ON THE CONDITIONS OF THE ANTARCTIC[1]

II.

ALTHOUGH no land *débris* of any kind was observed by us on the icebergs, there cannot be the slightest doubt that such is carried by them all over the region and distributed on the bottom. The samples brought up by the sounding instrument consist almost entirely of comminuted clays and sands, and the dredge always contained in considerable quantity, about the meridian of 80° E., chiefly basaltic pebbles, and, further to the eastward, pebbles and larger fragments of metamorphic rocks, granite, gneiss, mica-slate, hornblende-slate, clay-slate, and chlorite-slate.

While the evidence may be said to be conclusive that these icebergs have their origin on land, it seems to me that the presumption is greatly in favour of the land at their breeding-place having been comparatively low and flat, and bordered for a considerable distance by shoal water. Although the white ice which forms the exposed portion of the flat-topped southern icebergs is very hard, its specific weight is considerably below that of absolutely compact ice. Allowing for this difference, and supposing that one-seventh part of the ice is raised above the water, supposing also that the berg is symmetrical in form, which, from its appearance and probable mode of origin is likely to be the case; before it has been subjected to the action of the sea, the submerged portion would be 1,200 feet in depth, the berg would float in water 200 fathoms deep, and the average thickness of the land ice-cap would be 1,400 feet. From the comparatively small number of icebergs at the point where we crossed the Antarctic circle, and so far as we could judge from our own observations and the previous observations of others, for a considerable distance to the west of the meridian of 80° E., we were led to believe that the place of their formation, the land and the belt of shallow water girding it, was at a very considerable distance from us.

Although in the present state of our knowledge it would be rash to form any very definite opinion as to the conditions of the region included within the parallel of 70° S., still there are some indications which have a certain weight. We have no evidence that this space which includes an area of about 4,500,000 square miles, nearly double that of Australia, is continuous land. The presumption would seem rather to be that it is, at all events, greatly broken up, a large portion of it probably consisting of groups of low islands united and combined by an extension of the ice-sheet. One thing we know, that the precipitation throughout the area is very great, and that it is always in the form of snow, the thermometer never rising, even in the height of summer, above the zero of the centigrade scale.

Various patches of Antarctic land are now known with certainty, most of them between the parallels of 65° and 70° S.; most of these are comparatively low, their height, including the thickness of their ice-covering, rarely exceeding 2,000 to 3,000 feet. The exceptions to this rule are Ross's magnificent volcanic chain, stretching from Balleny Island to a latitude of 78° S., and rising to a height of 15,000 feet; and a group of land between 55° and 95° west longitude, including Peter the Great Island and Alexander Land, discovered by Bellingshausen in 1821; Graham Land and Adelaide Island, by Biscoe, in 1832; and Louis Philippe Land, by D'Urville, in 1838.

The remaining Antarctic land, including Adelie Land, discovered independently by Dumont D'Urville, and Lieut. Wilkes, in 1840, in long. 140° 2′ 30″, lat. 66° 45′ S.; Clairie Land, discovered by the same navigators about 3° farther to the westward; Sabrina Land, discovered by Balleny, in 1839; and Kemp Land and Enderby Land, discovered by Biscoe, in 1833, nowhere rise to any great height. If we were justified in adding the "strong appearances of land" reported by Lieut. Wilkes, which would virtually connect Ringgold's Knoll not far from the Balleny Islands, with a point in long. 106° 18′ 42″ E., lat. 65° 59′ 40″ S., by a continuous coast-line of moderate height, the extent of land of this character would be considerably increased.

The geological structure of the Antarctic Land is almost unknown. South Victoria is actively volcanic and consists doubtless of the ordinary volcanic products. D'Urville's party landed on Adelie Land and found rocks of gneiss. Wilkes reports having landed on an iceberg, long. 106° 18′ 42″, and finding "imbedded in it in places boulders, stones, gravel, sand, and mud or clay. The larger specimens were of red sandstone and basalt." At the same place Lieut. Ringgold found that "the icebergs near at the time presented signs of having been detached from land, being discoloured by sand and mud." From one iceberg he procured several pieces of granite and of red clay which had been frozen in. Beyond these observations, and our own on the nature of the pebbles brought up by the dredge, we have no information.

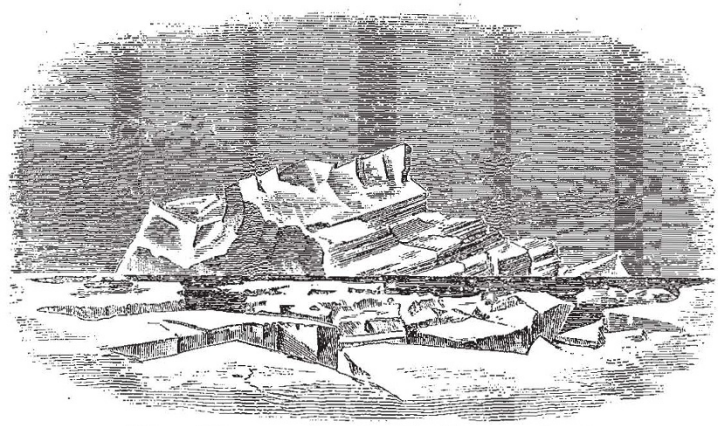

FIG. 3.—February 25, 1874. Lat. 63° 49′ S, Long. 94° 51′ E.

That the area within the parallel of 70° S. is continuously solid, that is to say, that it is either continuous land or dismembered land fused into the continental form by a continuous ice-sheet, I think there can be little doubt. The local cases of abnormal distribution of temperature which produce such remarkable conditions of climate even within the North Polar Sea exist in the southern hemisphere only to a very slight degree; and we know by the absence of any well-defined local Antarctic return-currents comparable with the Labrador current, or the current round the south of Spitzbergen, that the function of such currents as the Gulf Stream in ameliorating the northern climate, and breaking up the ice, and producing a circulation even in the highest northern latitudes, is not in any way represented in the south.

In favour of the view that the area in question is broken up, and not continuous land, two considerations appear to me to be very suggestive. If we look at an ice-chart we find that the sea is comparatively free from icebergs, and that the deepest notches occur in the "Antarctic continent" at three points, each a little to the eastward of south of the great land-masses, and I have little doubt that the explanation of this fact lately suggested by Dr. Neumayer is the correct one. The great equatorial current impinging upon the eastern coasts of the continents bifurcates upon

[1] The substance of a lecture by Sir C. Wyville Thomson, F.R.S., delivered in the City Hall, Glasgow, on November 23, under the arrangements of the Glasgow Science Lecture Association.] Continued from p. 106.

each, and both branches acquiring a slight but decided easterly set by their excess of initial velocity, pass northwards and southwards directed for a time by the land coasts. But the fate of the southern is very different from that of the northern branches. Instead of accumulating and "banking down" in the confined gulfs, the Atlantic, the Pacific, and the Indian Oceans, they at once pass into the waste of the "water hemisphere," and are almost merged in the great drift current which sweeps round the world occupying a belt from 600 to 1,000 miles broad in the southern sea. But while the greater portions of the Brazilian current, the East Australian current, and the southern branch of the Agulhas current are thus merged they are not entirely lost; for at their points of junction with the drift current of the westerlies the whole belt of warm water is slightly deflected to the southward, and it is opposite these points of junction that we have the comparatively open sea and the penetrable notches in the southern pack.

Thus Ross, in 1841 and 1842, after forcing his way through the moving pack, which he found sufficiently open to allow of his doing so, passed between the meridians of 170° E., and 170° W., to the latitude of 78° 11′ S. Weddell in 1823, and Ross in 1843, reached the parallels of 74° 14′ and 71° 30′ S. respectively, between the meridians of 15° and 30° W. The case of the Brazilian current is, however, a little more complicated than that of the others, for there is high and extensive land between the meridians of 55° and 65° W., in 65° south latitude, and the warm current already led far to the southward by the south-American coast appears to bifurcate upon Graham Land, and to produce another bight, in 90° west longitude, a little to the west of the southern point of the South American Continent. In this bight, Cook, in 1771, and Bellingshausen in 1821, pushed nearly to the 70th parallel of south latitude.

The opening caused by the deflection of the southern branch of the Agulhas current towards Kerguelen and the Heard Islands, has not yet been fully explored, but what has been already done in that direction seems to be in striking confirmation of this view. We had indeed arrived independently at the same conclusion before reading Dr. Neumayer's paper. At the point where we crossed the Antarctic Circle (Long. 78° 0′ E.), and for some distance to the westward there were few icebergs, and the sea was almost clear to the south-west. It was Capt. Nares' opinion that had it been considered desirable and had the attempt been made earlier in the season, it would have been easy for us to have pushed southwards in that direction—how far we had no means of ascertaining—but the pack was moving about round us, and for the reasons already given we believed the barrier to be at a considerable distance.

But we not only observed the effect of the influx of warmer water; we were able to detect its presence by the thermometer. Referring to the results of a serial temperature-sounding of February 14, with a surface-temperature of − 1°·2 C., between 300 and 400 fathoms there is a band rising to more than half a degree above the freezing-point. That this warm layer is coming from the north there is ample proof. We traced its continuity with a band at the same depth gradually increasing in warmth, to the northward; and it is clear that its heat can be derived from no other source, and that it must be continually receiving new supplies, for it is overlaid by a band of colder water tending to mix with it by convection.

It is of course possible that the three warm currents may, by coincidence, be directed towards three notches already existing in a continental mass of land; but such a coincidence would be remarkable, and there is certainly a suggestion of the alternative, that the "continent" may consist to so great an extent of ice as to be liable to have its outline affected by warm currents.

The second consideration is that during summer, the only time when these regions have been as yet visited, the greater part of the outline of the area representing the Antarctic continent has been found to consist of moving ice-pack. The prevailing winds within the Antarctic Circle are from the south-east, and as a rule the pack and the icebergs are moving to the westward, and fanning out from a centre. Almost all the navigators who have passed the belt of pack have received the impression that there was open water within, that, in fact, by that time, late in the summer, the pack of the year had been drifted a considerable distance from its nucleus—the land or the continuous ice-sheet. If this be so it would at all events indicate that the "Antarctic continent" does not extend nearly so far from the Pole as it has been supposed to do.

I conceive then that the upper part of one of these tabular icebergs, including by far the greater part of its bulk and culminating in the portion exposed above the surface of the sea, was formed by the piling up of successive layers of snow during the period, amounting perhaps to centuries, during which the ice-cap was slowly forcing itself over the low land and out to sea, over a long extent of gentle slope, until it reached a depth considerably beyond 200 fathoms. The lower specific weight of the ice then caused an upward strain which at length overcame the cohesion of the mass, and portions were rent off and floated away. If this be the true history of the formation of these icebergs, the absence of all land *débris* on the portion exposed above the surface of the sea is readily understood. If any such exist it must be confined to the lower part of the berg, to that part which has moved upon the floor of the ice-sheet.

The icebergs, when they are first dispersed, float in from 200 to 250 fathoms; when, therefore, they have been drifted to latitudes of 65° or 64° S., the bottom of the berg just reaches the layer at which the temperature of the water is distinctly rising, and is rapidly melted, and the mud and pebbles with which it is more or less charged are precipitated. That this precipitation takes place all over the area where the icebergs are breaking up, constantly and to a considerable extent, is evident from the fact that the matter brought up by the sounding-instrument and the dredge is almost entirely composed of such deposits from ice; for diatoms, *Globigerinæ*, and radiolarians are present on the surface in large numbers, and unless the deposit from the ice were abundant, it would soon be covered and masked by a layer of the exuviæ of surface organisms.

There is one point in connection with the structure of icebergs which is of great interest, but with regard to which I do not feel in a position to form a definite judgment. It lies, however, especially within the province of a distinguished professor in the University of Glasgow, Dr. James Thomson, and I hope he will find leisure to bring that knowledge and experience to bear upon it which have already thrown so much light upon some of the more obscure phenomena of ice. I have mentioned the gradual diminution in thickness of the strata of ice in a berg from the top of the berg downwards. The regularity of this diminution leaves it almost without a doubt that the layers observed are in the same category, and that therefore the diminution is due to subsequent pressure or other action upon a series of beds which were at the time of their deposition pretty nearly equally thick. About 60 or 80 feet from the top of an iceberg the strata of ice a foot or so in thickness, although of a white colour, and thus indicating that they contain a quantity of air, and that the particles of ice are not in close apposition, are still very hard, and the specific gravity of the ice is not very much lower than that of layers not more than 3 inches thick nearer the water-line of the berg. Now it seems to me that this reduction cannot be due to compression alone, and that a portion of the substance of these lower layers must have been removed.

It is not easy to see why the temperature of the earth's crust under a widely extended and practically permanent ice-sheet of great thickness should ever fall below the freezing-point; and it is matter of observation that at all seasons of the year vast rivers of muddy water flow into the frozen sea from beneath the great glaciers which are the issues of the ice-sheet of Greenland. Ice is a very bad conductor, so that the cold of winter cannot penetrate to any great depth into the mass. The normal temperature of the crust of the earth at any point where it is uninfluenced by cyclical changes is, at all events, above the freezing-point; so that the temperature of the floor of the ice-sheet would certainly have no tendency to fall below that of the stream which was passing over it. The pressure upon the deeper beds of the ice must be enormous; at the bottom of an ice-sheet 1,400 feet in thick-

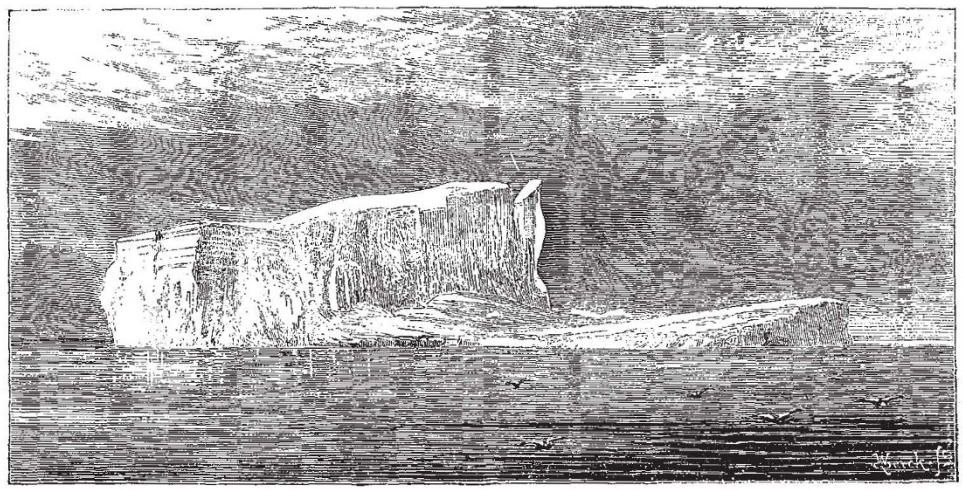

FIG. 4.—Iceberg passed on February 21, 1874. Lat. 63° 30', Long. 89° 6 E.

ness it cannot be much less than a quarter of a ton on the square inch. It seems therefore probable that under the pressure to which the body of ice is subjected a constant system of melting and regelation may be taking place, the water passing down by gravitation from layer to layer until it reaches the floor of the ice-sheet, and finally working out channels for itself between the ice and the land whether the latter be sub-aërial or submerged.

I should think it probable that this process or some modification of it may be the provision by which the indefinite accumulation of ice over the vast nearly level regions of the "Antarctic continent" is prevented, and the uniformity in the thickness of the ice-sheet maintained; that in fact ice at the temperature at which it is in contact with the surface of the earth's crust within the Antarctic regions cannot support a column of itself more than 1,400 feet high without melting.

When the icebergs are drifted in the summer a little to the northward—in the meridian of 80° E. to the parallel of 64° S.—they begin to disintegrate very rapidly. The water at the surface of the sea rises to zero and slightly above it, and dashing against the windward side of the berg, partly by its mechanical action, but more by the constant and rapid renewal of the warm water, it soon wears a deep groove in the face of the cliff. When the groove has cut in so far that cohesion will no longer maintain the weight of unsupported ice, which seems usually to be the case when it is 10 to 15 feet deep, a mass of the cliff falls down, and the weight of the berg being reduced on that side it tilts up more or less and assumes an inclined position; the stratification thus becomes inclined, although it still remains conformable with the plane of the top of the iceberg.

The sea now washes up on the low portion which has been exposed by the tilting of the berg, which it soon reduces to a beautiful curved slope to the bottom of the new cliff, and the process is repeated until by repeated falls of the face of the cliff one side of the berg is so much lightened, that the preponderating weight of the opposite side raises the newly exposed portion out of the water; giving the berg a double outline and the veining a high inclination.

We frequently saw table-topped icebergs with the upper surface very irregular; when that is the case evidence

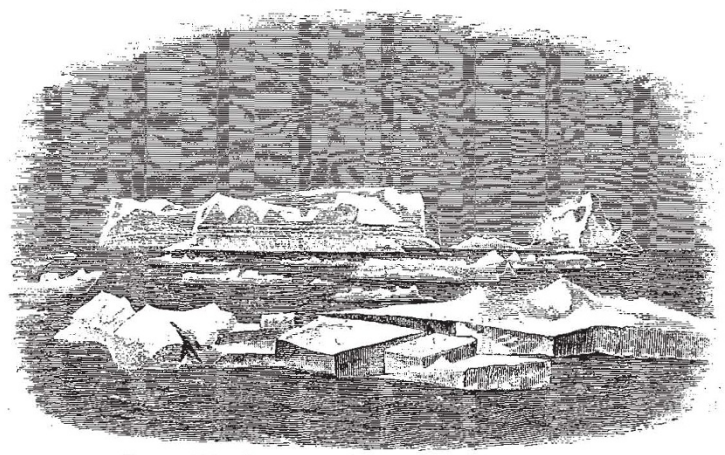

FIG 5.—February 25, 1874. Lat. 63° 49' S, Long. 94° 51' E.

may usually be found from the colour, the closeness of the veining, and other appearances, that it is not the original surface of the iceberg which is now presented to us, but a second surface produced by the cutting away by the sea of an entire story, as it were, of the berg; which athough it had no doubt at one time during the process been greatly inclined, had recovered its equilibrium on the whole of the upper layer having been more or less symmetrically removed. Fig. 3 is a view of an iceberg in which the whole of the upper tier seems to be breaking

up and disintegrating under the influence of the air and waves; it is fissured through and through, a large portion has already fallen away, exposing terraces of blue ice previously submerged, and the sea around is cumbered with the fragments. It is easy to see how almost any eccentricity of form may be produced by the irregular action of the waves upon the different sides of an iceberg tilted to different inclinations.

When an accidental hollow or other irregularity on the surface of an iceberg directs the action of the surf on any special point, a cave is speedily formed, and the effect constantly increasing with the deepening of the cavity, the ice is often honeycombed with caverns which penetrate far into the solid berg, and add wonderfully to its beauty by their lovely colouring in shades of cobalt blue, varying with every play of shade and light. The caves are, however, very fatal to the iceberg. From the ice not being thoroughly rigid, whenever the support is taken away from beneath, the layers above bend and give way; vertical fissures are produced which become filled with a breccia of ice and snow, often discoloured by sea-birds; the ice, instead of showing its original uniform horizontal stratification, is distorted into all sorts of anticlinals and synclinals; and fragment after fragment crashes down into the sea.

Fig. 2 gives an idea of the form of a beautiful vaulted berg. The sea was washing through and through it; and as we passed close by, we sat gazing, entranced, at the marvellous beauty of the colouring of the vaults of ice, and the waves, and the snowy spray illuminated by a red setting sun; but our gorgeous iceberg was evidently doomed to speedy destruction. Some glittering pinnacles were the only remains of the buttresses of former arches, and a quantity of *débris* floating round it showed that the whole fabric was undergoing rapid change.

Some few of the bergs which we saw were tilted up to an angle of upwards of 50°, and in various ways—by the inclination of the bergs, by the denudation of successive layers by the action of the sea, and by "dislocations of strata." I believe we saw at various times sections of icebergs to the depth of perhaps 400 feet. All such sections gave simply a continuation of the same phenomenon which we observed in the portion of the berg normally exposed, a gradual approximation of the lines of stratification and deepening of the blue colour.

Sometimes we saw small bergs which were very irregular in form, with all marked prominences rounded off, perfectly clear, and of a deep sapphire blue. These I conceive to be masses of ice from near the base of a berg, which, from extreme shifting of its centre of weight, has turned right over, and exposed the ice near the bottom, in which, by melting and regelation under great pressure, all structure has been lost.

The curious question naturally arises, Shall we ever be able to reach the South Pole? With our present methods and appliances I should think that the answer must be an unhesitating negative. Except possibly somewhere in the region where Ross penetrated, in 1842, to the parallel of 78° to the south of New Zealand, or about Graham Land, where Capt. Dallman, in 1873, continued the explorations of Capt. Biscoe, there seems to be no accessible lead of land; and Ross's southernmost point is upwards of 700, and Graham Land 1,200 miles from the pole. The remainder of the outline of the Antarctic continent appears to be a perpendicular cliff 200 to 250 feet in height, without shelter, and with a heavy pack broken up and kept in motion by frequent gales moving outside it during the greater part of the year, and bounding a vast expanse of glacier surface, a great part of it subject probably to high winds and to almost incessant falls of snow.

We have now learned that the North Pole, if not actually inaccessible, is much more difficult of access than we imagined, even with the long roll before us of the gallant men who have strained through many years the resources of human skill and bravery to the utmost in fruitless attempts to attain the barren issue; and we can only anticipate disasters multiplied a hundred-fold should the South Pole ever become a goal of rivalry among the nations.

C. WYVILLE THOMSON

NORDENSKJÖLD'S EXPEDITION TO THE JENISSEI[1]

THE expedition, of whose plan, equipment, and composition we have already given some account, left Tromsö in the steamer *Ymer*, on July 25 this year, and on the 30th entered Matotschkin Scharr, where they obtained some specimens of Novaya Zemlya salmon. An easy passage was made to the east side, where, during a stay of twenty-four hours, the naturalists did some collecting, dredging, &c. Leaving the Scharr on the 31st, the Kara Sea was at first found quite open, but after a few hours it became so blocked with loose ice in all directions that the *Ymer* was compelled to turn back, and was anchored on the inner side of the promontory which projects from the southern side of the sound, nearly half way between the entrance and Gubin Bay.

Here the sea is rich in varying animal forms, the land bleak and poverty-stricken. The mountains for the most part consist of black clay-slates, probably early Silurian, and grey dolomite beds, in which search was made for fossils in vain. On the other hand, the clay-slate is in many places full of quartz veins with numerous cavities, whose crystalline contents gave occasion to the unfortunate Tschirakin's statement that he had found here a block of stone set full with the most brilliant, beautiful, and valuable precious stones, for which, after his death, he was vehemently censured by his chief, Rossmylov, who sought in vain for the supposed treasure.

In one respect this part of Novaya Zemlya is of great geological interest; for here are to be seen no fewer than six clearly-marked beaches, situated at different heights one above the other, and showing that the land hereabouts has been elevated during the very latest geological period at least 500 feet. With the exception of certain parts of Greenland, where a considerable sinking of the land has taken place during recent centuries, a similar raising of the land has been observed in most other Arctic regions, and this raising of the land has without doubt played a very important part in the great geological changes which have occurred on the surface of the earth since the close of the Tertiary period. For the Swedish observer the phenomenon besides has quite a special interest, inasmuch as attention was first called to it in Sweden more than a century ago, and it then gave occasion to an impassioned discussion between those holding different opinions, which is well known in the history of science.

Matotschkin is surrounded by high, bold mountain ridges and summits, which continue to occupy the interior of the island for more than thirty English miles south of the sound. Farther south the mountain tops disappear completely from the interior, and the land passes into a level high-lying plain, nearly free of snow during summer and sloping gently towards the east coast and the Kara Gate, till it terminates most frequently with a precipitous face towards the sea.

A broad ice-free belt of water having in the meantime been formed along the east coast of Novaya Zemlya, the expedition took advantage of it, and sailed along shore. The greater part of the ice-fields were, however, now quite rotten, and it was clear that they would completely melt away during the remaining part of the summer.

Partly by ice, partly by fog, the *Ymer* was prevented making right across the sea, and it was not till the 12th that the ice-belt was so broken up that they could steam on round White Island, past the Gulf of Obi to the mouth of the Jenissei.

We sighted land here on the 15th, Dr. Nordenskjöld goes on to state, thus exactly a year after the rocks at Dickson's Harbour were first seen from the *Pröven*. This was some hours sooner than the dead reckoning promised, which at first was ascribed to the influence of an easterly current in the parts of the Kara Sea we had just traversed. When we came nearer, however, I was surprised to see before me a plain which was unbroken by any "berg-åsar," though I knew, from last year's observation, that

[1] Abstract of Prof. Nordenskjöld's Report in the *Göteborgs Handels Tianing*, October 24.