer weather.

In reference to the forced landing of an airplane it must be kept in mind that the surface of the ice is very uneven. This is true particularly about the ice off the northern coast of Alaska. An airplane would there have very little chance of landing safely and still less chance of taking off again, because in a very short time the tides and the winds modify the conformation of the ice surface.

THE DANGER OF ICE INCRUSTATION

Concerning the safety of traveling on a dirigible over the Arctic Regions technical and scientific men in England and in Russia were very doubtful and expressed their anxiety as to the possible danger of a crust of ice forming over the skin of the ship, a crust so thick as to force the dirigible to descend. During the trip this apprehension proved to be unfounded. On the other hand, as a result of our laboratory tests in Italy, I had foreseen that provision had to be made for the avoidance of this danger. Ice did form on the airship when it was obliged to fly in the fog. But, while the ice incrustation was very heavy on all the outer metallic parts of the ship, almost no ice formed on the skin. On the whole I believe that the ice did not increase the weight of the ship by more than a few hundred kilograms.

The real danger came afterward when the ice began to drop in pieces from the parts to which it was attached, and, falling in the path of the propeller blades, was hurled against the keel of the airship. The perforation of the gas bag and of the covering of the keel might have been the beginning of serious trouble. This danger had been foreseen but had not been taken care of completely. In the future it will be possible to avoid it easily either by covering all outer metallic parts with special grease or by protecting the propellers from the flying ice. Of course, the best solution is to avoid flying in a layer of damp and comparatively warm air.

For airplanes there is the same danger of ice forming, but it is certainly a relatively small matter.

SNOWSTORMS

Snowstorms may disturb aërial navigation in the Arctic. The Russian experts were particularly worried about that, but our experience, although we passed through many snowstorms during our flight from Russia to Alaska, was that they never gave us any trouble at all. The snow had no time to stick to the keel of the airship, and the wind carried away whatever small amount had a chance to deposit itself mechanically over the gas bag.

Protection of Motors and Gas Valves Against Low Temperatures

In Arctic exploration, besides taking into account the consequences of fog, snow, and ice, it is also necessary to envisage the dangers to which the vital parts of aircraft, namely, in the case of an airship, the motors and the gas valves, are directly exposed as a result of low temperatures.

From this point of view, granted that the vital parts of a dirigible are more numerous than those of an airplane, it is true that any trouble can be taken care of much more easily on the former than on the latter. For instance, during our flight one of our motors stopped frequently on account of the formation of ice in the gasoline pipe. The search for and repair of this trouble was not a small matter, and I have no doubt that the same trouble would have obliged an airplane to make a forced landing with all its consequences.

As regards gas valves I wish to point out here our experience during the World War. On many flights at that time we found out that ice incrustations, formed when the valves were open, often made it impossible for the valves to close tightly, with a consequent loss of gas. That is why, during the preparation for the transpolar flight, special care was given to the protection of the gas valves against the formation of ice. Grease was used, and, for added security against the outside humidity, we covered the valves with protective caps.

These precautions gave very good results, and during the whole flight no trouble at all was experienced with our valves.

Air Navigation in the Arctic[2]

As regards navigating in the Arctic, checking our route was supposed to be a source of difficulty. Practically everything, however, went off well.[3] The three magnetic compasses that were on board always functioned correctly, as had been foreseen, because of our route lying far away from the magnetic pole. The solar compass was also of much assistance during the first part of the flight, because it gave us the possibility of checking the accuracy of the values of magnetic declination shown on the maps; but a few hours after our passage over the pole, ice incrustation put that instrument out of order.

The drift and velocity of the ship in relation to the ground were measured with a Goerz drift-and-speed indicator. But all these measurements were uncertain on account of the poor knowledge that we had of the altitude, which was checked by means of a telemeter. In the future it will be possible to use better and more accurate instruments. At all events, our methods were practically sufficient for our purpose.

As a means of checking our route we used a sextant with an artificial horizon, used in Italy for ten years, which gave very good results. The radio was useful in the part of flight from Spitsbergen to the pole in determining the position of the ship. On board an airplane the use of the sextant and of the radio would not have been as practicable and easy as on board the *Norge*.

Results of the Transpolar Flight and Problems Still to Be Solved

In conclusion we may repeat that the dirigible is the best means of transportation for the exploration of the Arctic zone. The airplane and hydroplane can be used, but mainly as an auxiliary means of transportation.

We understand, of course, that the preparation of an expedition with an airship is technically more difficult and takes more money than an expedition with airplanes. The design and construction of the ship, the preparation of the stations, the choice and training of the personnel are problems more complex and of more difficult solution than when airplanes are used. On the other hand the results are much more important, as our expedition has shown. With an airship of com-

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[2] On this topic see also Mr. O. M. Miller's paper below.—Edit. Note.

[3] On the navigation of the *Norge* see Hjalmar Riiser-Larsen: The Navigation Over the Polar Sea, Chapter 10 of Roald Amundsen and Lincoln Ellsworth: First Crossing of the Polar Sea, New York, 1927, pp. 179–248 and the account by General Nobile of the transpolar flight in the Italian newspaper *Corriere della Sera* of Milan for June 24 and September 9, 1926.—Edit. Note.

paratively small size we flew from Rome to Teller in 165 hours of flight, of which 71 hours constituted a non-stop flight from Kings Bay to Teller—all this through all kinds of adverse weather, snow, fog, wind, ice.

It is easy to prophesy that other expeditions with dirigibles will follow our own. We have only started a new era in the history of polar exploration. We have shown which is the best way to attain that purpose successfully, and we have given a practical demonstration.

Although the fog made observation of the ground impossible for hours, we may draw the conclusion from our exploration of the great unknown Arctic area that between the north pole and Alaska there is no great land mass. We explored a zone perhaps 100 kilometers wide and 2400 kilometers long. But portions of this zone could not be seen on account of the fog (see Fig. 1). The depth of the sea was not sounded nor were magnetic nor gravitational observations made.

There is still a great deal of work to be done and a great amount of scientific data to be collected; and finally there is to be accomplished the exploration of the two great segments into which we divided the unknown area. All this work will be done in the next expeditions that we hope will take place soon.

Antarctic Exploration by Air

In the Antarctic, conditions are entirely different. In the Arctic there is a frozen ocean; in the Antarctic there is a great continent, with high lands and mountains. Meteorological conditions are also different, and, so far as we know, they are much less favorable to aërial navigation. The fact alone of the presence of a high land is an unfavorable condition. The violence and frequency of the storms is a further formidable obstacle. An expedition with dirigibles would require a large amount of money. What is needed is a great base on the coast of the continent and a huge airship able to fly a distance of 15,000 kilometers at a height of 5000 meters. Certainly the use of airplanes would to some extent be preferable in the Antarctic. But an airplane expedition should also be backed by a strong financial organization, establish many flying stations, and employ a considerable number of machines.

Captain BARTLETT comes from a Newfoundland family of mariners and is one of the foremost ice navigators of the day. His Arctic explorations began in 1897–1898, when he wintered with Peary at Cape d'Urville in the Kane Basin. He was Commander of the *Roosevelt* on Peary's polar expedition and went to latitude 87° 47′ N. with Peary on his dash to the pole. In the Canadian Arctic Expedition, 1913–1918, he was captain of the ill-fated *Karluk* (see "The Last Voyage of the *Karluk*," Boston, 1916). In 1917 he was sent as commander of the *Neptune* on the third Crocker Land relief expedition to North Greenland. He accompanied the Putnam expeditions of 1926 to North Greenland and of 1927 to Baffin Island as master of the *Morrissey*. On the latter trip he made the first oceanographical researches undertaken in the Foxe Basin. On numerous other voyages, to the American Arctic Archipelago (1910), to Hudson Bay and Strait, to the Arctic Sea north of Alaska and eastern Siberia (1923), he collected specimens of animal and plant life, dredged for plankton, and made current, tidal, and meteorological observations, turning over this material to scientific institutions in Washington and New York.

ICE NAVIGATION

Robert A. Bartlett

Polar Ships and Their Construction

Peary has this to say of building a polar ship: Of all the special tools that a polar explorer requires for the successful prosecution of his work, his ship stands first and preëminent. This is the tool which is to place him and his party and supplies within striking distance of his goal, the tool without which he can accomplish nothing. He says further: The builder should live with his craft from the time the keel is laid till she is complete and has made her trial trips. I do not suppose that any other explorer was so well qualified to say this or could so keenly feel the need of having his own ship to do with her just as he pleased and to go where he pleased. Having to charter the Newfoundland seal hunters at a high figure and within a limited time and area, he had to be content to land his party many miles from his base. Really the first ship built for polar exploration was Nansen's *Fram*. Nansen learned the lesson of thorough preparation from the long list of hastily improvised ships of the past, the *Polaris* and the *Jeannette* being then of recent date.

As a rule the commander of an Arctic expedition knows little or nothing of wooden ship construction. He therefore goes to a ship designer or architect who, if conscientious, will take advice from well-qualified men. It took many weeks and months and many changes of plans before Colin Archer, builder of the *Fram*, decided upon the right model and the strength commensurate with safety for the putting together of the *Fram*. Nansen was extremely fortunate in getting such a man as Colin Archer.

Captain Scott's *Discovery* (I shall have to designate her as "Captain Scott's," for there were several ships of that name) was designed very close to the Scotch whaler type, built in the Stevens Yard, Dundee, Scotland, where many steam whalers were built that have made history in Arctic and Antarctic exploration. The *Discovery* was the last ship constructed in that yard. The art of building wooden ships is now almost lost to Great Britain. Some of them are afloat today, seal hunting in the stormy months of March and April off the Newfoundland and Labrador coasts. Some are over fifty years old. The *Neptune* has brought her owners over one million hair seal. The *Terra Nova*, not quite fifty years old yet, is going strong and is good for twenty years more. The Coast Guard cutter *Bear*, an angel of mercy in northern Alaskan waters, is getting well along but is still hale and hearty. Three years ago I made a trip on her, and for forty-seven days we were beset in the heavy Arctic pack and drifted in its relentless grip from a few miles north of St. Lawrence Island through Bering Strait one hundred miles or so north over the continental shelf, and only after this did she work her way to freedom. For several hours in a gale of wind with blinding snow and a strong current she was caught between two very large sheets of heavy ice, and the pinch was at the engine room.

Nansen says the *stern* of a ship is the heel of Achilles. That is the vulnerable spot. I say in ships with steam boilers and reciprocating engines that the *engine room* is the vulnerable spot. And strong as the *Fram*, the *Discovery*, and the *Roosevelt* were in a heavy nip, unless they were fairly light it would go ill with them, for it is difficult with coal bunkers and engine room space to make sufficient thwartship bracing. Fortunately for the *Bear* she was not heavily laden, and her strength and design helped some, for had she not been able to rise upon the ice with the lateral pressure the corners of the floe would certainly have gone clean through her.

The history of Arctic voyages began away back in the days of King Alfred of England and in the voyages of the Norsemen to Greenland. The history of Antarctic explorations began at a much later period. It is unnecessary to go into details and describe the different expeditions that went south looking for the Great Southern Continent. It is amazing how these early explorers got their vessels around in uncharted waters, in fogs, gales of wind, strong currents, calms, ice, and bergs. Calm weather with a strong current is about as bad a thing as a wind-driven vessel has to contend with when in the vicinity of ice, icebergs, and growlers; and lots of these ships had inexperienced officers and crews.

We that know the game today and do it with auxiliary power in the shape of steam and oil engines wonder just how they managed it; and yet it is not hard to fathom the mystery, for those were the days of iron men and wooden ships. Ships and men since the days of Sir John Franklin, Scoresby, Parry, Wilkes, Ross, Cook, John Davis, and many others have changed in size, form, and speed. The advent of steam changed the method of ice navigation with ships, both as to their construction and method of handling, and of course lessened the hardship and dangers to life and property. Those of us who read the sailing-ship voyages of the early explorers and have gone over the same ground under similar conditions appreciate their great skill, their seamanship, and their tenacity of purpose. These qualities they must have had to do this tremendous task of getting ships through ice and fog, uncharted shoals, calms, light and strong head winds, and many other discouraging conditions. As I have said, up to the construction of the *Fram* many of the ships used in ice navigation had been sailing vessels built in Scotland, Norway, Canada, and the United States, whilst many more had been merchant ships, bomb vessels, and warships. As a rule they were strongly built but were awkward to handle in ice, where the success of getting a vessel along depends a good deal on her sailing and quick maneuvering qualities.

For the seal and whale-fishing industry some of these ships were equipped with steam power. I think the *Victory* of Sir John Ross in 1829 was the first; and, until 1870, steam power was used only in calms. In loose, open ice whalers particularly could not use their propellers when in the neighborhood of whales, for, as we know, a whale can hear the slightest sound under water. Even when whale-boats are used amongst the very thinnest of ice, the sound made by a moving boat drives away the whales. From thence to about 1880 many fine steamships for the seal and whaling industry were built in Scotland and installed with reciprocating engines and Scotch boilers which would drive many of the ships 9 to 10 knots. They of course had sail as an auxiliary as well. All or nearly all were barque rigged. Many of the fastest and largest of these ships were used in March and April off the Newfoundland and Labrador coasts, and later some of them were used by Peary, Greely, Scott, Shackleton, and Mawson in the Arctic and Antarctic. Several of them I have been master of on sealing cruises. In fact, my first ship, the *Panther*, owned by my grandfather, was built in New Brunswick and engined in Scotland. My uncle, then a very young man, sailed her across to Greenock, Scotland, to be engined.

Building polar ships today is a very expensive undertaking. Wooden material is harder to get and more costly than formerly. Laborers are also hard to get and very highly paid. When the *Discovery* was built she cost $250,000, that is including engine and boilers, mast sails, and equipment for sea service. Then it took one year to build her, and only two tenders were submitted to the committee on building. Today it is a question if she could be duplicated. This is the day of steel, of the puncher and riveter. The adze, saw, and plane are passing away. Seasoned wood and skilled workmen are hard to find. It would cost a fortune to build another *Discovery*. The *Roosevelt* cost $107,000 ready for sea. She was built in Bucksport, Maine. Fortunately in the yard where she was built there was on hand just about enough seasoned timber to build her. Today it would cost a lot of money and time to duplicate her. The Pacific Coast of the United States is in my opinion the only place where it could be done today. And that would entail a large sum of money. At least eighteen months to two years would elapse before the ship could be launched.

Instead of a coal burner an oil engine should be used, which of course is more economical in space and fuel when the ship is not operated in ice. It would save engineers' and firemen's pay and would also mean fewer men to carry along. The design of a polar ship should be changed a little from the earlier type. Modern inventions and labor-saving devices are required, and also deck space to erect hoisting apparatus to do scientific work that needs machinery. The Diesel engine would be necessary. The engine room should and could be made strong enough to resist pressure just like any other part of the ship.

The Training Grounds for Ice Navigation

Thirty-five years of experience have I had in ice navigation, beginning as a lad with my father, who was mate of the steamer *Panther*, the same *Panther* that in 1869 took Dr. Isaac Hayes and the artist Bradford to South Greenland and then north to Melville Bay. My uncle, John Bartlett, was captain; my uncle Sam, mate; my father, second mate. The two uncles later were for years captains of the Peary ships and of Canadian Government vessels when the Newfoundland seal hunters were employed for Arctic work.

Seal hunting in March and April in the Gulf of St. Lawrence can give one as much excitement as pushing a ship to Cape Sheridan. The ice in the Gulf of St. Lawrence is of course one season's growth. It starts making in December in the St. Lawrence River. Then, as it drifts down the river and into the Gulf, the water on the lee side of the drift ice becomes calm, and in a few hours the surface of the water is covered with young ice for many miles. In fact, on a calm night and with a low temperature, say 10°–12° F. below zero, the whole Gulf and Cabot Straits are frozen over. Sometimes forty-eight hours of calm during frosty weather prevails. Or the wind may continue blowing from the northwest for days with low temperatures. In that case in a week or two the ice drifts to the south and east, and from the eastern edge of St. Pierre Bank to Sable Island and to the Newfoundland and Nova Scotia shore there is nothing but ice moving to the east and south with winds and currents. After a few days of this, many of the large level sheets become rafted against the land and piled up twenty to one hundred feet high. Heaven help the ship caught on the weather side of Cape North or about the Magdalen Islands, Byron Island, Bird Rocks, St. Paul's Island, or along the shore ice from Cape Anguille eastward along the Newfoundland coast.

Once in a while steamers are lost by getting caught between the running ice and the land ice. I remember an experience of many narrow escapes we had on the *Panther*. In three days we killed our load of seals, but, owing to the ice being heavy and in large sheets, we couldn't get around in the ship to pick them up. When seals are killed they are skinned and the pelts piled up in heaps with "markers," that is, poles with flags. When the ice opens, the ship steams around and picks them up. After the load was killed we cleaned out the hold, which held our coal, and kept out what was left after the bunkers were filled. This coal, about 70 tons, was piled up on the deck aft. It was a beautiful moonlight night, not a breath of wind stirring, when almost as if by magic the big ice sheet on which many of our flags, or markers, lay was split open. We steamed in the fast widening crack to our pans, and had about six hundred seals on board when the crack came together so quickly that we had no time to make a "dock" to put the ship in. From the main mast forward the vessel was light, but aft of this she had the deck load of coal and the bunkers filled. This with the weight of boiler and engine kept her well down by the stern. The nip came in the wake of the main hatch. She didn't rise to the first onslaught. By this time nearly all hands were overboard with hatchets, cutting a trench about ten feet from the ship, but cutting it parallel with the ship. Many hatchets were kept going, in the hope that when the trench was made the ice would double up and pass under her bottom, thereby making a cushion or bed. The ice was fully four to five feet thick. Then the beams in the wake of the main hatch, where the nip was, began to buckle, her sides began to cave in, and the orders were to throw overboard the deck load of coal. In fifteen minutes it was off the deck, and up she came. It all happened in twenty to twenty-five minutes. At that time she had a two-bladed propeller fitted with a banjo frame. In the squeezing of the ice as it passed under her bottom the propeller blades were torn off and the holdings ruptured where the boss of the propeller fitted in the brackets or couplings. This after a time was hoisted on deck and repaired. We had several spare propellers, so we were all right in that respect; but she hove out so much that I could put my hand on the end of the propeller shaft where it came out of the stern post. Here was the advantage of a wooden ship. With shores and wedges her bent-in sides were wedged out to their former shape, caulked, and made as tight as ever. With other ships when master I had similar experiences, for one doesn't need to go into the Arctic to see sights like these.

The sealing grounds are the gridiron for Arctic experiences; and so, when in 1897 I went first into the Arctic as mate on the *Windward*, Melville Bay and Smith Sound[1] and Kane Basin ice were nothing

[1] Speaking of Smith Sound ice reminds me of the loss of the *Proteus* in 1881 off Cape Sabine. The previous year the *Proteus*, a Newfoundland sealer, brought the Greely party to within 12 miles of Fort Conger. Twelve days was the length of this trip, and the passage across Melville Bay through Smith Sound, Kane Basin, and Kennedy Channel to, as I say, 12 miles off Fort Conger was made without seeing any ice. The next season the *Proteus* came north again bound for Fort Conger but found conditions very different from the preceding season. Shortly after leaving Payer Harbor, Cape Sabine, she was crushed in the ice, sinking quickly with nearly all her provisions. That winter a naval court convened in Washington, D. C. The captain, who was a Newfoundland sealing master, was examined. He was asked this question: Did you ever in your experience of sealing off the Newfoundland coast see such ice as you were in when the *Proteus* sank? He said that he hadn't. Here he was mistaken. Probably the surroundings of the court for the time rattled him, for had he stopped to think he should have

new to me. At that time the *Windward* was the flagship. She, too, was formerly a Scotch whaler used by Jackson in Franz Josef Land on the Jackson-Harmsworth expedition.

Ice Navigating with Peary

In 1896 Peary was in London. He was hoping to go north the following summer, to Sherard Osborn Fiord, which was to be his base. This is on the Greenland side, about one hundred miles northeast of Robeson Channel. While he was in London the Scotch whaler *Terra Nova*, only about ten years old, with all her sailing and whaling gear was for sale in Dundee for $35,000. Here was his chance. A bargain indeed, for her whaling and sealing gear was worth at least half that money. It was a rare opportunity, but before help came from the United States a Liverpool firm bought her. They used her for sealing, and the first spring she went sealing for them she paid for herself. The Fiala-Ziegler Relief Expedition later bought her for $100,000, and the people who sold her to Fiala-Ziegler got her back for half that money. She afterwards went south to the Antarctic, first as a relief ship for Scott and later as his own ship on the journey on which he reached the south pole and lost his life. Had Peary secured the *Terra Nova* the north pole would have been his years before April 6, 1909—and, there is no doubt, the south pole as well, for at his time of life he wouldn't have rested with the discovery of the north pole. In the *Terra Nova* he would have had a very fine ice fighter, one that would have got him to Cape Sheridan, Grant Land. Anyway this prize slipped from his hands, and, while he was wondering what was to be his next move, Sir Alfred Harmsworth, afterwards Lord Northcliffe, met him. Northcliffe had heard the *Terra Nova* story. So he said: "Peary, the *Windward* is down in the London docks. You can have her, and I will give orders to have her provisioned and coaled and delivered to you in New York Harbor." That's all that was said. There were no "ifs" and "ands" or newspaper rights to the story, etc. The auxiliary ship that summer was the *Hope*, also a Dundee whaler. Father was then captain of her at the seal fishery. I was sealing in her as mate with father for three seasons. She was more like a gentleman's yacht—I mean her accommodations and apartments. Conan Doyle was surgeon on her when she was whaling. He afterwards told

known that in 1873 Captain Tyson was ice pilot on the *Polaris* when that ship was crushed in the ice only a few miles from where the *Proteus* went down. This was on October 12, 1873. The following April Captain Tyson and sixteen or seventeen of his party were picked up off Gready Island, Labrador (53° N.), by my uncle, who was captain of the sealer *Tigress*. The *Tigress* and several sealers from Newfoundland were following the old seals, as they worked north. This of course shows that the ice that comes from the Polar Basin southward through Robeson Channel, Kennedy Channel, Kane Basin, and Smith Sound works south with the northerly winds of winter and the swift south-flowing Arctic current through Baffin Bay and Davis Straits across the entrance to Hudson Strait off the Labrador coast and thence south over the Banks to find its destiny in the warm waters of the Gulf Stream. The Tyson party camped on the ice and remained on it until they were picked up.

me in London how much he enjoyed that summer's cruise on her. She was strongly built, a good sailer, could steam ten knots, and was a splendid sea boat. I was in her with a deck load of seals in a strong gale of wind. She was loaded very deeply and yet didn't ship any water worth while.

The *Windward* was the flagship, the *Hope* the auxiliary ship. We left Sydney, Nova Scotia, several days before her. I was then mate on the *Windward*. We were bark-rigged and could only steam, under the very best conditions, four knots an hour. That season there was a good deal of ice in Melville Bay. It was in large sheets with many holes and lots of good leads but here and there bars which stopped us. Although the *Hope* did the two hundred miles between the Duck Islands and Cape York in three days, it took us eight or ten days. I can remember later when leaving Etah together at this time there was some ice across the entrance of the fiord. The *Hope* steamed out through it and in a short while reached open water. But it took us in the *Windward* many hours to get through the narrow string into the open water beyond. We of course were bound north, our destination Sherard Osborn Fiord. The *Hope* sailed south and home. It was very provoking, "conning" the *Windward* through the loose ice. I had been in the *Iceland*, another Dundee whaler, and thence in the *Hope*. Father was captain on these sealing trips. The *Hope* was handy and could be spun like a top, although we had hand steering gear. On her we had a couple of hundred men. This meant fresh hands. With the double wheels four men for one hour spun the wheel almost as if it were steam steering gear. A ship that is lively with her helm is a great asset in panned-up ice. With steam steering gear and good speed and the well-rounded raking stem it is just like dodging in and out of traffic on Fifth Avenue with a good car. The *Hope* had all the facilities of a good ice hunter, i. e. speed, good maneuvering ability, raking bow and stem. Unfortunately, she was clean aft, i. e. had a falling in around the tuck which made her sharp aft. This caused the ice in passing along her sides to be drawn into the propeller, which often required us to stop or slow down the engine to save the propeller blades and shaft.

The man in the crow's nest has to look out for the best lead ahead. To be a good "conner" one mustn't let his mind stray from the job in hand. He must always look for the best leads and high up as he is and often with a heavy ship, deeply laden with supplies, he has to look out for hard corners of ice. Hitting stem on doesn't matter, for with the raking bow and stem the ship will slide up on a piece of ice, thereby easing the shock or momentum. He also has to watch her stern for the swinging of her quarter on to a hard point of ice. A tongue underneath the water may carry away propeller blade, shaft, and propeller. Then, if she is deeply laden, she may carom from the corner of a heavy piece of ice to a hard opposite corner, hitting her on the turn of the bow, which is liable to cripple her. In going astern the rudder always should be amidships. When bucking ice it is better to start her astern full speed. Then, as she gathers way, go slow astern. This has the effect of enabling the steam in the boiler to rise, so that when she comes ahead for the next butt she will have a good head of steam to help her break her way through the bar ahead. With hand gear the wheel chains are always racked going astern. It is dangerous in going astern not to leave the racking on the chains, for a man is likely to have his leg or arm broken or be thrown clean over the wheel should the rudder strike the ice in going astern or get a side clip either going astern or ahead. One has to exercise great caution in going astern. The officer on the bridge must be trained and skilled to watch every movement. As a rule I am aloft myself and come down only if I have a very competent man to take my place. One has to be tireless to move a ship through ice. The ice movements themselves may be very quick, and a few minutes lost may put one a long way astern. Patience, again, is a great virtue. The first thing is to keep your ship free. When she is free you can go where the breaks occur; if caught in the ice you are powerless and have to go where the ice brings you, but free you can take the first favorable opportunity or leads that open in the direction you want to go.

We were lucky in the *Roosevelt* not to have any naval or government restrictions. We had no insurance. She was registered in the New York Yacht Club—no underwriters, no Board of Trade. I had a British master's ticket, but she was an American yacht. So it didn't matter. The thing was to get her to Cape Sheridan or Porter Bay, Grant Land. We took a big chance leaving Etah so heavily laden that the deck was almost in the water. She looked like a muskrat swimming, only both ends above water, stem and stern. That was her condition in 1905 and again in 1908. She couldn't rise on the ice when in that heavy state if caught between floes. In that case she must have gone under in a short time. We couldn't help ourselves in 1905, for we had two years' provisions and a deck load of dogs and Eskimo whale and walrus meat. She burned twenty-five to thirty tons of coal in twenty-four hours of hard steaming. Ten days of hard steaming would make a big hole in our coal supply. Then there was the long winter and the return the following year. No sealing captain would think of loading his ship so deep or handling her as roughly as I did the *Roosevelt.*

Much of the ice we encountered going up Smith Sound, Kane Basin, Kennedy and Robeson Channels came from the Polar Basin, some of it the paleocrystic ice, which really is the ice foot or glacial fringe along the Grant Land coast. Then there is the ice that has formed in the Polar Basin and been held there for years and is at length drawn out through Robeson Channel anywhere from 20 to 150 feet under the water. The surface of some of these floes has the area of Manhattan Island. With a current running one to three knots and a gale of wind, force 6 to 7, striking against that 20 to 150 foot surface of many square miles of floes, a ship, no matter how well she was put together, when caught between the hard points, cannot rise unless she is of the right shape and is not heavily laden. But should she get hove up against the face of the ice foot and find no niche to run into she would have about the same chance as a man under the wheels of an express train in a subway. A short beamy ship with not too much draft and not too heavily laden has the best chance to escape. In building a ship it is a mistake to put in heavy wood when a lighter wood that is just as strong will do.

Varying Ice Conditions from Year to Year

Seasons in the Arctic vary from year to year. I crossed Melville Bay twice in the *Roosevelt* around the middle of July and saw no drift ice. But when I went north in the *Neptune* in 1917 it was a constant fight with ice from Sanderson's Hope to Cape Alexander. From Cape Alexander to Cape Sabine it was clear water. My destination was Etah, North Greenland. There I was to pick up the Crocker Land party and bring them home. I thought with such a ship as the *Neptune* I could do the job in six weeks; instead it took me two months.

In all my many experiences up to that time in that section of the country I never saw anything to equal the terrible ice conditions I encountered. Putting the ship in the ice a few miles off Sanderson's Hope was a constant struggle. Every foot of the distance north to Cape Alexander the ice ran from Greenland to Baffin Island and remained so all that summer and fall. Reading earlier accounts of whalers I find one similar year in over a hundred years of whaling. I used 800 tons of coal on the *Neptune*. Usually, in the time we were going from Sanderson's Hope to Etah and return, one would burn about 70 tons of coal. And only by the skin of my teeth did I get her out of the ice. Had I ten miles more to go in it I should have had to abandon her, for all her bow plates were gone and she was worn into the wooden ends, and the two deck pumps and several in the engine room could barely keep her free.

In the summer of 1926 the conditions were as follows. The first week of July I was at the Duck Islands (74° N.); there was not a sign of drift ice there, and by the look of the shore around the islands the ice had gone out of there at least ten or fifteen days earlier. In going across Melville Bay to Cape York no ice was seen, and by the temperature and color of the surface water of the bay it would appear that ice had moved out many days previous to our crossing. So it is—no one can tell a thing about ice conditions until he gets up there and sees for himself. It all depends on the winds early in the spring. No matter how mild or severe the winter is, the thing that does or doesn't give us open water to navigate in is continuous offshore winds. In a calm spring and summer the ice stays just where it is.

Of course with a powerful ice breaker one could negotiate the ice in July or August. The warm sun of June and July melts the top of the land ice, and this has the effect of sending large volumes of fresh water into the fiords. But it is the offshore winds that give the open water. Sometimes the winds are continuous southwesterly to west, and in this case they keep the ice north, thus offsetting the strength of the Arctic current. Strong north winds send the drift ice south, and the bergs also are set in motion. The ice is plowed up and broken into small floes. Then comes the surface current, accelerated by the melting of snows from the hills, valleys, and plains.

It has been my good fortune to see ice conditions in Bering Sea, Bering Strait, off and near the Siberian coast, and along the Alaskan coast eastward to Martin Point. Ice conditions there are much the same as we find them along the Greenland coast and in Davis Strait and Baffin Bay and through the straits, fiords, and basins north to the Polar Basin itself. Ice conditions vary there as on the eastern side of America. In getting along, if one hasn't a good ship, he has to play the waiting game. The same thing more or less applies to the eastern side. No one can make a good ice pilot who is afraid of losing his ship and having to face court-martial—and if he loses his ship he loses his job. The best thing for him to do is stay out of the ice or radio home "safety first." No government can afford to have ships lost or broken up. No captain in a government position ever lost his job by being careful of his ship. In Arctic work government expeditions are rarely successful.

Wooden Ships Versus Steel Ships

I myself have been amongst the ice in a sailing vessel only, and that with a small crew,[2] and have had to do lots of things that the old fellows in the days gone by had to do to get their vessels along. When first I went sealing nearly all the men that comprised the crew of the *Panther* had been on sailing vessels. They were inured to hardships and knew how to handle a brig as well as a Long Island Sound boy can handle a catboat. They used the square yards to back and fill in the ice, going through the evolution of going ahead and astern by bracing and balking the fore and after yards. They carried royals and skysails, also stemsails, on those sealers. About forty to fifty

[2] But for the large crews carried on the whalers and exploring ships, they never could have got along. Many of these small ships carried 150 men. In the *Roosevelt* we had only 15 sailors, firemen, engineers, cook, mates, and captain.

men handled a brig of sixty to one hundred tons. At the age of ten the Newfoundland sealer began his sealing. No wonder that all hands on board knew every rope and every evolution that was or would be performed.

I have been asked, "Why not build steel ships and use them in polar work?" We use steel ships for seal hunting; some of them of 4000 tons. So long as they are handled with care in light ice they do not suffer much damage. But when they have to work through the heavy Arctic pack trouble comes. After a sealing voyage many of the plates have to be removed and rerolled, especially around the struck parts, that is around the bows and stern, and from twenty to fifty barrels of rivets have to be used to make them tight. Sometimes the frames and stringers become bent—an expensive repair job. But the worst feature of going into the Arctic with steel ships and having to winter would be pumping, for, with the rivets started, leaks are bound to happen. Should a steel ship become squeezed in an ice rafter it would be a difficult matter to get the scantling, beams, and frames in place.

During the summer of 1910 I brought north the *Beothic*, a steel sealer of about 2200 tons burden and 15 knots speed. We had her loaded with coal, and along about June 20 we were at the Duck Islands, Melville Bay; and from there to Cape York, a distance of about 200 miles, the ice was from two to four feet thick. We crossed in about forty-eight hours, never once stopping. But after a few hours in the ice the fore peak became filled with water, the rivets having loosened. Being early, there was ice everywhere, and we kept moving in Whale Sound, Inglefield Gulf, and Murchison Sound. Right up to the Bache Peninsula, Kane Basin, and south into Lancaster Sound, and up Barrow Strait almost to Melville Island we had heavy ice. Turning around we steamed back over our track to Jones Sound. We were after musk oxen. I thought perhaps we might get to Melville Island, but the heavy ice in Barrow Strait frustrated that plan, hence I attempted to get into Jones Sound and thus to Cape Sparbo. Across the entrance to Jones Sound is a large island, Cobourg Island, with a strait at both entrances south and north. The two entrances were filled with ice, lots of it, drift ice packed in with the easterly and southeasterly winds, and there was some unbroken bay ice. I kept hammering at it and using lots of dynamite. Finally I broke my way through to the loose ice on the south side of Jones Sound. There it was another fight of 42 miles to Cape Sparbo, where we got our musk oxen. In coming out I tried to get around a point of ice and ran aground. I got the ship off, but with the heavy going through ice all the rivets in the bottom loosened up from stem to stern and all her tanks now were filled with water, so we came home on the tank tops or double bottom. Now, if we had had to spend a winter in the Arctic, it would have meant keeping up steam in one of the boilers to pump her out, for we were leaking badly above the tank tops. In other words, nothing but a wooden structure has the elasticity and strength to withstand polar ice without injury. And should you receive injury when squeezed in ice you can always drive things into place with wedges; and with oakum, tar, pitch, and canvas you can fix things up. A steel ship is crippled much more easily than a wooden ship. Her weight and thin plates, frames, stringers, and scantling make her rigid. There is no give; so, in resting on an uneven bottom, she is bound to strain, bend, and loosen rivets, plates, and frame. A wooden ship will generally conform more or less to her surroundings and after getting afloat again—if she is a well-constructed ship—will settle back to her former shape.

The great menace to a ship in ice navigation is inexperience. So many things have to be studied in regard to ice floes, weather, calms, frost, snow, rough and smooth water, bergs, growlers, currents, varying seasons, fogs, winds, and how these act on bodies of ice. Even on a very fine night a ship steaming in the direction of a light sky has to be careful because bergs and floating ice are then not thrown into relief at all. This is noticeable when going toward the south, where as a rule the sky is dark. In summer the part of the northern sky that is below the midnight sun has a long twilight arch.

Ice Movements in Baffin Bay and Labrador Waters

The amount of ice and its location and movement vary from year to year. A person beginning an Arctic voyage cannot tell what conditions he will meet. The regions of his visit are so vast and so little known from direct and special observation that no prediction can be vouchsafed. Since the Ice Patrol has been inaugurated we know about the drift of bergs in the North Atlantic, and I suppose in future years, should wireless be used for broadcasting weather conditions in the Canadian Arctic and Greenland, one would be able at the start of the trip in spring to get a better idea of northern conditions than in former times. The U. S. Hydrographic Office and of course the Canadian Government and the Danish Hydrographic Office give us much information. So far the only information of ice drift from our side was obtained from Tyson's drift on an ice floe and McClintock's in the *Fox*. After all is said and done, there is little or no reliable information regarding the Labrador Current. Only fragmentary information has been gathered by a few vessels that have gone north during the summer and fall months. There are no data for the winter season. On several occasions I have found little or no current on coming south. Neither the depth nor the breadth of the current is known. Of course we know that large volumes of cold water pour into the Atlantic and that the flow of the Polar Current has on several occasions been demonstrated by the drift of vessels beset in the pack east of Greenland; also by driftwood from America and Siberia, the wreck of the *Jeannette*, etc. This current flows close to the southern tip of Greenland, Cape Farewell carrying on its bosom the ice from the Polar Basin itself. The flow is north and west along the Greenland coast in a belt perhaps 30 to 50 miles wide. Near the Arctic Circle it ceases, here meeting the current that flows south out of Baffin Bay. This is not far north of the narrowest part of Davis Strait. I believe the great number of bergs seen off Newfoundland and the Grand Banks come from Melville Bay and from the parent glaciers north to the Humboldt Glacier (Kane Basin). With the southwest winds and calms there are seasons when the surface ice is late moving out of Melville Bay, consequently the bergs move slowly also. When this happens we have a congestion of ice along the whole west side of Baffin Bay and Davis Strait. And with so much southerly trend to the winds the northward flowing current that I have mentioned along the west coast of Greenland is accelerated and the Baffin Bay or Labrador Current retarded. Then you find the hardest ice conditions, as I found them in 1917. Sometimes we get fewer bergs. I have come south from Cape York in August and twice in September and found no visible pack, and in 1926 I took particular notice from hour to hour crossing to Holsteinsborg from a point twenty miles east of Cape Aston, Baffin Island (70° N.). We saw little or no drift ice, and what I saw was to the southwest in strings, though we had bergs until we were about 55 miles west of Holsteinsborg. Ten to fourteen miles farther west, or about 70 miles from the Greenland coast, bergs were scarce. In other words, in a belt between 55 and 70 miles from Greenland only three bergs (one of them large) were seen.

One year with the other it takes a Melville Bay berg a year and sometimes a year and a half to get to the Grand Banks. Field ice often checks the speed of an iceberg. In the days of sailing vessels, when there was a strong southerly current and calm weather the ship would make fast to a berg and if the berg was aground it would shift a lot of ice and enable the vessel to hold her own. Then, again, in strong wind a ship may be made fast stern on with the two ends of the line on board and the topsails all ready to loosen should the wind drop and the tide change. In this way a vessel can shift many, many miles of ice. Again, a vessel may be in danger of being crushed in a gale of wind when carried by the ice on to the weather side of a berg. Many ships and crews have been lost in this way. Steamers always make use of the lee of a berg to shift ice and save coal. With steam up you can cast off at any minute and make a lee on any side of the berg, should your first lee be closed up by ice closing in on you. By means of a berg many of the sealers would be carried into the seals.

In the ice fields the surface of the ocean is covered with a glistening expanse of ice dotted with towering bergs of every shape and size, and, in a gale of wind and blinding snow, drifting in the pack with a ship jammed unable to move, it is, to say the least, uncomfortable. A steamer is not so bad, for you can steam up to the wake of the berg and you are safe. In a sailing vessel you have to loosen sails, and, even if you are fortunate in catching the wake, it is hard to hold it in a gale of wind and beat to windward. Calm weather in open water and strong current with a small crew is a serious thing. Your only chance is to get the boats overboard and row, thus keeping her clear. In even a slight swell the berg is in motion and rears and plunges. If the berg is steady you still have the wash breaking on the sides and sometimes a ram or tongue of hard jagged ice long underneath. I have seen many accidents resulting from collision with bergs. Icebergs are really big ice plows. In many cases they tear through large floes as if they were pulp. The bergs are more affected by currents than the ice is; the latter owes its drift to both winds and currents. The wind of course helps bergs also, but often we see them plowing to windward in a strong breeze.

What a menace those white devils are to the cod traps of the Labrador and Newfoundland fisherman! Tens of thousands of dollars' worth of fisherman's gear are destroyed yearly. Often they get into coves in the height of the capelin school, that is the very haymaking time of cod fishing. Often they will stay and hinder the fisherman from putting his traps in the cove. Dynamite is the only thing to make them quit, but what fisherman has dynamite? And the icebergs are responsible for so many fatal accidents that occur through the foundering and capsizing of the fisherman's skiff. It's astonishing how easily bergs can be made to topple by the firing of a rifle or the cutting of a small piece off the side. A blow from an ax have I seen do it also. The noise of a berg rupture is often deafening. It is a great sight to see them turn over. As a rule when they reach the tail of the Banks they are becoming smaller, but there are cases recorded by the Hydrographic Office where bergs have been seen in the latitude of New York, with sharp spurs under water, as dangerous as a sunken reef. It's much safer to give them lots of room. A ship should always go to windward of an iceberg because the spalls, or fragments, are to leeward. Naturally they move faster than the berg. The small pieces are often more of a menace to navigation than the larger berg itself, because often they are the color of the water and float so low as to be seen only with difficulty.

Field ice is found from a point south of Sable Island northward to the pole. The ice in the Polar Basin varies in thickness from seven or eight feet to one hundred and over. It is astonishing how thick ice may get in the River St. Lawrence and along the north and west shores of the Gulf of St. Lawrence and between the Magdalens and the Rimouski Peninsula. I have seen floes fifty feet out of the water and drifting out of the Gulf. Of course many of the bays and inlets of the far north remain frozen for years, melting only in places with the sun of June and July. These berg pieces and old floes as they drift south become frozen together, and then a swell from the ocean breaks them up and the icebergs plow through, impinge upon heavy floes, butt the land ice, and thus destroy the acreage of the floes. Farther and farther south the ocean swell diminishes them still further, and they form dark, indigo-colored masses so low as to seem almost awash and rounded on top like a whale's back. These are the growlers. When the ice is spotted with growlers but is loose enough for a vessel to work through it there is danger. This war dance of the growlers has destroyed and crippled more vessels than anything else. A skirt of growlers is a terrible place. It's seldom you come out of it without at least a very severe pommeling, and lucky you are not to lose your ship. The weather edge of heavy ice in a gale of wind with a rough sea and swell is exactly the same as a line of breakers on a coral reef. Unless a ship is fitted for ice she has no right to enter the pack, although it is very tempting, for only a hundred yards or so inside the edge it is as smooth as a duck pond. Then, again, the edge may have many detached pans which labor and tumble menacingly. With a good strong Arctic ship you might get in between the rotating pieces unscathed, but care must be taken to watch the propeller, and one must be careful to judge the distance and time before passing between the pieces.

I had a very close call in the *Roosevelt* on the way home in 1909. We had an easterly gale; so I ran it out, but the wind hauled southeast with a big sea running. It was thick and I made the weather edge of ice. We were light with little or no coal. From aloft I saw one place that I thought I might enter, so I kept away, and on getting near the edge she rolled so that at times her quarter boats, although high up in the davits, often hit the tops of the waves. As I got near the two pieces where the entrance was it began to close. I couldn't haul by the wind; so when her stem entered I stopped the engine. The sails and momentum took her through, but she got an awful jar on the quarter. It shook her as if she had struck a reef. Only a few times her length, and we were in smooth water, though we could watch the sea breaking over the pieces of ice where we came in and the white-topped waves breaking still farther beyond. At length the outside edge began to wear away, so we had to move farther in, and so on till the wind and sea went down; and then after a few hours we pulled out again. In sailing-vessel days this would be a terrible experience, because the ice inside was too close-set to get through, but with steam we could push through. With a sailing vessel the only thing to do would be to carry along lumps of ice and make a bed for her. At times, where the ship is the ice is hard, so wooden fenders are used, and after a while these become broomed. The difficulty is with a narrow string of ice along shore and a gale of wind on shore raging with sea and swell. A ship getting on the edge runs for shelter. For awhile all is well, but in time the ice wears away and nothing is left next the coast line, so it's either go ashore or work offshore or run for a harbor if one can be reached. A steamer may get out of it, but often doesn't. I know of three steamers that were lost in this way. The crews were saved by getting on shore over the ice fringe before it was destroyed. One sailing vessel I knew drove over a shoal, and all of her crew was lost except one. I had a similar experience myself, losing my ship but saving my men.

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AIR NAVIGATION METHODS IN THE POLAR REGIONS

O. M. Miller

Aërial navigation generally will never call for such precise determinations of position as navigation at sea, and it is quite sufficient for the aërial navigator to fix his position within a radius of ten miles. In considering the methods of navigation that will be described in the present paper this point should be kept in mind.

The subject of navigation can be dealt with in two parts; the first of these is position finding, and the second direction finding, which includes the operations involved in steering a course.

Position Finding

By Dead Reckoning

To deal with position-finding methods first, dead reckoning is the principal method used by all navigators and is simply the process of determining position by distance and direction flown from a known starting point. In the polar regions the method differs in no essential from ordinary practice in aircraft.[1]

Its accuracy depends on the ability of the navigator to judge ground speed and to correct for the drift of the aircraft from the desired direction due to lateral wind pressure. In order to do these things, at present, it is necessary to know the air speed, the height of the aircraft above the surface of the earth, and to be able to see the latter, which should not be entirely featureless. Obviously, over the open sea, it is only possible to get a very approximate result by this method, but over an ice field, which is by no means featureless, sufficiently accurate results can be obtained, as has been demonstrated by Commander Byrd in his flight to the pole. As in all forms of aërial navigation, fog is the arch enemy of dead reckoning. Even supposing the navigator can be sure of steering in a straight line through it, there is still the difficulty of determining ground speed. The whole problem of dead reckoning through fog needs a practical solution.

By a Position-Line Method

Fog or no fog, the navigator cannot allow himself to place full reliance on the dead-reckoning method. He must have other means

[1] See H. N. Eaton: Aerial Navigation and Navigating Instruments, *Natl. Advisory Committee for Aeronautics Rept. No. 131*, Washington, 1922.

of checking his position. Now, because it is essential that the navigator determine his position practically on the instant while flying, most astronomical methods are valueless. However, there is one that can be employed which is simpler to use in the polar regions than in other parts of the world provided one knows Greenwich time, and there should be no difficulty about this in these days of wireless time signals and good chronometers, especially as it is not necessary to know the time with absolute precision.

The particular astronomical method in question has been employed by all the navigators in the recent flights in the polar regions for checking their dead-reckoning positions. It is sometimes described as the Marc St. Hilaire method with the pole as the assumed position,[2] but this is hardly an adequate description.

By observing an altitude of the sun or other celestial body it is possible to define one's position as being somewhere on a circle of equal altitude which has as its center the point on the earth's surface at which the celestial body was in the zenith or directly overhead at the moment of observation. The radius of this circle is equal to the zenith distance. When one is in the polar regions it is very easy, and requires no computation, to plot this position line on the chart, because the meridian which the heavenly body was crossing at the time of the observation is known and the distance from the pole along this reference meridian to the point where the circle of equal altitude cuts it is equal to the difference ($h - d$ in Fig. 1) between the sun or star's declination (d) and the observed altitude (h). If the altitude is larger than the declination, this point is between the pole and the sun or star; but, if the opposite is the case, then the point lies on the opposite side of the pole to the latter. The

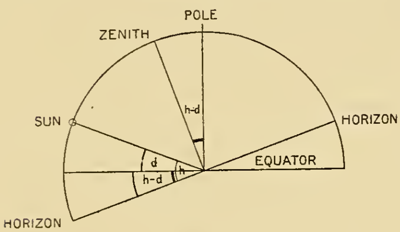

FIG. 1.

[2] The development of this method is interesting. As long ago as 1892 Professor Hans Geelmuyden of Christiania suggested (Stedbestemmelse paa høie Bredder, *Videnskabs-Selskabet i Christiania Forhandlinger*, 1892, No. 1) a graphic method of plotting position lines on a stereographic projection suitable for use in the polar regions, and undoubtedly Nansen used such a method on the voyage of the *Fram*. However, the particular simplification described in this paper was first suggested—at any rate in the English language—by Professor Harry Fielding Reid in a paper entitled "How Could an Explorer Find the Pole?" (*Popular Sci. Monthly*, Vol. 76, 1910, pp. 89–97). Later Mr. A. R. Hinks in a paper entitled "Notes on Determination of Position Near the Poles" (*Geogr. Journ.*, Vol. 35, 1910, pp. 299–312) suggested the same simplification as a method of checking up on explorers' observations. According to Lieutenant Hjalmar Riiser Larsen (Roald Amundsen, Lincoln Ellsworth, and others: Our Polar Flight, New York, 1925, p. 173), H. V. Sverdrup used the method on the voyages of the *Maud*, and it would appear that Sverdrup was the first to use it in the field whilst Larsen was the first to use it in an airplane flight, namely the first Amundsen-Ellsworth flight in May, 1925. Since then several descriptions of the method have appeared, e. g. G. W. Littlehales: Finding Geographical Position in the Region of the North Pole, *U. S. Naval Inst. Proc.*, Vol. 51, 1925, pp. 1339–1342; H. Coldewey: Ortsbestimmung im Polargebiet, *Annal. der Hydrogr. und Marit. Meteorol.*, Vol. 53, 1925, pp. 345–347; A. R. Hinks: Second Note on Determination of Position near the Poles, *Geogr. Journ.*, Vol. 68, 1926, pp. 58–62.

circle of equal altitude must cut this meridian at right angles; and, if the sun is observed or some star with a low declination, it is a sufficient approximation when flying within five degrees of the pole to draw the position line as a straight line; however, when farther away than this or when the declination of a star is high, it is necessary to take the curve of the position line into consideration. This may be done in several ways, though perhaps the simplest is to have templates made of a selection of suitable curves.[3]

The plotting of this position line (for examples, see Fig. 2) gives an observer an independent check on the accuracy of his dead reckoning, but by itself it is not an independent method of position finding. If, however, position lines are plotted at about hourly intervals it will be possible to obtain a rough indication as to the course being taken. This applies to sun observations; but, when the flight is undertaken at night or when the moon is available, the method becomes much more efficient, as it is then possible to observe altitudes of two or more heavenly bodies in rapid succession at azimuths which will make the plotted position lines intersect with well-conditioned cuts. When only one position line is plotted it is best that it should cut the line of flight at an angle of 45°. Should it cut the latter at right angles then it will be a good check only on the distance flown. Should it on the other hand lie more or less parallel to the line of flight then it is only a check on direction.

Suitable Sextants and Their Accuracy

In order to observe an altitude of a heavenly body the only instrument at all practical for use in aircraft is a sextant.[4] Of the many forms of this instrument probably the most convenient is the bubble sextant, as by using it dependence on a natural horizon and corrections for dip are avoided.

If on the other hand the natural horizon can be seen—and it is understood that in clear weather an ice field provides an excellent horizon when one is flying below 1000 feet and that in foggy weather the bank of fog does the same provided the aircraft can rise to 4000 feet—then the Baker sextant[5] is well worth the attention of polar

[3] For use with the American Geographical Society's navigational chart of the Arctic Basin (of which Fig. 2 is a section and Fig. 1 in Dr. Bauer's paper, above, is a reduced facsimile) the writer has had prepared celluloid sheets (9 x 5 inches) in which 10 curves have been cut. This number has been found sufficient for navigational purposes within the Arctic Circle when the declination of the heavenly body observed is not more than 25°. A small table for choosing the nearest correct curve with altitude and declination as arguments has also been prepared.

[4] K. H. Beij: Astronomical Methods in Aërial Navigation, *Natl. Advisory Committee for Aeronautics Rept. No. 198*, Washington, 1924; Air Navigation Instruments . . . By Command of the Air Council . . . Air Ministry (Directorate of Research), *Air Publication 803*, H. M. Stationery Office, London, 1924.

[5] Beij, *op. cit.; Air Publication 803;* T. Y. Baker and L. N. G. Filon: Position Fixing in Aircraft During Long-Distance Flights Over the Sea, *Trans. Royal Aëronaut. Soc.*, No. 2, 1920.

aërial navigators. This instrument by an ingenious device takes a sight simultaneously on the sun and the part of the horizon immediately beneath the sun and also on the part in the opposite direction, thereby eliminating errors due to uncertainty in the amount of dip correction and to the apparent change in the vertical caused by accelerations in the speed of the aircraft and sudden turns.

These errors in the apparent vertical are the chief objection to the use of bubble sextants, and attempts have been made in France to overcome this difficulty, and still not be dependent on the natural horizon, by utilizing the gyroscopic principle. At first such sextants were not satisfactory for use in aircraft, but it is understood that the method is being developed.[6]

APPROXIMATE REFRACTION
GIVING CORRECTIONS TO THE NEAREST 5′ OF ARC ONLY

(Assumed temperature, 0° F.)
(Assumed barometer at sea level, 29.5 ins.)

At Sea Level, Angle of Elevation Observed	Correction in Minutes of Arc	At 3000 Feet Above Sea Level, Angle of Elevation Observed
0° 00′		0° 00′
	35′	
0° 22′		0° 02′
	30′	
0° 55′		0° 35′
	25′	
1° 35′		1° 10′
	20′	
2° 32′		2° 02′
	15′	
4° 10′		3° 30′
	10′	
8° 00′		6° 50′
	5′	
22° 45′		20° 30′
	0′	
90° 00′		90° 00′

It is very important that the navigator before embarking upon a flight across unknown regions should know the maximum precision possible of altitude observations in the air with a sextant and also how far he personally is capable of obtaining this precision. As for the former, opinions on the subject vary;[7] and it appears that the best that can be said at present is that, under good flying conditions, namely the best piloting and observation and an absence of bumps, the average error of one bubble-sextant observation is probably somewhere between 5′ and 30′. Observations are likely to be more accurate on sea than on land, more accurate if taken in the line of flight

[6] G. W. Littlehales: The Search for Instrumental Means To Enable Navigators To Observe the Altitude of a Celestial Body When the Horizon Is Not Visible, *U. S. Naval Inst. Proc.*, Vol. 44, 1918, pp. 1808–1817.

[7] Eaton, *op. cit.*; Beij, *op. cit.*; H. N. Russell: On the Navigation of Airplanes, *Publs. Astronom. Soc. of the Pacific*, Vol. 31, 1919, pp. 129–149, San Francisco; J. P. Ault: Navigation of Aircraft by Astronomical Methods, Special Rept. in: Ocean Magnetic and Electric Observations, 1915–1921, [constituting] *Researches Dept. of Terrestr. Magnetism*, Vol. 5, Carnegie Instn., Washington, 1926, pp. 317–337; B. Melvill Jones: The Accuracy of Sextant Observations Taken from Aircraft, *Technical Rept. Aeronautical Research Committee for the Year 1922–23* (*Repts. and Memoranda No. 810*), Vol. 2, pp. 589–606, H. M. Stationery Office, London, 1924; G. M. B. Dobson: Design of Instruments for Navigation of Aircraft, *Geogr. Journ.*, Vol. 56, 1920, pp. 370–389; Chart of Route Flown by Lieutenant Commander R. E. Byrd . . . *Natl. Geogr. Mag.*, Vol. 50, 1926, p. 386.

than athwart, and more accurate in airships than in airplanes. It will be obvious that further investigation is needed on the subject of the precision of sextant observations, especially in respect to flying conditions in the polar regions.

In order to reduce errors, about six observations should be taken in rapid succession and the results meaned. The only correction required if a gravity or Baker sextant is used is that for refraction.[8] Very little is known about atmospheric refraction in the polar regions, and the question is one that needs investigation. However, for aërial navigation it need only be known approximately to perhaps the nearest $2'$ or $3'$, and extrapolations from the ordinary refraction tables are in all probability sufficiently precise. A convenient type of refraction table for use while flying is shown in the adjoining table.

Magnetic Checks in Position Finding

Another check on position suitable for aërial navigation can be obtained by observing the horizontal angle between a heavenly body and the direction indicated by a magnetic needle;[9] but this assumes a knowledge of magnetic declination and also an approximate knowledge of position. Consequently it is not likely ever to be of much value in the polar regions, for, apart from the large errors of observation due to the weakness of the horizontal component of the magnetic force, local magnetic disturbances, and instrumental errors due to acceleration, etc., the magnetic declination itself changes very rapidly and thus the probable error in the assumed position will create too large an error in the assumed magnetic declination.

Nevertheless there is a possible independent method of checking position by utilizing the earth's magnetism and obtaining the direction of total intensity with a dip compass. By measuring the angle of dip while flying,[10] the navigator could determine his magnetic latitude. Of course this method cannot be used until the polar regions have been properly charted magnetically, and it is also a matter for investigation as to how accurately dip compasses could be read in aircraft, but the method is suggested here for the reason that if it should prove practical it would provide an immediate check on position while flying through or above fog and, together with the astronomical position line, would provide a complete method of determining position independent of dead reckoning.

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[8] The correction for parallax can be considered negligible.

[9] Baker and Filon, *op. cit.*; Ault, *op. cit.*

[10] This method was referred to by G. M. Dobson, *op. cit.*, p. 383. A similar suggestion was made by D. Boykow and others: Die Navigation in der Arktis, Appendix 2 to "Das Luftschiff als Forschungsmittel in der Arktis," Internatl. Studiengesell. zur Erforschung der Arktis mit dem Luftschiff, Berlin, 1924, pp. 43–51. In this latter article it was proposed to measure both the horizontal and vertical intensity of the magnetic force and thereby locate the aircraft on position lines of equal magnetic intensity.

Gyroscopic Methods

Theoretically the gyroscope could be employed in the polar regions to determine position; but technical difficulties of construction and adjustment are such that it is not likely to be developed while there are simpler methods available, especially as it seems probable that if ever the short air routes across the polar regions are utilized commercially the radio compass or wireless direction finder will succeed in displacing all other methods of navigation.

Wireless Methods

Direction and position finding by wireless is being rapidly developed.[11] There are two systems in use. The first, and at present the most efficient, is for the aircraft to send out a signal whose respective direction from two or more ground stations is determined by them on receiving the signal. These direction lines when plotted on a chart should all intersect at a point, which is naturally the position of the aircraft. The ground stations then signal this position to the craft. Obviously it would be more practical for the navigator in the aircraft to be able to determine the direction of signals sent out from ground stations and plot the craft's position himself. This is the second method being developed. At present it is only practical over short distances, for even under good conditions and over

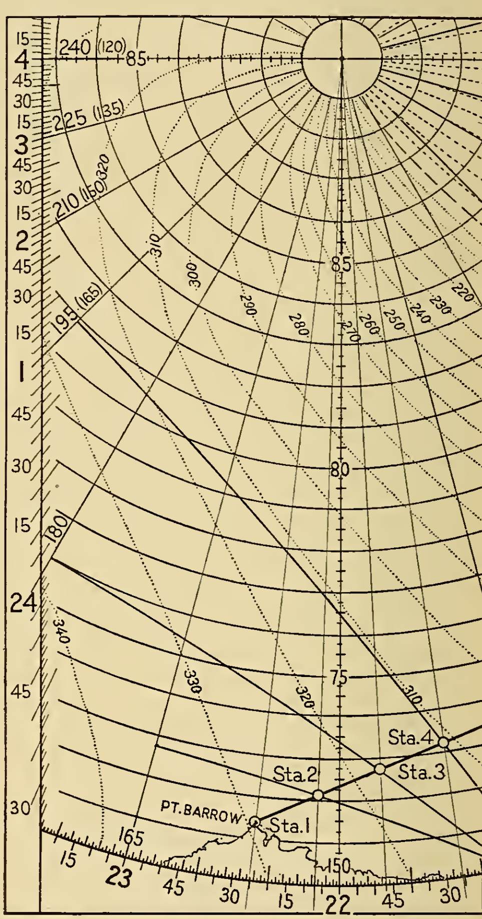

Fig. 2—An example of position and direction finding according to the position-line method described in the text. In this figure the example is plotted, and in the adjoining table it is worked out.

[11] R. L. Smith-Rose: The Reliability of Radio-Direction Finding for Navigation Purposes, *Year Book of Wireless Telegraphy and Telephony*, London, 1924, pp. 586–591; *idem:* The Progress of Radio Direction-Finding During 1924 As an Aid to Navigation, *ibid.*, 1925, pp. 543–547. For bibliography, see *Hydrogr. Rev.*, Vol. 3, 1926, pp. 200–205, Monaco.

short distances an angular error in direction of 2° must be expected.[12] This angular error increases with distance and, should the signal be sent from a region in darkness to a region in daylight or vice versa, may be as much as 90°. Nevertheless it is probable that the method will eventually be perfected, as it is applicable to all regions; and when this is done a complete solution of the problem of navigation

WORKED-OUT EXAMPLE

(*a*) *Finding Position*

	STATION 1 START OF FLIGHT	STATION 2 100 MILES	STATION 3 200 MILES	STATION 4 300 MILES
Place	Point Barrow	on course	on course	on course
Time (Greenwich Apparent Time)	22 h.	23 h.	0 h.	1 h.
Observed altitude		40° 21′	37° 01′	32° 07′
Declination	23°	23°	23°	23°
Altitude − Declination .		17° 21′	14° 01′	9° 07′

Position line is then drawn

(*b*) *Finding Direction*

From Chart: Latitude	71° 15′ N	72° 05′ N	72° 40′ N	73° 15′ N
From Chart: Longitude . . .	156° 20′ W	151° 45′ W	146° 40′ W	141° 25′ W
From Chart: Azimuth of course N. by E. . . .	60°	65°	70°	75°
From Chart: Hour angle approx.	354°	13°	33½°	53½°
Azimuth correction from table (Fig. 4)	2°	3°	6½°	7°
± 180°	180°	180°	180°	180°
Azimuth of sun	172°	196°	220°	240½°
Horizontal angle from direction of flight to sun clockwise	112°	131°	150°	165½°

in the polar regions will be provided. As an example of this suppose *A* and *B*, two radio stations sending out regular signals, are both situated on an important aërial trade route. An aircraft at *A* picks up the signals from *B*. Then all the navigator will need to do in order to reach *B* will be to follow the direction indicated.

Nevertheless, this perhaps is looking too far ahead; other methods of direction finding are being used at present and will probably continue to be used until the period of exploration is over, in spite of the fact that the airship *Norge* during her polar flight obtained checks on position by means of radio signals sent out from Kings Bay, Spitsbergen, and Nome, Alaska.

[12] An angle of 2° at 100 miles subtends an arc of about 3½ miles.

Direction Finding and Steering a Course

By Magnetic Compass

The conventional method of finding direction and steering a course by magnetic compass has many disadvantages when used in flights in the polar regions.[13] Apart from the fact that at present the polar regions are not adequately charted magnetically, the horizontal component of the earth's magnetism is very weak and, except for the region on the other side of the true pole to the magnetic pole, the lines of equal magnetic declination come very close together. Consequently the process of flying along a great circle by magnetic compass is very complicated.

But the magnetic compass[14] continues to be used and will continue to be used as a means of determining direction for flights because of its simplicity and because it functions in fog. As a guide in steering a course it is not likely to be much used in the future, although, again, until the radio compass is perfected it will remain the only method available in fog.

By the Use of Sun Azimuth Tables

A more satisfactory method of finding direction when flying in the polar regions, in that it indicates true north rather than magnetic north, is by the sun. Assuming that one's position has been determined approximately, then, knowing the Greenwich apparent time and consequently the difference in longitude between the position and the heavenly body (easily deduced from the chart) and knowing the declination of the heavenly body and the latitude, the navigator has sufficient data for solving the astronomical triangle (see Fig. 3). Now as one proceeds towards the pole the azimuth of the sun (measured S by W in north latitudes, N by W in south latitudes) becomes more nearly equal to the hour angle. Consequently it is herewith suggested by the writer that the most convenient astronomical way to determine azimuth in the polar regions is by applying to the sun's hour angle, from tables previously comput-

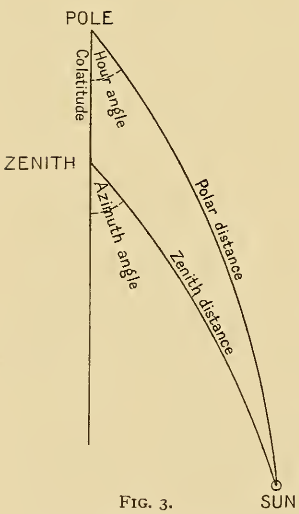

Fig. 3.

[13] The instrumental errors that have to be taken into account in finding direction and steering a course by magnetic compass are fully described in Boykow and others, *op. cit.*, pp. 43–47.

[14] J. A. C. Warner: Aircraft Compasses—Description and Classification, *Natl. Advisory Committee for Aeronautics Rept. No. 128*, Washington, 1925, pp. 22–50.

The Magnetic Compass in Aircraft . . . Air Ministry (Directorate of Research), *Air Publication 802*, H. M. Stationery Office, London, 1922.

ed, a small quantity dependent on the latitude of the observer and the declination of the sun.[15]

An example of such a table (for declination 23°) is shown in Figure 4 on page 454. It will be noted that the changes in azimuth due to changes in latitude are comparatively small. The effect of declination is smaller still. (For instance at latitude 80° N., with an hour angle of five hours, or 75°, and with a declination of 20° N., the azimuth is 78° 47′ S by W, and, with a declination of 23° N., the azimuth is 79° 23′ S by W). Consequently the tables are very compact, especially as it is necessary to give the corrections only to the nearest half degree.

By Sun Compass

The same principle is employed in the construction of the clockwork solar compasses[16] that were used in the recent flights over the north pole. The clockwork mechanism compensates for the gradual change in the hour angle.

Clockwork solar compasses are satisfactory, no doubt, for flying along a meridian; but it is likely that they would become unnecessarily complicated for use in a flight undertaken in any other direction.

Steering a Course by Ranging In

Though astronomical or magnetic methods are used extensively for finding direction, they are not so practical for steering a course.

In the case of astronomical methods a straight line or great circle course involves a frequent change in the angle subtended by the heavenly body and the direction of flight. This is due partly to the apparent movement of the heavenly body and also, except in flying along a meridian, to the convergence of the meridians. The latter reason also applies to the change in angle between the direction of the

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[15] Azimuth tables of an extremely compact nature are to be found in the Norwegian fisheries almanac for latitudes 70° to 90° (see "Retvisende peiling av sol, maane eller stjerne paa høiere bredder end 70° N.," pp. 51–61 in "Norsk Fiskeralmanak 1923, redigert av Trygve Haaland," Selskabet for de Norske Fiskeriers Fremme, Bergen). They are not, however, well adapted for use in aircraft because, before the azimuth is finally extracted, it is necessary to extract two other quantities from the tables and do three or four additions and subtractions.

"Arctic Azimuth Tables for Parallels of Latitude between 70° and 80°," by Lieutenants Seaton Schroeder and Richard Wainwright, was published at Washington in 1881 (*Bur. of Navigation, U. S. Hydrogr. Office* [*Publ.*] *No. 66*). The tables "were prepared for the use of the U. S. S. *Rodgers* in her search for the Arctic steamer *Jeannette.* As time did not permit of computing the azimuths for the whole time that heavenly bodies of northern declination would be visible in such high latitudes, they are given, at intervals of ten minutes, for six hours out of the twenty-four—that is (in the case of the sun), from 5 A. M. to 8 A. M., and 4 P. M. to 7 P. M." These tables also are not very well adapted for use in aircraft as each table is for a separate degree of latitude. As one degree of latitude is covered within an hour in an aircraft traveling north or south, it is much more convenient to have each table for one degree of declination, especially as the sun's declination is not likely to change more than a degree during a flight across the polar regions.

[16] The instruments used by the first Amundsen-Ellsworth flight and the flight of the *Norge* were designed by Boykow and made by Goerz, while Commander Byrd used an instrument designed by A. H. Bumstead of the National Geographic Society. (See, for the latter, Fig. 2 in Commander Byrd's article, above.)

magnetic needle and the direction of flight; but in addition matters are further complicated by the fact that a line of equal magnetic declination is not a straight line. Furthermore, the effects of magnetic disturbances cannot be ignored or compensated for; and errors in the

SUN AZIMUTH TABLES

FOR USE IN LATITUDES ABOVE 70°

SUNS DECLINATION 23°

Latitude / Hour angle (in arc)	0	15	30	45	60	75	90	105	120	135	150	165	180	Hour angle (in arc) / Co-latitude
89	-	-	-	0.5°	0.5°	0.5°	0.5°	0.5°	0.5°	0.5°	-	-	-	1
88	-	-	0.5°	0.5°	1.0°	1.0°	1.0°	1.0°	0.5°	0.5°	0.5°	-	-	2
87	-	0.5°	0.5°	1.0°	1.0°	1.5°	1.5°	1.0°	1.0°	1.0°	0.5°	0.5°	-	3
86	-	0.5°	1.0°	1.5°	1.5°	1.5°	1.5°	1.5°	1.5°	1.0°	1.0°	0.5°	-	4
85	-	0.5°	1.0°	1.5°	2.0°	2.0°	2.0°	2.0°	1.5°	1.5°	1.0°	0.5°	-	5
84	-	1.0°	1.5°	2.0°	2.5°	2.5°	2.5°	2.5°	2.0°	1.5°	1.0°	0.5°	-	6
83	-	1.0°	2.0°	2.5°	3.0°	3.0°	3.0°	2.5°	2.5°	2.0°	1.5°	0.5°	-	7
82	-	1.0°	2.0°	3.0°	3.5°	3.5°	3.5°	3.0°	2.5°	2.0°	1.5°	0.5°	-	8
81	-	1.5°	2.5°	3.0°	3.5°	4.0°	4.0°	3.5°	3.0°	2.0°	1.5°	1.0°	-	9
80	-	1.5°	2.5°	3.5°	4.0°	4.5°	4.0°	4.0°	3.0°	2.5°	1.5°	1.0°	-	10
79	-	1.5°	3.0°	4.0°	4.5°	5.0°	4.5°	4.0°	3.5°	2.5°	2.0°	1.0°	-	11
78	-	2.0°	3.5°	4.5°	5.0°	5.5°	5.0°	4.5°	3.5°	3.0°	2.0°	1.0°	-	12
77	-	2.0°	4.0°	5.0°	5.5°	6.0°	5.5°	5.0°	4.0°	3.0°	2.0°	1.0°	-	13
76	-	2.0°	4.0°	5.5°	6.0°	6.5°	6.0°	5.0°	4.0°	3.0°	2.0°	1.0°	-	14
75	-	2.5°	4.5°	6.0°	6.5	6.5°	6.5°	5.5°	4.5°	3.5°	2.0°	1.0°	-	15
74	-	2.5°	5.0°	6.5°	7.0°	7.0°	6.5°	5.5°	4.5°	3.5°	2.0°	1.0°	-	16
73	-	3.0°	5.5°	7.0°	7.5°	7.5°	7.0°	6.0°	5.0°	3.5°	2.5°	1.0°	-	17
72	-	3.0°	6.0°	7.5°	8.5°	8.0°	7.5°	6.5°	5.0°	3.5°	2.5°	1.0°	-	18
71	-	3.5°	6.5°	8.0°	9.0°	8.5°	8.0°	6.5°	5.0°	4.0°	2.5°	1.0°	-	19
70	-	3.5°	7.0°	8.5°	9.5°	9.0°	8.5°	7.0°	5.5°	4.0°	2.5°	1.0°	-	20
Latitude / Hour angle (in arc)	360	345	330	315	300	285	270	255	240	225	210	195	180	Co-latitude / Hour angle (in arc)

INSTRUCTIONS FOR NORTHERN LATITUDES

OBTAIN THE SUNS HOUR ANGLE IN ARC FROM THE CHART, BEING CAREFUL TO MEASURE IT CLOCKWISE FROM MERIDIAN OF OBSERVATION TO THE SUN'S MERIDIAN. THEN, WHEN THE SUN IS WEST/EAST OF THE MERIDIAN OF OBSERVATION, ADD TO/SUBTRACT FROM THE HOUR ANGLE 180° AND THE QUANTITY EXTRACTED FROM THE TABLES WITH LATITUDE, DECLINATION AND HOUR ANGLE AS ARGUMENTS. THE RESULT IS THE SUN'S AZIMUTH MEASURED CLOCKWISE FROM THE POLE

FOR SOUTHERN LATITUDES THESE INSTRUCTIONS HOLD GOOD EXCEPT THAT WHEN THE SUN IS EAST. ADD, AND WHEN WEST. SUBTRACT.

Fig. 4—Example of tables prepared by the writer giving the quantity in arc to be applied to the sun's hour angle to determine rapidly the sun's azimuth in polar latitudes. The tables have been worked out for latitudes above 70° and for declinations of 0° to 23° from the celestial equator towards the elevated pole.

direction indicated by the magnetic compass and swinging motions in the compass needle itself are caused by accelerations in speed, turns, and curving courses. These errors increase as the magnetic pole is approached and have their greatest effect when the navigator is flying in this direction. Consequently most navigators prefer in the absence of fog to steer a straight course by means of ranging in on natural objects or by taking back sights on smoke bombs dropped in the course of the flight. The first of these methods is quite practical over an ice field, as has been shown by Commander Byrd and Captain Wilkins.

Suitable Map Projection on Which to Plot Course

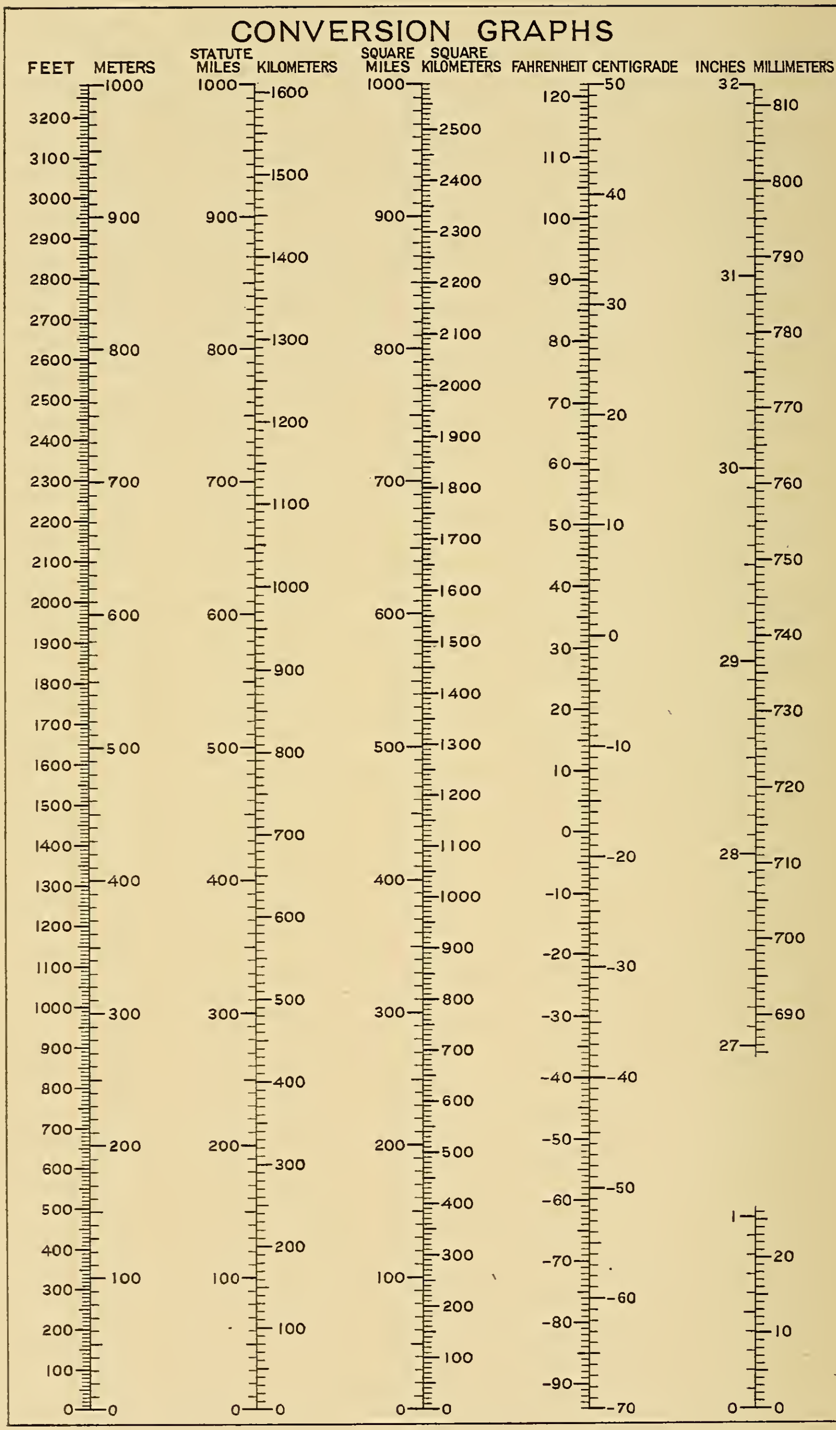
For purposes of general convenience the recording of the progress of a flight should all be done graphically on a chart; and consequently it is important to consider what projection is most suitable for such charting by the navigator in the polar regions. The Mercator projection, so useful to mariners in that it shows a rhumb line as a straight line, is out of the question because the polar regions cannot be plotted on it. Two projections worth considering are the polar gnomonic and the polar stereographic. The former has the advantage that all great circle lines are shown as straight lines, but scale distortions become very noticeable as the chart extends away from the pole. The polar stereographic chart on the other hand is fairly free from scale distortion in the polar regions and shows all great and small circles as circles on the chart, with the exception of meridians, which are straight lines. The second projection, therefore, is of great convenience in plotting astronomical position lines and in scaling distances, while the first is suitable for plotting direction. The ideal solution of the projection problem would be for navigators to carry polar charts on both projections; but exigencies of space and time would probably prevent this, at any rate on an airplane flight. Consequently it seems desirable to determine whether it would be possible to construct a compromise projection of the polar regions in which the errors of both the stereographic and gnomonic projections would be reduced to such an extent that for navigational purposes they could be ignored.

Need of Ability to Navigate Between Two Points Not on the Same Meridian

In conclusion it is absolutely necessary to emphasize one aspect of the problem. On the three flights in the neighborhood of the pole—namely the first Amundsen-Ellsworth flight, navigated by the Norwegian Lieutenant Hjalmar Riiser-Larsen, Commander Byrd's flight to the north pole, and the flight of the airship *Norge*—no attempt was made to fly for any sustained period in any direction except due north or south.[17] The reason for this is obviously because the objective of each of these flights was to reach the north pole. Without wishing in

[17] After the *Norge* had crossed the pole and lost track of her position owing to fog, her navigator took the first opportunity to take sun sights and plot position lines. As soon as one position line pointed nearly due north and south he followed the meridian indicated until he sighted the Alaskan coast.

any way to minimize the greatness of these flights as achievements, nevertheless it is a fact that a meridian is about the least difficult path to navigate. Furthermore, and this is the point to be emphasized, the future of flying in the polar regions will depend on ability to navigate between two points not on the same meridian. This must be so if all the polar regions are to be explored by aircraft, as there are few places situated on the fringe of the polar regions suitable as bases for the start of aërial exploratory expeditions. Again, few of the possible air trade routes pass directly over either of the poles. Consequently in considering the various methods of navigating it is necessary to judge them from the standpoint of the individual who desires to go directly from any point in the polar regions to any other.


CONVERSION GRAPHS
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ERRATA

p. 87, line 13: *for* Angora Land *read* Angara Land.
p. 138, line 5 from bottom: *for* Mattisen *read* Matisen.
p. 371, line 5 above footnote: *for* orsteri *read* forsteri.