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ANTARCTIC ADVENTURE
AND RESEARCH

GRIFFITH TAYLOR





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ANTARCTIC ADVENTURE
AND RESEARCH

By GRIFFITH TAYLOR

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*WALL-ATLAS OF AUSTRALIAN MAPS. OXFORD, 1929.

B. METEOROLOGY, etc.

*CLIMATE AND WEATHER OF AUSTRALIA. MELBOURNE, 1913.

AUSTRALIAN ENVIRONMENT. (GOVERNMENT PRINTER) MEL-
BOURNE, 1918.

AUSTRALIAN METEOROLOGY. OXFORD, 1920.

C. ANTARCTICA

WITH SCOTT—THE SILVER LINING. LONDON, 1916.

PHYSIOGRAPHY OF MacMURDO SOUND. (HARRISON) LONDON,
1922.

*HINTS TO SCIENTIFIC TRAVELERS (Vol. IV). THE HAGUE, 1926.

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D. PALEONTOLOGY

THE ARCHEOCYATHINAE (CAMBRIAN CORALS). ADELAIDE, 1910.

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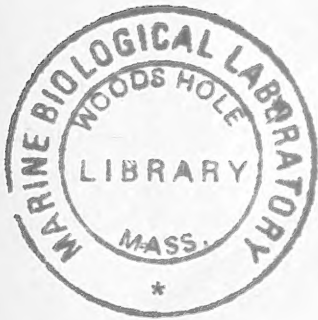
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ANTARCTIC ADVENTURE AND RESEARCH

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ILLUSTRATED

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PREFACE

NEVER has so much interest been taken in Antarctic exploration as at present. Three major expeditions, those of Byrd, Wilkins and Mawson, are still in the field (early in 1930). Norwegians are flying from whalers and charting new coasts (near Enderby Land) whose longitude has not been published. Thanks largely to the kindness of Dr. Bowman and Mr. Joerg of the American Geographical Society, this small book will be found to be up to date at the time the proof was corrected. The splendid Antarctic maps recently published by the same Society have been referred to repeatedly in this book—as also have recent articles dealing with the same area. The writer has also borrowed data with due acknowledgment from the Journal of the Royal Geographical Society which has always welcomed the records of Antarctic explorers. Lastly, John Murray has kindly permitted me to use one or two diagrams from my book “With Scott—The Silver Lining.” Although I can not altogether agree with his taste, the Editor of the series expressly asked for my own somewhat rough diagrams and sketches. So I hope that those readers who prefer something more artistic will blame the right man!

As regards the chapters dealing with research, they are concerned largely with work in the Ross Sea area

PREFACE

of Antarctica. Some readers may feel that other regions have been somewhat neglected, but I think that if the whole body of Antarctic literature be examined it will be found to deal very dominantly with this sector, i.e., that behind the coasts explored by Ross, Scott, Shackleton, Mawson, Byrd, and others. Almost all branches of science have been studied as regards their Antarctic aspects more fully in this sector than in any other. Moreover, it is the region with which I have personal acquaintance.

If this book gives the reader some conception of the last great unknown area of the earth it will have accomplished its purpose.

G. T.

University of Chicago.

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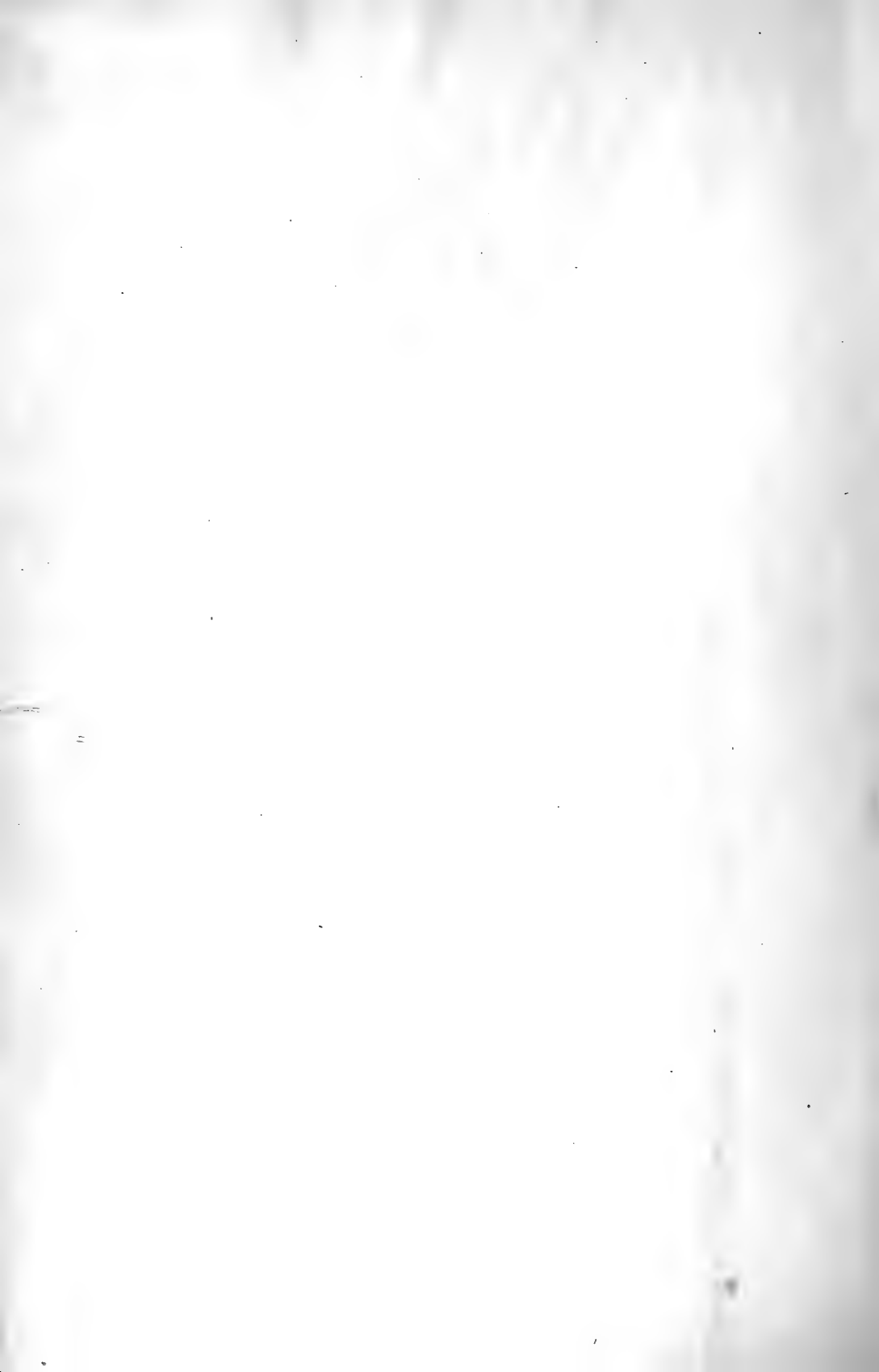
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CHAPTER I

THE VALUE OF ANTARCTIC EXPLORATION

IT has been some years now since it was my fortune to be a member of one of the greatest expeditions which set forth to explore the regions around the South Pole. Over and over again I have been asked, "What is the use of polar exploration?" It seems advisable, therefore, to consider this aspect of the problem, for assuredly readers who see no value in the subject of a book will not be tempted to read far beyond the first page.

It has been customary for promoters of a new expedition to dwell largely on the "quick returns" which may accrue from exploring an unknown land. Some good Antarctic friends of my own have, in this connection, stressed the fact that Alaska was bought for a song, when its resources were almost unknown, and that its gold yield has made it a very profitable investment for the United States. Subconsciously, I fancy, the hesitating supporter thinks, "Well, Alaska is a mighty cold place; so is Antarctica. Why shouldn't the expedition find a second Yukon near the South Pole?" Personally, I don't believe that this method of angling for support does much good. The hard-headed business man soon learns that hardly a single mineral product and certainly no vegetable products of present value

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have been discovered in the Antarctic,¹ and that the chances are against such being discovered in the relatively small areas of rock which are not covered deep beneath the Antarctic ice cap. But he gallantly sub-

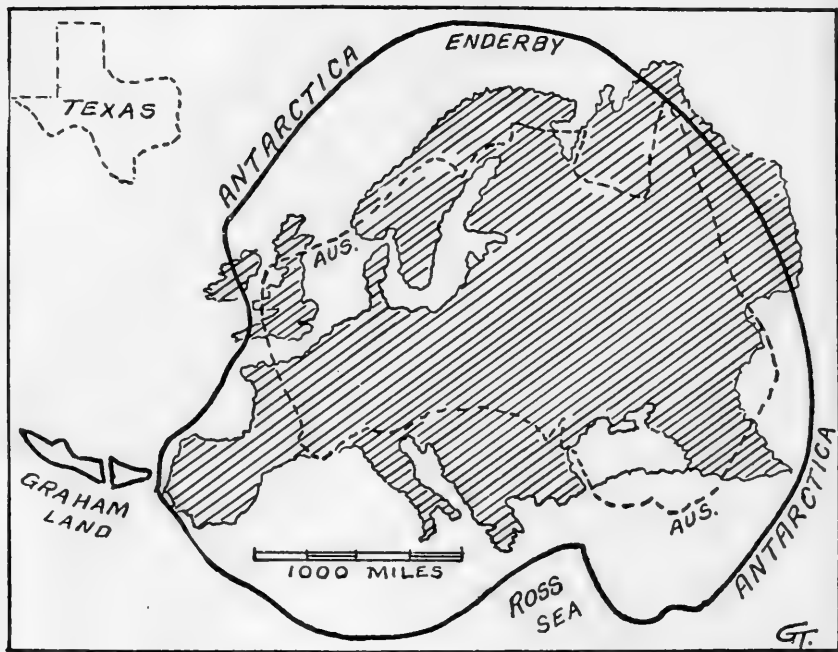


FIG. I.—RELATIVE AREAS OF ANTARCTICA, EUROPE AND AUSTRALIA (BROKEN LINE), ALSO TEXAS.

(NOTE: The United States is the same size as Australia.)

scribes to help on the cause of exploration. Why? Because other considerations beyond mere pounds, shillings and pence appeal to his pocket.

To my mind there are two very real reasons for which such expeditions should appeal to any intelligent man or woman. There is first of all the fundamental

¹ The inaccessible coal fields and the whaling will be discussed later.

THE VALUE OF ANTARCTIC EXPLORATION

“appeal of the unknown.” Our lonely little planet is, so far as we know, the only habitat of sentient beings of the human type. There are nearly two thousand million of us clustered on the fifty million square miles of the better-known continents. Surely it is the duty of man to learn all he can with regard to this great new continent of Antarctica, which is certainly not the least in area, for it is larger than Australia and quite probably larger than the whole of Europe. A fair estimate for the area of Antarctica is four and one-half million square miles—while these other continents are decidedly smaller.²

The world has been educated to revere astronomical research, and governments feel it part of their duty to support public observatories for the study of far distant stars. I hope for a time when the larger nations of the world will look nearer home and subsidize work on this very large segment of their own planet, whose study would repay them equally well in the advance of scientific knowledge. No *scientist* ever needs to be converted to a belief in the value of Antarctic exploration. There is hardly a branch of science which is not awaiting help from data to be studied properly only in the inaccessible lands of high latitudes. But since the layman is naturally not so familiar with these fundamental problems of science as he is with the more practical problems of applied knowledge, it will perhaps not be out of place for me briefly to traverse this aspect of Antarctic research.

² Australia has an area of three million, and Europe of three and nine-tenths million square miles.

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Let us first of all consider one of the chief problems of navigation. This science hinges very largely on the magnetic compass and on the distribution of the lines of magnetic force over the earth's surface. In almost every part of the globe there is a notable difference between the direction of the magnetic needle and the true north-south line (which is, of course, indicated by the meridian), and it is often stated that Columbus first noted this declination during his earliest voyage to America. Humboldt, about the year 1800, was the first to chart the lines of magnetic force over any large area of the world. In 1831 Sir James Ross observed that a freely suspended magnet dipped $89^{\circ} 59'$ (i.e. it was practically vertical) in Boothia Land ($70^{\circ} 5' N.$) on the north coast of Canada. This is the North Magnetic Pole and is situated 1,400 miles from the true North Pole. All the lines of equal declination (or variation from the true meridian) converge at this point.

The most fruitful Antarctic expedition resulted directly from this discovery, for in 1840 Sir James Ross was dispatched by the British Government to the unknown Antarctic regions precisely to advance our knowledge of magnetism. His chief aims were to set up magnetic observatories at St. Helena, Kerguelen, and Tasmania, and then if possible to plant the same flag on the South Magnetic Pole that he had set up in the north. As we shall see, he was blocked by the giant mountains of the Admiralty Range, but proceeding south he traversed the Ross Sea, far surpassed the previous southern record, and reached what has proved

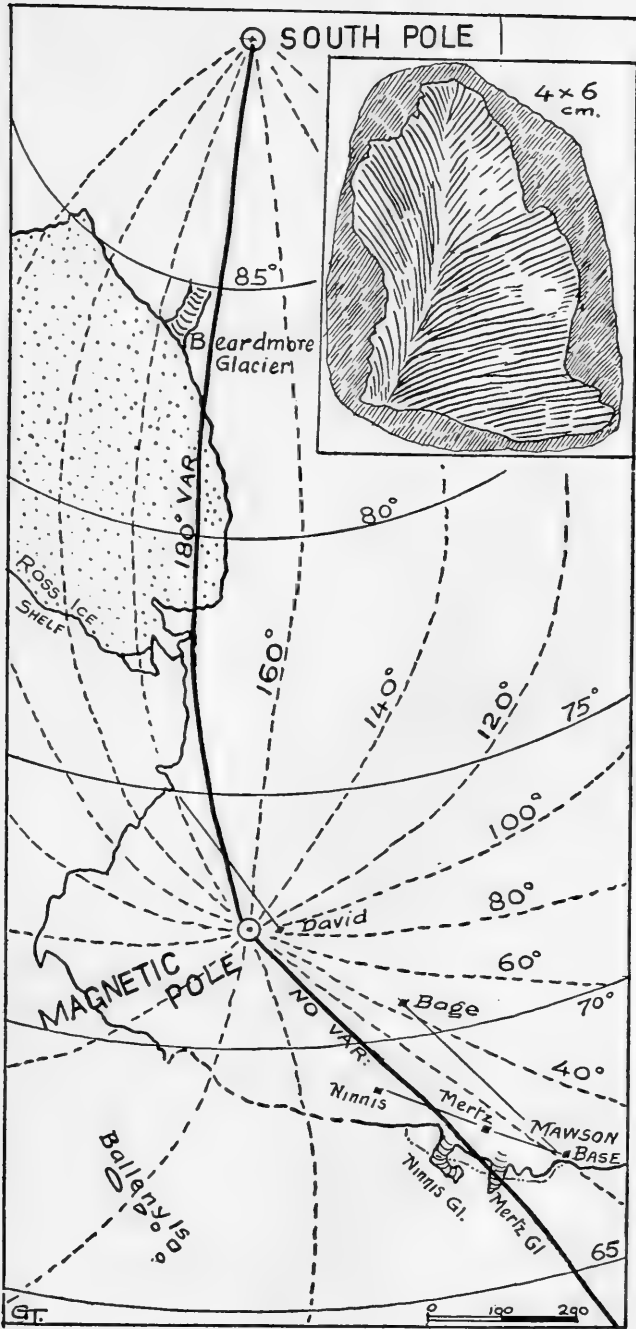


FIG. 2.—SKETCH MAP SHOWING LINES OF EQUAL MAGNETIC VARIATION IN SOUTH VICTORIA LAND.

Inset is *Glossopteris*, a Permian fern from the Beardmore Glacier. (From map by American Geographical Society, 1929.)

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to be the most fruitful area of Antarctic research. It was left to Scott in 1903 to be the first to cross that interesting line (at the head of the Taylor Glacier) joining the South Magnetic and South poles. This is the line of 180° variation and along it the south-seeking end of the needle points due north. In 1909 David reached the South Magnetic Pole, where the magnetic needle dipped vertically, and so he paralleled Ross in the north. This interesting locality is some one thousand two hundred miles from the true South Pole.

Another field of science for which a polar environment is essential is the determination of the shape of the earth. Owing to the polar "flattening," the effect of gravity is greater at the poles than at the equator. In fact a piece of lead tested on a spring balance would be found to be one half of one per cent heavier at the poles. This variation in the pull of gravity is of course measured by the swing of a pendulum at the required localities, and an accuracy of one part in two hundred and fifty thousand was attainable in the Antarctic.

Special interest attaches to the very abundant auroral displays in polar areas. These are found to be connected with sunspot phenomena and with magnetic storms. In North Polar regions the maximum zone for auroral displays passes close to the North Magnetic Pole, but we have not enough data to plot their distribution accurately in southern regions. Dr. Chree expressed the opinion that if they are due to electrical discharges from the sun, then these are probably of daily or hourly occurrence. As such, it is clear that Antarctica is a specially valuable area for their study.

THE VALUE OF ANTARCTIC EXPLORATION

Perhaps in the field of meteorology lies the most practical application of data obtainable only in the Antarctic. Sir Hubert Wilkins is carrying out his reconnaissance surveys in the south primarily with a view to finding localities suitable for a chain of meteorological stations all around the Antarctic continent. The layman knows that the general surface circulation of the atmosphere is from the colder regions toward the equator, and back again at higher levels. But it is only since Scott's discovery in 1902 that Antarctica is a gigantic ice-covered plateau that meteorologists have appreciated the special localized action of the phenomena at the South Pole. (There is, for instance, nothing of the kind at the North Pole, and indeed the meteorological pole in the Northern Hemisphere is to be placed in northeast Siberia rather than in the deep ocean at the Pole itself.) We may picture the poleward-flowing streams sinking to the earth at the intensely cold elevated South Pole and thence streaming out, either with moderate speed or as furious blizzards, back again to temperate regions. Indeed the phenomena in the heart of the Antarctic may be compared to an organic "heart," which pumps the streams back again to revivify regions of vital importance to man. In a later section I hope to show how closely linked are the climatic changes of Antarctica with those of the southern continents, so that it is not too much to say that the future long-range forecasting of droughts in south temperate lands will be greatly helped by increased knowledge of Antarctic meteorology.

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Turning now to fields of natural science, there is much of vital interest which can only be elucidated in Antarctica. Many of the problems in southern zoölogy turn on the paths followed by animals in the past in reaching the three southern continents. Broadly speaking, there are two schools of thought. One believes that all the vertebrates reached the southern continents by migration from the more extensive lands to the north, in most cases from Eurasia. The other school believes that Antarctica served as a sort of "half-way house" whence animals could spread by vanished "land-bridges" to South America, to South Africa, to Australia, and to New Zealand. To quote R. C. Murphy, "The real proof would be forthcoming only through the discovery of marsupials or other pertinent material in fossiliferous beds of Antarctica." We shall see that wonderful fossils, both of plants and animals, have been discovered in South Victoria Land and in Graham Land, which also throw a flood of light on the fascinating problem of past climates.

As regards plants, there are so few in the Antarctic that the botanical problems are not so interesting as those of zoölogy. No flowering plants occur there, but it is very curious that half the Antarctic lichens and thirty per cent of the mosses occur also in the Arctic regions and have not yet been found in the low latitudes between.

It is generally known that the regions now inhabited by the most progressive peoples were covered with a series of enormous ice fields in the last (Pleistocene) epoch. This occurred many thousand years ago, but

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the later phases were contemporaneous with important human populations. Moreover, the effects of the ice ages concern practically every dweller in the United States, in Canada, in Britain, and in north and central Europe. For instance, the environments of the Canadian wheat fields, the Great Lakes, the rivers and canals and scenery of the northeastern United States, the whole topography of Alpine countries, the routes of the transcontinental railways in Europe, the actual settlement in the deep valleys of Switzerland—all these features depend almost entirely on the phenomena of the Great Ice Age. We cannot now study what these lands were like during the period of maximum glaciation, but it was an attempt to solve in part this set of problems which led the writer to become a member of the British Antarctic Expedition of 1910. For several years he had been investigating the post-glacial scenery of the European Alps, but here it is very difficult to decide how much of the scenery is due to past ice action and how much to the action of rivers and streams of post-glacial origin. In the Antarctic I was so fortunate as to find ice-free valleys where all the features of the Swiss topography were displayed without the obliterating effects of many thousand years of rains and rivers.

In the realm of geology there are similar reasons why Antarctica should be closely surveyed. The two regions fairly well known at present belong to two differing provinces. In the Australian quadrant around the Ross Sea the rocks and structures are quite remarkably like those of Australia. They consist es-

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entially of blocks of the earth's crust bounded by definite north-south fault-scarps. The eruptive rocks are like those of South Australia. The fossils are also similar. In West Antarctica (Graham Land, etc.) we seem to see a continuation of the South American Andes. These are folded mountains occurring often in arcs, one of which appears to link Chile with Antarctica by way of the drowned islands of South Georgia, South Orkneys, etc. Here, moreover, the eruptive rocks belong to a different province from those of Victoria Land and consist of a calc-alkaline series of granodiorites and basalts akin to those of the Andes. Probably the greatest unsolved problem as regards the earth's structure is the relation of these two regions to each other. Are there *two* Antarctic continents, separated by straits or archipelagic areas? Or do the Antarctic Andes die away against an infinitely larger plateau of the Australian type? The latter seems probable, and if Antarctica as a whole is covered with an ice carapace, we shall probably wait many a long year for a satisfactory answer.

Finally the whole problem of the general evolution of the earth in geological times is only to be solved by frequent references to polar evidence. Recent research has shown that in the five hundred million years of which geology gives us the record the earth was for most of the time characterized by a more uniform environment both of topography and climate than in the present epoch. Plant and animal life was also more cosmopolitan than to-day. There was probably much less differentiation of those climatic *zones* (frigid, tem-

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perate, torrid) which control all plant and animal life to-day. Obviously if this thesis is correct the decisive data will be found in those lands which lie around the poles—and of these the Antarctic lands are much the most extensive. It is a very remarkable fact that though we now have an almost complete series of geological formations surveyed in Antarctica, dealing with the whole five hundred million years of the geological record, there is no evidence of any extreme glacial climates such as we know occurred in other parts of the world, either in Cambrian, Silurian, or Permian times. There is a vague indication of glacial beds of early Tertiary Age, but nothing suggesting that the awe-inspiring ice plateau of the seventh Continent dates back more than the last few million years in our long terrestrial epic.

It is the purpose of this small book to interest the reader in the adventures and researches of that extremely small number of the earth's huge population who have been willing to try to prove that polar exploration is well worth while.

CHAPTER II
EXPLORING ANTARCTIC SEAS
PERIOD 1739-1774

IT is always surprising to a scientist to see how long a geographical fallacy will hold ground, while an indubitable scientific fact of equal interest seems to take much longer to attract public attention. For instance, I found in Australia that few folk there know anything about the Sahara except the project to render parts of it fertile by flooding large adjacent areas, or of Central Australia save that since Lake Eyre is below sea level much might result from leading the sea into it. Neither of these projects is in the least advisable—or indeed practicable. So also in the early history of southern exploration there was an old legend of the Greeks which it took three hundred years to nullify. This was to the effect that a huge land must necessarily be situated south of the equator, to balance the known world in the northern hemisphere. Ptolemy lent it the weight of his authority in his remarkable maps of the Mediterranean and adjacent regions, and the cartographers of the Middle Ages adopted it very generally in the maps published to the end of the sixteenth century.

In Figure 2A I have sketched the map as published by Mercator in 1587. We can see at a glance that while

EXPLORING ANTARCTIC SEAS

the Old and New Worlds are fairly well represented in latitude (north to south), there is a good deal of error in the east-west direction. This is of course primarily due to the difficulty of obtaining longitude before the accurate use of chronometers was possible. Hence all the known continents are too wide. There is no sign of Australia, save a huge "hump" in the hypothetical land which occupies so large a part of the Southern

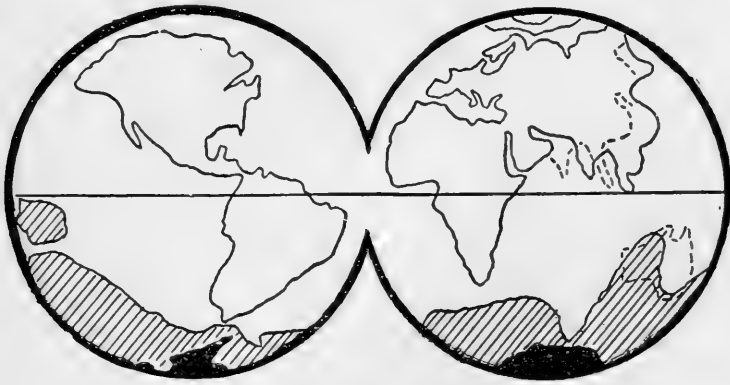


FIG. 2A.—MERCATOR'S WORLD-MAP, 1587.

For some 300 years explorers were reducing the large *ruled* "Southern Continent" to its true size, shown in black. (True position of Australia and East Asia indicated.)

Hemisphere. The only basis for this large area was perhaps the view of Tierra del Fuego seen by Magellan in 1520, when his voyage around the world clearly showed that Ptolemy's Terra Incognita was not joined to South America. Moreover, in 1578 Drake had been driven as far to the south of Tierra del Fuego as 57° and sailed through the broad strait now known by his name. This gap of some four hundred and fifty miles was apparently not known to Mercator.

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To the French must be given the credit for the first serious attempt to discover whether this southern continent really existed. In 1739 on New Year's Day, Bouvet discovered a new land which lay to the south of Capetown some 1,400 miles (see Figure 3). Owing to fog, he was unable to state if it were an island or part of a large continent, but he sailed along the edge of the ice pack in the vicinity for some four hundred miles, feeling sure that a large continent existed just to the south. Antarctica, however, lay still one thousand miles south of his track. It is a noteworthy fact that the small island of Bouvet was thereafter lost until 1898, when the "Valdivia" found it eight degrees *west* of the original determination. This is another example of the relative difficulty of fixing longitude, for the latitude (54° S.) was approximately correct.

The losses of France in Canada in part led to Kerguelen's voyages of 1772 and 1773 when he discovered the island (named after him) in the Indian Ocean in latitude 50° S. (see Figure 3). This again had little relationship with the Antarctic continent.

The greatest achievement of Captain James Cook was not his charting of the best-endowed coast of Australia in 1770, but his wonderful work in delimiting the southern boundaries of the three great oceans in his voyages from 1772 to 1775. Cook first came into prominence through his charts of the Saint Lawrence, where he took part in the siege of Quebec. Some of these charts and the copy of his Australian log are the prized possessions of the National Museum

EXPLORING ANTARCTIC SEAS

at Canberra, Australia, where other relics of Australian and Antarctic exploration are gradually being gathered.

We may summarize his first and third voyages as follows. In the first he doubled Cape Horn from the east and observed the transit of Venus at Tahiti. He discovered and charted the east coasts of both New Zealand and Australia, and returned home through Torres Straits between New Guinea and Australia. He reached England in July, 1771. His third voyage was chiefly directed to the North Pacific in an attempt to reach the Atlantic Ocean by way of the Behring Straits. This has, of course, not been done to this day, though several ships have managed to make the voyage in the opposite direction, like the "Vega" (1878-9) along Siberia, and the "Gjoa" (1903-6) along Canada. Cook discovered many islands in the Pacific and surveyed much of the northwest American coast. He was killed at Hawaii in February, 1779.

It was in his second voyage, however, in which he "put a girdle round the earth, and had enough over to tie the knot." Dalrymple, a well-known writer of this period, was convinced that there existed a great continent around the South Pole. He wrote in a letter to the King, "That unknown part is a quarter of the whole globe, and so capacious that it may contain in it double the kingdoms and provinces of all those your Majesty is at present lord of." Cook left England in July, 1772, and his first object was to survey Bouvet "Land." They sighted ice on December 10th and soon proved that Bouvet Land was not part of a large continent, for they sailed in open water far to

ANTARCTIC ADVENTURE AND RESEARCH

the south. As Lieutenant Clerke wrote in his log, "If my friend Monsieur found any land, he has been confoundedly out in the latitude and longitude of it."

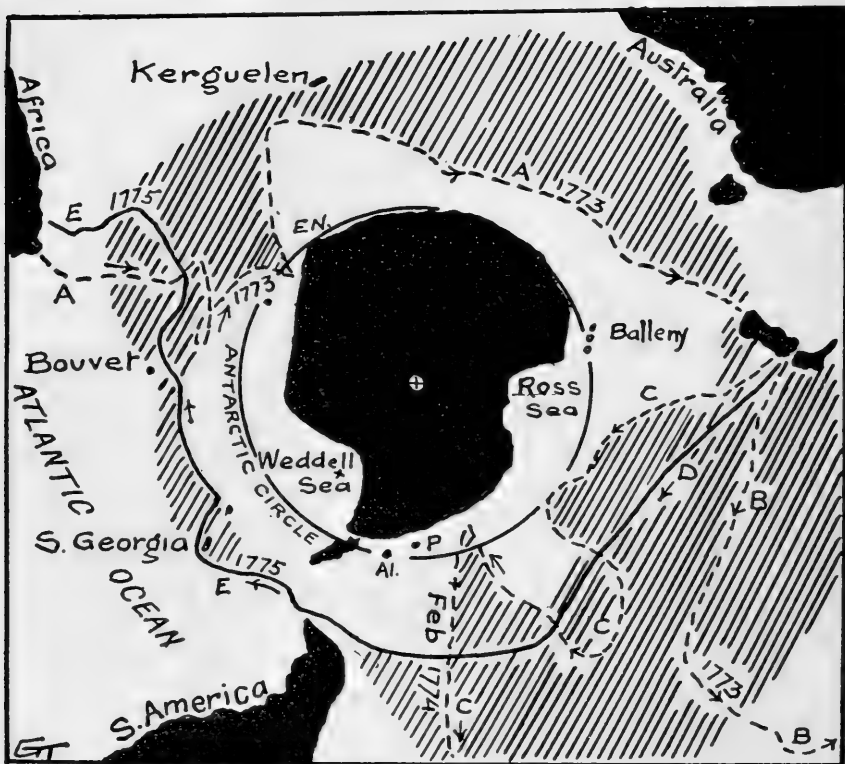


FIG. 3.—COOK'S EXPLORATIONS (1772-1775) OF ANTARCTIC SEAS ARE SHOWN RULED. A, B, C, D, E ARE CRUISES. THE INNER WHITE AREA SHOWS THE ANTARCTIC SEAS YET TO BE EXPLORED. CONTINENTS ARE BLACK.

Alexander Is., Enderby Land and Peter Is. are indicated, while X shows Weddell's furthest.

On the seventeenth of January, 1773, the Antarctic Circle was crossed for the first time not far from Enderby Land in longitude 40° E. As far north as

EXPLORING ANTARCTIC SEAS

this Circle (owing to the tilt of the earth's axis) the sun shines for twenty-four continuous hours on December 22nd, so that sunset and sunrise occur due south at the same instant.

Cook now sailed to the northeast to survey the land of Kerguelen of which he had received a report, but he was again unlucky and missed this second French discovery. He then returned to southern latitudes and for four weeks sailed along latitude 60° S. (see A, Figure 3). On March 16th he left the Antarctic area and proceeded to the rendezvous with his other ship in New Zealand. In June he proceeded to examine the region east of New Zealand and sailed through an empty sea right across Dalrymple's conjectured continent (see B, Figure 3). He returned by a northern route to New Zealand. On the approach of summer Cook sailed south once more for his most remarkable cruise (see C, Figure 3). For six weeks his ships were buffeted by the storms of the "Shrieking Sixties" and on two occasions he crossed the Antarctic Circle. The first was on longitude 140° W. where, however, the Antarctic coast is still quite unknown. After the second crossing (near 106° W.) he penetrated to latitude 70° , and on January 30th, 1774, he was blocked by mountainous ice in a position which has not yet been surpassed in this region, though the "Pourquoi Pas" approached it in 1910. Thereafter he made for warmer waters and returned northwest to New Zealand.

On his last southern cruise (see D, Figure 3), he left on November 10th, 1774, and sailed along lati-

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tude 56° S. for Cape Horn. Here again he crossed the supposed continent and found no land whatever. From the Horn he followed a course to Capetown far south of that usually taken. His initiative was rewarded by the discovery of the large rocky island of South Georgia, which lies on the submarine ridge connecting the Andes of South America to the Andes of West Antarctica. Somewhat to the east he sighted further "peaks" of the same ridge which he named the Sandwich Group. Then he made one more attempt to sight Bouvet Island, and he must have passed only a few miles to the south of it. After crossing his original track of 1772 he turned to the north and reached Capetown March 21st, 1775.

Probably no other voyage, not even excepting Magellan's, has done so much to remove "false lands" from the world map. Cook's first cruise in large part mapped the ice pack south of the Indian Ocean. His second main cruise did the same work for the Pacific, while his last cruise completed his task in the Atlantic. On two occasions he practically reached the Antarctic continent, first near Enderby Land and secondly to the west of Peter Island. Of supreme importance also was his fight against scurvy, so that all his crew save one withstood this scourge throughout three years of unparalleled navigation. It was his misfortune to miss the great continent which actually surrounds the South Pole, for he only discovered two outlying isles off South America. Of these South Georgia is, however, the chief center of industry in Antarctic waters. The same cruises were, however, much more successful in

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placing the islands of the South Pacific on the map, though that is outside of the province of this brief study.

PERIOD 1775-1838

As is so often the case in exploration, there was a period of quiescence after an epoch of great discovery. For some forty years exploration was confined chiefly to those seas to the south of America where the whaling industry obtained the illuminating oils of the period. Americans and British took part in the industry, but there were many more American ships. However, a Britisher, Smith, discovered the South Shetland Isles in 1819, and they were surveyed by a British sailor, Bransfield, next year. In 1821 the American, Palmer, discovered the archipelago which hugs the west coast of Graham Land (see Figure 7), and next year a Britisher, Powell, found the South Orkneys, which lie halfway between the South Shetlands and South Georgia. There has been a good deal of controversy as to who first discovered the actual mountains of Graham Land (or West Antarctica), but this perhaps is of less importance now that Wilkins has shown that this large land mass is in turn isolated from the main continent by Stefansson Strait (Fig. 7).

The splendid voyages of Bellingshausen have never received the credit which they deserve. He was a Russian sailor who was commissioned by Emperor Alexander I in 1819 to circumnavigate the South Pole. His discoveries much resembled those of Cook. He sailed from South Georgia to the east on December

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27th. During the next few months he cruised along the edge of the pack, often within the Antarctic Circle. He was able to show that no land existed far south of Cook's cruises (see A and E, Figure 3) in these waters. He reached Sydney at the end of March, 1820. After a cruise in the Pacific, Bellingshausen again sailed south and made a wonderful voyage again very largely within the Antarctic Circle. On the twenty-second of January, 1821, he sighted Peter Island (see Figure 7) and a week later Alexander Land far to the east (see P and A, Figure 3). Early next month he met Palmer and other whalers near Graham Land, and thence returned to Russia. His voyage had "lopped off" the projecting unknown areas which Cook did not traverse; and his discovery of land so far south as 68° S. remained a record until the wonderful voyage of Ross in 1841.

One of the most fortunate voyages in Antarctic history was that of Captain Weddell in a brig of 160 tons. His main object was to hunt for seals, but finding the region to the south of South Georgia remarkably free from ice, he and his consort (a boat of 60 tons) determined to push south as far as was possible. On the eighteenth of February, 1823, he reached 73° S., and not a particle of ice was to be seen (see Figure 3), though they were some two hundred miles nearer the Pole than Cook's record. On the twentieth he turned back at $74^{\circ} 15'$, for his ships and equipment were not intended for exploration.

The famous merchants, the Enderby Brothers of London, encouraged the captains of their whaling fleet

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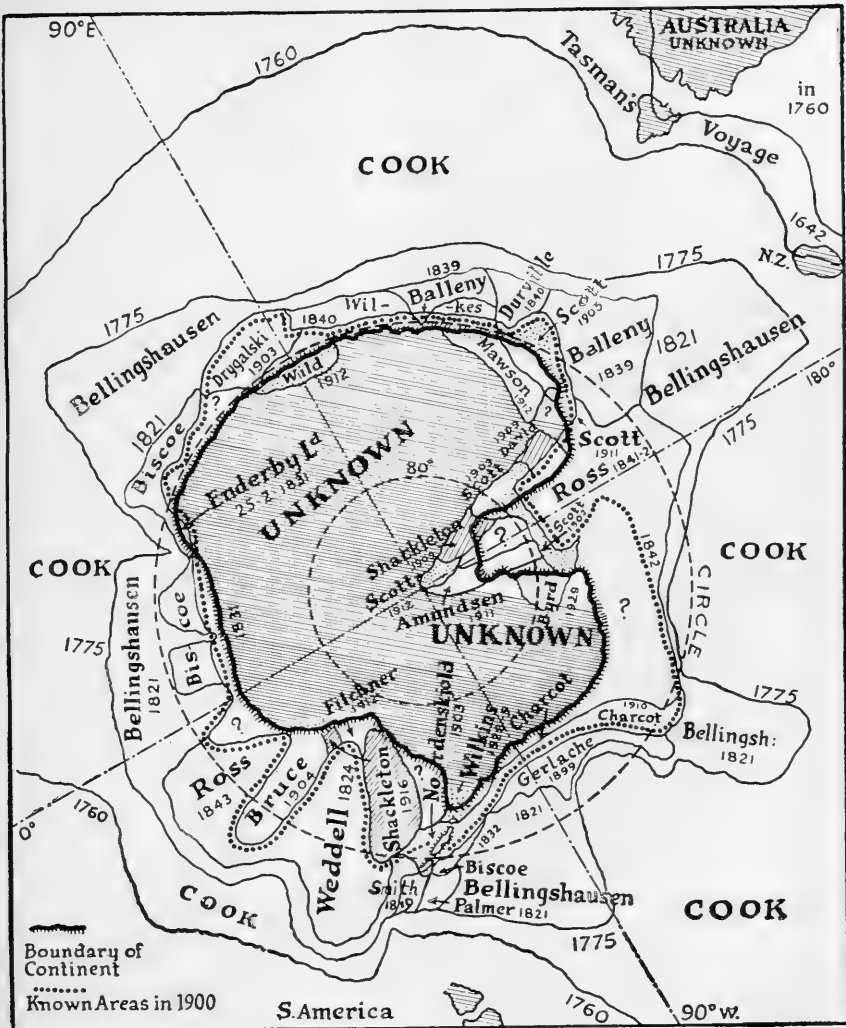


FIG. 4.—CHART SHOWING ANTARCTIC DISCOVERIES WITH DATES.

Recent British discoveries are ruled or dotted.

to attempt the exploration of new waters. In 1831 Captain Biscoe met with very favorable conditions, so that he was able to sail for five weeks within the Antarctic Circle. He sailed to the east directly south of

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Africa in an area which has hardly been visited since, though it is the venue of the present Australian expedition under Sir Douglas Mawson in 1929-30. On February 25th, 1831, when just on the circle he saw "an appearance of land" about longitude 48° , and for nearly three weeks Biscoe fought the pack and the blizzard in an attempt to reach the continent. From March 1st to the 8th the hurricane lasted without intermission; the bulwarks were stove in and several boats lost or broken. On the sixteenth he again saw the black cape projecting through the icy highlands, to which he gave the name Cape Ann (see Figure 4). To the whole coast, which seemed to extend for several hundred miles east and west (from 48° E. to 56° E), has been given the name of Enderby Land. This occasion marks the true discovery of the Antarctic *continent*. He then made for Tasmania, where he was rejoined by his cutter, the "Lively," whose crew had nearly died of starvation near the site of Melbourne before they could make the port of Hobart. Biscoe returned to England *via* the southern Pacific route. Near the Russian discoveries he met with very open water and so discovered Adelaide Island to the north of Alexander Land. He also landed on the Palmer Archipelago, and the vast rocky ranges to the east were named Graham Land after the First Lord of the Admiralty.

Another famous captain of the Enderby whalers was Balleny. He sailed south from New Zealand and in February, 1839, he discovered the group of volcanic islands just on the Antarctic Circle (longitude

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163° E.) which has been given his name. Some weeks later some one thousand five hundred miles to the west he saw an appearance of land in longitude 120° E. to which the name "Sabrina Land" was given (see Figure 4). While this is a doubtful discovery, later voyages by Wilkes and J. K. Davis (1911) make it likely that land lies in just this position.

PERIOD 1837-1843

The first great period of Antarctic discovery resulted from the national expeditions commanded by Cook and Bellingshausen. The second notable period was also due to expeditions dispatched by various governments, in this case France, United States, and Britain. Since there was some rivalry between these three expeditions, it will be well to give in tabular form a summary of their voyages and discoveries. All the voyages were in the southern summer, usually in January and February.

D'Urville was sent south by Louis Philippe to explore the Weddell Sea and if possible to approach nearer to the South Pole than previous voyagers. His attempt was not very successful in this respect for he only reached 63° 39' S., not far south of South Orkney. Then he returned to the west and sailed along the coast of Graham Land. He gave the names of Louis Philippe Land and Joinville Island to areas which had certainly been roughly charted by Powell before. However, these names have been adopted on all modern maps. D'Urville devoted the next two years to the exploration of the Pacific, especially to the ethnology of the primitive peoples, a work which

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appealed to him much more than Antarctic exploration. However, early in 1840 he decided to win for France the credit of reaching the South Magnetic Pole. He left Hobart on New Year's Day and on January 19th, 1840, the first land of the continent itself was sighted

DATE	WEST ANTARCTICA	EAST ANTARCTICA
1838	<i>D'Urville</i> (Jan.-Feb.) off Graham Land.	
1839	<i>Wilkes</i> (Feb.) South Shetlands and near Peter Island.	
1840		<i>D'Urville</i> (Jan.) Adelie Land. <i>Wilkes</i> (Jan.-Feb.) Adelie Land and west to Termination Land.
1841		<i>Ross</i> (Jan.-Feb.) Ross Sea and Barrier.
1842		<i>Ross</i> (Jan.-Feb.-March) East of Ross Sea.
1843		<i>Ross</i> (Dec. '42-Mar. '43) Weddell Sea.

due south of Tasmania, to which he gave the name Adelie Land (see Figure 5). "It stretched as far as the eye could see and was entirely covered with snow, and it might have a height of one thousand to one thousand two hundred meters." Several small islands were seen in the vicinity and here rocks were collected, and the adjacent cape was called Pointe Geologie. A

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dramatic meeting took place with one of Wilkes' ships on the thirtieth of January, but Ringgold misunderstood D'Urville's actions and sailed away without communicating with the French. About one hundred and

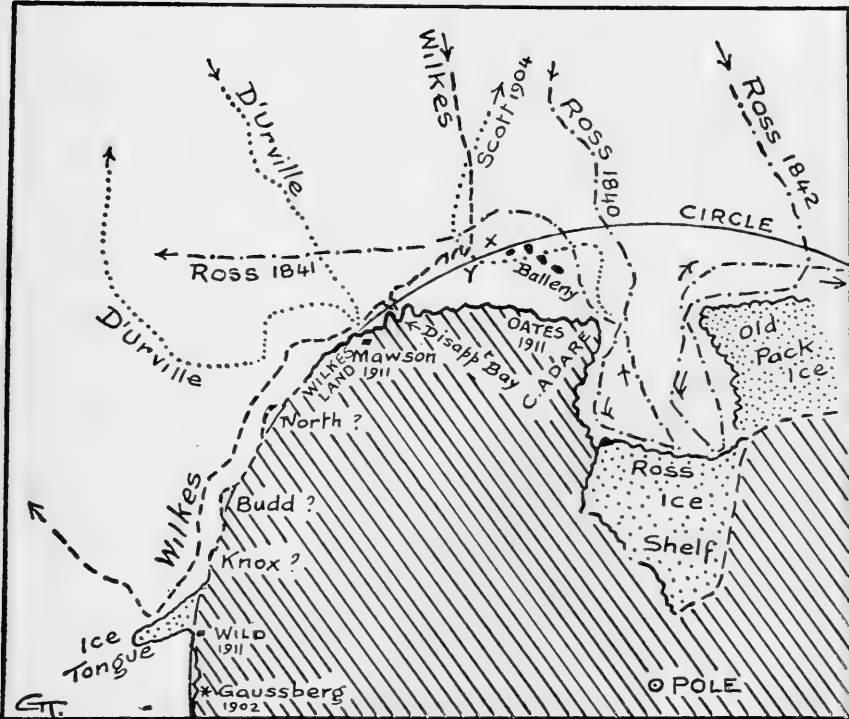


FIG. 5.—VOYAGES IN EAST ANTARCTICA OF D'URVILLE, WILKES AND ROSS.

X and Y are the doubtful positions of Ringgold Knoll and C. Hudson.

twenty miles to the northwest of Adelie Land the French leader sighted an ice barrier about one hundred feet high. To this he gave the name of Cote Clarie; but this ice was not part of the *fixed* land-ice for it had disappeared in 1912. The French left Ant-

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arctica on February 1st, 1840, and have sent no later expedition into these eastern waters.

Although the United States has taken a great interest in Arctic exploration, as was shown in the Franklin Relief Expeditions and later, she has not given much official attention to Antarctic seas and lands. Almost the sole exception until the present century was the important expedition dispatched in 1839 under Commander Charles Wilkes.¹ His instructions were to survey the waters frequented by American whalers, and to make two summer cruises towards the South Pole south of America and Tasmania respectively. He was not equipped for lengthy Antarctic exploration. He sailed on the sloop "Vincennes," together with three other small boats, and made two determined attacks on the unknown regions to the south. Early in March, 1839, they cruised among the islands at the north end of Graham Land and the "Porpoise" was nearly wrecked on Elephant Island, where Shackleton's men were to shelter in 1916. The other two boats penetrated into the heavy pack west of Graham Land and the "Flying Fish" (of only 96 tons) reached 70°, near the region explored by the "Belgica" in 1898, where it is likely that they mistook high icebergs for land. In December, 1839, the ships left Sydney for their second Antarctic voyage. They were most poorly equipped, and Wilkes records that he felt it was "unwise to attempt such service in ordinary cruising vessels, but we had been ordered to go, and that was

¹ Charles Wilkes, *Narrative of the United States Exploring Expedition* (London, Whittaker, 1845).

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enough, and go we should.”² On January 13th they approached the Balleny Islands (see Figure 5), but it is unlikely that they saw indications of the land for they were about one hundred miles away. On the sixteenth several officers were satisfied that land was visible. “The mountains could be distinctly seen stretching to the southwest as far as anything could be discerned. Two peaks in particular were very distinct.” Both these discoveries of the thirteenth and sixteenth were probably errors of judgment, for the “Erebus” and “Terror” sailed across one “land” in March, 1841, and the “Discovery” found no sign of the other in those latitudes in 1904. Yet even here it may be that Wilkes saw islands like Bouvet Isle which will elude accurate survey for many decades. It must be noted that the “Aurora” in 1916 obtained very shallow soundings near Wilkes’ doubtful lands. On January 23rd the American expedition reached a deep bay (in 67° S. and 147° 30’ E.), and obtained a sounding at 320 fathoms. It seems likely that Wilkes was now between the Ninnis and Mertz Glacier tongues, which were mapped in detail by Mawson’s expedition in 1911-12. On January 30th the “Vincennes” coasted Adelie Land, noting the black rocks which D’Urville had examined only ten days before. Wilkes writes, “I gave the land the name of the Antarctic Continent.” On the same day (January 30th) the “Porpoise” met D’Urville farther to the westward, as has been narrated.

² E. S. Balch, *Antarctica* (1902).

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Wilkes was badly handicapped by crippled ships and the ill-health of his crew, but he stoutly held on to westward, and after longitude 137° E. again sailed along the land for sixty miles to the west. In longitude $131^{\circ} 40'$ he sighted and named Cape Carr on the seventh, and on the tenth and twelfth he determined the land to lie in about $65^{\circ} 20'$ of latitude. On the thirteenth the day was very clear, and he could see seventy-five miles of the coastline. Many rock specimens embedded in the ice were obtained here. In longitude $97^{\circ} 37'$ the ice cut off his progress to westward. He had come up against the Shackleton Ice Shelf (see Mawson's expedition), and so he turned northward and sailed to Tasmania (see Figure 25).

Thus closed a very memorable Antarctic voyage, concerning which there has been considerable controversy. It has been claimed that Wilkes discovered land on January 13th and 16th and therefore antedated D'Urville's discovery of January 19th. But in the light of later voyages in these regions it seems very doubtful if any of his observations before January 23rd concerned the mainland, though as stated he may have seen an island which has since escaped notice. Thus D'Urville has priority by four days. On the other hand, Wilkes' fine voyage with ill-found ships apparently *along the coast* most of the way from longitude 148° E. to 108° E. is an achievement which has not yet been repeated. Certainly no other ship has cruised in that latitude from Adelie Land past North, Sabrina, Budd, and Knox lands, for Wilkes was favored by an unusually open state of the sea. As to

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whether the name, Wilkes Land, is to be given to all this coast or to the restricted area (in 134° E.) mapped on Mawson's expedition and by him named Wilkes Land, it is difficult to decide. Even Balch in his lengthy discussion of the point is unable to say who first used the term "Wilkes Land" in the larger sense, though he notes that it appears in Stieler's Atlas published in Germany in 1866.

The discovery of the North Magnetic Pole in 1831 by John Ross and James Ross greatly enhanced the interest of scientists and laymen in earth magnetism. It was fitting that the official British expedition fitted out in 1838 and 1839 to investigate the magnetic field in the Southern Hemisphere should be under the leadership of Captain James Ross, who had studied magnetism under Sabine. Hooker, one of the famous trio of Victorian scientists (Hooker, Darwin, and Huxley), accompanied Ross as surgeon and botanist. Ross was directed to establish magnetic observatories at Kerguelen and Hobart and then he was to sail southward and try to reach the South Magnetic Pole. When Ross arrived in Australia, he found that D'Urville and Wilkes had both made discoveries in the region which he proposed to explore. He therefore boldly decided to cruise farther east than their tracks, and to try to penetrate the pack ice where Balleny had reported open water in 1839 (see Figure 5).

Early in January, 1841, he reached the pack ice and his stout bomb-ships readily traversed it, for the first time in history, in about nine days. The magnetic needle was dipping at 85° , so that the Magnetic Pole

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could not be far away. However, the massive peaks of the Admiralty Range barred the way to the Magnetic Pole and Ross turned southward for 430 miles along one of the most remarkable scarped coasts in the world. In spite of its high latitude, it seems likely that much of the Ross Sea remains open throughout the year; so that Ross was able to pass Weddell's record ($74^{\circ} 15'$) on January 22nd, and there was still open water to southward. However, on January 29th he reached the famous volcanic island crowned by Mount Erebus (thirteen thousand feet) and since named after himself. The ships now sailed to the east along the Ross Ice Shelf for some three hundred and fifty miles near latitude 78° S., a feat which can in all probability never be beaten elsewhere, for it is unlikely that another huge open gulf should exist in the at present uncharted Antarctic coasts. He returned to Cape Adare, in the northwestern part of Ross Sea, and reached Hobart again in April, 1841.

Next summer Ross again journeyed south. On this occasion he made his southing considerably to the east of his former route. The ships had a very hazardous journey through the pack, during which the rudder of the "Erebus" was rendered useless, and that of the "Terror" was smashed to pieces. He reached the head of the Ross Sea not far from King Edward VII Land. Here Ross gained his farthest south point at $78^{\circ} 9'$, and it remained the record for some sixty years. On their return they coasted the heavy ice pack which bounds the east of the Ross Sea, and nearly

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met with disaster on March 9th. The ships were entangled in icebergs, and in the attempt to avoid one of these monsters, the "Terror" collided with the "Erebus." We may quote Captain Ross's own words. "Our bowsprit, foretopmast and other smaller spars were carried away, and the ships hanging together entangled with their rigging, and dashing against each other with fearful violence were falling down upon the weather face of the lofty berg under our lee, against which the waves were breaking and foaming to near the summit of its perpendicular cliffs." After extricating themselves the ships just managed to pass between two giant bergs and gained comparative safety in their lee. On April 6th they reached the Falkland Islands.

Ross made a third voyage to the Antarctic in the following summer, this time to the south of America. He cruised off the end of Graham Land and Hooker made some valuable collections of plants, but the attempt to follow Weddell was unsuccessful. Ross penetrated to $71^{\circ} 30'$, where he was no great distance from Coats Land, but he there turned north and the ships ultimately reached England after their long cruises in September, 1843.

CHAPTER III

EXPLORING THE GREAT CONTINENT

PERIOD 1897-1907

AFTER the return of Ross from the Antarctic in 1843, public interest centered in North Polar regions. Sir John Franklin, who had, as governor of the colony, helped Ross materially in Tasmania, took command in 1845 of a very large and well equipped expedition of 129 men to explore the Northwest Passage. Not a soul ever returned, and no accurate knowledge of their fate was learned until 1859. The Antarctic has luckily shown no tragedies to compare with this. In South Polar seas the Norwegian and Scotch whalers penetrated both the Weddell and Ross seas in search of whales. In 1893, Larsen discovered Foyn's Land on the southeast coast of Graham Land, while Bruce and Murdoch made their first voyages in the adjoining seas. Bull and Borchgrevinck made the first landing on Cape Adare in January, 1895, though their whaling was not successful.

In 1897 took place the first expedition in which scientific investigation ranked as importantly as the charting of new lands. The Belgian, Gerlache, gathered a cosmopolitan crew, many of whom rose to fame in later years. Amundsen, the Norwegian sailor, Cook, the American doctor, and Arctowski, the Polish cli-

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matologist, were members of this expedition. They coasted along Graham Land, making numerous landings in Belgica Strait, and then penetrated west of the region between Alexander and Peter islands, passing to the south of the latter island (see Figure 4). Here they were beset and spent the first Antarctic night drifting from $80^{\circ} 30' W.$ to $102^{\circ} W.$ They seem to have suffered a good deal from confinement and inadequate food, but carried out scientific observations in many useful fields.

To Borchgrevinck must be given the credit for first landing on the continent and spending a winter there after his ship had returned to temperate climes. On the seventeenth of February, 1899, he landed on Cape Adare at the northwest extremity of the Ross Sea in latitude $71^{\circ} S.$ The party consisted of seven Scandinavians and three Britishers, including L. Bernacchi and W. Colbeck, who both joined later expeditions. The locality was unfavorable as a base for sledging, but valuable meteorological observations were made. The zoölogist, Hanson, died at Cape Adare from some disease akin to scurvy. In January, 1900, their ship picked them up and cruised south to the great Ross Ice Shelf. On February 19th they made a sledge journey of a few miles to the south and reached $78^{\circ} 45',$ which was perhaps forty miles south of Ross's record in 1842.

With the new century began the most famous period of Antarctic exploration. From 1772 to 1900 nothing was known of the interior of Antarctica. An ice-bound north coast was indicated by Wilkes' discoveries. A stupendous mountain coast flanked the Ross Sea on the

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west, and a great barrier of ice blocked it to the south. But an area greater than Europe lay to the south of these discoveries, and many folk believed that it might turn out to be an archipelago of islands like that forming the polar lands north of Canada. Indeed, we are not yet certain that such is not the case in part at least in the huge unknown Antarctic regions, but it is to two men, Scott and Shackleton, that our main knowledge of the interior of the new continent is due.

The British Expedition of 1902 was largely a naval expedition financed by the British Government, but generously aided by private contributions. The "Discovery" was specially built at Dundee and had a registered tonnage of 485 tons. Captain Scott was given command.

On Christmas Eve, 1901, the "Discovery" left New Zealand and reached Cape Adare on January 8th (see Figure 6). They coasted down the great mountain scarp of Victoria Land until the twentieth when they entered Granite Harbor, which was considered for possible winter quarters. Thence they sailed eastward along the great Ice Barrier which constitutes the free northern edge of the Ross Ice Shelf. On January 29th they were south and east of the extreme position reached by Ross in 1842. Still proceeding eastward they sighted and named King Edward VII Land, but found no suitable site for winter quarters and turned back towards MacMurdo Sound. *En route* at Balloon Bight Scott made the first balloon ascent in Antarctica. On February 8th Scott reached the southwest corner of Ross Island—and here at Cape Armitage he an-

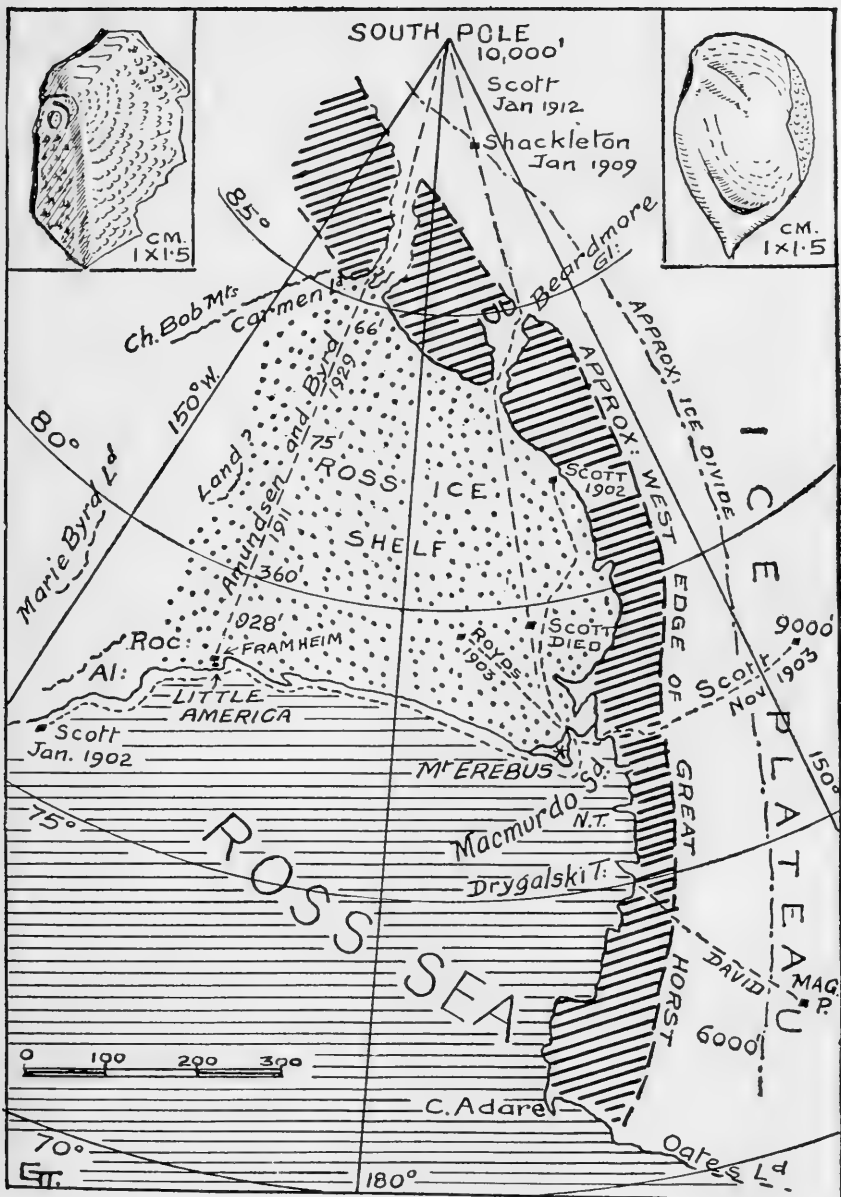


FIG. 6.—MAP OF SOUTH VICTORIA LAND AND VICINITY.

The Great Horst (Fault-Block) is shown by heavy ruling. Main routes of Scott, Shackleton, Amundsen and Byrd are shown. Insets are fossil fish-plates from Granite Harbor. (According to Gould, Carmen Land is largely non-existent.)

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chored the "Discovery" for the long winter. Here he built the 1902 hut (see Figure 8), but it was not used as the expedition lived in the ship.

Various short sledge journeys were made, one being to Cape Crozier, east of Ross Island, to leave a record of the voyage. On the return some of the men were caught in a blizzard, and not realizing their danger tried to reach the ship in the storm. Nine of them slid down the steep icy slopes below Castle Rock (near the hut), and one man, Vince, lost his life. Unfortunately he wore fur boots so he was unable to regain his footing and was dashed into the icy sea.

The return of the sun on August 21st made longer sledging possible. In October Royds went again to Cape Crozier and here discovered the "rookery" of the Emperor Penguins. Early in November Scott, Wilson, and Shackleton started their fine journey to the south, which traversed the first third of the long journey to the South Pole (see Figure 6). The men were assisted by dogs, and Scott gained the poorest opinion of dog sledging on this journey. On December 15th they approached the Great Scarp (to the west) in latitude $80^{\circ} 30'$, but found their way barred by an enormous chasm some three-quarters of a mile wide. Here they left a depot and continued southward parallel to the coast. Symptoms of scurvy developed in Shackleton, but they pushed on to $82^{\circ} 16'$ S. To the southwest towered a twin peak some fifteen thousand feet high, which they named after Admiral Markham. An attempt to reach the land across the great chasm was unsuccessful. On the return the dogs were practically

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useless and could barely stagger eight miles a day; in fact, they "walked alongside the sledges." Scott had difficulty in picking up their depot, which, however, was attained on January 13th. The last two dogs (out of nineteen) were killed near here as they were unable to pull. Shackleton's scurvy became rapidly worse and on January 18th his strength gave out and he was unable to help, and indeed for a time was dragged on the sledge. However, on the twentieth they reached the depot at Minna Bluff ($78^{\circ} 45'$). Shackleton was now very ill, but Scott and Wilson managed to bring him back to the ship, which they reached on February 2nd. They had covered 960 miles in 93 days.

Meanwhile the western party under Armitage left on November 29th to penetrate the mountains (see Figure 8). They ascended the Blue Glacier to six thousand feet and then glissaded down Descent Pass to a level of two thousand feet on the Ferrar Glacier. Then they ascended the latter glacier below wonderful cliffs, which it was my privilege to examine in detail eight years later. On the twenty-third of December they reached the ice divide between the two apposed glaciers, the Ferrar Glacier in the southern valley and Taylor Glacier in the northern valley. Continuing up the Taylor Glacier, they reached the Plateau on New Year's Day at a height of 7,500 feet, being the first to achieve this feat. In January, 1903, they reached nine thousand feet (near latitude 78, longitude 158) and then returned by the same laborious route up Descent Pass, not knowing that an easy track down the Ferrar Glacier lay before them.

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Late in January a relief ship, the "Morning," under Captain Colbeck, reached MacMurdo Sound. Shackleton returned home in her, being replaced by Mulock. It was impossible to free the "Discovery" and so a second winter was spent in the Antarctic. After several preliminary spring journeys Scott started on October 12th for his long plateau journey. He arranged for Ferrar, the geologist, to spend several weeks in these great glacial troughs. On October 18th Scott discovered that the sledge runners were in very bad condition and had to return to refit them. On the twenty-ninth they were once more above Solitary Rocks, on the Taylor Glacier, and reached their former depot. Here the gales had resulted in the loss of various articles, including Scott's mathematical tables. They were held up for a whole week in a blizzard in this locality. On the twelfth of November they reached the great plateau and advanced steadily to the west. Scott found that some of the party were in poor condition and so he sent them back under Skelton, and he proceeded west with seaman Evans and engineer Lashley. They marched over an undulating ice surface diversified only by marked sastrugi (snow ridges due to wind). "These are shaped like the barbs of a hook with their sharp points turned to the east, from which direction many look high and threatening."¹ On calculating Scott's positions on their return it was found that he had reached $146^{\circ} 33'$ E. and latitude 78° S. (see Figure 6). They had a very anxious

¹ See Scott's *Voyage of the Discovery*, Vol. II, p. 264.

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time on their return journey since they ran out of food and oil and had no accurate idea of their position. They fell down three hundred feet of steep slope in drifting snow, and found they had actually approached their glacier depot. A few hours later Scott and Evans simultaneously fell into a wide crevasse. It was a terrible experience, for Lashley could not help them, as the sledge from which they were suspended was broken and only held back by his efforts. Scott climbed out unaided, and soon the party reached their depot. They then reached the snout of the glacier later named by Scott after the writer, and returning down the Ferrar Glacier reached the ship on Christmas Eve (see Figure 8).

On January 5th, 1904, two relief ships reached MacMurdo Sound but could not get to the "Discovery" by some six miles. After trying to cut a passage for the latter with ice saws, they had recourse to explosives; but the swell from the north finally broke up the pack ice on February 14th. On the seventeenth the "Discovery" ran aground in a gale near Cape Armitage, but luckily no great damage was done. On March 2nd they passed Sturge Island in the Balleny group, and then proceeded west to find Wilkes' landmarks: Eld's Peak, Ringgold's Knoll, and Cape Hudson (see Figure 5). Scott writes on March 4th, "I must conclude that as these places are nonexistent, there is no case for any land eastward of Adelie Land." On April 1st the "Discovery" reached Lyttelton Harbor, N. Z., and on the tenth of September, 1904, the ship anchored at Spithead in the Isle of Wight.

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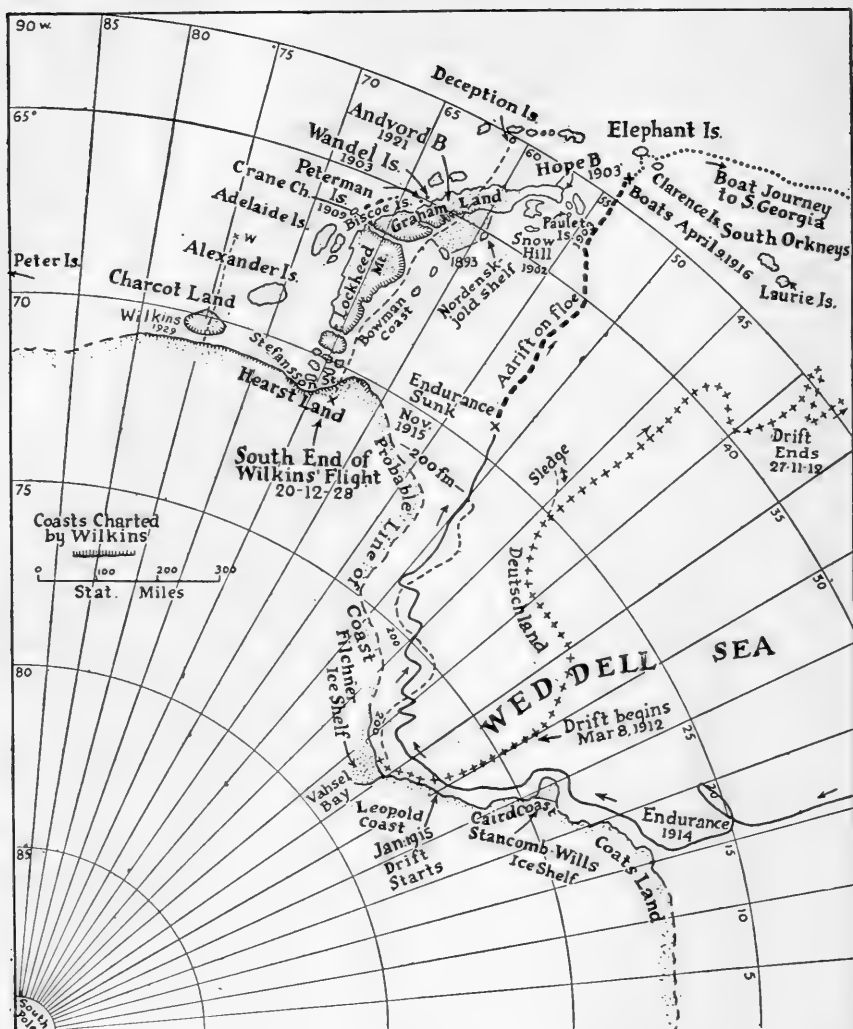


FIG. 7.—CHART OF THE WEDDELL SEA (INCORPORATING WILKINS' DISCOVERIES).

W. marks the start of Wilkins' flight to Charcot Island late in 1929. (Based on *American Geographical Review*, July, 1929.)

Drygalski.—We must now devote some attention to the expeditions sent out in the same year, 1901, by Germany and Sweden. The former was in charge of

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Professor Drygalski in the ship "Gauss," named after the famous German authority on magnetism. After landing at Kerguelen Island in the Indian Ocean, they sailed south to the region where Wilkes had turned north in 1842 (see Figure 4). Towards the end of February they reached shallow soundings and on the twenty-first saw land some forty-six miles to the south. Here the "Gauss" was beset, and the expedition spent the winter just north of the Antarctic Circle. They sent out some sledging parties, none of which made long journeys. A large mass of volcanic rock projected as a nunatak from the icebound coast and was called the Gaussberg. On the return of spring the "Gauss" broke free from the ice and struggled to the west in the pack for two months. This expedition added little to the map of Antarctica, but very valuable records in the domain of oceanography and meteorology were obtained (see Figure 5).

Nordenskjold.—The Swedish expedition was one of the most adventurous and successful which has ever sailed to the south. It was commanded by Dr. Nordenskjold, who was specially interested in the structure of South America and wished to investigate similar problems in West Antarctica (Graham Land). They reached the Falkland Islands on the thirty-first of December, 1901, and the South Shetland Isles on the tenth of January, 1902. Nordenskjold tried to pierce the ice to the south without success, and followed the edge of the pack to the east to longitude 44° W. (see Figure 7). Driven back by storms, he decided to make his winter quarters on Snow Hill Island ($64^{\circ} 30'$

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S.) where there was a promising collecting ground for fossils. The ship "Antarctic" left them on the fourteenth of February, 1902, and here the party remained until the tenth of November, 1903 (see Figure 7).

During October of 1902 they sledged south about two hundred miles to latitude 66° S., but most of their time was spent in exploring and collecting within a few days' journey of their hut. No ship came to their relief in December, 1902, and they spent a second winter in the Antarctic. In October, 1903, Nordenskjöld was exploring the region to the west when he met two begrimed and ragged beings who turned out to be two of his countrymen, Anderson and Duse, who had tried without success to reach him from his relief ship early in 1903. They had therefore built a stone hut at Hope Bay, some one hundred miles to the north of Snow Hill; and after a winter there had managed to get in touch with him. Meanwhile Captain Larsen on the "Antarctic" had met with dire misfortune, for the ship was crushed by the terrible pack ice of the Weddell Sea, and sank on the twelfth of February, 1903. Larsen and his crew of nineteen reached Paulet Island, about seventy miles northeast of Snow Hill, and here a third hut was built, and so a third party spent the winter of 1903 on the coasts of Graham Land. When the ice broke out Larsen set off in a boat to visit Hope Bay and then Snow Hill, where he arrived an hour after the relief expedition sent by the Argentine government in the ship "Uruguay." On the second of December, 1903, they all reached Buenos Aires safely. While not much was added to the map of Antarctica,

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perhaps no other expedition has been so successful with its geological and paleontological investigations in Antarctica. These will be described in a later chapter.

Bruce.—It is natural that Scotland, from which so many whalers set out year after year, should be interested in polar exploration. In 1892 Dr. Bruce had made a voyage with the whaling fleet to Graham Land, and in 1902 he was successful in leading a scientific expedition to explore Antarctic regions. The "Scotia" left Scotland in November and reached the Falkland Islands early in January, 1903 (see Figure 4). Bruce made two voyages into the Weddell Sea area in the successive summers. On February 2nd they reached the Pack Ice at $60^{\circ} 28'$, whereas Ross found it at 65° and D'Urville at $63^{\circ} 30'$. They visited the South Orkneys and then pushed to the southeast across the mouth of the Weddell Sea, gradually getting farther south as they moved to windward. They were unable to proceed farther than $70^{\circ} 25'$ on February 22nd, when they were in the vicinity of Coats Land, though this area was still to be discovered. For a week they were nearly beset, and as the season was fairly late they turned north, making valuable soundings. Bruce decided to winter in the South Orkneys, which were practically unknown scientifically and very poorly charted before his expedition's advent. On the beach at Scotia Bay in Laurie Island (see Figure 7), they built a stone hut for the observers in spring. The island is about twelve miles long and is cut up by long bays running northwest and southeast. Silurian graptolites were discovered at the eastern end, and the

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island was found to be wholly built of sedimentary rocks. This indicates its former connection with a large continent, and is of much interest, for islands far distant from land are generally built of coral or volcanic rocks.

Late in February, 1904, the "Scotia" again sailed south, making for the same region she had visited the year before. On March 1st they found open water where there had been impenetrable pack. Next day they discovered a lofty ice barrier and were able to approach within two miles of it. On the sixth they had traced one hundred and fifty miles of this coast, which was named Coats Land after the Glasgow merchants who had made the expedition possible. Many continental boulders were dredged, but no rock was seen on the barrier. They reached $74^{\circ} 1' S.$ and for some days the chance of escape from the heavy pack seemed small, for the "Scotia" was held fast by the bows. However, on the fourteenth of March they broke loose and steamed north along the meridian of $10^{\circ} W.$, making a series of soundings. They made a brief visit to Gough Island, 1,500 miles from the Cape, and reached Capetown on May 5th.

Charcot.—In August, 1903, the French expedition under Dr. Charcot left Havre to investigate the west side of Graham Land. They entered Gerlache Strait but could not penetrate the pack near the Biscoe Islands and so established winter quarters on Wandel Isle in latitude $65^{\circ} S.$ They made detailed investigations of the geography and geology of the surrounding coasts, reaching the small Biscoe Islands in a whale boat.

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The ship was not able to leave Wandel Isle until mid-December, when they proceeded to the southwest and discovered Loubet Land to the east. They also obtained a view of Alexander Land (1821) on the eleventh of January, but were then compelled to steer north. After an exciting collision with an iceberg they safely reached American waters (see Figure 7).

1907 TO 1913

In December, 1908, Charcot was again in the Antarctic in the ship "Pourquoi Pas," with a group of eight scientists and a very complete equipment. He surveyed the coast in greater detail and added a great deal to our knowledge of the lands south of the Antarctic Circle. A large gulf lies to west of Adelaide and Alexander islands. He made a careful study of the region south of Adelaide Island and climbed Jenny Island. He reached within a few miles of Alexander Island and was able to chart approximately a coastline some two hundred miles long to the east, which he called Fallieres Land. (This is part of what Wilkins calls South Graham Land, and is really a large island.)

The ship was unable to find a suitable harbor on Fallieres Land and sailed north to Lund (or Peterman) Isle a few miles south of Wandel Isle. They made an attempt to explore the region to the east and climbed a glacier to a height of three thousand feet, but the rugged topography foiled their efforts to reach the summit. Late in November, 1900, they left winter quarters and after visiting Deception Island for stores, they sailed again to the southwest to the seas

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traversed by Gerlache in 1898. Charcot was able to reach more southern latitudes so that he discovered Charcot Land in latitude 70° S. and longitude 77° W. He proceeded to the west, passed Peter Island, and reached longitude 120° W., where he was well south of latitude 70° S., and only about seven hundred miles from Edward VII Land. From the shallow soundings, Charcot was sure that land lay not far to the south along much of his cruise (see Figure 4).

Shackleton's First Expedition, 1907-1908.—No man has done more to decipher the secrets of the South Pole than Ernest Shackleton. Of his four voyages the first under Captain Scott has been described. His second voyage was by far the most important. His expedition was financed privately and set sail in the "Nimrod." Murray, a biologist, and Priestley, a geologist, came from England with Shackleton. They were later joined by two eminent scientists, Edgeworth David and Douglas Mawson, from Australia. Adams, Marshall, and Wild were other notable members. Shackleton, like Scott, had no belief in dogs, but he made a new departure in southern exploration by taking eight Manchurian ponies to Antarctica. They left New Zealand on New Year's Day, 1908, and to save coal his ship was towed to 66° S. by a steamer.

Shackleton had hoped to build his hut at Edward VII Land, but he was unable to find a suitable site, and like Scott he turned to the west and made his winter quarters at Cape Royds, on Ross Island, about fourteen miles north of Scott's hut of 1902-3. The first exploit was to climb Mount Erebus, which tow-

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ered thirteen thousand feet above the hut to the east. On March 5th, 1908, six men, led by David and Adams, started their ascent. They dragged a sledge up to 2,750 feet, where they camped. On March 6th they reached 5,630 feet before camping in the oldest crater of Erebus. They left the sledge here, and, carrying bags and the tent, but no poles, reached 8,750 feet on the evening of March 7th. The temperature here was 20° below zero Fahrenheit. Here a blizzard beset them, and without tent poles they were in a precarious position. Brocklehurst was nearly frozen to death and Mackay fainted from mountain sickness near the summit. Here they found another ancient crater with a wall one hundred feet high and containing many snow-cowled fumaroles emitting steam. At their camp at 11,400 feet it was found that Brocklehurst was severely frostbitten, and he lost a toe as a consequence. The other five men reached the summit at 10 A.M. on March 10th (see Figure 11).

“We stood on the verge of a vast abyss, and at first could see neither to the bottom nor across it on account of the huge mass of steam filling the crater and soaring aloft in a column one thousand feet high. After a continuous hissing sound there would come from below a big dull boom, and great masses of steam would rush upwards. . . .” Mawson’s angular measurement made the depth of the crater nine hundred feet. Beds of lava or pumice alternated with white zones of snow in the crater wall. They returned to the hut in two days.

One of the most adventurous journeys in polar history was that which commenced on October 29th,

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1908, with the South Pole as its object. Shackleton chose Lieutenant Adams, Dr. Marshall, and Frank Wild for his companions. Each man led a pony sledge and for a few days a supporting party accompanied them. They had a bad time with crevasses on the Ross Ice Shelf where it presses around Minna Bluff, but thereafter progressed directly to the south. The pony, Quan, enlivened their journey by eating harness, ropes, rugs, and all he could reach. On the twenty-first of November they were south of the 81° parallel, and here the first pony was shot. Some of the pony flesh was used for food, being eaten practically raw as it became too tough when cooked. They were now approaching Scott's record and marching abreast of a new range of mountains. On November 23rd they made a fine march of almost eighteen miles, and on November 26th were south of Scott's "farthest" of $82^{\circ} 16'$. The barrier surface had the form of long undulations, the width from crest to crest being about one and a half miles. The second pony was shot at Depot C and the third at $83^{\circ} 16'$, leaving only Socks. The mountains showed great granite cliffs six thousand feet high in places. The range now trended across their path and Shackleton decided to ascend one of the many glaciers flowing from the Plateau (to the west) down to the Ross Ice Shelf. On December 3rd they climbed Mount Hope (3,350 feet) and "from the top of this ridge there burst upon our view an open road to the south. We could see the glacier stretching away south inland till at last it seemed to merge in high inland ice." (See Figure 6.) They climbed two thousand

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feet over a pass and then descended to the foot of the great Beardmore Glacier. On December 7th Wild was leading the pony over a snow bridge when "he felt a sort of rushing wind, the leading rope was snatched from his hand and he just caught the further edge of the chasm. Sock's weight snapped the swingle-tree of the sledge so that it was saved. We lay down on our stomachs and looked over into the gulf, but no sound or sign came to us; a black bottomless pit it seemed to be."

They struggled among bad crevasses from December 7th to December 16th for nearly one hundred miles and had risen six thousand feet up the Beardmore Glacier. On December 17th Wild found specimens of coal in the cliffs of Mount Buckley to the north, but it was not till December 27th that they really reached the head of this enormous glacier at a height of 9,820 feet. They were all somewhat affected by the altitude, and found it severe work to pull 150 pounds per man. On January 6th they marched thirteen miles against a strong blizzard with a temperature of 57 degrees of frost, and on January 9th they reached $88^{\circ} 23' S.$ in longitude $162^{\circ} E.$ No explorer, either north or south, has ever made so great an advance on previous records as did Shackleton on this wonderful unsupported march of 420 miles in unknown and dangerous country (see Figure 6).

Their return journey for a time was easier, as on January 19th when they marched nearly thirty miles a day, helped now by the southern blizzards. Their descent of the Beardmore Glacier was full of dangers,

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and they exhausted all their food on January 26th, but soon picked up their depot and reached the Ross Ice Shelf again on January 29th. Early in February all suffered greatly from dysentery, but on the twelfth they reached the depot where the pony, Chinaman, was shot and they feasted on his liver. On the nineteenth they sighted Erebus and next day reached Depot A. Marshall became very feeble and was left with Adams while Shackleton and Wild pushed north to Hut Point on Ross Island. Here they found open water separating them from Cape Royds. After some time they managed to make a signal fire, and on March 1st they were aboard the ship. Shackleton immediately started back to bring in Marshall and all the expedition were united on March 4th.

On October 5th the Magnetic Pole party started with Professor David as leader. He was accompanied by Mawson and Mackay. They sledged up the western coast of Ross Sea, a hazardous journey on the sea-ice in view of the probable breaking up of the ice without notice. On October 26th they crossed the mouth of Granite Harbor, and on November 1st they made a depot of much of their food and gear at Depot Island (latitude $76^{\circ} 40'$). This was necessary because they could only relay four miles a day owing to the load and heavy surface. On November 11th they reached the Nordenskjold Ice Tongue and crossed it in two days (see Figure 6). A fortnight later they first saw the much larger Drygalski Ice Tongue, that "scaly horror with his folded tail," as David describes it (see Figure 19). On the twenty-ninth they started to cross

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it, but were foiled for some days by the chasms and ridges, but made a successful traverse between December 6th and 11th. They halted for a few days here and killed seals and penguins to supplement their food, for their further journey of two hundred miles to the Magnetic Pole. On December 17th they made their way inland, having a risky time with crevasses which nearly engulfed the whole party. A difficult track over the north side of the Larsen Glacier enabled them to ascend to the Great Ice Plateau, which was reached by a fairly smooth route on December 28th. By January 10th the Great Ice Plateau had gradually risen to seven thousand feet. On the fifteenth they were so close to the daily fluctuating "Pole" that Mawson thought it might swing beneath them! However, they marched some miles farther and on January 16th arrived at $72^{\circ} 25'$ S. latitude and $155^{\circ} 16'$ E., which Mawson deduced to be the Magnetic Pole (see Figure 2). On their return they had to make over sixteen miles a day to be at the coast in time for the relief ship. Descending the Larsen Glacier they had a very difficult task in crossing the weathered and crevassed ice near its junction with the Great Ice Shelf, but on the third of February they ended their splendid journey on the coast, just north of the Drygalski Ice Tongue. It was a dramatic finish that this exhausted party should have been met by the ship on the very day they reached the coast, for they would have had little chance of a safe return to headquarters by their own efforts.

Many other exciting incidents occurred on this expedition. Thus the Western Geological Party was car-

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ried away for twenty-four hours on an ice floe from New Harbor towards the open sea and only just saved themselves at a momentary contact with fixed ice. Macintosh and a sailor had a wild journey with letters from the ship off Cape Bird to Cape Royds. The sea ice broke up into small floes and after waiting some days on the rocky coast they made their way five thousand feet up the slopes of Ross Island. By some miracle they escaped the fields of crevasses and reached the 1907 hut without food or gear on January 12th.

Scott, 1910-1913.—The most tragic of Antarctic expeditions was that led by Captain Robert Falcon Scott to the southern continent in 1910. It had two objects. Firstly, the leader wished to surpass Shackleton's journey and reach the South Pole. Secondly, there were many scientists on the expedition whose special aim was to make detailed surveys in as many coastal regions as might be found possible. All these objects were attained, but the tragic loss of the five members of the pole party involved the deaths of Scott, the leader, of Wilson, the director of science, of Oates, the officer in charge of transport, of Bowers, who was in charge of all stores, and of Evans, the chief petty officer.

The expedition left Lyttelton in New Zealand on November 26th, 1910. They experienced a furious gale which nearly sank the "Terra Nova" in the "Furious Fifties" near Campbell Island.² The ship was held back by the dense pack for some three weeks, an un-

² This incident is described later on page 108.

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usually long period, for ice extended from $64^{\circ} 30' S.$ to $71^{\circ} 30' S.$ On January 3rd Scott tried to land at Cape Crozier, but this being impossible he sailed up MacMurdo Sound and fixed his headquarters at Cape Evans, about halfway between the huts of the 1902 and 1907 expeditions (see Figure 8). Fine weather enabled the hut to be rapidly built, so that the depot-laying party and the Western Geological Party were able to leave on the twenty-fourth of January, 1911. Thereafter the ship sailed toward King Edward VII Land where Campbell's party was to make a base for scientific survey. On arrival at the Bay of Whales they found Amundsen there in the "Fram." Campbell, therefore, was transferred to Cape Adare, where the northern party spent the ensuing year (see Figure 6).

The southern party with the ponies, under Scott, carried a large store of food to One Ton Camp, about one hundred miles south of Ross Island. They had many narrow escapes from crevasses, but the most hazardous experience was when Bowers' party of three found themselves adrift after camping on the sea-ice near the 1902 Hut (see Figure 8). For many hours they tried to bring off the ponies by jumping the floes, but finally only one pony was saved. The others fell into the sea and were devoured by killer-whales. The first western party under my leadership, with Wright and Debenham as fellow-scientists, marched up the Ferrar Glacier making detailed topographic, glacial, and geological surveys (see Figure 8). We crossed the Ice Divide at Knob Head and then sledged down the adjacent Taylor Glacier to its snout, some twenty-

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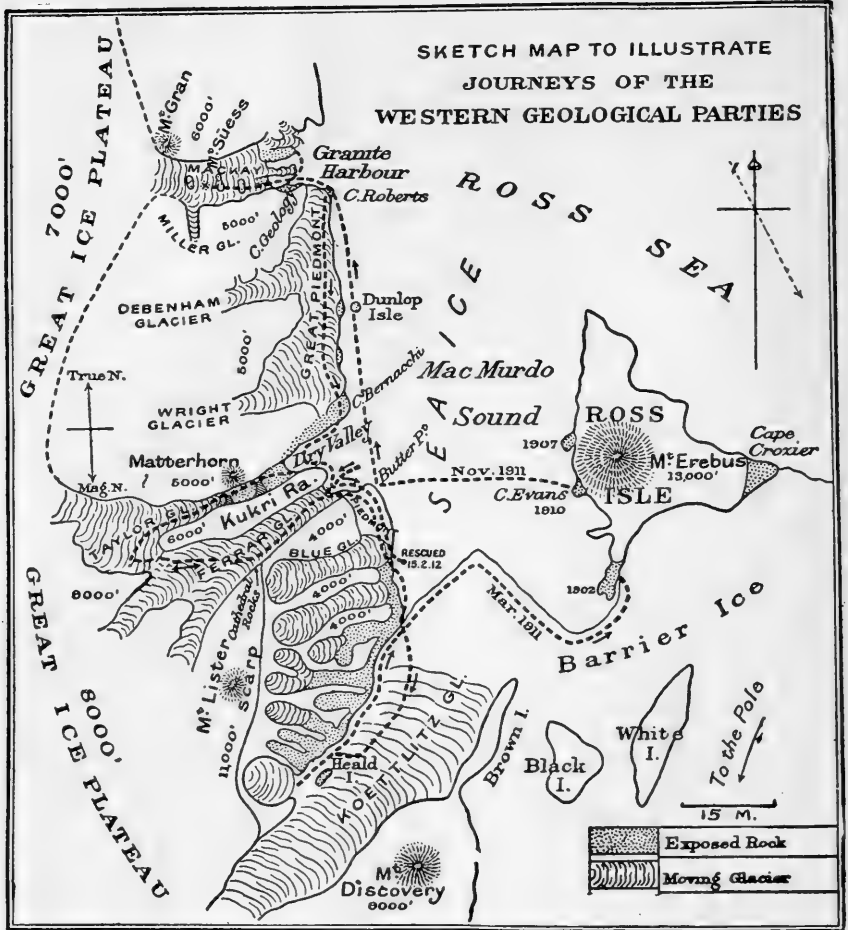


FIG. 8.—MAP OF MacMURDO SOUND, SHOWING ROUTES OF THE AUTHOR'S PARTIES IN EXPLORING THE FOUR GREAT OUTLET GLACIERS.

(By permission of John Murray.)

five miles from the sea. The unique snow-free valley offered most interesting topographic examples of the way in which the continent was carved by the waning glaciers. Returning we traversed the Bowers Piedmont Glacier and made our way up the pinnacled ice

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of the great Koettlitz Glacier. Here a subglacial stream twenty-five miles long was surveyed. We sledged back round the breaking Barrier to the old 1902 hut at Cape Armitage, where we arrived a week later than the depot party. Here the two parties were held up by open water from March 15th till April 11th, when we managed to find a route free from crevasses along the slopes of Erebus to Glacier Tongue, and so reached Cape Evans on April 13th (see Figure 8).

The outstanding feature of the winter was the journey of Wilson, Bowers, and Cherry-Garrard to obtain data as to the evolution of those primitive birds, the emperor penguins. These lay their eggs in midwinter at Cape Crozier, and the party spent five weeks under almost unbearable conditions with the objective of obtaining the eggs. Their only light was either from the moon or from a special candle lamp. The temperature fell to -77° F. and was constantly below -60° . Their tent and gear were blown away in a furious blizzard and much of it lost. It was so cold that for weeks they were unable to obtain proper sleep, and at the end dozed while marching. Well has this been termed the "Worst Journey in the World."

On the thirty-first of October, 1911, in the second summer, Scott left Cape Evans on his last journey. He had to traverse some nine hundred miles to the Pole, of which three hundred and fifty miles lay at an elevation of nearly ten thousand feet above sea level. Another one hundred and fifty miles was expended in ascending the Beardmore Glacier, while four hundred and twenty miles was on the Ross Ice Shelf near sea

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level. The two motor sledges were not very successful in transporting stores, and unfortunately Scott placed little reliance on dog sledging. As in the case of Shackleton's journey, ponies pulled most of the load to the foot of the Beardmore Glacier, but south of latitude 83° the sledges were hauled by men. Various supporting parties turned back before the Pole was reached. Thus Day's party turned near 81° ; Meares and the dogs reached the Beardmore; Atkinson and three others went back from 85° S. at the top of the Beardmore on December 21st. By the end of the year the two remaining parties had reached 87° S., and on January 4th Lieutenant Evans, with Lashley and Crean, turned back when they were one hundred and forty-five miles from the Pole. Evans nearly died of scurvy on this journey, but was saved by the gallantry of his two companions, who dragged him many miles on the sledge to safety. By January 8th the polar party had beaten Shackleton's record, but very difficult surfaces made the last one hundred miles a terrible ordeal. Sometimes it would take nearly five hours to pull six miles with a fairly light sledge, for they had depoted almost all their food by now. On January 16th they found the cairn and flag of the Norwegian party and so knew that they had been forestalled by four weeks. On January 17th they made their sixty-ninth camp at the Pole on the high plateau some ten thousand feet above the sea with a midsummer temperature of -22° F. Scott writes in his diary, "We built a cairn, put up the Union Jack and took a photograph—mighty cold work, all of it." (See Figure 6.)

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The homeward march began on January 19th. It was hard work, for they had to rise one thousand feet in the next week's marches. However, the stern wind helped them somewhat. Blizzards slowed down their speed and the surface ice deteriorated to "sandy crystals" with similar results. On February 7th they reached the head of the Beardmore Glacier after seven weeks of low temperatures and almost incessant wind. Here Petty Officer Evans sustained concussion from a bad fall, and as a result the strongest man of the party became a drag on their progress. On the seventeenth of February he fainted and died the same night, just near Mount Hope at the foot of the Beardmore Glacier. The journey on the Ross Ice Shelf was marked by head winds, bad surface and by very low temperatures, so that a rise to -20° seemed a great improvement. Oates was feeling the cold more than the others and his feet were giving him great pain from frostbite. On the seventeenth he walked out of the tent into the blizzard and died in a vain effort to give his comrades a better chance to reach safety. With a northerly wind in their faces and a temperature of -40° , on the nineteenth of March they struggled to their last camping ground, about eleven miles from One Ton Camp, with only two days' food. It is sad to realize that a dog team with two men had been at One Ton Camp from the third to the tenth of March, when the food for the dogs was almost exhausted, and they had to return. If the plans for relief had not been totally upset by the illness of Lieutenant Evans, it is probable that a longer relief journey could have been made and so

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four members of the Pole party might have been saved. A blizzard held Scott and his comrades to their tent for nine days and the last message was dated March 29th. Seven months later, when winter had passed, their bodies were found by a party under Atkinson, and left there under a giant snow cairn in the Antarctic solitudes.

A few words must be given to the northern and western parties. The latter under myself with Debenham and two others spent three months in mapping in detail the coast line north of our previous journey. A careful topographic and geological survey of Granite Harbor was made, and the party sledged up the Mackay Glacier to Mount Sues, which was ascended (see Figure 24). Near here coal and Devonian fish were found. The ship could not pick us up owing to the heavy belt of pack ice so we traversed the thirty-mile-wide Wilson Piedmont and were picked up by the ship on the fourteenth of February, 1912, near the Koettlitz Glacier. The northern party had not been able to sledge far from Cape Adare, but made very valuable records of glaciology and meteorology in this distant locality. The ship brought them south to the Ice Shelf north of the Drygalski Tongue. Here they were left on January 8th, 1912, with six weeks' food, to explore the hinterland north of where David had been picked up in 1909. They made a valuable map of the region and Priestley found very interesting Permian fossil trees. The ship was unable to reach this party owing to the heavy screw pack, so that on March 16th they started to burrow into a snow drift to form a snow

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hut. Here they dwelt, cursed by darkness and semi-starvation until October 1st. One of the men was so ill that it was necessary to drag him on the sledge. On October 29th they had their first full meal, from a depot, left by myself on Cape Roberts; and they reached the hut safely on November 7th after a wonderful journey, considering their debilitating winter conditions.

Meanwhile the most complete record yet obtained of Antarctic weather had been made at headquarters by Dr. Simpson, and it is believed that these and other voluminous scientific memoirs in geology, glaciology, topography, surveying, and biology will make this expedition as notable in the annals of science as it is in the record of polar exploration.

Amundsen.—This explorer was a member of the Belgian expedition in 1899 and had since done fine work in the "Gjoa" in Arctic seas. His plan to reach the North Pole was forestalled by Peary, and so he decided to attempt the South Pole, before using the "Fram" to explore the North Polar ocean. He informed the crew of the change of plan at Madeira and then proceeded to the Ross Barrier Shelf, which was reached on the eleventh of January, 1911. On the fourteenth he started to build his station on a portion of the shelf which appeared to be immovable. Here Amundsen took a grave risk, which success justified, for much of the shelf to the west breaks away each year. Another great advantage was that it was so far from the Great Ice Plateau that few blizzards, due to "gravity flow" of the air, hindered their plans. Furthermore, it was much nearer the Pole than Cape Evans

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and was, of course, in touch with the south, while Cape Evans was isolated in summer from the Ice Shelf by open water. In the first summer Amundsen laid a depot to 82° S. and after an uneventful winter they started for the Pole on September 8th (see Figure 6). The cold was, however, too severe and they returned to make a final start on October 19th. Five men formed the party, Amundsen, Bjaaland, Wisting, Hasel, and Hansen. They had fifty-two dogs, who pulled so willingly that the men either rode the sledges or were dragged right across the Ross Ice Shelf for some four hundred miles. They reached the foot of the outlet glacier on November 10th. On November 12th Carmen Land³ was seen, an elevated region which bounds the Ross Ice Shelf to the southeast.

Amundsen had considerable difficulty in reaching the Ice Plateau. They ascended two thousand feet to find that cross valleys blocked their way, and after reaching ten thousand feet through a maze of glaciers there was still no clear route to the Plateau. For twelve days they journeyed through the mountains amid enormous crevasses and were often shrouded in fog. They killed all but eighteen dogs, and on December 1st struggled through to the Plateau. Here they often made marches of twenty miles a day. In 88° S. they were over ten thousand feet above the sea, but the Plateau descended somewhat to the Pole, as Scott also found on his traverse to the west. The Pole was reached on December 14th, and after taking careful

³ Dr. Gould reported in December, 1929, that no land occurs where Amundsen places Carmen Land.

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observations during several days they turned back to the north. On January 6th they were back on the Ross Ice Shelf, and with plentiful food and active dogs we get the impression that Amundsen held the dogs back in order to reach Framheim just on the twenty-fifth, as he had foretold. The journey of 1,860 miles had taken 99 days, and was a triumph of good arrangement and adequate transport.

As a scientific journey, however, it was largely a waste of time, for Amundsen brought back hardly any cartographic data and practically no geological or topographic material. When we think of Scott's party dragging their invaluable geological specimens back when they knew they were doomed; or of Bowers' wonderful navigation data and his meteorological log; or of the books filled with accurate drawings by Dr. Wilson; there is little question as to which party had the true interests of discovery most at heart. A useful journey by Amundsen's lieutenant (Prestrud) to the east resulted in some further knowledge of King Edward VII Land. On January 16th a Japanese vessel arrived at Framheim, but the Japanese appear to have done little of note during their dash to the Antarctic. Amundsen left the Bay of Whales on January 30th and reached Hobart early in March, 1912.

With the achievement of the South Pole by two nations we may fittingly close this chapter on Antarctic exploration, for though there have been half a dozen noteworthy journeys since 1912, they may well be considered in a new chapter under the heading of recent exploration.

CHAPTER IV

RECENT EXPEDITIONS TO THE ANTARCTIC

IN the last chapter we have seen how our knowledge of the great continent was so remarkably advanced during that short period between 1901 and 1912. Before that nothing was known of the interior, and nothing of winter conditions except at two or three localities at relatively low latitudes. Since 1912 we have had a reasonably good idea of most of the varying environments which are to be found in Antarctica, whether it be High Plateau, floating Ice Shelf, outlet glaciers of the Great Scarp, or subglacial topography as shown in the empty valleys west of MacMurdo Sound. Furthermore, five winters have been spent in the latter vicinity and full weather data obtained for a region as far south as 78° S.

There still remains nine-tenths of the continent to be explored and more than half the coast line (see Figure 34). The outstanding problem of the region between the Pole and the Weddell Sea—is it lowland, gulf, or high plateau?—is still unsolved. But apart from this, we may perhaps say that there are not likely to be so many novel polar environments still unknown as were investigated in the "Golden Period of South Polar Exploration" from 1901 to 1912. Perhaps one should extend this period to include the Australasian

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expedition led by Sir Douglas Mawson during the years 1912 and 1913, and the voyage of Filchner in 1912 to the head of the Weddell Sea. But as I have stated previously, the conquest of the Pole in 1911-12 seemed a momentous event which separated earlier expeditions from all which took place in later years.

MAWSON

In December, 1911, the ship "Aurora" set sail from Hobart with Mawson and his expedition on board. He hoped to have four parties at far distant bases, whose meteorological results could be compared. Three of these were actually established. The first was placed on Macquarie Island, which lies some nine hundred miles southeast of Hobart. Here Ainsworth, from the Melbourne Weather Bureau, and four companions maintained wireless communication with Australia. Valuable geological and biological collections were also gathered on this sub-Antarctic island.

Twenty-six men, largely young graduates from Australian universities, were landed at Commonwealth Bay in Adelie Land (in latitude 67° S. longitude 143° E.) on January 8th (see Figure 2). Here a rocky "oasis" amid the encircling ice was discovered on which the hut was erected. This patch of rocks was only about a mile long, and no similar area seems to exist along the hundreds of miles of coast explored by Mawson's Expedition. The "Aurora," under Captain Davis, sailed west to land the party of men under Wild. On the twenty-fourth of January high land was sighted (near longitude 135° E.) to which Mawson gave the

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name of Wilkes Land. Totten Land seems to have been wrongly placed by Balleny if it exists. On February 7th Davis found his progress blocked, as had Wilkes, by the great ice shelf of Termination Land. But he considered that an open sea might lie to leeward and was rewarded for his acumen by discovering Davis Sea. Here he landed Wild on February 15th in Queen Mary's Land some 1,200 miles west of Adelie Land. (See Figure 25.)

The expedition encountered an environment of blizzards far more violent than in any other polar region. The average wind force for the year was fifty miles an hour, more than five times that experienced in the United States. In spite of this disability many remarkable journeys were made. On November 9th Mawson with Ninnis and Mertz started on their traverse to the east over the margin of the great Ice Plateau. They found their route crossed by two tremendous glaciers which projected far into the sea as the Mertz and Ninnis ice tongues. These were fifty miles apart and gave rise to terribly crevassed country. On December 13th they had sledged two hundred and eighty miles. Mawson and Mertz were ahead when Ninnis with his dog team and nearly all the food was engulfed in a tremendous crevasse. Only ten days' food remained for the two men and nothing for the dogs. They turned back, on a more southern track, hoping thus to escape many of the crevasses. Mertz rapidly weakened, and on the seventh of January he became delirious and died. Mawson was still one hundred miles from the hut, and his march has never been

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surpassed for difficulty and endurance. On the seventeenth he fell completely into a crevasse and only with the utmost difficulty managed to reach his sledge. Thereafter he carried a rope ladder to enable him to climb out of any future crevasses. When five miles from the hut he was held up in a small ice cave for seven days, but he reached headquarters safely on the eighth of February, 1913. (See Figure 2.)

A party of three men under Lieutenant Bage journeyed toward the Magnetic Pole and covered a distance of about three hundred miles before turning back. They reached within about one hundred and seventy-five miles of David's position in 1909, careful magnetic observations being made by Webb (see Figure 2). They obtained a dip of $89^{\circ} 43'$ with the needle and estimated that they were only fifty miles from the Magnetic Pole. The Ice Plateau was here 5,900 feet above the sea. A fine coastal journey over the dangerous sea-ice was made by Madigan and two comrades to the east. They found a number of outcrops of gneiss and crossed the tongues projecting from the Mertz and Ninnis glaciers. In spite of the risk of the ice breaking away, they proceeded eighty miles to the east and discovered Horn Bluff, where dolerite sills penetrate a sandstone resembling the Beacon sandstone. (See Figure 2.)

The western party, under Wild, built their hut just a few miles north of the Antarctic Circle on the ice shelf named after Shackleton. In August, 1912, a depot was laid twenty miles to the east amid granite outcrops. In this region men were lifted from the

ANTARCTIC ADVENTURE AND RESEARCH

ground by the blizzards and flung twenty feet. One party endured a blizzard which held them in their tents for seventeen days. In November Wild led a party to the east, where two great glaciers entering the Shackleton Ice Shelf were discovered and named the Denman and Scott glaciers. Immense chasms four hundred feet deep prevented their progress to the east. Another party under Jones marched west for two hundred miles, and on December 22nd they reached the Gaussberg, where relics of the German expedition of 1902 were found. The party was relieved on February 22nd, 1913, and taken back to Australia. (Figure 25.)

Mawson had not returned in time to be relieved at Commonwealth Bay, missing the "Aurora" after his terrible journey by a few hours only. With six companions he carried on work during a second winter. On February 15th wireless contact was made with Macquarie Island, and on February 22nd messages were sent to Australia. On December 12th the "Aurora" returned and picked up the remainder of the expedition. On her cruises the "Aurora" had done much oceanographical work and Davis discovered Mill Rise—a submerged mountain, some two hundred and fifty miles south of Tasmania.

FILCHNER

Filchner in command of a German expedition succeeded in establishing a record in the Weddell Sea, which so far has not been broken. He left Grytviken in South Georgia on the eleventh of December, 1911,

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and after being held up for a time in the pack ice he made rapid progress to the south down the east side of the Weddell Sea (see Figure 7). Apparently this region is at times kept fairly free of ice, owing to the dominant easterly winds. On the thirtieth of January he saw the Continental Ice in latitude $76^{\circ} 48'$. Ice cliffs about sixty feet high bounded an ice cap margin some eight hundred or one thousand feet high. He followed this coast to 78° when he was blocked by an ice shelf like that in the Ross Sea (see Figure 7). This is named after Filchner and the bight at the junction after Captain Vahsel, who died six months later on the ship. Filchner followed this barrier over one hundred miles to the west. He attempted to make his winter quarters near the barrier, but on February 18th a high tide broke the ice loose, and he lost much of his material. On the eighth of March his ship was beset in $73^{\circ} 43'$ S. by the pack ice, and drifted to the northwest. In the last week of June Filchner with two companions made a sledge journey of one hundred miles to the northwest to see if Morell Land lay in that direction (as stated by Morell in 1823). He found no sign of land, however. In the autumn months they drifted north, and in October the westerly winds north of 65° S. drove them irregularly to the northeast. They escaped from the pack on the twenty-seventh of November in latitude 63° S. Filchner was given no opportunity to return to the south, but his voyage is especially noteworthy from the discovery of the shelf which blocks the head of the Weddell Sea.

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SHACKLETON, 1914

The most remarkable of all Antarctic voyages as regards dangers encountered and vanquished is that of Shackleton in the "Endurance." He planned a trans-Antarctic expedition, which involved the landing from the "Endurance" of a party of men on the Filchner Shelf who were to march across the continent to depots laid down on the Ross Sea side by sledging parties from the "Aurora." On December 5th, 1914, the "Endurance" left South Georgia for the Weddell Sea and entered the pack near the Sandwich Isles on December 7th. The ship made a fair voyage to the south through the pack ice and on New Year's Day was just north of 68° S. The explorers were blocked by the ice early in January near latitude 70° S., but on the 8th reached open water and soon passed the record of Ross (1843) and then came in sight of Coats Land in $72^{\circ} 34'$ S. They obtained shallow soundings here, of 155 fathoms, with a bottom composed of igneous pebbles (see Figure 7). They discovered new land (named after Caird) between Coats Land and Leopold Land. The most prominent feature is a gigantic ice promontory which projects some fifty miles from the continent. This mass of ice is fifty miles wide and is probably floating, as the sea is 1,300 fathoms deep hereabouts. Two great glaciers were discovered just to the south.

On the eighteenth of January, 1915, the "Endurance" was beset off the north end of Leopold Land. The whole of February was spent off Vahsel Bay about

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latitude 77° . During March the ship drifted to the northwest, and this course was maintained during the next three months. The ship's track made curious zigzags first north and then west quite regularly over the shallow continental shelf, which lay about two hundred fathoms below the surface of the sea. After July 1st (latitude 74° S.) the drift was to the north, and the effects of pressure on the pack ice became more apparent. On August 1st the floe surrounding the ship broke up, and the ship listed to starboard. During the last days of September the roar of the pressure-movements grew louder. On October 18th the "Endurance" was thrown over on her side, and on October 27th, in latitude 69° S., crushed by the driving pack. She sank on November 21st, after a drift of some 1,500 miles, leaving the explorers 346 miles from Paulet Island, the nearest place where food was available (see Figure 7).

They shifted their stores to a thick old floe forming Ocean Camp. They had great difficulty in getting enough food from the ship and were always rather short of flour and biscuits. In December they attempted to march nearer land, but were only able to proceed seven miles for the ice was too broken for travel. They therefore formed Patience Camp on a large floe. By the middle of February even the flesh foods became short, but luckily they caught a few seals and some penguins. On April 2nd all the dogs were shot for food. They had now drifted well north of Graham Land into latitude $62\frac{1}{2}^{\circ}$ S. and indeed had seen Joinville Island on March 23rd, but the ice was

ANTARCTIC ADVENTURE AND RESEARCH

too close-set for boats and too open for sledges. On April 8th they saw Clarence Island and Elephant Island (latitude 63° S.) and next day they took to the three boats for their hazardous trip to Elephant Island. At nights they camped on a floe, which broke right under them on one occasion, Holness being rescued from drowning while in his sleeping bag. The temperature was close to freezing point, and the men lay in each other's arms for warmth. To add to their troubles they had no fresh water, having had no time to get fresh ice from a berg when launching the boats. As they approached Elephant Island they found it flanked by icy cliffs, fragments of which alleviated their thirst. On the fifteenth of April they landed on the Island, but transferred their camp to a gravel spit some seven miles to the west.

On April 23rd Shackleton with a crew of five made an adventurous boat journey of eight hundred miles in the stormy seas of the "Furious Fifties" to South Georgia. His journey of sixteen days was one of "supreme strife amid heaving waters." The boat was nearly sunk by a gigantic wave on May 5th. After they had sighted land, they met with one of the worst hurricanes ever experienced by any of the sailors. "The wind simply shrieked as it tore the tops off the waves." On May 10th they landed on the barren west coast of South Georgia. A most dangerous journey of thirty-six hours across this mountainous island, which was covered with glaciers, crevasses, and rocky arêtes, brought Shackleton and two of his companions to the whaling stations on the east side of South Georgia.

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The last chapter of this Antarctic epic deals with Shackleton's gallant efforts to relieve the twenty-two men on Elephant Island. After trying unsuccessfully to reach them in the steel whaler "Southern Sky" from South Georgia, he made two other equally unsuccessful efforts from the Falkland Islands and from Puntas Arenas. At last the "Yelcho" succeeded on August 30th, 1916, finding Wild's party with only four days' supply of food in hand.

The Ross Sea party under Captain Macintosh left Hobart on December 24th, 1914. Their main object was to lay a large depot at 83° S. for the benefit of Shackleton should he succeed in crossing the Antarctic continent. They reached MacMurdo Sound on January 16th. After some short journeys to the south, ten men united at Cape Evans on June 2nd to spend the winter there. Early in October they started to lay the main depots to the foot of the Beardmore Glacier (see Figure 6). On the twenty-sixth of January they reached the site of the final depot and here came across some of Scott's sledges. Early on the return Spencer-Smith's condition became alarming, while Macintosh was so weak he had to be dragged on the sledge. Later Hayward also became affected badly by scurvy. On March 9th Smith died and was buried on the Barrier, and two days later they reached the 1902 hut on MacMurdo Sound. They marched 1,561 miles between September 1st and March 18th, which is a wonderful performance under Antarctic conditions.

On May 8th Macintosh and Hayward tried to cross the young sea-ice to the main (1910) hut at Cape

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Evans. They were caught in a blizzard and drowned. The "Aurora" had been anchored in the Sound off Cape Evans, but on May 6th, 1915, the ship, helplessly fixed in ice, drifted to the north. On June 14th they were off Nordenskjold Ice Tongue. Still drifting in the pack, they experienced heavy pressure on July 21st which smashed the rudder like matchwood. On August 6th they sighted Cape Adare, and on September 22nd were between Oates Land (of which a sketch was made) and the Balleny Islands, and for two months the ship was still near these islands (see Figure 5). For a time Wilkes' elusive Cape Hudson seemed in sight, but later disappeared. A very shallow sounding of 194 fathoms was obtained on the Antarctic Circle on November 17th. All through December and January the ship was still beset, and finally broke out of the ice on February 12th, about latitude 65° S., and on March 14th cleared the last of the pack ice in latitude $62^{\circ} 27'$ S. She reached New Zealand on April 2nd, adding another spectacular voyage to the journals of the second Shackleton expedition.¹

In January, 1917, the "Aurora" under Captain Davis (with Shackleton on board) was again at Cape Evans and brought back the seven survivors from Ross Island.

COPE

On the twelfth of January, 1921, a party of four under J. L. Cope, of Shackleton's former expedition,

¹ See the account and map in the *Geographical Journal* (London), September, 1921.

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was landed by Norwegian whalers at Andvord Bay, a little north of Charcot's bases, in latitude $64^{\circ} 48'$ on the west coast of Graham Land (see Figure 7). Their object was to cross the mountains and continue the exploration of the Weddell coasts south of Nordenskjold's survey. Unfortunately they were unable to scale the glacierized slopes with their sledges and dogs. Hence Cope and G. H. Wilkins² returned to get further supplies, while Lester and Bagshawe spent the winter in a hut made out of a boat. They stayed there for a complete year, but were obviously unable to do much more than collect geological specimens in the vicinity and keep a simple weather log and tide record. On their return they made an interesting survey of Deception Island, the headquarters of the whalers in West Antarctica.³

SHACKLETON, 1921

Sir Ernest Shackleton's last expedition started late in 1921 in the "Quest," a small ship of only 125 tons. He planned to explore the coasts which lie south of Africa, of which only the small region discovered by Biscoe in 1831 had been charted. Trouble with the engines and gear was experienced all the way to South Georgia. Here Sir Ernest died very suddenly on the fourth of January, 1922, and his grave was dug on the icy slopes above the whaling station of Grytviken, where he finished his perilous traverse in May, 1916. Captain Frank Wild now became

² Later Sir Hubert Wilkins.

³ See *Geographical Journal*, September, 1923.

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leader. On January 17th they sailed eastward and entered the pack, between Coats Land and Enderby Land, in longitude $15^{\circ} 21'$ E. The "Quest" pushed south against heavy difficulties until February 12th when they reached $69^{\circ} 17'$ S. Here a sounding of 1,089 fathoms was obtained. They were unable to proceed farther in their small boat and returned across the Weddell Sea to South Georgia on April 6th.

WILKINS, 1928-29⁴

Just as the years 1841 and 1903 were wonderful years in Antarctic exploration, so December 20th, 1928, was the most wonderful day, for in ten hours Sir Hubert Wilkins settled more problems and sketched more new coast lines than any other expedition had accomplished in West Antarctica. He had been twice before in Antarctic waters, once with Cope in 1920 and again with Shackleton in 1922, and was well known for his remarkable flight across the North Polar region. In November, 1928, he reached Deception Island on the whaler "Hektor" with two Lockheed-Vega monoplanes. Lieutenant Eielson with three others constituted his party. They hoped to use the sea-ice of the drowned crater as a runway, but it was found to be abnormally thin. They therefore cleared a runway half a mile long on land over the volcanic ash (see Figures 4 and 7).

⁴ These accounts of the work accomplished by the Wilkins and the Byrd expeditions are based mainly upon the articles in the *Geographical Review* for April and July, 1929. See also Joerg's *Brief History*, 1930.

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At 8:20 A.M. on December 20th they were headed for the south and at 9:50 were crossing the flat plateau of Graham Land between Bransfield Strait and Drygalski Bay. Several great fiords were discovered entering this bay which were named the Hektoria Fiords. Soon below them were the giant crevasses of the Nordenskjold Shelf "broad bottomless yawning blue abysses . . . into which our machine could have fallen and left no trace." Exactly on the Antarctic Circle lies Crane Channel, a circuitous strait which apparently divides Graham Land into two parts and opens on the west into Matha Bay. (The writer suggests Wilkins Land as a more suitable name than South Graham Land for this southern island.) To the south of this channel the rocks appeared to contain seams of coal near latitude 67° S. A mighty mass of mountains was named after the Lockheed Company, and at latitude $69^{\circ} 30'$ S. they reached a broad channel some seventy-five miles across, which was nearly filled by the large Scripps Island in the north and the group of small Finley Isles in the south. "A smooth slope, wide and unbroken, reached southward. We called the strait Stefansson Strait and the land beyond it Hearst Land. The edge of Hearst Land, which we believe to be part of the great Antarctic continent, was distinguishable to the eye by a comparatively low ice cliff, which failed to show in the photograph. To the east . . . the edge was marked with a few small low nunataks . . . far beyond in the dim distance I could see huge tabular icebergs, and concluded that they must have been at one time afloat." Their furthest point was

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estimated to be about latitude $71^{\circ} 20'$ S. and longitude $64^{\circ} 15'$ W.

On the return they met with south winds at first, then winds from the east, and then they entered a calm belt. They landed safely at Deception Island after an epoch-making journey of 600 miles each way, the whole being accomplished in ten hours. A flight of 250 miles on January 10th, 1929, confirmed the data obtained in the northern portion of their earlier flight. In December, 1929, Wilkins flew south from his ship over Charcot Island, and was able to define 300 miles of coast. This is shown approximately on Figure 7.

BYRD, 1928-30

On December 25th, 1928, Commander Richard E. Byrd⁵ (like Wilkins, famed for his North Polar flights) reached the Ross Ice Shelf with a large expedition prepared to stay two years. He fixed his headquarters near the Bay of Whales but somewhat to the east of Framheim. Commander Byrd was supplied with several aëroplanes for which this site, the calmest so far known in the Antarctic, is particularly well suited. On the twenty-eighth of January, 1929, the first long flight was carried out to the northeast along the Barrier edge (see Figure 6). Scott's Nunataks and the Alexandra Mountains were sighted, and also King Edward Land, which may perhaps be an island. About fifty miles west by south from Scott's Nunataks a new range was discovered and named Rocke-

⁵ Now Rear-Admiral Byrd.

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feller Range. Fourteen peaks of about two thousand feet elevation were distinguished. On February 19th a second flight was made to the east, and the Rockefeller Range was reached. From here more mountains, perhaps ten thousand feet high, could be seen to the east beyond the British area (which extends to 150° W. longitude) in a region which Byrd claimed for the United States and called Marie Byrd Land. To the south the land sighted by Amundsen in $81^{\circ} 30'$ was seen in the distance.

The exploits of these last two expeditions show clearly how valuable is the aëroplane in polar reconnaissance. But there are limits to its uses, for a rapid aëroplane survey, without landing, will do little to extend the detailed knowledge of the polar environment of a kind which I have tried to summarize in the present book. Moreover, as I stated in an article published in August, 1928, in the *London Times*, it is difficult to see how the aëroplane can be anchored to withstand the blizzards, whose chief feature is their sudden development and extreme force. Byrd's expedition is facing these difficulties. Already one of his planes has been destroyed in a blizzard, luckily without loss of life. Early in March, 1929, Gould, the geologist, with a pilot and radio man, flew to the Rockefeller Range to commence a local survey. They had barely arrived when a blizzard developed, reaching an estimated velocity of 120 miles per hour. This tore away all the anchors of the plane, and it was dashed to matchwood. After ten days' bad weather Byrd managed to

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fly out and search for them. He accomplished their rescue and two days later all were safe at their camp in Little America. However, in spite of this loss of one of their planes, the American expedition in 1928 observed from the air some forty thousand square miles of new territory.

THE FLIGHT TO THE SOUTH POLE

During November, 1929, Byrd completed his plans for flying to the Pole. A geological party under Gould had already set out with sledges to the Queen Maud Range, which Amundsen had discovered 450 miles south of Byrd's base at Little America in $78^{\circ} 30' S$. Before describing the flight we may well consider some of the difficulties which faced Byrd in the air. The Ross Ice Shelf along this route varies in height from nine hundred feet near Byrd's headquarters on its northern edge, to sixty-three feet just before the mountain scarp is reached. In places crevassed areas are encountered, especially near latitude $81^{\circ} S$. It is, however, in surmounting the great mountain range that aviators will always experience great difficulties and dangers. Not many scarps are so pronounced as that forming the eastern face of the great Antarctic Horst. A number of the peaks reach fifteen thousand feet and hang like the Himalayas over the plains beneath. The great glaciers which enabled Amundsen to reach the plateau rise much higher than the Beardmore used by Scott, for the ice divide at the top of Liv Glacier and Axel Heiberg Glacier seems to be well over ten thousand feet. Thereafter there is a descent

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to the surface of the "Devil's Dancing Floor" at 7,600 feet. Again the icy plateau rises to 10,300 feet in latitude 88° S. to fall once more to nine thousand at the Pole.

Another great difficulty in Antarctic flying, especially in dull weather, is to gain an adequate idea of distance. For instance, I have at times been at a loss in Antarctica as to whether a snow hollow before me was three feet or thirty feet deep. This renders it very difficult to make a safe landing with an *aéroplane* on the icy surfaces of the southern continent. The greatest difficulty is naturally due to the sudden changes in wind velocity, and my own experiences may be worth recording. Thus, on the last day of May in 1911 there had been a perfect calm for several hours. Within ten minutes the wind rose to a howling gale of forty or fifty miles an hour. Nearly as rapid a rise occurred a few months later on the first of September. Lastly, there are special difficulties in navigation in flights near the South Pole. It is, of course, only possible by astronomical measurements to tell when the South Pole is attained. It is merely an unmarked spot on an illimitable ice plateau. Moreover, at the South Pole, *all* routes lead north, and a slight error in returning will land the aviator in the wrong section of Antarctica. Furthermore, at the South Pole "time" has a special meaning since here all lines of longitude meet. Thus, if the aviator flies around the Pole, he theoretically passes through twenty-four hours of time, though it may take him only as many minutes.

Food for three months and sledging equipment to

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give the party a chance of return were placed on board. On November 18th Byrd had made a depot of fuel and food at the foot of the Queen Maud Range in 85° of latitude. Finally, on November 28th the local meteorologists at Little America and also wireless information from Gould, then approaching the mountains, indicated fair weather. At 3:29 P.M. Byrd set out on his most hazardous flight. The great Ford plane passed over Gould's sledges at 8:15, dropping mail to them. His plane was so heavily laden that it was not expedient to climb above twelve thousand feet, and obviously he had not much margin in crossing the ice divide at eleven thousand feet. On reaching the great scarp Byrd decided to attempt the valley occupied by the Liv Glacier, which lies just to the west of the Axel Heiberg Glacier used by Amundsen. As they climbed between the giant walls of the cañon it was found necessary to lighten the plane. Byrd, accordingly, risked his safe return and threw overboard nearly half the store of food. He was flying only about three hundred feet above the crevassed glacier. By midnight they had safely reached the plateau and were approaching the South Pole last attained by Scott's ill-fated party of five in January, 1912. Around 1:30 A.M. Byrd cruised about the Pole in order to be sure of covering the exact region. In returning Byrd had two checks on his direction. He could use the sun compass, which was based on the known position of the sun at the time of observation. He could also use the magnetic compass, which was fairly reliable at that distance from the South Magnetic Pole. The south-

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seeking end of the needle pointed, of course, to the latter and so picked out one "north direction" out of the infinite number radiating from the South Pole.

On the return they could fly higher and reached thirteen thousand feet. As they approached the "up-thrust block" of the Queen Maud Range, they saw towering mountains to the east which seemed to reach twenty thousand feet. However, Captain McKinley's mosaic of aerial photographs should help to decide this matter. Byrd descended by the Axel Heiberg Glacier, meeting with dangerous air eddies and currents. At 4:33 A.M. he landed at the depot on the Ross Ice Shelf at sea level, and here spent an hour refueling the plane. On rising he made a detour to the east, covering new ground and helping to fix the eastern limit of the great Ross Ice Shelf. The Charles Bob Mountains in latitude $83^{\circ} 30'$ were more closely surveyed and then Byrd headed for Little America, where he landed safely at 10:10 A.M. on the twenty-ninth of November. His wonderful journey of 1,600 miles had only occupied nineteen hours and had made him the flying conqueror of both the North and South Poles.

Dr. Gould, the geologist with Byrd, made some remarkable discoveries on his sledging journey in December, 1929. Mount Fridjof Nansen stands between the lower slopes of the Heiberg and Liv glaciers. Gould climbed up 6,000 feet, and found the cap-rocks to consist of Beacon Sandstone with carbonaceous layers. Sledging eastward he demonstrated that there is no Carmen Land as Amundsen supposed (see Figure 10). Hence there may be a strip of low land or even in parts

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sea-ice connecting Ross Sea with the Weddell Sea. (The writer suggested this on his map in the *Geographical Journal*, November, 1914, p. 366.)

MAWSON, 1929-1930

Sir Douglas Mawson is in command of an expedition whose main purpose is to explore the shallow seas and coasts south of the Indian Ocean. Captain John King Davis is in charge of the ship, which is Scott's old vessel the "Discovery." They left Cape Town on October 19th, 1929, and called at the Crozet group and then at Kerguelen and Heard islands. On December 20th the ship crossed the Antarctic Circle in 73° E. On the last day of the year she was on the Circle in 65° E. longitude, and here the scout aëroplane was put in use. Land could be seen about fifty miles to the south, flanked by a narrow belt of open water. The explorations are still in progress. A full equipment for sounding and dredging is carried, including an echo sounding machine.⁶

⁶ Based on W. L. Joerg's *Brief History of Polar Exploration* (New York, 1930). (This deals with Polar flights only.)

CHAPTER V

THE CONTINENT, ITS GEOLOGY AND RELATION TO OTHER LANDS

BUILD OF ANTARCTICA

IN the writer's opinion no theory concerning the general arrangement of the continents is so suggestive as that propounded by Lowthian Green¹ in 1875 and strongly supported by J. W. Gregory² in 1899. I refer to the Tetrahedral Theory, which seeks to show that the earth is a flattened sphere (geoid) slightly modified toward the shape of a tetrahedron or pyramid. The antipodal arrangement of land and sea, shown by more than 90 per cent of the land surface, was explained by this theory long before we knew anything at all about the condition of the surface at the poles. It was Scott's expedition as late as 1902 which revealed the fact that the Antarctic area consisted essentially of a gigantic plateau, and it was only by Nansen's drift in the "Fram" (1893-96) and Peary's soundings near the Pole (1902-1909) that the equally interesting phenomenon of a deep Arctic ocean could be demonstrated (see Figure 9). Thus the essential feature of the "World Plan" is clearly this fact of antipodal ar-

¹ Lowthian Green, *Vestiges of the Molten Globe* (London, 1875).

² J. W. Gregory, "Plan of the Earth," *Geographical Journal*, 1899.

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rangement, whereby the lands and seas are opposed, as indicated in the following table:

Antarctica	opposite	Arctic Ocean
Eur-Africa	“	Pacific Ocean
America	“	Indian Ocean
Australia-E. Asia	“	Atlantic Ocean

The narrow southern portion of South America is the only notable exception to the general rule. Hobbs³ has pointed out that if we add the drowned continental margins, then the land areas are increased by ten million square miles, and in some respects the antipodal arrangement is emphasized. Around Antarctica the continental shelf presents some special features, showing evidence of greater drowning than usual, as we shall see in a later chapter. On the other hand, the Arctic Ocean is surrounded by a remarkably broad and shallow series of shelf seas. It may be mentioned that when a hollow glass sphere is blown by the glass-maker it has a strong tendency to collapse to a perceptible tetrahedral shape as it contracts on cooling. Something of this sort may have given rise to the plan of the earth. It is clear that the mobile waters of the oceans would accumulate on the “faces” of the tetrahedron, since here the gravity pull is greatest. So also the projecting edges of the tetrahedron would constitute the main land masses. This is possibly the basis of the ring of lands round the Arctic Ocean, and of the three south-pointing land masses of Eur-Africa, Amer-

³ W. H. Hobbs, *Earth Evolution* (New York, 1921).

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ica and Austral-Asia. It also accounts for the ring of oceanic waters surrounding the Antarctic Plateau.

Let us now consider where Antarctica fits in among the continents as regards *structure* (see Figure 9).

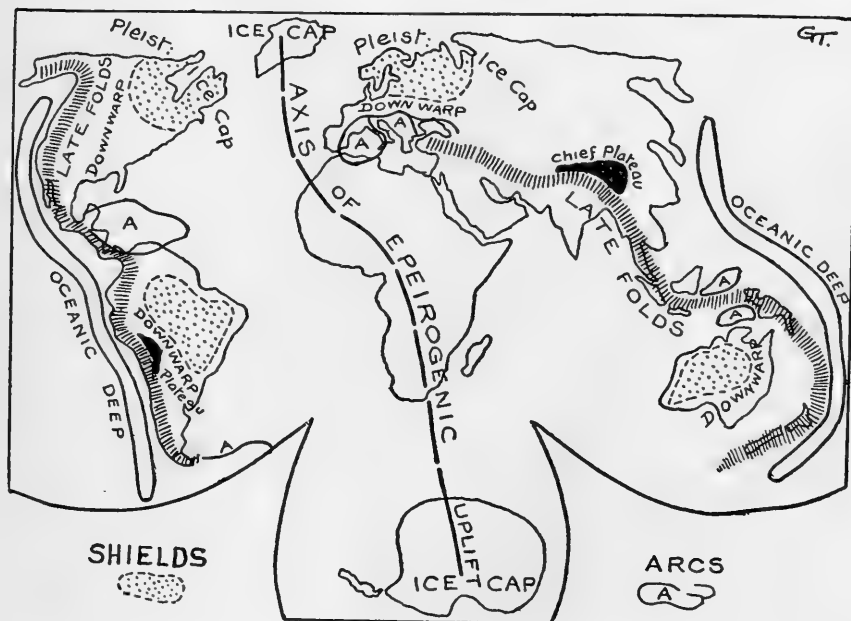


FIG. 9.—SYMMETRY OF THE WORLD ABOUT AN AXIS OF EPEIROGENIC (EN MASSE) UPLIFT, FROM ANTARCTICA THROUGH AFRICA TO GREENLAND. (ON MOLLWEIDE EQUAL AREA PROJECTION WITH ANTARCTICA ADDED.)

Note the order of the structures: (1) axis; (2) shield; (3) down-warp; (4) folds; (5) oceanic deeps.

W. M. Davis⁴ has long ago pointed out that North America and Eur-Asia have many features in common, but arranged more or less symmetrically on each side of the Atlantic Ocean. Thus the Laurentian Shield

⁴ W. M. Davis, *International Geography*, London, 1903.

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TABLE OF THE WORLD ENANTIOMORPHS *

LATE UPLIFTS	DOWN- WARP PLAIN	SHIELD	CENTRAL RESISTANT CONTINENT	SHIELD	DOWN- WARP PLAIN	LATE UPLIFTS
<i>Northern Hemisphere</i> Rockies	Prairies	Laurentian	African Plateau	Scandi- navian	Russian- Siberian	Alps and Himalayas
<i>Southern Hemisphere</i> Andes	Orinoco La Plata	Brazilian	Antarctic Plateau	West Australian	Artesian and Murray Syncline	Highlands (and New Zealand?)

* Such a pair of enantiomorphs consists of an object and its reflection in a mirror, or the right and left hands.

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parallels the Scandinavian Shield. The Great Lakes are like the Baltic Sea and Lakes. The Appalachian Mountains resemble the Hercynian chain in Europe. The great mountain arcs of the West Indies are akin in time and shape to those surrounding the Mediterranean Sea, etc., etc. These two continents are therefore closely allied. Perhaps we may compare the southeast of Asia, with its huge plateau, block faults, mountain arcs and festoon islands, with the western portion of North America.

Far different from these is the solid resistant block of Africa, with barely a sign of late folding throughout its vast extent. It lies perhaps at the other extreme of continental "build." Australia and South America form another pair, somewhat symmetrical about the Pacific Ocean. Thus the great Brazilian Shield may be equated with the Western Shield in Australia. The long geosyncline (down-warp) from Adelaide north to the Gulf of Carpentaria resembles the lowland belt from Buenos Ayres to the Orinoco; the humble Eastern Highlands of Australia with their drowned neighbors to the east are due to crustal ripples probably moving outward from the Pacific, just as are the giant ranges of the Andean Cordillera. We can perhaps show this secondary *symmetrical* aspect of the world plan in tabular form. (See Figure 10.)

I have ventured to insert Antarctica in the above table as a continent more akin to Africa than any of the other continents, and like it, to some extent, lying between, though to the south of, associated pairs of enantiomorphs. Just as we find Africa characterized

ANTARCTIC ADVENTURE AND RESEARCH

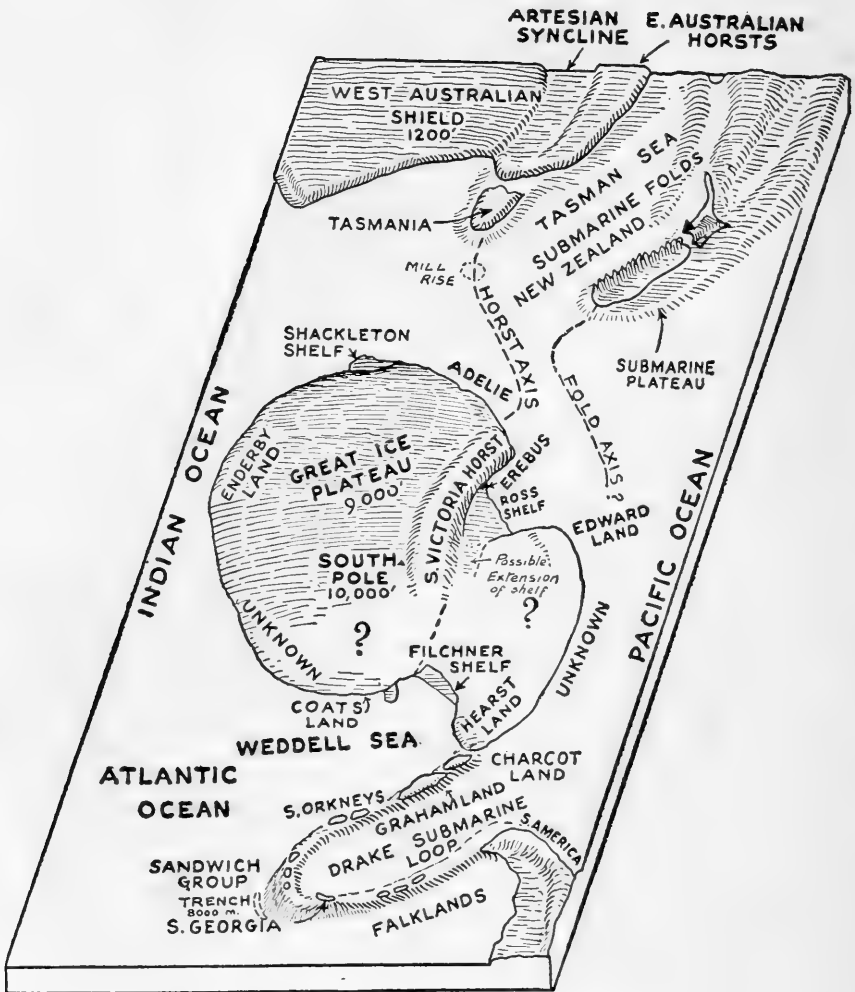


FIG. 10.—GENERALIZED DIAGRAM ILLUSTRATING THE SALIENT FEATURES IN THE “BUILD” OF ANTARCTICA AND ADJACENT CONTINENTS.

Gould's discovery (Dec., 1929) of the extension of the Ross Ice Shelf is indicated.

by high plateaus and by great fault scarps, with only a fringe of earth ripples in one corner (Morocco, etc.), so also Antarctica is preëminently a great plateau

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bounded in places by great fault scarps, and only in one segment, Graham Land, exhibiting anything like the characteristic foldings of the late Tertiary crustal buckles. Moreover, Wilkins' recent exploration seems to show that this Antarc-Andean folding of Graham Land dies away at latitude 70° against the low plateau of Hearst Land. On the other hand, there may be a line of folded ranges extending from South America to New Zealand which have been crumpled from the Pacific against the solid resistant shield of East Antarctica. It is precisely in this region between the Weddell Sea and Edward VII Land that we know so little. We have some assurance for believing that the African and Australian quadrants of Antarctica form one solid Plateau Shield (see Figure 10). The American quadrant includes a great drowned mountain range akin in origin to the Andes. But what is the build of the hypothetical Pacific quadrant, most of which is entirely unknown from Charcot Land to Edward VII Land? It is an interesting speculation, but worth suggesting, as I did in 1914, that the West Australian Shield, the Australian Horst,⁵ the Tasman Sea and New Zealand are to be equated with similar structures in the South. These are the Great Ice Plateau (shield?) of East Antarctica, the South Victoria Horst, the Ross-Weddell depression and the Graham Land-Edward Land Folds.

Geology.—In two regions only has there been adequate mapping and collecting of the geological data. These two areas are those to the west and southwest

⁵ HORST: An elevated crustal block bounded by scarps.

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of the Ross Sea, and the islands in the vicinity of Graham Land. It is a curious and gratifying fact that the two localities are largely complementary. Thus the Ross area is rich in Paleozoic rocks and fossils, but offers little to help in the deciphering of Mesozoic and Tertiary deposits, while Graham Land has a fine sequence of rocks of precisely these ages.

Summary.—The accompanying geological sections (see Figure 11) show in a somewhat generalized fashion the main features of Antarctic geology. They are both due to Sir Edgeworth David. Commencing with the section across MacMurdo Sound (in East Antarctica) we see that the basal portion of the continent here consists of granites, gneisses, and other metamorphic rocks such as various schists. Probably this series of rocks is more or less universal throughout Antarctica. The oldest sedimentary rocks of which we have much data are limestones of the Cambrian Age, in which the writer was able to identify the coral-oid organisms *Archeocyathina* in 1910. These fossils have since been found near the Beardmore Glacier in 1911 and in rocks dredged from the Weddell Sea.⁶ Above the Cambrian limestones is a tremendous series of nearly level-bedded sandstones and shales which extend probably throughout later Paleozoic time and quite probably into early Mesozoic time without much deformation or great breaks in the sequence. This is the remarkable Beacon Sandstone formation which probably extends from Mount Nansen (85° S.) and

⁶ W. T. Gordon, *Archeocyathina* from the Weddell Sea (Roy. Soc., Edin., 1920, pp. 681-714).

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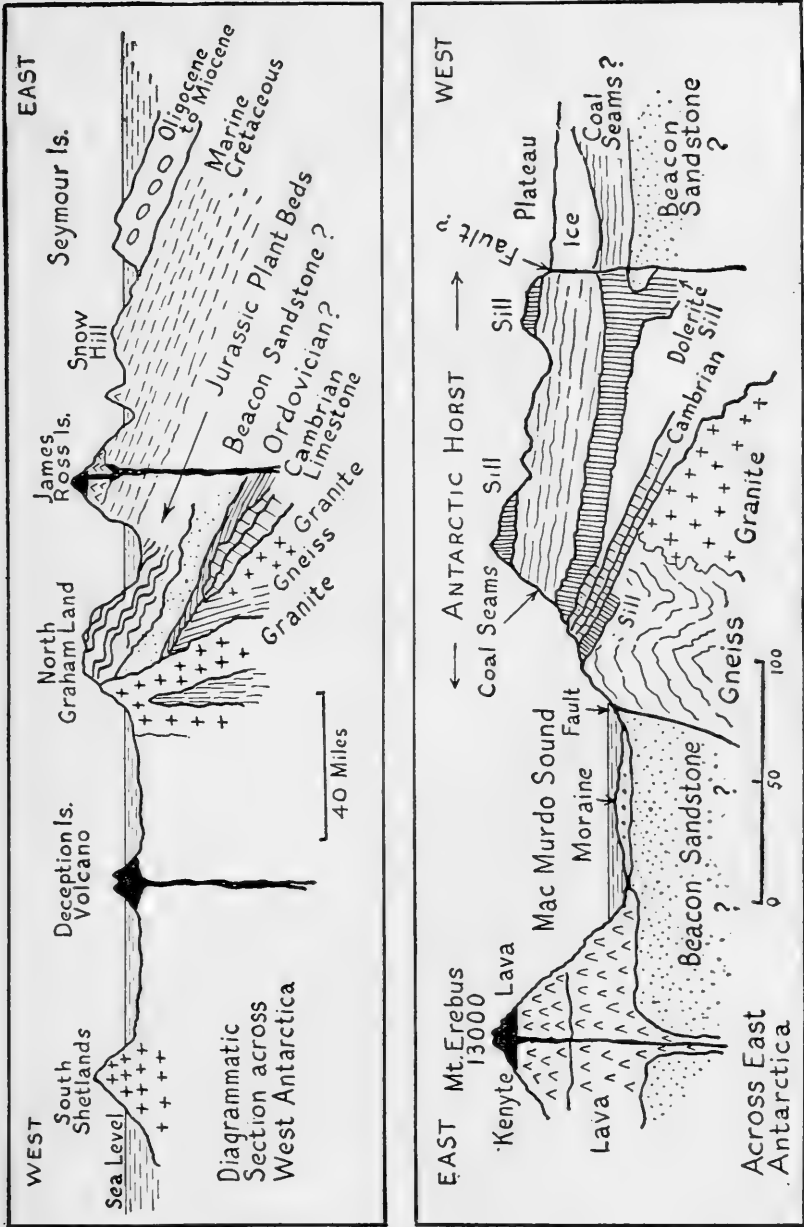


FIG. I I.—GEOLOGICAL SECTIONS ACROSS ANTARCTICA.

(Both after T. W. E. David.)

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the Beardmore Glacier right across to the Weddell Sea. It contains Devonian fish, Permian ferns and probably Triassic tree remains. No further deposits of importance occur in the MacMurdo region, though there are many eruptive rocks which will be described later.

On the American side of Antarctica in the vicinity of Snow Hill, there are basal rocks of granite and gneiss which are capped by Jurassic shales and sandstones containing many fossil plants. Above these are marine Cretaceous beds, and lower Miocene sediments with fossil penguins and fossil leaves of trees allied to the beech and giant conifers (*Sequoia*) of California. In this same richly endowed district are late Pliocene conglomerates containing *Pectens* and other fossil shells.

DETAILED GEOLOGY IN EAST ANTARCTICA

Metamorphic Rocks.—H. T. Ferrar showed in 1901-4 that the coast line of South Victoria Land from Granite Harbor to the Koettlitz Glacier consisted of a foundation series of metamorphic rocks. Towards the plateau the great glacial valleys rise so rapidly that the basal rocks are soon hidden beneath the later sedimentary and igneous rocks. No good junctions of metamorphic and later sedimentary rocks have been observed. To the south of New Harbor the metamorphics form the tops of hills at five thousand feet, but to the northward their summits appear to be about one thousand feet above sea level. They are older than the granites, for fragments are often included in the latter. (See Figure 8.)

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Crystalline limestones, coarse and of a white color, are the most noteworthy of these metamorphics. They occur at Heald Island, where they are eight hundred feet thick, and at Salmon Hill, north of Davis Glacier, they are about five thousand feet thick and dip steeply to the northeast. Another good example occurs near the Suess Glacier in Taylor Valley. Here I "washed" in a miner's dish the débris at the junction of this limestone with augen-gneiss, in the vain hope that some gold might be present. These limestones are rich in chondrodite⁷ and spinel. In Granite Harbor Debenham also found similar limestones.

Pyroxene granulites were found included in granite, at Granite Harbor and elsewhere, as erratics all along the west coast of the Ross Sea. Hornblende schists seem to be associated with them. Tilley has described a rock from Eyre's Peninsula in South Australia of similar character which is due to the metamorphism of impure dolomites. A similar origin is likely in Antarctica.

Crystalline Schists.—These occur with a thickness of two thousand feet in Heald Island where muscovite-schists rich in graphite are common. Many other outcrops occur in the Kukri Hills and nearby, where a garnet-sillimanite-schist is common. In places lenticles of biotite amphibolite probably represent metamorphosed basic dykes. (See Figure 8.)

Gneisses.—These rocks grade into gray granites in very many localities in South Victoria Land. They

⁷ *Chondrodite* is a fluo-silicate of magnesium, somewhat resembling olivine.

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may represent intrusions into the limestone series, and may have given rise to the chondrodites mentioned earlier.

David and Priestley believe these rocks to be pre-Cambrian in age, since the Cambrian limestone of the Beardmore Glacier with *Archeocyathus* is quite unmetamorphosed and therefore presumably younger than the crystalline limestones. Further, the granulites are like those of Brittany, which are considered to be pre-Cambrian, and are so like the series from South Australia that they may be considered to be of the same pre-Cambrian age. Near Terra Nova Bay (latitude 75° S.) Priestley found rocks of much the same type, mostly in moraines but sometimes *in situ*. It is clear that the glaciers cut through a basement series of metamorphic rocks, chiefly biotite-gneiss, granulites, or graphitic mica-schists.

Slate Graywackes.—In the region of Robertson Bay, near Cape Adare, in latitude 69° S. Priestley has described a series of sediments which differ very considerably from those found so far in other parts of the Ross Sea area, or even in Mawson's area to the northwest. The oldest rocks near Cape Adare appear to be a series of sediments ranging from fine-grained slates to a coarse graywacke.⁸ They are of a greenish-gray color. The main cleavage lines run north and south, and the bedding is indistinct. The series is thrown into anticlines and synclines, the axes of which are approximately meridional, and has been observed

⁸ Graywacke is a cemented aggregate of small fragments of quartz, slate, etc.

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in situ for some thirty miles along the west of Robertson Bay. These rocks present characteristics usually associated with Paleozoic or Algonkian sediments, and resemble the Ingleton series of Yorkshire to some extent. The grains of the rocks appear to be angular, indicating frost-shattering, but they are evenly graded, which to some extent suggests wind rather than ice. Priestley suggests that they are shore deposits laid down in a dry cold climate, under conditions like those at present prevailing in parts of the polar regions.

Cambrian Limestones.—On Shackleton's journey on the Beardmore Glacier, in 1908 and 1909, some fragments of a limestone breccia were obtained about eight miles south of Mount Hope (latitude 84° S.). This was examined in Australia in 1910, and then handed over to me, since it seemed to contain fossils belonging to the *Archeocyathinæ* family. It is a curious coincidence that I should have spent 1908 and 1909 at Cambridge University studying these fossils (from a huge fossil coral reef in South Australia) just before my two years' experience of Antarctic conditions. The sketch appended (see Figure 12) shows that these organisms resembled corals in structure, while they were somewhat spongelike in general form. Three or four genera (and several species of one genus) were identifiable. In 1911 Wright (on the last Scott expedition) collected a finer specimen of *Archeocyathus* from somewhat the same locality. No fossils have been found *in situ* of this age, but David is of the opinion that the original limestones may occur in basal beds of the huge Beacon Sandstone Formation. Some

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such occurrence was described by Shackleton's party from Buckley Island (latitude 85° S.) at the head of the Beardmore Glacier. Debenham, however, thinks Mount Bell (84° S.) is a more likely locality.⁹ Below the summit of Mount Nansen (latitude 75°) there ap-



FIG. 12.—GOMPHOCEPHALUS, THE LARGEST ANIMAL OF ANTARCTICA (1 MILLIMETER LONG). BELOW: ARCHEOCYATHUS, THE OLDEST FOSSIL IN ANTARCTICA, WHERE DWARF FORMS, A FEW MILLIMETERS WIDE, OCCUR.

peared to be limestones older than the Beacon Sandstone, which David suggests may also be of the Cambrian Age. They are present in Coats Lands, as we shall see later.

Beacon Sandstone.—The structure of the whole “horst” block, which bounds the Ross Sea and the

⁹ *Sedimentary Rocks of South Victoria Land* (British Museum, 1921).

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Ross Ice Shelf on the west, consists of a series of tabular mountains.

Their horizontal structure is due to the level-bedded character of the main sedimentary formation of sandstone, which has been stiffened by massive intrusions of a later dolerite in the form of very extensive sills. Since the base of this formation has been proved to be of Devonian age at least, we have to regard the whole area as one of great stability and freedom from lateral earth movements. The sandstone formation has an enormous extension, for it is found in Adelie Land in latitude 68° S. and judging from Amundsen's photographs probably also in latitude 86° S.—DEBENHAM, 1921.

The sandstone is very uniform in composition, though the lower beds in this huge formation are less pure as thin beds of limestone and shale are to be observed. Apparently the sandstone rests on a level surface of granite, but generally the junction is masked by intruding sills of dolerite. However, the latter seem in places to have lifted the level sandstones bodily off the granite. In the scarp below Mount Lister (thirteen thousand feet) the sandstone with its included sills of dolerite is at least five thousand feet thick.

Ripple marks and sun cracks seem to indicate shallow lakes or pools during sedimentation. The cement is either calcareous or siliceous or even bituminous in places. Charring of included woody stems is to be noticed, but this may be due to the intrusion by the dolerite, perhaps in Cretaceous times.

Coal has been found in the Beardmore outcrops and

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also by my party near Mount Sues (latitude 77° S.). Dr. Gould has reported carbonaceous shales near the foot of Liv Glacier. The Mount Sues seams appear to occur with dark shales near the base of the sandstones. It is a hard bright coal with a large amount of ash. Probably it has been baked by the dolerite sills. The Beardmore coal, however, contains 14.5 per cent of volatile constituents and has not been baked to the same extent. Here Frank Wild recorded three hundred feet of coal measures containing seven seams of coal, from one foot up to seven feet in thickness. Fossil wood was obtained in the vicinity in 1908, which appears to belong to a gymnospermous plant, but much finer specimens of fossils were brought back by Dr. Wilson in 1912, and found near his body.

The fish remains collected by Frank Debenham and the writer on the moraine below Mount Sues in December, 1911, consist of dermal plates and scales. They are all isolated and scattered, showing that the fishes were disintegrated before burial, but the fragments are beautifully preserved, and in transparent sections their histological structure is perfectly observable. The plates appear as whitish or bluish-gray patches on the gray rock, and were so polished in some cases that the writer was reminded of the elytræ of beetles. Woodward states that *Ostracoderms*, *Elasmobranchs*, *Teleostomi* and *Dipnoi* are all represented. One specimen, *Bothriolepis*, is a common Upper Devonian fossil both in Europe and North America. (See inset in Figure 6.)

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Of greater importance still were the fossil specimens obtained by Scott and Wilson at the head of the Beardmore Glacier under Mount Buckley. Here Scott wrote on February 8th, 1912, "The moraine was obviously so interesting that when we got out of the wind I decided to camp and spend the rest of the day geologizing. We found ourselves under perpendicular walls of Beacon Sandstone, weathering rapidly and carrying coal seams. From the last Wilson with his sharp eyes has picked several pieces of coal with beautifully traced leaves in layers." These were specimens of *Glossopteris indica* (see Figure 2) which, as Seward remarks, is one of the few genera which can be identified with confidence from fragmentary specimens. Their occurrence only three hundred miles from the Pole throws a light on the remarkable changes of climate which have occurred in the past history of the globe. Seward reconstructs the environment as follows: "The granites and gneisses from which the material of the Beacon Sandstone was derived, were in all probability exposed to the disintegrating action of wind-blown sand in a climate sufficiently mild to permit of the existence of *Glossopteris* and other plants. Fragments of leaves and twigs with larger logs of wood were carried by rivers or marine currents and buried in the barren sand that was being piled up on the floor of an Antarctic Sea, to be subsequently uplifted as vast sheets of sedimentary strata, which at a later stage were penetrated by the products of a widespread volcanic activity." These latter were the enormous dolerite sills already referred to.

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This genus *Glossopteris* ranges from Upper Carboniferous to Rhaetic (Upper Triassic) period. Probably at Mount Buckley the beds are of Permo-Carboniferous age just as they occur in the coal measures of Australia. At the end of Carboniferous times, environments changed all over the world so that the old *Lepidodendron* flora (of Lower Carboniferous days) branched into two different types; one without much change in the Northern Provinces (Canada, Europe, China); and the other developed into the southern *Glossopteris* flora of India and the three southern continents. In most of these latter localities glacial deposits are commonly associated with the *Glossopteris* ferns. Marked rings of growth occur in the trees of Permo-Carboniferous times, indicating strong changes in the seasons during the year. These are absent in the *Lepidodendron* floras. Thus we are led to believe that in the southern hemisphere and in India the configuration of the land favored the growth of glaciers and icebergs while in the northern province there were extensive swamps and ice-free hills. Seward does not, however, think that the paleobotanical evidence is favorable to a view involving an alteration in the position of the earth's axis. But he inclines to a belief in an Antarctic land on which were evolved the elements of a new flora which spread in diverging lines over a Paleozoic Continent (generally known as Gondwanaland).

Sir Edgeworth David has endeavored to estimate the extent and possible value of the coal reserves in Antarctica. The Beacon Sandstone is proved to cover

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twelve thousand square miles of available territory, but it is unlikely that coal measures are developed throughout. Our parties found no coal in the Ferrar-Taylor valleys. Possibly a great deal of coal exists under the Polar Ice Cap at a lower level than in the South Victoria Horst, where alone it has been observed so far. Probably it lies two or three thousand feet below the surface of the ice. If this hypothetical coal field were 700 miles long by 143 wide, and if the seams were only 12 feet thick, there are coal reserves here second only to those of the United States. (See Figure 11.)

Granites.—We may devote some space to a consideration of the eruptive rocks in Victoria Land. There are several types of granite, each associated with various dyke rocks. Gray granite occurs near Mount Larsen (latitude 75° S.) and near the Beardmore Glacier. Mawson thinks this is somewhat older than the pink granites, while both are perhaps younger than the diorites and gabbros which occur at intervals along the same coast. Somewhat similar granites and schists characterize Edward VII Land. The gray granites are low in lime and magnesia and high in potash and soda. This chemical composition of the older granites and porphyries is widely different from that of the Pacific type, and is essentially an Atlantic type of rock. So also the dolerites and Kenytes belong to the same general facies, though the diorites and quartz-dolerites (in David's opinion) have some resemblance to Pacific types of rock. David quotes the following differences as distinctive:

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Atlantic type—microperthitic intergrowths in felspar, feldspathoid minerals, quartz only in acid rocks, soda-bearing amphiboles, etc., mica and garnets common.

Pacific type—zoned felspars, no feldspathoids, quartz in intermediate rocks also, diopside and common hornblende abundant, mica not common except in the more acid rocks.

Quartz dolerites, as already stated, occur in the form of huge sills, which have penetrated both the granites and the Beacon Sandstone series throughout South Victoria Land. The rock in its amount of potash closely approaches to essexite. The commonest pyroxene is hypersthene but enstatite is also present. Interstitial patches of granophyre are common, and the whole facies of the rock resembles that forming the sills of Tasmania. The Tasmanian occurrences have intruded Trias-Jura rocks and are themselves intruded by tertiary basalts. The Antarctic quartz-dolerites may therefore also be classed provisionally as Cretaceous in age. Somewhat similar rocks in South Africa are perhaps a little older. The famous Palisades near New York are stated by Dr. Prior to be of a very similar character. (See Figure 11.)

Kenytes and Basalts.—These volcanic rocks belong to a series of Tertiary eruptions, and are found very abundantly along the west coast of the Ross Sea, especially on Ross Island, which is almost exclusively volcanic in composition. There is a series of trachytes on this island consisting often of sanidine and aegyrine.

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The basalts occur as dykes or flows chiefly on the flanks of Mount Erebus and Mount Bird. The same series is found also on the mainland, notably near Cape Adare. Interesting magnetite basalts are met with at Cape Barne and Tent Island in the west of Ross Island. Jensen is of the opinion that the heavier lavas, such as the basalts, flowed from fissures in the sides of the main crater, tapping lower portions of the magma. The upper portions gave rise to the lighter Kenytes, which are the most typical eruptive rocks of East Antarctica. (See Figure 8.)

Mount Erebus and Its Kenytes.—No description of the geology of the Ross Sea area would be complete without some reference to the dominating volcano of Erebus. This towers over thirteen thousand feet above the Ross Sea and together with its extinct neighbor, Mount Terror, practically forms Ross Island. The main bulk of the cone is built of the remarkable lava called Kenyte, which is closely allied to the rhomb porphyries of Norway, and also to Gregory's series from Mount Kenya in East Africa. The chief characteristic of the Kenytes is the presence of large crystals of anorthoclase felspar, usually about one inch long. On almost all the outcrops these felspars weather out of the fine-grained ground mass under the action of frost so that the surface of the Kenyte resembles a medieval church door studded with huge nailheads. The chief constituents as given by Prior are silica 56 per cent, alumina 21 per cent, soda 7 per cent, and potash 4 per cent. Data as to the period of the initiation of these eruptions are wanting. They are con-

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nected with the great tectonic movements of middle and late Tertiary times in this portion of the globe, but no fossils have been discovered of Tertiary age in the Ross Sea area which might furnish an answer to this question. (See Figure 11.)

Detailed Geology in West Antarctica.—We owe to Sir Edgeworth David a comprehensive discussion of the geological data from this sector of Antarctica, and the writer has made much use of it in the following brief account. There is clear evidence of a close connection between the rocks of Graham Land and those of South America. The basement rocks contain intrusive gabbros and granodiorites which exhibit the most characteristic Andean affinities. Hence they belong to the Pacific types of eruptive rock. In South Georgia, which appears to arise from the submarine ridge already described, the rocks are formed chiefly of old schists in which no determinable fossils have been found. In the South Orkneys on the same ridge, Dr. Bruce's expedition discovered Ordovician graptolites and phyllocarids. Just to the southeast of these islands a specimen of Cambrian limestone containing Archeocyathinae has been dredged, which shows that Cambrian rocks must occur in the vicinity (see Figure 7).

Overlying these old rocks in Graham Land are strata of Mesozoic age which are folded mostly from west to east. At Hope Bay ($63^{\circ} 15' S.$) beds containing a rich Jurassic flora rest on coarse conglomerates which in turn repose on current-bedded sandstone with obscure plant remains. Among the plants are *Clado-*

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phebis, *Pterophyllum*, *Sagenopteris*, *Thinnfeldia*, etc., all of which also lived in Australia in Jurassic or Triassic times. This would seem to indicate a land connection between the two continents in Mesozoic times. The plants were found in a hard slaty rock, and show a lacustrine rather than a marine environment (see Figure 11).

At Snow Hill Island, one hundred miles to the south, Dr. Nordenskjold collected abundant Cretaceous fossils. These imply the existence of a mild climate with comparatively warm ocean currents at this period. Corals are abundant, such as *Cycloseris*, *Parasmilia* and *Oculina*. Cephalopods like *Phylloceras*, *Lytoceras* and *Desmoceras* have been described by Kilian from this locality. From Seymour Island close to Snow Hill comes a suite of Tertiary fossils of which the leaves of *Araucaria* and *Fagus* are specially interesting. These show that the relatively warm conditions persisted into Oligocene or Miocene times. In marine strata of about the same age numerous bird bones were discovered, which have been referred to five new genera of penguins. They seem to be akin to the penguin bones of Eocene Age from Oamaru (N. Z.). Finally at Cockburn Island, near Snow Hill, Anderson found a conglomerate 160 meters above sea level containing numerous *Pecten* shells. This is probably of the Pliocene Age.

Adelie Land and adjacent areas. The region explored by Mawson's parties seems to exhibit much the same geological formations as were found near MacMurdo Sound. At Horn Bluff (150° E.) cliffs

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	WEST ANTARCTICA	ADELIE LAND, etc.	ROSS SEA AREA
Recent	Moraines, etc.		Moraines, Kenyite lavas
Upper Tertiary	Pecten beds		Trachytes, phonolites, etc.
Eocene	Penguin beds		
Cretaceous	Ammonites at Snow Hill	Quartz dolerites	Quartz dolerites
Jurassic	Plant beds at Hope Bay		
Permian		Beacon beds with coal	Upper Beacon beds with coal
Devonian			Lower Beacon beds with fish plates
Ordovician	Graptolites (S. Orkneys)		
Lower Paleozoic			Slate Graywacke (Cape Adare)
Cambrian	Archeocyathinae limestone		Archeocyathinae limestone
Upper Pre-Cambrian		Granites	Younger granites, etc.
Lower Pre-Cambrian	Schists (S. Georgia)	Gneisses	Gneiss, schists, crystalline limestones.

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one thousand feet high are composed of red (Beacon?) sandstone containing coal and carbonaceous shales. They are capped by an immense thickness of dolerite sills. Here also gneisses and granites are common and constitute the basal beds. The Gaussberg to the far west is an extinct volcano built of leucite basalt. Even off Enderby Land (49° E.) dredgings by the "Valdivia" revealed much of the same series of rocks.

We may conclude this chapter on Antarctic geology by a table indicating the dominant geological formations so far discovered.

CHAPTER VI

SCENERY AND TOPOGRAPHY

SCENERY

BEFORE discussing in some detail the characteristics of the topography in Antarctica—and it was to study these that I took part in the 1910-13 Expedition—it may be of interest to describe various aspects of the landscape and seascape which impressed themselves vividly on my memory. I should like first to mention the storms which are so characteristic a feature of the “Furious Fifties”¹ and the “Shrieking Sixties.” Three days after leaving New Zealand, the “Terra Nova” was nearly sunk by a violent gale. After being some twenty-four hours exposed to its fury all the pumps refused duty, and the hold and engine room were rapidly filling. Only a Gustavus Doré could do justice to the scene which ensued. We bailed out that boat of five hundred tons with buckets by hand labor in a fashion which has rarely been duplicated. Three successive iron ladders led from the floor of the engine room up to the poop deck, and this was occupied for twenty hours by a bucket gang chiefly consisting of scientists. Outside was the sound of the booming gale

¹ The “Roaring Forties,” “Furious Fifties,” and “Shrieking Sixties,” refer to the winds in the latitudes concerned.

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shrilling through the shrouds and ratlines in one continuous shriek. While the upper end of the "chain" of buckets was in an Antarctic atmosphere, down below the steaming waters which had risen over the furnace bars filled the engine room with heat. Hence the workers at the lower end of the chain were naked as the imps in the nether regions. The toll of the gale was heavy, as we lost several of the ponies and dogs and much of the port bulwarks was carried away by the waves.

A week later we were beset by the pack ice and remained without making much progress therein for three weeks. Let us climb onto the crosstrees at midnight and survey the unusual environment presented to us. All around lies the pack no longer like pancakes, but much thicker and (keeping to homely similes) now resembling shortcake. The ice is crossed by the meandering lines of the open "leads"; to the north the heavens are banded with arcs of salmon cloud, while the sea in our rear is a vivid brownish-pink with an oily sheen reminding one of moist putty. Across it runs a long dark line extending indefinitely to the north. This is the shadow of the ship due to the midnight sun. He "sets" due south and "rises" in the same spot, for we are just on the Antarctic Circle. Far ahead of us two geysers shoot into the tranquil air and seem to touch the golden edge of a low bank of purple cloud. They come from two whales which are piloting us on our voyage to the south.

Early in January we caught our first glimpse of the

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great Ross Ice Barrier² near Cape Crozier. In the far east where the "ribbon" of the ice wall reached the horizon, there was a marked difference in the sky to north and south respectively. To the north it was dark gray with heavy cumulus, but southward in a definite arc over the great Ross Ice Shelf this was changed to a pearly gray and the clouds were almost white. I saw nothing so striking as this "Ice-Blink" on any other occasion on our journeys. Just below the great wall of ice, here sixty feet high, were bands of brash ice. On this bobbing and rotating surface sported flocks of penguins, performing marvelous feats of equilibrium and nowise disturbed by the huge bulk of the ship towering over them. The Barrier front was deeply undercut by the waves at the water level and small berglets were constantly dropping off above this line of weakness.

At the end of January we were gaining our first experience of sledging up one of the giant glaciers which carry the ice from the Plateau down to the Ross Sea. Let us compare this glacier valley with a valley in more familiar lands. There is no vestige of green anywhere, no sign of life present or past. Owing to the absence of men, trees, or houses it is impossible to estimate distances, for there are no familiar standards. Time and again explorers have decided that a point for which they are making is only a mile or so away, to find that they have underestimated the distance

² This structure is a barrier to a ship, but morphologically is an ice shelf. The latter term is preferable and should replace the older term.

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two or three times. So here in the Ferrar Glacier Valley it was difficult at first to realize that it was four miles wide, and that the cliffs at the side were four or five thousand feet above the glacier. Very characteristic were the smooth walls of the valley, free from any of the ridges or spurs which partly block the view in a river-cut valley (see Figure 15). It was as if a gigantic carpenter had planed off every projection on the great walls. And indeed the Ice King with his glacier had done precisely that bit of crustal shaping!

Yet it must not be thought that the scene lacked variety or even color effects. The cliffs were built up of alternating layers of reddish granite, black dolerite and yellow Beacon Sandstone. Below these appeared the broad belt of dark brown talus, contrasting with the flashing white surface of the great glacier. As for the latter, every few yards often exhibited fresh ice structures. Here were deep irregular bowls with their floors covered with fan crystals of ice. Alongside were topsy-turvy icicles joined at the lower ends only. Farther on, the solid ice was marked by glassy arabesques, probably where stones had sunk into the glacier. Again there were dome-shaped roofs covering pools of water, through which one fell at frequent intervals. Bounding the glacier was a colonnade of ice pinnacles some thirty feet high. The sun glistening on the ice minarets made a most impressive sight.

A week or two later we explored a most unexpected region in the Antarctic. Below the Taylor Glacier lies a huge valley, some twenty-five miles long and several miles wide, in which there is hardly a vestige

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of snow or ice, except a few small glaciers on the steep slopes at the side and a few frozen drainage lakes on the floor (see Figure 13). Carrying our food and gear on our backs, we marched mile after mile down this great valley which had never before been traversed

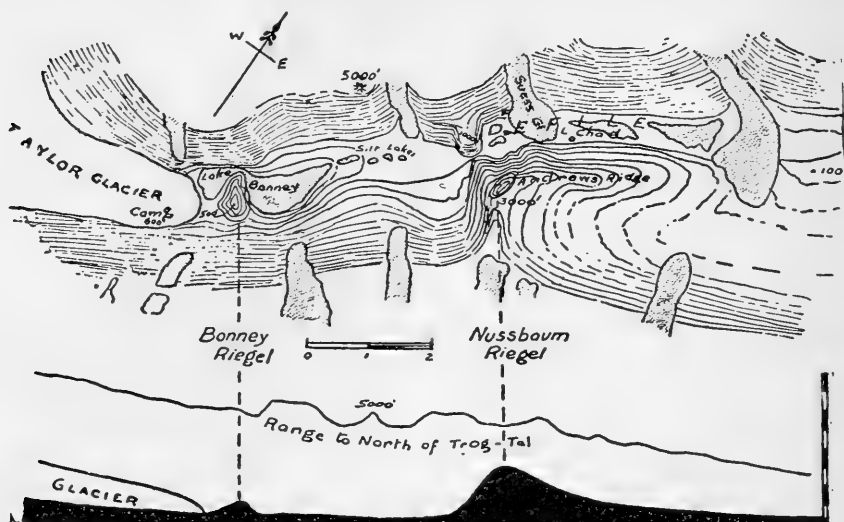


FIG. 13.—PLAN AND SECTION OF TAYLOR VALLEY SHOWING TWO RIEGEL.
(Scale of miles.)

by man. The floor was covered with tumbled débris of all shapes and sizes of ground moraine, with here and there patches of gravel and examples of soil-flow. No better opportunity for studying the way in which a great glacier has eroded the earth's crust can be imagined, and many pages of notes and sketches resulted from our journey down the Taylor Valley, which will be referred to later in the chapter (see Figure 15).

One last glimpse will serve to show how the Antarctic in 78° S. appeared in the middle of winter. On the twenty-second of June, when the sun was farthest

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north and had not been seen for eight weeks, I took a walk in the vicinity of Cape Evans. There was a hint of twilight to the north, appearing as a gray-blue sky extending across the outlet of MacMurdo Sound. This gave some little light which was reflected by the universal covering of snow. It was impossible to make out ridge or hollow on the snow surface, in the dim light; but a distant black object like Tent Island was faintly visible, while a snow cliff just ahead could not be detected. There happened to be no wind, though the temperature was -25° F., and so I was able to walk for a time without a helmet. The most picturesque time in Antarctica, however, is when the sun is just setting and rolls along the horizon like a great golden football. Thus late in March I noted that the landscape, in place of a monotonous white, now glowed a rosy-pink where the sun glanced on the snow fields. The open water appeared salmon or buff in color, while the newly frozen ice was iridescent like tar. The shadow of Brown Island to the south was lemon-green, changing to purple in the distance over Mount Discovery. For a few minutes our own shadows were the most vivid bright blue!

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In this section I propose to describe principally those features of the topography which give it its special facies and differentiate it from a region undergoing normal erosion by rain or rivers. I shall follow somewhat the order in which an investigator would meet with the examples, i.e., the coastal features come first,

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the inland valleys and cliffs next, and the nunataks, etc., last. I shall deal mainly with the Ross Sea area.

Islands.—The geographer is always interested in small islands, for from them he may often learn much as to the relative movements of land and sea. Unfortunately in the Antarctic no very definite evidence of elevated beaches, notches, caves, etc., was apparent. This was partly no doubt due to the fact that the more or less permanent sea-ice prevents the formation of many beaches and allied features. The steep-to cliffs of some of the islands in the southwest of the Ross Sea indicate fairly late subsidence, and this, if generally true of the locality, naturally hides most of the evidence of marine erosion.

Shore lines.—No doubt the usual shore line of the Antarctic consists of the inhospitable ice-front of the great Plateau ice cap. This permits no study of the underlying topography. The writer was fortunate, therefore, to be stationed in MacMurdo Sound (see Figure 8). Here on a coast line of about two hundred miles, from Cape Bird to Gregory Island, the following varying shore lines occur :

<i>Ice</i>	<i>Approx. miles</i>
(a) Vertical ice walls over 50 feet high, usually moving ice	14
(b) Vertical ice walls 5-50 feet, often stagnant ice	75
(c) Low glacier snouts, Barrier ice	35
(d) Ancient sea-ice	3
TOTAL	127

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Rock

(e) Steep rocky cliffs or headlands over 500 feet	15
(f) Capes and crags 50-500 feet	22
(g) Low-angle morainic shores	33
(h) Beaches	3
TOTAL	73

The writer only examined three small beaches in all this stretch of coast. At Botany Bay, in Granite Harbor, a beach occurred about half a mile long composed of granite boulders. These were undoubtedly water-worn, and nearby such boulders extended fifty feet above sea level. Perhaps here we have evidence of uplift. David and Priestley describe raised marine deposits near Mount Larsen which may have been thrust up by movement of large glacial masses. On the whole, however, the shore lines seem to indicate subsidence, as witness the drowned cirque at the head of Granite Harbor. (See Figure 24.)

Capes.—The importance of lists of capes as given in the old-style geography is to be discounted, but it is apparent that the capes in Antarctica are perhaps the most important portions of the continent. Some are historic, such as Cape Adare, Cape Armitage, Cape Royds and Cape Evans. The occurrence of capes is due, of course, to the presence of more resistant material, while the less resistant has been hollowed out and in general is still overwhelmed by the covering of ice. Yet there has been very little marine erosion, so that the coasts of Antarctica are characteristically *linear* or

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broadly curved. Possibly the original fault planes are better preserved in Antarctica than they would be along a coast subjected to river and marine erosion. Most of the capes around MacMurdo Sound stand out as rounded headlands, generally fifty or one hundred feet above the sea. In the vicinity of that curious "desert" locality, the lower Taylor Valley, the headlands are free from snow or ice for a distance of several miles from the sea, but as we proceeded north this bare area became more and more restricted by the increase in the width of the ice sheet behind.

On the east side of MacMurdo Sound, Cape Royds had a rocky hinterland which extended a mile from the sea and three miles along the coast. In the lakes in this hinterland the geologists of the 1907 expedition made many surprising discoveries of frozen but living fresh water fauna and flora (see Figure 8). Cape Evans was triangular in plan, each side being about half a mile. It exhibited very interesting features in the shape of *débris* cones from five to thirty feet high, which were proved to be the erosion relics of giant erratics. Cape Armitage promontory is about nine miles long and one and a half miles wide, but only about three miles of the southern end is partly free from ice. Here were fine examples of *solifluction*, usually in the form of pentagonal patches of gravel marked out by narrow grooves, the patches being some twenty feet across. Curious gullies ran around the slopes near Hut Point, along the contours. They were probably due to peripheral streams flowing around the edge of the Ross Ice Shelf, when it occupied successive posi-

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tions from three hundred feet down to one hundred and twenty feet above sea level. (See Figure 8.)

The cliffs around Granite Harbor and on the Kukri Hills were given special attention, to see how they had been affected by the glacial covering which had just receded from them. They were generally formed of granite and were characterized by a pronounced shoulder between the upland surface and the cliff proper. Everywhere were couloirs or gullies either snow-filled or empty. Usually these widened at the top, and their sides were covered with fragments of the adjacent rock. On sunny days they often contained a considerable amount of thaw water which carried down a slushy mixture of stones, gravel and snow. In my opinion we have here the initial conditions which often lead to the development of a cirque, if the general temperature conditions remain satisfactory for a long enough period. This problem, however, will be discussed at more length a little later.

Only in one or two localities have caves been discovered. The writer's party found one in Granite Harbor which was about fifty feet high and thirty feet deep. Priestley describes another from Robertson Bay. They are obviously very rare on the east Antarctic coasts.

Lakes and Tarns.—To the student of erosion, lakes indicate an interruption in the normal cycle, and in a glaciated region they are of special interest for even if frozen they show that relatively large masses of fresh water are possible in the region. We observed many types of lakes or tarns. In the ground moraine

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there were lake-filled hollows which seemed in general to be due to the melting of extremely ancient masses of ice, once covered by the moraine. These were common on the west side of the Koettlitz Glacier, where Alph Lake was nearly a mile long, and is in part still walled in by ancient ice. Others were due to moraines which blocked the outlet of the valley, as, for instance, below the Garwood Glacier, where the lake was two miles long. Lake Bonney below the Taylor Glacier



FIG. 14.—DÉBRIS-CONES BETWEEN EREBUS GLACIER AND THE SEA-ICE, NEAR CAPE EVANS.

Successive stages shown by a, b, c, d, e. The cones are from 5 to 15 feet high.

is also two miles long. It seemed many feet deep and full of algæ, but we had not time to cut through the ice surface and investigate it more fully. There appears to be a rock sill between Lake Bonney and the sea, for the defile at its eastern end is over one hundred feet above the sea (see Figure 13).

David and Priestley describe at length many of the small lakes near Cape Royds (see Figure 8). These were investigated during the winter by means of trenches. Most of them lay in the hollows in a long

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shallow glacier-cut depression extending along the hinterland from Cape Barne to Cape Royds and beyond. Blue Lake was about six hundred yards long, the others being much smaller. Green Lake was about one hundred yards across and about five feet deep. Below the ice was found a reservoir of liquid brine with the low temperature of 21° F. The temperature of the ice at the bottom was -2° F., while it was -23° F. near the surface. Clear Lake was a little larger, and the ice was eight feet thick. At this lower level the ice was $+29^{\circ}$ F. while the air outside was about -10° F. There was four feet of water at the bottom with a temperature of $+35^{\circ}$ F. Blue Lake was fifteen feet deep, and at the bottom growing algæ were found which contained living rotifers (see p. 218). This indicates that the suspension of animation in these organisms must extend over many seasons, for it can be only very rarely that Blue Lake melts to the bottom. Farther south, near Cape Barne, is Sunk Lake, whose ice surface was twenty feet below sea level and whose floor was some fifty feet below the sea, which was only one hundred and fifty feet distant. Ice-Dam Lakes on Cape Evans, resembling in miniature the Glenroy Lakes of Scotland, are described in the writer's large monograph.

Débris Cones.—A few days after our arrival at Cape Evans the geologists were advised to inspect what our informants described as "little volcanic craters," which were seriously stated to be parasitic cones on the lowest slopes of Mount Erebus. These cones were scattered all over the rock platform between the low

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promontory of Cape Evans and the icy mantle which covered most of Erebus. They consisted of conical piles of kenyte fragments from five feet up to twenty feet high. It was not for some months that we had the opportunity to investigate distant examples, and then their origin was quite clear. About one mile south of Cape Evans, near Lands End, we found all stages of these cones. There was Seal Rock (see *a*, Figure 14), a solid mass of kenyte about ten feet high, but in all probability an erratic block. Higher up the slopes was Thumb Cone (*b*) with a mantle of débris just beginning to form at the base. Nearby was another cone about twelve feet high (*c*), with only a small portion of the original erratic left at the top. In the vicinity also were small cones where none of the original erratic was visible (*d* and *e*). I cut into a débris cone behind Cape Evans and found a solid core of homogeneous kenyte within. Here "thaw-and-freeze" erosion (nivation) had obviously been prevented from acting upon the central portion of the base of the erratic. At Mount Sues we found a *composite* cone which was twenty-five feet high (and about fifty by thirty yards in plan). It was surmounted by a block of sandstone lying on edge and about two feet high. But the southwestern end of the same cone was formed of fragments of basalt which were partly covered by sandstone fragments. Evidently here two monoliths of different rock lying side by side had weathered simultaneously.

Moraines.—All types of these structures occur in Antarctica but they differ in quantity largely from

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those of temperate regions. Thus visitors to the Alps in New Zealand see the lower mile or two of the glaciers completely covered by surface moraine, so that the ice is invisible. Débris is falling on to the moving glacier and gradually building up lateral and medial moraines. "Glacier milk" pours out of the ends of the glacier owing to the grinding of the floor by the mobile glacial "plane." But none of these phenomena is to be seen in Antarctica. The glaciers are practically free from débris. Their glacial streams, as far as I saw them in two summers, were practically clear. Nowhere in two hundred miles of Antarctic coast line did I find a well-defined terminal moraine, though there were half a dozen possible sites. But the ends of the glaciers were all of clear ice, except for a few silt bands and occasional fragments of larger rock. This condition is not so marked, I believe, in glaciers nearer the Antarctic Circle, but in 77° and 78° S. the climate is much too cold for the maximum effects of glacial erosion to be developing to-day.

Behind Cape Evans I was unable to find any very clear indication of a terminal moraine. Only in two small areas was there any definite arrangement of heaps a few yards long and a few feet high, which could be differentiated from the general tumbled heaps of débris, no doubt partly ground moraine, which littered Cape Evans. At the head of Granite Harbor was a small moraine across Cuff Cape. It was about five hundred yards long and about fifty feet thick perhaps. The most favorable site for a huge moraine would be at the snout of the Taylor Glacier—which lies some

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twenty miles from the sea (see Figure 13). But its terminal moraine is an irregular heap of débris some twenty-five feet high and about one hundred yards in length. So also at the end of Hobbs Glacier (see Figure 8), where the face of the ice is sixty feet high, there occur only two curious terminal "piers" of silt about thirty feet high and one hundred feet long. These had the appearance of "eskers," but may be the relics of a former continuous terminal moraine, though I think it unlikely.

The small glaciers occupying the numerous cirque valleys to the south of the Ferrar Glacier were also practically free from surface moraine, nor were there any terminal moraines anywhere near their present snouts. At the mouths of the cirque valleys, where they joined the main Koettlitz Valley, there were indefinite heaps of morainic material across these cirque valleys. I was never quite able to decide if these moraines were *terminals* due to the former earlier cirque glaciers or were merely portions of the ancient *lateral* moraine of the mighty Koettlitz Glacier, etc. The occurrences of morainic material *upon* the present glaciers (which occasionally were met with in our traverse) will be described in the chapter dealing with glaciology. (See Figure 17.)

Sections across the Taylor Valley.—This region probably represents better than anywhere else so far investigated in Antarctica the subglacial topography of the continent. It is shown in a somewhat diagrammatic fashion in Figure 15. Starting from New Harbor at the mouth of the valley, the latter presents the

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typical catenary cross-section of a glacier-cut valley. A splendid pair of walls with the characteristic slope of about 33° defines the glacier trough. There is no terminal moraine near the sea, which seems to denote

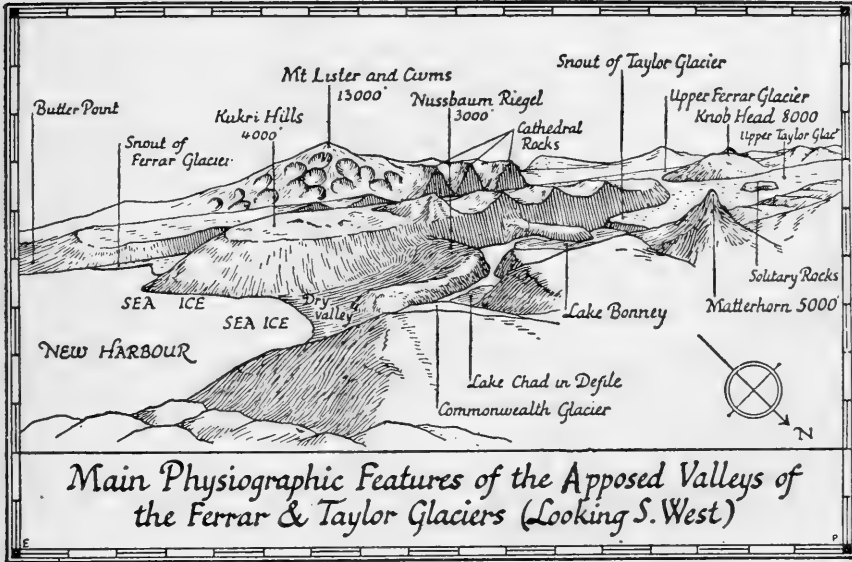


FIG. 15.—BLOCK DIAGRAM SHOWING THE ICE-FREE TAYLOR VALLEY, 18 MILES LONG, AND THE ICE DIVIDE BETWEEN THE TAYLOR AND FERRAR GLACIERS.

(By permission of John Murray.)

a fairly uniform and perhaps rapid retrocession of the glacier. About six miles from the coast a narrow defile appears on the north side, but a rounded valley floor rises gradually to two thousand feet over the greater part of the trough. West of this point there is a sudden drop from this great rock barrier (which I called the Nussbaum Riegel³) into the next bowl of

³ Riegel is used in the Swiss Alps to indicate such a rock bar.

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the valley. This is filled with morainic material to the depth of a hundred feet or so, for the drainage of the bowl is away from the sea to the salty waters of Lake Bonney. The defile previously mentioned is about 1,500 feet deep, and would seem to be a water-cut gorge denoting an interglacial period. Lake Bonney is separated into two portions by a granite bar five hundred feet high. This also is traversed by a narrow gorge on the northern side of the trough, and is a smaller edition of the Nussbaum barrier or riegel. Then about half a mile west we reach the snout of the Taylor Glacier, which appears to be over-riding moraine material at its extremity. (See Figure 13.)

Visitors to Switzerland will recognize how closely the alternation of gorge, riegel, and bowl recalls the classic glacial valley between Airolo and Biasca. It is the writer's opinion that similar forces of erosion have produced these similar but far distant topographies. The evolution of this peculiarly complicated structure in the floor of the large glacier-cut troughs of the Ferrar-Taylor Glaciers is to be explained in my opinion by a study of cirque-erosion.

Cirques.—These land-forms are very abundant throughout the glacial topographies of the world, and it is rather surprising that their origin was not at all understood until the research of certain American geologists in the western United States about 1900. The cirque is a peculiar valley which has been compared in shape to an armchair. It has a more or less circular base and steep bounding walls on three sides, being open on the lower fourth side. The scarp of

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Mount Lister (thirteen thousand feet) shows some of the finest cirques in the world. The summit itself, as viewed from the east, appears to have small cirques on two sides while another at nearly the same level appears on the sky line to the right. Then there is a row

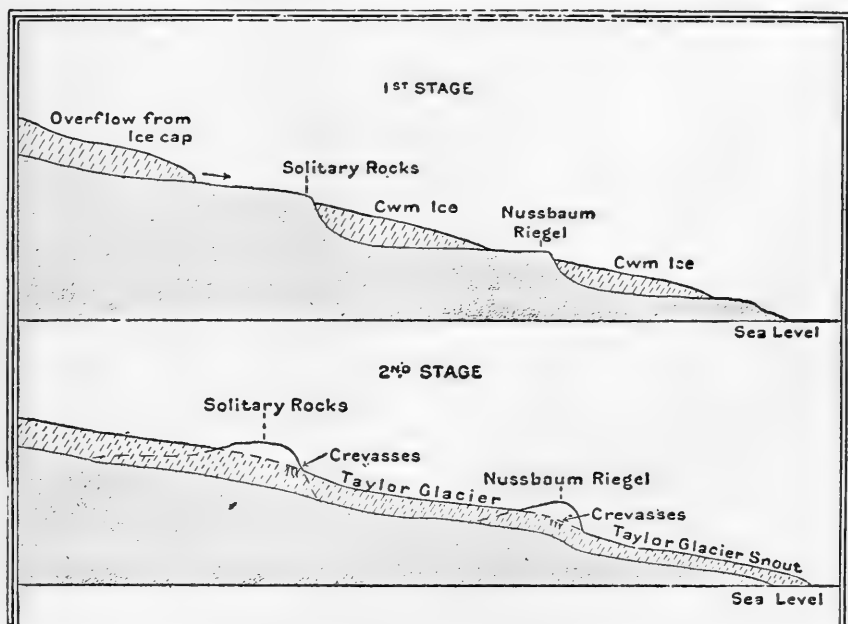


FIG. 16.—SECTIONS ILLUSTRATING THE EVOLUTION OF THE RIEGEL IN TAYLOR VALLEY.

Stage 1 shows hypothetical cirque (or cwm) valleys, later overwhelmed as in stage 2. (*Geog. Journal*, 1914.)

of four cirques immediately below this series. Finally five or six cirques are packed together in the lowest rank immediately above the foothills at the head of the Blue Glacier. Cirques are of all sizes from the small drowned cirque in Granite Harbor to the giant Walcott Cirque just south of Mount Lister, which is eight

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miles across and has a rear wall some eight thousand feet high. The absence of any collecting ground at the head of many of these cirques certainly indicates that they are not due to normal glacier erosion. My Antarctic experience led me to believe that nivation (i.e. thaw-and-freeze chipping) as described by Hobbs in his book, *Existing Glaciers* (1911), is the major process involved. I give a full discussion, based on local examples, in my book, *Physiography of Mac-Murdo Sound* (1922).

Charles Darwin advised young naturalists to seek for evidence of evolution in a given group of organisms among the specimens themselves. If enough samples are present there are, said he, likely to be many different stages represented. Applying the same principle in Antarctica, I believe that I can see varying stages in the evolution of the topography of the Taylor Valley indicated in adjacent land-forms (see Figure 8). Thus all along the Royal Society Range to the south is a suite of eleven cirque valleys extending over some thirty miles in length, which constitutes a "Fretted Upland," as Hobbs terms it. These usually contain small stagnant glaciers, which the first observers called "Ice Slabs." Such glaciers are situated at the heads of the valleys concerned. Above these lower cirques are several series of smaller cirques in the scarp of Lister itself, in shape looking as if a giant had pressed his thumb repeatedly into a slope made of putty. The writer believes that this type of cirque topography is the first which developed on the onset of the Ice Age.

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The subsequent phenomena are described in terms of the Palimpsest theory.

Palimpsest Theory.—If now we turn to the great outlet valleys, such as those occupied by the Taylor or Ferrar glaciers, we find evidence of a similar cirque-cut topography drowned by the overflow of plateau-ice from the hinterland. This is made clear in the diagrams annexed. In the upper figure (see Figure 17) we see several cirque (or cwm) glaciers burrowing into the sloping land surface. One lies below Solitary Rocks and one below Nussbaum Riegel (see Figure 16). Later the Taylor Glacier overflows from the Plateau and pours down over the cirques, cutting away part of the Solitary Rocks and Nussbaum Riegel. These barriers on recession are still visible. The constrictions in the valley and occasional steeper falls in the Ferrar Glacier are probably due to the same cause. Thus on recession we see somewhat faintly preserved the relics of the cirque-erosion cycle in the shape of bars across the floor of the valley, which on the whole is due to normal glacier planation. This combination of topographies is expressed in the term palimpsest, which means that older writing can be observed on a parchment below the present scrip. The pre-glacial stage, the stage of cirque-erosion, and the ice-flood stage are all indicated in Figure 17.

Nunatak and Nunakol.—These are rock “islands” surrounded by a sea of glacier ice. The term nunatak means “like a land” and it expresses an irregular rocky residual, too hard to be eroded completely, and still towering above the glacier. But in Antarctica and

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elsewhere there is another type of rock-residual which has been very markedly smoothed off by overriding ice

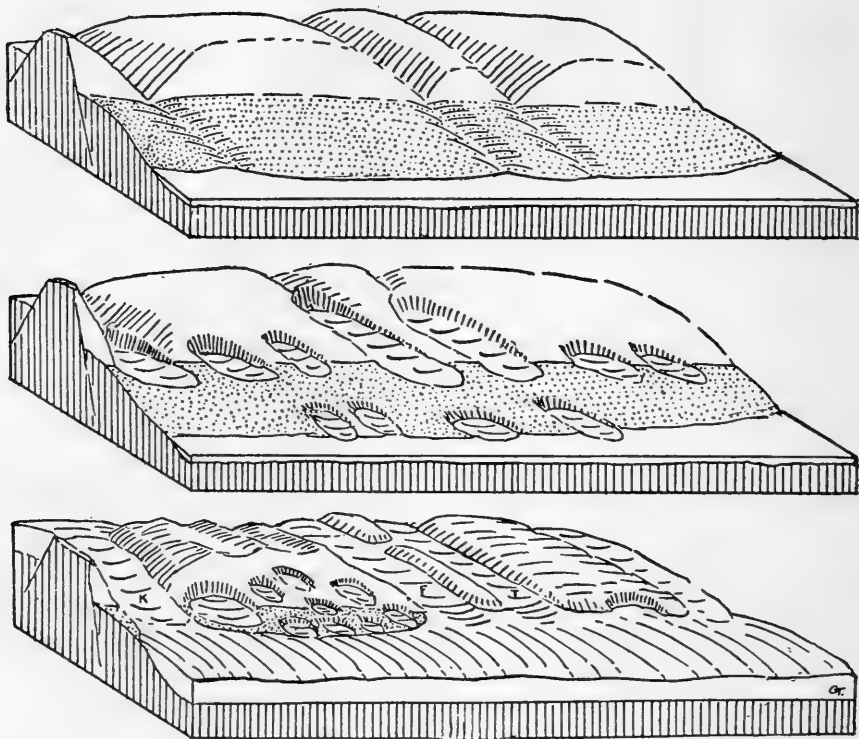


FIG. 17.—BLOCK DIAGRAMS ILLUSTRATING THE “PALIMPSEST THEORY” OF GLACIER EROSION APPLIED TO THE ROYAL SOCIETY RANGE.

In the upper figure the pre-glacial topography is suggested; in the central figure the advancing hemicycle with much cirque-erosion by headward recession; in the lower figure the period of ice-flood when the outlet glaciers were at their maximum. (K. F. T. indicate Koettlitz, Ferrar and Taylor glaciers.)

which has since retreated. My Norwegian colleague, Gran, suggested the Icelandic term *nunakol* (lonely rounded ridge) as suitable for this land-form, which

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has had a very different history from the nunatak. Examples of both types are to be seen in the block diagram of the Mackay Glacier (see Figure 24). Thus Mount Suess is a nunatak. I doubt if the main glacier ever surmounted it, though it is quite likely that cirque-cutting gave rise to the sharp ridges and peaks of its summit. To the north is Gondola Ridge, a typical nunakol which was littered with moraine and has only recently been freed from its ice covering. Just to the southeast is Redcliff Nunakol of a similar nature.

Water Erosion.—We may conclude this chapter by a brief reference to the agents which have cut out the Antarctic topography. Wind has not much power in a land covered with ice and snow, though I give a number of examples of wind transport and erosion in my memoir. But I was especially struck with two facts in my study of the Ross Sea area. Firstly, most of the ice is stagnant nearly all the year round and cannot therefore be eroding much. Secondly, although the average *air* temperature was only 25° F. in the *warmest* months, yet there was a great deal of running water at far colder air temperatures. Thus on September 17th, 1911, I noticed snow melting on black rock when the air temperature was 25° degrees *below freezing*. So that numberless examples of water erosion were visible, such as gullies, meanders, terraces and small deltas at mouths of streams. One of these streams was twenty-five miles long and flowed under the Koettlitz Glacier ice until the middle of March, when the air temperature was -8° F. (i.e. 40° below

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freezing). So that it seemed to me that the present ice-cut topography dated back largely to much warmer conditions, while the chief erosion at present (at 78° S.) was possibly due to normal water erosion and nivation, of course confined almost wholly to the warmer parts of the year.

CHAPTER VII

ICE SHEETS AND GLACIERS

THE CONDITIONS OF MAXIMUM EROSION

I HAVE investigated glacial conditions in many countries both in the northern and southern hemispheres, and my studies have led me to certain perhaps novel conclusions with regard to the real meaning of the onset of an ice age. Any one who has done much flying knows that there is an environment in many ways suited for an ice age within a mile or two of any temperate city. It occurs, of course, vertically overhead. It is profitable, therefore, to look upon the approach of an ice age as essentially due to the lowering of certain isothermal zones or layers from an overhead position until such zones intersect more or less of the land surface concerned.¹ These zones have a slight slope from the equator to the Pole. If we travel from New York to the North Pole or from Sydney to the South Pole, we reach latitudes where this Ice Age layer comes down to sea level, at about 60° of latitude in both cases. This layer corresponds essentially to the permanent snow line. No part of the world perhaps is better suited for a study of the optimum temperature

¹ Fluctuations in the amount of snowfall are of secondary importance.

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for glacial erosion than the lands bordering the southwest corner of the Pacific Ocean. For in Australia we have Mount Kosciusko (7,328 feet) with its clear evidence that the erosive agents of the Ice Age had only operated for a short time when the favorable glacial environment vanished (see Figure 18). There is Tasmania with its low mountains of three thousand to five thousand feet showing much more markedly the results

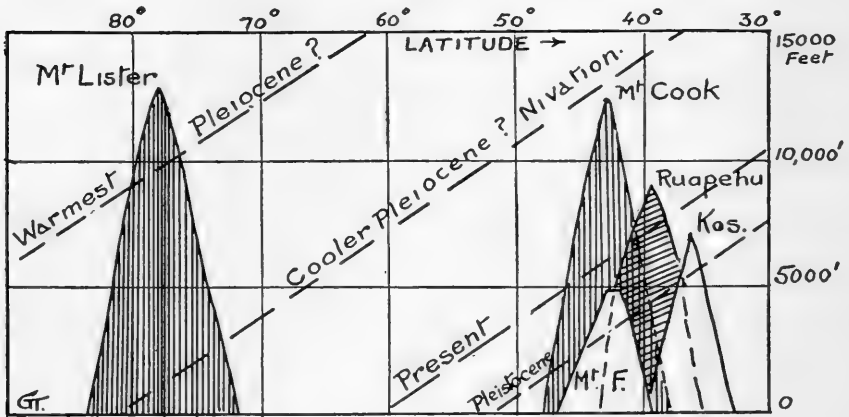


FIG. 18.—DIAGRAM SHOWING POSITIONS OF THE LAYER OF MAXIMUM NIVATION AT PRESENT, AND IN THE PLEISTOCENE. PLEIOCENE CONDITIONS ARE MERELY SUGGESTED.

of a less brief visit of the Ice Age. There is New Zealand with small glaciers in the North Island, and large glaciers (very much greater than most others in temperate lands) around Mount Cook (12,345 feet) in the South Island. Finally, there are the record glaciers of Antarctica to be included in the comparison.

I do not propose to dwell on these comparisons, but no glaciers show *active glacial erosion to-day* better than those of the Mount Cook region in the center of

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the South Island of New Zealand. Here the conditions of a plentiful snowfall are combined with a suitable position of the *isothermal layer* of 32° F. It is this last control, the environment where freeze-and-thaw action is naturally most active, which is all-important in eroding a landscape by the action of ice. Each time the temperature sinks below freezing point (32° F.) a wedge of ice is formed in every crevice of rock. This may crack off a fragment of rock, which falls away when thaw sets in. When this is repeated day and night during many months, the amount of erosion must be tremendous. The actual wearing away of a valley *floor* by a glacier is, no doubt, more striking and on a larger scale. But it only affects a relatively small portion of the topography, whereas nivation (freeze and thaw) attacks the whole landscape. So also the river only cuts out its *bed*, but the rains and rills wear away fragments from an infinitely greater area.

A good deal of rather ill-defined evidence in the Antarctic indicates that movement of the ice (and consequently glacial erosion) is much more active in the summer months than in the winter. Even Cape Adare (in latitude 71°) has only one month above freezing point, while at Cape Evans (latitude 78°) the hottest month has an average temperature of only 25° F. The writer has formed the opinion that temperatures fluctuating around 32° F. are the most favorable for pronounced glacial erosion, but we have no accurate measurements in Antarctica on this question of seasonal variation in erosion. However, in Greenland Ryder

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found that the Upernivik Glacier moved one hundred and twenty-five feet a day in August (40° F.) and only thirty-three feet a day in April (12° F.). The following table (partly based on Hess)² gives the velocities of various glaciers. It is obvious, however, that the velocity depends largely on the size and slope of the glacier concerned—as well as on the temperature conditions.

GLACIER	COUNTRY	LATITUDE	VELOCITY (usually yearly average)
Karajak	Greenland	71° N.	59 feet per day
Muir	Alaska	60° N.	7 feet per day
Mer de Glace	Switzerland	46° N.	1.6 feet per day
Rhone Glacier ...	“	46° N.	1 foot per day
Hintereis Glacier.	“	46° N.	0.5 foot per day
Tasman.....	New Zealand	44° S.	1.5 feet per day
Franz Joseph	“ “	44° S.	16 feet per day
Mackay.....	Antarctica	77° S.	2.8 feet per day (summer)
Barne Glacier ...	“	77° S.	30 feet per year
Taylor	“	78° S.	Stagnant
Ferrar	“	78° S.	32 feet (Feb. to Oct.)
Ross Barrier	“	80° S.	1.4 feet per day
Beardmore	“	85° S.	3 feet per day (?)

In the preceding diagram (see Figure 18) I show five typical glaciated regions: Kosciusko is in Australia and Mount Field in Tasmania, Ruapehu and Cook are in New Zealand. Mount Lister is on the west side of MacMurdo Sound in Antarctica. The heavy black line shows the present position (in latitude and elevation) of the temperature layer of 32° F. (the “Nivation Layer”). Hence cirque-cutting is occurring to-day

² Hess, *Die Gletscher* (Brunswick, 1904).

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quite actively on Mount Cook and Ruapehu which are intersected by this layer. The lower sloping line (on the right) shows where this nivation layer was situated in Pleistocene times. It had in fact descended about one thousand five hundred feet below its present position, and cirques were being actively cut on Kosciusko and Mount Field at that period. It will be noticed that neither of these "layers" intersects the Antarctic mountains. But we have a good deal of evidence that world temperatures were warmer in Pliocene times than they are to-day. It is possible, therefore, that the cirques of Antarctica were cut several million years ago, possibly during late Pliocene times.³ At any rate the cirques high on the slopes of Mount Lister have a present-day temperature of -25° F. On no theory of glacier erosion can the cirques be due to the temperature or snowfall conditions obtaining there to-day.

CLASSIFICATION OF GLACIERS

There have been a number of different categories proposed for the differing types of glaciers. It is quite clear, as Hobbs has pointed out, that classes which depended on knowledge gained in the European Alps were quite unsatisfactory. The Mer de Glace is merely the dwindling relic of one limb of the mighty glacier which formerly filled the huge Chamonix Valley. Hobbs in his book, *Existing Glaciers*, produced a useful classification which took into account the

³ See the writer's paper on this aspect of glaciation in *Proceedings of the Pan-Pacific Scientific Congress* (Tokyo, 1926); with five block diagrams.

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method by which the glaciers were nourished, and also the relation of relic-glaciers to their original shape and size. Priestley and Wright in their large memoir (based on their research while on the Scott expedition of 1910-13) have welded previous classifications into a comprehensive scheme, and this, with some modifications, the present writer believes to be the best advanced so far.

Priestley and Wright divide glaciers into three major classes :

CLASS A

FORMATIONS OF THE AREA OF PREDOMINANT SUPPLY

<i>Types</i>	<i>Synonyms</i>
Continental Ice	<div style="display: flex; align-items: center;"> <div style="font-size: 3em; margin-right: 5px;">{</div> <div style="text-align: left;"> Ice cap type (Hobbs) or Greenland type </div> </div>
Island Ice	
Highland Ice	
Cirque Ice	Nivation (Hobbs)
Snowdrift Ice	Glacieret (Taylor)

CLASS B

FORMATIONS OF THE AREA OF PREDOMINANT MOVEMENT

<i>Types</i>	<i>Synonyms</i>
(a) Wall-sided glaciers	(a) Curtain glaciers (Taylor)
(b) Valley glaciers	<div style="display: flex; align-items: center;"> <div style="margin-right: 5px;">(b₁)</div> <div style="text-align: left;"> Dendritic Transection } Hobbs Outlet (Taylor) </div> </div>
	(b ₂) Alpine type (Heim)
	Cliff (Taylor)

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CLASS C

FORMATIONS OF THE AREA OF PREDOMINANT WASTAGE

<i>Types</i>	<i>Synonyms</i>
Expanded Foot Ice	
Ice Tongues Afloat	
Piedmont Ice	Alaskan type (Werth)
Confluent Ice	
Avalanche Ice	

CLASS D

<i>Type</i>	<i>Synonym</i>
Shelf Ice	Barrier Ice

These classes are illustrated in Figure 19.

Continental ice in Antarctica is of gigantic size, probably covering four million square miles. No other similar example occurs, though the ice cap in Greenland is of the same general form. Smaller examples occur in Iceland, Norway and the Arctic Islands.

Highland ice is defined as a comparatively thin ice sheet conforming to the undulations of the land beneath. It is not common in East Antarctica, but an example occurs near Cape Adare. (See Figure 19.)

Island ice is a sheet of ice covering an island, usually with a regular domed surface. They are common off Queen Mary Land.

Cirque ice may be confined to the nivation hollow which has been sapped into the side of a scarp, or the snowfall may increase and hence the cirque glacier may spill down hill. Cirque-erosion is due primarily to

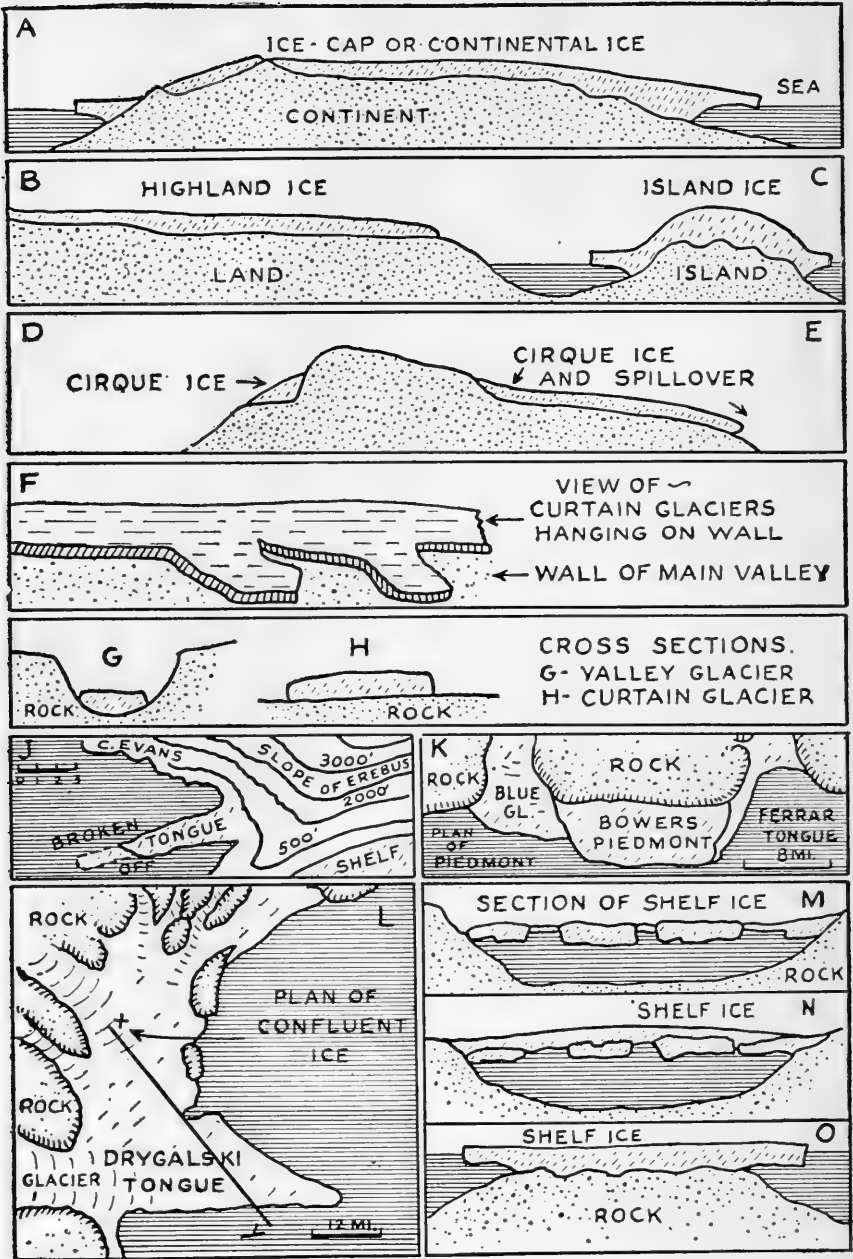


FIG. 19.—SKETCHES ILLUSTRATING THE CLASSIFICATION OF GLACIERS.

All are sections, except F, J, K and L. (Mainly based on Priestley and Wright.)

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nivation and not to pressure or rasping by the glacier.

Curtain Glaciers.—Examples are present on the north side of the Taylor Valley near Solitary Rocks. The glaciers are usually stagnant, and often override débris, instead of excavating a valley (see Figure 19 at F).

Valley Glaciers.—Apparently Priestley and Wright include both large and small glaciers, which have carved out a valley, under this general head. The present writer prefers to subdivide them according to their size and slope, etc. Thus we have among valley glaciers:

Outlet glaciers—large glaciers of significance in draining the surplus of the Continental Ice to the sea.

Transection glaciers—tributaries which have linked adjacent outlet glaciers, e.g., near Knob Head and south of Mount Sues.

Dendritic glaciers—Hobbs' terms for small tributary glaciers, more or less isolated from the main valley glacier, to which they originally were feeders. These may be *graded* if they have cut down their valleys to the level of the main valley, or *discordant* if they hang above the main valley. Many cliff and curtain glaciers are of this latter type. It is clear that some glaciers are intermediate in character and can be classified differently according to the stress laid on one or the other criterion.

Expanded Foot Glacier.—The ice expands below the main outlet valley into a vacant valley below. This

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form is present in the empty main valley below the Taylor Glacier. Blue Glacier (see K, Figure 19) to some extent expands on entering the sea.

Ice tongues need little description. They may be simple or end in several "tonguelets," or may be asymmetrical as at the snout of the Ferrar Glacier (see K, Figure 19).

Piedmont Ice.—Broad areas of ice at low level usually fed by one or two valley glaciers. Their crevasses are generally along the long axis of the ice sheet. Sometimes (as in Bowers Piedmont) they are relatively stagnant, without supply from glaciers.

Confluent Ice.—Ice sheets due to the confluence of several ice tongues but held together by a land barrier (see L, Figure 19). They are not common.

Shelf ice or ice shelf is a broad sheet of ice due to extensions of land ice, with or without interstitial sea-ice; or it may be due to the accumulation of snow upon old sea-ice. In Figure 19, at M, is shown an early stage of the composite type (with land- and sea-ice). At N is a later stage when snow has obliterated the difference in levels. At O is an example which has collected mainly upon banks or low islands.

THE GREAT OUTLET GLACIERS

In my sledge journeys during the summers of 1911 and 1912 I investigated the characteristics of four outlet glaciers, each of which presented features of special interest. Thus the Mackay Glacier was unusually broad, and flowed through an "archipelago" of nunataks and nunakols. It reached the sea by several

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snouts, one of which formed the Mackay Ice Tongue. The Ferrar Glacier was simpler in plan and occupied the finest valley. It offered a relatively unbroken slope to the Plateau and was joined in Siamese-twin fashion to the Taylor Glacier. The latter was stagnant and its empty lower valley has already been referred to. The Koettlitz Glacier was the largest of the four and offered an unrivaled study of the effects of thaw-waters and surface weathering on a broad surface of relatively stagnant glacier. A detailed description of a traverse of the Ferrar Glacier will give a good idea of their characters (see Figure 8).

Their positions and dimensions are as follows :

Name	Position, S. Lat.	Length, Miles	Width, Miles	Approx. Height of Plateau, Feet	Approx. Average Slope
Koettlitz....	78° 30'– 77° 50'	45	5 to 12	5000	1 in 45
Ferrar	77° 50'	50	6	6000	1 in 35
Taylor	77° 40'	30*	5 to 12	6000	1 in 30
Mackay	77°	30	6 to 10	4000	1 in 40

* Has retreated 20 miles from the sea.

It will be noticed that the grades are by no means steep. Usually for long stretches the glacier is nearly level, and then a considerable rise is encountered where the glacier flows over some sub-glacial and nearly worn-down bar (riegel). Here are numerous crevasses, which also occur opposite the tributary glaciers, owing to the thrust of these latter upon the ice of the main glacier. Were it not for these icefalls and tribu-

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tary crevasses, the ascent of these outlet glaciers would be a comparatively easy task.

THE FERRAR OUTLET GLACIER

We were landed by the "Terra Nova" off Butter Point on the twenty-seventh of January, 1911. We sledged westward over sea-ice for four and one-half miles until we reached the center of the snout of the Outlet Glacier. The latter was only three feet above the sea-ice at this point. The peculiar tongue of the Glacier along the Bowers Piedmont is shown in Figure 19 at K.

The valley of the lower Ferrar Glacier is about four miles wide and extends southwest for about thirty miles. The northern face is a marvelous wall-like cliff, two thousand to three thousand feet above the glacier, as stated previously, as straight and smooth as if planed by a giant carpenter. On the south side the wall is breached by tributary glaciers coming in from the Blue Glacier and the snow slopes of Mount Lister.

The chief features of the lower portion of one of these huge glaciers can best be realized by a description of a traverse of the Ferrar Glacier across the snout.

Center to South.—At its mouth the Ferrar Glacier is bounded by bare cliffs with the normal angle of about 33° , which reach a height of three or four thousand feet. The glacier end is from three to six feet above sea level and is obviously not contributing much in the way of icebergs. Our camp was on the sea-ice at the junction. From the camp I made a rapid traverse to the southern slopes which further proved that

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the glacier was nearly stagnant, though it seems to me that some differential movement is shown. Indeed, some movement was indicated by the stakes inserted by Wright and Debenham level with Cathedral Rocks, but the condition of the southern portion of the snout would seem to indicate that it is not transmitted in this portion of the glacier. The surface was seamed by numerous channels and cut into small pinnacles and thaw pools in a manner which showed that it had not altered its position for many years. On the northern side, however, there was a striking ridge of heaped up pressure-pinnacles which lead me to believe that there is motion in this moiety of the glacier. The sea-ice was free from the pressure ridges which we saw in Granite Harbor, hence the movement is less than in the Mackay Glacier.

After walking for about half a mile over the sea-ice, south from our camp, I was surprised to find a prolongation of the Glacier extended as a lateral tongue for four miles along the southern shores. It was necessary to cross this to reach the hill slopes. After crossing half a mile of the tongue, I reached the first moraine heap. There was no very definite arrangement of the *débris* along continuous ridges, but here and there oval piles of stone and gravel were scattered about the glacier. The ice was usually melted into a pool at their bases. The first moraine heap was seventy yards long and about ten feet high. It showed an extraordinary mingling of powder and large blocks, of which the latter were all somewhat rounded. Among the stones were specimens of gneiss, dolerite, felspar,

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porphyry, "Shap granite" and a few boulders resembling troctolite. A few small striae were visible on some boulders. The latter varied in size from four feet in diameter down to fine powder. At the side were pools filled with yellowish water. Here was one of the few occurrences of fine silt which I observed.

Other heaps occurred close by, of irregular shape and not quite so high. About seventy yards away to the west appeared another ridge and between were a few big blocks. Possibly there was moraine between covered by the ice, but the lack of débris on other glaciers makes me doubt it. The southern margin of the glacier was intersected by numerous small streams. Here on January 28th, 1911, the main stream was two feet wide and about one inch deep. There was, however, much greater flow along the northern bank of the glacier.

There was an interesting zoning in the character of the débris covering the valley slopes hereabout. Next to the glacier was a belt at a low angle consisting of clayey silt containing stones one or two inches long. A hundred yards south this deposit had become a sort of *gravel meal* which is very characteristic of Antarctic surfaces. Then came a belt of sharp shingle or angular gravel, each piece being about two inches long with very little powder visible. Above this (to the south) were the coarser blocks, which became fairly continuous at about four hundred yards from the glacier edge. Here I was about two hundred feet above the ice. Just below the granite erratics, which were up to four feet in length, though mostly less than one foot, was a large patch of moss about sixty feet long

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and fifteen feet wide. There were apparently two genera present, one reminding me of the alga *Ulva*.

Next day I climbed up the hill slopes just north of the snout of the Ferrar Glacier to a height of two thousand five hundred feet. The rock was a flaky gray granite with numerous dark dykes. The diabase morainic material of the ancient Ferrar Glacier seemed to reach about 1,900 feet above the present surface of the glacier, and in the lower portions of the climb were numerous erratics of garnet gneiss, pegmatite and varieties of basalt (see Figure 15).

At my highest point I was well above the "shoulder" of the Kukri Hills though not near their summit, which is here about 3,500 feet. I could see that the hanging "curtain" glacier alongside originated in a nearly level snow field. A sharp arete separated its snow field from another to the west. Undoubtedly the upper slopes of the Kukri Hills form a sort of very flat roof-ridge. The resemblance is indeed very close to an old roof of galvanized iron where the individual sheets have sagged down between the rafters. Each of the depressions is a snow field occupying a shallow, elongated cirque. In fact these are evidently the senile cirques of the Ice Flood Age.

Traverse up the Center.—Here as elsewhere the lower glacier surface is much dissected by thaw water, etc., while the upper reaches are of hard blue ice. The glacier ice is in wide undulations and the surface drainage runs diagonally from south to north across the glacier. About five miles above the snout on the twenty-ninth of January there were four shallow

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streams crossing the glacier in this fashion, with water three inches below the surface. This diagonal direction is probably due to the aspect of the midday sun, which eats back the "alcoves" dissected in the ice and ultimately produces a north-south channel.

Above the four small drainage streams, the surface degenerated. During the first mile we traversed three well-marked undulations, which were nearly abreast of the Overflow Glacier on the south side of the Ferrar. About one mile higher up was a relatively deep snow-covered valley crossing the glacier. On both sides were numerous crevasses, but the widest was less than three feet across. Most of them had definite snow bridges across. At our second halt we found a dead seal.

The slope higher up was not steep, only 3° as measured roughly with my Brunton level, and the crevasses were insignificant. The lateral moraine became more prominent on the lower slopes as we ascended the glacier. Five miles above the Overflow the clear ice began to show through the snow cover.

At 9:00 P.M. we reached the main moraine on the south side of the glacier between Descent Pass and Cathedral Rocks. Here we made a depot, and proceeded west to reach the Taylor Glacier. The chief features hereabout were the beautiful tessellations on the north side of the Ferrar. These products of solifluction indicated that a heavy moraine covered the base of the northern cliffs. (See Figure 8.)

We then had a stiff pull up the glacier, about 5° for a mile. The glacier ice was split into rough rectangles by cracks, which, however, did not hinder our

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progress. A fine low-level tributary enters at grade just beyond Cathedral Rocks. The majority of the other tributaries have not entered at grade since the main glacier was some two thousand feet thicker.

On the evening of the thirty-first of January we reached the top of the steeper portion of the Lower Ferrar and found ourselves on a small plateau about 3,200 feet above sea level. On the south it received its main supply from the South Arm. From the west it receives no supply, as all the ice from the upper glacier seems to enter the Taylor Glacier (see Figure 15).

There is no rock outcrop along the Ice Divide which separates the Lower Ferrar drainage from the Taylor Glacier drainage. The older maps showing the so-called Upper Ferrar⁴ draining into the Lower Ferrar are quite incorrect, though it is possible that a little ice may flow almost due north from South Arm into Taylor Valley as Priestley suggests.

In my opinion the two glaciers are "apposed" like Siamese twins. No doubt at some earlier period there was a flow across the divide and at a later date the two moieties, Ferrar and Taylor, will be quite disconnected as they were in the earlier phases of the glacial hemicycle.

THE BEARDMORE GLACIER

No account of Antarctic glaciation should omit some reference to the largest glacier in the world. The

⁴ The so-called Upper Ferrar Glacier is really the upper half of the Taylor Glacier. (See Figure 15.)

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length of the Beardmore is about one hundred miles from Mount Hope at the base of Mount Darwin (see Figure 6). Its breadth varies from about eight miles near the bottom to twenty-five miles at the top. On the plateau the Ice Divide, where reached on the four traverses so far made by means of these outlet glaciers which cut through the horst, is only a few hundred miles from the coast. Hence most of the ice of the Plateau must escape on the other coasts, i.e. to the west of the horst, and not by way of glaciers like the Beardmore. A very noticeable feature is the granite bar or knob of Mount Hope which lies in the outlet of the glacier and is 2,750 feet high. Its origin is obscure. The slope of the glacier is not very steep, being only seven thousand feet in one hundred miles or seventy feet to the mile. Markedly crevassed areas occur northeast of the Cloudmaker ($84^{\circ} 30'$) and southeast of Mount Darwin ($86^{\circ} 40'$). Wright believes that the velocity of the glacier is less than three feet a day in its most swiftly moving part. Little moraine material is visible on the glacier surface. Only small tributaries are received on the west side, but Keltie and Mill glaciers bring large supplies of ice from the east side near the upper portal. It is of interest that cirques occur in the region north of the Cloudmaker, and some of these, in Wright's opinion, have been overwhelmed by the great glacier.

THE HERBERTSON CLIFF GLACIER

This may be taken as a type of the "dendritic" tributary glaciers (see Figure 20). It enters ap-

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proximately at grade, and still supplies some ice to the Ferrar Glacier just south of its snout. Its supply of snow and ice occupies a saddle-hollow or large cirque above the valley slope, down which it descends with some crevasses and falls. It reaches the Ferrar Glacier in a series of large ice steps. Apparently it is strong enough to push the main glacier to one side for about one hundred yards, and it here raises a series of low

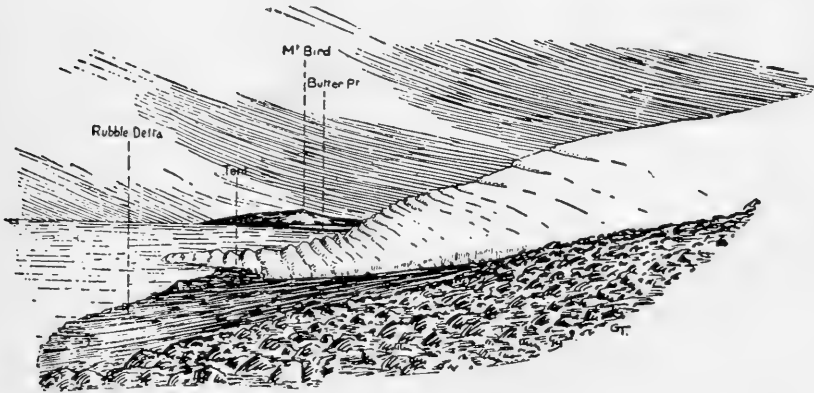


FIG. 20.—THE HERBERTSON GLACIER PRESSING INTO THE FERRAR GLACIER ON THE LEFT.

Looking east from the hill slope.

ridges in the main glacier. However, there are indications that a permanent tide-crack or stream separates the two, and it is in the arrangement of the pressure-ridges that the chief interest lies.

The snout of this small glacier is about one quarter of a mile wide, and along its western side is a well-marked silt-fan or delta. The lower portion of the Herbertson Glacier was at an angle of 27° and it was broken into steps each about twelve feet high. In the

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main Ferrar Glacier there were three or four low ridges due to the lateral pressure, which were about six feet only above the general level and very broad. These pressure ridges in the Ferrar Glacier were directly *opposite* the Herbertson Glacier, and not somewhat downstream as one would expect if the Ferrar were moving. Evidently the Ferrar Glacier is nearly stagnant along this wall, as indeed the ice tongue fixed to Bowers Piedmont a little lower down also indicates.

I have elsewhere drawn attention to the similarity in structure between these "ice-steps" and ridges due to lateral pressure against the Ferrar and the fault blocks and graben of southeast Australia. It may be that pressure from the direction of New Zealand against the resistant shield of Western Australia has broken the Victorian Highlands into a similar series of fault blocks or horsts, as the topography indicates.

GLACIER TONGUES

Four of these peculiar structures were examined by the writer in some detail. Six miles south of Cape Evans is the well-known tongue which is probably the sole example on Ross Island and may therefore be called the Ross Island Tongue (see J, Figure 19). Across MacMurdo Sound is the tongue forming the southeast extremity of the Ferrar Glacier. It differs considerably from the other three in that it is stagnant and asymmetric. In Granite Harbor on the southern coast is the small Harbor Tongue which is connected with the Wilson Piedmont. Finally the most impressive of the four is the Mackay Tongue which occupies

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a large portion of inner Granite Harbor. Much larger examples are known to the north of MacMurdo Sound; i.e. Drygalski in latitude 75° S. and the enormous tongues explored by Mawson's expedition near the Antarctic Circle (66° S.). (See L, Figure 19.)

The chief dimensions, etc., of some of these Tongues are given in the table following:

Name	Locality	Length, Miles	Breadth, Miles	Height, Feet	Origin
Ross Island	nr. C. Evans	now 4	$1\frac{1}{2}$	100	Glacier and drift
Ferrar	$77^{\circ} 39'$ S.	$3\frac{1}{2}$	1 (av.)	50	Chiefly relic
Harbor	77° S.	$1\frac{1}{3}$	$\frac{1}{4}$	20	Glacier and drift
Mackay	$76^{\circ} 57'$ S.	6	2	200	Glacier end
Nordenskjold	$76^{\circ} 10'$ S.	8	2	100	" "
Drygalski ..	$75^{\circ} 30'$ S.	38	14	200	" "
Ninnis	68° S.	80	18	200	" "

THE ROSS ISLAND TONGUE

Early in 1911 this tongue was about six miles long and from one to one and a half miles wide (see J, Figure 19). For a large part it was about one hundred feet above the sea, but this elevation varied considerably, for the surface is by no means level, but consists of a series of regular undulations running across the main axis. The difference in height between the top and bottom of these undulations may be as much as fifty feet. The sides are also as a rule lower than the central axis, and where a furrow reached the side it might be only fifteen or twenty feet above the sea-ice.

The surface of the tongue consisted chiefly of solid ice with comparatively few crevasses on the south side

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but more on the northern side. On the twenty-fourth of January, 1911, I crossed it near the end and noted that it was cracked into large hexagonal areas and I wrote in my notebook, "It is marvellous that it has not gone out." On the first of March, 1911, about one and one half miles broke off and drifted across Mac-Murdo Sound to remain for a while on the western coast near Granite Harbor. (See Figure 8.)

We crossed it again without difficulty about halfway along its length on the eleventh of April, 1911. We found only a few crevasses more than one foot wide. Some areas were much worse than others and small irregular crevasses had made it look like a dish of drying starch. But there was no "Skauk" (or field of crevasses) as at the root of the Mackay Tongue. The snowdrifts piled up against the sides during winter but these were carried away with the sea-ice in the summer. This tongue helps to lock the sea-ice into the bays near its head.

The undulating surface is probably connected with the method of formation of the tongue. Perhaps it is due to the ice "plug" being pushed through a restricted rocky gully or cirque at its root. It is difficult to account for these undulations as due to the blizzard drifts, for the drifts take the form of beautifully smooth wedges. The undulations are from ten to eighty feet high, and there are four or five of them to the mile.

It seemed possible at first that each undulation might be the expression of a year's forward movement, for the motion is probably greater in summer. But this is not the full explanation, for Scott was of the opinion

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that it had not altered much since 1902. Considerable accretions were, however, due to snowdrifts. This was evident in the fresh cross sections of the stranded tongue which we saw later near Cape Bernacchi. The snow sections showed great folds in the layers but were possibly only marginal accretions built up from ancient cornices.

I am of the opinion, however, that the tongue is partly a relic of piedmont-ice buttressed by a submarine ridge or moraine near the coast. For the most part it is floating, as there is no tide crack between it and the sea-ice. In the past it was moving outwards and we see signs of this in the large undulations, but there seems no "driving-power" to cause these nowadays, for there is little ice immediately behind the tongue. Blizzard snows contribute somewhat to its substance, but do not obliterate the deep furrows which form the typical indented margin of the tongue. (The structure of the Drygalski Tongue is referred to in the next section.)

THE ROSS ICE SHELF

This structure has aroused more interest than any other single glacier unit in Antarctica. No colossal sheets of ice of this type are known in Arctic seas, possibly because the temperatures and conditions of snow supply are very different in the north. Little is known of the other two large examples, i.e. the Filchner Ice Shelf at the head of the Weddell Sea, and the Shackleton Ice Shelf near Mawson's West Base (longitude 100° E.). The Ross Shelf occupies the southern

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end of the Ross Sea (see Figure 6). It is triangular in plan and is about five hundred miles wide by five hundred miles deep. The terminal face runs nearly east and west in latitude 78° S. Here it effectively bars the progress of ships and here only is the term Ross Barrier really applicable. This "sea wall" varies in height from six to one hundred and sixty feet above the sea.

The northern edge is floating for most of its extent, as is shown by the fact that the "Nimrod," when moored to the ice, moved up and down with the tide in unison with the ice shelf. Captain Scott in the hut called our attention to the extreme tenuity of this sheet of ice. For if it be assumed that it is about seven hundred feet thick, this is a very small dimension compared with its extent of one hundred and fifty thousand square miles. He compared it in shape to a sheet of paper floating on the surface of the sea. The surface is slightly undulating, but where it approaches land at the margins, or where glaciers enter it, it is thrown into pressure waves some forty feet high and one or two miles from crest to crest. Its rate of movement has been determined from the movement of a depot laid down by Scott in 1903. The rate is about four hundred and ninety-two yards a year in the portion one hundred miles south of Ross Island. Here also it was determined that eight feet two inches of snow (with a density of 0.5) had been deposited in six and one half years.

Sir Edgeworth David has given a good deal of attention to the origin of the Ross Ice Shelf. He bases

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his conclusions largely on the character of the confluent ice just north of the Drygalski Tongue (see L, Figure 19).

Here the Larsen, Reeves, Priestley, and Campbell glaciers all send down ice which unites to form a more or less uniform sheet with the northern edge of the Drygalski Tongue. Strains have produced vertical

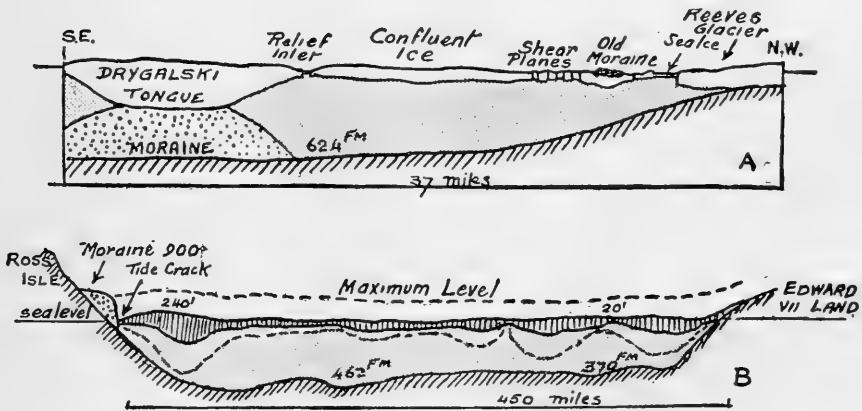


FIG. 21.—A VERTICAL SECTION THROUGH “CONFLUENT ICE” AND DRYGALSKI TONGUE (SEE FIG. 19 AT L). B. VERTICAL SECTION ALONG FRONT FACE OF ROSS ICE SHELF, LOOKING NORTH.

(Both after David.)

cracks in this sheet, and in places it seems to be composed only of thin sea-ice, for David found salt water at the base of certain curious gullies or dongas in the ice surface. In the confluent ice, the thicker portions correspond to where the ice streams enter from the glaciers behind the sheet (see A, Figure 21).

David considers that the Ross Ice Shelf is merely confluent ice on a grander scale. He shows a cross

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section of the Ross Shelf (see B, Figure 21), which suggested that the higher portions of the shelf are sunk deeper in the sea. The highest point noted on the Barrier in 1908 was 240 feet above the sea. If we assume that the density of the ice is eight-tenths that of water, then the lower edge of the ice will be deep sunk in the water as shown in the diagram. If the density is greater (nine-tenths of water), then the lower edge of the shelf is shown by the lower broken line. These higher portions may therefore represent the portions directly fed to the Ross Shelf by huge outlet glaciers of the south, such as the Barne, Shackleton, and Beardmore glaciers. The regions between may be largely composed of snow, which fell on the shelf, or in part of frozen sea-ice. He compares the whole structure to a shield formed of a wickerwork frame and covered with hide. Here the rods represent the glacier tongues, the smaller osiers the pressure-ridges, while the drift and fallen snow represent the hide. This theory agrees with the section shown in Figure 19 at N. Obviously portions of the Ross Shelf may resemble (or have formerly resembled) Figure 19 at M. Where Amundsen's and Byrd's headquarters are situated, it seems likely that the structure locally is like Figure 19 at O. The whole front has retreated about thirty miles since the survey of Ross. At the Ice Flood Epoch it is likely that the Barrier was one thousand feet above sea level, and at that time it was probably resting largely on the sea floor. This point is also discussed in the next chapter.

CHAPTER VIII

OCEANOGRAPHY AND SEA-ICE

BATHYMETRY

IN the following brief account of various characteristics of Antarctic oceanography obviously only a few of the leading features can be discussed. Perhaps the most complete work in this field is that done by the German expedition of 1902 under Professor Drygalski, and much of the following data on currents is derived from his research. The effect of conditions in Antarctica upon the climates of the settled lands of the world, more particularly those in the south temperate areas, is profound. We have seen that with the exception of the South Victoria Horst, the continental coast as a whole consists of the icy margins of the huge Ice Cap which end in abrupt walls. From these margins break off the great tabular icebergs, to be considered later. Fringing these walls in winter is a belt of pack ice, which breaks away in summer and is carried north to chill the waters of the South Pacific, South Atlantic, and South Indian oceans. Currents carry this chilled water almost to the equator, notably on the western coasts of the southern continents. There is every indication, that the changes from drought years to good years in southern settlements are in no

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small degree controlled by the train of events in distant Antarctica.¹

Mawson has pointed out that soundings are especially valuable in connection with the possibility of islands in Antarctic waters. Where sea and land are covered with ice it is very easy to miss an island, but soundings should show where such land-forms are probable. (I have already referred to the shallow soundings near the site of Wilkes' doubtful landfalls.) Sonic depth-finders, using electrical signals and the time of return of their echoes, are especially suited for such work. Moreover, the delineation of the submerged continental shelf gives a real indication of the boundary of the rock areas beneath the great continental ice cap, and this again can be ascertained with some accuracy by careful soundings.

The soundings in East Antarctica reveal some curious features. I have based the diagrams in Figure 22 on that invaluable map published in 1928 by the American Geographical Society. The shelf around Antarctica seems to be submerged distinctly deeper than those around most other continents. Off the Weddell Sea the sharp angle between the gentle continental slope and the steep dip to the abyss lies between six hundred and one thousand meters below the surface of the sea. In the diagram the submarine contour for five hundred meters is charted, so far as our data permit, for three especially interesting regions. In general this contour

¹ See my discussion, "Climatic Relations Between Antarctica and Australia," *Problems of Polar Research* (Amer. Geog. Soc., New York, 1928).

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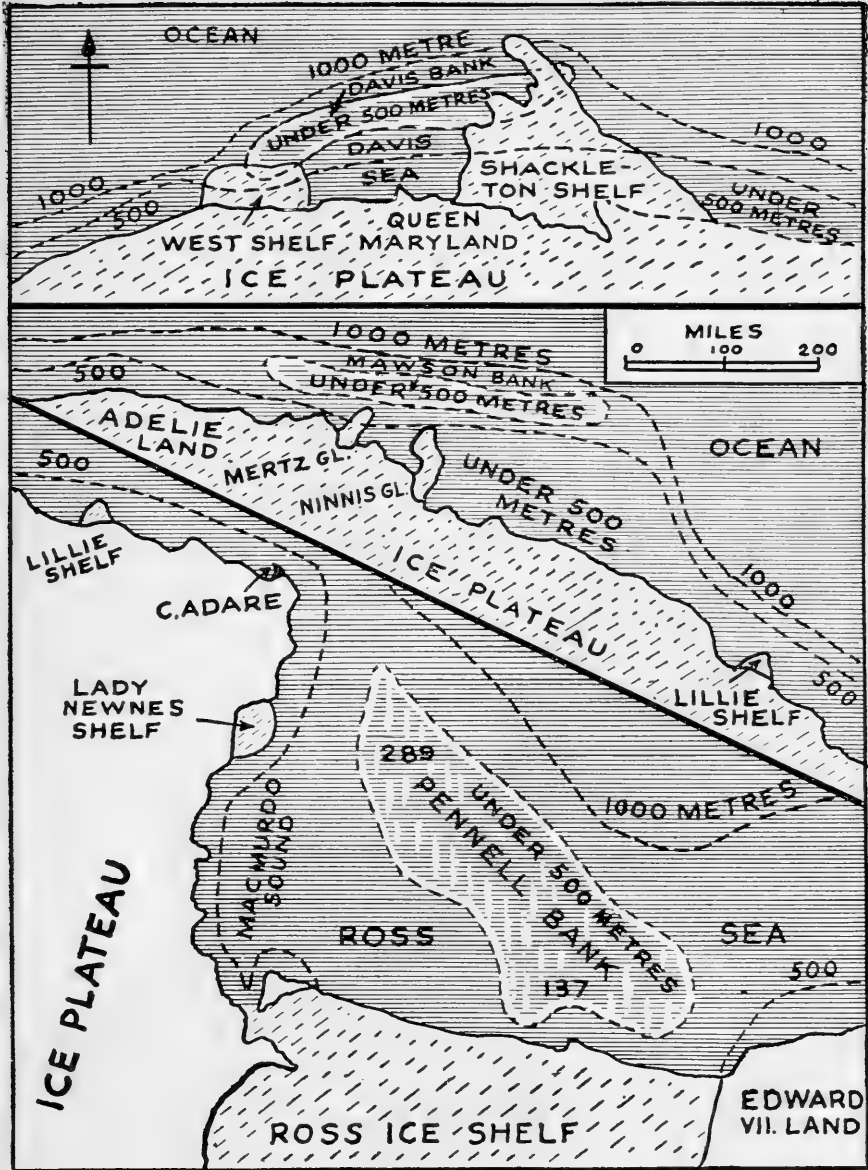


FIG. 22.—BATHYMETRIC MAPS OF EAST ANTARCTICA.

(Based on the large map produced by the American Geographical Society in 1928.)

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lies less than fifty miles from the coast, or at any rate from the edge of the ice cap. But in the three localities mapped, off Queen Mary Land, off Adelie Land, and in the Ross Sea, these shallow soundings extend much farther out to sea. Furthermore, in all three cases there is deeper water separating a more or less wide submarine ridge from the coastal shelf. Off Queen Mary Land this ridge is three hundred miles long and thirty miles wide. A similar structure with similar dimensions lies off the coast of Adelie Land. A large part of the Ross Sea is unusually shallow for southern waters. Here a large submerged plateau or bank 500 miles by 140 miles extends from Cape Adare to Edward VII Land, with several knobs on its surface which approach within some 250 meters of the surface. I have ventured to name these interesting land-forms after Captain J. K. Davis, Sir Douglas Mawson, and Commander Harry Pennell, R.N. The latter commanded the "Terra Nova" on her Antarctic voyages, carried out much oceanographic work in the Ross Sea, and died in command of his ship early in the World War.

The reason for this condition of the sea floor is not obvious. Possibly these shallow areas, which roughly fringe the continent, are of the nature of vast terminal moraines, deposited when the great ice sheet extended from one to three hundred miles farther from the Pole. It is rather a coincidence that the largest ice shelf and the largest glacier tongues are associated with these abnormally shallow seas. Thus off Queen Mary Land is the Shackleton Ice Shelf, which ends in an ice

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tongue two hundred miles from the main Ice Cap (see Figure 22). At the other end of the submerged ridge is a large ice shelf to the west of Davis Sea. Off Adelie Land is that curious pair of giant tongues, the Mertz and Ninnis glaciers, of which the latter is so irregular that it has some of the appearance of a relic of a sheet of ice shelf. So also the great Ross Ice Shelf lies just south of the submerged plateau of the Ross Sea. At the Ice Flood Epoch possibly the sea waters

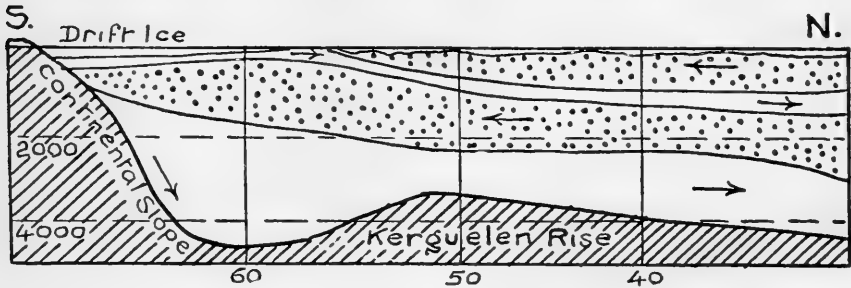


FIG. 23.—VERTICAL SECTION OF OCEAN NORTH OF GAUSS-BERG, SHOWING STRATIFICATION OF WATER.

Warm waters are dotted. Depths in meters. (After Drygalski.)

were locked up in the enlarged ice cap to such a degree that the shallowest part of the Pennell Bank was only two hundred feet below the then level of the sea. There is little doubt that the much larger Ross Ice Shelf at that epoch would be driven high out of the water over this shallow bank.

OCEAN CURRENTS

Drygalski shows that the effective cooling of Antarctic waters is confined to certain layers of the southern ocean. He gives a section of the Indian

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Ocean, from Mauritius to the Gaussberg (approximately along longitude 80° E.), which I reproduce in the adjoining figure. There is seen to be a massive intermediate layer of warm water from the tropics, which separates cold layers above and below both flowing from the Antarctic to the equator. There is an upper cold layer (of temperature -1.8° C.) about four hundred meters thick which gradually sinks below the warm surface waters to the north of 55° S. latitude to a depth of one thousand meters. Then, below this is a layer of tropical water possibly some two or three degrees warmer which is about 1,200 meters thick. Then below this again, reaching to the bottom, 4,000 to 5,000 meters, is a mass of somewhat colder "bottom water" due to a mixing of the very cold upper layer with the tropical water. It is slowly making its way toward the equator. The warm layer reaches to the shoulder of the continental shelf, but does not touch the icy walls of the ice-cap some fifty or one hundred miles farther south. Its salinity is considerably higher than that of the cold layers. There is a thin indefinite layer of surface water, which differs from place to place in regard to temperature and salinity. It is derived in part from the melting of pack ice and icebergs.

The dominant winds play a great part in the direction of the upper layers of water. Around the Antarctic these blow fairly steadily from east to west. The Ferrel Effect also tends to deviate the currents to the left. Hence this cool surface layer about two hundred meters deep tends to hold the drift ice together, and to keep it near the continent. As regards deep sea

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deposits, there is a special southern zone of glaciomarine sediments, which have been deposited from glacier ice, icebergs, etc., during several hundred thousand years. This zone extends as far north as the ice drifts. Diatoms are very plentiful in Antarctic waters but they are shrouded by the larger bulk of the glacial débris. However, just north of this latter zone is a belt of diatom-ooze, which in its turn extends somewhat farther northward below cold currents. The warmer waters supply globigerina (foraminiferal) ooze, and this extends farther south below warm currents. To quote Drygalski, "the distribution of the bottom sediments furnishes evidence of the development of the present and former currents."

FORMATION OF SEA-ICE

According to C. S. Wright, the first stage in the formation of sea-ice in the open sea is the production of myriads of small ice plates in the body of the water. These form a thick scum, and are akin in origin to the frazil ice which forms in fresh-water rivers, or attached to ropes in cooling sea water. The ice is much less saline than the sea water, and the saltier water is squeezed out, as it were, and sinks. This frazil ice appears on the surface of the Antarctic seas about the end of March. The crystals are squarish in shape and up to half an inch across. The layer of horizontal plates grows thicker and forms a feltlike mass. It is not rigid owing to included layers of salty liquid. The writer vividly remembers Captain Scott jumping up and down on new sea-ice, only three or four inches

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thick, to test its strength. The ice undulated like rubber, but did not break.

Later ice crystals in the sea develop as vertical plates having a somewhat triangular form. Often there is a layer of square plates about two inches thick above a layer of more or less vertical plates which is some eight or ten inches in thickness. It is these wedges of vertical plates which give rise to the fibrous appearance of new sea-ice, and this is partly due to the layers of air entangled between the crystals. A very important result of this structure is that sea-ice tends rather readily to break into cakes along these vertical planes of weakness. On the under side of older ice there is a great tendency for melting to occur irregularly. Holes one or two inches deep penetrate the ice, primarily along these planes of weakness, where the ice is particularly saline.

David and Priestley recorded the history of the sea-ice in MacMurdo Sound off Cape Royds in 1908. At the end of February Pancake Ice developed from countless ice crystals which had given the sea the appearance of paraffin wax. "Little by little these crystals felted themselves together into small cakes, which jostled by the gentle breezes continually collided along their growing edges. The latter being very flexible became gradually turned up to form raised rims, and the whole pancake became slightly saucer shaped." Often a large pancake would be formed from a lot of little pancakes jammed together.

Very curious structures called "ice flowers" develop during a sudden fall of temperature, when the sea-ice

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freezes rapidly. On March 16th the sea was at a temperature of 20° F. while the air was about 6° F. The sea was covered with frost smoke "as though it had been boiling." On March 19th the temperature fell to -9° F., the surface froze rapidly, and a splendid crop of "flowers" resulted. Later as the temperature rose the centers of the flowers melted, for they were formed of saline solutions squeezed up from below, while the "tips" of the flowers persisted longer as they were due in part to the frost smoke. Some of the "petals" of the flowers were plates two inches across.

The ice over MacMurdo Sound was nine to ten inches thick during the early days of March, 1908, but blew out with the blizzard mentioned above. The next ice layer grew to a thickness of eighteen inches, when it was removed early in April, except a patch which held in near Cape Royds. A few days later the final freezing occurred which persisted all the winter. The sea-ice was about five feet thick at the end of July, and grew to a thickness of six or seven feet by the end of September. Thereafter the cold air had no great effect on the water beneath the ice, which protected it from further cooling. It stayed at a temperature of about 29° F. although the air only six feet above it was at a temperature of -51° F., i.e. 80° colder. During the winter I often thought that a diving-bell would be a very comfortable dwelling place, at any rate as far as temperature was concerned.

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BAY ICE OR FAST ICE

The general principles governing the formation of bay ice are much the same as in the case of pack ice. But owing to the proximity of land, a number of special forms are developed. These include pressure ridges, shear cracks, and cloven-hoof ice. The ice foot also may be briefly considered here. All these features were well shown in Granite Harbor, from which the following examples are taken.

A prominent feature in the sea-ice (near land) is the presence of permanent breaks to which Scott and Wilson gave the name "shear crack." These are due primarily to the tension in the sea-ice existing between two islands, or an island or cape or an ice tongue and cape. The sea-ice is of course raised or lowered by the tide, and is affected no doubt by currents and winds to a lesser degree. Thus there were numerous fairly permanent examples off Cape Evans. Their features were all much the same. The two edges of the broken sea-ice (somewhere near six feet thick) would grind together and large fragments would fall between the moving masses. In places the adjoining edges were pressed together so strongly that the edges upturned, forming a wall of ice six feet high. Even in the middle of winter one could always see open water in these shear cracks, which were accordingly favorite places for seals.

An interesting series of nearly a dozen shear cracks due to the pressure of the Mackay Tongue was observed in Granite Harbor. They are shown in Figure

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24. The Mackay Tongue moves in summer nearly a yard a day. Such motion obviously prevents bay ice from being locked to the land, and makes it probable that much of the bay ice is not more than a few seasons old. The crack running northwest from Cape Geology was up to twenty feet wide in places with islands of ice floating within it, which made it possible to cross

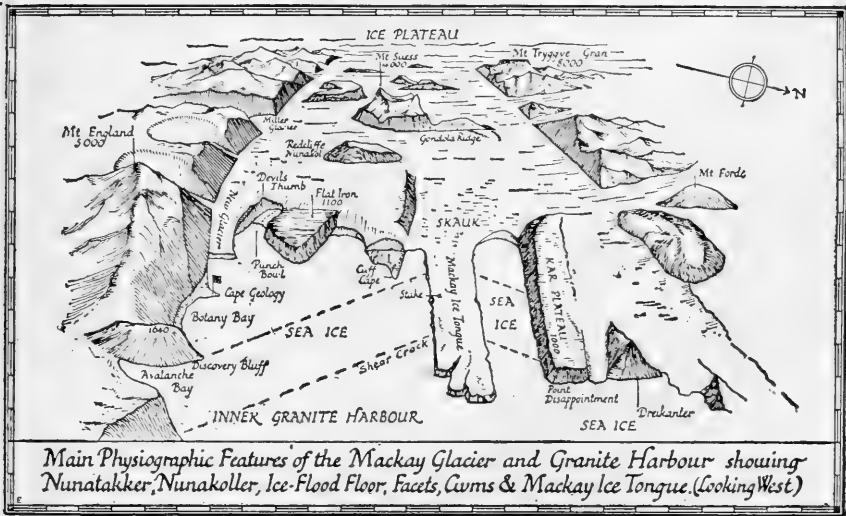


FIG. 24.—BLOCK DIAGRAM OF GRANITE HARBOR.

(By permission of John Murray.)

with sledges. Some cracks had peculiar deeply serrate edges which indicated where they had been torn apart by the tension.

PRESSURE RIDGES

These were very interesting structures due to the pressure either of land-ice or sea-ice upon capes, etc. The writer made a careful study of a set of fifteen

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such ridges just off Cape Geology (see Figure 24). They were from one hundred to three hundred feet long and from three to ten feet above the level of the ice. Each ridge closely resembles a capsized canoe, and they recall the earth folds in the Juras or Appalachians. Between the ridges were their complements, the Pressure Pools, where the sea-ice was warped down below water level. The largest ridge was where the pressure was greatest, i.e. where Cape Geology projected farthest. The ridges were parallel to each other, with their axes about northeast-southwest, or nearly at right angles to the shear cracks described above. This six-foot ice can be buckled into remarkably sharp folds—but usually the apex of the fold cracks under the strain. These ridges changed somewhat in form during the month we were surveying Granite Harbor. Other examples have been noted on a larger scale where the Ross Ice Shelf presses onto Cape Crozier, and just south of Cape Evans where a small glacier enters the Bay Ice near Turk's Head.

In very sheltered bays, such as the drowned Punch Bowl cirque in Granite Harbor (just southeast of the Flat Iron in Figure 24), or again on the southeast side of Cape Roberts, I came across peculiar forms of bay ice, which do not seem to be described elsewhere. Here a mass of old ice shaped just like a hoof has been driven up into the bay presumably by pressure from the later sea-ice. In accommodating itself to the smaller width of its new position it has split down the center, hence the name Cloven Hoof. In the Punch Bowl cirque the sheet of ice was about six hundred yards

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wide and eight hundred yards long along the central split. The inner end had been shoved up some six feet by pressure from the east. The whole structure was floating. Another example occurred just southwest of Cape Roberts. (See Punch Bowl, Figure 24.)

ICE FOOT

This structure is a narrow shelf of ice adhering to the coast line. It varies in width from a foot or two to a belt of ice one hundred yards wide. It forms best on shores which have a gentle slope, and roughly speaking the width depends on the extent of shallow water within the one-fathom line.

Its formation is closely bound up with the position of the tide crack, and with the direction of the prevailing winds. As the sea-ice becomes thicker the distance of the tide crack from the shore tends to become larger, for the maximum shear in the ice is, of course, just where the moving sea-ice reaches the solid rock.

The sea-ice between the tide crack and the rock is, of course, held firmly by its attachment to the latter, and this fixed belt of sea-ice constitutes the ice foot.

From the above considerations it will appear that the ice foot is in general wider where the shore is shallow, and this is generally true. Also where the shore consists of a vertical cliff there is rarely an ice foot, and the reason is obvious, for the cliff itself forms the logical boundary between moving ice and fixed coast.

But the above simple explanation is complicated by the action of wind and spray. In gales, when the tem-

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perature is well below 28° F. (the freezing point of sea water), the water congeals as soon as its motion is arrested, and this occurs when it has been dashed on to the ice foot. The natural consequence is that on all exposed coasts the ice foot becomes much thicker, often much broader and in general much less level and less like an esplanade.

Since the ice walls at the front of a glacier are almost universally vertical, when they happen to reach the sea, there is never an ice foot along a glacier coast.

Moreover, there is a very considerable elasticity in a glacier, even though it be five hundred feet thick. Hence there is usually no tide crack at the distal end of a floating glacier tongue. As the proximal end is approached, where it merges into the fixed ice over the land, the tide crack begins to appear and close to the root of the tongue it is as wide and striking a feature as along a fixed piedmont glacier or a rock coast.

WIDTH OF THE PACK ICE

This varies very greatly from year to year, and this is perhaps the chief difficulty in determining programs of an expedition's work. Thus the "Nimrod" in January, 1908, met with no pack at the mouth of the Ross Sea, though enormous fleets of bergs were passed in the latitude of the pack. In December or January the pack ice is here found between latitude 66° S. and latitude 72° S., though these limits have been exceeded at times. When the "Terra Nova" entered the pack on the ninth of December, 1910, we hoped to be through it in a few days. But we were still within it on

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Christmas Day, and at times the ship (in spite of all its buffeting of the pack) was farther from Antarctica on a succeeding day owing to the general northward drift of the pack. On the twenty-seventh of December we were still drifting aimlessly in the thick pack, for Scott was afraid to waste coal by raising steam if no sign of a "lead" were apparent. However, towards the evening of the twenty-ninth we began to hope that the pack was showing similar features to those we met on entering. Very beautiful were some of the piled-up pressure-blocks. I remember one of the nature of a glacier-table. A flat-domed slab some three feet across was perched on a slender support above the floe. Pendent from the table were numerous long icicles, consequent on the warm weather. The lower surface of the table owing to repeated reflection was a beautiful ultramarine, which was seen through a curtain of icicles. The whole structure reminded me of one of those resplendent medusæ which float placidly on a tropic sea with their tentacles hanging from the fringe of the "umbrella."

Hereabouts the floe became thinner and more uniform. It was broken into wide subangular pieces with vertical sides, and at nine o'clock we entered a wide lane where the calm water of the "leads" was replaced by short choppy waves. Then we met an area of "pancake ice" with rounded outlines and upturned edges, and finally just at midnight we crossed several belts of east-west brash ice and at long length entered the open Ross Sea in latitude $69\frac{1}{2}^{\circ}$ S. We had traversed

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490 miles of ice, though the average is 288 miles at this season, while in 1915 the "Aurora" only met with one mile of pack.

As experience in traveling through the pack ice has accumulated, it is clear that the worst conditions occur

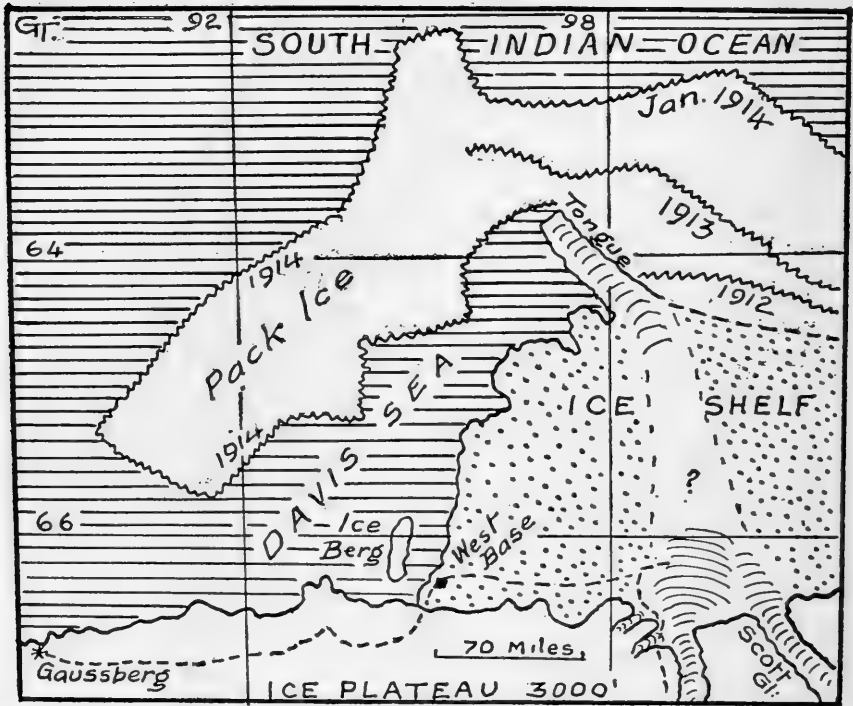


FIG. 25.—VARIATIONS IN WIDTH OF PACK ICE OFF QUEEN MARY LAND.

Note the Shackleton Ice Shelf, possibly buttressed by glacier ice. (After Mawson and Davis.)

on coasts facing the east and the dominant winds. The drifts of the three ships, the "Deutschland," "Endurance," and "Aurora," show clearly that the ice moves to the northwest and tends to pile up on the west coast of the Ross Sea and on the west coast of the

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Weddell Sea. This led to the "marooning" of Scott's northern party at Terra Nova Bay in 1912, and made it impossible to pick up the writer's western party on the same coast—though the latter party managed to get back the shorter distance to the hut before the advent of winter. It seems clear that ships entering either of these seas should keep down the east side of the seas, where open water remains much later than on the western side.

As Priestley points out, the weather which produces most pack ice is rather a *stormy winter* than a cold winter. In Robertson Bay he watched pack ice forming and then being blown north again and again. He states that sufficient ice to fill the Bay at least five times was produced in 1911. In a *calm* cold winter, only *one layer* of pack ice is formed and then freezing practically ceases. It seems likely that the excessively windy conditions of 1911, 1912, 1913 would result in an unusual width and massiveness of the pack ice. Captain J. K. Davis reported continual broadening of the pack ice off Adelie Land and westward between 1912 and 1914. This is shown in the annexed figure, and elsewhere (see footnote p. 158) I discuss the bearing which this change in the volume of the pack ice may have on the climate of Australia.

Turning to the other side of Antarctica a valuable table has been compiled by R. G. Mossman² which shows how the bay ice varied in Scotia Bay in the South Orkneys during the twelve years 1903 to 1914.

² See the *Geographical Journal* (London), December, 1916.

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This is in latitude 61° S. and the bay is two miles wide and faces to the southeast.

YEAR	SCOTIA BAY CLOSED	MONTHS
1903.....	April to November	8
1904.....	May to January	9
1905.....	May to September	4
1906.....	June to December	7
1907.....	June to January	8
1908.....	July and August	2
1909.....	June to October	5
1910.....	August to November	4
1911.....	July to September	3
1912.....	June to January	8
1913.....	June to November	6
1914.....	June to December	7

ICEBERGS

On the evening of the eighth of December, 1910, in latitude $63^{\circ} 30'$ we saw our first icebergs in the shape of two silvery pyramids glistening in the setting sun. This was about seventy miles north of where we met the pack ice. At two o'clock on the next day there were twenty-seven bergs visible, and this number rather decreased as we moved south. The bergs expose more surface both to currents and winds than does the pack ice, which is the reason why they outstrip the pack ice in their march to the north. Occasionally a berg reaches Australian waters, and one was seen right in the Australian Bight by Captain Grant Smith (in 1926, I believe). In Arctic seas there are practically no icy coasts as in Antarctica, and the bergs are the result generally of the outflow of relatively small glaciers.

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Hence they are much more irregular and crevassed than the southern tabular bergs. Still the southern examples are often *tilted*, owing to fragments breaking off asymmetrically; or they may be *domed* and derived perhaps from the undulations of a small glacier tongue. Many of the bergs are traversed by huge vertical cracks, between which portions seem to have slipped down—forming “graben,” in geological language. (These cracks originated in the land-ice as already shown in Figure 21.) On one occasion I saw a huge isolated column rising one hundred feet into the air just like the “Old Man of Hoy” and like that rock resulting from wave erosion acting on vertical cracks. It was attached to the adjacent tabular berg by the submerged “ram” of the iceberg, which is such a danger to shipping. Often the cracks weather into caves.

Many bergs are grounded near the Antarctic coast and several of these were closely examined near Cape Evans. The wonderful Tunnel Berg, of which the photograph by Ponting has so often been reproduced had a varied life history. When we first saw it in January, 1911, the berg projected about one hundred feet above the sea-ice and was pierced by an oval tunnel about fifty feet high and twenty feet across. I have little doubt that this picturesque tunnel was a thaw-water channel (cut out of the original glacier) of the same type as we saw on the Koettlitz Glacier. This mass of ice broke away and floated so that the “bedding planes” (as we may term them) were now nearly vertical, as also was the tunnel. During the winter we may assume that a large fragment broke off the south

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of the berg, and so it had taken up a new position by September. The old water line on the berg is usually indicated by a smooth concavity cut by the waters under the surrounding pack ice.

No bergs seen in the Arctic rival those of Antarctic seas in size. On the last voyage of the "Terra Nova" in January, 1913, Captain Pennell passed close to a berg twenty-one miles long (in latitude $64^{\circ} 15' S.$). But perhaps the largest recently seen was that measured by Mawson in 1912 off the Mertz Glacier, which appears to have been forty miles long. It was seen again next year about fifty miles to the northwest of the glacier. Most of the bergs are formed of "cloudy bubbly ice" (in Priestley's phrase) of which the typical ice tongues are formed. The ice is, however, often stratified showing its origin as snow in the distant past. But sometimes true bergs formed of *névé* were seen. Here the ice consists of loosely coherent grains, each about one-sixth of an inch in diameter, with much air between.

Priestley has classified icebergs into the following groups :

- (a) *Tabular bergs*, derived from ice shelf or tongue
- (b) *Glacier bergs*, irregular, broken by crevasses
- (c) *Unconformity bergs*, partly blue ice, partly *névé*
- (d) *Ice Island bergs*, domed bergs easily mistaken for islands
- (e) *Névé bergs*, from regions of unusually heavy snowfall
- (f) *Weathered bergs*, overturned, irregular and of obscure origin

CHAPTER IX

CLIMATOLOGY

POLAR CLIMATES

ALL the expeditions in this century have realized the paramount importance of a knowledge of the meteorology and climatology of the Antarctic. Among these the Belgian expedition included Arctowski, the French expedition Rouch, the German expeditions Bidlingmaier and Barkow, the Scotch expedition Mossman, and the Swedish expedition Bodman. The British expeditions have been accompanied by L. Bernacchi, Sir Edgeworth David, G. Ainsworth, and especially G. C. Simpson. The writer went south as a government official in the Commonwealth Weather Service and was in charge of the station while Simpson was sledging. C. S. Wright carried on the work during 1912. As mentioned previously the chief aim of Sir Hubert Wilkins' expeditions is to make preparations for a complete meteorological survey of the Antarctic continent.

While the Antarctic climate has a great bearing upon the climates of the southern continents, the latter are so far distant that there is no similarity in the climates themselves. Thus Africa is 2,400 miles away, Australia 1,800 and America about 1,100 miles from the main mass of the southern continent. As re-

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gards data we have lengthy records from the South Orkneys (61° S.) where a station was founded by Bruce in 1903 and has been maintained since by the Argentine Government. Within the Antarctic realm the longest records come from MacMurdo Sound, where so many expeditions have now wintered. Cape Adare and Adelie Land each have two years of records. Near Gaussberg we have Drygalski's and Wild's records and near Framheim, Amundsen's and Byrd's. The Weddell Sea has a number of records mostly kept on shipboard except for those associated with the Swedish expedition. The weather in the seas and coasts west of Graham Land has also been recorded, with intervals, over a number of years. (These are shown in Figure 34.) For the vast bulk of Antarctica we have no records.

We may perhaps commence the discussion of the South Polar climate by considering what a polar climate means, and whether the Antarctic climate is as severe as that of the Arctic. There are a number of criteria which may be considered as defining a polar climate. They are more often considered in the northern realm than in the southern. For instance, in Arctic regions one good standard is the *absence of any real tree growth*. Since there is not only no tree growth, but also no growth of any thing higher than a moss in Antarctica, it is clear that we cannot usefully employ this criterion in the south. Mecking¹ has devised a formula which considers the warmest and coldest months at a locality in determining if it has a polar

¹ Geography of Polar Regions, p. 73, New York, 1928.

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climate. This formula is $W = 9^{\circ} - 0.1 C$. Thus in Siberia if the coldest month (C) has a temperature of -40° C., then (by substitution) we see that the warmest month (W) of the place can be $(9 + 4)$ or $+13^{\circ}$ C. and yet it may be included within the polar belt. In Staten Island (near Cape Horn) the coldest month is $+2.5$, so that the warmest should be $(9 - 0.25)$ or 8.75 , which is a trifle colder than the hottest month at Staten Island. It is therefore just *outside* the polar climatic area. At Cape Farewell (Greenland) the coldest month is -5.7° , the hottest $+6.2^{\circ}$ C. It falls within the polar climates, though here birches and willows grow in "forests" to the height of over twelve feet. Some climatologists accept a summer temperature of 9° C. (or 48° F.) as limiting polar regions. This isotherm is plotted in Figure 26 at A and we see that all Antarctica and the surrounding ocean fall well within it. Furthermore the area with a summer temperature lower than this is much larger in the South Polar regions than it is in the north. (See B, Figure 26.)

Considering the northern and southern regions, there is no comparison in the general environments owing to the absence of all plant life in Antarctica; there is no land animal life (excluding a few insects) and therefore no human settlers if we may except a few explorers! Yet the average annual temperatures are not very different, while northern Siberia has colder records than anything experienced by explorers in a southern winter. The whole difference lies in the summer temperatures and this is best indicated in the diagrams

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shown herewith (see Figure 26). Since most life hibernates during the winter in polar regions, it is of relatively little importance how cold the climate in this season becomes. Hence the very large area with a

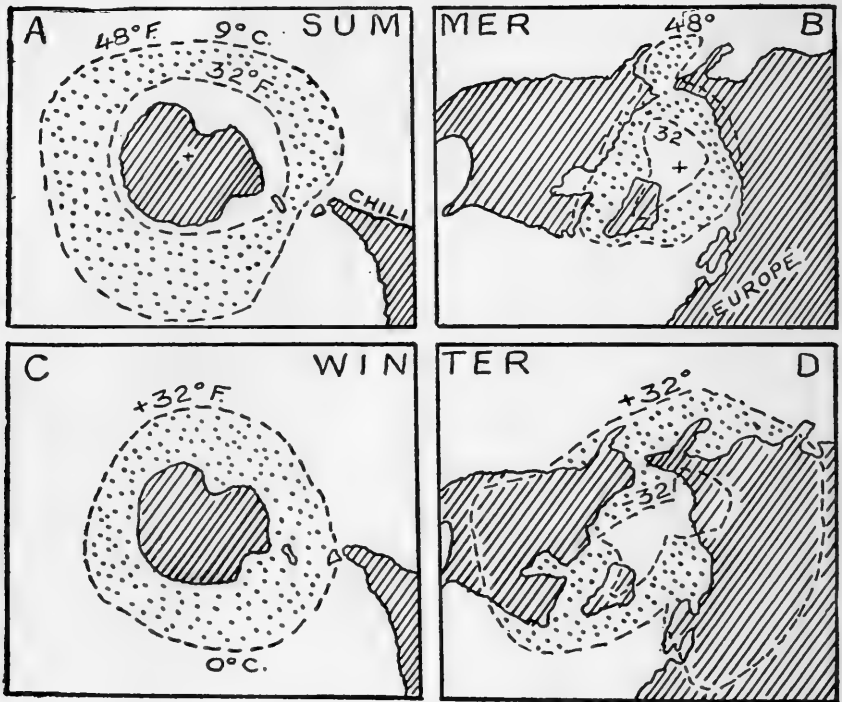


FIG. 26.—SUMMER AND WINTER TEMPERATURES IN ANTARCTIC AND ARCTIC REGIONS.

Compare isotherms of 48 deg. F. in A and B, showing the very cold summer in the Antarctic. (After G. Philip.)

temperature below freezing in winter around the North Pole (see D, Figure 26), has little effect on animal or plant growth.

We have no data as to the temperatures in the heart of the Antarctic continent except in midsummer. The

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two parties at the South Pole around the New Year 1911-12 experienced temperatures of -22° F. and -28° F. This record was taken at an elevation of about nine thousand feet. It seems certain that the annual *range* of temperature in the heart of a continent will be much greater than that recorded on the coast at Cape Evans. The annual range at the latter is about 45° F. Perhaps we may therefore assume that the July temperature at the South Pole is about -60° F., which is much the same as that of the coldest place in Siberia (Verkhoyansk -59° F.). Probably the highest point on the Queen Maud Range (some six thousand feet higher) is the coldest place on our earth, as I indicated in my discussion of this problem in 1920 (see my *Australian Meteorology*, Figures 50 and 51). These very cold temperatures are of course like those of the "isothermal layer" (or tropopause) which lies some six miles above us in temperate lands. Above this height the drop in temperature of the outer atmosphere is only very gradual with increased height.

GENERAL SOUTHERN CIRCULATION

In the southern hemisphere it has long been known that the region is dominated essentially by two belts of low pressure and an intermediate belt of high pressure. Thus Hann records the average pressure near the equator at 757.9 mm. From here it increases as we move south to latitude 30° S., where it is a maximum (for the world) of about 763.5 mm. Proceeding south again we find that by far the lowest *average* pressures occur about the Antarctic Circle, somewhere

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about 739.7 mm. It is also well known that these belts are to a considerable degree the tracks of moving eddies (cyclones and anticyclones) which in general move to the east round the earth at varying rates averaging perhaps four hundred miles a day.

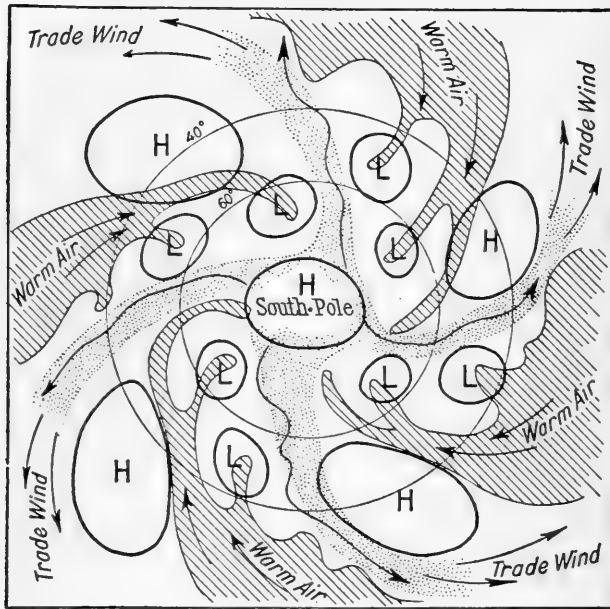


FIG. 27.—ATMOSPHERIC CIRCULATION IN THE SOUTHERN HEMISPHERE SOUTH OF THE TRADE WIND BELT, ACCORDING TO THE "POLAR FRONT" THEORY, SHOWING THE BELT OF LOWS (L) SURROUNDING THE ANTARCTIC ANTICYCLONE (H).

(Slightly modified from E. Kidson.)

It is when we consider the world circulation to the south of the Antarctic Circle that our data become sparse and rather difficult to interpret. In the older books it was assumed that the pressure fell off to a minimum near the South Pole. When the presence

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of a huge icy plateau at the Pole was demonstrated, it seemed likely that this intensely cold region would

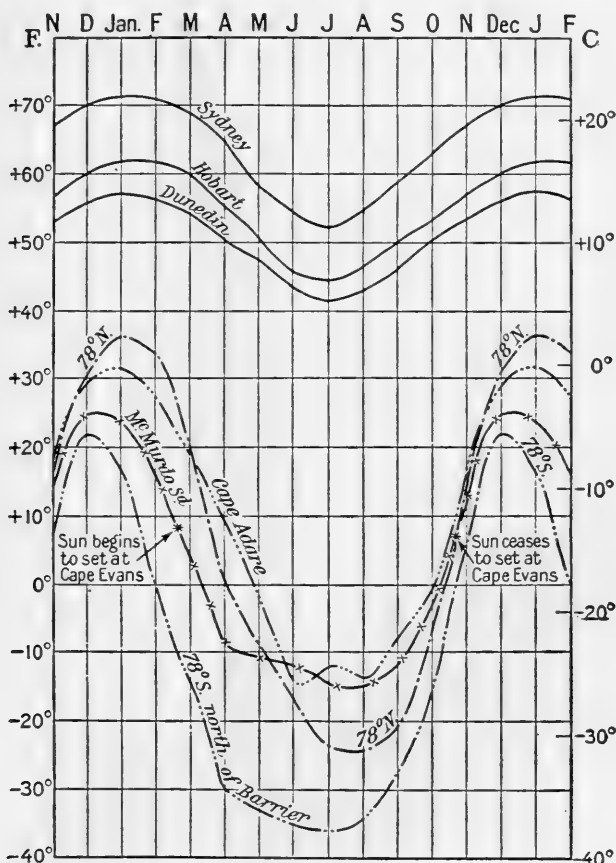


FIG. 28.—MEAN MONTHLY TEMPERATURES AT CERTAIN AUSTRALIAN AND ANTARCTIC STATIONS.

For comparison the mean monthly temperature in 78 deg. N. is also given. (Antarctic and Arctic values from Vol. I, pp. 84-85, of report of G. C. Simpson. From *Geographical Review*, 1928.)

exhibit a fairly permanent high pressure control and this still seems to be the dominant control close to the polar surface. But considerations of wind circulation in the upper air in Antarctica and of the precipitation

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TEMPERATURE IN

Year	Place	Lat.	Jan.	Feb.	Mar.	Apr.	May
1911....	Cape Adare	69	+29	25	20	+ 9	0
1911....	Cape Evans	77	+22.4	+19	+ 7	- 1	-11
1911....	Framheim	79	+14.5	+ 4.2	- 6	-17.5	-31.5
1903....	Snow Hill	64	30	25	13	8	- 2
1904-7..	S. Orkney	60	32.5	33.1	31.6	27.5	19.6

of snowfall over the interior of the Plateau make it unlikely that this is a complete solution of the problem.

Captain Kidson has applied the fruitful theory of Bjerknes to the question of Antarctic circulation, and he pictures these two belts of anticyclones (along 30° S. latitude) and cyclones (along 60° S.) as developing along the margins of inflowing and outflowing currents of air (see Figure 27). These latter maintain the interchange between cool dry air from the Pole and warm moist air from the equator, and the cyclones develop as eddies where the polar front moves alongside the tropical front. This whole series of eddies and currents probably is to be conceived as moving round the Pole *en masse* from west to east, while the winds composing the highs (or anticyclones) rotate counterclockwise about its center (and vice versa for the lows or cyclones). If his scheme is correct, there may be a real connection between the blizzard winds and the southeast trades. For (as I suggested in 1920) as regards direction and relation to dominant pressures, we might quite reasonably describe the characteristic "southeasters" of Antarctica as the "polar trade winds."

Summarizing the winds of the southern hemisphere,

CLIMATOLOGY

THE ANTARCTIC

June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
-16	-15	-14	- 2	+ 2	+20	+28	+ 7
-13.5	-21	-21	-16	- 3	+12	+22	0
-30	-33.5	-48.5	-35.5	-11.5	+ 4	+20	-13.5
- 4	- 6	- 3	+ 4	13	17	29	
15.3	9.7	15.2	19.2	25.1	29.4	30.6	24.1

we find the southeast trades blowing fairly steadily about latitude 20° , along the northern side of the belt of rotating highs which move to the east in latitude 35° . To the south of this belt is a region dominated by the Brave West Winds, which blow along the northern side of the series of Antarctic lows. The latter appear to move to the east along latitude 60° , but we have no accurate data, as few ships sail so far south. South again of this belt of cyclones or lows is the domain of the Antarctic southeasters, which are dominant all round the margin of the southern continent. This, indeed, has been demonstrated by studies of the movements of the pack ice. In Antarctica proper the winds are variable, the strong blizzards always blowing from the south or southeast but in places lighter northerly winds are common. On the Great Plateau we have only records of a few summer journeys, but the snow ridges (sastrugi) give some clue to the dominant winds of the year.

GENERAL CLIMATIC ELEMENTS

It is not possible to give more than a brief discussion of the temperature, pressure, precipitation, and wind

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conditions. I shall confine my attention principally to the conditions on Ross Island, which have been observed longer than in any other place so far south as 78° S. The temperature changes are shown graphically in the graphs in Figure 28, based mainly on G. C. Simpson, where a record for 78° N. is added for comparison with 78° S. (of course with months changed as required). It is seen that the southern locality is nearly 20° F. colder in summer, autumn, and winter though in spring the temperatures are much closer.

Temperatures varied very greatly within fairly short distances near Ross Island. Thus in the winter of 1911 Wilson's party on the Barrier on July 6th experienced -76° F., while at Cape Evans it was -43° F., involving a difference of 33° . So also just before Scott died near One Ton Camp the temperature on March 8th was $+2^{\circ}$ F. at Cape Evans (latitude 78°) and -33° F. at latitude $79\frac{1}{2}^{\circ}$. Yet later when Dr. Atkinson made a short journey on the Barrier on March 28th and 29th the temperature had risen to -5° and -7° F.

We may consider briefly the differences of summer temperature close to the North Pole and at the South Pole; again using Simpson's data:

Latitude	88° North	June	28.6° F.	July	31.1° F.
Latitude	88° South	December	-22.6°	January	-28.2
	Difference		51.2		59.3

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So far as temperature is concerned, there is not much doubt as to which is the more comfortable region. As regards fall of temperature with height, the balloons sent up in 1911 show us that in summer the figure is about 6.8° C. per kilometer, which is much the same as in Europe and America.

The rise in temperature consequent on a blizzard is well shown in the records of September 16th and 17th, 1911. Before the blizzard the air was calm, the temperature -35° F. At 8 A.M. the sky began to cloud over and radiation was cut off, so that the temperature began to rise a little at once. It had risen to -15° F. before the blizzard began, when all the cold air was removed, and the air temperature jumped some 20° to $+5^{\circ}$ F. As the blizzard dropped the temperature fell to -12° F. Such a fall is usual in these cases.

The low summer temperatures recorded in Antarctica were at first very unexpected. If we neglect atmospheric factors, we might expect the South Pole on December 22nd to be the hottest place on earth, for the earth is then nearest the sun, and solar radiation is focusing on to the Pole throughout the twenty-four hours. But Simpson points out that nearly all this energy is lost by direct reflection from the snow, and that the remainder is not sufficient to raise the temperature of the air to freezing point, before the sun reaches the solstice and the energy commences to decrease. Moreover, there are no warm winds near the South Pole, which are a potent factor in warming the North Pole.

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	Jan.	Feb.	Mar.	April	May	June
C. Evans	9.1	16.3	17.9	14.3	16.0	17.0
Framheim	7.8	—	—	9.8	6.5	8.9

WIND IN THE ANTARCTIC

Most Antarctic explorers return with an intense aversion to strong winds! It is not the low temperatures which matter, so much; for the writer has stripped to a vest when sledging at temperatures 30° below freezing, *when there is no wind*. But wind drives the cold air right against the skin, and any temperature below freezing soon becomes unpleasant under such circumstances. The preceding table shows the mean wind velocity during the four years 1902, 1903, 1911, and 1912 at Cape Evans (or Hut Point) in miles per hour. (Amundsen's base at Framheim is added below.)

These velocities varied greatly from year to year. Thus in June, 1911, we experienced an average of 31.8 miles per hour throughout the month, or four times the velocity registered at Amundsen's headquarters. This was the highest to date in the Antarctic, but was far below the records obtained by Mawson next year in Adelie Land, where his average *for the year* was fifty miles an hour or "gale force" the whole time! We may quote from Mawson's account of his experience in Adelie Land during July, 1913.

The wind was frightful throughout the whole month of July, surpassing all previous records and wearing out our

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July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
17.1	16.8	14.5	14.3	13.5	10.4	14.8
10.5	9.2	9.8	14.5	11.4	10.7	—

much tried patience. On July 2 we noted "Thick as a wall outside with an eighty-five miler." And so it commenced and continued for a day, subsiding slowly through the seventies to the fifties; and then suddenly redoubling in strength rose to a climax about midnight on July fifth of one hundred and sixteen miles an hour. For eight hours it maintained an average of one hundred and seven miles an hour, and the hut seemed to be jarred and wrenched as the wind throbbled in its mightier gusts. These are probably the highest sustained velocities ever reported from a meteorological station.

At Cape Evans almost all the surface winds (84.4 per cent) came from the east or thereabouts, and about 9 per cent from near the north. The *steam banner* of Mount Erebus showed which way the winds were blowing at an elevation of about fifteen thousand feet, and here the chief winds were from the west. The *cirrus* drift was more or less equally divided from north, west, and east.

Graham Land.—We owe to R. A. Mossman a discussion of the winds in this region, which may be summarized as follows. There appears to be a bar of high pressure over the region mentioned which acts as a "wind divide." Hence the east is under the control of a Weddell Sea low, while the west is affected by a

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Bellingshausen Sea low. On the Pacific side strong northeast winds prevail south of latitude 62° S., while farther to the west the "Belgica" seemed to find strong monsoonal winds, i.e. easterly in summer and westerly in winter. On the east side near Snow Hill, etc., the prevailing wind is southwest, while at the South Orkneys it is west-southwest. The observations during the drift of the "Endurance" and "Deutschland" in the Weddell Sea show that strong easterly and northeasterly winds are met with, which prevail as far south as 78° S. in summer and early autumn. The west side of the Weddell Sea seems to exhibit southwest winds as if there were a cyclonic circulation in this area.²

SNOWFALL

No rain fell during our stay in the Antarctic, either at Cape Evans or at Cape Adare, but a rainbow was seen to the north-northeast of Cape Evans on February 14th, 1911. No satisfactory method has yet been found of measuring the amount of snowfall, as it is usually accompanied by high wind. I have mentioned elsewhere that Taylor Valley seems to receive practically no snowfall, and the change in environment as we proceed from this region to the vast ice carapace extending into the sea all along the coast opposite Australia would lead us to suppose that the snowfall increases considerably to the north. The record of the snowfall on the Barrier (as deduced from a buried

² See the *Geographical Journal* (London), December, 1916.

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depot) has already been referred to (see page 154). As regards snowfall in Adelie Land, the "Home of the Blizzard," Mawson describes his experiences in the following words: ". . . we led a strenuous existence at winter quarters buffeting with a sea of drifting snow which poured fluid-thick over the landscape. For months the drifting snow never ceased, and intervals of many days together passed when it was impossible to see one's hand held at arm's length. Such weather lasted almost nine months of the year."

ANTARCTIC CIRCULATION

There is much to be learned about the local circulation on the continent, but several fairly well established facts stand out. In the first place there is no doubt that in the Ross Sea and the Weddell Sea and almost everywhere where ships have cruised along the coast for any lengthy period, the dominant winds are from the southeast. In the southern hemisphere this is precisely the circulation required if we assume that an anticyclone covers most of Antarctica. Secondly, the *upper* winds are very different in direction. Thus the steam of Erebus (fifteen thousand feet) is blown chiefly from the west and southwest, while the upper clouds move from northwest or west. This is almost exactly the opposite of the surface winds at Cape Evans, which were from the east or southeast. So also Barkow (on Filchner's expedition) sent up sounding balloons from Vahsel Bay (78° S.) and found east winds up to about twenty thousand feet, when the wind shifted sharply to south and southwest. This appears

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to show that the anticyclone is confined to the *lower* layers of the atmosphere.

We have not much knowledge of winds on the plateau except in midsummer. On the longer journeys the dominant winds (and direction of snow ridges) were as follows:

	Date	Locality	Wind and Sastrugi
Scott	1903	Above Taylor Glacier	WSW. (near Horst)
Shackleton	1908	Above Beardmore	SSE
David	1908	To Magnetic Pole	West near Horst, SE.
Scott	1911	To South Pole	SSE. to SSW.
Bage	1912	To Magnetic Pole	SE.
Mawson ..	1912	Queen Mary Land	SE.
Filchner ..	1916	Southeast of Weddell Sea	E.

The writer from his experience of many weeks spent in the valleys of the great outlet glaciers is sure that the winds in these deep troughs (often four thousand feet deep) have little relation to the true circulation. They are almost entirely controlled by the topography and blow up or down the valley, usually the latter. So also the winds in the three permanent stations of Cape Armitage (1902-4), Cape Royds (1908), and Cape Evans (1911-12) are largely determined by the gigantic walls of Erebus (thirteen thousand feet) on the east and the Lister scarp (ten to twelve thousand feet) on the west. It is not safe to draw deductions as to the general circulation without taking this topographic factor into account. The writer remembers a journey of only half a dozen miles on the seventeenth of April, 1911, from Cape Evans to Glacier

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Tongue. There was a north wind at Cape Evans, a west wind off the sound halfway, and a little later we found a strong southeaster driving snow over the root of Glacier Tongue. These were local winds which did not indicate the onset of a blizzard.

Another phenomenon to be noted is the increase in temperature as a blizzard approaches from the southeast. The intensely cold and stagnant air of the coastal margin is soon swept away by the blizzard, and the temperature usually rises. This rise in temperature is of the same kind as is found in foehn winds, and is due to *adiabatic* heating, the air generally being compressed by descent from the plateau. We must also take note of the rapidity with which a furious blizzard develops from what has often been practically calm weather. Accurate data on these points are given in Simpson's large memoir. (See also p. 79.)

There have been several attempts to weld these facts into a harmonious whole. We may briefly consider those of Meinardus, Hobbs, and Simpson. Meinardus based his report of 1911 on Drygalski's data. He was chiefly struck with the fact that there must be a *large supply of snow* in the interior of the plateau to maintain the ice cap, and the constant drain due to the bergs breaking off all round the margin. He therefore believes that the fundamental feature on the plateau is a cyclone which occupies the region above seven or eight thousand feet, and which is fed by constant westerly winds at that level. He states that in anti-cyclones the air flows in at the center in the upper layers, descends, becomes relatively dry and, as it

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streams out on the surface, removes moisture from the central region.

W. H. Hobbs lays great stress on the domelike shape of the ice cap (see Figure 29), which is some ten thousand feet near the Pole, and thence descends fairly slowly and then more steeply to sea level in Mawson's region (66° S.). The plateau is about eight thousand

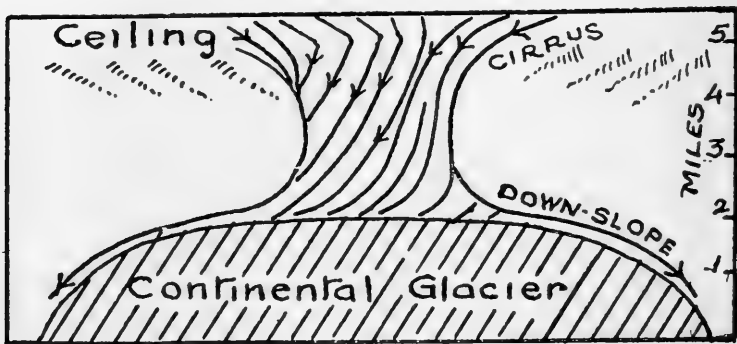


FIG. 29.—THE GLACIAL ANTICYCLONE (IN SECTION).

(After W. H. Hobbs.)

feet at latitude 77° and seven thousand feet at latitude 73° . He states his case somewhat as follows:

If there were no extensive high and snow-covered areas in the Antarctic it is clear that the circulation would be less vigorous. When the slope is very gentle air drainage is necessarily sluggish, and such regions (when there are no higher surrounding mountains) can and do establish (1) a circulation of the upper air from the ocean to the higher portions of the plateau; (2) a well defined increase of temperature for the first few hundred meters of elevation; (3) a slow settling of the air onto the cold surface below; (4) the precipitation, without cloud, of fine snow crystals

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(frost snow); (5) drainage of this chilled and relatively dense air to lower levels; (6) drifting of the snow with the winds, and the consequent extension so far as temperature and other conditions will permit of the ice-covered area.³

Hobbs believes that sufficient snow supply is obtained in the interior of the plateau from ice crystals in the cirrus clouds which descend in the interior of the anticyclone and are first melted and then vaporized by the adiabatic elevation of the temperature. The snowfall resulting from these cirrus crystals in Hobbs' opinion consists of those minute spicules and plates described by sledgers near the Pole, which differ greatly from the snowfall near sea level. (The present writer would expect to find the cirrus layer at the Pole considerably lower than the five miles indicated in Hobbs' figures.)

G. C. Simpson in 1923 offered another solution which in part combines the theories of Meinardus and Hobbs. He writes :

Over the snow-covered surface of the Antarctic, whether at sea level or at the height of the plateau, radiation is so strong that the air is abnormally cooled, especially in the layers immediately above the surface. This cooled air is heavier than the surrounding air, and therefore the pressure increases from the exterior to the interior of the polar area; in other words the pressure distribution is anticyclonic and the air movement in general outwards. Above each anticyclone a cyclone forms on account of the rela-

³ Quoted by Hobbs, *Glacial Anticyclones* (New York, Macmillan, 1926), p. 182, as a good summary of his theory by Humphreys.

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tively rapid vertical pressure change caused by the cold dense air. The descending air is warmed giving clear cloudless skies . . . as one penetrates the Antarctic. (See Figure 30.)

The clear skies in their turn facilitate radiation, as does the small absolute humidity of the air. In consequence the air and the snow surface become abnormally cold and there is a great tendency to the formation of temperature

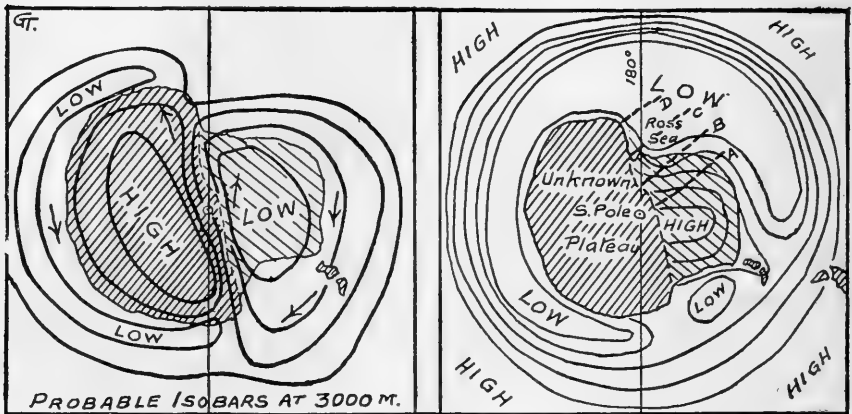


FIG. 30.—PROBABLE ISOBARS AT SEA LEVEL (RIGHT) AND AT 3,000 METERS (LEFT).

Broken lines A, B, C, D show successive positions of pressure waves. (After G. C. Simpson.)

inversion, especially in the lower atmosphere. On these normal fine weather conditions are superposed a series of *pressure waves* which travel more or less radially outwards from the center of the continent. These waves alter the surface pressure conditions, and cause air motion which is frequently accompanied by forced ascending currents. The abnormally cold surface air is forced upwards in these currents, rapidly cooled in the ascent, and the water contained is precipitated as snow, which when com-

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bined with the high surface winds produces the typical Antarctic blizzard.

Hence Simpson follows Meinardus as regards the method of precipitation from an upper cyclone. But he raises the "snow-supplying cyclone" more than three thousand meters above the plateau so that it does not show in the figure. He thinks that the plateau itself is everywhere controlled by a shallow *surface* anti-cyclone, but his map omits this as its position is indefinite.

Some attention may now be given to these Antarctic pressure waves on which Simpson lays great stress. It is found that local variations in pressure in this region are usually not accompanied by changes of wind direction, as in lower latitudes. A series of these waves moves across the Ross Sea area, first affecting the Southern Plateau and Framheim (see Figure 30), and then moving to the northwest and reaching Ross Island and lastly Cape Adare. The mean length (time of passage) of such a barometric wave is one hundred and fifty hours, and the mean variation amounts to 0.572 inch. These waves apparently have a velocity of about forty miles an hour. They seem to affect much of Antarctica, but have not been detected in New Zealand.

The usual pressure conditions near Ross Island consist of a more or less permanent low over the warm Ross Sea, and a permanent high over the cold Plateau. Thus the normal winds would be southerly or southeast winds. Simpson believes that the pressure waves

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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.

AURORA AUSTRALIS

Throughout the winter we maintained an aurora watch primarily with a view to determining their relation to magnetic or meteorological phenomena. The first observation was made on April 2nd, 1911, by Captain Scott. He noted that it extended to within 10° of the zenith from the south. It was of a reddish hue and took the form of a curtain with two folds. On the 28th of April I was on watch and saw an elaborate display about 9:10 P.M. It affected the whole sky to the east (behind Erebus). At first isolated grayish streamers reached over 8° ; they had a reddish tinge, but were not bright enough to show the "auroral line" in the spectroscope. The whole brightened until it became a continuous band of yellowish light. It concentrated with a movement to the north, reminding one of a caterpillar's motion as the more vivid mass of light undulated towards Erebus. At one moment it clotted into a globule of light not unlike a meteor, pointing to the crater, with a streamer extending up and slightly to the south. During the maximum the streamers were over 20° from the horizon. Dr. Wilson saw traces of orange and purple in the borders. The display lasted six minutes.

Mawson records that at Cape Royds in 1908 they saw auroras from March 26th to October 4th. They

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seemed to be more abundant after 7:30 P.M., and had little color except the usual yellowish green. Arches, curtains, and searchlights are the chief shapes. He noted that the display often began to the north, passed east behind Erebus and drifted to the south. They thus kept away from the Magnetic Pole, which lay to the northwest. No very definite results could be expected with regard to their relation with magnetic storms, for the aurora watch was spoiled by frequent blizzards and was never really continuous. However, Dr. Chree found that in 1911 41 per cent of the most striking aurora were associated with very marked magnetic disturbances. Ponting was unable to photograph the auroras and we are not clear as to their origin. Arrhenius believes that negatively-charged particles are driven through the sun's atmosphere by light-repulsion and reach the earth's atmosphere, thus forming auroras.

CHAPTER X

FLORA AND FAUNA

FLORA

IN discussing the flora of Antarctica one is irresistibly reminded of the famous essay on "The Snakes of Ireland." It is comprised in the sentence, "There are no snakes in Ireland." So also one may almost dismiss the land flora of the continent in the sentence, "There are no flowering plants in Antarctica." Still as there are over a hundred lichens and many species of mosses and algæ, some little description of these will be of interest. I believe that I discovered the largest vegetated region so far seen on the Antarctic mainland, and I am under the impression that I found the largest living land animals. Possibly the reader will not be much impressed by these records when he hears the particulars!

On my first day's sledging in the Antarctic (January 28th, 1911) on our journey up the Ferrar Glacier, I made a detour to examine the slopes at the foot of the valley wall near the Herbertson Glacier. On the gravels some dozen or so feet above the surface of the Ferrar Glacier, I was amazed to see a carpet of green moss, as flourishing as any in more temperate regions. I sat down on a granite erratic and noted that there were three different species present, but as I was not

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aware how rare was such an occurrence at 78° S., I regret to say that I did not collect specimens. One species was sessile and tufted, another resembled the alga *Ulva*, while a third was markedly fibrous. This patch of green was sixty feet long and about fifteen feet wide, and owed its existence to its sheltered snow-free position facing the midday sun.

On our second summer's sledging we came upon another relatively heavily vegetated region in Antarctica. This was at our permanent camp at Cape Geology on the southwest side of Granite Harbor. Here amid the boulders and groins of granite were "chunks" of dormant moss, which, however, showed practically no sign of growth that season. We found frondose lichens also clustered on the rocks at the base of Discovery Bluff nearby. The botanical specimens which we collected here led us to name the adjacent shores "Botany Bay," and we found the moss abundant enough to fill the crevices in the stone hut which we built at the camp. Elsewhere I noted very small patches of lichen now and again, but nowhere else did I come across any abundant growth even of moss or lichen in the several hundred miles of rocky coast which we explored.

However, in the warmer regions of West Antarctica there are more numerous examples of the vegetable kingdom. There are actually two flowering plants found in the northern part of the islands of Graham Land. One of these is a grass called *Deschampsia antarctica* and the other is *Colobanthus crassifolius*, allied to the pinks and campions. It is worth while

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to contrast the flora of the northern point of Greenland (in latitude 83° N.) with this very poor representation in 65° S. This is how Peary describes his first view of Academy Land in July, 1891.

It was almost impossible to believe that we were standing upon the northern shore of Greenland, with the most brilliant sunshine all about us, with yellow poppies growing between the rocks, and a herd of musk oxen in the valley behind us. Down in that valley I had found an old friend, a dandelion in bloom, and had seen the bullet-like flight and heard the energetic buzz of the bumble bee.

Or compare with the southern continent Rasmussen's account of the same region with its fifty flowering plants. "Thick well developed grass grew in many places . . . everywhere sturdy Arctic willow, poppy, saxifrage and Cassiope." As a result there is a permanent Arctic fauna including musk oxen, lemming and hares.

The typical form of Antarctic flora is, however, the lichen and of these nine specimens were collected by Hooker in 1843 at Cockburn Island (64° S.) near Snow Hill. For fifty years this was the only list of lichens from the continent. These genera are *Parmelia*, *Physcia*, *Lecanora*, *Pertusaria*, *Verrucaria*, and *Collema*. Of these *Physcia* and *Lecanora* have since been recorded from Victoria Land. Just over one hundred Antarctic species were known when Darbishire published his lengthy report in 1911. Of these Borchgrevinck collected two, Gerlache fifty-one, Bruce six, Charcot six, Scott (in 1904) twelve, and Nordenskjold

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eighteen. No less than sixty-seven of these are endemic in Antarctica. It is interesting to note that while thirty-two are also found in South America, no less than twenty-five also occur in far-away New Zealand. Furthermore, practically half the Antarctic lichens are common also to the Arctic flora. Darbishire's list shows the following as important genera in Antarctica in addition to those specified above; *Lecidea*, *Rhizocarpon*, *Gyrophora*, *Cladonia*, *Placodium*, *Buellia*, and *Acorospora*. *Lecanora* has twice as many species as any other.

FAUNA

It is clear from the preceding description of the land flora that there is no food available for higher animals on the Antarctic mainland, and I do not propose to discuss the flora and fauna of the sub-Antarctic islands in this necessarily brief account. But the seas teem with life, at any rate in the summer. I shall never forget our first sight of a penguin rookery at Cape Crozier on New Year's Day, 1911. The sea was perfectly full of the birds cruising about in search of shrimps (*Euphausia*, etc.) for food. I have never seen seas so teeming with life. The explanation is that these polar waters are free from bacteria which break up protoplasm and so render it to some extent useless for food. The cold waters act as a kind of cold storage, and supply unlimited food material for higher organisms in the form of diatoms, algæ, and protozoa which quickly vanish after death in warmer regions. At the other end of the scale of life in the

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Antarctic are the warm-blooded killer-whales (*Orca*), of which we saw a party of three busy gobbling up penguins. I was greatly struck with this "proto-plasmic cycle" as it may be termed, and indeed on several occasions the explorers themselves were attacked by the killer-whales and nearly took a part in the cycle also. The presence of the following rhyme may perhaps be excused in view of the very real biological concept which is illustrated therein! (Figure 31.)

I propose to confine my attention primarily to the whales and seals in marine biology, and to the birds on land. All of these animals are, however, only sojourners on the Antarctic shores. None is a true dweller in the Antarctic and none ever ventures inland, except perhaps an aged seal to die.

I have based my account of the fauna chiefly upon notes taken verbatim from Dr. Wilson, my colleague in the Antarctic, or from his writings. There are two main classes of whales, divided according to whether they are toothed, or provided with baleen (whalebone). To the former class belong the sperm or cachalot (*Physeter*), the bottlenose, the killer, and porpoise. To the latter the giant rorqual (*Balaenoptera*), the right whale (*Balæna*), and the humpback (*Megaptera*). Of the whales the most prominent off the Antarctic coast is the large carnivorous dolphin, the killer-whale or *Orca gladiator*. It is usually about fifteen feet long and hunts generally in packs of a dozen or more. In a northern specimen, which was twenty-one feet long, the remains of thirteen seals and thirteen porpoises were found in a more or less digested



FIG. 31.—THE BIOLOGICAL CYCLE IN THE ANTARCTIC.

The diatom *Corethron* and *Euphausia* appear in front of the procession, but not to scale. Then follow penguin, seal and killer-whale. The Afterguard were the officers. (By permission of John Murray.)

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state. Fourteen was apparently its unlucky number, for the animal appeared to have been choked in an endeavor to swallow another seal. They are a constant menace to the penguins and seals, especially in the pack ice or bay ice, and many of the crab-eater seals are marked with terrible scars as the result of the *Orcas'* attacks.

Undoubtedly they attempt to shake the seals off the floes into the sea, and on several occasions men in our expedition were attacked in the same way. For instance, early in January, 1911, just as we were unloading the ship eight killer-whales attempted to capture some of our dogs who were loose on the ice. Ponting was taking photographs of the killers, and ventured too near them in his enthusiasm. He narrates that they lifted their wicked heads above water to look at him, and he was just pressing the button when he felt as if an earthquake had hit him. The whole floe was being broken away, and he was drifting from the firm ice. He lost some valuable equipment, and did not stop for the photo! A similar incident, but luckily not so exciting, happened to me in the bay ice off the Ferrar Glacier; the men rescuing the ponies who were adrift on the floe on March 1st near the Barrier were closely surrounded by eighteen of these predatory brutes.

Two other dolphins are not uncommon on the edges of the pack ice. One of these is called the Dusky Dolphin from its dark brown back; while the other has a white hourglass on its side, but has not yet been properly investigated.

Of the real whales, the rorqual is fairly common,

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especially near the Balleny Islands. It is the largest mammal and sometimes occurs nearly one hundred feet long. It is characterized by a broad blue slate-colored back with a small dorsal fin. Its spout rises twelve or fifteen feet into the air. On our return in March, 1912, we sighted a school of eight sperm whales, but we were then in New Zealand waters. The humpback whale is said to reach a length of sixty feet. It earns its name from the low dorsal fin. The back is black, the belly yellowish, and the flippers white. There are two other finner whales to be met with in the Ross Sea. One is round-backed, black, solitary, and twenty feet long. It has a very small hooklike dorsal fin. The other is gregarious and has an enormous dorsal fin two or three feet long. It is black above and lighter beneath. I shall refer further to these mammals in the following chapter.

Seals.—There are five species of seals to be seen fairly often in or near East Antarctica; of these three commonly occur south of the Antarctic Circle. The huge sea elephant (*Macrorhinus*) is very abundant at Macquarie Island (latitude 54° S.) but only one or two specimens have ever been known to wander down to the Antarctic. The sea leopard (*Stenorhyncus*) is a solitary animal and is not uncommon at Cape Adare, though I only saw one specimen as far south as Ross Island (78° S.). The sea leopard is about twelve feet long and has almost a snakelike appearance owing to its slender shape, which enables it to swim remarkably quickly. Its diet consists of fish, penguins, and even

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small seals. Its color is dark gray with a black back, sometimes somewhat tawny beneath. The teeth differ greatly from those of the relatively harmless Weddell seal. In the sea leopard the canines are very sharp, while the twenty post-canines are three-lobed tridents, adapted to catch and tear fish to pieces. Its only enemy is the killer-whale.

The common seal of the pack ice is the crab-eater (*Lobodon*) which is often so light-colored as to be practically white. Usually, however, there are many individuals of a chocolate color with handsome dapplings. It is smaller than the other common Antarctic species (the Weddell) being about eight feet long. It lives almost entirely upon shrimps which it grubs off the bottom of the sea together with much gravel. The teeth are curiously divided, and apparently act like the whale's baleen, for the seal squirts out all the water through the teeth, which act as a sieve, while it retains the shrimps and stones. Apparently the latter help to grind its food. This seal is usually observed in little groups of five or six lying on the floes, so that it is the first seal to be seen by the explorer.

The Ross seal (*Ommatophoca*) is the smallest of all, being only about seven feet long. It is very rare in East Antarctica but is apparently commoner in West Antarctica. The Weddell seal (*Leptonychotes*) is the most important of the shore fauna, for it is an invaluable source of food, fuel, and hides to the explorer. Luckily its fur is not attractive to the sealers, for it is long and coarse with no thick under-fur such as is found on the true fur-seals. We used several skins

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as a roof for our granite hut at Cape Geology, and the fur reminded me of that of an ordinary cow. In this position on the roof the hide was comparatively translucent in spite of the covering of fur. The Weddell seal is sluggish and collects in large herds. In October and November especially one may see many hundred seals congregated in favorable places along the tide-cracks and shear-cracks in MacMurdo Sound.

The Weddell seal is not so frequently attacked by the killer-whale as its cousin, the crab-eater, which lives out on the open pack ice. Like all these animals and birds, it seems quite devoid of fear when on land. At the Cape Roberts rendezvous in January, 1912, we were rather short of food and there were three seals basking on the ice off the cape. I killed one the first week, the other two, who were only a yard or two away, taking little interest in the gory business. Next week I killed the second seal, and in the third and last week of our enforced wait I killed the third, so that if we could not cross the crevasses of the Wilson Piedmont Glacier and had to return, we might find some food available for the next week or so.

The Weddell seal is sometimes ten feet long, and has a brownish coat richly marked with black and gray and silvery white. The young are born during the last week of October and the beginning of November. At birth they have a thick and woolly coat of dull ochre, gray and black, which drops off after a fortnight or so. The teeth are sharp and curved to enable it to catch fish and are also used to open holes in the sea-ice. Before I went south I used to wonder how a seal

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could cut a hole through six feet of winter ice in order to breathe. I don't believe they ever cut through the ice, but I have watched a seal laboriously enlarging a natural hole in a tide-crack or shear-crack, so as to make it large enough for an outlet. It opens its jaws to the widest, and uses the teeth as a sort of rasp on the edges of the hole. After many hours of this unpleasant work, no doubt it files away some inches from all round an accidental hole, and so is able to shoot out on to the sea-ice.

Some twenty miles up the Koettlitz Glacier, we were surprised to find many seals, and came to the conclusion that they swam up the subglacial stream, which I named the Alph River. On one occasion I prodded one of these seals with my ice ax. After some sneezes and grumbles, he proceeded to sing to me. He lay over on his side and produced a whole octave of musical notes from his chest, ranging up to a canarylike chirrup. Later I found that Dr. Wilson and Dr. Racovitzi had already recorded the musical ability of Antarctic seals. When the seal approaches the end of life, it seems to wander from the sea. At any rate we came on a number of carcasses several thousand feet up the Ferrar Glacier, and nearly twenty miles from the sea. Even in the Dry Valley of Taylor Glacier we found desiccated carcasses on the ground moraine. Presumably they had crawled up the valley over a carpet of snow or ice which had disappeared when we first traversed it in 1911.

Birds.—Wilson records twelve species of birds seen in East Antarctica, but only three went as far south as

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our winter quarters. A little north of the pack the Fulmar petrel and Antarctic petrel were fairly abundant. In the northern waters of the Ross Sea we saw a few giant petrels, snow petrels, and Wilson's stormy petrels. On Ross Island the only flying bird was the McCormick skua (*Megalestris*) which lived on fish when there were no penguin eggs or chicks to devour. The old name of Cape Evans was "The Skuary" and so these gulls were very common round our hut. It is a large brown bird with a white patch on each wing. It breeds all along South Victoria Land in hollows in the rocks. Practically no nest is built, though I noticed at Cape Geology a few feathers or moss in some of the "nests." Two eggs are laid early in December, which are brownish with darker splashes of color, but only one chick is reared. On Cape Roberts early in January, 1912, we observed three nests of these gulls. Two of the pairs of birds were disturbed by our proximity, and simplified their home life by eating up their own or each other's eggs. The third pair abandoned their dark little chicken, which we attempted to feed, regretting the destruction we had caused. The sledge poet recorded his end, as follows:

So little Blackie reigned supreme,
Until one day when he was fed
 (By that kind and humane leader
 Foster father, foster feeder)
On rich and tasty lumps of blubber.
His little tummy stretched like rubber,
Stretched too much—
 and now *he's* dead!

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Penguins.—There are many species of penguins but they are all restricted to the southern hemisphere. Even the fossil forms do not occur north of the equator. As we have seen (p. 105) several fossil penguins have been discovered near Graham Land, while there are others from Patagonia and New Zealand. It seems likely that the penguins separated off from other birds early in their history. There is no doubt that originally the penguin used the wing for flight, though now it has degenerated to a flipper. It is quaint to see the penguin still tuck its beak under the flipper, an ancient habit apparently, for it cannot gain much warmth therefrom. Wilson states that the feather tracts are distributed like a lizard's scales and the arrangement is in no way as advanced as that of a domestic fowl. The largest penguin, the Emperor, has primitive leg bones in which the three parallel shank bones are still distinct, though in all other birds they are fused.

Of the seven or eight common penguins, only two occur in the Antarctic. These are the emperor and Adelie penguins. The emperor penguin (*Aptenodytes forsteri*) is surely the most unusual of all living birds. Some of his primitive characteristics have been mentioned, but his breeding habits are unique. No other bird and surely few other forms of life choose the middle of the fiercest winter on earth for their breeding season! Only two regions are known where this penguin lays its eggs. The first was discovered at Cape Crozier in 1902, and the second in Queen Mary Land in 1912. In a small bight, just where the edge of the great Ross Barrier ice touches the cliffs of

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Ross Island, there is a patch of sea-ice which remains in all through the winter. Here the emperor penguin passes the cold dark months, and it was to obtain eggs in an early stage of incubation that the "worst journey in the world" (see p. 55) was undertaken. Dr. Wilson found one hundred birds here, incubating their eggs, in July, 1911, and he was able to obtain three eggs,

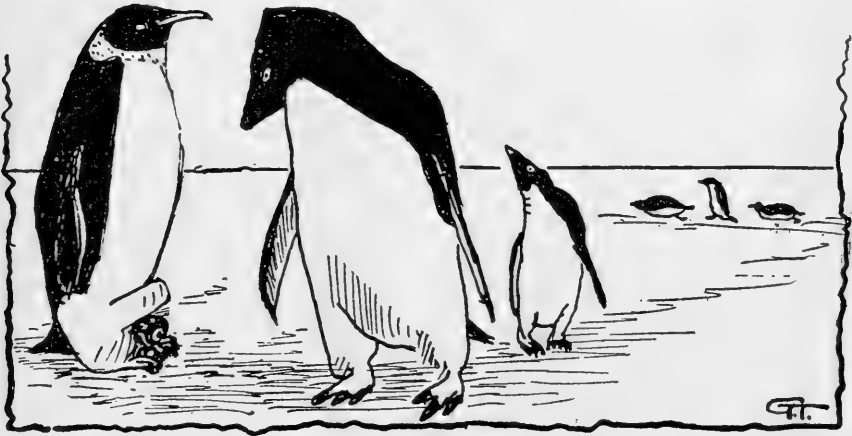


FIG. 32.—EMPEROR PENGUIN AND CHICK; ALSO ADELIE PENGUINS PONDERING, ECSTATIC AND TOBOGGANING.

Winter and summer scenes are conjoined here.

each containing an embryo. In July the temperature at times falls to -76° F., or 108° below freezing. Earlier, in 1903, Wilson had discovered that by September all the eggs were hatched and there were only a few living chickens. These were perched on the parents' feet and were protected by a curious feathered fold or lappet which hangs down from the parents' breast. When the chick is hungry or inquisitive, it pokes out from under the lappet a piebald downy head,

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emitting its shrill and persistent pipe until the parent fills it up! Wilson's account of the life of a penguin chick cannot be improved upon.

I think the chickens hate their parents, and when one watches the proceedings in a rookery it strikes one as not surprising. In the first place there is about one chick to ten or twelve adults and each adult has an overpowering desire to "sit" on something. Both males and females want to nurse, and the result is that when a chicken finds himself alone there is a rush on the part of a dozen unemployed to seize him. Naturally he runs away and dodges here and there until a six-stone emperor falls on him, and then begins a regular football scrimmage in which each tries to hustle the other off, and the end is too often disastrous to the chick. Sometimes he falls into a crack in the ice, and stays there to be frozen while the parents squabble at the top; sometimes rather than be nursed I have seen him crawl in under an ice-ledge and remain there where the old ones could not reach him. I think it is not an exaggeration to say that of the 77 per cent that die, no less than half are killed by kindness.

The young bird moves out to the breaking floe and soon floats out to sea. His first feather plumage appears in January when he is five months old. Then the silver gray changes to blue gray with a white front. A year later a second moult occurs and then the orange patch appears on the neck, and the head and throat turn black. His food consists of fish which he catches readily in his sharp beak. In the water these quaint birds swim like Plesiosaurs, or at any rate not like

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other birds, with the body submerged and the long snakelike heads projecting above the surface. The birds stand nearly four feet high, and as they waddle along erect on their feet like a man, it was a matter of common occurrence to mistake them in the polar twilight for fellow explorers!

Adelie Penguins.—Of all birds the penguin is best adapted to aquatic life. It swims entirely under water by means of its wings, which have modified to form veritable flippers. To breathe it jumps out of the water in the fashion rendered familiar to voyagers by the dolphins. The Adelie runs along upright and reminded me of a tiny child learning to walk, who runs quickly to his mother, knowing that a topple at the end does not matter. Then he will stop and flap his wings (one was going to say arms) and bow and turn his head around in a most human and unbirdlike way. The most striking feature, I think, is the stiff little tail which he drags on the ground as he toddles along, and which seems to help to support him. Possibly the scientific name (*Pygo-scelis*, tail-leg) refers to this habit. The bird stands about two feet five inches in height. The coloring of pure white breast and black back reminds one of a stout little man in a swallowtail coat and a white shirt, both much too big for him.

The most complete study has been made by Dr. Levick at Cape Adare ($71^{\circ} 14' S.$) during 1911. During the winter the birds probably live on the northern edge of the pack ice, some five hundred miles north of their rookery on land. The first penguins arrived

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on October 13th, and on the seventeenth there was a thin sprinkling scattered all over the rookery. They were tired and rested on the old nests, but on October 18th a few started to build. The male birds collected the stones, while the females mounted guard over the construction. As the later birds arrived some of them climbed one thousand feet up Cape Adare to make their nests. By October 29th the migration had ceased. The mating is accompanied by a definite "proposal" to the hen, the "ring" taking the form of a pebble. When two birds have agreed to pair they assume the "ecstatic" attitude, raising their beaks vertically and rocking from side to side. Rival cocks fight viciously, breast to breast, hitting each other rapidly with their flippers until one is exhausted. (See Figure 32.)

On November 3rd several eggs were found and up to this time no bird had eaten any food since arrival. They eat snow readily, however. Many starved for twenty-seven days in spite of all the fighting and hard work involved in collecting stones. The second egg is laid about three days later and incubation lasts about thirty-five days. After the eggs are laid the birds take turns to go down and feed on shrimps (*Euphausia*). They swim either entirely below water, or occasionally with their heads alone projecting. They are expert divers and Levick records their "upward dives" on to ledges five feet above the water. The sea leopard is their deadly enemy and in the stomach of one specimen no less than eighteen penguins were found in various stages of digestion. The young chicks feed by pushing the head inside the parents' throat and so helping itself

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direct from the gullet. The growth is rapid, for it weighs about three ounces when hatched, twenty-five ounces in eight days, and forty-two ounces in twelve days. The big chicks are herded in a clump and guarded by a few old birds, while all the rest go out collecting shrimps to feed the clump. The young learn to swim as soon as their plumage is acquired, and then the old birds give up feeding them. On March 12th all had left Cape Adare for their winter quarters on the ice pack.

Cherry-Garrard has given us a pen picture of survival among the Adelie penguins. I quote a paragraph.

The life of the Adelie penguin is one of the most unchristian and successful in the world. The penguin which went in for being a true believer would never stand the ghost of a chance. Watch them go to bathe. Some fifty or sixty agitated birds are gathered upon the ice-foot, peering over the edge, telling one another how nice it will be, and what a good dinner they are going to have. But this is all swank; they are really worried by a horrid suspicion that a sea leopard is waiting to eat the first to dive. The really noble bird according to our theories would say, "I will go first and if I am killed I shall at any rate have died unselfishly, sacrificing my life for my companions," and in time all the most noble birds would be dead. What they really do is to try and persuade a companion of weaker mind to plunge; failing this they hastily pass a conscription act and push him over. And then—bang, helter-skelter in go all the rest.

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MICROSCOPIC LIFE

Some interesting notes on the inhabitants of the lakes in Cape Royds have been recorded by James Murray. Orange colored algæ were found to carry myriads of living things. Creeping rotifers were the most numerous, while water bears and mites were often observed. The stones of Coast Lake were often covered by bright red patches, as though they had been sprinkled by blood, and these patches consisted of tightly packed rotifers. Experiments showed that temperatures of -40° F. did not kill these animals. Drying, freezing, thawing, moistening them or leaving them in brine seemed to have no effect on them. It is noteworthy that the adult forms, not the eggs, were tested, and some of them lived until after their arrival in London. The rotifers are minute worms, while the water bears are allied to the insects. Of the former *Hydatina*, *Adineta* and *Philodina* are common genera. Of the water bears *Macrobiotus arcticus* is common. It was previously only known from the Spitzbergen region. It is to be noted that some of these rotifers were found below fifteen feet of ice on Blue Lake. This ice did not melt during the expedition's stay at Cape Royds, so that the rotifers well understand how to suspend animation.

When we started on our second summer's sledging, Dr. Wilson asked us to keep a lookout for insects living in the moss which we might come across on our journey. Previously only fragments of various "spring-tails" had been discovered among moss ob-

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tained in 1903. One evening at the end of November, 1911, I noticed some dark specks floating on a little rocky pool at Cape Geology in Granite Harbor. With no organic matter in the air this seemed unusual and on closer examination I found that these were the long-desired insects. They were little dark bluish fellows shaped like a cigar, with six legs and no wings. Each insect was about one millimeter long, and they clustered together like aphides (see Figure 12).

Later we found them under most of the stones near the moss, clustering among the whitish roots (or hyphæ) of the moss. They would be frozen stiff in a thin film of ice until one turned the stone into the sun. Then the ice would melt, and they would move sluggishly about until the sun left them, when their damp habitation froze again. I cannot imagine a finer example of hibernation, for it looked as if they pursued an active life only when a beneficent explorer let in a little sunlight on them! There was also a much more active reddish insect, so small that one could only just see it; but the *Gomphocephalus*, as the larger blue genus is called, was readily visible to the naked eye.

Nordenskjold has described a wingless mosquito, called *Belgica*, as the largest animal living continuously in Antarctica. This is four millimeters long, a perfect giant compared with my little *Collembola*. But since Wilkins has shown that all the Graham Land region is merely a cluster of islands, and as it is moreover mainly north of the Antarctic Circle, I think I may perhaps claim for *Gomphocephalus* the proud record of being the largest living Antarctic animal!

CHAPTER XI

COMMERCIAL AND POLITICAL ASPECTS

THE WHALING INDUSTRY

IN Antarctica it would appear that the flag follows the trade. No nation made any definite claim to Antarctica until the development of whaling in southern waters showed that, however poor the land might be, here was a very valuable territory. In recent years 70 per cent of the whale-fishery of the world has taken place either near Graham Land or in vicinity of the Ross Sea. In this chapter, therefore, these two aspects of Antarctica, the commercial and the political, may well be considered side by side.

We owe to Gunnar Isachsen a peculiarly timely account of the development of the whaling industry in Antarctic waters. (*Geographical Review*, July, 1929.) He points out that there have been four main stages in the development of whaling, as we see it to-day. The Vikings perhaps first commenced to hunt the huge mammal (for it is, of course, in no wise akin to the fishes) off the coast of Norway. Possibly they taught the craft to the Basques, for we first hear of whaling in the tenth century in the Bay of Biscay. In the sixteenth century whaling was a brisk industry in the north Atlantic, and soon spread to Spitzbergen and

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Greenland. By this time the nordcaper, the bowhead, and the bottlenose whales were all hunted. Early in the eighteenth century the second phase of whaling commenced when American whalers hunted the sperm whale in temperate and tropical oceans. In 1840 there were some eight hundred vessels so engaged, mostly from New England ports. All these whales were slow swimmers and were harpooned from boats. The sperm-whale industry had practically died out by 1918.

Before the end of the eighteenth century there were whalers in the Falkland Islands, and we have seen that these hardy seamen greatly extended our knowledge of the Antarctic Islands south of America. They chiefly hunted the right whale, *Balæna australis*. Between 1804 and 1817 American ships took one hundred and ninety-three thousand right whales in southern waters. They also took sperm whales (*Physeter*) and humpbacks. This southern whaling lasted through most of the nineteenth century, Enderby Brothers being one of the best known British companies about 1840. When the northern whales were killed off, the Norwegian and Scotch whalers voyaged to the Weddell and Ross seas around 1892-94. The whales, however, were found to be chiefly the swift rorquals, which could not be taken by the old technique. However, the Norwegian, Foyn, had invented the grenade harpoon some years earlier and this led to the third phase in whaling, beginning in the north about 1886. It reached a climax in the north seas about 1905, and here the swifter whales again became depleted by 1915.

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The fourth phase begins about 1904, when Captain Larsen returned from his Antarctic experiences with Nordenskjöld, and founded a whaling company in Buenos Ayres. He was very successful in the first year and took full ships back to Sandefjord in Norway. Nowadays the industry is largely concentrated in South Georgia, South Orkneys, and South Shetlands. Licenses are issued from the Falkland Islands to whaling companies, of which in South Georgia there are four Norwegian, two British, and one Argentine. In 1923-4 Captain Larsen extended his operations to the Ross Sea and successful cargoes have been obtained each year from East Antarctica as well as West Antarctica.

A good account of the whaling at Deception Island is given by M. C. Lester.¹ Large floating factories leave Norway by the third week in September. They call first at Cardiff for coal and then proceed to Montevideo where they pick up the whale catchers. These are small boats, each manned by a dozen men. There are usually three catchers to each "factory." Then the small fleet proceeds to the Falklands, where the British license is obtained, and finally they reached their center at Deception Island (latitude 63° S.) about the third week in November. Whaling is carried on throughout Bransfield Strait and in Belgica Strait down to 65° S. Shortly after Christmas the whale catchers go south to Belgica Strait, where the ice now begins to break away. The factories soon move down to Port Lockroy at the south end of Belgica Strait, and they

¹ *Geographical Journal* (London), September, 1923.

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may remain here to the end of the season, about April 12th. (See Figure 7.)

Each year the ships concerned in whaling are being made bigger and more powerful. Thus the "Sir James Clark Ross," the factory ship in the Ross Sea, is 12,450 tons. Even as late as 1911, it seemed impossible to us on the "Terra Nova" to get an *iron* steamer through the pack ice, yet these whalers have suffered no disaster to date. The Norwegians now have three land stations in the Antarctic, eighty-five whale catchers and twenty-four floating factories. Some factories do not approach land at all, but drag the one hundred foot whale right on board for flensing and cutting up. One of these boats is said to be 22,000 tons register.

It is difficult to say how long the industry will last under this terrific onslaught. The humpback was the chief prey till 1912 as it was the easiest to catch, but it is now much less abundant. The blue whale and the finback are the mainstays of the Antarctic whaling to-day. Last season whale oil worth three and a half million dollars was brought back from southern waters. The oil sells at about 100 to 150 dollars a ton and is used for soap and lubricants and to replace tallow, lard, and margarine. The yearly output is still increasing, and between 1906 and 1927 the following was the harvest of oil: South Georgia, 3,830,000 barrels; South Shetland (Deception Island), 2,645,000 barrels; and Ross Sea, 199,000 barrels. It is stated that twenty thousand whales have been killed in the Antarctic seas in recent years. Suarez in his report to the League of

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Nations in 1925 gave his opinion that there were not more than twelve thousand whales surviving.

Luckily the world does not now ignore the destruction of a valuable international asset. The fees accumulating from the whaling licenses in the Falklands region have been in part devoted to carrying out research as to the environment, migrations, and food of the whales. We owe to A. C. Hardy a valuable account of the scientific work being carried out on the research ship "Discovery."² This boat is the same which was built for Scott's first expedition and is now (1929-30) on loan to the Australian Government for Mawson's new expedition to the Enderby region.

The whales taken south of the Falkland Islands, apart from the right and sperm whales which are only occasionally met with, belong to three species. These are, as stated above, the two large rorquals, the blue and fin whales, and the humpback whale. These are all toothless whales, and therefore they feed on surface organisms or plankton. These whales separate the small shrimps from the water by means of the sieving apparatus of baleen plates in the mouth. The destruction of whales was particularly rapid during the War, for the whale oil was of great importance as a source of glycerine; and in the 1915-16 season eleven thousand seven hundred and ninety-two whales were killed.

In October, 1925, the research ship "Discovery" sailed with Dr. Kemp as director of research to carry out a study of the environment of the whale. Re-

² A. C. Hardy, "Work of Royal Research Ship Discovery," *Geographical Journal*, (London), September, 1928.

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search work in South Georgia is revealing data as to breeding times, rate of growth, food of whales, and the chemical composition of the innumerable samples of sea water. Already Mr. Mathews' work here shows that the three South Georgia whales live exclusively

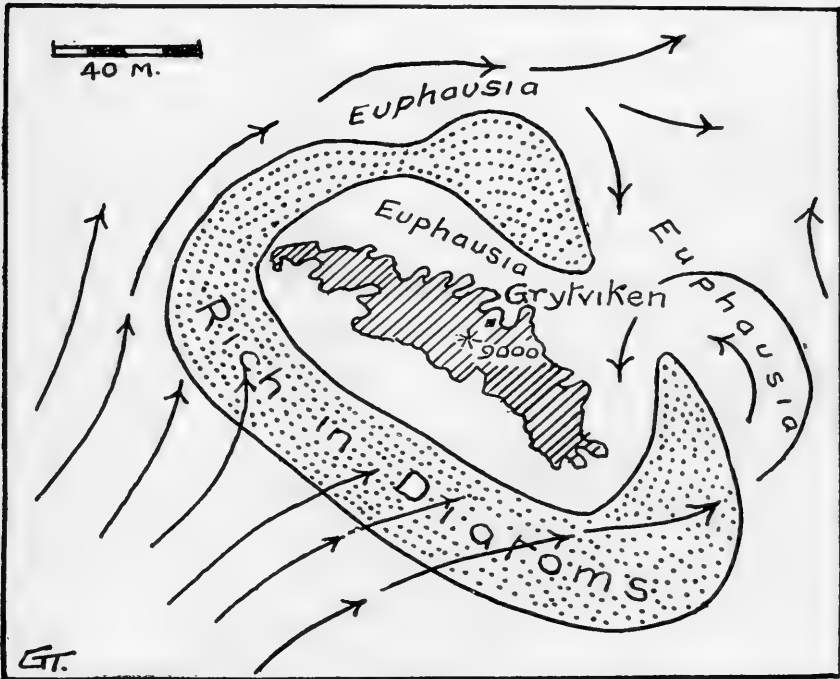


FIG. 33.—MAP OF SOUTH GEORGIA SHOWING DISTRIBUTION OF WHALE FOOD.

Main currents indicated. (After Hardy.)

on the shrimp, *Euphausia superba*. A good deal of whale-marking with discs is also being done to discover the migrations of the whale.

Mr. Hardy gives a most interesting map of South Georgia which showed that almost all the *Euphausia* are concentrated on the northeast side of South

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Georgia (see Figure 33). Immediately at each side of the island is a zone some fifteen miles broad very poor in plankton (floating organisms), and outside this an encircling zone of thick plant plankton, largely diatoms of the species *Corethron valdiviæ*,³ and outside this again is an area of more mixed, but less dense, plankton. This curious distribution is largely due to the supply of phosphate which wells up from deep waters along the west side of the island in response to the dominant ocean currents. The diatoms growing here are carried round to the sheltered northeast side of the island, where there has developed an extremely rich area of *Euphausia*. This is perhaps why South Georgia is one of the richest whale-feeding grounds in the world.

POLITICAL REGIONS IN ANTARCTICA

We have seen already that there are no very well defined regions in the Antarctic so far as we know at present. There is a general tendency to call that region east of the Greenwich meridian East Antarctica and that in the other half of the time-circle West Antarctica. This division links King Edward Land with Graham Land and Coats Land, and splits the Ross Ice Shelf between the two Antarcticas. The second method of subdivision is to use four quadrants, opposite to the three southern continents and the Pacific Ocean. The third method is to ignore large divisions and discuss each region according to the name given by its dis-

³ Sketches of *Corethron* and *Euphausia* (not to scale) appear in Figure 31.

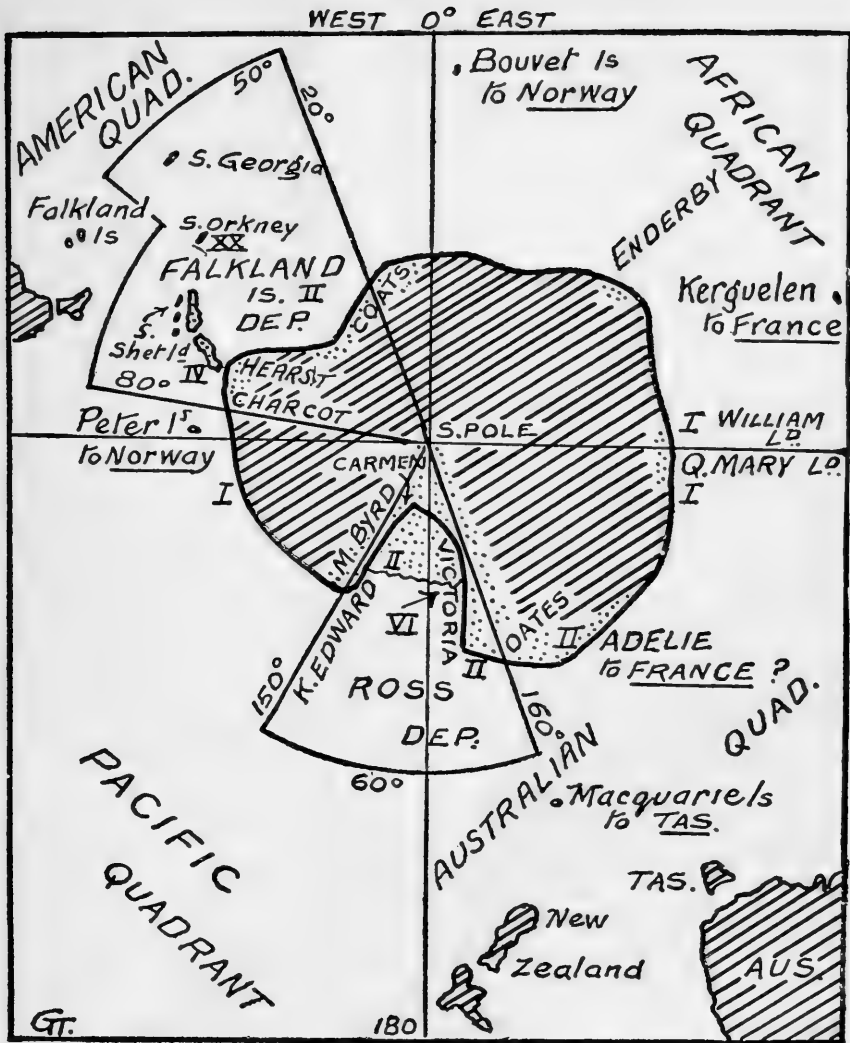


FIG. 34.—MAP ILLUSTRATING NOMENCLATURE AND RECENT ANNEXATIONS.

Dotted regions show the only areas charted in Antarctica. Admiral Byrd claims Marie Byrd Land for the United States. This high land is partly separated by a long fiord (along 150° W.) from King Edward Land. Carmen Land is probably non-existent. Roman figures show number of winters recorded at meteorological stations.

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coverer. This latter is the preferable course. The following table illustrates the three methods. It is seen at a glance that Mawson's present expedition has practically a *terra incognita* in the African quadrant (see Figure 34).

Primary Subdivision	Secondary Subdivision	Tertiary Subdivision
East Antarctica	African Quadrant	Enderby Land
	Australian Quadrant	Queen Mary Land Adelie Land Oates Land Victoria Land
West Antarctica	Pacific Quadrant	Ross Ice Shelf King Edward Land Marie Byrd Land Peter Island
	American Quadrant	Charcot Land Graham Land Hearst Land Leopold Land Coats Land

The cartographer is now faced with yet another set of arbitrary boundaries, which is based apparently on the fancies of the colonial offices of Britain, France, Norway, and the United States. We may rapidly traverse the events which led up to the first definite proclamation in 1908.

Captain Cook took possession of South Georgia in 1775, while Captain Biscoe did the same for Graham Land in 1832. Most explorers since have raised the flag of their nation and taken possession in the name of

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the king or ruler. To quote D. H. Miller (*Polar Problems*), "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, i.e. notification of the fact to other Powers."

In July, 1908, Letters Patent from the British Crown appointed the Governor of the Falkland Islands to be Governor of South Georgia, the South Orkneys, the South Shetlands, the Sandwich Isles, and Graham Land. The territory lay "south of the fiftieth parallel of south latitude and between the twentieth and eightieth degrees of west longitude." The original limits apparently included Tierra del Fuego and other lands of Chile and Argentina. But an amended definition gave the boundaries shown on the map, which extended along the two meridians to the South Pole. Thus the Weddell Sea became a British territory. (Figure 34.)

In July, 1923, a second dependency was constituted which places the Ross Sea beneath the Union Jack under the jurisdiction of the Governor General of New Zealand. Here the sixtieth latitude is the northern boundary, the other two being the 160th degree of east longitude, and the 150th degree of west longitude. In January, 1841, Ross had taken possession of these lands on Possession Island near Cape Adare. Sir Edgeworth David raised the flag at the South Mag-

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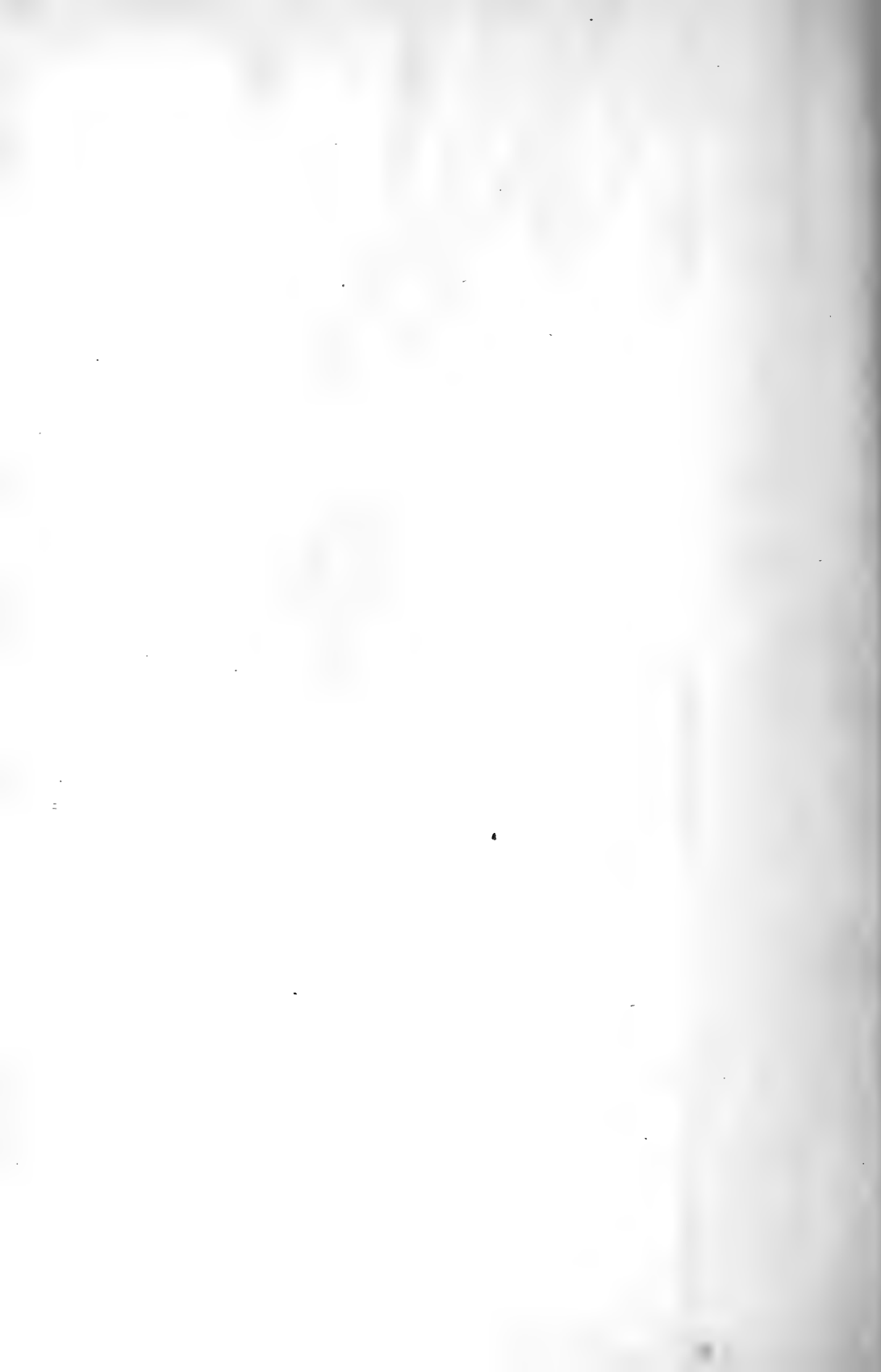
netic Pole in January, 1909. Shackleton first traversed the Polar Plateau in 1908 though Amundsen took possession of the polar region itself in the name of the King of Norway. Supposing valuable minerals are discovered at the Pole, it will be an interesting legal point as to where the *hinterlands* of the coasts shall have their furthest southern limit, if the Pole itself is to belong to Norway! It seems a great pity that those in authority did not choose 155° E. longitude, instead of 160° , as the western boundary of the Ross Dependency. For the Magnetic Pole and all the mountains discovered by Scott between 79° S. and 83° S. are outside this limit. In fact, the most striking feature in Antarctica, the great South Victoria Horst (see Figure 10), winds east and west across this political boundary from Cape Adare to the Pole

The French Government in March, 1924, has attached Adelie Land to the Government of Madagascar, together with Kerguelen Island and St. Paul and Amsterdam islands. The statement is vague, the region being spoken of as "that portion of Wilkes Land known as Adelie Land." As mentioned earlier there is no unanimity as to what constitutes Wilkes Land. We have seen that D'Urville spent only one week in East Antarctica or perhaps less time than almost any other explorer. He did not land on the main land. In view of Mawson's splendid achievements in cartography and science, and his sojourn during two Antarctic winters in this region, it seems likely that Australia will make out a good case for the British claims to Adelie Land, especially as the hinterland

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areas, at the Magnetic Pole, at the head of the Taylor Glacier, and in the vicinity of Barne Inlet, have all been mapped by British expeditions.

Norway is the third nation to expand its territories in the Antarctic. In November, 1927, the ship "Norvegia," under Captain Christensen, sighted Bouvet Island, that elusive island in the South Atlantic Ocean. He fixed its position at $54^{\circ} 26' S.$ and $3^{\circ} 24' E.$ (see Figure 34). The island is pentagonal in shape and about eight kilometers wide. Its snow-clad sides rise evenly to a central plateau of about nine hundred meters elevation. There was practically no vegetation, but the seas teemed with life, and a number of fur-seals were killed. The ship stayed there during December. In November, 1928, the British waived any claims to the island in favor of Norway. In the last whaling season (1928-29) the "Norvegia" made a journey to Peter Island ($90^{\circ} W.$ and $69^{\circ} S.$) and annexed it to Norway. This island was the first land seen south of the Antarctic Circle, and was discovered by the Russian, Bellingshausen, in January, 1821. Thus Norway has just taken possession of two of the most interesting localities discussed in Antarctic history. Perhaps they epitomize Antarctica as a whole. Land covered by ice, hard to discover, valueless for commerce, but surrounded by richly endowed seas and touched with mystery and the romance of the unknown.



REFERENCES

CHAPTER I

The Value of Antarctic Exploration

I know of no general account stressing the *scientific* value of polar exploration, though the subject is touched upon in most polar books. H. R. Mill's *The Siege of the South Pole* (London, 1905), is the best introduction to a study of Antarctica. Mawson in the *Geographical Journal* (June, 1911), stresses the structural interest. His chapter in *Problems of Polar Research* (New York, 1928), is very suggestive. The whole of this latter book, in fact, should be read by every student. The present writer in his *With Scott, the Silver Lining* (London, 1916), has endeavored to give in popular language some account of the many problems tackled by his scientific colleagues and himself in the Antarctic.

CHAPTER II

Exploring Antarctic Seas

The author has turned to original volumes where possible. Heawood's *Geographical Discovery* (Cambridge, 1921), is useful. The *Siege of the South Pole* is excellent for an account of exploration up to 1904. The claims of Wilkes are discussed by Balch in *Antarctica* (Philadelphia, 1902). See also J. K. Davis' *With the Aurora* (London, 1919). *The Antarctic Manual*, published by the Royal Geographical Society (London, 1901), gives the logs (or important extracts) of Biscoe, Balleny,

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Wilkes, D'Urville, Arctowski, and Bernacchi. There are many articles in the journals of the older geographical societies dealing with these explorations.

CHAPTER III

Exploring the Great Continent

Journals of all the later voyages are available in most large libraries. In English are accounts by Cook (1900) and Bernacchi (1901), of Gerlache's and Borchgrevinck's expeditions. The volumes of the great expeditions are classic. *The Voyage of the Discovery* (1905), *The Heart of the Antarctic* (1909), *Scott's Last Expedition* (1913), and *The Home of the Blizzard* (1915). I may be pardoned for referring to the remarkable series of books which describe the 1910-13 expedition with which I was associated. Scott's account appeared in 1913, Priestley's in 1914, Taylor's in 1916, Evans' in 1921, Ponting's in 1921, and Cherry-Garrard's in 1923. Levick and Gran have also written books thereon. These are, of course, in addition to the large volumes on special scientific subjects.

CHAPTER IV

Recent Expeditions to the Antarctic

Filchner's voyage is described in *Petermann's Journal* (1913), page 57. Shackleton's last two voyages are described in books entitled *South* and the *Voyage of the Quest*. The number of the *American Geographical Review* for July, 1929, contains a valuable article by Sir Hubert Wilkins from which I have been permitted to quote largely. My account of Commander Byrd's exploits is also mainly based on an article in the *Review* for April, 1929.

REFERENCES

The Brief History of Polar Exploration by W. L. A. Joerg has just been published (1930) by the American Geographical Society. It deals especially with exploration by flying, and is accompanied by two invaluable maps.

CHAPTER V

The Continent; Its Geology and Relation to Other Lands

As regards geology, I hasten to acknowledge my indebtedness to the best single memoir yet produced by an Antarctic expedition. I refer to *Geology*, Vol. I by David and Priestley (Heinemann, London, 1914). This deals with physiography, glaciology, meteorology, and paleontology, as well as the usual geological research. Ferrar's account (*Discovery Expedition, 1902*) is still the foundation of all stratigraphic work in East Antarctica. Nordenskjöld's volumes (Stockholm, 1910), especially those dealing with the fossils, must be consulted. Woodward's account of the Devonian fish (1921) and Seward on the Permian ferns (1914) are published by the British Museum.

CHAPTER VI

Scenery and Topography

This chapter on topography is based almost entirely on the writer's quarto memoir *Physiography of MacMurdo Sound and Granite Harbour* (Harrison, London, 1922). No other expedition has come across such large areas of ice-free country, so that no other memoir perhaps deals so fully with these problems. I contributed a very lengthy paper on the subject to the *Royal Geographical Journal* for October, November, and December, 1914; and I have

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borrowed one or two maps therefrom. A few illustrations are from my book, *With Scott*.

CHAPTER VII

Ice Sheets and Glaciers

Glaciology is discussed in my large memoir, and I have used in this book a number of illustrations therefrom. But I am much indebted—as are all Antarctic students—to the very fine memoir (*Glaciology*, Harrison, London, 1922), produced by my sledge-mates (and brothers-in-law!) Priestley and Wright. Some data have also been taken from the earlier memoir by David and Priestley (1914). The textbook by W. H. Hobbs, *Characteristics of Existing Glaciers* (New York, 1911), should be consulted by all who are interested in glacial erosion.

CHAPTER VIII

Oceanography and Sea-Ice

Oceanography was investigated closely by the German expedition under Drygalski. I have used one drawing from his chapter in *Problems in Polar Research* (q.v.). I am indebted to the American Geographical Society for much data incorporated in their splendid large-scale map of the Antarctic (1928). The other references are mentioned in Chapters VI and VII.

CHAPTER IX

Climatology

For the climatology I have used my own chapter in *Problems of Polar Research*. A book of particular value concerning the general circulation is *Glacial Anticyclones*, by W. H. Hobbs (New York, 1926). I have

REFERENCES

referred in many places to the three volumes of meteorology written by my colleague on the expedition, Dr. G. C. Simpson (Calcutta, 1919). Mawson's brief account of auroræ (*Heart of the Antarctic*) has been quoted.

CHAPTER X

Flora and Fauna

The volume on botany produced after Nordenskjöld's expedition is important (Stockholm, 1910). Dr. Wilson's very readable account of the Antarctic fauna will be found at the end of *Voyage of the Discovery*, Vol. II. A number of references concerning whaling are mentioned in the text.

CHAPTER XI

Commercial and Political Aspects

The journals consulted are referred to in the text. There is no book dealing specifically with the commercial and political aspects of Antarctica. However, two general books which have appeared recently may be referred to. They are *Polar Regions* by Rudmose Brown (London, 1927), in which, however, most of the space is given to Arctic areas; and *Antarctica* by Gordon Hayes (London, 1928). The latter is a large volume, marked by controversial discussions as to the relative merits of various expeditions. It is by an armchair writer who has apparently little belief in the value of detailed scientific research in the Antarctic regions, which in his opinion "savours of solemn trifling." As the present writer holds the opposite view, he is not much in sympathy with Mr. Hayes' arguments, though the latter's industry has compiled a very readable book.

I have also written a long chapter dealing with equip-

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ment, etc., for Antarctic travelers in Brouwer's series of *Practical Hints for Scientific Travellers*, Vol. IV (Nijhoff, 1926, The Hague). A special collection of books and apparatus is to be seen at the Polar Institute attached to the University of Cambridge, England.

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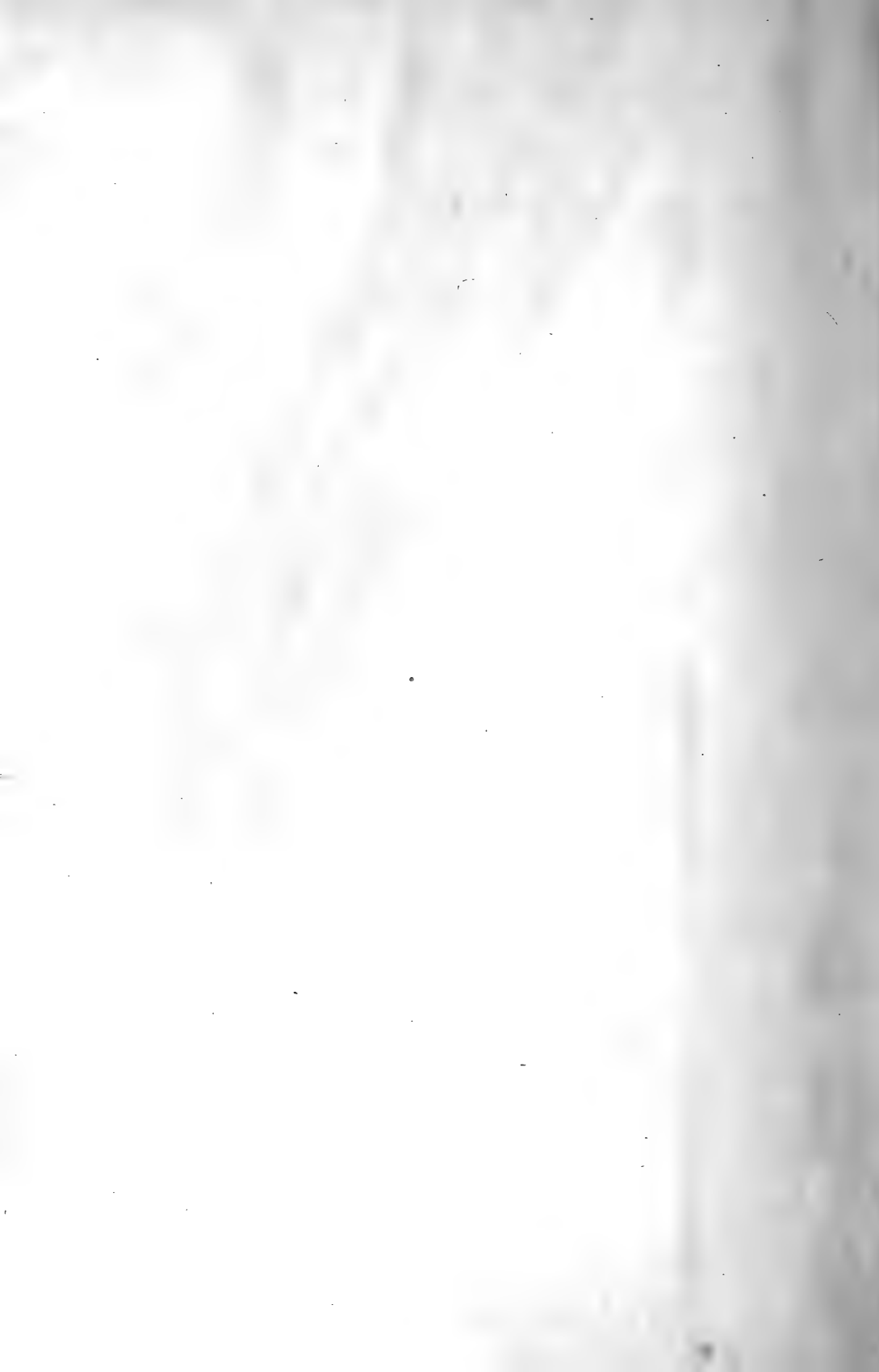
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