## II—.GEOLOGY.

### Art. XXIX.—*On the Foliated Rocks of Otago.*

By Professor F. W. Hutton, F.G.S.

[*Read before the Philosophical Institute of Canterbury, 4th November, 1891.*]

The foliated rocks of Otago are found in two districts, separated from each other by a band of sandstones and slates, about eight miles broad at its narrowest, which belongs to the Maitai or Carboniferous system.

#### 1. Northern Otago.

The first of these districts is in north-eastern and central Otago, the rocks found in it being the "foliated schists" of Sir James Hector,* and the "Wanaka and Kakanui formations" of my "Report on the Geology of Otago" (Dunedin, 1875), p. 26. These rocks extend in a band—some one hundred and thirty miles long and eighty miles broad—across the north-eastern part of Otago, where they form a single broad anticlinal curve, the axis of which runs from near Dunedin, west of Cromwell, to Lake Wanaka. The rocks lie remarkably flat (for foliated schists) over the whole area, dips of more than 45° being rare, and almost exclusively confined to the flanks of the curve. The average dip is between 25° and 30°. The rocks are not contorted or plicated in the usual meaning of the terms, but in the lower part of the Wanaka series they often have a waved or corrugated structure. All the rocks of the Wanaka series are foliated, and nearly all are true mica-schists, varying from coarsely foliated, with lenticular plates of pure quartz, to finely foliated, with nearly parallel foliæ. The Kakanui series is composed at the base of fine-grained mica-schists and silky phyllites, passing upwards into beds of quartzite and clay-slate, which is cleaved only in the plane of stratification. There is, however, no distinct separation of the Wanaka from the Kakanui series, but one passes insensibly

* Quar. Jour. Geol. Soc. of London, 1865, vol. xxi., p. 128.

into the other. Graphite-schists, sometimes 13ft. thick, occur in the lower part of the Wanaka series, at the Carrick Ranges; and chlorite-schists, also belonging to the Wanaka series, are found near Queenstown.

The *Mica-schists* of the *Shotover River* (Wanaka series), near Queenstown, are distinctly foliated with quartz and mica, and break readily along the plane of foliation. The foliæ often have parallel sides and extend far, but occasionally they are lenticular. The broader quartz foliæ are always lenticular in shape. The quartz is white and milky, being filled with innumerable gas-pores, arranged in bands, which are oblique to the plane of foliation. There are no liquid cavities in the quartz, but many of the gas-pores are irregular in shape, and look as if they had at one time been filled with liquid. In these cases the long axis of the cavity lies in the direction of the band. The quartz elements are dovetailed grains, from 0·004in. to 0·014in. in diameter, and occasionally they show undulose extinction. In some specimens there are patches of amorphous, isotropic quartz. The micaceous layers are dark-grey and glittering to the naked eye. The microscope shows small flakes of muscovite, from 0·014in. to 0·022in. in length, oriented to the plane of foliation. Part of the muscovite is altered to a green mica with undulose extinction and no axial interference figure. A colourless mineral, apparently zoisite, is very abundant in grains and in jointed columns; and a fine dust of secondary magnetite is sometimes present, scattered in clouds drawn out in the plane of foliation.

At *Clyde* the mica-schists differ from those of the Shotover in the absence of the bands of gas-pores from the quartz, much of which is amorphous.

The *Phyllites* of *Kingston* (Kakanui series) are composed of elements uneven in size, but mostly smaller than those of the mica-schists. They also occasionally contain patches of a fine aggregate, which is probably part of the original rock, as well as broken grains of feldspar. The mica is brownish-yellow, not dichroic, and with low polarisation colours. It is probably muscovite, but the scales are too small to examine with convergent polarised light. Zoisite is present as in the mica-schists, which latter differ from the phyllites chiefly in having undergone more vertical segregation as well as more alteration.

The *Chlorite-schists* of *Queenstown* are formed of much larger elements than the mica-schists, and they also contain small quantities of feldspar. The quartz has large gas-cavities, but no bands of gas-pores. The chlorite is in bluish-green flakes, which are either isotropic or else have dull polarisation colours. It is associated with abundant grains of yellow epidote, or pistacite, and crystals of secondary magnetite are

not uncommon. These schists are probably altered eruptive rocks.

*Age of the Rocks.*

Up to the present it has been the general opinion of New Zealand geologists that these foliated rocks are the metamorphosed equivalents of the Ordovician and Silurian rocks of Nelson, and by the officers of the Geological Survey some of the schists are considered as probably still younger. My reason for holding this opinion was that the publications of the Geological Survey showed these schists passing northwards continuously through the Victoria, Brunner, and Lyell Mountains to Mount Arthur in Nelson. But in 1887 I examined the rocks of the Buller River, and found that the schistose rocks of the south were not stratigraphically connected with those of the north, as I had previously supposed,* and this led me to reconsider the whole question. The absence of plication, and of cleavage oblique to the stratification, throughout the district are sufficient proofs that the foliation is not due to crushing, or dynamic metamorphism, while it cannot be considered as a region of contact metamorphism, for the only eruptive rocks are those near Queenstown, and they have been foliated along with the rest. The metamorphic action would therefore appear to be due to the internal heat of the earth at a very early period of its history, when the temperature-gradient was much steeper than now. In other words, they are, in all probability, of Archæan age, and may have been deposited almost in their present condition.

The Pre-cambrian, or Archæan, rocks have been separated into two divisions. The upper of these is, in part, detrital, and has been called the Huronian, or the Proterozoic, or the Algonkian. The lower is altogether crystalline, and is known as the Laurentian, or the Azoic, or the Archæan in a limited sense. In the Northern Hemisphere there is usually, but not always, a break between these two divisions, while in all cases there is a great discordance between the upper division and the overlying Cambrian or Ordovician rocks. Our Wanaka series can be received as the equivalent of the lower division without much hesitation; and, as there is no break between it and the Kakanui series, it is more probable that the latter belongs to the Archæan than to the Palæozoic era.

*Equivalents elsewhere.*

The Otago schists sweep round to the north-west, and have been traced by Sir Julius von Haast and Mr. S. H. Cox as far north as the Teremakau River. Beyond this point

* "On the Geology of the Country about Lyell," Trans. N.Z. Inst., vol. xxii., p. 387.

they have not been followed; but in Cannibal Gorge mica-schists and phyllites occur, which probably belong to the Kakanui series, and are probably continuous with the schists of the Teremakau. According to Mr. S. H. Cox these mica-schists are underlain by slates and limestones;* but this is very improbable; and most likely these carbon-slates, calcareous slates, and white limestone belong to the Reefton series—perhaps more or less altered by contact with the granite of the Victoria Mountains—and lie unconformably on the mica-schists.

North of Cannibal Gorge the schists are overstepped by sandstones and slates belonging to the Maitai system, and it is uncertain whether the schists of western Marlborough and eastern Nelson should be considered as belonging to them.

In the Collingwood district mica-schists and phyllites are found near the mouths of the Aorere and Parapara Rivers, which pass under grey and dark-blue slates of the Aorere series containing diprionidian graptolites† undoubtedly of Ordovician age. It seems probable that these schistose rocks are the equivalents of the Kakanui series, and underlie the Aorere series unconformably; but this last point has not yet been made out distinctly.

### 2. Western Otago.

The foliated rocks of the West Coast sounds, from Milford to Dusky—forming the gneiss-granite formation or crystalline schists of Sir James Hector, and the Manapouri formation of myself—have been generally regarded as consisting principally of typical gneisses of Archæan age, and as passing below the mica-schists of northern Otago.‡ Last summer, during the excursion of the Australasian Association to the Sounds, I collected a number of these rocks from Wet Jacket Arm, from George Sound, and from Milford Sound, which I have examined microscopically, and found to consist chiefly of plagioclase and hornblende or biotite, quartz being almost completely absent. The rocks, therefore, are not gneiss-granites, but schistose diorites and gabbros, and their microscopical texture shows that all of them are plutonic eruptive rocks which have undergone strong dynamic metamorphism. In the following short descriptions I have con-

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* "Reports of Geological Explorations," 1883–84, p. 4, Nos. 2 to 4 of the section.

† *Phyllograptus folium*, His. I have also recognised *Didymograptus quadribrachiatus*, Hall, and *D. octobrachiatus*, Hall. All three are found in the Lower Silurian slates of Victoria. Both genera are Lower Silurian only.

‡ Haast, "Geology of Canterbury and Westland," Christchurch, 1879, p. 225.

sidered them as hornblende diorites; but, as the hornblende is in all cases allotriomorphic, it is probable that they were originally augite diorites.

*Schistose Mica Diorite.*

*George Sound.*—A black-and-white coarsely-speckled rock, indistinctly foliated, but not breaking easily along the plane of foliation. Composed of feldspar—chiefly, if not entirely, plagioclase—and biotite, with a little hornblende, the ferromagnesian minerals occupying less than half the rock. The feldspars range up to 0·1in. in length, but usually they do not exceed 0·04in., while the biotites go up to 0·03in. A slight pressure-granulation is visible.

This is the rock of the Gertrude Waterfall, at the head of the sound.

*Hornblende Diorite.*

*Milford Sound.*—A black-and-white coarsely-speckled rock; not foliated. Composed of plagioclase and hornblende, the latter occupying less than half the rock. The plagioclase crystals go up to 0·08in. in length, the hornblendes to 0·04in. The feldspar shows pressure-granulation, and the hornblendes are much broken up and granulated.

From the boat-landing below Lake Ada, Arthur River.

*Schistose Hornblende Diorite.*

*Milford Sound.*—Coarsely-grained black-and-white-speckled rocks with the foliation distinct, sometimes so pronounced as to make the rock split readily along the plane of foliation. Often containing pink garnets, sometimes large sometimes small, in which case they are often clustered in bands, averaging about ½in. broad, lying in the plane of foliation. The rocks are composed essentially of plagioclase and hornblende, with a little quartz and, occasionally, some muscovite. The hornblende occupies from half to less than half the rock. Sphene is often abundant. The feldspars go up to 0·04in. in length, and the hornblendes to 0·06in. There is no appearance of pressure-granulation, but the feldspars are often full of inclusions.

From Harrison's Cove, and from Metal Point, below Mitre Peak. These rocks, which are very common in Milford Sound, pass into gabbros.

*Dusky Sound.*—A black-and-white fine-grained rock, distinctly foliated, and breaking readily along the plane of foliation. Composed of plagioclase and hornblende, the latter occupying rather less than half the rock. A small quantity of quartz is also present. Sphene is abundant. The feldspars go up to 0·04in. in length, and the hornblendes to 0·05in. No pressure-granulation.

### *Enstatite Diorite.*

*Dusky Sound.*—A rather pale-grey, finely-grained rock, not showing foliation. Under a lens it is finely speckled with black and white. Composed of plagioclase and hypersthene, the latter occupying about one-quarter of the rock. The feldspars go up to 0·1in. in length, but show pressure-granulation. The hypersthene is mostly in uncleaved small grains enclosed in feldspar, but occasionally it is in allotriomorphic crystals up to 0·04in. in length. It is strongly pleochroic, and not schillerised.

From the head of Wet Jacket Arm.

### *Enstatite Gabbro.*

*Milford Sound.*—A dark, almost black, rock, composed of hornblende and feldspar, the latter occupying less than half the rock. The feldspars are chiefly plagioclase, but some seem to be microcline. In addition to the hornblende there is a little enstatite, which is nearly colourless, and slightly pleochroic. There is also a little muscovite. No pressure-granulation.

From Harrison's Cove. A similar rock is found in many places in Milford Sound, and has been called hornblende-schist.

### *Age of the Rocks.*

The large size of the elements of these rocks shows that they are of plutonic eruptive origin, while the pressure-granulation observable in many of them shows that the foliated structure is of secondary origin. It will be noticed that the size of the elements is approximately the same all through, and the coarseness or fineness of the grain depends upon the amount of segregation the minerals have undergone.

They have been considered as Archæan on account of lithological structure, and not from any stratigraphical evidence. Consequently, this opinion cannot now be sustained. On the contrary, the absence of contortion, and the almost universal westerly dip of the foliation planes, is strong evidence that they are not Archæan. What their age may be it is impossible to say at present. Sir James Hector says that "wrapping round these crystalline strata, and sometimes rising to an altitude of 5,000ft. on its surface, is a series of hornblende-schists, soft micaceous and amphibolic gneiss, clay-slate and quartzite, associated with feldstone dykes, serpentine, and granular limestone;" and he believes these "to be metamorphic rocks of not very ancient date—probably of Devonian age."* Some of these are no doubt sedimentary rocks, altered by contact with the eruptive diorites, and the diorites

* "Outlines of the Geology of New Zealand," Wellington, 1886, p. 51; and Quart. Jour. Geol. Soc. of Lond., vol. xxi. (1865), p. 124.

are therefore probably younger than Devonian. When the boundaries between the eruptive and the surrounding sedimentary rocks have been carefully examined, and when the relation of the limestones in Caswell Sound and other places with the diorites has been clearly made out, it will then perhaps be possible to assign them to their proper place with some degree of certainty. And it may be found that the eruptive diorites of Milford Sound are connected with the greenstone-tuffs of the Route Burn and Greenstone River, west of Lake Wakatipu, which form the type of the Te Anau series of Sir James Hector.

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## ART. XXX.—*Note on the Boulders in the Port Hills, Nelson.*

By Captain F. W. HUTTON, F.G.S.

[*Read before the Philosophical Institute of Canterbury, 4th November, 1891.*]

A GOOD many years ago I pointed out that the Arrow rock, at the entrance of Nelson Harbour, was composed of a conglomerate of large boulders, and that boulders of the same nature were also found in the sandstones forming the northern part of the Port Hills.* These boulders are rounded, go up to 3ft. or more in diameter, and are composed of a granitoid rock which I took to be syenite. Last July, when in Nelson, I collected a fragment of one of these boulders for microscopical examination, and find that it is a biotite diorite. There is a small quantity of quartz, but it is quite subordinate to the feldspars, which are chiefly plagioclase, which has suffered but little decomposition. The ferro-magnesian constituents are biotite and brown hornblende, the former being the more abundant. There is also a little magnetite.

From this description it will be seen that these boulders differ materially from the syenite of the boulder-bank, in which the orthoclase is more abundant than the plagioclase, and the hornblende much more abundant that the biotite.† I do not know any rock in the district from which these boulders could have come, but probably it will be found near Motueka or Separation Point.

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* "Reports of Geological Explorations," 1873–74, p. 49.

† Proc. Royal Soc. of N.S. Wales, 1889, p. 124.