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THE SEDIMENTARY ROCKS OF SOUTH VICTORIA LAND.

No. 4a.—THE SANDSTONE, ETC., OF THE McMURDO SOUND, TERRA NOVA BAY, AND BEARDMORE GLACIER REGIONS.

BY

F. DEBENHAM, O.B.E., B.A. (Cantab.), B.Sc. (Sydney), F.G.S.

Fellow of Gonville and Caius College, Cambridge. Geologist on the Expedition.

No. 4b.—THE SLATE-GREYWACKE FORMATION OF ROBERTSON BAY.

BY

R. H. RASTALL, Sc.D., M.Inst.M.M., F.G.S.

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WITH EIGHT FIGURES IN THE TEXT AND ONE PLATE.

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INTRODUCTION.

THE reports * of former expeditions to South Victoria Land have described very clearly the general features of the coast which runs from Cape Adare in Lat. 71° S. to the Beardmore Glacier in Lat. 85° S. and is formed by the faulted escarpment of the Antarctic plateau. To the east lies the sunken area of the Ross Sea with a fairly uniform depth of about 2,000 feet (610 metres), and to the west is the plateau with an average height of about 6,000 feet (1,830 metres) above sea-level. Between the two there is a narrow strip of foothill country along most of the coast, varying from 2 to 20 miles in width; and it is from this strip that most of the information about the structure of the country is derived, for there only are the few outcrops of bare rock to be found.

The faulted edge of the escarpment is for the most part tilted upwards and the plateau behind is generally a little lower than the edge. A series of cross-faults have given rise to "horsts" in places, the blocks of which have been denuded into the form of peaks reaching a maximum height of about 15,000 feet (4,570 metres).

With the exception of the Cape Adare region (see p. 121) where the slates are strongly folded, the structure of the coast is horizontal and gives rise to a large number of tabular mountains which are the most remarkable feature of the topography when viewed at a distance. This horizontal structure is due to the level-bedded character of the main sedimentary formation of sandstone which has been stiffened by massive intrusions of a later dolerite in the form of very extensive sills. Since the base of this formation has been proved to be of Devonian age at least, we have to regard the whole area as one of great stability and freedom from lateral earth-movements. It is much fractured and there are local tilts of the strata, especially in the Beardmore Glacier

* National Antarctic Expedition, 1901–4. Natural History. Vol. 1 (1907).
British Antarctic Expedition, 1907–9. Geology. Vol. 1 (1914), Vol. 2 (1916).

region, but the only folded rocks from Lat. 75° S. southwards are the foundation metamorphic series which are referred to the Pre-Cambrian age. The sandstone formation with dolerite sills has an enormous extension, for it is found in Adelie Land in Lat. 68° S. and Long. 150° E., and judging from Captain Amundsen's photographs probably also in Lat. 86° S. and Long. 170° W.

On account of the inaccessibility of many of the outcrops and the peculiarly barren character of the sandstones that constitute the chief horizon, palaeontological evidence as to the character and age of the sedimentary formations has been difficult to secure. The first discovery of value was made by the party under Sir Ernest Shackleton, who found fragments of a Cambrian limestone in the moraines of the Beardmore Glacier (see p. 118). The outcrop has not been found and from the specimens it appears possible that they come from the main horizontal sandstone formation of late Palaeozoic age, having been derived from Cambrian strata.

The only other fossil evidence as to the age of the formations are the fish-remains of Upper Devonian age found in the Granite Harbour region, Lat. 77° S., in morainic débris from the base of the main tabular series (see p. 109); and the plant-remains from the upper portions of the formation which were found by Captain Scott's Pole Party on the Beardmore Glacier and by R. E. Priestley in the Terra Nova Bay region, and have been referred to Gondwana age (see p. 111).

Volcanic action of Tertiary age is evident along most of the coast, with its two main centres in McMurdo Sound, and in the Cape Adare region from Lat. 71° S. to 74° S. This action has left sedimentary deposits of tuff in places, but these have so far yielded no fossil evidence, and it seems that most of those examined were deposited on land.

THE McMURDO SOUND REGION.

This region, extending from the Koettlitz Glacier in Lat. 78° 30′ S. to Granite Harbour in Lat. 77° S., is the best-known locality on the Antarctic continent, and is naturally taken as the type with which others may be compared. The geology of the mainland was first investigated by H. T. Ferrar of the National Antarctic Expedition of 1901–4, and the various journeys of that and other expeditions up the Ferrar Glacier have made that district familiar. On proceeding up the deep trough-like valley of the glacier one meets first the foundation rocks of Pre-Cambrian age, much folded and metamorphosed, then some twenty miles inland the dolerite sills, and finally above one of them, at a height of about 5,000 feet above the sea, is seen a yellow level-bedded rock, the sandstone, forming some of the summits of the massive Kukri Hills. Farther west this rock is seen in greater thickness, the lowest beds that are visible being about 3,000 feet above sea-level.

Some thirty miles farther north, a similar though broader valley, containing the Mackay Glacier, comes down from the plateau, and the sequence of the rocks as one passes up the valley is precisely the same. The sandstone formation is here a little lower, the lowest beds seen being about 2,000 feet above sea-level. The contrast of the yellow sandstone associated everywhere with the dark dolerite suggested to Ferrar the name Beacon Sandstone which is now used for the same formation wherever it occurs in South Victoria Land.

In the region under consideration the sandstone has very uniform characteristics. In the lower beds it is less pure as they contain bands of limestone a few inches in thickness and many thin beds of shale. Near the base the shaly bands grade into soft coal, and in one area, Granite Harbour, there is a shale of an earlier (Upper Devonian) age which is apparently conformable with the sandstone itself.

The total thickness of the sandstone formation cannot be stated definitely since

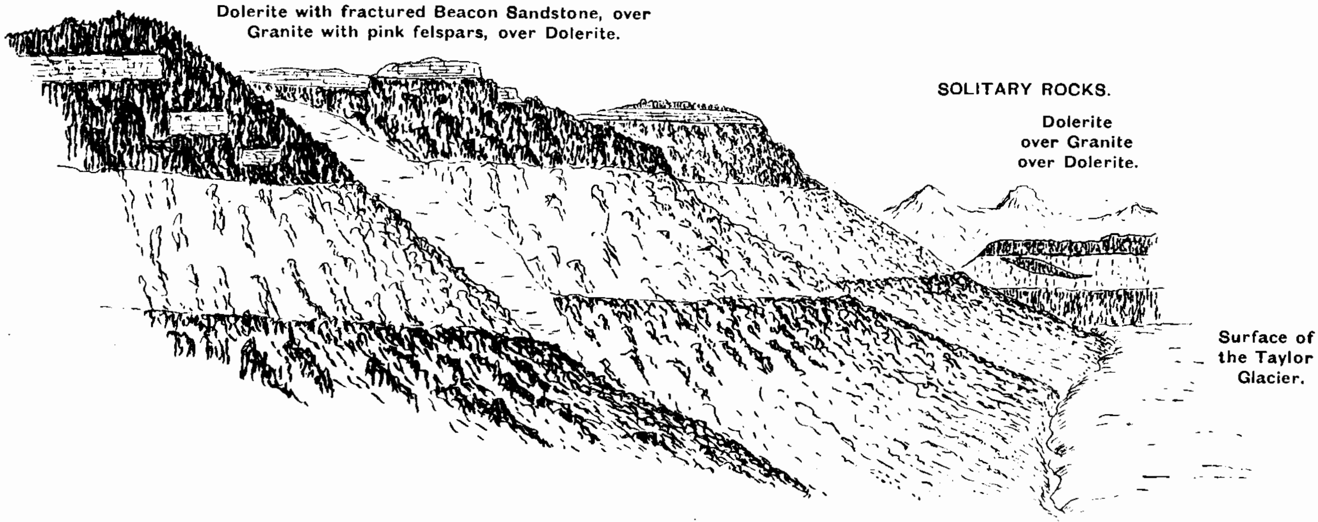

FIG. 1.—Sketch of the north side of the Kukri Hills, Ferrar Glacier, looking west from a point above the snout of the Taylor Glacier. Hills about 3,000 feet above glacier surface, showing the level granite platform on which the sandstone was laid down.

the upper limit has never been observed. The base can be seen in one or two places but has not been examined closely. It is important to note that where the base can be seen it is resting upon a comparatively level bed of granite (see Fig. 1). In the Kukri Hills in particular the dolerite has intruded between the granite and the sandstone over a large area, raising the latter many hundreds of feet without much fracturing or tilting. The junction between the dolerite and the granite is extraordinarily even and horizontal, and since this was the former bed of the sandstone it seems to be established that the base of the formation was laid down on an even bed which had been degraded to base level.

At the Inland Forts, Ferrar * measured a thickness of the sandstone of 2,000 feet without seeing either the top or the bottom, and there is no doubt that the maximum thickness in the McMurdo Sound region far exceeds this figure.

* Nat. Ant. Exp., 1901–4. Natural History. Vol. 1 (1907), p. 40.

In the bold escarpment of the Royal Society Range (see Fig. 2) the horizontal bands of the dolerite with the sandstone can be seen to a thickness of at least 5,000 feet. In the steep sides of Mt. Gran in the Granite Harbour area the level bedding is visible for a thickness of about 4,000 feet. In neither of these cases can we definitely see the upper limit of the sandstone as the caps of the mountains are either of weathered sandstone or dolerite. On the whole it may be said that the Beacon Sandstone is at least 3,000 feet thick in the McMurdo Sound region. It was noticed by Ferrar that the upper layers appeared to be more dense and consisted of more uniform layers of fine sand than the lower, but these terms can only be used in a relative sense since we do not know what the uppermost layers consist of. They are visible high up in the cliffs of the Royal Society Range but have never been visited.

In the absence of definite fossil evidence, variations in lithological character

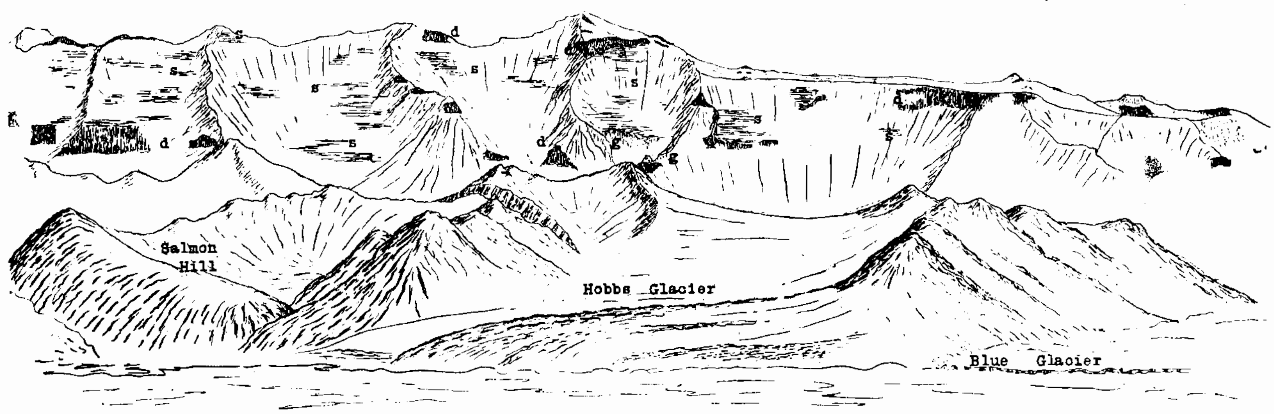

FIG. 2.—Panoramic sketch of the Royal Society Range showing the Beacon Sandstone resting on granites and intruded by dolerite sills. Sandstone marked s, dolerite d, granite g.

become of some importance in determining the mode of deposition of the sediments. Thus in some horizons of the sandstone there are a large number of short bands of pebbles and grits few of which seem to be continuous for more than a few yards horizontally and none of a thickness greater than one foot. The pebbles are in most cases much waterworn but occasionally are quite angular. In the Granite Harbour area, as Ferrar found at the Inland Forts, these pebbles are almost all of vein-quartz or hard quartzite, but in the moraine in the centre of Mackay Glacier a large number of coarse-grained specimens of the sandstones were found which contained pebbles of limestone. One of these in particular is angular but most of the others have been partially dissolved leaving a cavity lined with crystals of quartz and calcite. Unfortunately no sign of any fossil was found in this limestone, so it cannot be definitely referred to the same (Cambrian) age as the limestone pebbles of the Beardmore Glacier. Thin bands and patches of shale in the lower layers of the sandstone also furnish some evidence as to the conditions of deposit. They are mostly lenticular in shape and thin, suggesting that the mud was deposited in pools in the sand. More direct evidence of such pools and a comparatively dry climate with some rainfall is afforded by the ripple-marks and sun-cracks (Fig. 3) which were observed on the central moraine of the Mackay Glacier. It is not clear from the ripple-marks whether they were caused by wind or water, but it is immaterial as either would mean a sandy waste with occasional pools of shallow water.

The sandstone varies very much as to hardness and durability. Some layers are so dense as to outlast the dolerite while others are so friable that they crumble to the original sand at a touch. The cement for the most part is siliceous but on some horizons it is entirely calcareous. Prior * notes that the more compact

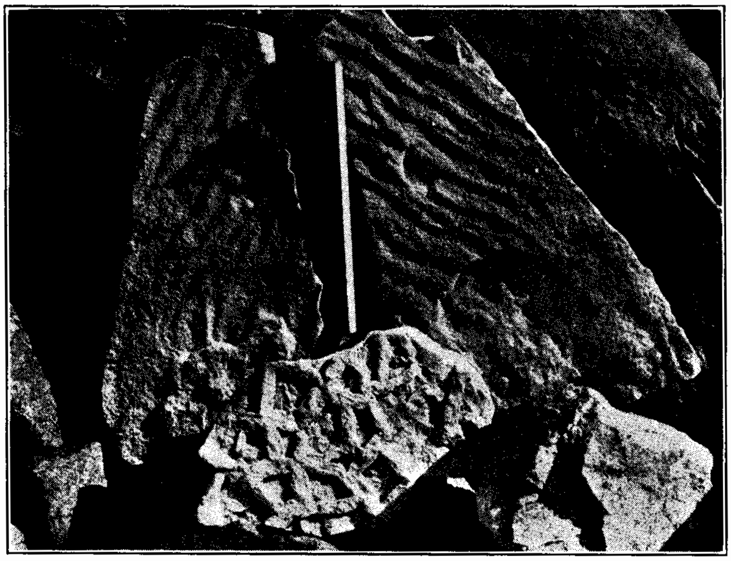

FIG. 3.—Ripple-marks and sun-cracks in the Beacon Sandstone. From Mount Suess, Granite Harbour.

layers have a large amount of siliceous cement which has recrystallized round the original grains in optical continuity with them. This points to heated solutions percolating through the sandstone, evidence of which is also afforded by the occasional occurrence in the rock of cavities filled with crystals of quartz wholly or partially replacing calcite.

Evidence of considerable thermal action is manifest in other ways. Ferrar found much carbonized plant-material in the outcrops he visited, and in the last expedition large masses of charred stems were found both in the Granite Harbour region and in that of Terra Nova Bay. The stems are drift-material, as pointed out by Professor Seward, and occur both in the pure and in the shaly sandstone. A still more definite example of intense heating is afforded in the same regions by the large blocks of perfectly black sandstone, in which the colour is due to a dense bituminous cement. None of this rock

* Nat. Ant. Exp., 1901–4. Natural History. Vol. 1 (1907), p. 134.

was found *in situ* but one naturally supposes it to be adjacent to the coal beds: much of it contains large nodules of pyrites. There appears to be no doubt that this charring and baking was due to the intrusion of the dolerite, probably in Cretaceous time.

Ferrar and David both refer to the occurrence of ferruginous concretions in the Ferrar Glacier area and the same thing occurs in other places to a less degree. In the McMurdo Sound region generally the Beacon Sandstone is fairly pure and usually of a white or light-yellow colour, but in the Granite Harbour area a great deal of it is coloured green, either throughout or in patches, owing to the presence of chlorite.

With regard to the constituent grains there is also a good deal of variety. The pure white stone is composed almost entirely of clean quartz grains, in some cases so much rounded as to suggest wind- rather than water-action. In other cases the grains are distinctly angular, though one must be careful to distinguish fractures of the original grains by pressure and heat from initial irregularity due to lack of erosion. Secondary fractures are particularly clearly seen in some of the very much indurated samples from the neighbourhood of the dolerite.

In the more discoloured specimens the grains are seen to be of a more varied character. Quartz is still the dominant mineral, but fragments of very fresh-looking felspar, mica, and other aluminous minerals are present, together with grains of garnet, apatite, and rutile. In the coarser layers fragments of mica-schist are found. It would seem, therefore, that the material of the Beacon Sandstone in the McMurdo Sound region was largely derived from granites, to a less degree from the metamorphic series, and to a still less degree from a limestone possibly belonging to the same formation as the Cambrian limestone of the Beardmore area.

The small amount of cementing material, the freshness of the felspars, and the general absence of red oxides of iron are all noticeable features and seem to point to very dry conditions. The false-bedding may be due either to wind or water, and the abundant evidence of pools and stranded plant-material establishes the existence of water in small quantity.

The coal beds in the Granite Harbour area (Fig. 4) were unfortunately not visited *in situ*, as they were seen only in inaccessible places. They undoubtedly occur towards the base of the whole formation in company with moderately thick beds of shale, and we therefore have evidence of a gradual change of climate during the deposition of this great thickness of material.

The fragments of coal which were picked up on the central moraine of the Mackay Glacier were all similar in character. It is a hard bright coal and is associated with a dark soft shale. The coal consists almost entirely of fixed carbon with a high percentage of ash. In it are found charred fragments of stems which are unrecognizable. The specimens bear all the marks of having been subjected to high temperature, and the absence of any noticeable amount of volatile hydrocarbons supports this suggestion. The finding of sandstone impregnated with bitumen seems to complete the story. One or two of the smaller fragments appear to be of better quality, but one is forced to recognize that probably the dolerite has destroyed most of the coal beds in this area and reduced them to what is the equivalent of anthracite with an excessive amount of mineral ash. The larger specimens have almost a slaty cleavage, which was no doubt due in part to the loss of its volatile constituents while

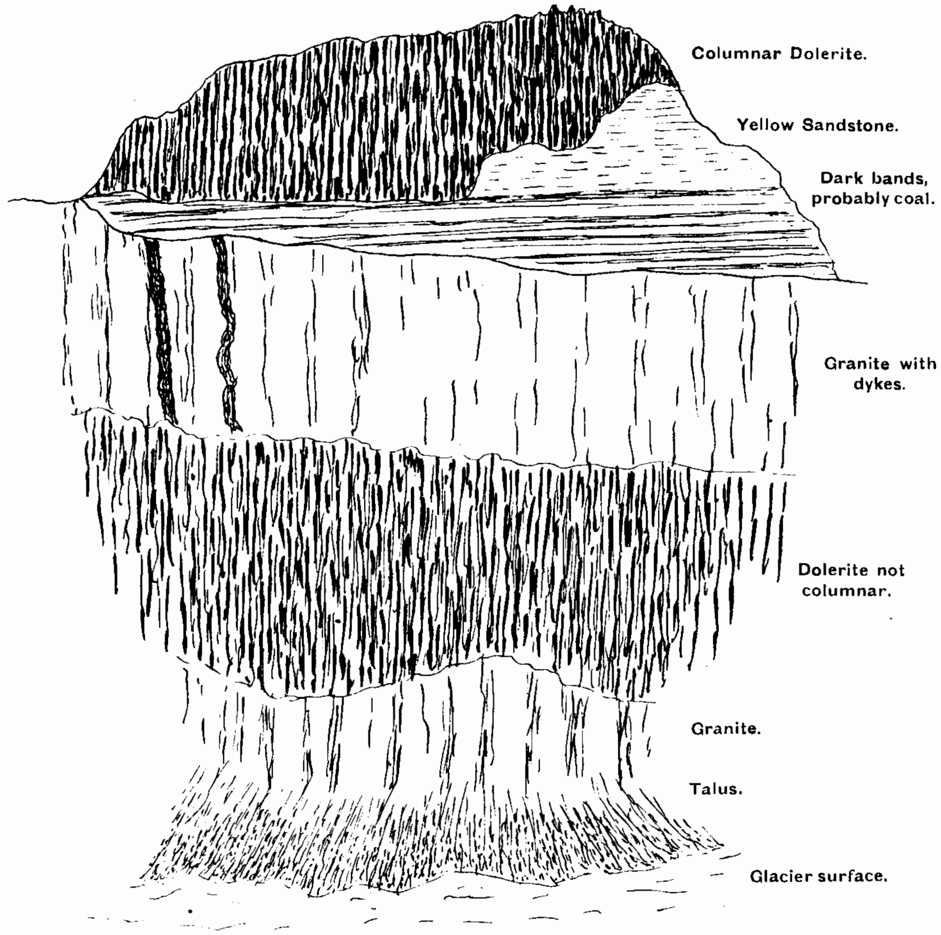

FIG. 4.—Cliff-section on the south side of the Mackay Glacier, Granite Harbour region. Total height of cliff above glacier about 1,200 feet.

under pressure. The Beardmore Glacier coal, on the other hand, has not undergone such a baking, for in this the volatile constituents reach 14·5 per cent., fixed carbon 68 per cent., and ash 13·5 per cent.*

On the same moraine of the Mackay Glacier were found the remains of fish which have been described by Dr. Smith Woodward in No. 2 of this volume, and have been referred by him to Upper Devonian age. These occur in pieces of shale and shaly

* British Antarctic Expedition, 1907–9. Geology. Vol. 1 (1914), p. 250.

sandstone which are identical in outward appearance with the bands of shale that are found in the lower layers of the Beacon Sandstone, both in Granite Harbour and in the Depôt Nunatak on the Ferrar Glacier. In one case the fish-scales are in a finely laminated shale, but generally they are in irregular pieces of rock which has no definite cleavage and contains a good deal of rather coarse sand. As none of the fish-remains were found *in situ*, the problem is to make room for the Upper Devonian horizon between the granite floor of the formation and the coal beds which, in view of the definite proof of Gondwana age for the Beardmore coal, one provisionally places on the same horizon. For the present it may be assumed that the base of the formation contains a thin series of Devonian sediments, and that there is no marked unconformity between them and the Permo-Carboniferous series of shales and sandstones. One is tempted to add that the conditions of deposit were also somewhat similar, for the sands of the fish-scale specimens are precisely similar to those of the upper layers. It is hardly likely that the fish-scales can have been derived from a Devonian deposit elsewhere, and have been included unharmed amongst the products of erosion that built up the Beacon Sandstone.

THE TERRA NOVA BAY REGION.

This is a convenient name for the area between 74° 30′ S. and 75° 30′ S., in which the most commanding feature is the tabular mass of Mount Nansen, marking the edge of the continental escarpment. Other features are the symmetrical cone of the extinct volcano of Mount Melbourne to the north-east, and the peculiar sheet of ice known as the Drygalski Glacier Tongue which bounds the area on the south side and represents the confluence of several large glaciers coming from the vicinity of Mount Nansen.

The evidence for a discussion of the sedimentaries of this region is somewhat slender. The area has been visited by two parties, one under Professor Sir T. W. Edgeworth David in 1908, and one under Lieut. Victor Campbell, R.N. in the summer of 1912. In neither case were the geologists able to reach sedimentary rocks *in situ*, but they made collections from the large glacial moraines.

The sequence of the rocks seems to be identical with that found in the McMurdo Sound region. On the coast are the low islands and foothills composed for the most part of the foundation metamorphic series of gneisses, schists, and granulites. Intruded through these and forming the bulk of the higher foothills are the granites which will be discussed in No. 6 of this volume. High up on the Mount Nansen *massif* and on the mountains to the north of it can be seen the familiar level-bedded appearance due to the Beacon Sandstone formation, intruded by dolerite sills as in the McMurdo Sound region but to a less extent. It is not possible to estimate the thickness of the formation with any accuracy, but from the evidence of photographs and from the field-notes of the geologists it can hardly be less than 2,000 feet, that is to say, it is of the same order of thickness as farther south.

Little more than this bare estimate of thickness can be said of the formation *in situ*, as it has never been approached nearer than ten miles, and for further description we have recourse to the specimens collected from moraines. A large number of these were obtained by Priestley who was the geologist of Campbell's party, and it is worthy of note that nearly all of them were collected from the southern and western side of the moraines of the Priestley Glacier. This suggests that on the northern side there are no outcrops of the sandstone and that there is a fracture along the line of the glacier valley which has hidden the formation.

With regard to the specimens, Priestley noted the striking resemblance they presented to the sandstones of the Ferrar Glacier valley. There are the same coarse conglomerates, coarse yellow sandstones, and felspathic grits; and the same variation from almost pure quartz sandstones, extremely hard and dense, to friable uncemented rocks with much decomposed material. On the other hand, the proportion of impure sandstones is much greater, ranging from yellow sandstones with scattered grains of carbonaceous material, to dark-brown grits with much volcanic débris as well as the almost universal fragments of stems. Unfortunately these plant-remains, although abundant, were in most cases much charred by heat. A few petrified specimens were obtained, however, and these have been described in No. 1 of this volume by Professor A. C. Seward who, from the petrified stem (*Antarcticoxylon Priestleyi*) and from a winged spore (*Pityosporites antarcticus*), has referred them to an early Mesozoic age.

We have seen that the shales associated with the Beacon Sandstone formation in the McMurdo Sound region are of Upper Devonian age and they are undoubtedly at the base, so that we arrive at a provisional estimate of the age of the formation as late Palaeozoic, stretching into early Mesozoic. Unfortunately the quality of the evidence so far does not warrant our placing the age with any greater certainty than this, but we may without much doubt conclude that the Devonian horizon is of small thickness and that the coal-measures, or Permo-Carboniferous series, is of the greatest thickness. It appears that the Terra Nova Bay region is remarkable for a greater extension of the later sediments than is found farther to the south.

It should be noted also that in one of the specimens collected from the coal-bearing horizon of the Beardmore Glacier region was found a fragment of coniferous wood which appears to be comparable with those found on the Priestley Glacier moraine.* Although no specimens of coal were picked up from this moraine, coal is probably present in the sandstone series of the region, for not only is it much too fragile to bear transport for great distances but its similarity of colour to the basaltic rocks which are frequent in the moraines makes its discovery a matter of difficulty.

The strong probability of the presence of coal is also suggested by the occurrence of bituminous sandstones of exactly the same type as in the Granite Harbour district. These are somewhat felspathic sandstones containing many charred fragments of stems,

* "The Heart of the Antarctic." E. H. Shackleton. 1909, vol. 2, p. 300.

and the whole rock is so impregnated with bitumen that it is quite black, the grains of quartz and felspar standing out clearly in a shining matrix of the bitumen. One or two of the specimens gave off a distinct bituminous smell on being brought to red heat, but in most cases the black product appears to be carbon, as it has lost all trace of volatile constituents.

The occurrence of the charred fragments with the bituminous impregnation gives rise to a peculiar problem. The woody stems are evidently the result of drift, since they are distributed irregularly through the rock, and we may imagine estuarine sands which occasionally received floods as the original state of this area. But the stems could hardly remain in a fresh state for a very long period and the charring must have taken place within a reasonable time of their deposition. The heating of the coal beds which drove off the volatile constituents into the surrounding sandstone must have occurred at a much later time presumably. In fact in the Granite Harbour district it seems to be correlated with the intrusion of the sills of dolerite which must have happened late in Mesozoic time. It seems, therefore, that we have to postulate two periods of heating of the beds.

In the Terra Nova Bay series of sediments we meet with a type of rock which is not found in the more southern areas, viz., very coarse tuffs. These form an extremely interesting series and their age seems to be definitely fixed as that of the Beacon Sandstone from the fact that they also are loaded with charred fragments of stems, and in places with angular fragments of quartz similar to the coarser varieties of the sandstone. They therefore point to a period of volcanic activity coincident with the deposition of the sands. They contain also fragments of a green chert. Further reference to these tuffs will be found in the chapter on volcanic rocks.

We are now perhaps in a position to venture some suggestions as to the conditions under which the greater part of the typical Beacon Sandstone was laid down. In the first place the climate seems to have been arid. The freshness of the felspars and other less stable constituents of the sandstone points to this, and it is supported by the comparative barrenness of the rocks, except those close to the coal bed horizon. The extremely rounded appearance of the sand-grains on some horizons appears to postulate considerable wind-erosion, while the presence of coarse and ill-sorted grits at other levels also seems to argue the absence of running water. The existence of ripple-marks and sun-cracks (see Fig. 3), as well as the frequent lenticular beds of fine mud, requires the occurrence of occasional pools in the sandy waste. The false-bedding which is very characteristic of the more barren sections of the sandstone seems to be evidence of a dune formation. On the other hand, the thin beds of limestone found particularly in the Ferrar Glacier district point to the near neighbourhood of a coast-line or large bodies of water. These seem to occur more frequently towards the base of the formation.

Speaking more particularly of the McMurdo Sound area we may perhaps imagine the conditions as follows. At the close of the Devonian period the area was rising from the sea which had held the fish the remains of which are found in Granite Harbour rocks. There was a wide expanse of low coastal country and the climate was not at first quite arid. Occasional changes of level allowed thin bands of limestone to form in amongst the expanse of sand-dunes that formed the greater part of the area. Conditions of climate then altered sufficiently to allow of the growth of swamp and bog plants and the formation of beds destined to turn into coal, but these conditions gradually gave place to those of great aridity involving the return of the wave of sand. The sand was derived, partly by water and partly by wind, from the uplands, apparently to the west of the area, which were composed of the metamorphic series and numerous acid plutonic rocks. Rivers from the more favoured uplands crossed the sand area with continually shifting beds, bringing coarser gravel and pebbles as well as broken stems of vegetation in their flood periods. But on the whole the conditions must at this time have been unfavourable to a vigorous growth of vegetation even in the uplands. Towards the north, volcanic activity produced a local variation in the deposits, but for the most part the conditions were very uniform over a large extent of country.

We cannot tell how the period ended for the upper limits of the deposits have not been seen, but it is certain that the area must have remained above sea-level for most of the time since the close of that period as there is no sign anywhere of later deposits, and the Beacon Sandstone itself has been heavily eroded.

The conditions towards the Beardmore Glacier appear to have been slightly different, but there is far too little evidence upon which to build any hypothesis as to the climatic relations between the two regions.

It should be added that although there seems to be a definite break in the continuity of the Beacon Sandstone formation between the Terra Nova Bay region and the Cape Adare district, yet it does apparently continue in a northerly direction, for it occurs in massive cliffs in Adelie Land as found by one of the parties of the Australasian expedition under Sir Douglas Mawson in 1912.

THE BEARDMORE GLACIER REGION.

This region may be taken as extending from about 83° 30′ S. to 85° S. on the 170th meridian E., following the line of the great glacier discovered and traversed by Sir Ernest Shackleton in 1908 and used by the parties under Captain Scott on their way to the Pole in 1911 (see Map, Fig. 5).

This vast outlet for the plateau ice-sheet is at least 130 miles long and for about 100 miles of its length is enclosed by valley-walls rising well above the stream itself and presenting steep slopes, many of which show bare rock. Its average width is about 20 miles, though in one place it is under 12 miles. The greater part of its surface is much disturbed by crevassed areas, particularly on the eastern side where

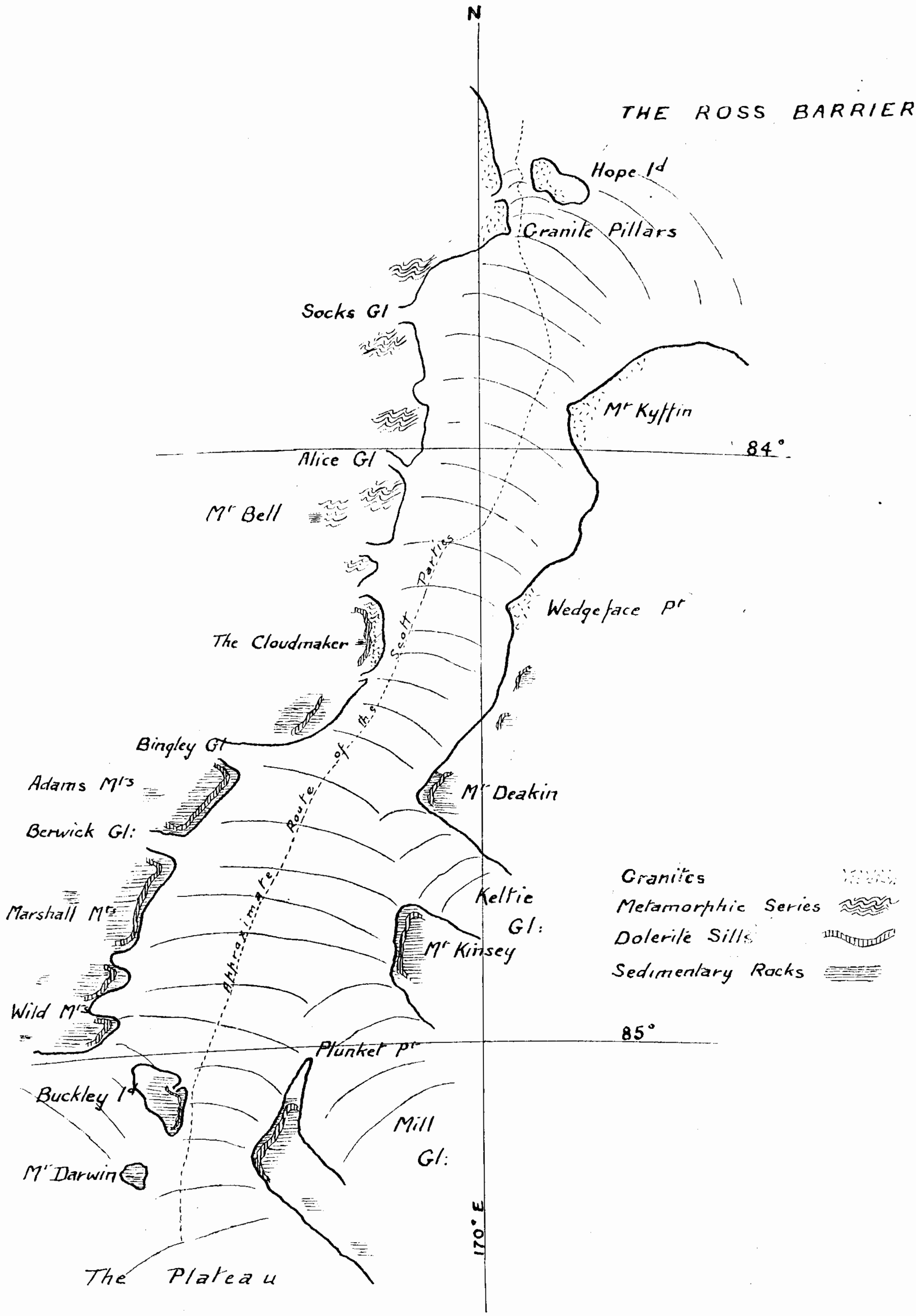

Fig. 5.—Sketch-map of the Beardmore Glacier. (Scale approximately 10 miles to the inch.)

two very large tributaries enter, so that the route to the summit is a circuitous and arduous one.

The glacier is thus briefly described in order to account for the extreme paucity of the geological evidence that we possess about this region. Although four parties have now traversed it from end to end, the rocky sides of the valley have as yet only been visited in three places. These are, the Granite Pillars and Mount Hope at the foot of the glacier, the Cloudmaker mountain half way up, and Buckley Island, a large nunatak rising above the ice, at the summit. The collections from these places, together with specimens picked up from the moraines on the glacier itself, supply all the direct geological evidence that we possess. No trained geologist has been a member of the parties, but with the aid of the photographs of Mr. C. S. Wright and others of those parties and of the extraordinarily accurate pencil sketches of the late Dr. E. A. Wilson it is possible to make some general remarks about points that have not been visited. Some of these generalizations are made on analogy with better known parts of the continental escarpment and may be accepted without much doubt. For instance the mountains at the lower end of the valley are in general irregular in shape and distribution with a tendency to a rounded outline, but with many sharp comb-ridges. This is a topography which is typical of the plutonic and metamorphic rocks as seen in the foothills of the Royal Society Range in the McMurdo Sound region. Above the Cloudmaker, on the other hand, the mountains are tabular in form and the valleys are straighter, while the steep slopes are either uniform or evenly-terraced. This is a topography that is common all along the escarpment, caused by the almost universal capping of level-bedded strata of the Beacon Sandstone.

But when the only evidence is the colour of the rocks as seen at a distance the identification is less certain, except where taken in conjunction with Wilson's sketches, often made with aid of binoculars, in which the typical forms of weathering are a fairly sure guide.

The first point that strikes a geologist who knows the other regions is the great similarity in both the facies and the distribution of the rocks in this area to those in the McMurdo Sound region. In the lower glacier we meet with the same types of foundation metamorphic rocks intruded by younger granites as those which form the Kukri Hills in Lat. 77° 30′ S. At the Cloudmaker, half way up the glacier, we come to the first signs of the sedimentaries, just as at the Cathedral Rocks on the Ferrar Glacier Very clear stratification can be seen at the summit of Mount Bell at a height of about 9,000 feet above sea-level, while in the Cloudmaker itself appear the dolerite sills which are such constant associates of the sedimentaries farther north. The lower sill appears to be about 6,000 feet above sea-level, and there is an upper less well-defined sill near the summit with indications of thin beds of sedimentaries above it, that is, at about the same height as those on Mount Bell, a few miles to the north. From the talus slopes at the base of the mountain, "slaty rocks with reef quartz" were collected by Shackleton. Southward and westward of this point the sedimentaries appear in a truly grand series of massive beds intruded by several sills of the dolerite. They have a very uniform dip to the south-west, that is, towards the plateau, precisely in the same way as the Beacon Sandstone series does in the upper Ferrar Glacier.

The Adams, Marshall, and Wild Mountains present steep faces towards the main glacier, showing a magnificent section of the whole of the sediments, but unfortunately the route trended away from these mountains and only distant views were obtained.

The thickness of the series cannot be less than 4,000 feet and may well be 6,000 feet. It consists of alternating light and dark bands intersected by the very dark dolerite. As seen in the photograph (Fig. 6) it is precisely similar to the formation on the upper Ferrar Glacier, and the sketch by Dr. Wilson (Fig. 7) incidentally shows what a very great deal a keen observer like Dr. Wilson could do in the absence of more accredited

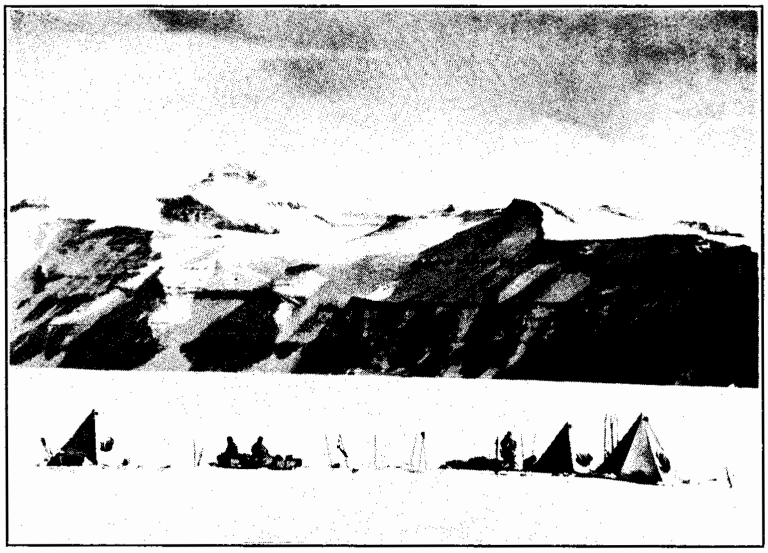

FIG. 6.—Wild Mountains, Beardmore Glacier, showing the Beacon Sandstone formation with its intruded sills of dolerite.

geologists. The "unconformity" is an instance, so common in the McMurdo Sound region, of the differential lifting of the sedimentary beds by the intrusions of dolerite.

On the eastern side of the glacier the same section is apparent, but is more broken up by the intersection of sills, and not so continuous because of the large tributaries which enter on that side. On both sides the dip is less than 5 degrees to the south-west except at one place near the summit at Plunket Point, which is carefully noted and sketched by Wilson, where over a small area the dip of the sediments is about 10 degrees to the east. That this is a local faulting or displacement is proved by the fact that in the same sketch appears the regular slight south-westerly dip of the main mass.

At Buckley Island, where the surface of the glacier is nearly 6,000 feet above sea-level, one is well above the base of the sediments, which appears to be about 9,000 feet high at Mount Bell, and it is from this locality that most of the direct information comes.

A very full description of this outcrop is to be found in No. 1 of this volume by Professor Seward, which treats fully of the *Glossopteris* flora found there in association with the coal beds.

The sandstones which are in abundance in these beds are for the most part very similar in lithological character to the Beacon Sandstone from the McMurdo Sound region. They are distinctly more calcareous and have a far larger proportion of shaly beds intercalated, but their mode of derivation seems to be in the main similar. Some specimens containing comparatively little-altered grains of felspar suggest derivation from granitic masses, others again are composed almost entirely of quartz,

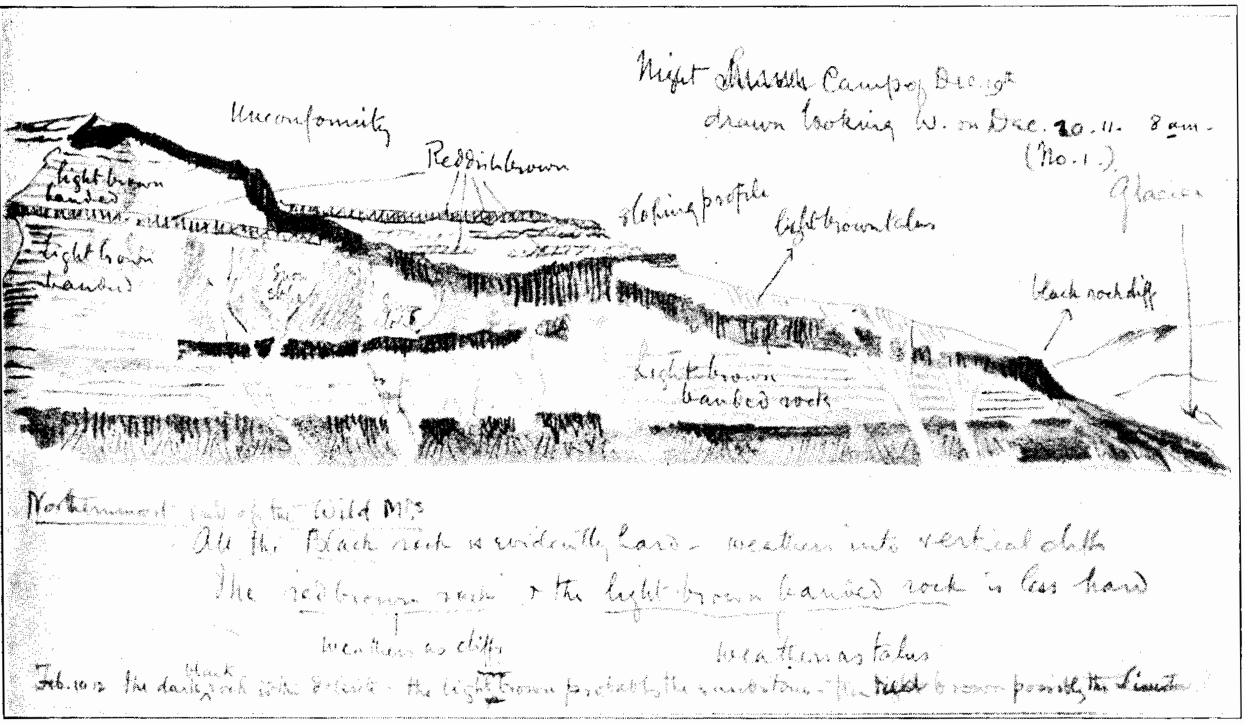

FIG. 7.—Sketch of Wild Mountains by Dr. E. A. Wilson.

although the very even-grained pure and hard quartz sandstone of the Ferrar Glacier region does not appear to be present on this horizon.

Lithologically then we must agree with the verdict of Professor David that we have the equivalent of the Beacon Sandstone here. The impure grey limestone which forms a good proportion of the specimens from Buckley Island is somewhat similar to that found in the Granite Harbour region, being, as there, often associated with hard shales on the one hand and calcareous grits on the other. No specimens of pure limestone are recorded from this place. The moraine from Mount Darwin, a nunatak still further to the south, shows the same sequence of rocks with a preponderance of calcareous sandstone which in the distance has a pink appearance.

There is no unconformity to be seen in any of the photographs nor is it anywhere noted, with the exception of the faulted block on Plunket Point, and this corroborates the idea of the extraordinary stability of the whole of South Victoria Land suggested by the observations made in the more northern regions. Yet it would be very dangerous to conclude that this four or five thousand feet of sediments represents a single geological period, the Permo-Carboniferous, as determined by the *Glossopteris* flora on one of the horizons. If we are right in assuming from the evidence of the fish-remains in Granite Harbour and the fragments of stems in the Terra Nova Bay region that the Beacon Sandstone formation of those places stretches from late Devonian to early Mesozoic time we must be prepared to accept the same for the Beardmore area as well. There is nothing reported from this region that can be definitely asserted to be younger than the Beacon Sandstone except the dolerites; but fragments of lavas found in the moraines seem to show that only search is required to show the presence of the equivalent of the McMurdo Sound volcanics in this district also.

On the other hand, there is the very best evidence for the existence of earlier sediments somewhere in the region. In 1908 a fragment of a brecciated limestone was picked up in the moraine near the Granite Pillars at the lower end of the glacier and many much larger fragments were reported there. This proved to contain embryonic forms of the Cambrian fossil coral *Archaeocyathus*.*

This discovery had a curious confirmation in the dredgings of the *Scotia* in the Weddell Sea on the other side of the continent for in them were found specimens of a white limestone containing *Archaeocyathus*.†

The last expedition has also confirmed the discovery in the Beardmore region but again only from specimens gathered from the moraines.

The interesting point about these discoveries is that so far the fossils have always been found in a coarse breccia of limestone fragments, very dolomitic in character and held together by a lighter calcareous cement which includes also fragments of sandstone, angular fragments of quartz, and shale. As far as can be ascertained none of the fragments have been picked up above the Cloudmaker, and certainly they all seem to belong to the western lateral moraine. That would lead us to suspect an origin from the very base of the sediments as seen in Mount Bell, since the base only comes above the glacier surface about there. That there is a definite Cambrian horizon there, however, is very uncertain, and, in view of the fact that only a breccia of peculiar character has been found as yet with these fossils, Professor David's suggestion is possibly correct that the breccia was at the base of the Beacon Sandstone formation and was derived from strata in another locality. At any rate there seems no good reason for suggesting, as was done by one of the original discoverers, that the calcareous limestone of Mount Darwin on the summit is the parent of these breccias, for Mount

* British Antarctic Expedition, 1907-9. Geology. Vol. 1 (1914), pp. 235-243.

† Scottish National Antarctic Expedition. Trans. Royal Soc. Edinburgh, 1920, vol. 52, pp. 681–714. Cambrian Organic remains from the Weddell Sea. By W. T. Gordon.

Darwin appears to be merely a continuation of the sandstone beds of Buckley Island as it has the same appearance and gentle dip to the south-west.

On the evidence at hand, therefore, we regard the Beardmore region as very similar in structure and history to the greater part of the plateau escarpment of South Victoria Land, with its universal level-bedded sandstone formation resting on a foundation of plutonics and Pre-Cambrian rocks.