

about 12 feet in diameter, and weather to a bright-chocolate colour. At its junction (668) with the sandstone it becomes finer in texture, and it has obviously altered the sandstone for a distance of two feet, at least, from the contact. At one spot a mass of sandstone has been caught up in the sheet, and, near by, a pipe of dolerite 50 yards in diameter cuts vertically across the bedding-planes of the sandstone. The sheet extends along the side of the valley towards Finger Mountain and is interrupted by occasional small faults, the throw of which is always less than 100 feet.

The Inland Forts (Fig. 20).

On the north side of the Ferrar Glacier the hills are very uniform in height and are capped by a dark rock for a distance of 20 miles. At the point γ_1 a pipe or dyke of the dolerite cuts through the sandstone and joins the mass above, and at γ_2 there are two sheets of dolerite separated by sandstone. Further east again, at C_7 , the cap of dolerite has been removed by denudation, and the lower sheet, which is reduced to under 100 feet in thickness, caps these isolated hills. Near the Inland Forts three dykes of the dolerite were examined, and a series of specimens



FIG. 25.—COLUMNAR DOLERITE OF DEPÔT NUNATAK.

(682-688) of dolerite and sandstone was collected along a line transverse to one of these dykes. These dykes are about 12 feet across and rise vertically through the sandstone to join the dolerite-sheets above. Where the dolerite meets the sandstone weathering has been accelerated, and the dykes lie in chimneys* which are sometimes 20 feet deep. One of these pipes is on the south end of West Groin, the other on the north end of East Groin and close to West Fort (C_6).

Finger Mountain (B) (Fig. 22).

This mountain is 7084 feet high, and is composed of alternate layers of sandstone and dolerite. The lowest rock visible at the base is Beacon

* A. Geikie, 'Ancient Volcanoes of Great Britain,' 1897, vol. ii, p. 120.

Sandstone, of which not more than 100 feet appears. Above this there is a sheet of columnar dolerite 200 feet thick, which on the west side of the hill unites with another sheet of dolerite. These two sheets are separated by the wedge of sandstone already referred to in Chapter VI. The bedding-planes of this wedge are horizontal, and are made conspicuous by the intrusion of numerous thin sills of dolerite along them. The wedge tapers to the west, and at this end the columns of dolerite do not appear continuous throughout the cliff, but break and bend over to the west at a line which follows the inclination of the upper surface of the now absent wedge. Finger Mountain narrows eastward to a sharp spur (b_1 - b_2). The upper sheet of dolerite ends at a scarp at the summit of B, while the lower continues some distance and is cut off by a structure-line, parallel to the line of transgression followed by the sill above the sandstone-wedge. This spur is capped by an outlier of the dolerite, which is separated by sandstone from a lower sill of transgressive dolerite 200 feet thick.

Specimens were collected both from the last sheet (692) and from a dyke (691) cutting across the bedding-planes between this and the one above. Dykes and sills are numerous at this rather disturbed locality. A sill of dolerite 30 feet thick extends for a hundred yards along a bedding-plane, then terminates suddenly with a vertical end. Another sill 10 feet thick runs along a bedding-plane for 50 yards, breaks steeply downwards for 50 feet, and then, forcing its way along a bedding-plane for 100 yards, finally thins out and disappears. A third sill, 2 feet thick, extends 50 yards along a horizontal bedding-plane, but gradually decreases in thickness and ends as a wedge.

The specimens (695, 696; see p. 138) were collected from the base of x , from a sheet of dolerite below 200 feet of sandstone. Here also the dolerite occurs in sheets which alternate with the layers of sandstone, and dykes and thin sills are numerous.

KNOB HEAD MOUNTAIN (B_3) (Fig. 26).

At a height of 3000 feet above the sea, and 30 miles inland, close under the foot of Knob Head Mountain, which is over 8000 feet in altitude, there is a cliff, 100 yards in length and 200 feet high, composed of columnar dolerite. Above the cliff the hillside slopes up more gently, and is covered with drift-blocks of granite and dolerite; the covering is broken only by this exposure of rock near its base. The outcrop shows columns 12 feet in diameter, and from 20 to 200 feet in height. There are occasional horizontal cross-joints, but cup-and-ball structure is not developed. The Beacon Sandstone appeared to rest upon this dolerite-mass (661); it forms the main mass of the mountain, but the junction of the two could not be found. The hill B_3 , three or four miles to the west, consists mainly of sandstone, but is riddled by dykes which form a network on its surface. On its west side there is

a pipe of dolerite about 100 feet in diameter, which rises vertically through the sandstone, but cannot be traced to a junction with any of the overlying sheets of dolerite.

THE KUKRI HILLS (Fig. 27).

The bluff D forms the western extremity of the Kukri Hills and, as already stated, consists mainly of dolerite. If reference be made to the section along the Kukri Hills (Section III, Plate VII) it will be seen that two parallel sheets of dolerite, each

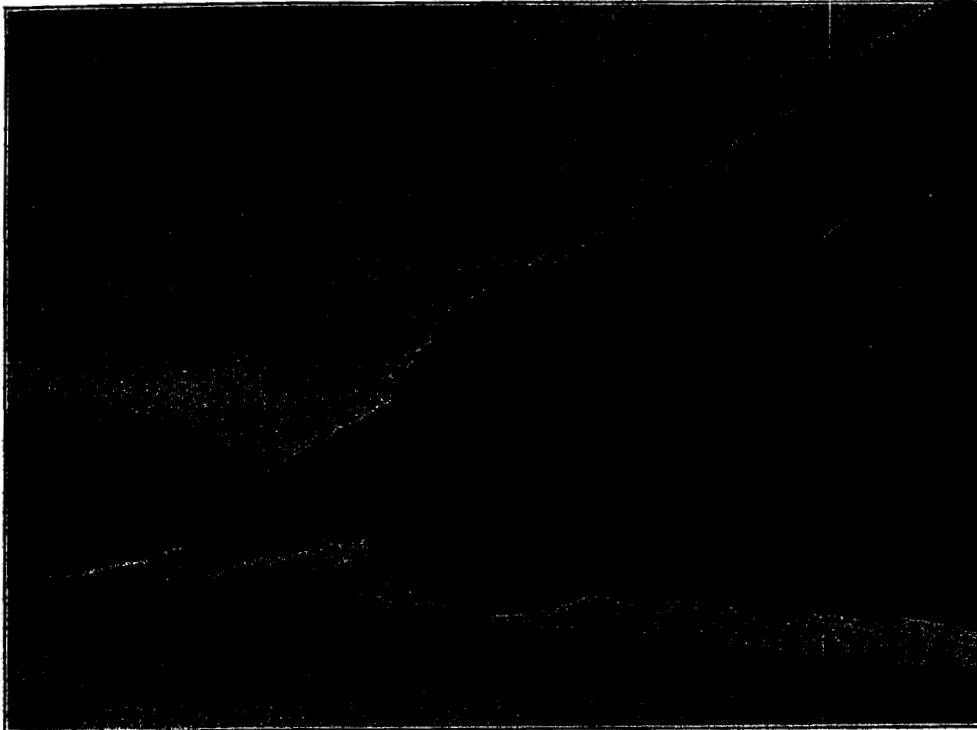


FIG. 26.—COLUMNAR DOLERITE AT THE FOOT OF KNOB HEAD. THE LARGE BOULDER ON THE SKY-LINE IS OF GRANITE.

about 2000 feet thick, run together at D. These sheets dip to the westward, and a specimen (704) obtained shows that the dolerite becomes finer in texture at its junction with the granite. The specimen was got from just above the lower junction and below D. The junction here is most striking and extends in an absolutely straight line for a distance of 10 miles along the side of the East Fork.

From the regular alternations of yellow and dark-coloured rock, I was at first inclined to suppose that there are two sandstone-deposits, but further work proved that the intrusive sheets cannot be continuous over the whole area. It would, however, be interesting to know what structural weaknesses have induced the

dolerites to maintain uniform horizons for so great a distance, and to remain always separated by the same thickness of sandstone. The sandstone between the sills is always about 500 feet thick.

THE FORMER EXTENSION.

On consideration of the facts stated above, it will be seen that wherever a dark rock was encountered it proved to be dolerite; further, all the abundant dark fragments in the moraines belonged to that kind of rock. Dolerite has been shown to cap the highest sandstone seen, and to be intrusive into it on each side of the upper Ferrar Glacier. Some mountains are entirely composed of dolerite, and others, such as the Beacon Heights or Knob Head Mountain, have mere caps of that rock, which may be remains of a once continuous sheet. At the Cathedral Rocks dolerite must rest upon granite, and apparently at one time have been continuous with the sheet which caps the granite in the Kukri Hills. Further, the Royal Society Range, which is a faulted crust-block* and is higher than any of the surrounding country, has strongly developed plateau-features (Fig. 9, p. 23); the rock which forms the highest peaks is dark and therefore probably dolerite. If this be so, we may be sure that both dolerite and the Beacon Sandstone Formation extend quite 50 miles in an east-and-west direction.

Next, dolerite caps the Beacon Sandstone at the Inland Forts, and the hills for at least 10 miles north are capped by rock which cannot be other than dolerite. The contrast in colour between cap and sandstone is always so strong that this inference could be made even without regard to the evidence of abrupt changes in the hill-outlines at the junctions. For similar reasons there can be no doubt that the dolerite still caps the sandstone-hills, which extend 10 miles to the south of the main Ferrar Glacier (Fig. 28). These facts render it extremely probable that the



FIG. 27.—THE DARK BAND IN THE KUKRI HILLS ON THE RIGHT SHOWS THE DOLERITE-SHEET RESTING UPON THE EVEN SURFACE OF THE GRANITE.

* Gregory, 'The Great Rift Valley,' 1896, p. 220.



Table Mountain, E
 Knob Head, B
 FIG. 28.—THE SOUTH ARM, WITH TABULAR FEATURES EXHIBITED ON THE LEFT, AND KNOB HEAD ON THE RIGHT.

sandstone-dolerite area is at least 50 miles long in a north-and-south direction, and has an extent of 2500 square miles at least.

A few of the hills in this neighbourhood, and especially the hill we called Obelisk (C_3), 10 miles east of Inland Forts, are pointed (Fig. 39, p. 72) and resemble the hills in the Torridon Sandstone districts of north-west Scotland; we may surmise that in these cases the cap of dolerite is lacking.

In Granite Harbour a dark rock which weathers like columnar dolerite may be seen above the granite (see p. 32), and further up the coast to the north the higher peaks of many of the hills were formed of a dark rock and stood out in striking relief over the Inland-ice against the cloudless sky. The black tabular formation is most striking about latitude $77^{\circ} 0' S.$, longitude $164^{\circ} 49' E.$, and again in latitude $75^{\circ} 57' S.$, longitude $163^{\circ} 56' E.$

The area occupied by the Sandstone Formation is a question still to be solved. At the outskirts of the area indicated above there seems to be no doubt the sandstone has an enormous thickness, roughly 2000 feet. Lieutenant M. BARNE records horizontal structures in latitude $80^{\circ} S.$, and Lieutenant E. H. SHACKLETON has taken a photograph still further south which shows the plateau-features to be still prominent there. Towards the north we need only mention Mount Nansen in latitude $75^{\circ} 30' S.$, and the pyramidal forms of the peaks of the Admiralty Range discussed above.

CHAPTER VIII.

THE SEA-ICE AND THE SHORE-ICE.

THE SEA-ICE.

DURING the winter months the surface of the sea in high latitudes often freezes in a uniform sheet which does not vary greatly in thickness. This covering has had many names given to it, but on the whole Sea-ice is perhaps the most suitable, as suggesting that the ice is derived directly from the sea.

Sea-ice requires to be distinguished from other floating ice (ice at sea) of different origin, and this

can readily be done by the close examination of even a small fragment. *The Structure* of sea-ice has been dealt with by Dr. AXEL HAMBERG,* Dr. VON DRYGALSKI,† and others. Dr. VON DRYGALSKI describes sea-ice as being composed of bundles of fibres packed together perpendicularly to the surface of cooling. A point not mentioned by him is, that, when the sea first freezes, the upper two inches consists of plates, a quarter of an inch across

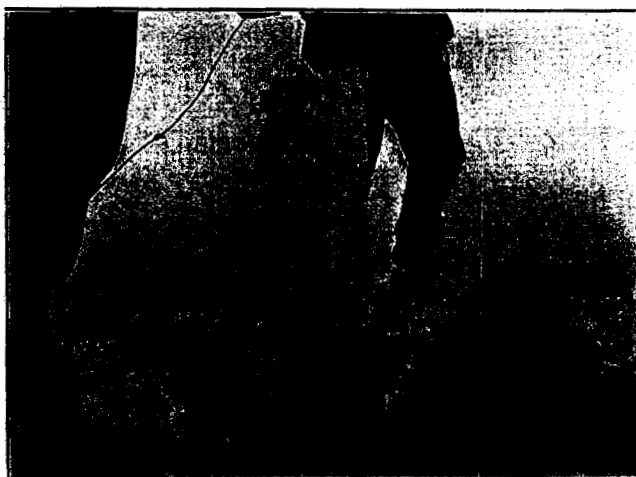


FIG. 29.—CRYSTALS OF ICE WHICH HAVE GROWN UPON A FISHING LINE SEVERAL FATHOMS BELOW THE LOWER (OR FREEZING) SURFACE OF THE SEA-ICE.

and a sixteenth of an inch thick, which lie horizontally, and only gradually do these give place to the sheaves of vertical fibres which make up the greater mass of the ice. Between the plates and the fibres is a layer of ice, about half an inch thick, of which the structure is very confused. Fig. 29 shows a mass of ice-crystals which have grown upon a fishing line. Mr. Hodgson records these crystals as occupying a length of 17 fathoms of his line, and gradually diminishing in quantity from the surface downwards.

The Salinity * † seems to depend more upon the rate of freezing than upon the depth or distance from the surface. Both the authors quoted above have made

* Axel Hamberg, *Bihang, K. Svenska. Vet.-Akad. Handl.*, 1895, Bd. xxi, Afd. 2, No. 2.

† Drygalski, '*Grönland-Expedition*,' 1897, Bd. i, p. 424.

observations in this connection, and have proved a great amount of variation. Our observations show that the variation is even greater than they have recorded. We may mention here that the average amount of salt in dry sea-ice is about 4.3 grams a litre, whereas 32.8 grams a litre is the average salinity of the sea.

Ice met with at sea is more variable, and the amount of salt contained in it depends upon the previous history of the ice.

Near the shore, where floe-ice has buckled below the level of the sea-surface, shallow ponds form, and a gradual concentration of the dissolved salts takes place. Solutions containing as much as 266.6 grams of salt a litre have been found in such pools.

When the open sea first freezes, part of the concentrated solution left yields well-crystallized rosettes (ice-flowers) on the upper surface of the ice. The rosettes

are usually two to three inches across and about an inch high and are scattered thickly over the surface; they are always extremely saline. If the sea-ice becomes depressed by a great accumulation of snow, the original upper surface is still always capable of identification through this local first salt-concentrate.

The Snow on the sea-ice in McMurdo Sound does not often accumulate to a thickness greater than two feet. Where any object

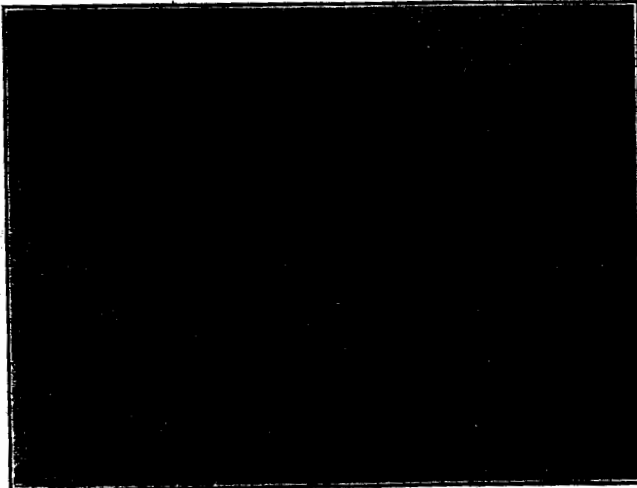


FIG. 30.—THE PACK-ICE, SEEN FROM THE CROW'S NEST OF THE SHIP.

interrupts the uniform level of the ice, snow-drifts form. The amount of the drift depends upon the magnitude of the object; such an object as our vessel produced a drift some 30 feet thick. The accumulation of local drifts has little ultimate effect upon the depth of the lower surface of the ice, for the snow, as it accumulates, pushes down the underlying layers into a region where the temperature of the water approaches that corresponding to greatest density; the lower ice then melts and is transported by the currents of the water (Fig. 49, p. 85). The equivalent of more than 18 feet of snow has been observed to be removed by this means during two consecutive years. From this observation it would seem impossible that a very thick sheet of ice could be entirely built up through continued deposition of snow on sea-ice or oceanic ice.

At a hole near the ship the upper surface of the snow was three feet above

water-level, and the original freezing surface of the ice had been depressed to four feet below water-level. The total thickness of snow accumulated at this spot during the two years was more than 20 feet; as the thickness here when the ice broke up was only 15 feet, the whole of the original ice and the earliest deposits of snow must have been entirely removed by the melting action of the sea-water previous to the final break-up. By this means, water-vapour from low latitudes is condensed in high latitudes and transported again to low latitudes, without taking part in the glaciation of the polar land-masses.

Size of floes. Names * such as Pancake-ice, Bay-ice, Field-ice, Pack-ice, Stream-ice, are given to sea-ice at certain periods of its short life. Thus Pancake-ice is the first product of the frozen sea. It is an aggregation into roughly circular masses of the ice-plates which first crystallize. The flat cakes thus formed are about an inch thick and one to two feet across, and have notably turned-up edges. In a sheltered bay where these cohere to form a thin sheet, the result is called Bay-ice. Later, this thickening extends to large areas and the ice is then called Field- or Fast-ice. During the summer Field- or Floe-ice breaks up into *floes*, which float out northwards from McMurdo Sound and join the belt of Pack-ice (Drift-ice, *Treib-eis*) encircling the Antarctic regions (Figs.

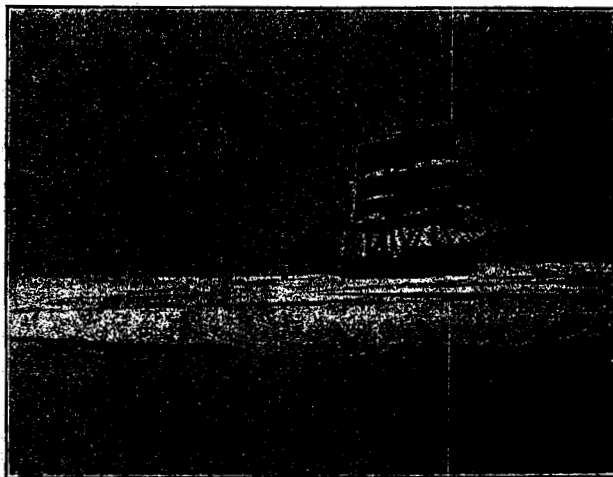


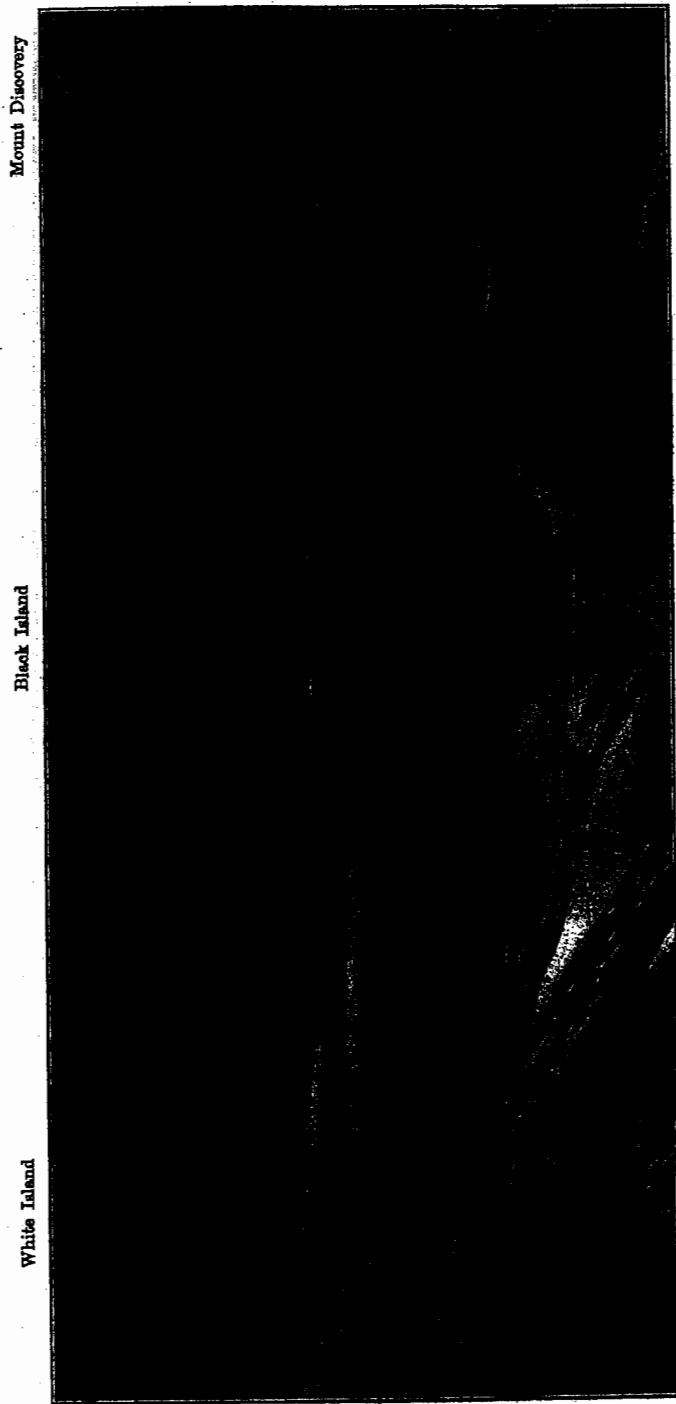
FIG. 31.—THE 'DISCOVERY' BROUGHT TO A STANDSTILL BY PACK-ICE.

30, 31). As the floes drift north they break up and dissolve away, and they are met with at sea in elongate and scattered patches which are termed Stream-ice. The size of the floes varies greatly; one may be 100 yards across, another may be two miles or more, but the thickness in the Ross Sea is never more than six feet. The floes are necessarily larger † on the south side of the belt of pack, as there they are protected from the swell by the stream-ice. Outside, the swell is most destructive and rapidly breaks up any large ice-field.

Hummocks are rather exceptional in the sea-ice of South Victoria Land, and all that occurred in McMurdo Sound were less than three feet high. These seemed to be caused by the ice in the outer part of the bay breaking for a time

* Markham, 'The Antarctic Manual' (Roy. Geogr. Soc.), 1901, p. xiv; H. Rink, 'Danish Greenland,' 1877, p. 78.

† Colbeck, Geog. Journ., 1905, vol. xxv, p. 408.



Mount Discovery

Black Island

White Island

Fig. 92.—WATER-HOLES IN SEA-ICE AT CAPE ARMITAGE AND HUT POINT IN JANUARY, 1904.

Hut Point

Cape Armitage

from the inner ice which is fixed, and then impinging on it again and again. In the belt of pack-ice, hummocks are rare and usually less than 10 feet in height.

The Ross Ice-sheet presses against the sea-ice on the south-east side of the Winter Quarters peninsula, and produces a series of hummocks some two miles long. Some of the hummocks rise as bucklings of the sea-ice, here 8 feet thick; in others the sea-ice breaks into pieces about 20 feet long and these are forced up on end. Four parallel rows stretched out south-west from Pram Point and grew very gradually before the movement of the ice-sheet, only becoming conspicuous at the end of the first winter.

The Thickness.—The sea-surface freezes during the winter, but its ice rarely exceeds a thickness of 8 feet. Our observations on the thickness of sea-ice are rather exceptional for McMurdo Sound as a whole; for in one case the ice-gauge was placed where a strong current was known to exist, and in the other case the ice-gauge was placed in a sheltered bay, in ice which was always wind-swept and free from snow. At the former spot on March 1st, 1903, a water-hole was open: on the 24th of April the ice in it was 3 feet thick; and by about mid-winter (June 27th) it had grown to 5 feet. On August 23rd the thickness was 6 feet 6 inches, and water

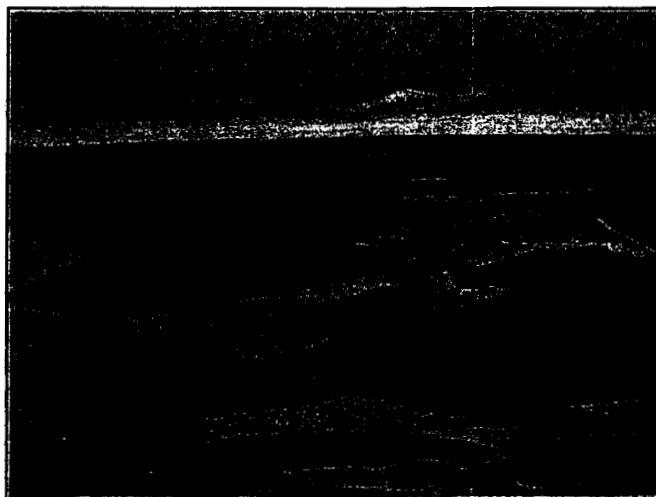


FIG. 33.—SEA-ICE BREAKING AWAY FROM THE WINTER QUARTERS IN 1902.

continued to freeze until December 5th, by which time it attained its maximum (8 feet 5½ inches). After this date the ice began to disappear from below, and by January 28th was all gone. A water-hole off Cape Armitage (Fig. 32) was observed to open each year, which shows this melting action of the sea on sea-ice to be important. In 1904 the ice which surrounded the 'Discovery' broke up naturally and rapidly floated away, and the rate at which the break-up took place seemed to be independent of the thickness (Figs. 33, 34).

Transport.—During the winter-months cracks in sea-ice, radiating from both Hut Point and from Cape Armitage, were formed. These cracks are produced by the ice in the middle of the strait being pushed forward faster than the ice at the sides. The pressure is always in one direction, and is caused partly by the movement of the Ross Ice-sheet and partly by accumulations of snow along the shore. The cracks

freeze up soon after they are formed, and no movement in the reverse direction can therefore take place. Cracks made in this way seldom open much more than two inches at any time, but during the year have indicated a movement of more than 20 yards. Sea-ice therefore is removed in three ways: (1) through corrosion by sea-water, (2) breaking up and floating away piecemeal, (3) creeping bodily away from the land.

The "creep" of sea-ice is very small compared with the movement which takes place when an ice-field breaks up at the end of the winter; but it is important, as it prepares the field-ice for the action of the ocean-swell which breaks it up during the

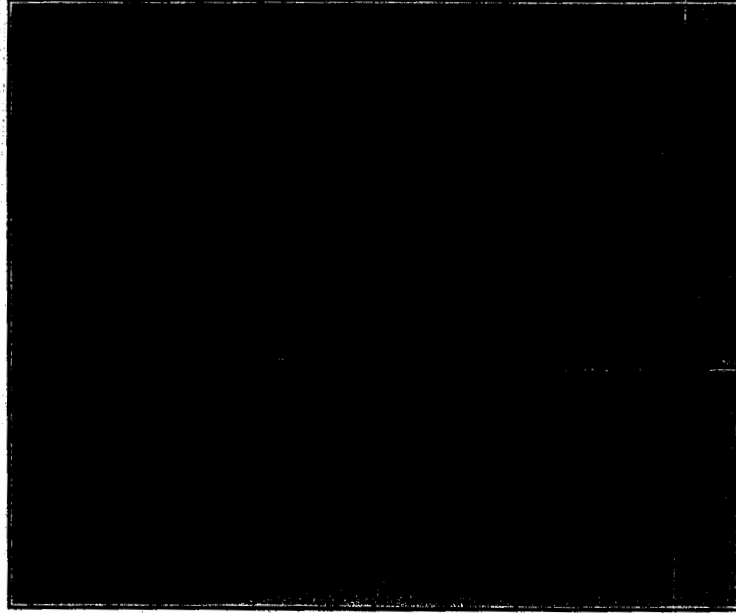


FIG. 84.—THE RELIEF-SHIPS FORCING THEIR WAY THROUGH THE BARRIER OF FLOE-ICE IN 1904.

summer. As the field-ice breaks up, the floes that are formed drift northwards to augment the pack-ice.

Thawing.—Virtually no surface-thawing of the sea-ice takes place, for the air-temperature in the open is always far below the freezing point, and the snow reflects most of the radiant heat. Locally dust and other extraneous particles sink into the ice or snow, but the holes thus formed are filled by the silting action of the snow. Mention has already been made of the action of the sea in reducing the thickness of the floe-ice, and it is noteworthy that during sunny days the sea-temperature itself is slightly raised and then the water melts more quickly the ice at its seaward edge. This greater capacity for melting the ice has been observed for at least two miles within the margin of the fast-ice of McMurdo Sound.

THE SHORE-ICE.

The shore of South Victoria Land is always fringed with ice, which ends sharply seawards in a perpendicular wall (Plate II). The wall varies in height from

3 to 300 feet, and two types of fringe may be distinguished.

(1) *Fringe due wholly to the frozen spray.* Such fringing ice never attains a height of more than six feet. The fringe of ice around the land in Granite Harbour is perhaps most characteristic, and forms a typical ice-foot.* It remained firmly frozen to the land all the year

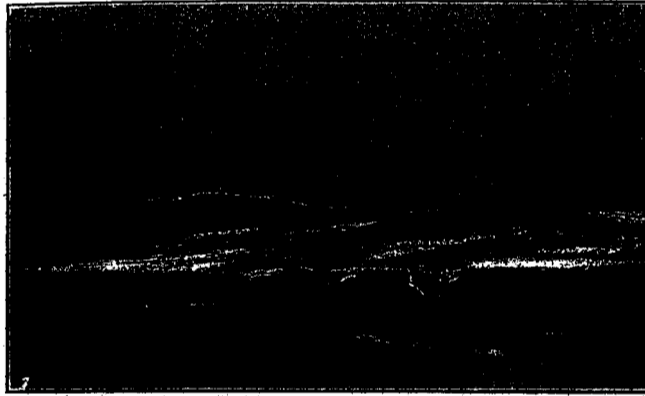


FIG. 85.—THE ICE-FOOT AT HUT POINT.

round. It is not materially added to by snow-precipitation, and dissolves rather than increases during the few summer-days when the sea washes against it. As the maximum rise and fall of the tide is less than three feet, a low ice-foot, as contrasted with the high ice-foots of Arctic regions, is to be expected. The breadth of the fringe varies from 6 to perhaps 60 feet, and the surface, which is usually fairly flat, often contains pools of water during summer. The chief action of the fringe is conservative.† It protects the land from the action of eroding breakers and floating ice, and more especially protects the rock-cliff by cementing together its talus.



FIG. 86.—SHORE-ICE WRAPPING THE LAND NEAR THE FOOT OF CASTLE ROCK.

(2) *Fringe of glacier-ice adherent to the land* (Figs. 35, 36). The ice is free from salt, shows the well-known blue bands, and has a well-marked granular structure. Such fringes vary much in

* Drygalski, 'Grönland-Expedition,' 1897, Bd. I, p. 285.

† Bonney, Quart. Journ. Geol. Soc., 1902, vol. LVIII, p. 699.

their dimensions. The height varies from 6 feet to 300 feet, and the breadth from 10 yards to a mile. The surface usually dips at about 20° towards the ice-cliff.

As in the case of the first type, the action is wholly protective, but is even more effective owing to the greater size of the fringe.

A fringe of glacier-ice wraps the west side of Winter Quarters peninsula from the base of Mount Erebus to Crater Hill; near Castle Rock, where the ice-cliff reaches 300 feet, the fringe is perhaps at its highest.

Around Winter Harbour the cliff varies from 10 to 40 feet in height, and has a breadth which is sometimes as much as 100 yards; there, and in several other places, this type of fringe forms a sort of ill-marked terrace about 100 feet above sea-level, and slopes gently out towards its seaward face.

As in the case of glacier-terminations, it would seem that a lofty ice-cliff has always correspondingly deep water immediately adjoining it.

CHAPTER IX.
THE LAND-ICE.

THE following classification of the land-ice of South Victoria Land has been found convenient. The headings are largely taken from Dr. E. von DRYGALSKI'S 'Grönland Expedition,' and from Dr. ALBERT HEIM'S 'Handbuch der Gletscherkunde,' but have been to some extent modified to meet local requirements.

- (1) *Ice-sheet,** or *Inland-ice,** is the name applied to a mass of ice which covers a continental area of land. In South Victoria Land the sheets are of unknown extent, and enwrap and obliterate the inequalities of the interior land-surface, leaving coastal land-fringes comparatively free from ice.
- (2) *Local Ice-caps,†* *Hochlandeis,†* the ice covering partially or wholly a limited land-mass. This ice may extend as an unbroken mass right down to the sea, or may escape as ice-streams. Such a cap may be defined as an ice-sheet on a small scale. These terms are necessarily relative, for we frequently speak of a polar *ice-cap* with reference to the earth as a whole, or again of a "*local ice-cap,*" such as that upon Hayes Peninsula, quite a small area.
- (3) *Piedmont-glaciers ‡* are formed by ice crowding on to a coastal plain at the foot of a mountain-range. In South Victoria Land three types are distinguished: (a) normal piedmonts-on-land; (b) piedmonts-aground; (c) piedmonts-afloat.
- (4) *Glaciers of Greenland type, or Ice-streams,§* drain an ice-sheet and end in the sea.
- (5) *Glaciers of Norwegian type ||* consist of streams of ice flowing down well-defined valleys (fiords) from a large firnfield.
- (6) *Glaciers of Alpine type, ¶* *Valley-glaciers,* drain small intermontane basins (firnmulden): seldom advancing far from their mountain-sources, they never reach the sea.

* H. Rink, 'Danish Greenland' (1877), p. 89; Drygalski, 'Grönland-Expedition,' 1897, Bd. i, Chapter IV; Heim, 'Handbuch der Gletscherkunde,' 1885, p. 51; Garwood and Gregory, Quart. Journ. Geol. Soc., 1899, vol. lv, p. 682; Nansen, 'First Crossing of Greenland,' Chapters XV to XVIII.

† H. Rink, 'Danish Greenland' (1877), p. 866; Drygalski, 'Grönland-Expedition,' 1897, Bd. i, p. 118; Chamberlin, Journal of Geology, 1895, vol. iii, p. 66.

‡ I. C. Russell, 'Glaciers of North America,' 1897, p. 2.

§ H. Rink, 'Danish Greenland' (1877), p. 869; Heim, 'Handbuch der Gletscherkunde,' 1885, p. 51, ff.; Drygalski, 'Grönland-Expedition,' 1897, Bd. i, Chapter IV (Die Karajak-Eisströme und ihr Nahgebiet).

|| Heim, 'Handbuch der Gletscherkunde,' 1885, p. 50; Drygalski, 'Grönland-Expedition,' 1897, Bd. i, p. 298, ff.

¶ Heim, 'Handbuch der Gletscherkunde,' 1885, p. 55; Drygalski, 'Grönland-Expedition,' 1897, Bd. i, p. 298, ff.; A. Geikie, 'Textbook of Geology,' 4th edit., 1908, vol. i, p. 585, ff.

- (7) *Cliff-glaciers*,* *Re-cemented glaciers*, *Glaciers remaniés* are broken glaciers of the above types, which having a *Thalweg*, too steep in places to hold the ice, have areas of bare land separating the firnfields and the final tongues of ice which they produce.
- (8) *Hanging glaciers*,† *Corrie-glaciers*, *Hängegletscher*, are masses of snow and ice lying in *cirques*, corries or hanging valleys. The ice in these disappears by melting, or by ablation, or by both processes, before the glacier can reach the main ice-stream.
- (9) *Ice-slabs* are apparently peculiar to South Victoria Land, and are glaciers which, from the cessation of ice-supply, have slipped away from their former firnfield.
- (10) *Icebergs*‡ are common to both the polar regions, and may be appended to this list as products of the breaking-up of all glaciers which reach the sea.

1. THE INLAND-ICE.

We have seen that the mountain-belt of South Victoria Land, quite 60 miles in breadth, buttresses a firnfield of vast but unknown extent. This ice-sheet has a horizontal upper surface, which on the west of the Royal Society Range has an elevation of 7650 feet. It flows eastward through the range in a deep-sided valley which bifurcates downwards in a most peculiar way. In the Prince Albert Range the flow passes between nunataks, which are sometimes 20 miles long, in arms ten miles across. The nunataks are usually broadside on to the present flow. The passes are shorter than they are broad, and have a striking similarity to those on the west coast of Greenland.§

In the ranges lying south of the Royal Society Range are deep and narrow channels termed "inlets" by Captain SCOTT. These channels are ice-filled, but lie much below the level of the adjacent mountain-ranges and have very steep sides. A theodolite showed only a very slight rise in the horizon along these, so that if the *Hinterland* rises at all high it must lie many miles west of the coast. The Inland-ice flows through these channels to feed the Ross Piedmont or Ice-sheet.

The surface of the Inland-ice, where observed, consists entirely of soft snow-powder and shows no gradual passage through granular snow to compact ice. The soft snow-powder, being readily taken up by wind and whirled about, is removed in bulk and transported bodily into the Ross Sea.

* Heim, 'Handbuch der Gletscherkunde,' 1886, p. 58.

† Heim, 'Handbuch der Gletscherkunde,' 1886, p. 45.

‡ Heim, 'Handbuch der Gletscherkunde,' 1886, p. 278; Drygalski, 'Grönland-Expedition,' 1897, Bd. i, Chapter XIV.

§ Drygalski, 'Grönland-Expedition,' 1897, Bd. i, Chap. IV. and maps at end of vol. i.

2. LOCAL ICE-CAPS.

The icy covering of Mount Erebus provides, perhaps, the best example of an Antarctic local ice-cap, and its features are exactly those of the Greenland ice-caps on a small scale. Snow covers the greater part of the area, ice-streams flow down between bare nunataks,* *e.g.* The Turk's Head and The Skuary, and there is the bare coastal fringe between Cape Royds and Cape Barne.

The streams of ice which radiate from the mountain are too ill-defined to be called true glaciers. They have no snow-sheds, neither have they any well-defined banks. Still, all the mountains of Ross Island are completely covered with snow, and at definite points give off icebergs, which float away to the open ocean. The upper parts of Mount Erebus are covered by snow so thin that the outlines of lava-streams near the summit can be recognised at a very great distance. The middle slopes have occasional patches of bare rock protruding through the snow, and rising up or dipping so steeply that snow cannot long remain upon them. The lower slopes are even more broken by bare lava, and the ice must always average less than 700 feet in thickness, for the ice sea-cliff is never more than 100 feet high.

The surface of Mount Erebus shows numerous ice-falls in which the crevassed ice-surface stands out above the level of the more even normal ice-covering. Mount Terror, Sturge Island of the Balleny Group, Coulman Island and Mount Melbourne, all form centres of local ice-shedding (see Plate I and Fig. 1 (p. 3), Fig. 3 (p. 5), Fig. 37).



FIG. 37.—ICE-FOOT AND PACK-ICE IN WOOD BAY AT FOOT OF MOUNT MELBOURNE.

3. PIEDMONTS.

Masses of ice, which have a breadth greater than the length measured along the direction of flow, and lie at the foot of all large areas of high land, are conveniently referred to as *pedmonts*. These masses in South Victoria Land differ from such a

* I. C. Russell, 'Glaciers of North America,' 1897, Tacoma, p. 82, Fig. B.

typical piedmont as the Malaspina Glacier* in that they are supplied by driftings and snow-cascades from the adjoining land-mass, whereas the Malaspina Glacier lies below the snow-line and is only fed by distinct valley-glaciers.

Three types of piedmont are distinguishable.

(a.) *Normal piedmonts, piedmonts-on-land.*

On the west side of McMurdo Sound, between the moraines and the Northern Foothills, there is a continuous ice-belt without apparent source of supply and lying wholly upon low land. This ice-belt occupies an area 10 miles long and 5 miles broad, and appears to be fed by the snow drifting over the lower passes of the foothills. On the west it covers the hills to a height of quite 1000 feet, but on the east it ends as an insignificant marginal sea-cliff less than 50 feet high. On the north it slopes sharply down towards the depression of the Ferrar Glacier, but on the south it merges into the Blue Glacier. On the whole the surface is convex, and slopes more steeply around the outer edge. The whole of the ice rests on land, and seems, by entirely burying the shore, to protect it from denudation.

Occasionally, along the base of the Prince Albert Range, the convex ice-slopes, such as the one discussed, connect definite ice-streams, which, strangely enough, are always at a lower level. From Cape Bernacchi to Granite Harbour, and from there to Cape Gauss, there are two notable unbroken stretches of ice-covered land. These areas may be regarded as series of land-piedmonts. Occasionally, conspicuous sea-washed rock-cliffs protrude through them, and the ice-cliff facing the sea is obviously the edge of a broken ice-lenticle. The length of the mass varies from 10 to 50 miles, but the breadth cannot be more than about 10 miles. The evidence would seem to suggest that piedmonts are rather relics of a former greater ice-supply than products of the present conditions; their action would appear to be now entirely protective.

(b.) *Piedmonts-aground.*

Piedmonts-aground are well represented along the sides of Coulman Island, which has bare cliff-sides and a flat snow-covered top (Fig. 3, p. 5). It is surrounded by a comparatively low ice-wall produced by a talus of snow, which drifts off the top of the cliff and accumulates along the cliff-sides to form a continuous belt. Sometimes the talus is a mixture of rock and ice, but as a rule rock-matter was conspicuously rare. Small cascades of ice fall over the rock-cliff along the dykes and joint-cracks, which are seldom large enough to be called valleys.

This fringe has in section a convex upper surface. Near the rock-cliff it becomes steeper. At the seaward edge the convexity increases, and the termination is a cliff 100 feet high. Sections parallel to the shore would show a series of undulations, the crests being opposite to the main points of supply. Such fringes

* I. C. Russell, 'Glaciers of North America,' 1897, p. 109.

as that of Coulman Island are sometimes as much as 15 miles long, but are rarely more than 2 miles broad. The snow encircles the rock-cliff up to heights of 200 to 400 feet above sea-level, and the seaward edge is not often more than 70 feet above water. The distinction between "piedmont-on-land," and "piedmont-aground" is to some extent hypothetical, for it is difficult to make sure that ice at any particular point does not extend below sea-level (Fig. 56, p. 93).

On Sturge Island of the Balleny Group, a transition from "piedmonts-aground" to "piedmonts-afloat" is also evident, for sometimes the undulating fringes flatten out along definite lines parallel to the shore and extend at least 5 miles out to sea, and so are probably partly afloat (Fig. 1, p. 3).

(c.) *Piedmonts-afloat.*

Piedmonts-afloat are represented by four important examples, (1) the sheet of ice which fills up Lady Newnes Bay, (2) the sheet at the foot of Mount Neumayer, Drygalski Piedmont, (3) the sheet which extends from Cape Gauss eastwards for 20 miles at least, Nordenskiöld Piedmont, and (4) the Ross Ice-sheet, or Great Ice Barrier of Ross. All these are characterised by great extent with flat or slightly undulating surface, and by a cliff-edge between 50 and 200 feet high, which has enough water immediately in front of it to completely float the ice. The best known of these floating piedmonts is the ice-mass which Ross in 1841 called the Great Ice Barrier, but as this name entirely fails to convey the idea of vast extent, we conclude not to adopt it as a general type, but prefer rather to class the Ice Barrier of Ross and similar ice-masses as a subdivision of Russell's term 'Piedmont.'*

The Ross Piedmont has a seaward edge some 500 miles long, and its terminal edge rises to an average height of 150 feet (Fig. 38). The depth of water close to this ice-face is usually between 300 and 400 fathoms, and the sea-floor is covered with fine rock-flour. If reference be made to the chart at the end of the volume, details of heights and depths along it may readily be seen. If it be assumed that aerated glacier-ice floats with at most six-sevenths of its volume immersed in sea-water,† we may take it that the height in feet of the sea-cliff above is equivalent to the depths in fathoms below, and hence that this ice-cliff must be afloat. Further evidence that it floats is afforded by the tide-crack around Mount Terror, White Island, and in many other places. The uniform horizontality of the upper surface was proved by Captain SCOTT in his sledge-journey to the south, and by Lieutenant ROYDS and Mr. BERNACCHI in their trip for 155 miles to the south-east.

The intimate structure of Piedmont-ice shows that as far as water-level it consists of normal glacier-ice. On the surface away from the land only fine snow was met

* I. C. Russell, 'Glaciers of North America,' 1897, pp. 2 and 8.

† Heim, 'Handbuch der Gletscherkunde,' 1885, p. 278, and H. Rink, 'Danish Greenland,' 1877, p. 358.

with, but close to the shore crevasses and pressure-ridges show massive and vesicular ice. The vesicular ice contains air * amounting on the average to about 8.5 per cent. of its own volume, and the ice-grains are usually less than a quarter of an inch across. Near White Island the grains are at least half an inch across and of a very uniform size. This occurrence, however, is exceptional, for though no running water was seen, the patches of bare ice are quite saturated with water, and it has already been proved by Herr EMDEN † that growth of glacier-grains takes place most rapidly at or near the freezing point. All observations made seem to show



FIG. 88.—THE ROSS PIEDMONT FROM THE SIDE OF MOUNT TERROR, SHOWING THE CLIFF-EDGE AND FLAT UPPER SURFACE.

that the Ross piedmont is produced by ice-streams, not able to melt upon land, being pushed out to unite in a shallow bay, after which the ice-mass floats off towards the deep sea. It is remarkable that along the whole cliff-face from Cape Crozier to Cape Colbeck no trace of foreign matter in the ice could be observed. At the eastward end the land is completely buried in snow, but along the west side the land is comparatively bare. Rock-débris was never met with more than a very few miles from land. The chasm ‡ that skirts the west side is in itself sufficient to

* Heim, 'Handbuch der Gletscherkunde,' 1885, p. 118.

† Emden, Neue Denkschr. schweiz. nat. Ges. 1893, Bd. xxxiii, Abth. 1.

‡ Scott, Geog. Journ., April 1906, vol. xxv, p. 366, plate.

prevent boulders rolling on to the surface, but well-developed moraines on it are seen where, on Minna Bluff and Black Island, the ice hugs the shore. These moraines, however, will be discussed later; they are mentioned here as evidence that the ice-sheet does transport matter upon its surface. The movement of this piedmont seems to be comparatively rapid. Where measured by Lieutenant BARNE at Minna Bluff, it was proved that a point moved through 608 yards* in thirteen and a half months.

4. GLACIERS OF GREENLAND TYPE. (Plate III.)

Under this head will be included such ice-streams as flow from the Inland-ice. In the Antarctic region this type of glacier is magnificently developed, and every gradation, from streams 5 to 60 miles long, and 5 to 10 miles wide, is to be seen.

The Prince Albert Mountains exhibit features so similar to those of the west coast of Greenland that one description would suffice for both. Attention may, however, be drawn to the fact that the Greenland ice-streams end in fiords and come down between nunataks free from snow, whereas the ice-streams of the Prince Albert Range, though they may, perhaps, lie in fiords, project as if towards the edge of some coastal platform parallel to the mountains and well above the snow-line. The nunataks are wholly encircled by snow-slopes which are rather higher than the ice between them. The Ferrar Glacier is the only one that has been entirely traversed. Situated as it is on one of the highest ranges of South Victoria Land, it can hardly be considered quite typical, though steep inlets, which break directly from the coast and back into the high mountains, are peculiar to the whole region. The Ferrar Glacier has its source in the Inland-ice which lies at an altitude of 7600 feet above sea-level to the west of the Royal Society Range. The head of the glacier is an amphitheatre some 10 miles across, and is marked off by a few small nunataks. The sudden rise to the Inland-ice is almost semicircular and stretches round from Depôt Nunatak to the North-west Nunataks, with a curve concave to the east. This concave curve is marked by two parallel ice-falls, each about 500 feet high. From the foot of this fall the ice moulds itself to the valley, and between straight, parallel, and almost vertical, rock-walls flows off eastwards. Near Finger Mountain the valley widens somewhat, the north wall continues its straight course, but the south wall recedes irregularly to the base of Knob Head, and in this way leaves the depression at the Solitary Rocks (*D_s*) through which the ice from Windy Gully and South Arm enters. The ice from South Arm splits on a submerged water-shed and part flows first westwards and then northwards into the North Fork, while the rest, considerably supplemented by the discharge from the west of the Royal Society Range, fills up the East Fork, and eventually floats in the narrow fiord between the Lower Kukri Hills and the Northern Foothills.

* Scott, Geog. Journ., April 1905, vol. xxv, p. 368.

At the same time, of the ice from the upper portion of the Ferrar Glacier, part flows round the south side of Solitary Rocks and unites with that from Windy Gully and South Arm; part ends short of the *col* between the Solitary Rocks (D_s and D_{sa}) in a gradually attenuated tongue; and the rest, which hugs the north side, probably extends past D_{sa} to be joined by that from the two tributaries from the south. Captain SCOTT travelled down the North Fork, and tells me that the ice there ends in an insignificant cliff some 12 feet high, leaving the lower portion of the valley strewn with moraines and in part occupied by small frozen lakes.

At γ_1 the height of the north wall is not more than 1000 feet above the ice, but by about 10 miles farther eastward the valley-bed has fallen 1000 feet while the adjoining mountains remain at about the same altitude. The valley deepens continually; near the Kukri Hills it has fallen nearly 5000 feet below the mountains and is bare of ice. The south wall, west of Finger Mountain, averages 500 feet above the ice, though the mountains are very much higher and culminate in the tabular mass T.

Windy Gully and South Arm also probably come down from the Inland-ice, which, about 20 miles further south, lies at an altitude of 7600 feet. The cañon-like form of the valley, therefore, is not so pronounced here as in the North Fork. Where Cathedral Rocks face the Kukri Hill, the East Fork is 6 miles wide, and, having sides 4000 feet high, is remarkably cañon-like. It is about 20 miles long; further eastwards it passes into the long fiord (nearly 15 miles long) which lies between the Lower Kukri Hills and the Northern Foothills.

The surface of the ice is locally crevassed, and it is noticeable that the crevassed areas, as on Mount Erebus, stand up above the general ice-surface. Crevassed areas are found: (1) in the middle of the glacier, six miles north-east of Dépôt Nunatak; (2) close to the foot of Finger Mountain, where the valley-wall begins to retreat southwards; (3) close to b_2 , where the ice is forced sharply round into the Dry Valleys; (4) on the south side of Solitary Rocks, where the ice enters North Fork; and (5) in the middle of East Fork, opposite Cathedral Rocks and three miles from them. Marginal ice-cliffs are a constant feature of the glacier, and moraines are rarely entirely absent.

5. GLACIERS OF NORWEGIAN TYPE.

The Norwegian type of glacier is well represented by the Blue Glacier referred to in connection with the gneissic series of rocks. The Snow Valley, which lies parallel to the base of Royal Society Range, has at one time fed five or six valley-glaciers which flowed out eastward into Discovery Gulf. All except the Blue Glacier have been broken across by diminution of ice-supply; and the Blue Glacier, draining a very extensive firnfield, is so nearly stagnant that, where measured, it had not moved more than about three feet in the year.* Its length, measured from the

* Ferrar, Geog. Journ., April 1905, vol. xxv, p. 381.

point where definite banks begin to be evident, is some twelve miles; but, if measured from the foot of the mountain-range, is about double that amount.

The surface of the glacier is snow-covered, and on the north side the snowdrifts of the foothills quite blend with those of the glacier-ice. No definite *Bergschrund* could be made out. For the last four or five miles the north side of this glacier adjoins the land-piedmont described above; but here again no evidence of movement was seen. The south side of the glacier is bare ice, and below the hill J_1 crevassed areas, as in the ice of the Ferrar Glacier, stand in relief. Again, on the south side of the glacier-snout, the ice stands off from the land and leaves the conspicuous channel noted so frequently. The ice-wall adjoining this channel shows sections of enclosed dirt-bands and moraine, and these are specially abundant in the lower part. As the cliff forming the snout is very clean and free from rock-*débris*, such matter as is now being carried must be close down upon the sole of the ice. The Koettlitz Glacier may belong to this class, but little is known of its upper reaches, and it apparently ends to the south of the Southern Foothills. At this point an ice-tongue from the Koettlitz Glacier breaks into the lower part of one of the minor valleys of the foothills, stagnates, and is no longer joined by the local glacier of the valley. The latter still exists as an ice-slab higher up. The main glacier advances a little further along its main valley and feeds the floating ice of Discovery Gulf (see Plate VI).

Two glaciers flow into Granite Harbour and join at the sea-edge, but as their sources are unknown they also cannot be classified with certainty. They are peculiar in that they too lie in narrow valleys which have very steep and straight sides, and from a distance are very like the Ferrar Glacier. All these valleys lie approximately at right angles to the main trend of coast and mountain-range, and seem to be a characteristic structural feature of the region. Glaciers of similar type are quite numerous among the snow-covered foothills of the Admiralty Range; some of them come down from valleys in the main range, while others arise in the snowfields of the foothills themselves. Into Robertson Bay flow some ten or twelve great glaciers which appear to drain the Inland-ice to the west of the mountains.* The Cape North portion of the mountains is traversed by at least two of the trough-like valleys carrying glaciers, but as the whole region is completely covered with snow and ice it is not easy to distinguish the types of the glaciers.

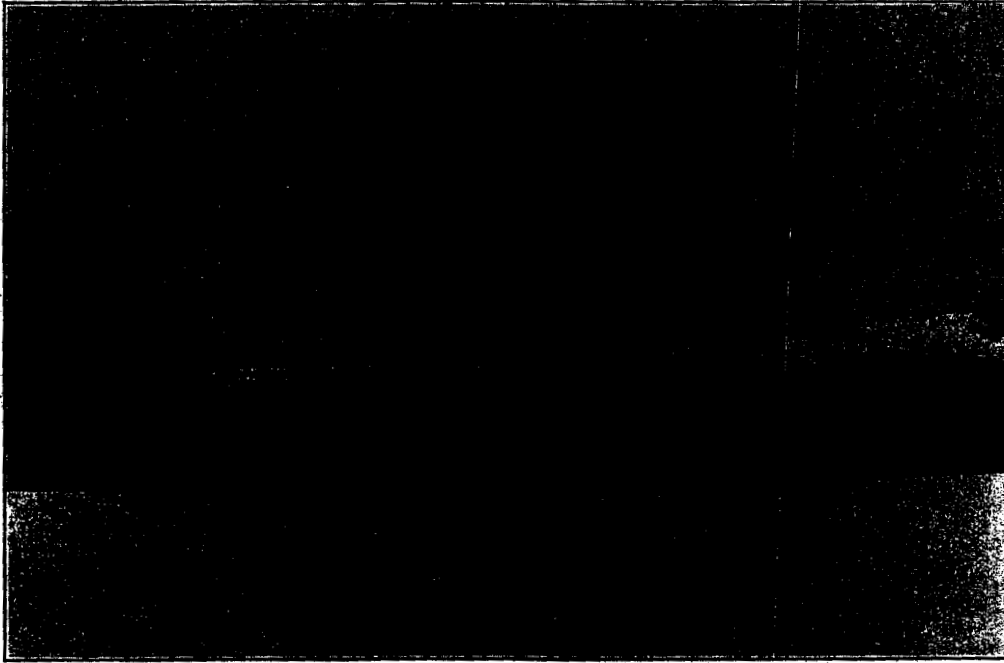
6. GLACIERS OF ALPINE TYPE: VALLEY-GLACIERS.

The most picturesque glacier of Alpine type is that of the deep and narrow valley between the hills E_2 and E_3 of Cathedral Rocks. This glacier is partly supplied with snow from the plateau south of Cathedral Rocks. It is about five miles in length and one in breadth. It is crevassed from end to end. It joins the Ferrar Glacier about 2500 feet above sea-level, and causes at least three transverse bucklings on the surface of the latter.

* Bernacchi, 'The Antarctic Manual' (Roy. Geogr. Soc.), 1901, p. 508.

On the north wall of the North Fork, three glaciers drain out of one firnfield and end about 1000 feet above the ice of the main valley (Fig. 39). Two of these are cliff-glaciers, for the ice breaks off at the edge of a cliff and falls in avalanches which are lost in the main glacier at the foot of the cliff. The third has lately been a cliff-glacier, but its present loss by ablation exceeds the supply, and it now ends some distance from the edge of the cliff and therefore is of Alpine type. The south side of the Upper Kukri Hills has a numerous series of hanging valleys distributed at regular intervals between D and D₄. There are at least eight in a

A. Dolerite Sheet.



The Obelisk C,

FIG. 39.—THREE ICE-TONGUES FALLING INTO NORTH FORK.

distance of 10 miles. Of the eight between D and D₄, five have glaciers of Alpine type which, keeping their continuity, fall as cascades into the main valley below, and give rise to little or no disturbance in the latter.

7. CLIFF-GLACIERS.

The three other glaciers between D and D₄ are true Cliff-glaciers and, ending some 700 or 800 feet above the main glacier, discharge only as avalanches down the face of the cliff. The width of these glaciers is usually less than a quarter of a mile. They extend most of the way down the cliff, which is here about 4000 feet high. The

hanging valleys all hang about 300 feet above the ice of the main valley, and therefore at about 2000 feet above sea-level. In some of them the hanging lip is very evident, while in others the *Thalweg* is very nearly uniform all the way.

8. HANGING GLACIERS ; CORRIE-GLACIERS (Fig. 20, p. 42).

Four Corrie-glaciers are worthy of mention. These lie on the south side of the Inland Forts and occupy the *cirques* below the *cols* which link up the Forts. Three of these glaciers are quite isolated, but the fourth is joined by a tributary from the west side of Round Mountain (C_1). All flow southwards, but fail to reach the ice of the main valley, and are now building up crescentic moraines at their terminations. The interest of these glaciers lies in the fact that, though they now flow southward, they were formerly forced northward by the Ferrar Glacier into another drainage-system. Their supply is local from the Inland Forts, and the *cols* at their heads are completely bare.

9. ICE-SLABS (Plate VI).

Ice-slabs are found in all valleys on the east side of the Southern Foothills of the Royal Society Range. These slabs are masses of ice, four to six square miles in extent and about 50 feet thick. They are the relics of glaciers which once drained the Snow Valley; but, owing to diminution of ice-supply, this has now become an inland basin, and its overflows have slipped away from it, leaving a subsidiary watershed bare. The surface of the ice-slabs is quite clean, and free from mud or stones. It is convex and slopes gently outwards from a centre. The ice-cliffs which bound ice-slabs show abundant dirt-bands and scattered morainic matter in their lower parts. In each valley in the Southern Foothills there is a glacier of this type, and it would seem that their development is due to the peculiar forms of the hills and their surroundings.

10. ICEBERGS (Fig. 40).

Icebergs have been defined by HEIM as masses of glacier-ice floating in the sea. They are common to both polar regions. The icebergs of South Victoria Land are usually tabular in form, and the vast majority seem to be derived from some common source. Shore-ice is not prolific in the formation of bergs, as such ice remains firmly fixed to the land throughout the year. Blue Glacier was under observation for over sixteen months, and during that time no berg broke away from it, the snout remaining firmly frozen on to the sea-ice from the year 1902 to the year 1904. Within a mile of Blue Glacier, however, five bergs were aground, and could only have been derived from it.

If no ice-stream moved faster than does the Ferrar Glacier the number of bergs would be almost negligible. Doubtless the numerous ice-streams crossing the Prince Albert Mountains must give rise to a certain number of bergs, but even then the number is probably small. The piedmonts-on-land, lying on a flat shore and receiving only a small supply of snow, can seldom provide enough ice to form icebergs. Cliffs that encircle shore-ice hold snowdrifts which are sometimes as much as 60 feet thick. These always float out to sea during the summer, and produce small bergs which may easily be mistaken for the broken-up masses of

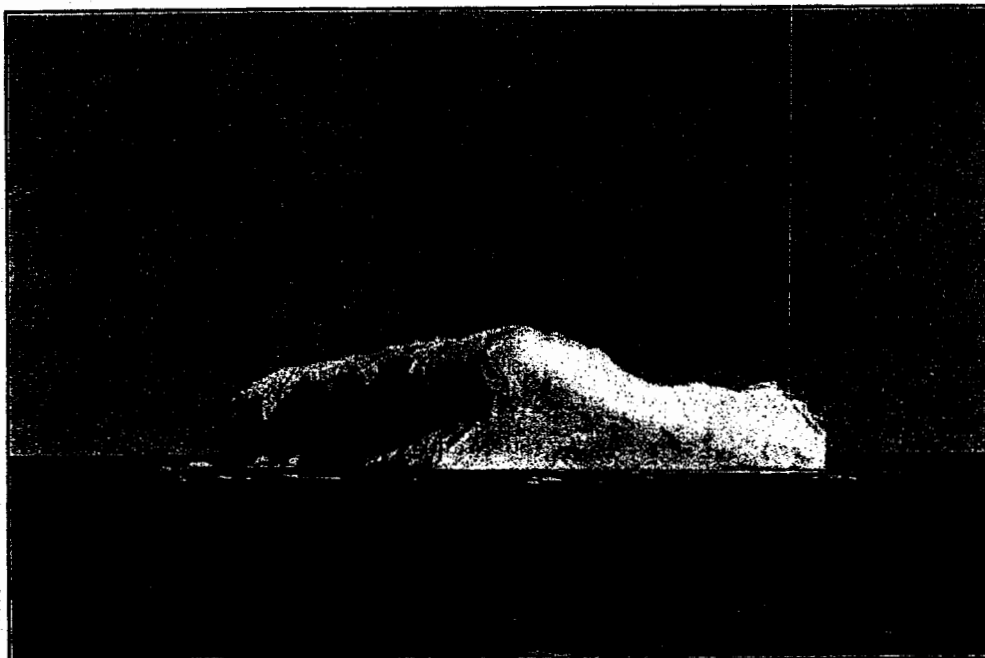


FIG. 40.—AN ICEBERG, OVER 150 FEET HIGH, TILTED THROUGH NEARLY 90°.

tabular bergs. Piedmonts-aground do appear to produce icebergs which have irregular shapes and are produced in the manner of text-book icebergs.

On the Balleny Isles, where the snowfall is much greater, the piedmonts creep further out to sea and therefore supply larger bergs. It is, however, to floating piedmonts that we must ascribe the great majority of Antarctic bergs, and when we remember that the edge of the Ross Piedmont, whose ice is advancing northward faster than any other ice in South Victoria Land, has lost a belt averaging 15 miles in width during the last sixty-five years, we see that it must have given rise to innumerable bergs.

Piedmonts-afloat, from their configuration, can only supply tabular bergs, and the sizes of these vary enormously. Although the Ross Piedmont rises over 200

feet above sea-level, bergs over 150 feet high were seldom seen. Most bergs are less than a quarter of a mile long and about 70 feet high. The largest bergs seen were near King Edward VII Land, where there were many over 150 feet high; they had grounded in places where soundings showed 100 fathoms of water. Local ice-caps supply few bergs. Mount Melbourne, for example, has its ice-cliffs cavernous and overhanging, and we may conclude that years have elapsed since bergs separated from them (Fig. 37, p. 65).

Distribution.—Icebergs float northward along the coast of South Victoria Land bearing with them their burden of mud and stones, and soundings seem to show that most of this is dropped within the Antarctic Circle. In latitude 67° S. the sea-floor proved to consist of mud and ice-scratched stones, whereas only diatom-ooze had been obtained in the deeper water of latitude 60° S. The distribution of bergs in latitudes which are being constantly navigated is represented on the Admiralty Ice-chart, No. 1241, and a short paper by Mr. H. C. Russell* gives some measurements as to the sizes of the bergs. For our purpose, however, the northerly migration along the coast is the point of interest; the long string of bergs grounded near Cape Adare seemed to have formed a banner-shoal; melting there, they must deposit the moraine brought by them from higher latitudes.

Icebergs are destroyed by two agents, the sea and the sun. Some bergs float north into the warmer waters of more temperate latitudes and are there quickly melted. As the berg is undermined by the warm sea-water it becomes top-heavy and sometimes turns over, large pieces being broken off in the process. Some bergs ground in high latitudes and are only slowly dissolved. At certain stages these may float off the shoal and go to swell the mass of drifting ice.

Bergs containing mud, sand or gravel absorb radiant heat, and some ice is melted. The water produced distributes the mud over the surface and the rate of destruction is increased; on December 7th, 1903, a hot day, a berg was seen to have rivulets over all the sides turned towards the sun. A berg becoming inverted may carry mud and stones from the sea-floor above water, and these the sun immediately utilizes for the disintegration of the berg. In latitude 77° S., thawing of ice is of little importance except in December and January. Melting begins in the middle of November, becomes comparatively rapid by the middle of December, continues through January, and virtually ceases about the middle of February.

* H. C. Russell, Journ. Roy. Soc., New South Wales, 1898 (1897), vol. xxxi, p. 221.

CHAPTER X.

THE LAND-ICE—*continued.*

Englacial rock-débris may usually be seen near the terminal ends of glaciers. It occurs in well-defined bands interlaminated with bands of almost pure ice. The ice-walls which form the edge of a glacier also show rock-matter, and, as near the

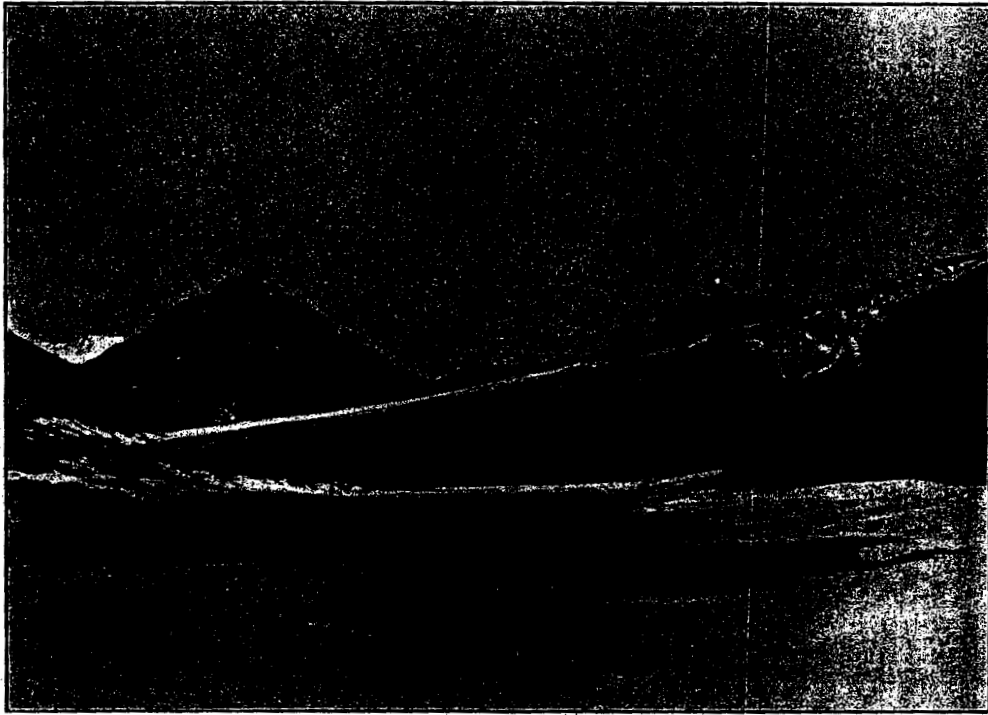


FIG. 41.—UPLIFT OF MORAINIC MATERIAL IN THE ICE AT THE FOOT OF KNOB HEAD.

snout, the rock-matter is more abundant in the lower layers. In the upper reaches of the Ferrar Glacier, the ice-cliffs though 100 feet high show only occasional small stones, but in the middle reaches, *e.g.*, at the base of Knob Head Mountain, boulders up to four feet across were observed low down in the ice-cliff. These boulders are ice-scratched and sub-angular: they are mixed with numerous small stones and some sand. At this spot also two streams of ice meet, and at their junction the englacial matter is forced up 70 feet and appears as a normal medial moraine (Figs. 41, 42).

Below the hill D, the chasm between ice and rock is only about 50 feet deep and some 30 feet wide. The lower 20 feet of the ice-cliff is heavily charged with rock-débris of all shapes and sizes. Rounded and apparently water-worn boulders up to 12 feet across are exuded from the ice, together with fine sand and mud.

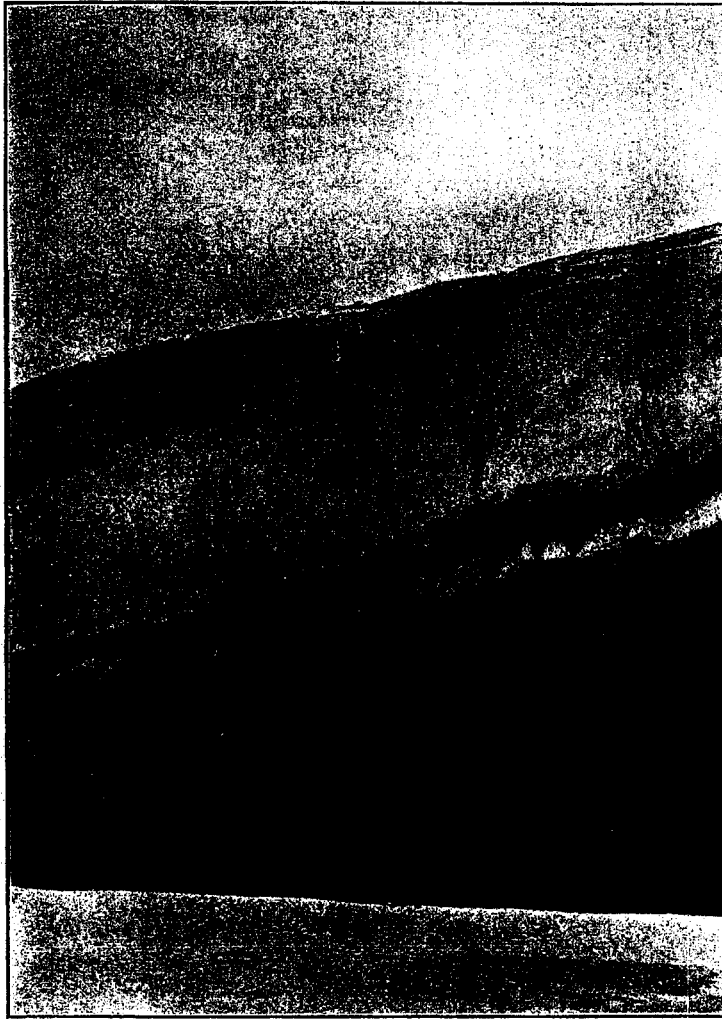


FIG. 42.—THE DARK BAND OF ICE-WITHOUT-GRAIN, BELOW NORMAL GLACIER-ICE, AT THE FOOT OF KNOB HEAD.

The sun is wasting the cliff away so rapidly that a lateral moraine is appearing below the general level of the glacier, and a small stream flowing along it is carrying away the finer material which is being dropped into it by the rapidly thawing ice.

On the south side of the snout of the Blue Glacier and 50 feet below the upper surface, there occur a channel and ice-cliff, like those of the Karajak ice-stream figured by Dr. DRYGALSKI;* along the channel, bands of mud and stones are visible in the ice-cliff. In one of the ice-slabs of the Southern Foothills sandy englacial matter occurs in much the same way as in the Ivory Glacier of Spitzbergen.†

Supraglacial matter is remarkably scarce. In this respect the glaciers of the Antarctic region stand in contrast with those of Switzerland or New Zealand. The latter are so much covered with angular rock-*débris* that no ice can be seen within three miles of the actual snout. The lateral and medial moraines on the Ferrar Glacier are not often as regular in distribution as moraines of other regions. Sometimes they begin suddenly about five miles from the nearest rock-exposure,

and, after extending some way down the valley, end as suddenly as they began. Again, though bare rocks, such as *Depôt Nunatak*, shower talus upon the ice, the moraine produced can only be followed some two or three miles down the valley. In the Dry Valleys, the moraines appear to be melting off and to be falling back into the channels between ice and rock. A few isolated moraines are also scattered at random over the surface of the invading Ferrar Glacier.

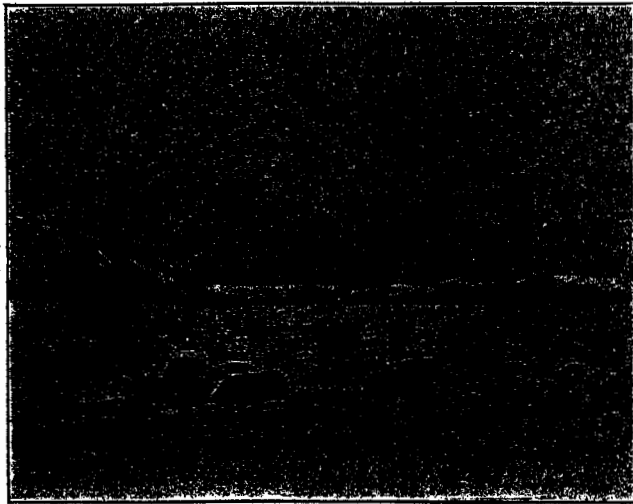


FIG. 48.—MORaine ON THE FERRAR GLACIER.
KUKRI HILLS ON THE LEFT, GRANITE-HILLS (G₁, G₂) ON THE RIGHT.

The moraines which are brought down by South Arm are perhaps the most striking in the region. Five of them are very prominent. One in the middle of this tributary extends north past the base of Knob Head, then turns for a time north-west, and finally curves round to the north-east, and on entering the North Fork is lost. Two pairs of moraines, rather nearer the east side of the glacier, bend round into East Fork and following the ins and outs of the valley, eventually find their way on to the floating ice at its mouth (Plate III). This double pair, as seen from Descent Pass, looks like the single pair of wheel-tracks of a waggon, but, as a matter of experience, at least half a mile of bare ice separates one pair from the other.

* Drygalski, 'Grönland-Expedition,' 1897, Bd. I, plate 14, p. 64.

† Garwood, Quart. Journ. Geol. Soc., 1898, vol. liv, plate 16.

The moraines consist of three-foot boulders of dolerite, granite and sandstone, which are accompanied by very little fine material (Fig. 43). The moraines are 30 feet wide, and the boulders are scattered thickly over the whole width. At the base of Cathedral Rocks another moraine commences and accompanies the other four. They produce parallel furrows in the surface of the ice which increase in depth as the boulders disappear. About 10 miles east of Cathedral Rocks these moraines are still represented by the parallel depressions, but the boulders are few and isolated, and numerous patches of coarse-grained ice mark the positions of those which have sunk through. Out on the floating portion of the Ferrar Glacier the boulders are even more scattered, and solitary survivors, about 100 yards apart, are all that represent the moraines of the upper reaches.

It was among these moraines, at heights between 3000 and 4000 feet, that we found numerous mummified carcasses of the crab-eating seal (*Lobodon carcinophagus*). These are interesting in that the movements of seals ashore are always slow and laboured; how they could have travelled 40 miles uphill over rough ice and soft snow is an unsolved mystery. A pecten shell was also met with in gravel 10 miles up the Ferrar Glacier and 20 feet above the sea. The gravel had formed a glacier-table (Fig. 44), and the ice around was all glacier-ice, but is not above the reach of some exceptional tidal wave.

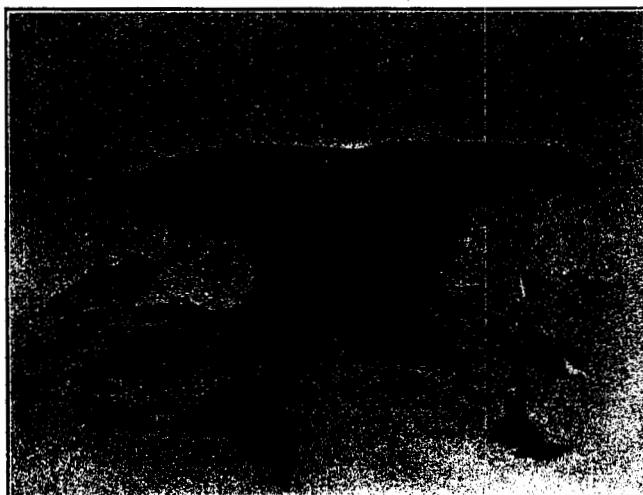


FIG. 44.—GLACIER-TABLE FORMED BY A LAYER OF GRAVEL.

On floating ice at the head of McMurdo Sound there are great quantities of moraine (Figs. 45, 47); the latter completely covers the ice and makes it difficult to make sure that this great mass is really afloat. There is, however, the tide-crack, which, following the land-boundary, marks off this *débris*-strewn area as a stagnant but floating mass. Our observations seem to show that the ice is really an overflow from the Ross Piedmont. In Discovery Gulf, also, the surface of the floating ice carries much rock and some organic (512, 513) *débris*, and extends for a distance of more than 20 miles from land. Between Black Island and Brown Island the morainic matter is unworn, its stones being usually angular. The moraines occur in long trains of cones which often rise 50 feet above the general

level of the ice. Sometimes the cones blend with one another, and produce a series of ridges whose direction follows the former direction of movement.

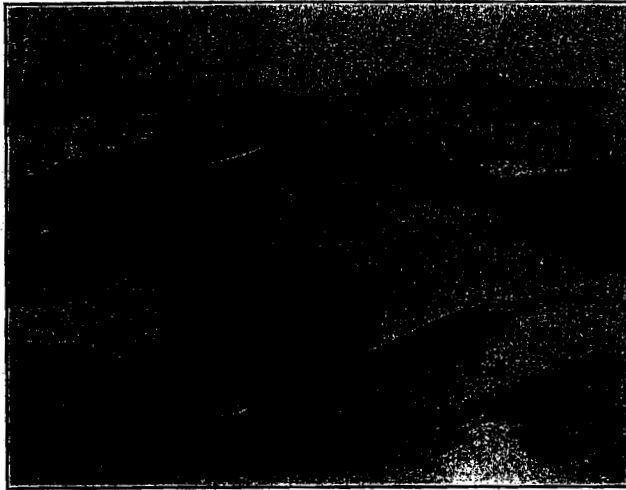


FIG. 45.—MORAINES ON FLOATING ICE AT THE HEAD OF McMurdo SOUND.

On rounding the north end of Black Island, the lines of cones curve westward, and are further continued northward to the "pinnacled ice" or old ice-edge. Occasionally large boulders up to four feet in diameter are found, but these disappear and are replaced by great quantities of coarse sand (261), which is often blown about by wind. It is this sand which, by inducing melting, produces the rivulets. These give rise to the fantastic

"pinnacled ice" which presents so insuperable a difficulty to the sledge-traveller.

Re-sorted moraines were observed at Cape Adare; the "beach," from which so varied an assortment of pebbles has been taken, is one mass of such moraines. The average height of the beach is about 20 feet above the sea, but only 30 yards of the northern fringe has recently undergone modification by water. In detail the beach consists of parallel series of ridge-and-furrow with amplitude of about four feet. The ridges curve with the rock-wall. Sometimes the fine material appears stratified, but the covering of pebbles usually hides all evidence of structure. The ridges, which are occupied by penguins, flatten northward; and the depressions which contain stagnant water sometimes join up and form large digitating ponds. At an elevation of more than 800 feet on Cape Adare are other moraines. These cross the peninsula to the

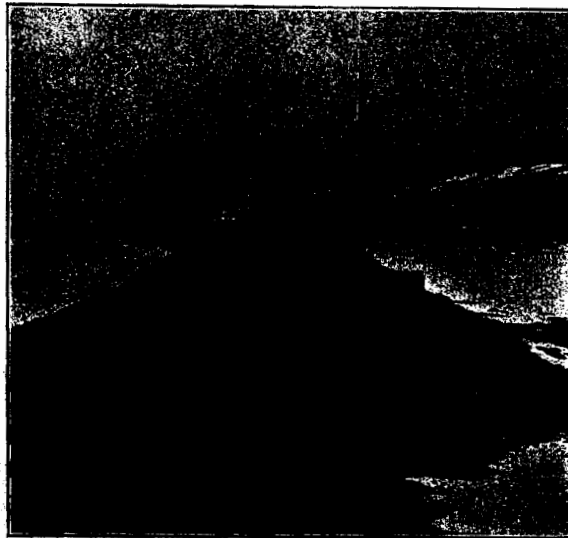


FIG. 46.—MORaine-cone of ice-scratched stones, on which the *Balanus* shells were found, on the floating glacier-ice in the bay between White Island and Black Island.

north-east; they consist of small stones, some ice-scratched boulders, and a few blocks of rock up to 12 feet across. The beaches of Possession Island, Wood Bay and Franklin Island, appear to be similar to the Cape Adare beach.

Stranded moraines also occur above Cape Crozier on the slopes of Mount Terror at heights of 300 to 500 feet. Others on the south-east side are very striking. They lie 800 feet above sea-level and are 200 or 300 feet above the level of the Ross Piedmont. Other moraines occur on that shoulder of Mount Erebus which terminates in Cape Royds. They occur up to a height of 1000 feet, and are very well seen near the 800-foot contour. They cover some three square miles of area. Granites, and rocks like the dolerites of the Royal Society Range, are the most conspicuous components.

The moraines on the west side of McMurdo Sound are developed on a larger scale than any other moraines in South Victoria Land. An area there, 5 miles by 3, is one mass of *débris*-cones, some of them being as much as 100 feet high (Fig. 47). These cones rest in some cases upon land, in other cases upon fixed ice, and occur on a flat which is not more than 4 feet above the sea. The cones are more or less in lines, and the lines appear to radiate irregularly from two points, one set of them converging near the snout of Blue Glacier. Though the cones rise considerably above the edge of the land-piedmont described on p. 66, they follow its eastward border.

On the south side of Blue Glacier these cones are replaced by a continuous line of moraine, and this hugs the edge of the Southern Foothills for a distance of some 30 miles.

Before leaving the subject we must briefly mention the ice which supports the cones and occasionally protrudes through the covering of *débris*. In particular cases it is often impossible to say what part of the material is ice and what part is rock-*débris*, and hence no attempt has here been made to distinguish between moraines still being carried by ice and moraines now resting upon the land. Even on Cape Royds water oozing from some of the ridges showed that the latter contained ice. During summer the fine material is continually being separated from the coarse by the water from melted ice (Fig. 52, p. 89). In some cases, however, the cloak of *débris* is too thick to allow the heat of the

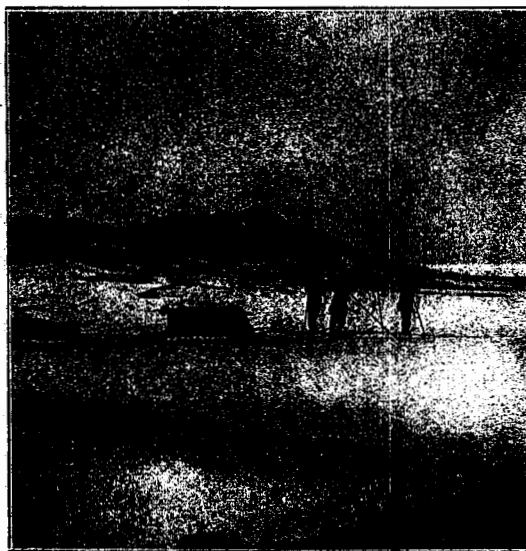


FIG. 47.—MORAINES SUPPORTED BY ICE, ON THE WEST SIDE OF MCMURDO SOUND.

summer sun to get through, and the ice beneath it may then be preserved almost indefinitely.

The characteristic sheer ice-walls bounding the glaciers of South Victoria Land show that under present conditions the sides are receding from the land. The intervening channels often contain frozen ponds, which in some cases, though only 50 yards broad, are more than a mile in length. The large pond at the base of Knob Head may be contrasted with the Marjelen See, in that it follows the straight side of the main valley instead of merely occupying the dammed-up end of a tributary valley (Fig. 41, p. 76).

The structure of the ice between the bands of intra-glacial material at the base of Knob Head shows remarkable variations. The uppermost 40 feet appears to be quite normal vesicular glacier-ice and is free from rock-*débris* (Fig. 42, p. 77). Below this are several notable dirt-bands, and among them other bands from 2 to 10 feet thick, perfectly clean, and clear as rock-crystal. On melting small fragments from these bands no granular structure could be seen, and it is suggested that they are, in part at least, due to intrusive thaw-water. Other bands showed air-vesicles elongated at right angles to the banding. The ice which contains the majority of boulders has a structure comparable to that of ordinary rock-fault breccias, and it would appear that the ice here glides forward as a series of rigid sheets along parallel thrust-planes.

Up-thrust of morainic material similar to the up-thrust in Spitzbergen described by Professor GARWOOD,* was also observed at Dépôt Nunatak, where Beacon Sandstone boulders are brought up to the surface. Up-thrust was again in evidence behind the Solitary Rocks on the Ferrar Glacier. Up-thrust produced by impact of two streams of ice is further seen at the foot of Knob Head, where the dirt-bands with large boulders bend up and appear on the surface 70 feet above their usual position (Fig. 41, p. 76).

Ice-movement.—Owing to the great distance which separated Winter Quarters from any glacier, our observations on the rate of ice-movement have been few in number. The rate at which the ice from South Arm forces its way into East Fork of the Ferrar Glacier is probably less than six feet per month. Other observations made at its snout indicate that the rate is extremely small. The Blue Glacier moves less than four feet a year, while the Ross Piedmont, as measured by Lieutenant BARNE from the dépôt off Minna Bluff, moved no less than 608 yards in 13½ months. The movement of Ferrar Glacier or Blue Glacier causes little disturbance of the sea-ice; slight movements are transmitted to the latter and become lost in its more ordinary movement. Where the Ross Piedmont abuts against Mount Terror, three parallel and well-defined ridges appear. These are at least 50 miles long and usually some 50 feet high. They have been traced by Lieutenant ROYDS towards the north end of White Island, but gradually flatten out and fan. At Pram Point four lines of parallel hummocks, each about 15 feet high,

* Garwood and Gregory, Quart. Journ. Geol. Soc., 1898, vol. liv, p. 219.

are caused by an overflow of Ross Piedmont. Captain SCOTT found that the ice of such channels as Mulock Inlet pushes the piedmont-ice away from the land and leaves a chasm,* some 100 feet deep, in the intervals between them. At such outstanding points as Minna Bluff, cracks and crevasses radiate outwards, particularly towards the east and north-east; but a sledge-party, by giving the land a wide berth, was able to avoid most of these. Near the north end of White Island also, series of radiating cracks are found. It would therefore seem probable that the Ross Piedmont is moving northwards bodily.

The ice-falls of Ferrar Glacier indicate movement, but, as the crevasses always remain drifted up with snow, the rate must be exceedingly slow. In the channel at the foot of Knob Head, where the evidence of up-thrust is recorded above, the banks of the frozen ponds have several small ridges alongside and parallel to the glacier-side. These ridges, which are occasionally broken along their length, indicate a certain amount of movement; as this is the only spot where rupture caused by shearing movement is obvious, the fact is noteworthy.

Near the sea, where the ice-tongue floats in its valley, the tide-crack follows the side of the glacier for a distance of at least 10 miles. Near the foot of the hill G₂, the crack trends towards the centre, and, gradually disappearing, is replaced by other cracks which trend inwards up the valley. It would seem that the point of replacement indicates the floating of the ice, and that the oblique cracks show a slightly more rapid forward movement of the mass of ice behind.

In the amphitheatre or depression of the Ferrar Glacier, two miles from the foot of Knob Head, the ice shows a network of ribbon-like cracks or fracture-lines (*Risse* †). These are often less than two inches apart, and, without opening more than a hair's breadth, extend for great distances. Parties camped on this ice have observed on several occasions that very rapid splitting or bursting asunder takes place with loud report, as soon as the hills cast their shadows on the ice. The reports which accompany the splitting are loud and frequent, and often resemble the noise of independent rifle-firing. The noises frequently continue for an hour and a half at a time. Rupturing has also been observed at several other spots, and seems to be caused by strain set up by changes of temperature in the ice. That the ice is in a state of strain is proved by the fact that a blow from an iron-shod ski-stick has produced cracks which have extended 50 yards across the surface of a mass of ice not less than 100 feet thick.

Snow.—The usual accumulation of snow took place during violent blizzards when the air became thick with fine snow-dust (Fig. 48). On a few occasions in the summer, however, large flakes fell gently from a cloudy sky. Sometimes soft hail in rounded pellets and soft woolly hexagonal snow-crystals descended from an overcast sky. Occasionally also, during summer, hexagonal ice-crystals up to half an inch across fell

* Scott, Geog. Journ. April 1906, vol. xxv, p. 866, plate.

† Drygalski, 'Grönland-Expedition,' 1897, Bd. 1, p. 80; Heim, 'Handbuch der Gletscherkunde,' 1885, p. 202.

from a clear sky; on the surface of the Ross Piedmont, they supplied much of the superficial ice of the area. In the course of a day or two the crystal-plates break up into grains, which drift hither and thither with the wind. After a blizzard, soft snow usually becomes tightly packed, and the snow-dunes which have been formed show a smooth and hard surface. Later this dune-snow granulates, notwithstanding that the temperature remains constantly below 0° F. If a wind springs up, the grains are carried away and the dunes disappear. Graduated pegs were set up in the snow to determine the changes which take place in its surface, and the observations show that during two years much snow drifted past them. Wind carries the snow bodily away; the importance of this factor in reducing the height of the inland-ice of South Victoria Land will be appreciated if we recall the six and a half days during which the sledge-parties were weather-



FIG. 48.—UNDULATING SURFACE OF HARD "MARBLED" SNOW.

bound on the edge of the inland-ice. During that week, the air, which passed at an average rate of 50 miles an hour, was so charged with fine snow that objects 10 yards away were indistinguishable. That this is not unusual may be inferred from the fact that at Winter Quarters the days on which no silting, or surface-drift, of the snow took place were few.

The winds by carrying snow on to the surface of sea-ice help to drain the

land; and the sea-ice, as it breaks up and floats north, takes away much superfluous water-substance which has had no opportunity of glaciating the land (Fig. 49).

The snow-dunes usually took the form of crescents and symmetrical elongated domes, never more than three feet high. The longer axes of the domes were parallel to the direction of the prevailing winds, those of the crescents transverse. As soon as their substance becomes granular, the winds remove and obliterate all trace of them.

During the process of destruction, snow-surfaces resemble a wind-worn surface of false-bedded and slightly indurated sand. The less granulated layers are the more indurated, and stand out beyond the coarser and less resisting bands, thus giving the appearance of stratification. The forms assumed by the disintegrating dunes are very variable,* and some become very fantastic. The silting snow helps

* Vaughan Cornish, Geog. Journ., August 1902, vol. xx, p. 187.

the wind and behaves like a sand-blast, cutting away both the soft and the hard layers.

No transformation from snow to glacier-ice could be observed. Present climatic conditions are such that thawing, even partial thawing, only takes place very locally, and all the surfaces encountered were either granular white snow or compact ice. Even at the head of the Ferrar Glacier the change from snow to ice is absolutely sudden, and along the base of the great cascades the ice presents its characteristic rippled surface. Local accumulations of snow do occur in the larger depressions, but the line separating granular snow from glacier-ice is always sharp. A few snow-dunes were also seen, consisting of opaque white snow, too hard to be cut even with an iron spade.

In 1902 Lieut. ARMTAGE travelled up Ferrar Glacier over soft snow, and at one of his camp-sites left pieces of spun yarn, a tin and a piece of wood; they were found by our party a year later and lay loose upon hard transparent ice; the tracks of his men and sledges could have been followed all the way up the glacier. The sledge-tracks appear as two parallel ridges, standing in relief nearly an inch above the general ice-level. The footprints of the men also stood in relief, but the dark objects left lying about were not so raised. From these facts it would seem that in this locality loss by ablation exceeds gain by precipitation.

A surface of white snow absorbs little incident radiant heat. Owing to the low temperature of the air, the growth of the grain can therefore only take place slowly. In sheltered spots or near bare rock, snow and ice melt rapidly during summer, and even in the open long furrows filled with water* appear. The best example of this was seen among the hummocks near Black Island, where long furrows filled with fresh water separate rows of hummocks (*Hügel* †) from one another.

Temperatures at fixed depths in the ice were determined during 1903, and the observations show that the variations from day to day are surprisingly small. It will suffice here to note that the highest temperature recorded at a depth of six feet was -9° C. and the lowest -24.4° C. The change was gradual throughout the year.



FIG. 49.—THE TWO LOWER MEN ARE STANDING UPON THE UPPER SURFACE OF SEA-ICE DEPRESSED BY SNOW BELOW WATER-LEVEL.

* Drygalski, 'Grönland-Expedition,' 1897, Bd. i, p. 78, plate.

† Drygalski, 'Grönland-Expedition,' 1897, Bd. i, p. 86, plate.

The minimum reading was taken after mid-winter and the maximum occurred in January, and hence a considerable lag in temperature is produced by the six feet of ice. Temperatures at greater depths in the crevasses * show that there the lag in temperature is even greater, and also that the maximum temperature reached by the ice is far below the melting point. The following observation from a crevasse near the junction of the ice of South-west Arm with that from inland is of interest:—

November 3rd, 1903, 7 P.M. Depth of crevasse 30 feet.

Temperature of the air $+20^{\circ}$ F. (-6.7° C.).

Temperature of the ice -21° F. (-29.4° C.).

* Drygalski, 'Gronland-Expedition,' 1897, Bd. i, p. 450; Heim, 'Handbuch der Gletscherkunde,' 1886, p. 288; Nansen, Meteorological Report, 1894, 1895, 1896.

CHAPTER XI.
DENUDATION.

Wind-action.—The winds in South Victoria Land prove to be as strong and as constant as any oceanic trade-wind. Around Winter Quarters the bare land-surfaces are usually covered to a depth of six inches by a loose cloak of rock-*débris*. Below this the earth is permanently frozen throughout the year, and here rock-surfaces due to fracture often seem to remain quite unweathered. The layer of rock-*débris* consists of a mixture of occasional boulders, abundant small stones and rock-chips, embedded in a matrix of impalpable flour, and all would seem to be rapidly disintegrating. Many of the boulders seem to have no very definite outer boundary, and the protected surface may be seen to pass gradually through a state of crumbling (547) into impalpable powder (446). This cloak is usually damp for a week or two in summer, but becomes dry and loose when frozen during winter. Here decomposition and disintegration proceed simultaneously, and any particles loosened by frost from the upper surfaces are at once blown away by the wind; the fine material which remains is always an inch or so below the loose layer of stones at the top of the deposit.

The loose stones are often smoothed and pitted (325) in the manner peculiar to the wind-worn stones of desert regions,* and some of the harder ones have a superficial glaze. Some of the boulders are too granular to receive polish; gradually crumbling away, they for a time leave patches of small angular fragments, still too large to be transported by the wind, to mark the spots they once occupied.

The wind has carried away the smaller rock-fragments from the summits of Observation Hill and Castle Rock. Those which remain are upwards of two inches in diameter. The summit of the former, which is composed of trachytic lava, is

* Walther, Abhand. math.-phys. Cl. d. k. sächs. Ges. Wiss., 1891, Bd. xvi, p. 447. (Dreikanter.)

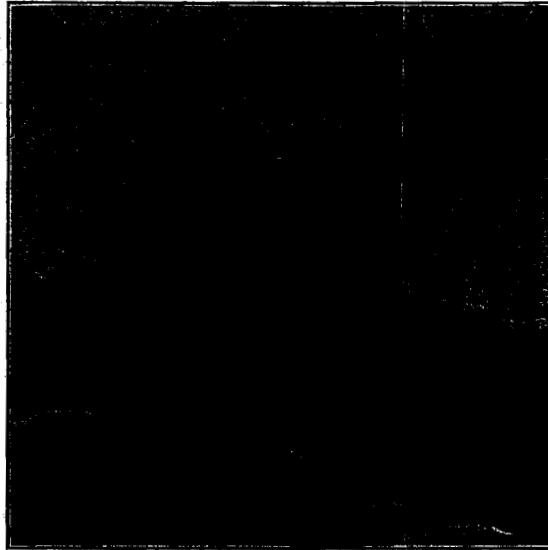


FIG. 50.—HOLLOWED GRANITE-BOULDER WITH INCORUSTATION OF CALCIUM CARBONATE, NEAR DESCENT PASS.

honeycombed to a remarkable extent. The boss of trachyte above Cape Crozier, the kenyte of Cape Royds and basalts of other areas, show similar wind-effects.

The Beacon Sandstone of the Royal Society Range, likewise, was almost free from the fine disintegration-products, particular beds being often bare for lengths of a mile or more. The loose quartz-grains derived from these seem only to remain in crevices or below projecting rock-shelves. Dolerite-columns, too, are quite smooth, and are coated with a bright chocolate-coloured crust (670) rarely more than one-eighth of an inch thick.

Hollowed granite-boulders (Fig. 16, p. 34; Fig. 50) were observed at the foot of Royal Society Range near Descent Pass, and two types may be distinguished.

(A) In fairly normal granite. The rock (555, 556) is a grey to pink granite

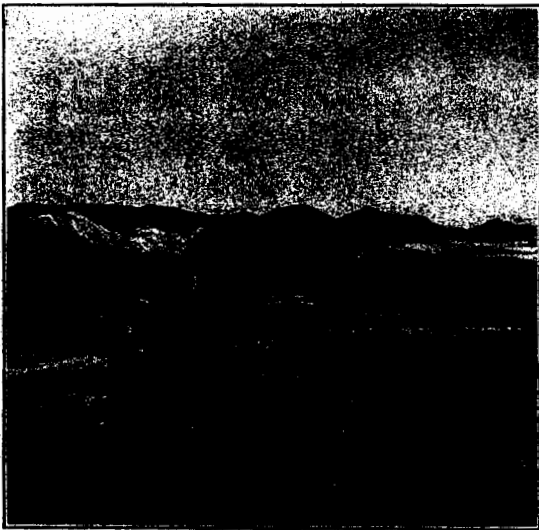


FIG. 51.—SALINE POND IN MORAINES ON WEST SIDE OF McMurdo SOUND.

with feldspars usually about a quarter of an inch long; it appears to be quite fresh even on the surface, and has a marked superficial glaze on both convex and concave surfaces. The most striking cavity is on the south and weather-side of a large block and therefore faces away from the sun; it is about eighteen inches across at the opening, and the diameter increases inwards to at least two feet. The depth of the cavity is a little more than a foot, and the back wall is partially covered with a hard mamillated or botryoidal crust (554), consisting mainly of calcium carbonate, the surface being white, and harsh to the touch. The crust was lamellar, scarcely more

than one-eighth of an inch thick, but the projecting botryoids, which are sometimes partially hollow, may be more; it was firmly fixed to the granite-face, so that it was impossible to decide whether the surface beneath was or was not glazed.

(B) In a very coarse granite containing abundant large crystals of orthoclase. The hollowed blocks (557, 558) are rounded, but the surface, owing to the rapid disintegration, is roughened rather than glazed. The largest cavity is in a block 6 feet by 4 feet by 4 feet, which is hollowed almost to a shell. The cavity is four feet long, three feet deep, and two feet high, and has four apertures varying from a foot to eighteen inches in diameter, one on each side of the block. The lip of the apertures is exceedingly sharp, the angle being certainly not greater than 30° . No incrustation was seen on the walls of this cavity, but on the floor is a

sprinkling of the finer disintegration-products of the granite which abundantly litter the surrounding area.

These cavities in crystalline rocks apparently resemble the cavities in granite observed by Mr. F. F. TUCKETT* and Professor T. G. BONNEY † in Corsica and by the Rev. R. BARON ‡ in Madagascar, but the incrustation of calcium carbonate shows that wind is not the only factor involved in their formation. As in Corsica, many saucer-like depressions and a few potholes were observed, and seem to mark stages in the development of the completed cavities. Internal incrustations do not seem to be recorded, but Mr. BARON mentions a "white powder alkaline to the taste" as occurring in the hollowed blocks of Madagascar.

Water-action.—Water, as an agent of denudation in South Victoria Land, is at present a factor of limited importance (Figs. 51, 52, 53). On glaciers it merely washes away the finer material already thawed out of the ice. On bare rock it seldom appears, but along the south side of the Kukri Hills and in other places a marked water-channel occupies the marginal ice-area, and in summer water flows along the junction of ice with rock. Water, therefore, may undercut rock-cliffs and tend to widen and terrace the sides of valleys. Any ice thawed away by water is at once replaced by the advance of fresh ice, a process which tends to render permanent the course of the water-channel. Actual undercutting of rock-cliff was only seen occasionally, but at the foot of the hill D, along the Cathedral Rocks and along the foot of the granite hills G_s, was most evident.

During the summer, water everywhere distributes mud and sand over the ice. Much of this mud is derived from the moraines which protect ridges of ice, and the running thaw-water sorts sand from gravel and fine mud from sand. In this way stratified and false-bedded sands and gravels may be derived and appear among morainic accumulations (Fig. 52). Channels cut in the floating glacier-ice are common at the head of McMurdo Sound, and during summer

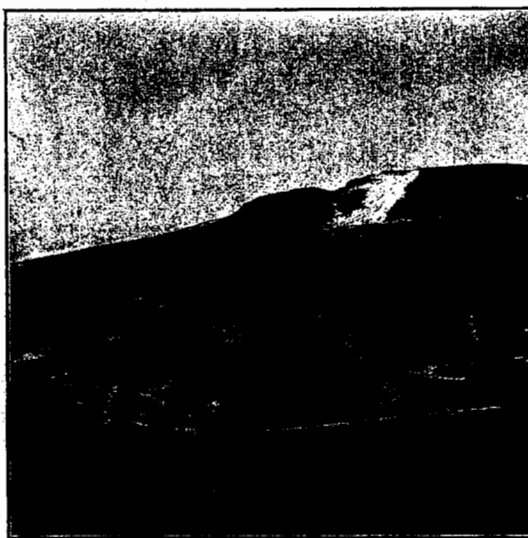


FIG. 52.—WATER SEPARATING MUD FROM GRAVEL IN THE MORAINES ON MINNA BLUFF.

* Tuckett, Geol. Mag., Dec. V, 1904, vol. i, p. 12.

† Bonney, Geol. Mag., Dec. V, 1904, vol. i, p. 389.

‡ Baron, Geol. Mag., Dec. V, 1905, vol. ii, p. 17.

the water flowing through them often spreads sand and mud over the surface of the sea-ice.

The most notable effects of water-action in the area were seen on the north-east side of Brown Island, an island which retains practically no snow on its surface. In January, 1902, a very warm clear day followed a summer snow-storm, and caused a rapid melting of the snow just deposited. Rivulets becoming confluent produced comparatively large streams, which coursed in straight and narrow trenches down the hillside. The slope here is very steep, and trenches sometimes 20 feet deep had been eroded. The coarser



FIG. 53.—WATER-CHANNEL ON FLOATING ICE IN MCMURDO SOUND.

material washed off the hillside spreads out as a delta on land, but much of the finer material is carried further by the muddy stream, in and out among the lines of moraines, and distributed over the surface of the floating glacier-ice. We observed a stream increase in depth from one foot to three feet in the space of a few hours. The swollen stream cuts into the protected moraines and, overflowing the more level areas, there deposits its silt. Finally, the stream coursing northwards into McMurdo Sound passes off the pinnacled or floating glacier-ice* on to the sea-ice which its finest sediment then sullies (Figs. 53, 54).

A similar flood must have occurred early in

J. Blue Glacier G



FIG. 54.—SEAWARD EDGE OF THE GLACIER-ICE FLOATING IN MCMURDO SOUND.

* Ferrar, Geog. Journ., April 1906, vol. xxv, plate, p. 874.

December, 1903, for an area of sea-ice, six square miles in extent, was found with an average of eighteen inches of muddy water upon it. Some of this water may possibly have been produced in place, for this inundated area lay along the north edge of the floating glacier-ice, and during the winter-gales must receive foreign matter.

Chemical action.—Chemical decomposition of rocks is more obvious in the dry climate of South Victoria Land than in other areas, for rain can usually remove soluble salts as fast as they form. On Hut Point all rock-fragments have thin incrustations of sodium sulphate (398). The incrustation is sometimes so abundant that the rocks look as if they have been dusted over with lime or flour; if the loose surface-matter be scraped away, thin discontinuous beds of the pure salt may be seen dipping gently into the hill. The surfaces of many boulders in The Gap are covered by a lace-like network of white lines (262, 263) consisting of calcium carbonate.

Near the north end of White Island a great quantity of perfect crystals of sodium sulphate (298) was obtained on a mound of the floating glacier-ice (Fig. 55). The percentage of water in this salt, as determined by Dr. Prior, was 55.86, which is virtually identical with that characteristic of pure Mirabilite or Glauber Salt.

Near the isolated moraines in the bay between White Island and Black Island, on floating glacier-ice, there are five or six mounds, two feet high and up to five feet across, of the same white salt (623). The mounds are entirely composed of the salt, which is in well-formed crystals, though the outer ones have effloresced to some small extent. The moraines near these mounds contain *balanus* shells (612) together with ice-scratched granite and other boulders (Fig. 46, p. 80). In one of the moraine-cones on the west side of McMurdo Sound, a bed of this salt (741), about eighteen inches thick, is traceable horizontally for about ten yards. This bed is at least 50 feet above a pond of brackish water which occurs at the foot of the moraine. Dr. E. A. WILSON also found this salt (740) near the head of Discovery Gulf, and Mr. T. V. HODGSON (742) on Inaccessible Island. As many of the ponds among the moraines are much too saline for drinking, it is possible that this peculiar and abundant concentration of soluble salt may be due to a former crystallization from similar ponds.

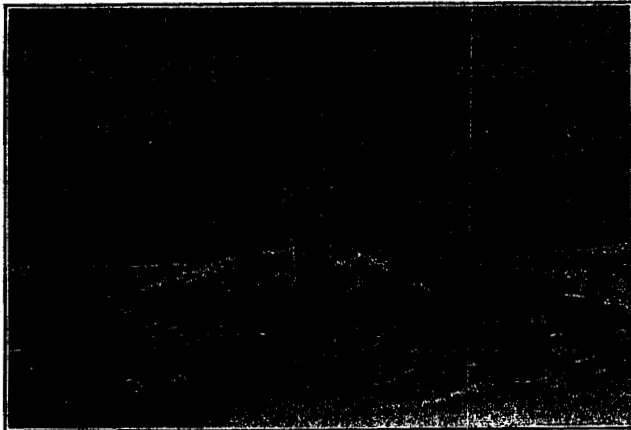


FIG. 55.—FRACTURED DOME IN THE FLOATING GLACIER-ICE, NEAR THE SPOT WHERE SODIUM SULPHATE CRYSTALS WERE FOUND, TWO MILES FROM THE NORTH END OF WHITE ISLAND.

Frost-action.—Owing to the very low temperatures prevalent in high southern latitudes, the denuding action of frost is not strikingly conspicuous. As a rule, the wind removes all snow from bare rocks, and a marked line always divides the local snow-fields from the areas free from snow. Thawing and freezing only occur near the edge of snow-fields, and, therefore, owing to the general absence of water, frost-action is once more rendered impotent. Castle Rock was perhaps the best example of a frost-riven mass near Winter Quarters. It rises sheer above the snow-covered peninsula; but the side facing the sun (the north side) slopes steeply down to shore-ice nearly 1000 feet below. Snow is drifted by the prevailing easterly wind on to the north side, and in summer large riven blocks fall down and litter the area below. The north side of Cathedral Rocks is similarly shattered; from its pinnacled outline it would appear to be more subject to frost-action than the isolated peaks further to the west.

The dolerite, though forming no prominent talus-slopes, appears more prone to split than other less-jointed rocks and a conspicuous ledge is always left at its contact-junctions. Where dolerite occurs above sandstone, a terrace of the sandstone stands out in front of the steep dolerite-cliff. Fans of dolerite-talus are very conspicuous in the smaller of the Dry Valleys, also below the hill D, and along the south side of the Kukri Hills.

No screes encroach upon the upper parts of the Ferrar Glacier, and the dolerite usually rises perpendicularly from the ice. Along the ice-streams talus-fans are rarely abundant enough to become continuous even at their base. The sandstone undergoes little frost-action. Often its surfaces still retain the rounded outlines which have been produced by ice-action. All transport of rock-material is now accomplished by wind, which carries off the sand-grains as fast as they are loosened.

An important agent in wearing down the sandstone, and one which can hardly be classed with any of the ordinary agents of denudation, may be included here. The columns of dolerite, in falling down the cliffs, break away the softer sandstone-beds and produce a sort of "chimney talus-shoot," which conveys the *débris* to the fan at the bottom. Other fragments follow this line of descent, and thus the deepening of the gully is accelerated. On the hill *x* several such gullies may be seen. At a height of about 500 feet above the ice, the edges of the sandstone-beds which have been caught up by the dolerite (see p. 46) are serrate, and at one spot a groove or gully, 20 feet wide, of U-shaped section, has been produced. This groove has perpendicular sides, and the uppermost bed of sandstone has been cut back 20 feet from the edge of the cliff.

The granites of Antarctica, as of other regions, seem prone to form screes. In the metamorphic limestone area, the hills are usually so rounded that there is seldom an opportunity for a loosened block to change its position, and no transport takes place until the rock is so finely disintegrated that it can be carried off by the wind.

Ice-action.—Adopting the same plan as before, we shall briefly review the general action, as a geological agent, of each specified form of ice. The sea-ice, as already pointed out, seldom runs aground, and is therefore negligible as an agent for striating or abrading rocks or for contorting beach-deposits. Sea-ice forced up on to the land has been observed at only one spot. This was the very exposed north-east corner of the stranded moraines on the west side of McMurdo Sound, where sorting and rearrangement of the moraines is so constantly happening that no permanent effects of sea-ice could be traced. As a transporting agent, sea-ice is not very effective. Sometimes a boulder may roll across the fringe of shore-ice on to it and be taken out to sea. The original boulder may be angular or it may be ice-scratched; its condition when on the ocean-floor can hardly be said to indicate its method of transport. Dust and fine sand are often blown on to sea-ice and may then be further transported. In Wood Bay great numbers of pumice-pebbles (899) had been blown on to sea-ice, which would be drifted far to the North by the prevalent ocean-currents before it melted.

The shore-ice has a conservative* effect upon the land. It binds together the talus of the hills, and so protects talus and rock from the eroding action of drifting ice-floes or waves. When a piece of an ice-foot floats out to sea it usually

carries a great load of *débris*. Stones roll on to the surface, and, through the melting of the ice around, work downwards. Pockets of dust (*Kryokonit*)† are exceedingly numerous; probably also much rock-material is held within the sole. All these must be transported. As ice which has left the shores of South Victoria Land seldom grounds, the abrading or striating action of shore-ice there must be small.

The glaciers taken as a whole are not now modifying the form of the land to any great extent. The corrie-glaciers and ice-slabs appear to be aggrading rather than excavating the valleys in which they lie (Fig. 56). The corrie-glaciers at the Inland Forts have a *Bergschrund*, but, judging from the small amount of terminal



FIG. 56.—A GLACIER DESCENDING FROM THE TOP OF COULMAN ISLAND INTO THE SEA.

* Bonney, Quart. Journ. Geol. Soc., 1902, vol. lviii, p. 699; Bonney, Geog. Journ., 1898, vol. i, pp. 481-499.
† Drygalski, 'Grönland-Expedition,' 1897, Bd. i, p. 94, ff.

moraine encircling them, no serious "plucking" of large rock-masses* can now be taking place. This plucking does seem to be illustrated in the ice-free *cirque* to the north of the Forts. There several blocks of Beacon Sandstone, as much as 20 feet in diameter, have been extracted and transported about 50 yards; the sockets from which the boulders are derived are still very evident, and contain frozen water-ponds.

The ice is everywhere retreating; some few valleys are now quite bare and are moraine-covered. No obvious ploughing effects of ice were seen, and *roches moutonnées* are not by any means conspicuous. In Granite Harbour a few perched blocks and a few ice-planed rock-surfaces were observed. This harbour is fiord-like, and has depths of over 100 fathoms within a quarter of a mile of the shore. At G₁ of the Northern Foothills, close to the Blue Glacier, the metamorphic limestones are beautifully rounded more than 1000 feet above the present ice-level and perched blocks are everywhere abundant. Observations at the snouts of several glaciers seem to show that no regular shedding of bergs is going on. Bergs from the Blue Glacier would contain a great quantity of rock-matter, and in former times must have transported an enormous quantity of *débris*.

Of the many icebergs met with, few showed rock-*débris* on their surfaces, and, as piedmonts supply the vast majority of bergs, this freedom from rock-material is not surprising. A few bergs showed angular rock-fragments on their upper surfaces, and one or two had coloured dirt-bands interstratified with the snow-layers. Icebergs aground often capsize and bring up material from the local sea-floor; this may be further transported, for through the melting of the berg its draught diminishes. At the same time the rock-flour, which is a very wide-spread deposit in the Ross Sea, is likely to be contorted by the moving berg. On the whole, then, we may conclude that owing to the form of the coast of South Victoria Land, rock-surfaces abraded or scratched by floating ice must there be exceptional.

It would also seem probable that as the sea-ice diminishes during the summer, so are the floating piedmonts now diminishing. The numerous soundings taken by the 'Discovery' along the edge of the Ross Piedmont, at places which at the time of the voyage of Ross (1841) were beneath the ice, show that the sea-floor is covered with a stiff yellow clay (soundings 10-41), which contain tests of foraminifera, many diatom-frustules and a few sponge-spicules. A somewhat similar clay (soundings 176, 177, 178) was found 10° further north near Balleny Island, also from 368 fathoms, (sounding 13) off the Nordenskiöld Piedmont. In water shallower than 100 fathoms oceanic currents apparently remove the fine material and, as in other regions, deposit it beyond the littoral zone. The whole of the floor of the Ross Sea seems to consist of rock-flour milled by the great glaciers of South Victoria Land.

* Willard D. Johnson, *Journal of Geology*, 1904, vol. xii, p. 578.

APPENDIX TO THE REPORT ON THE FIELD-GEOLOGY.

NOTES RELATIVE TO MACQUARIE AND AUCKLAND ISLANDS,
OUTSIDE THE ANTARCTIC CIRCLE.

MACQUARIE ISLAND (Fig. 57).

MACQUARIE Island is situated in the South Indian Ocean in latitude $54^{\circ} 30' S.$, longitude $158^{\circ} 30' E.$, and it has been suggested that it is part of the "zone of

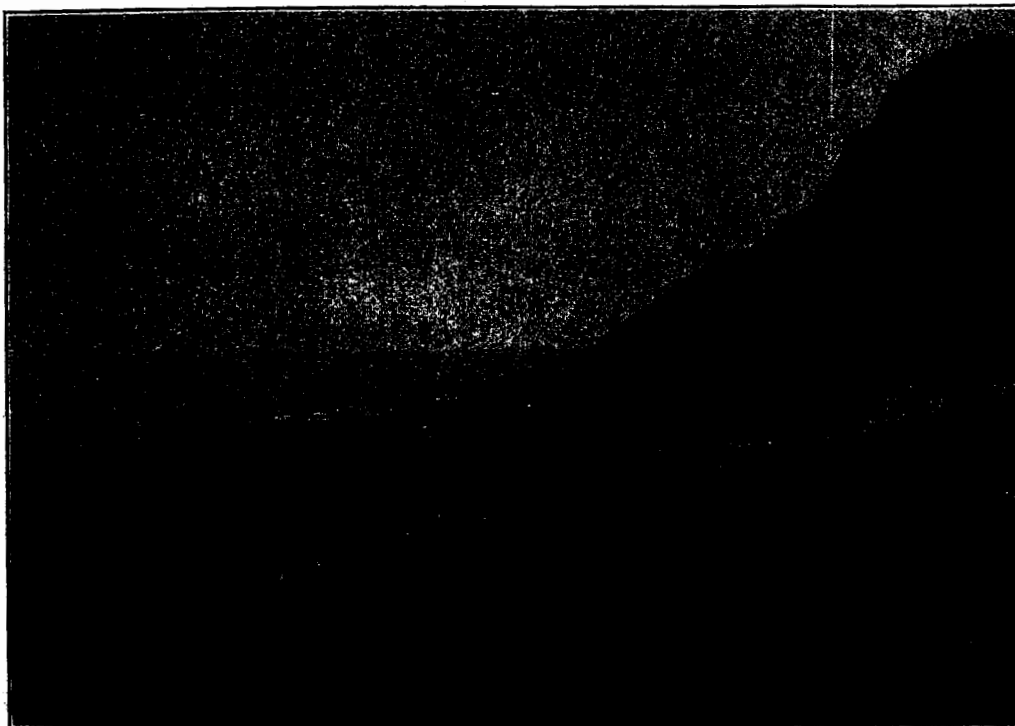


FIG. 57.—THE STRAND AND THE STEEP COAST-LINE OF THE EAST SIDE OF MACQUARIE ISLAND.

fire"* which connects New Zealand with Mount Erebus and Mount Terror. It is about 23 miles long and five miles broad. It has an average height of 500 feet, but one of its peaks rises to quite 2000 feet. The longer axis is in a north-east and south-west direction and the south-east side is a precipitous cliff almost 200 feet high. The foreshore is narrow and the cliffs are remarkably straight; they

* Judd, 'Volcanoes,' 8rd edit., 1865, p. 230; Scrope, 'Volcanos,' 2nd edit., 1862, p. 471; Bonney, 'Volcanoes,' 1899; map of distribution of Volcanoes at end of the volume.

extend for about 10 miles on either side of Lusitania Anchorage, where the 'Discovery' remained for about four hours.

The cliffs do not rise directly from the foreshore but from a slightly raised platform or strand about 100 yards wide, and, in many places, more or less covered with talus. In places the cliff is broken by steep gully-like water-courses coming down from the plateau behind. The exposures in these gullies show that the rocks all dip at about 10° to the north-west.

Small peat-bogs occur behind the harder rock-outcrops which hold back the streams; in the bogs round pebbles and sandy gravel occur. On the seaward side of the hard outcrops a terrace at the level of the peat-bogs behind, at least 20 feet above the level of the stream, extends some way towards the sea. The terrace, sometimes 100 yards or more in breadth, consists of stratified clays, sands and gravels. In plan it has the form of a delta which has been cut into by the present stream and it may possibly be a raised beach. The rock-specimens obtained are dolerites and basalts (see p. 109) which show little relationship to those from South Victoria Land.

All the specimens are volcanic, many of them are slickensided, and others, such as (9), have obviously been considerably crushed. The specimens (1) to (6) inclusive were collected successively on our way up the gully. The specimen (11) came from a height of about 1000 feet, from a bold crag overlooking the peat-bogs.

A few dykes are seen crossing the strand. One of these (13) is 20 feet across, and, with another (12), runs out to sea as a dangerous reef.

AUCKLAND ISLANDS (Fig. 58).

This group of islands was visited by Sir JAMES CLARKE ROSS, and the specimens collected have been described by Dr. PRIOR.*

The hills surrounding Ross Harbour rise over 1200 feet; they appear to be built up of series of basaltic sheets,† but owing to the extreme density of the vegetation few exposures could be found. These occur as "scars" or small cliffs, over which streams sometimes plunge as waterfalls, but the scars are seldom high enough to rise above the brushwood. The lowest rocks exposed along the shore are all basalts, and are much more porphyritic than those (879 and 880) from the summit of Mount Eden. All the basalts at sea-level are prominently columnar; the columns are about two feet in diameter and are sometimes, *e.g.* Deas Head, 300 feet high.

The eastern coast of the main island is a maze of fiords into which flow the streams coming down from the western peaks. All the higher peaks lie

* Prior, *Mineralogical Magazine*, 1899, vol. xii, p. 71.

† Hector, *Trans. New Zealand Inst.*, 1870 (1869), vol. ii, pp. 179-188.

close to the western shore, where the land rises sheer from the sea as an enormous cliff. This cliff would seem to be undergoing rapid denudation by reason of the prevailing westerly winds. The basalt-sheets dip slightly to the eastward, and at sea-level occasional dykes (877, 892, 893) may be seen.

Another point of interest is the delta at the head of Laurie Harbour, the inner land-locked part of Ross Harbour. This consists mainly of sand and shingle, but has occasional shell-layers which in some cases are several feet above the high-tide mark. The main stream of the Laurie Harbour valley now cuts into this and it would therefore appear, that here, as in Macquarie Island, we have some evidence of very recent elevation. Again, near Erebus Cove, a low spit of rock is covered by about 3 feet of clay (874) and boulders. All the boulders are rounded and



FIG. 58.—THE SOUTH SIDE OF ROSS HARBOUR, AUCKLAND ISLANDS, SHOWING SUBMERGED VALLEYS.

water-worn; they vary from two inches to a foot in diameter. The smaller boulders occur in layers as if stratified, and the whole is overlain by a bed of peat. Basalt-outpourings were found in Enderby Island, and in addition curious deposits of clay and sand also occur. The clay seems to cap the basalts of the interior and is easily distinguished by its covering of tussock-grass. The sand appears in Sandy Bay as a bare hill edged with trees.

SUMMARY.

ALTHOUGH the geological work of the 'Discovery' Expedition was confined to a limited area, the collections of rocks and photographs which have been obtained provide materials for forming some definite conclusions as to the geological history of the region. The other expeditions, which lately entered the South Polar Regions, worked in localities much more than 1000 miles distant from the 'Discovery' area and from each other, and information obtained in one area may not hold for all.

Chapter I deals with most of the islands which occur at intervals along the straight north-and-south coast of South Victoria Land, and also with various islands lying between New Zealand and Cape Adare and within the Antarctic Circle. They are bounded by inaccessible cliffs, and the surrounding sea is comparatively shallow. Apparently they all consist of recent volcanic rocks.

Chapter II deals with the islands in the vicinity of Mount Erebus and our Winter Quarters. This group I have spoken of as the Ross Archipelago, and of the greatest of the group as Ross Island. This island has been built up by the volcanoes Erebus and Terror, of which the former is still active; only steam, never any lava or solid matter, was seen to be emitted from the vent at its summit, 12,000 feet above the sea.

In Chapter III the relations of the conical volcanoes on the mainland are considered. The conical volcanoes lie at the foot of a great wall-like range of mountains, which in latitude 78° S. (the Royal Society Range) has a simple tabular structure. This range is at least 800 miles long, trends due north-and-south, and occasionally rises to peaks 13,000 feet high. On the east it ends abruptly in the open Ross Sea, and on the west, for a distance of 200 miles at least, it forms a great plateau some 7000 feet above sea-level.

In Chapters IV, V, VI and VII, the rocks which build up this great range are considered in the order in which they occur in the field.

The gneisses have been found at sea-level and at the base of a series of rocks quite 12,000 feet thick, and may safely be regarded as forming the ancient platform on which the central part of South Victoria Land is built.

The granites belong to two periods, one older and one younger than a certain sheet of dolerite. The older granite lies upon the gneissic rocks at the foot of the Cathedral Rocks, and dykes from the former ramify into the latter. A peculiarity of this mass of granite is that it has a nearly horizontal upper surface which can be traced for many miles along the sides of the Ferrar Glacier.

The Beacon Sandstone Formation is a deposit about 2000 feet thick and remarkably uniform in texture. It proved to be quite barren of organic remains

except near the top, where, at a height of nearly 7000 feet above sea-level, fossil plant-remains were found. Unfortunately, owing to decay of the plants and to changes produced by a neighbouring sheet of dolerite, their characters are almost indeterminate. This intrusive dolerite, though it gives no evidence of surface-flows, forms the highest peaks of the Royal Society Range. The plateau-features are still obvious, but the original plateaux seem to have been dissected prior to the earth-movements which dislocated the sandstone.

Chapters VIII, IX and X, describe the ice as met with in the Ross Sea area. The thickness, salinity and behaviour of the sea-ice, the shore-ice (ice-foot), and the glaciers are described. The inland-ice, local ice-caps and piedmont-glaciers are contrasted with those that have been observed in the Arctic regions. Temperatures in the ice at various fixed depths were determined; they show that at these depths the ice remains permanently some degrees below its melting point. Ice-slabs, or glaciers which have slipped away at their heads owing to decrease in the supply of water-substance, occur among the foothills of the Royal Society Range, and appear to be of a type not yet observed elsewhere.

There is one fact on which most of the observers, in both the Arctic and Antarctic regions, seem to agree, viz., the recession of the ice. TYNDALL* foretold that the ice would be tending towards a minimum when the condensation on both poles was about equal; whereas J. D. WHITNEY† maintains that only general glaciation can occur when there are bi-polar ice-caps, and that we are now entering upon a glacial epoch. The ice in the 'Discovery' area was found to be developed on a comparatively small scale, the steep-sided valleys providing almost ideal rock-exposures.

In Chapter XI the agents of denudation are discussed. The wind plays a comparatively important part in this dry area, while the effects of water-action are conspicuous by their absence. Chemical action is very pronounced in some localities, while frost-action, owing to the small amount of precipitation, is almost quite absent. The geological action of the ice is only briefly touched on.

In an Appendix are given some brief notes relative to Macquarie and Auckland Islands, at which brief stays were made during the voyage.

It is my pleasant duty to express my thanks to the many kind friends who have assisted me in my work. To Captain R. F. SCOTT, R.N., C.V.O., D.Sc., and the officers of the 'Discovery,' my thanks are due for the interest taken in my work

* Tyndall, 'Heat: a Mode of Motion,' 1896, 11th edit., p. 281, and 'The Forms of Water,' 1892, 11th edit., p. 154.

† Whitney, 'The Climatic Changes of later Geological Times,' Mem. Mus. Harvard Coll., 1882, vol. vii, p. 821.

and the ever ready help they accorded me; all assisted me in collecting, and the photographs taken by Engineer-Lieutenant R. W. SKELTON, R.N., are invaluable; the arrangements made for me by Captain SCOTT were all that I could have wished.

I am indebted to Dr. G. T. PRIOR for the names of the rocks and minerals mentioned in the text.

Lastly, I am very grateful to Mr. W. G. FEARNSIDES, M.A., F.G.S., Fellow of Sidney Sussex College, for kindly reading the whole of the manuscript and suggesting many improvements in the text.
