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ORIGINAL ARTICLES.

I.—The Antarctic Ice-cap.

By H. T. Ferrar, M.A., F.G.S.,
Geologist to the late "Discovery" Antarctic Expedition,
of the Survey Department, Cairo.

In a recent number of the Geological Magazine, Dec. V, Vol. III, March, 1906, p. 120, there is an article by Prof. E. H. L. Schwarz which deals with the thickness of ice-caps during the various Glacial periods. At the outset Professor Schwarz takes the data furnished by Captain Scott's narrative of the voyage of the "Discovery" as the main support of the physicists' contention that an ice-sheet cannot exceed 1,600 feet in thickness.

It is true that at the present day no ice more than 1,600 feet has been recorded. Dr. Nansen estimates the thickness of the Greenland ice-sheet to be nearly four times that amount, and, judging by the size of the icebergs said[1] to have been met with in the Southern seas, maintains[2] that the Antarctic Ice-cap must attain a very great thickness. These estimates, however, may be neglected, as the recent expeditions seem to show that the size of icebergs recorded in the Antarctic seas has been exaggerated. Both Von Drygalski[3] and Captain Scott[4] show that in times past the ice-caps of Greenland and South Victoria Land respectively attained a much greater thickness than they do now, and if we wish to prove that ice-sheets ever exceeded the 1,600 feet limit we have only the traces left by previous Glacial periods to fall back upon.

The thickness of an ice-sheet or iceberg, estimated by means of the unsubmerged height, is only very approximate. Von Drygalski gives 300 feet as the maximum height above water, and maintains that any iceberg which is higher than 300 feet must have turned over. In high latitudes the air is commonly misty, though in certain

[1] H. C. Russell: Journal of the Royal Society of New South Wales, vol. xxxi (1897), p. 241, reference number 172.
[2] Nansen: *Nature*, vol. lvii (1898), p. 424.
[3] Drygalski: Greenland Expedition, p. 33.
[4] Scott: Geog. Journ., April, 1905, p. 360.

localities clear bright days predominate: under these conditions, when no shadows are produced, it is exceedingly difficult to be certain which was originally the upper surface of a disintegrated iceberg. The accompanying illustration shows an iceberg estimated to be 200 feet high which still has a portion of its original upper surface intact. If this portion were removed it would be extremely difficult to make sure whether the berg had turned over or not. To argue that such icebergs as those figured in a great number of publications have all turned over, is hardly safe, especially as bodies with diameters of unequal length appear, in the majority of cases, to float with the longer diameter horizontal. It therefore seems highly improbable that a berg would increase its height by turning over.

A berg, however, may increase its height, and probably often does so, in the following way. A newly calved iceberg usually has vertical sides; the waves beat against these and, undermining them,

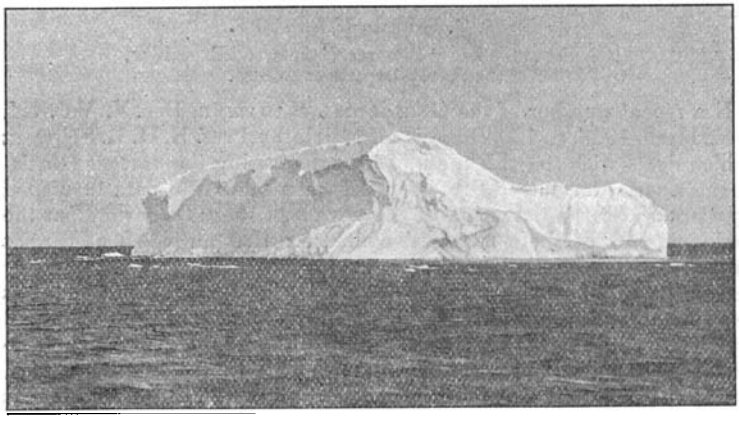

FIG. 1.—An iceberg which has turned through nearly 90°.

cause pieces to split off. This splitting will probably take place along vertical planes, parallel to inherent planes of weakness, and this undermining is accelerated by the temperature of the water at the surface being raised by radiant heat from the sun. The visible part of the berg will thus be reduced in mass, and consequently the berg will rise. That this is a common occurrence may be seen in almost any of the narratives of polar voyages, where one constantly finds references to the toe of an iceberg.

For icebergs floating freely in the sea, Von Drygalski gives the proportion of normal glacier ice above water to ice below water as 1 is to 4. Rink[1] makes the proportion as 1 is to 6; Steenstrup as 1 is to 7; Sir John Murray as 1 is to 7; and Scott[2] as 1 is to 5. The cannonading performed upon an iceberg by H.M.S. "Challenger,"

[1] Rink: Danish Greenland, London, 1877, p. 358.
[2] Scott: Geog. Journ., April, 1905, p. 356.

showed that the density is not uniform. Our experience upon the Ross Ice-sheet proved that normal glacier ice could be capped by any thickness of *firn* or loose snow; and therefore of two bergs with equal volumes immersed, if the visible part of one consisted wholly of snow and that of the other wholly of ice, the ratios of the visible to the submerged portions would be widely different. Again, the temperature and salinity of the sea-water have some effect in buoying up the ice, but this may be neglected. However, the aeration of the ice varies greatly, but for normal glacier ice Helland gives 0·886 as the specific gravity, while my results show a specific gravity of 0·83. Therefore, in Antarctic sea-water with an average density of 1·025 grammes per cubic centimetre, glacier ice would float with four parts immersed and one visible. This figure agrees closely with the results of Von Drygalski and Captain Scott obtained by actual measurements at glacier snouts. The greatest ice-cliff observed by

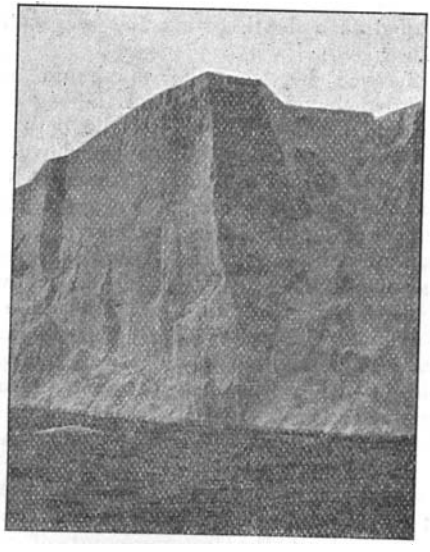

Fig. 2.—The edge of the Ross Ice-sheet near the point where it is thickest.

the staff of the "Discovery" was the edge of the Ross Ice-sheet floating in the vicinity of Cape Crozier. The height here was 240 feet and the depth of water 460 fathoms. As the surface here was unbroken and the cliff-face uncrevassed (see Fig. 2), it is hardly likely that this extreme thickness was produced by pressure as Professor Schwarz [1] suggests.

The question as to the limit of 1,600 feet being exceeded depends, as Professor Schwarz rightly points out, upon the temperature of the lower surface of the ice being below its melting-point. As far as I remember, the figure 1,600 feet is the height of a column of ice

[1] Schwarz: Geol. Mag., Dec. V, Vol. III, March, 1906, p. 122.

which would by its own pressure liquefy its sole if the temperature were 1 degree Fah. below its normal melting-point, and therefore the limiting thickness of 1,600 feet is far *above* the maximum for ice resting on land at the melting-point of ice.

At the "Discovery's" Winter Quarters, under the shadow of Mount Erebus, latitude 77° 51′ S., longitude 166° 45′ E., the mean annual temperature was —4·6° F.,[1] and hence the point where a temperature of 32° F. would be found must be below the surface. Whether this point be well below the sole of the thickest ice has not been determined, but as the glaciers are practically stationary their ice must be out of reach of this temperature. A series of observations of the temperature of glacier ice at fixed depths was made. The observations were commenced in April, after the temperature of the ice had begun to fall, and extended throughout the following Winter and Summer, until the month of February, when the ensuing fall of temperature due to the increasing cold began. The highest temperature recorded at a depth of six feet was —9° C., and the lowest —24·4° C.

The large difference between the maximum and minimum temperatures recorded below the ice and the lag caused by the six feet of ice would seem to show that the point which is not influenced by seasonal variations is still deeper down. Now if we take a value once adopted by a British Association Committee for the earth's mean temperature gradient, we get a rise of 1° F. for every 64 feet increase of depth. Therefore, for a rise of 36 Fahrenheit degrees (our mean annual temperature below the freezing-point) the 32° F. isothermal would be at least 2,300 feet below the surface. On the inland ice Captain Scott's observations show temperatures of 10°, 15°, or even 20° below those registered simultaneously at Winter Quarters. Therefore the mean annual temperature on the inland ice would be below the mean at Winter Quarters and the 32° F. isothermal surface proportionally lower down.

Von Drygalski's results point to the same conclusion, but it must be remembered—(*a*) that some of his temperatures were recorded from crevasses which were open to the air and to water during the Summer thaw; (*b*) that in Greenland during Summer the air temperature remains above the freezing-point of ice for several weeks, and often rises 8 or 10 degrees above that point.

Professor Schwarz does not seem wholly in favour of the view that a warmer climate in the Antarctic would produce a thickening of the ice-cap, sufficient to exceed the physical limit.[2] The German Antarctic Expedition and other earlier expeditions which remained near the Antarctic Circle record a great snowfall as compared with that experienced by the British Expedition in higher latitudes.

[1] All the temperatures quoted are our uncorrected values. Reference should be made to the "Discovery" Reports on Geology and Meterology, which are to be published by the British Museum (Natural History) and the Meteorological Office respectively.

[2] Tyndall: "Heat a Mode of Motion," 1898, 11th edition, p. 231 ff.; "The Forms of Water," 1892, 11th edition, p. 154.

The amount of snow on South Victoria Land was observed to diminish in quantity as the "Discovery" steamed south along the coast, and in latitude 77° South the glaciers were found to be retreating. By means of graduated stakes (snow-gauges) and blocks of ice exposed to the air throughout the year, it seems to be established that the ablation of the ice is greater than the precipitation. The mean temperature for the two Summer months was −4·3° C., and it was only when the sky became overcast and the air temperature rose a degree or two above the mean that any measurable quantity of snow fell.

It is as evident to those of us who have been in high latitudes that the isotherm of 0° C.[1] (which is near the Antarctic Circle) is an effective barrier to the transport of snow to higher latitudes; as it is evident to those who have been on both coasts of Ireland, on the south coast of Africa and the Karroo, that the mountains are a shield and cut off the rain from districts further inland. Professor Schwarz uses the argument that a high temperature during maximum glaciation will consequently produce more running water, and

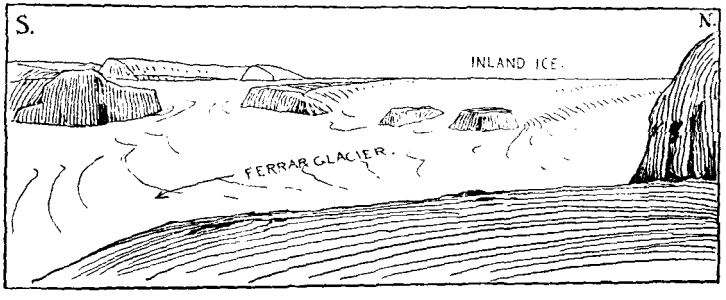

FIG. 3.—The inland ice falling down between nunataks from the inland plateau. From a sketch by H. T. Ferrar, greatly reduced.

attributes the deepening of glaciated valleys, not to the greater power of the ice, but to that of sub-glacial streams.[2] If this is so, then the deeply incised valleys of the Royal Society Range, with their stagnant glaciers, would afford additional evidence that a rise in temperature, and consequently a southerly migration of the zone of maximum precipitation, had taken place at some former period.

In his article, p. 123, Professor Schwarz says Scott found the highest points to sink below the horizon directly the level ice-cap was reached. Scott expressly says, on p. 414 of his narrative—"when we reached the interior plateau at a height of 8,900 feet we observed nunataks to the north standing above our own level." Mount Lister is given as 13,000 feet high, and stands on the edge of the plateau. The accompanying Fig. 3 is a sketch of the South Victoria Land ice-sheet as it falls together and becomes moulded into the Ferrar Glacier. The height between the graded surface of the

[1] Buchan: "Challenger" Reports, Physics and Chemistry, plates.
[2] Garwood: Q.J.G.S., vol. lviii, pl. xl.

glacier and the plateau is nearly 1,000 feet. Scott points out that this land at the back of the Royal Society Range appears to be higher than that to the north or to the south. This means that he thinks the Royal Society Range is the end of an elevated mass of land, with its length transverse to the coastline (i.e. east and west), and that a measure of the thickness of the Antarctic Ice-cap on this elevated transverse ridge would therefore be inaccurate.

That Captain Scott found it approximating to the physicists' maximum limit of 1,600 feet, no doubt is a very strong argument in favour of the view that the physicists' extreme limit is never exceeded. But when I repeat that the glaciation of South Victoria Land is approaching to a minimum, and that all glacialists require a great thickness of ice to explain the phenomena which they have described, I think it will be conceded that—(*a*) any thickness of ice may be accumulated so long as the loss by ablation, melting, and discharge is less than the gain by precipitation; (*b*) that the facts noted above are more in harmony with the glacialists' requirements than with Professor Schwarz' contention that the physicists' theoretical maximum of 1,600 feet cannot be exceeded.

II.—On the Interglacial Question.

By T. F. Jamieson, F.G.S.

A GREAT difference of opinion seems to exist among geologists, not only in Britain but also in other countries, in regard to the supposed occurrence of warm Interglacial periods during the age of ice. Those who incline to the views propounded by Adhemar and Croll as to the causes which produced the extraordinary climate of that time naturally look for alternations of cold and warm periods.

Precession of the equinoxes and variations in the excentricity of the earth's orbit are astronomical facts which must have had their influence, and the changes they might bring about in the direction and force of ocean currents, to which Croll attributed so much importance, have also to be considered. These astronomical causes and their accompaniments are not to be ignored, but their precise effect upon the climate of the period in question is still a matter of much uncertainty and one in regard to which our knowledge has made very little progress.

Mr. Lamplugh, in his recent address to the Geological Section of the British Association, lays much stress on the absence of any clear evidence of warm intervals or even of one such interval in the British Islands, and as no one is better acquainted with the drift beds of England his opinion must have much weight.

It seems to me that there is one important circumstance which may have led to this obscurity and which has not received the consideration it deserves, and that is the persistence of the vast masses of ice which accumulated during the intensity of the glaciation, and the consumption of heat required to dispel them. The Scandinavian glacier alone seems to have spread out in some