II.—Shackleton Antarctic Expedition, 1914-1917: Geological Observations in the Weddell Sea Area. By J. M. Wordie, M.A., F.G.S. *Communicated by* Professor J. W. GREGORY, F.R.S. (With Four Plates and Four Figures in the Text.)

(MS. received May 10, 1921. Read June 20, 1921. Issued separately October 31, 1921.)

CONTENTS.

	PAGE
1. COATS LAND	17
2. SOUTH GEORGIA	17
3. ELEPHANT ISLAND, SOUTH SHETLANDS	20
(a) Physiography and Geology	20
(b) Petrography (by G. W. TYRRELL, F.G.S.)	25
4. RELATIONSHIP	26

1. COATS LAND.

The original plan of the Shackleton Expedition, had it been realised, would have yielded geological results of no little value. The base would have been on Coats Land, and next in importance to crossing the Antarctic continent was the projected geological sledging trip across the Wilhelm Barrier, westwards from the head of the Weddell Sea to the southern continuation of Graham Land. Had it been carried out, it would of course have settled finally the relationship of Graham Land to the rest of Antarctica. The besetment and destruction of the *Endurance*, however, put an end to the original plan, and no landing was ever made either on the eastern or on the southern side of the Weddell Sea.

On the Caird Coast of Coats Land, which was sailed along and charted from 72° 30' S. to 76° 30' S., no bare rocks were seen: the coast was one long line of barrier cliffs, beyond which could be made out gentle snow- and glacier-covered mountains, rising to great heights in the interior. There was no evidence of this shelf-ice being aground, except in 76° 30' S. lat., where tide-marks were seen on the ice-cliffs. A rather unusual feature is the Stancomb Wills Promontory, a protruding mass of shelf-ice flanked by 20-100 feet high barrier-like cliffs. It appears to stand as a remnant, witness to a much greater seaward extension of the continental ice at a not very distant date. The finding of a barrier berg, 20 miles in length, not far away shows on what a large scale the shelf-ice must break up.

In 1912 Lieut. FILCHNER charted the Leopold Coast farther south; his ship, however, was never very near the coast except in the extreme south. Nunataks of bare rock were found at several places—for instance, Bertrab Nunatak in 77° 55' S., 34° 30' W.; Moltke Nunatak; and others;—but he was never able to reach any of them and report on their geological constitution. Knowledge of Coats Land geology, therefore, depends at present entirely on the numerous deep-sea soundings and dredgings made in the Weddell Sea. The material from this source does not prove, but certainly gives weight to, the prevailing idea that Coats Land in geological structure resembles Victoria Land rather than Graham Land.*

2. SOUTH GEORGIA.

A four weeks' stay was made at South Georgia in November 1914. The specimens secured at that time were certainly the most interesting collected during the expedition,

* J. M. WORDIE, *Trans. Roy. Soc. Edin.*, vol. lii (1921), p. 784 sq.

but they were unfortunately all lost a year later when the *Endurance* was crushed by the ice. The field notebooks only were saved. The loss of the specimens justifies only the briefest of descriptions of South Georgia; but, as the interpretation of the structure differs markedly from that put forward by Mr FERGUSON, publication has been felt to be absolutely necessary.*

Mr FERGUSON's excellent photographs furnish a very good picture of the appearance of the east coast of the island, and to a more limited extent of the mountain backbone. Based on these photographs is a short physiographic description by Professor GREGORY, who among other things has pointed out the main subsidence and the successive elevations which the island has undergone in more recent times. Mr FERGUSON gives a useful account of the history, and of the geological work done previous to his visit. In the last twenty years the island has been frequently visited, but the only accounts available are those of THURACH (who was not there himself), FERGUSON, and HEIM. From time to time also numerous small collections have been made by whalers; and these, together with Mr FERGUSON's rocks, have been described petrographically by Mr TYRRELL. The value of these descriptions would certainly have been much greater had the field relationships of the different rocks been recorded; but, thanks to Mr TYRRELL's work on them, the petrography at least of South Georgia is now well known, and is certainly far in advance of the stratigraphy and general geology.

Mr FERGUSON divides the rocks into two series: a lower, Cape George Series, unconformably overlain by an upper, Cumberland Bay Series. The latter is subdivided into three divisions according to the dominant colour produced by weathering. These divisions are shown on a map and section. On the map the lower Cumberland Bay division appears as a fringe round the coasts, the boundary between it and the middle division indicating horizontal beds. The entire south-west coast is coloured as belonging to the upper division; but apparently visits were made only to Adventure Harbour, Wilson Harbour, and Cape Nunes. The section shows the Cape George Series as folded into a gentle anticline, and the overlying Cumberland Bay Series as a monocline dipping very gently to the south-west; N.W.-S.E. strike faults are given prominence; and the central mountain range is represented as the result of faulting.

The portion of the island which the present writer visited in 1914 was the east coast between Leith Harbour and Larsen Harbour. With one exception the rocks seen were grits, shales, slates, and tuffs, for the most part massively bedded. The exception was the south-east end of the island, round Drygalski Fjord and Larsen Harbour, where the chief rock seemed to be either diorite or fine-grained gabbro, weathering into jagged mountain peaks not unlike the Coolin in Skye. Occasionally olivine occurred in quantity; and in one case the rock was distinctly banded. Dykes, mostly dolerites, were very numerous, both vertical and inclined; at least two different sets were recognised; these dykes weathered red in many cases, and were among the most prominent features on the bare glaciated mountain-sides.

The above-mentioned igneous complex is presumably the same as that hurriedly visited by Dr HEIM in 1911; in his short account of the geology he refers to the rocks as "altvulkanischer"—a term which I take to mean pre-Tertiary igneous rocks.† When South Georgia comes to be surveyed, the unravelling of this district will be a big problem itself. There have already been recorded dolerite, basalt, "greenstones," epidiorite, spilite; diorite, granite; quartz trachyte and soda-felsite. How these are related one to another and to the folded Cumberland Bay Series is still uncertain. The most probable view is that after the deposition of the Cumberland Bay Series, and probably also after the folding took place, there

* D. FERGUSON, *Trans. Roy. Soc. Edin.*, vol. 1 (1915), p. 797.

† FRITZ HEIM, *Zeit. Ges. Erdk. Berlin*, 1912, p. 451.

occurred an outburst of volcanic activity round Drygalski Fjord, followed by plutonic intrusions and dykes, etc.; and that it is the eroded remnant of this complex which is now found forming the striking scenery of Drygalski Fjord and Larsen Harbour.

The rest of the island consists of an apparently great thickness of massive bedded grits, shales, phyllitic shales, slates, thin limestones and tuffs; but, as the rocks are crumpled and folded to a degree, the real thickness may well be less than it looks. The folds strike N.W. (true) on the average, but occasionally W.N.W. and N.N.W., many of them appearing as recumbent folds of considerable size overfolded apparently from the south-west. The rocks in some localities are strongly cleaved, the strike of the cleavage invariably running N.W.-S.E. The trend lines, therefore, are practically parallel to the axis of the island.

The Shackleton party visited Gold Harbour, Royal Bay, George Bay, New Fortuna Bay, Cumberland Bay, and Stromness Bay. The longest stay was made at Cumberland Bay, headquarters being made at the small harbour known as Grytviken. Mr FERGUSON's naming of the rocks at these various localities as the Cumberland Bay Series is most appropriate; the nature and structure of the rocks can nowhere be more strikingly developed than they are on the mountain cliffs round that great bay. The strongest exception, however, must be taken to his unfortunate attempt at subdividing the series. This was done on the assumption that the rocks constituted a simple monoclinical block gently tilted S.W.: the higher divisions, therefore, were to be expected on the top of Mount Paget. As no one has been within four miles of the mountain, it is rather premature to draw a finished geological section; and as the structure of the rest of the island is not a monocline, but a series of overfolds, it is pretty certain that Mount Paget, when visited, will not have the structure assigned to it in Mr FERGUSON's section. His is an error not difficult to make, since most of the coast sections are along the strike; at Larsen Point, for instance, and N.W. from it, the rocks appear as one continuous horizontal series; but quite close, in Stromness Bay (fig. 1; cf. Plate II, fig. 1), a dip section is found, showing reduplication of the beds by isoclinal folds with axial planes dipping steeply to the south-west.

FIG. 1.—Sketch of mountain face, about 2000 feet high, on south side of Stromness Bay.

The structure being of this complicated nature, it is quite clear that geological boundary lines will not follow the ins and outs of the coast-line, but run right across the bays more or less parallel with the strike. Such, however, is not the case on the Ferguson map. Had it not been for the error in interpreting the structure, there would probably have been no attempt made to subdivide the Cumberland Bay Series. If that series can be subdivided, it must be done on definite palæontological or petrological grounds; but no such evidence is forthcoming. Mr FERGUSON records that the distinction was one of weathering; but the petrological examination by Mr TYRRELL definitely destroys this idea, since he says the rocks are similar, whether labelled as coming from the lower, middle, or upper division: tuffs and radiolarian cherts, for example, are found in all three.

The structure being of this complicated nature, it is quite clear that geological boundary lines will not follow the ins and outs of the coast-line, but run right across the bays more or less parallel with the strike. Such, however, is not the case on the Ferguson map. Had it not been for the error in interpreting the structure, there would probably have been no attempt made to subdivide the Cumberland Bay Series. If that series can be subdivided, it must be done on definite palæontological or petrological grounds; but no such evidence is forthcoming. Mr FERGUSON records that the distinction was one of weathering; but the petrological examination by Mr TYRRELL definitely destroys this idea, since he says the rocks are similar, whether labelled as coming from the lower, middle, or upper division: tuffs and radiolarian cherts, for example, are found in all three.

It has been necessary to emphasise the unity of the Cumberland Bay Series, as far as present knowledge of it goes, for the characters and identifications of some fossils collected by Mr. FERGUSON led Professor GREGORY to put forward the view that there might be an unconformity in the series. It must be admitted, however, that the determination of Mr FERGUSON's fossils as of Palæozoic age is not convincing. Professor GREGORY says: "Though it must be recognised that opinions based on such uncertain fossils are hazardous, the fossils seem to me pre-Devonian. Dr BASSLER tells me that the opinion of himself and his colleagues is that these Camarocladoid fossils must be post-Cambrian or pre-Devonian."

The other fossil occurrences are three in number. Radiolaria were collected by Mr FERGUSON, and were stated by Dr HINDE to be post-Palæozoic and pre-Tertiary in age, and to come in probably between Triassic and Cretaceous; Dr OTTO NORDENSKJÖLD found a lamellibranch, which was identified as a *Posidonomya* and probably Mesozoic; and the Filchner Expedition found an ammonite, which is now regarded as a Cretaceous *Acanthoceras*. All these fossils were found in the Cumberland Bay Series. Their identification is of a more definite nature than that of the so-called Palæozoic fossils. One can safely say, therefore, that Mesozoic rocks are present in South Georgia; that the Palæozoic is also represented is a possibility merely.

Mr FERGUSON gives an account of a lower series, the Cape George Series, which he regards as lying unconformably below the Cumberland Bay Series. Two outcrops are shown on the map: the writer has only visited the one north of the Nordenskjöld Glacier, whereas the other exposure seems to have served as the type. In the former locality, however, no evidence for the rocks there being separated from the Cumberland Bay Series could be found. One important point should be noticed: Mr TYRRELL sees no difference between the petrography of these rocks and those of the Cumberland Bay Series. Before accepting the unconformity, therefore, one must have much better evidence than that so far supplied.

At present all that can be safely said about the geology of South Georgia is as follows:—The backbone of the country consists of metamorphosed sediments, the Cumberland Bay Series, probably Mesozoic in age, strongly folded and cleaved and striking N.W.–S.E.; in the south-east there is an igneous complex possibly younger, in which both volcanic and plutonic rocks are represented; the relationship of these two sets of rocks to each other has not yet been settled.

3. ELEPHANT ISLAND, SOUTH SHETLANDS.

(a) *Physiography and Geology.*

In area Elephant Island and its neighbour Clarence Island, collectively known as the Powell Group, are relatively small; their geological and geographical importance, however, is considerable, for the position of these islands makes them a link between the other South Shetlands, namely the Smith Group, and the South Orkneys. That the otherwise unfortunate Shackleton Expedition should have at last reached *terra firma* here is, therefore, a matter for congratulation; though the work which could be done by a shipwrecked party was necessarily limited, it nevertheless has value, seeing that it provides the first scientific account of the group.

Clarence Island, which is the smaller of the two islands, has on the chart a somewhat oval ground-plan. It is also the more regular, and seen from the south has the appearance commonly called "sugar-loaf." The Shackleton party made no landing here, preferring on various grounds to steer for Elephant Island. The latter, originally known as Sea-Elephant Island, is as irregular as Clarence Island is the reverse; the sky-line is broken up into

numerous peaks, and the outline which passes current on charts shows numerous bights and bays. Although the island has never been properly surveyed, it now, of course, has a settled form on the Admiralty chart; how this was arrived at is a mystery, as all previous maps are more or less at variance. Taking the present Admiralty chart as a basis, the length of the island from east to west is not quite 30 miles; and the greatest breadth from north to south just under 15. The latter measurement is at the western end, whereas D'URVILLE's map* makes the island broadest in the east. D'URVILLE's chart was made in 1838; no further surveys have been made, and yet the British Admiralty chart is now very different from the French admiral's. The Shackleton Expedition, while rowing towards the island from the south-east, got the impression that the island was broader at the eastern end than is shown on the chart, and more resembles what D'URVILLE made it; lack of glacier equipment, unfortunately, made a journey across the island to settle this quite impossible.

Rock collections were made at two points, namely, at Cape Valentine, the north-east point of the island, and at Cape Wild, 6 miles farther west. Observations were also made on the

FIG. 2.—Sketch outline of coast between Cape Wild and Cape Valentine, Elephant Island.
Scale: roughly $\frac{1}{4}$ inch = 1 mile. The shading indicates glaciers.

dip of the beds along this six-mile stretch of coast during a boat journey, and a few days later WILD and the writer made a sketch of this coast, in so far as we could remember it (fig. 2). Cape Belsham, which marks the western limit of the sketch, is a name taken, like Cape Valentine, from old charts. Its exact location was doubtful; it could only have been applied, however, to a prominent feature, and lay about eight miles from Cape Valentine; it is here used for the headland one mile west of the less important Cape Wild.

Of the country beyond Cape Belsham the Shackleton party saw practically nothing. A great glacier wall, according to FRANK WILD, commencing there extends westwards for possibly 15 miles; this feature was not, however, visible from Cape Wild; the only rocks seen beyond Cape Belsham were numerous islets and skerries which are no doubt the more easterly of the Seal Islands.

The eastern part of the island can be described in a general way as a plateau country, whose average height must be about 1500 feet, and from whose apparently fairly uniform surface rise numerous ice-covered mountains, some to over 3000 feet. The plateau and the heights on it are almost entirely smothered by an ice-sheet of the nature of highland-ice, which escapes to the coast in large valley glaciers between mountains smaller in size and showing more bare rock than those of the interior. The gradient from coast to plateau is a

* J. S. C. DUMONT D'URVILLE, *Voyage au Pole Sud et dans l'Océanie*, Atlas.

steep one, the slopes being either scree-covered or rocky, sometimes even precipitous; occasionally wall-sided and cascading glaciers spill over, and in some cases reach the coast. On two occasions an effort was made to climb these slopes to the plateau: once at Cape Valentine, when the screes were badly iced, but after a height of 800 feet had been reached, further progress proved too much for men in such an exhausted state; the other occasion was at Cape Wild, when advantage was taken of the snow being at its best for mountaineering, but the way this time was stopped by a cascading glacier.

The mountains along the coast, when of bare rock, have precipitous slopes and serrated crests of the "frayed cardboard edge" type. The latter feature is the outcome, of course, of their structure—steeply tilted crystalline schists; these break along foliation planes and along two sets of joint planes at right angles to the former. These features are admirably illustrated by the mountains at Cape Belsham (Plate III, fig. 2) and by Mount Houlder, the mountain which stands as a seaward sentinel on the east side of the Furness Glacier.

Frost and sea and glaciers are playing such a part on the coast that it is about as inhospitable as one could well imagine. The screes and cliffs generally run straight down to the water edge; there the sea is actively engaged in attacking them, and has in many localities already produced a broad rock platform. Elsewhere, in more favoured spots, small beaches have formed, but of no great breadth, such as that at Cape Valentine. It was the meagreness of the shingle beach at the latter point—a mere ledge below cliffs and screes—which forced the Shackleton party to transfer camp westwards to Cape Wild. The north coast was then found to be a succession of bays, hardly offering a foothold, separated one from the other by sharp promontories ending in precipitous stacks and skerries. Cape Wild differed from the other points in being a small rocky island attached to the mainland by a short "spit" of rocks and shingle. There was no doubt, however, that even there, when the seas were ice-free, storms swept right across the spit; but, bad as it might be, no better camping site was available along the whole north coast of the island.

The origin of the so-called spit at Cape Wild was at first rather a problem. When the spring weather had cleared away the snow, however, its history became fairly obvious. At one time the Furness Glacier was larger than it is to-day, and extended probably over Point Lookout (Penguin Hill) and certainly across the flat ground forming the spit; it has left evidence of this more extensive glaciation in the shape of "roches moutonnées," a stiff clay, and moraine debris. For a time, then, the spit appears to have been the right lateral moraine of the Furness Glacier, seeing that it is formed of boulder clay on which lie angular fragments of the local schist. Since then the glacier has retreated, and it is doubtful whether the spit will long endure without the protection of the ice which formed it. The west side is the weather coast and is being actively eaten into; at the northern rock (Point Lookout) caves are being formed, and a broad rock platform is already developed. The east side is only in part a lee; shingle and pebbles are being deposited only at the extreme south-east corner, and nowhere else. The amount of shingle, however, in comparison with the glacial deposits of the spit is a mere trifle, and is apparently not much of an offset against the erosion going on on the west side. At first one was tempted to regard the spit as a "tombolo," but, inasmuch as it has mainly a glacial not a marine origin and has a solid foundation of rock below, that term is certainly inapplicable.

Described in the language of the physiographer, the coast comes under the category of submerged coasts. The profile is that of late youth, as the two ideal sections (fig. 3) show; but the shore-line seems rather to represent early youth, since beaches are rare, and there are no bars.

At Cape Valentine the strike of the rocks is E. by N. Siliceous schists, cut at right angles to the bedding by small quartz veins, dip S. by E. at an angle of about 30° . Occasionally dark black and chloritic beds, more or less intimately associated, are embedded with the gritty schists. All these beds on the coast south of Cape Valentine dip uniformly southward, and show no folding. The cliffs, however, immediately behind the stack at the cape, at a height of 400 feet above sea-level and over, consist of black and green beds and appear horizontal; despite this, at the stack itself directly below, the schist dips southwards (as it also does elsewhere south-south-east of the cape) at about 30° inclination. It is true that this observation of horizontal beds high up on the cliffs at Cape Valentine was made from the sea; but it does not seem to be satisfactorily explained by foreshortening.

From Cape Valentine to Cape Wild the observations were made from a boat, but, since she clung to the coast most of the way, they are considered quite reliable. The first bay west of Cape Valentine was estimated as $1\frac{1}{4}$ mile across. On the western stack the rocks dip 70° northwards (estimate). A prominent peaked mountain marks the western point of the second bay; and immediately beyond it is a small cove where perpendicular cliffs show vertical foliation. From here to Cape Wild is one large double bay with several minor indentations. In the more western half occurs Castle Rock, on which the beds dip 30° – 40° northwards. At Cape Wild and Cape Belsham the dip is still northerly, but at a considerably steeper angle than on Castle Rock.

At Cape Wild fuller and more detailed observations were made than were possible anywhere else on the island. The collecting radius, however, was limited by lack of equipment for crossing glaciers. The west was entirely cut off on this account; it may be stated, though, that with rope, etc., it would be a very simple matter to gain the interior *via* the eastern edge of the Furness Glacier. Eastwards, aided by ice-foot, the coast was passable towards but not quite as far as Castle Rock, for a small glacier again blocked the way; and with the snow in a favourable state it was also possible to climb some distance up the mountains to the south, until either cliff glaciers or precipitous rocks stopped further progress. Southwards up the mountain-side and eastwards along the coast were therefore the only possible directions open for investigation.

Cape Wild (Plate IV, fig. 2) is hardly large enough to be called a cape, being more of the nature of a point. It consists at the northern end of a rocky knob, 95 feet in height, called Lookout Point or Penguin Hill, joined to the mainland by a level spit of rocks and shingle resting on a solid rock basement; the level part of the cape is almost exactly 100 yards in length, the breadth not quite 40 yards. At its south end there is a small slope of dead ice, which at one time was part of the Furness Glacier, and is to-day not entirely separate; it thus offers an easy and practicable way of getting on to the glacier. This ice-slope seems to be plastered on to the precipices of Mount Houlder. A map of Cape Wild and the neighbourhood showing these features was made by Mr JAMES (fig. 4).

FIG. 3. — Diagrammatic sections of coast-profile, Elephant Island.

The rocks at Lookout Point consist of grey-green phyllites, occasionally siliceous. Small quartz veins, similar to those at Cape Valentine and occurring in ladder-like groups, are not uncommon. The strike is N. 75° E. (true), and the dip of the foliation approximately 60° towards N. 15° W. Generally speaking, though not invariably, crumpling of the rocks is absent. The central part of the knob consists of soft green schists with specks and dashes of blacker opaque material; these are overlain on the north by slightly more siliceous beds, and underlain on the south by a hard quartzose schist. Even in these more siliceous beds, laminæ and thin beds of the softer greenish-black schist are found. Taken as a whole, the latter rock, either spotted or banded, predominated at Cape Wild.

Similar rocks with similar dip are presumed to form the basement of the spit. Collections

FIG. 4. — Map of Cape Wild, Elephant Island.

from the south end of the spit, at the foot of Mount Houlder, show the green-black schist again prominent. In this case the steep foliation planes form the actual slope of the mountain.

At one place a thin bed of pure green material about 1 foot thick is interleaved with the predominant green-black schist, and the whole reduplicated by concertina folding. Lower down in the section is a thin bed richer in iron and weathering to a bright-red colour. By climbing up the slopes, still lower beds were found, for the most part grey-black phyllites, but with at one point a thin lime-bearing band. Here and there the rocks are covered with blue glaze; a small calcite vein occurs, and pencil cleavage is found now and then in the grey-black phyllites. The most striking feature of the section, however, is the concertina folding of the green, black, and red beds.

The process which produced the concertina folding and the foliation appears to have been one and the same thing. To a later set of movements, however, should probably be ascribed the bigger folding indicated by the variations in dip along the north coast; on a small scale

it seems represented by low arches and minute crumplings in the rocks of Cape Wild. The crumpling (which is not, however, common) in one case has gone so far as to produce strain-slip-cleavage. The quartz veins also may date from this latter period of stress and folding.

Reference has been made to the small beach forming at the south-east corner of the spit. The majority of the pebbles were of schists resembling those collected in the neighbourhood, but among them well-rounded specimens of igneous rocks were also found. Biotite granite with white felspar was very common; and we also saw hornblende granite, syenite (possibly), and gabbro; quartz-felspar-porphry; andesite (common) and basalt (very common); olivine basalt; a hybrid rock with large rectangular flesh-coloured felspars, breccia, sandstone, and shale (all uncommon). There were no data for determining the exact locality from which these rocks had come; many, however, can be paralleled with specimens collected on King George Island by Mr FERGUSON.

(b) *Petrography.* By G. W. TYRRELL.

The rocks from Elephant Island are very uniform in composition and texture, but are of rather puzzling character, and present considerable difficulties in mineral identification and determination of origin.

In hand specimens they are dark-grey, indigo-blue, bluish-green, and grey-green phyllites of fine texture and glossy surface. The variously coloured types are intricately interleaved one with the other. Some bands are slightly coarser and grittier than others; but many of the rocks are profusely veined and permeated with secondary silica, which is partly the cause of the impression of coarser texture in certain specimens.

Quartz, "chlorite," an opaque greyish substance, and calcite are the principal minerals observable in thin section. The calcite is always, the quartz frequently, of secondary origin. These minerals are arranged in elongated parallel lenses of microscopical dimensions, presenting a small-scale flaser texture indicative of intense pressure metamorphism.

Original quartz occurs as comparatively large angular grains, often enwrapped by wisps of chlorite; or as a mosaic of smaller grains which are frequently in poikilitic relation to large plates of calcite. Lenticles of this material alternate with long-drawn-out folia of the above-mentioned opaque substance.

The greenish minerals included under the term "chlorite" comprise at least three different substances. A true chlorite, of a very pale green colour, occurs in large grains along with grains of quartz and felspar, involved in folia of the greyish opaque material. This variety polarises as an aggregate and displays typical "ultra-blue" polarisation tints. Another variety is yellowish-green in colour, is very finely divided and structureless, and is often intermingled with siliceous dust. A third type is brownish-green in colour, micaceous in habit, and quite strongly pleochroic. This occurs in streaks or folia, with quartz grains, alternating with the folia of opaque material.

The opaque substance above mentioned is dirty-grey in colour, and in slides of the usual thickness is quite opaque and structureless. It has much the same appearance as the "leucoxene" developed by the alteration of ilmenite, or the dense, whitish, opaque substance which is the product of the "kaolinisation" of felspars. In very thin sections or on the thin edges of ordinary sections this material may be resolved by a high-power objective into an aggregate of minute, colourless rods and plates with parallel arrangement, and intermingled with finely divided chloritic and siliceous material. These colourless rods and plates give straight extinction and very subdued polarisation tints; but the latter is due simply to their extreme thinness. Their microscopic appearance is similar to that of the substance identified

as sericite by ROSENBUSCH in such rocks as "Sericitschiefer" (*Gesteinslehre*, 1910, p. 562). They possibly represent the beginnings of sericitic alterations in crushed feldspars. In some slides much darker streaks occur within this opaque substance. These may be carbonaceous in some of the specimens (notably the indigo-blue phyllite), but in one slide at least similar material appears to be derived from original iron-ores.

The difficulty of identifying these rocks is further increased by the extensive siliceous replacement they have undergone. They are penetrated by quartz veins in every direction, and the silica has insinuated itself along the foliation and shear planes. One rock consists of shattered fragments of phyllite cemented together by a fine-grained secondary quartz aggregate.

As far as a guess may be hazarded from the meagre evidence available, these rocks possibly represent very fine muddy andesitic or basaltic tuffs, or the wash from a region of basic igneous rocks, interbedded with layers of more argillaceous or more siliceous materials.

Some of the specimens have a distinctly fragmental appearance in thin section (the grey phyllite), and these rocks may have constituted bands of coarser material in the prevailing muds. These show uncrushed angular grains of quartz, uniform areas of chlorite probably representing original ferro-magnesian minerals, and even one large grain which can be positively identified as a plagioclase feldspar. Then among the dense opaque sericitic matter above described there are often elongated elliptical areas of slightly different colour or texture from the surrounding material, and these have the appearance of flattened fragments, possibly of original feldspar. These clearly fragmental rocks somewhat resemble the sheared tuffs of South Georgia.

These rocks do not resemble in the slightest degree any of the specimens recently collected by Mr D. FERGUSON from the South Shetlands, the Palmer Archipelago, and the Danco Coast, or any of the rocks of these regions so far described. They may have somewhat closer affinities to the folded and sheared tuffs, slates, and phyllites of South Georgia and the South Orkneys, but are by no means identical.*

4. RELATIONSHIP.

The Elephant Island rocks, in view of Mr TYRRELL's description, must be regarded as separate in type from anything got elsewhere in the Antarctic or sub-Antarctic islands. They may be allied to certain sheared tuffs, slates, and phyllites from the South Orkneys; but, if so, they are much more highly metamorphosed; and it would be rash to insist on their being closely allied. As this was the first time geological collections had been made in the Powell Group, it was hoped that affinities would be found either with the South Shetlands or with the South Orkneys. So far as the Shackleton collection goes, this is not the case. Elsewhere on Elephant Island and on Clarence Island other rock types may be developed; but the present writer thinks not. The Shackleton Expedition was never very close to Clarence Island in daylight; but Mr DAVID FERGUSON, on board one of Messrs SALVESEN's whalers, in 1913, came within about 5 miles of the island, and has written an unpublished description which at once recalls the appearance of the country round Cape Wild, and makes it probable, therefore, that Clarence Island is geologically similar to Elephant Island.

The existence of the so-called Southern Antilles has been claimed on the evidence of deep-sea soundings and of the geology of the different countries in this Antarctic sector. The existence of a submarine rise linking the different islands is certainly indicated by

* TYRRELL, *Trans. Roy. Soc. Edin.*, vol. 1, pt. iv, 1915, pp. 823-830; *Geol. Mag.*, 1916, p. 436; *ibid.*, 1918, p. 487.

soundings, but by no means fully proved; a great many more soundings are required before it can be settled. The geological evidence is more complete, but has certainly not supplied a final solution of the problem. As will be shown below, it might be advisable to suspend judgment on the question till more is actually known.

On Graham Land* and the South Shetlands (excluding the Powell Group) the oldest rocks are probably certain mudstones and greywackes collected by Mr FERGUSON in the South Shetlands. The main rocks, however, in the South Shetlands are andesite lavas; whilst on Graham Land plutonic granites, diorites, and gabbros are dominant. In both cases the age is provisionally considered as late Cretaceous or early Tertiary. They are regarded, therefore, as younger than the folded Jurassic rocks of Joinville Peninsula and the undisturbed Snow Hill-Seymour Island beds of Cretaceous age. Still younger, however, are certain basalt tuffs of Miocene age on James Ross Island and a Pliocene conglomerate on Cockburn Island. Every one of these beds has its equivalent in South America. The similar petrographic nature of the granite-gabbro series in Patagonia and Graham Land was first clearly shown by NORDENSKJÖLD: and lately G. W. TYRRELL's examination of the South Shetland andesites shows an equally striking consanguinity with the Andean lavas, and makes the geomorphological identity of Graham Land and Patagonia a certainty.†

That Graham Land was once connected to South America must be acknowledged. The evidence from the igneous rocks, both plutonic and volcanic, is too striking to be set aside. It is a question, then, whether the connection was *via* the island groups or not. At present evidence from this source is most unsatisfactory and inconclusive.

The Elephant Island (Powell Group) rocks are too far metamorphosed to be properly identified. The usual strike is N. 70° E.

The South Orkneys consist, in part at any rate, of Palæozoic greywackes and shales much compressed and folded, and striking N.W. and N.N.W. They do not correspond with any other Antarctic rocks, unless perhaps faintly with certain South Georgia rocks.‡

From the South Sandwich Group the only rocks collected have been described as basaltic lavas of sub-alkali composition. The absence of trachytes distinguishes them from the majority of sub-Antarctic islands. They are described as of so-called Pacific type.§

South Georgia is built up of folded greywackes, slates, mudstones, and tuffs which cannot be paralleled in other Antarctic localities except perhaps in the South Orkneys. They strike N.W.-S.E. on the average, and are probably Mesozoic in age. The geology of this island, however, is still a very open question.||

There are no rocks, therefore, on any of the island groups which can be definitely pointed to as evidence for drawing an arc through them. It is still possible, for instance, that South Georgia and the South Orkneys may be remnants of an old continental mass like Brasilia. On the other hand, when the strike lines are plotted on the map, they show a concentric arrangement which is very suggestive of parallel folds. It seems to the writer, however, that, in view of the dissimilarity of the geology of the respective islands, the final evidence on their supposed relationship can ultimately only be furnished by a fuller charting of the ocean depths in this sector, and that till this is done the question should be left open.

* J. GUNNAR ANDERSSON, *Bull. Geol. Inst. Upsala*, vii (1906), "On the Geology of Graham Land."

† G. W. TYRRELL, in paper read before Roy. Soc. Edin. on March 15, 1920.

‡ J. H. HARVIE PIRIE, *Proc. Roy. Soc. Edin.*, xxv (1904-5), p. 463.

§ O. BAECKSTRÖM, *Bull. Geol. Inst. Upsala*, xiii (1915-16), p. 115, "Petrographische Beschreibung einiger Basalte von Patagonien, Westantarktika und den Süd-Sandwich-Inseln."

|| J. W. GREGORY, G. W. TYRRELL, D. FERGUSON, *Trans. Roy. Soc. Edin.*, l. (1915); G. W. TYRRELL, *Geol. Mag.* 1916 and 1918.

Mr J. M. WORDIE: "Geological Observations in the Weddell Sea Area."—PLATE I.

Mount Paget Range, South Georgia, seen from Dusefell. Moraine Fjord on left; Moraine Plain left centre; Grytviken Whaling Station on extreme right.

Mr J. M. WORDIE: "Geological Observations in the Weddell Sea Area."—PLATE II.

FIG. 1.—Leith Harbour, South Georgia. Folded Cumberland Bay Series.

FIG. 2.—Head of Moraine Fjord, South Georgia. Typical appearance of Cumberland Bay Series.

Mr J. M. WORDIE: "Geological Observations in the Weddell Sea Area."—PLATE III.

FIG. 1.—Larsen Harbour, South Georgia. Igneous complex.

FIG. 2.—Elephant Island. View west from Cape Wild. Furness Glacier on left; Cape Belsham on right. (Composite photograph.)

Mr J. M. WORDIE: "Geological Observations in the Weddell Sea Area."—PLATE IV.

FIG. 1.—Elephant Island. View east from Cape Wild. Castle Rock on left. Typical coast scenery.

FIG. 2.—Cape Wild, Elephant Island.