The Metamorphic and Intrusive Rocks of Southern Westland.

By F. J. Turner, Otago University.

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CONTENTS.

SCOPE OF WORK.

In a recent paper (Turner, 1930a) the writer gave a preliminary account of the metamorphic rocks and peridotites of the lower part of the Cascade Valley, South Westland, based upon observations carried out during January and February of 1929. The district was again visited early in 1930, with the object of investigating further the "Older Metamorphic Rocks" and ultrabasic intrusives of the Cascade Valley, and examining the metamorphic rocks of the region between the Haast and Cascade Valleys, where constant floods had rendered field work impossible during the 1929 expedition.

The present paper includes the results of this second visit, in so far as they apply to the metamorphic rocks, and the intrusive igneous rocks which frequently invade them. Observations were confined to the more accessible portions of this region, namely, the valleys of the Makarora and Haast Rivers, the coastal belt between the mouth of the Haast and the Arawata, and the Jackson, Matyr, and Cascade Valleys still further south.

The whole of this area is extremely rugged and mountainous, the peaks of the major chains ranging from 6000 feet to over 8500 feet in height, while the fast-flowing intervening rivers occupy deep and precipitous recently-glaciated valleys. The main rivers—the Haast, Okuru, Waiatoto, Arawata, and Cascade—rise among the permanent snowfields and glaciers of the Main Divide, and are liable to frequent summer floods as a result of torrential warm rains from the north-west. Except where isolated settlers have cleared the land in the vicinity of Okuru and the mouth of the Haast, dense forests cover the mountain sides to a height of a little over 4000 feet above sea-level, and effectively conceal the outcrops. On account of these natural difficulties and the inaccessibility of the area, detailed mapping was not attempted, and indeed would be possible in the future only if several months could be devoted to field work.

PREVIOUS WORK.

The literature referring to the geology of the Cascade Valley and the Jackson's Bay district has already been summarised (Turner, 1930a, p. 172).

In addition to this, a brief report on the metamorphic rocks north of the Haast River is given by Cox (1877a, pp. 72-74), while Haast himself (Haast, 1879, pp. 46-56) gave an interesting account of his early geological explorations in Southern Westland during 1862 and 1863, when he travelled from Lake Wanaka across the Haast Pass to the West Coast by way of the Haast Valley, returning later by the same route. In the same volume (pp. 249-265) a considerable space is devoted to the metamorphic rocks of Westland, which were divided by Haast into three groups: a lower series or Gneiss Granite Formation and two overlying series, the Westland and Waiho Formations respectively. Haast was unfamiliar with much of the country with which the present paper deals, and for this reason, and in the absence of descriptive petrography from his account, his work will not be considered further.

OUTLINE OF GEOLOGICAL HISTORY.

The basement rocks of Southern Westland are a series of hornfelses, gneisses, schists, phyllites, and slates which cover most of the area examined, and which are continuous with the Maniototo Schists of Central Otago on the east, and northwards with the schists of Westland, which extend throughout the full length of the province along the western flank of the Alps. On account of marked difference in metamorphic grade between the rocks respectively east and west of the peridotite belt, the metamorphic rocks of the Cascade Valley were originally tentatively divided (Turner, 1930a, p. 186) into a western or "Older Metamorphic Series," and an eastern series showing a lower metamorphic grade and correlated with the Maniototo Series of Central Otago. At the same time it was pointed out that the "Older Metamorphic Series" might later prove merely to be the more intensely metamorphosed equivalent of the Central Otago schists, a view which has since received strong support from evidence obtained further north in the Haast Valley. Stratigraphic subdivision of the metamorphic rocks is therefore considered no longer advisable, and the term "Older Metamorphic Series" has been dropped.

All the metamorphic rocks are now grouped in a single metamorphic series, which exhibits well the phenomena of progressive metamorphism on a regional scale. Subdivision based upon grade of metamorphism and chemical composition has been attempted. While most writers hold that the rocks of Westland were metamorphosed during the great orogeny of the Lower Cretaceous, the present writer believes that the date of metamorphism is much more ancient, and possibly even as remote as the Middle Palaeozoic.

Contemporaneously with the main metamorphism, deep-seated masses of granite now represented by pegmatites invaded the western portion of the area, where resultant hornfelsing is also much in evidence.

At a subsequent date the schists of the Cascade Valley were invaded by a great intrusion of peridotite, together with associated minor dyke-rocks, which is believed to have accompanied the folding movement of Lower Cretaceous times, and to be contemporaneous with the other ultrabasic intrusions of the South Island. All these rocks show signs of dynamic metamorphism resulting from shearing after intrusion, while the ancient metamorphic rocks of the Cascade and Jackson Valleys have suffered contemporaneous partial retrogressive metamorphism under epi-zone conditions.

Still later minor intrusives include diorite-pegmatites, and a group of tinguaites and camptonites which possibly belong to the Early Tertiary, and which have recently been described by the writer.*

Strongly folded Tertiary grits, sandstones, and limestones unconformably overlie the basement metamorphic and ingneous rocks, and are to-day represented by a small residual mass described by Cox (1877b) in the vicinity of the old Jackson's Bay settlement. Still more recent are the probably Late Pliocene conglomerates which underlie the Cascade Plateau, and outcrop along the northern wall of the lower Cascade Valley. The significance of these rocks has been discussed in a recent paper (Turner, 1930b, pp. 527-529).

In the latter publication the physiographic evolution of the southern half of the area now under consideration was dealt with, and need not now be recapitulated. It is sufficient to state that the whole area has been profoundly glaciated during Pleistocene times. Unconsolidated moraines belonging to this period are especially conspicuous on the surface of the Cascade Plateau, where they mantle the Pliocene conglomerates over an area of some 10 or 20 square miles.

Alluvium and river gravels form extensive infillings in many of the larger river valleys, while the shore-line from Jackson's Bay to beyond the Haast is flanked by a coastal belt, sometimes several miles in width, built up of Pleistocene and Recent alluvium and beach deposits.

The rocks of South Westland may be summed up in downward sequence as follows:—

(9.) Recent alluvium and beach deposits.
(8.) Pleistocene moraines and gravels.
(7.) Pliocene conglomerates of Cascade Plateau.
(6.) Mid-Tertiary marine sediments.
(5.) Tinguaites and Camptonites (? Early Tertiary).
(4.) Diorite-pegmatites.
(3.) Peridotites and associated minor intrusives (? Lower Cretaceous).
(2.) Granites and pegmatites (? Palaeozoic).
(1.) Metamorphic rocks (? Early Palaeozoic).

* F. J. Turner, *Trans. N.Z. Inst.*, vol. 62, pp. 215-229 (1932).

PETROLOGY AND DISTRIBUTION OF THE METAMORPHIC ROCKS.

Quartzo-feldspathic Schists, Gneisses, etc.

In the majority of the metamorphic rocks of southern Westland quartz and feldspar in highly variable proportions are the dominant minerals, though either chlorite, muscovite, or biotite is always present as an additional essential constituent. These rocks are grouped by the writer as quartzo-feldspathic phyllites, schists, hornfelses, etc.

The rocks are further subdivided into nine distinct groups, each of which is characterised by a fairly constant mineral assemblage or texture, depending partly upon variation in chemical composition of the original rocks, but more especially upon the degree and type of metamorphism to which the rocks in question have been subjected. As would be expected, there is often a certain amount of gradation from one group to another, so that intermediate petrological types may be recognised in these instances.

(1.) *Slates and Phyllites:* True slates (Nos. 1289*, 1306) were found in one locality only, viz., in the vicinity of Haast Pass at the head of the Mule Valley, where they outcrop abundantly, striking approximately north and south, the dip being always nearly vertical.

They are fine-grained, silky grey rocks with a highly perfect slaty cleavage, which is crossed obliquely by closely spaced strain-slip planes. In section the average grain-size is seen to be about 0.01 mm., though individual grains may occasionally reach 0.1 mm. in diameter. The most important constituents are quartz, mica, epidote, and fine dusty magnetite, while pale green chlorite and an alkali feldspar, though constantly present, are much less plentiful. In No. 1306 at least 50 per cent. of the rock consists of a fine-grained mosaic of quartz grains, while epidote and magnetite are especially abundant, mica in this specimen being of minor importance. No. 1289 is considerably more micaceous, however, and probably contains nearly 50 per cent. of fine muscovite. In all cases the mica is a pale green poorly birefringent variety, apparently similar to that described by Brammall (1921) from slates and phyllites from Bolivia, and identified by him as a slightly impure sericite, containing small amounts of iron and magnesium. The epidote, which in No. 1306 occurs as idioblastic minute prisms as well as in shapeless grains, is a nearly colourless and poorly birefringent type rich in the clinozoisite molecule and poor in iron. Pale blue and brownish tourmaline is a plentiful accessory in No. 1289, where it occurs as perfectly formed unoriented prisms which vary from 0.05 mm. to 0.2 mm. in length, thus greatly exceeding the average grain size of the other minerals present. Small veinlets of clear granular quartz cross the sections in all directions, while in No. 1306 there are a number of clear spots 1 mm. in diameter, consisting entirely of quartz and colourless muscovite.

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* Unless otherwise stated, numbers refer to specimens and sections in the collection of the Geology Department, Otago University.

Lustrous bluish grey phyllites (Nos. 1267, 1290) are exposed continuously along the gorge of the Haast River for a distance of about two miles on each side of its junction with the Wills. They pass gradually southward into the slates of the Upper Mule Valley, while to the north they grade with increasing metamorphism into quartz-albite-muscovite-chlorite-schists (e.g., No. 1307). The strike varies considerably both east and west of the general northerly trend, but north of the Wills it is fairly regular, and lies between 15° and 25° west of north. The dip is always nearly vertical.

No. 1267 (half mile south of Wills River, Haast Gorge). The hand-specimen shows well-defined bands, from 0.25 mm. to 1 mm. in thickness, which are rich alternately in quartz and in micaceous minerals, the quartzose bands being about twice as thick as the micaceous layers. Quartz veinlets, frequently crumpled and folded, cut across the schistosity at all angles. The essential minerals are quartz 50%, feldspar 10%, mica 10%, chlorite 10%, and epidote 20%. The grain size varies in different bands from 0.1 mm. to 0.4 mm., but is fairly constant throughout any particular layer. The quartz is in clear interlocking, sometimes sutured grains, with slightly undulose extinction, while the feldspar, which from its low refractive index is probably albite, is scattered in similar irregular untwined grains through the quartz mosaic. The mica is still the poorly birefringent sericite observed in the slates, but is more perfectly crystallised, and the greenish tint is very faint. The chlorite occurs in ragged flakes faintly pleochroic in pale green tints; the elongation is positive, and strong dispersion combined with very low birefringence produce the Prussian blue anomalous interference tint, when vertical sections are viewed between crossed nicols. It is thus a negative pennine such as Winchell (1927, p. 379) classes as delessite. The epidote is the normal ferriferous type, yellowish in colour, and highly birefringent, and is concentrated mainly in the micaceous layers of the rock. Accessory minerals include abundant small idioblastic prisms of light brown or pale blue tourmaline, a few small prisms of apatite, and rare magnetite grains.

No. 1290 (quarter mile north of Wills River, Haast Gorge) is closely similar, but contains minor actinolite in the form of scattered pale green or almost colourless needles, while one large porphyroblast measuring 3 mm. × 0.3 mm. and several smaller ones, all more or less parallel to the schistosity, were noted.

Several points in the mineral composition of the slates and phyllites described above call for comment. In the first place the abundance of quartz relative to mica is somewhat unusual. For example Dale (1914), in the numerous petrographic descriptions which accompany his account of the slates of the United States, in nearly every case lists the essential minerals in order of abundance as muscovite, quartz, and chlorite, though carbonates, biotite, or carbon may rise to predominance in particular instances. In the rocks under consideration the high quartz or quartz-feldspar content is more noticeable in the phyllites, probably due to the fact that the mineral composition may be estimated with much greater accuracy in these relatively coarse-grained rocks than in the fine-grained slates. It is on this account that the members of the slate-phyllite series are grouped among the quartzo-feldspathic rocks.

A second and more unusual feature is the invariable presence of abundant epidote in all specimens of slate and phyllite examined. The rarity of this mineral as an essential constituent in slates may be gathered from the fact that it is never mentioned, even as an accessory, among the petrographic descriptions of United States slates given by Dale (1914). Similarly it is absent from the slates of Ardennes, which, according to the careful investigations of A. F. Renard (1882), consist of muscovite 38% to 40%, chlorite 6% to 18%, quartz 31% to 45%, haematite 3% to 6%, rutile 1% to 1.5%, together with small amounts of limonite in some instances. In British slates, epidote though not usually plentiful, is by no means unknown, and may sometimes be moderately abundant. For example, Hutchings (1890, p. 267), in discussing the origin of a slate from the vicinity of Newcastle-on-Tyne records the presence of a considerable proportion of epidote which originated by decomposition of clastic biotite, which was itself derived from the breaking down of a two-mica granite. The same writer (Hutchings, 1890, p. 318) suggests that the abundant epidote of some of the Welsh roofing slates may also have originated in this way. He goes on to state (Hutchings, 1890, pp. 316 to 319) that in very fine fireclays the minute shreds of biotite, muscovite, kaolin, and exceedingly fine feldspar waste react with one another under slate-forming conditions to give new mica (sericite) and needles of rutile. On the other hand, in coarser-grained silts where abundant quartz is present, the large flakes of biotite undergo a different type of alteration, and give rise to epidote without the formation of rutile. The presence of abundant quartz and epidote and absence of rutile in the Haast rocks accord well with the conditions outlined by Hutchings; but the relatively low mica content of many of these rocks is difficult to explain on the assumption that the epidote is the result of decomposition of original clastic biotite, since according to Hutchings this reaction also results in the formation of considerable amounts of sericite.

Brammall (1921, pp. 221-223) has outlined a probable mechanism by which accessory epidote may be produced in some slates during the reconstitution of chloritic substances, but it must be admitted that a reaction of this sort could not give rise to such abundance of epidote as has been observed in the present instance.

Two other possible sources of epidote suggest themselves, namely, calcareous or basic igneous material in the original sediment. The presence of considerable amounts of sodic plagioclase and magnetite in some of these rocks appears to favour the latter of these two sources, a view which will be substantiated when the other members of the metamorphic series have been considered. It may be noted that Hutchings (1892, p. 219) states that in some of the ash-slates of the Lake District, epidote, accompanied by chlorite and calcite, has been generated by decomposition of the augite and other ferromagnesian silicates in the original ash.

A third point of interest is the almost universal development of relatively large perfectly idioblastic prisms of tourmaline, which in some cases are oriented parallel to the schistosity. Even though the grade of metamorphism is low and the nearest known outcrop of granite is many miles distant, the presence of this mineral suggests, according to the observations and deductions of Barrell (1921), the contact influence of a subjacent plutonic mass.

(2.) *Quartz-albite-chlorite-schists:* Under this heading are included a large number of schists in which quartz and sodic plagioclase, in variable proportions, are the dominant minerals, while in addition chlorite is always an important constituent. Typically the chlorite is accompanied by fairly plentiful muscovite (Nos. 1292, 1305, 1307), but in some cases (Nos. 1224, 1304, 1311, 1315) it may be almost or completely absent. Epidote and magnetite occur in relatively small but constant amounts, apatite is a universal accessory, while tourmaline and sphene were occasionally noted. The plagioclase, which in some cases may reach as much as 60% of the total composition of the rock, is always almost pure albite in clear, usually untwinned grains, with definitely positive sign and low refractive index. Orthoclase in small amounts was observed in only one section—No. 1224 (Turner, 1930a, p. 185)—but on re-examination of the section this determination is now listed as doubtful. The chlorite is an optically negative pleochroic variety (X = light yellow, Y = Z = deep green, Z > X) with small optic axial angle and low birefringence, in most cases giving the anomalous Prussian blue interference tint. Following Winchell (1927, p. 379) this may be classed as negative pennine or delessite. The mica is a typical colourless muscovite, but, as has frequently been observed in muscovites of low-grade metamorphism, the optic axial angle is often small. The epidote includes both iron-rich types with moderate birefringence and distinct pleochroism, and the nearly colourless poorly birefringent variety in which the clinozoisite molecule is greatly predominant.

Rocks of this type are well developed in the Haast Valley from about two miles north of the Wills confluence to two or three miles north of the junction of the Haast and the Burke. Southward they are seen to pass insensibly, through types such as No. 1307, into the phyllites of the Haast Gorge, while with increasing metamorphism they grade northwards into the biotite-bearing schists which outcrop just above the junction of the Haast and its great trbutary, the Landsborough.

The rocks which form the northern end of the Olivine Range east of the peridotite belt are also of this type. Though the valleys of the Arawata and Waiatoto Rivers east of the Olivine Range were not explored, it appears highly probable that a great area of schists, mainly of this type, continues east from the Olivine Range across the Main Divide, and connects with the Lake Wanaka region, where exactly similar schists of the "Central Otago" type are prominently developed.

Although not collected within the area at present under consideration, two specimens of quartz-albite-chlorite-schist from the Main Divide in the vicinity of Mount Aspiring are here recorded, on account of the inaccessibility of the region where they occur, and also since their presence lends some support to the suggestion that the whole of the area between Lake Wanaka and the Olivine Range consists mainly of schists of this type. The specimens in question (Nos. 1304 and 1305) were collected by Mr E. Miller, of Dunedin, to whom the writer's thanks are here expressed.

The following are typical examples of this group of schists:—

No. 1307 (McBride's Bluff, half mile south of Burke Hut, Haast Valley). Megascopically the rock is very similar to the phyllites further south (e.g., No. 1267), but the schistosity is more marked, and the bands of different mineral composition are more sharply defined, while the grain-size is sufficiently coarse to warrant classification as a fine-grained schist rather than a phyllite. Numerous secondary veins of quartz cut across the schistosity. The average composition of the rock as seen in a section perpendicular to the direction of foliation is quartz 35%, albite 25%, delessite 20%, muscovite 15%, epidote 5%, magnetite 1%, together with accessory idioblastic tourmaline. Sharply defined bands from 1 mm. to 3 mm. thick may consist entirely of quartz and a little albite. Others contain delessite and albite in equal proportions as the dominant minerals, while bands especially rich in muscovite and albite are less common. The muscovite is frequently interlaminated with delessite, but may also take the form of simple individual flakes. The epidote occurs as small granular crystals, with which patches of fine magnetite are usually associated.

No. 1292 (stream entering the Haast from the west, one mile below the Burke). The rock is typical of the muscovite-bearing schists of this group, and represents a slightly higher grade of metamorphism than No. 1307, as is indicated by considerably coarser crystallisation and even more perfectly developed schistosity. Albite and somewhat less plentiful quartz, in irregular grains from 0.3 mm. to 0.5 mm. in diameter, together make up about 70% of the rock. The remaining minerals are delessite 20%, and muscovite 10%, frequently interlaminated with one another, and about 3% of colourless clinozoisite which occurs as grains and subidioblastic prismatic crystals (sometimes reaching 0.4 mm. in length), that are always associated with fine grains of magnetite, and usually contain plentiful inclusions of the same mineral.

No. 1305 (summit of Mount French, Mount Aspiring district). The rock is a coarse-grained dark greenish schist composed of quartz 50%, albite 20%, delessite 10%, muscovite 10% to 15%, magnetite 3%, a small amount of pale poorly ferriferous epidote, and tourmaline as a rare accessory. In some parts of the section the grains of quartz and albite often reach from 1 mm. to 1.5 mm. in diameter, while in others they are much smaller and show sutured margins. The albites frequently contain inclusions of fine magnetite as dense patches and parallel bands, with which crystals of epidote may sometimes be associated. Normally the delessite occurs as ragged flakes arranged parallel to the schistosity, but in one part of the section it takes the form of a group of vermicular transversely fibrous inclusions included in a large grain of quartz. A single large crystal of tourmaline with a blue central zone and a brown border was observed, completely surrounded by one of the larger crystals of albite.

No. 1304 (summit of range east of Mount French) is a closely related rock, but is richer in albite, while muscovite is much less plentiful. The crystals of albite are often considerably larger than those of other minerals, and the texture thus approaches closely to porphyroblastic. Colourless, poorly birefringent epidote (Pl. 26, Fig. 1) is relatively abundant (5% to 10% of the total composition of the rock), and occurs as idioblastic prisms which sometimes attain a length of 0.4 mm., and are often associated with the usual dense clouds of magnetite, epidote-magnetite knots of this type frequently being enclosed in the albite porphyroblasts. There are several large grains of brownish sphene.

No. 1311 (200 yards east of peridotite margin, Red Spur, north end of Olivine Range). Megascopically this is a soft greenish rock with very distinct foliation, comparable with many of the schists of Central Otago. The component minerals are quartz 50%, albite 30%, delessite 10% to 15%, epidote 5% to 10%, and muscovite 1%. Alternate bands consist of albite and subsidiary quartz, pure quartz, and delessite, epidote, and albite in approximately equal proportions. The grains are highly irregular and often have sutured margins, while the average grain size is comparatively fine, varying between 0.05 mm. and a maximum of 0.3 mm. in the quartzose bands. The rock is certainly allied to the schist which outcrops two miles south on Martyr Spur, just east of the peridotite margin. This latter rock (No. 1224) has been described previously (Turner, 1930a, p. 185), and differs from No. 1311 mainly in the much greater abundance of yellow epidote, which is concentrated in well-defined bands consisting entirely of epidote and subsidiary chlorite.

(3.) *Corrugated Quartz-albite-muscovite-chlorite-schists:* The rocks included in this group were observed *in situ* in only one locality —on the western bank of the Jackson River, about 300 yards above its junction with the Arawata. This rock (No. 1334) is a thoroughly corrugated schist in which the original schistosity planes have been crumpled into close isoclinal folds. The mineral composition is close to that of the normal quartz-albite-chlorite-schists described above, an approximate estimate giving quartz 60%, plagioclase 30%, chlorite (delessite) 5%, muscovite 5%, together with accessory clinozoisite, magnetite, apatite, and sphene. The grain size varies in different bands from 0.1 mm. to 0.3 mm. The plagioclase is albite (about $Ab_{92}An_8$), and occurs as untwinned grains, somewhat elongated parallel to the schistosity, and usually showing somewhat rounded terminations. The quartz, on the other hand, is in highly irregular grains with perfectly sutured margins and showing undulose extinction. As is usual with schists of this composition, the chlorite and muscovite are often interlaminated.

In a previous paper (Turner, 1930a, p. 199) it was suggested that the Jackson Valley marks the north-easterly continuation of the great shear-zone which is occupied further south by the peridotite intrusion of the Cascade Valley, a view which has since been substantiated by further field evidence. Now the rock just described (No. 1334) actually outcrops at a point on this shear-zone. The structure and texture of the rock themselves point to complete recrystallisation under considerable stress, while the mineral assemblage is also typical of low-grade metamorphism, where shearing stress is the dominating influence and static pressure and temperature are relatively unimportant. In sharp contrast, the rocks which are exposed only a few yards west of the outcrop of corrugated schist are biotite-hornfelses and injection-rocks of distinctly different metamorphic facies, which continue for a distance of at least two miles west of the Jackson Valley.

The view is therefore put forward that the corrugated schist has been formed at a relatively late stage in the metamorphic history of the area, by complete recrystallisation of biotite-hornfels under localised intense stress in the Jackson Valley shear-zone. Since the change involved is one in which an assemblage of minerals formed under relatively high-grade metamorphic conditions has been broken down to a low-grade mineral association, the resulting rock is the product of retrogressive metamorphism, and is a true diaphthorite as originally defined by Becke (1909). In a recent paper on retrogressive metamorphism Eleanora Knopf (1931, p. 27) states that in cases such as the present instance, where the mineralogical adjustment to low-grade conditions of metamorphism has proceeded to completion, the resultant rock is often indistinguishable from a normal low-grade schist—in this case a normal quartz-albite-chlorite-schist —and the field relations alone indicate the true history of the rock. In this connection it may be mentioned that other evidence of retrogressive metamorphism in the Jackson and Cascade Valleys has been found, and some has already been noted (Turner, 1930a, p. 184).

Corrugated quartz-albite-muscovite-chlorite-schists similar to the above, but usually more micaceous (e.g., No. 1341), occur as boulders in Laschelles Creek. They are derived from the Cascade Plateau moraines, and their ultimate source probably lies among the schists of the Olivine Range towards the head-waters of the Cascade River.

(4.) *Quartz-plagioclase-biotite-schists:* Quartz-plagioclase-schists carrying varying amounts of biotite are especially well developed along the south side of the Haast Valley between the Landsborough junction, where they pass gradually into quartz-albite-chlorite-schists, and a point some distance west of Thomas Bluff, where with increasing metamorphism they grade into the quartz-plagioclase-biotite-gneisses of Big Bluff. As in the case of the rocks of the Upper Haast, the strike varies between 20° west of north and 20° east of north, and the dip which is always at high angles appears to be mainly towards the east. Biotite-bearing schists, corresponding to the least metamorphosed of the biotite-schists of the Haast, also occur along the south-eastern side of the Jackson Valley, where they appear to pass eastwards into quartz-albite-chlorite-schists, while on the north-west they are sharply limited by the Cascade-Jackson Valley

Fault. Rocks of this type are plentifully represented among the boulders of Turnley Creek and the Jackson itself.

The rocks of this group are invariably highly schistose with sharply marked thin layers alternately rich in mica and the light-coloured constituents. The most abundant minerals are quartz, plagioclase, biotite, and muscovite, but the essential petrographic feature of all members of this series is the presence of biotite, which now wholly or partly takes the place of the chlorite of rocks of lower metamorphic grade.

The feldspar is plagioclase, into the composition of which the anorthite molecule now perceptibly enters as the grade of metamorphism advances. In one abnormal instance (No. 1283) nearly pure albite was noted, but usually the anorthite-content reaches about 7% or 8% in the less metamorphosed members of the series, while in those rocks which approach the quartz-plagioclase-biotite-gneisses in composition and structure it may rise to between 15% and 30%.

A mineral of the epidote group is nearly always present, and occasionally may make up as much as 10% of the total mineralogical composition, while in one instance it reaches about 20%. Magnetite is a constant accessory, while apatite and tourmaline may also occur.

No. 1325 (boulders, Turnley Creek, Jackson Valley). In hand-specimen the rock is a grey schist closely similar to the quartz-albite-chlorite-schists described above, but with scattered spots of golden brown biotite showing up on the schistosity planes. The constituent minerals are quartz 30% to 40%, plagioclase 30% to 40%, muscovite 10%, epidote 10%, biotite 5%, and chlorite 5%. The grain-size averages 0.1 mm. to 0.2 mm. The water-clear irregular grains of albite have a refractive index lower than either that of Canada balsam or that for the ordinary ray in quartz, while the optic sign is positive, and the extinction angle X to 001 cleavage in sections perpendicular to the acute bisectrix is about 18°. The anorthite content is thus not greater than 5%. The muscovite is faintly pleochroic (Y = Z = pale green, X = colourless), with a relatively small optic axial angle. Biotite, with strong pleochroism from pale yellowish to deep yellowish brown, occurs as scattered irregular porphyroblastic knots which may reach 2 mm. or 3 mm. in average dimensions, and also as small wisps associated with the sparsely distributed flakes of pale green chlorite. The epidote takes the form of small colourless or yellowish grains, with fairly low birefringence indicating a low percentage of iron. Accessory sphene is also present.

No. 1309 (boulders, Turnley Creek, Jackson Valley) is a somewhat similar rock representing a slightly higher grade of metamorphism, and hence more typical of the biotite-bearing schists than No. 1325 described above. The biotite is better crystallised and more plentiful, and is strongly pleochroic from pale yellowish to deep sepia brown, while the anorthite content in the albite is about 7% or 8%. The latter mineral tends to form small porphyroblasts a little larger than the surrounding grains of quartz.

No. 1282 (Thomas Bluff, Haast River). The rock is a highly fissile, finely banded schist, and may be taken as typical of the great series of biotite-schists which outcrop over a distance of some 15 miles along the south side of the Haast Valley west of the Landsborough junction. In section the schistose texture is marked by sharply defined banding, and by elongation of the quartz grains and orientation of the micas parallel to the foliation. Grains of quartz averaging about 2 mm. in diameter, with sutured margins and pronounced undulose extinction, make up 50% of the rock. The plagioclase (about 10% of the total composition) is albite-oligoclase, $Ab_{90}An_{10}$. Strongly pleochroic biotite ($X =$ pale yellow, $Y = Z =$ deep reddish brown) is abundantly developed as ragged flakes up to 1.5 mm. long, which constitute 25% of the rock, while small oriented ragged flakes of muscovite are also abundant. Epidote, fine-grained magnetite, apatite, and rare prisms of brown tourmaline are the accessory minerals.

Nos. 1286 and 1288, which were collected from large masses and boulders in the bed of Douglas Creek, Haast Valley, are of interest in that they show the effects of somewhat more intense metamorphism than do the other biotite-schists of this part of the Haast Valley, and may therefore be regarded as intermediate between the biotite-schists and the biotite-gneisses to be described in a later section. Megascopically both rocks resemble the normal quartz-plagioclase-biotite-schists in the development of sharply defined, thin, alternately micaceous, and quartzose bands, but the grain is somewhat coarser and the rocks are noticeably more coherent than is usual in the biotite-bearing schists. On the other hand, the grain is much finer than in the coarse biotite-gneisses such as those of Big Bluff, Haast Valley.

No. 1286 consists of quartz 50%, muscovite 30%, biotite 15%, plagioclase 5%, and accessory apatite, magnetite, and tiny prisms of zircon. The quartz is in highly irregular, interlocking sutured grains from 0.1 mm. to 1 mm. in diameter, with marked undulose extinction. The plagioclase occurs in scattered, sometimes twinned grains with a maximum refractive index above that of the ordinary ray in quartz, while the maximum extinction angle is 6° to the albite twinning plane in sections perpendicular to 010. The sign is indeterminate since the optic axial angle approaches 90°. The variety is therefore oligoclase, with composition approximately $Ab_{85}An_{15}$. Muscovite and deep reddish brown biotite both occur in long ragged flakes oriented parallel to the schistosity.

In No. 1288 (Pl. 26, Fig. 2) the component minerals are plagioclase 40%, quartz 20%, biotite 15%, chlorite 15%, clinozoisite 10%, magnetite 1%, and accessory tourmaline. The grain is distinctly coarse, the average grain-size being 0.5 mm., while some crystals, notably the biotites, may attain as much as 2 mm. in diameter. The feldspar occurs in irregular grains, sometimes showing polysynthetic twinning, optically negative, with a maximum extinction angle of 17° to the albite twinning plane in sections perpendicular to 010. It is thus an acid andesine, about $Ab_{68}An_{32}$. It frequently contains finely vermicular quartz, which evidently represents an early stage in the development of the myrmekitic intergrowths that are so well displayed in many of the coarsely crystalline composite biotite-gneisses (see p. 202). An unusual feature is abundance of pale green nearly isotropic chlorite. The epidote mineral is mainly very poorly birefringent clinozoisite, as idioblastic prisms 0.3 mm. × 0.1 mm., which sometimes grade into poorly ferriferous epidote, the birefringence of which reaches 0.25. Idioblastic prisms of brown tourmaline are unusually plentiful in some parts of the section.

(5.) *Biotite-hornfelses:* In the previous paper already referred to (Turner, 1930a, pp. 174-180) a number of hornfelses, contact schists, hornfelsic paragneisses, and composite gneisses were grouped together as the " Older Metamorphic Series " of the Cascade Valley, and their distribution was described as fully as was then possible. Further field work has since shown that these rocks, except where mantled by small areas of Tertiary and Pleistocene deposits, underlie the whole of the coastal area between the Hope and Arawata Rivers north-west of the Cascade-Jackson Valley fault, while specimens supplied to the writer by Mr Eric James, of Makarora, indicate that rocks of this type also extend considerably south of the Hope River itself. North of the Arawata they reappear on the coast just south of Okuru at Mussel Point, where they outcrop from beneath the Quaternary alluvial and beach deposits, which constitute the coastal plain between Jackson's Bay and the Haast. Gneisses belonging to this group also are exposed in the large bush-covered knoll about one mile south of Mr J. Cron's homestead at the mouth of the Haast River, and again at Big Bluff some six miles inland.

Though the hornfelses and gneisses of this area are alike, in that all show marked effects of contact metamorphism by a subjacent mass of granite (see p. 204), rapid local variation in the relative importance during metamorphism, of such agents as heat, stress, injected igneous material, and magmatic emanations, has resulted in the production of a variety of distinct petrographic types. These are so intimately associated and grade so rapidly into one another that it is impossible to represent them separately upon the map.

The most widespread of these types is biotite-hornfels, which occurs very abundantly from Mussel Point southwards, though not yet observed among the rocks of the Haast Valley. The rocks are typically greenish-grey to brown in colour, fine-grained or less commonly of medium grain, without visible foliation, and show beneath the microscope the granoblastic texture typical of the hornfels group. The essential constituents of the unaltered rock are quartz, biotite, and plagioclase (albite-oligoclase to acid andesine in most cases), while muscovite is also present, usually to a minor extent only. Partial alteration of the biotite frequently gives rise to abundant chlorite, sphene, and sometimes epidote, while the feldspars may be partially or completely replaced by sericitic mica. With increasing development of these secondary minerals the biotite-hornfelses pass into chlorite-hornfelses, the origin of which will be discussed in the section dealing with rocks of that class.

The following are descriptions of typical biotite-hornfelses:—

No. 1329 (Arawata Valley, 1½ miles west of mouth of Jackson River). Macroscopically this is a medium-grained hornfelsic rock with scattered lustrous porphyroblastic crystals of muscovite from 3 mm. to 5 mm. in diameter, plainly visible on the broken surface. The rock, which is normally brown in colour, is irregularly blotched with lenses and patches of a light green colour where the biotite has been replaced by chlorite. The constituent minerals are quartz 50%, biotite and chlorite 20%, feldspar 25%, muscovite 5%, and sphene, apatite, magnetite, and a little epidote as accessories. The texture is granoblastic, the average grain size of the three essential components being about 0.2 mm. The quartz is in highly irregular sutured grains which show undulose extinction. The feldspar occurs as xenoblastic untwinned or rarely polysynthetically twinned grains, the optical properties of which indicate that it is albite carrying about 5% to 7% of anorthite. In a few cases it is almost unaltered, but usually it is partially or even wholly replaced by aggregates of fine sericite. The biotite is strongly pleochroic from pale yellowish to sepia brown, and shows all stages from incipient to complete replacement by a chlorite which is uniaxial, optically negative, and very poorly birefringent, thus corresponding to negative pennine or delessite. Finely granular sphene, representing the titanium content of the original biotite, is usually plentifully associated with these chlorite pseudomorphs. In addition to the secondary sericite there are several large highly irregular porphyroblasts of clear primary muscovite which enclose numerous grains of quartz to give a typical sieve-structure. Calcite occurs as occasional granular patches 0.1 mm. to 0.5 mm. in diameter, and is probably to be regarded as a secondary product developed during sericitisation of the plagioclase. The most plentiful accessory mineral is sphene, which was observed as large irregular primary grains in addition to the secondary sphene derived from biotite, while apatite and magnetite are somewhat less common. Epidote, also a decomposition product of biotite, was noted in one or two instances.

No. 1328, from the same locality as No. 1329, is a very similar though somewhat finer-grained rock, in which the alteration of biotite and feldspar is more complete and has proceeded along somewhat different lines from those followed in the previous specimen. The rock consists of a mosaic of clear quartz grains, among which numerous aggregates of biotite, sericite, epidote, and finely granular sphene are interspersed. The biotite occurs as ragged flakes, each of which typically is set in a mass of fine sericite mica containing plentiful grains of poorly birefringent epidote and pale yellow sphene, while magnetite and chlorite are occasionally present. The relation of the biotite to the sericite, and the presence of sphene associated with the latter mineral, suggest that the biotite is a primary product of hornfelsing, while the sphene and part at least of the sericite are secondary products derived from it. Though feldspar is absent from this section, its former presence is indicated by abundant clinozoisitic epidote associated with the sericite, much of which may thus have been derived from original plagioclase. It is therefore concluded that the aggregates of sericite, epidote, and sphene are the result of simultaneous alteration of biotite and sodic plagioclase during a late stage in the metamorphic cycle, subsequently to the crystallisation of a quartz-biotite-plagioclase-hornfels at an earlier stage.

The hornfelses from the vicinity of the bridge across Martyr Gorge (Nos. 1200 and 1201) and from alongside the track about one mile south-west of this locality (Nos. 1204 to 1207) have already been described (Turner, 1930a, pp. 175, 176), and little need be added with reference to these rocks. They are considerably coarser in grain than those from the Arawata Valley, and at the second exposure mentioned above are so closely veined with narrow dykes of granite and granite-pegmatite that the whole composite mass might be described as a coarse-scale lit-par-lit gneiss. The features which are characteristic of the injection-gneisses described later in this paper are confined, however, to narrow zones from 1 cm. to 5 cm. wide bordering the intrusive veins, while the intervening rock remains typically hornfelsic. It therefore seems advisable in comparing these rocks with those from other localities such as the Arawata Valley to consider the whole mass as a normal hornfels invaded by unusually plentiful granitic veins, rather than as a composite coarsely-banded gneiss.

Re-examination of the original sections and examination of fresh material has necessitated certain corrections and additions to the earlier descriptions cited above. The most important correction is with reference to the feldspars of the hornfelses, which were originally described as andesine, accompanied by a somewhat less amount of orthoclase. Though sericitisation renders determination of the optical properties somewhat difficult, it is safe to say that orthoclase could not be determined with certainty in any of these rocks, and is probably altogether absent. The plagioclase is usually oligoclase, but sometimes may be as basic as acid andesine, and varies between about $Ab_{90}An_{10}$ and $Ab_{70}An_{30}$ (No. 1204). As in the hornfelses from the Arawata Valley, the alteration product, which obscures most of the crystals of feldspar to a greater or less extent, is mainly sericite, and not kaolin as was previously stated. When chloritisation of the biotite has taken place, finely granular sphene and less commonly magnetite accompany the chlorite (e.g., Nos. 1200, 1201).

Biotite-hornfelses are plentiful among the boulders of Laschelles Creek, Cascade Valley. These are partly derived from the great series of conglomerates which underlie the Pleistocene moraines of the Cascade Plateau (Turner, 1930b, pp. 527-529), and partly from the large area of hornfelsic rocks which is drained by the upper portion of the creek itself. A general description of several representative specimens (Nos. 1215 to 1218) has already been given (Turner, 1930a, pp. 179, 180).

No. 1342 (boulder, Laschelles Creek) is typical of a porphyroblastic type of hornfels, which, although common at this locality, was not formerly recorded. Macroscopically the rock is a hard greenish-brown fine-grained hornfels mottled with small but conspicuous patches of white mica. The mineral composition is approximately quartz 40%, feldspar 25%, biotite 20% to 25%, muscovite 10% to 15%, and small grains of accessory magnetite, epidote, tourmaline, apatite, and sphene. Quartz, biotite, and feldspar constitute an equigranular mosaic throughout which are scattered large, highly irregular unoriented porphyroblasts of muscovite containing a great number of included grains of quartz, and thus showing perfect sieve-structure. Biotite, magnetite, and epidote may also occur as rare inclusions in the muscovites in some cases. The biotite is the usual reddish brown strongly pleochroic variety, and is unaltered. The feldspar includes equal quantities of microcline and plagioclase. The former occurs as water-clear often irregular crystals which frequently show the characteristic twinning of this mineral, while the plagioclase—medium oligoclase about $Ab_{80}An_{20}$—takes the form of angular or subangular untwinned grains which usually show incipient alteration to fine sericite.

Two main types of biotite-hornfels with intermediate gradations may thus be recognised among these rocks from Laschelles Creek. The more usual variety (Nos. 1215 to 1217) consists mainly of a granoblastic mosaic of quartz and biotite with minor muscovite, feldspar being absent or present in small amounts only. The presence of small quantities of labradorite and green hornblende in No. 1217 is an unusual feature worthy of emphasis. In the second type (e.g., No. 1342 just described) both plagioclase and microcline are present in considerable quantity in addition to the usual quartz and biotite, while large porphyroblasts of muscovite with perfect sieve-structure impart a distinctive appearance to the rock both in section and in hand specimen.

Biotite-hornfelses have also been described from the northern portion of the Hope-Blue River Range. A mineral provisionally identified as prismatine (Turner, 1930a, p. 179) was noted in a specimen (No. 1214) from this locality.

The origin of the biotite-hornfelses is intimately connected with that of the other metamorphic rocks with which they are associated, and its consideration will be left till a later section, when the sequence of events in the metamorphism of the whole area will be discussed. It is here sufficient to state that in texture they are typical hornfelses, the recrystallisation of which was governed mainly by high temperature, the influence of directed stress being negligible. They are the contact-metamorphic equivalents of original sediments. Comparison with associated gneisses and schists suggests that coarse porphyroblastic muscovite and interstitial microcline, when present, may have been developed by the action of percolating magmatic aqueous solutions rich in potash, emanating from the subjacent mass of granite magma to the presence of which the hornfelsing was itself due. Tattam (1929, p. 17) suggests a somewhat similar mode of origin for porphyroblastic muscovite of the " schistose hornfelses " described by him from North-east Victoria.

(6.) *Chlorite-hornfelses:* In almost every locality where the biotite-hornfelses are exposed they show patches of variable extent, where the normal brownish-coloured rock has undergone local alteration to light green chlorite-hornfels. This feature is well illustrated along the track between the Martyr-Jackson Saddle and Martyr Bridge, and again about one mile south-west of the bridge itself. Though the resultant rock is usually best described as normal biotite-hornfels mottled with greenish altered patches, in some cases, especially when the original rock was fine-grained, alteration is complete and the whole mass now consists of chlorite-hornfels.

The essential features of these rocks are granoblastic texture upon which the effects of more or less severe shattering have been superimposed, and the presence of chlorite and sericite replacing original biotite and feldspar (presumably plagioclase).

No. 1354 (boulder, Martyr Creek, 400 yards below gorge) is a typical fine-grained greenish chlorite-hornfels, crossed by highly irregular veinlets of secondary quartz about 1 mm. wide, which probably mark shear and fracture planes. The essential constituents are quartz 50%, chlorite 35%, and white mica 15%. The quartz is mostly in grains from 0.2 mm. to 0.4 mm. in diameter, some of which display incipient breaking down to smaller grains as a result of crushing. Constant features of the larger grains are undulose extinction and the development of bands of minute inclusions which are roughly parallel throughout the section. The chlorite is delessite (negative pennine), with strong pleochroism from fairly deep green (Y and Z) to light greenish yellow (X). It forms subidioblastic flakes which always contain numerous inclusions of granular sphene, and occasionally enclose grains of epidote or magnetite. As in the partially altered biotite-hornfelses described in the previous section, the chlorite obviously replaces biotite, the titanium content of which is now represented by the enclosed sphene. The white mica is mostly sericite in the form of patches or aggregates of small irregular flakes derived from feldspar, remnants of which may still be observed in rare cases. There is also a subsidiary amount of muscovite as relatively large, more regular crystals, comparable with the primary muscovite of the unaltered biotite-hornfelses. Very rarely grains of clear microcline were also noted. Coarse irregular grains of apatite and small idioblastic crystals of colourless to pale yellow tourmaline are plentiful accessories.

No. 1346 (boulder, Laschelles Creek, Cascade Valley) is a fine-grained green hornfels, with numerous tiny ramifying veinlets and streaks consisting largely of quartz and calcite. In section the rock is somewhat similar to that just described, but the effects of crushing are much more marked, so that a cataclastic texture has been developed. The grains of quartz, originally about 0.3 mm. in diameter, have been intensely shattered, so that residual angular grains of this dimension are now set in a crushed matrix consisting of small grains of quartz, along with pale green chlorite (delessite) and flaky sericite, respectively derived from biotite and feldspar. Granular sphene is everywhere included in the chlorite, while in some parts of the section occasional relics of biotite still persist. Irregularly disposed planes of intense shearing are marked by the presence of finely granular epidote, crushed quartz, and irregular streaks of calcite, the latter mineral probably representing the calcium content of now sericitised plagioclase.

No. 1218 (boulder, Laschelles Creek), described in a previous paper (Turner, 1930a, p. 180), is a chlorite-hornfels derived from an originally biotite-bearing rock containing occasional porphyroblastic sieve-muscovites and a small amount of clear microcline, both of which remain unaltered. The titanium of the biotite has given rise to the perfect development of needles of sagenetic rutile in the chlorite pseudomorphs which have now replaced it. Grains of sphene are fairly plentiful throughout the section.

The chlorite-hornfelses are believed to be the product of retrogressive metamorphism of rocks of the biotite-hornfels group, the chief mineralogical changes being chloritisation of biotite and sericitisation of feldspar, with the production of minor amounts of epidote and calcite in some cases.

In dealing with the mineralogical criteria of retrogressive metamorphism (diaphthoresis of Becke), Eleanora Knopf (1931, p. 22) emphasises the presence of sagenetic rutile in chlorite as a sure indication of its origin from biotite. The universal presence of inclusions of sphene in the chlorites of the chlorite-hornfelses under consideration doubtless has similar significance. Furthermore the transition of biotite to chlorite is often actually observable in the associated biotite-hornfelses, and the negative pennine or delessite so produced agrees well in its optical properties with the relatively dark-coloured strongly negative chlorite which Goldschmidt (1920, p. 45) considers to be indicative of diaphthoresis in the rocks of Stavanger district, southern Norway (E. Knopf, 1931, pp. 20, 21). Sericitisation of plagioclase and accompanying formation of clinozoisitic epidote are changes familiar enough in the low-grade metamorphism of igneous rocks, and have also been noted as retrogressive processes by Kieslinger (1926). (E. Knopf, 1931, p. 22.)

The mechanical effects of crushing and shearing displayed to some extent by all the chlorite-hornfelses examined, also lend strong support to the view that the mineralogical peculiarities of these rocks are due to retrogressive metamorphism. In this connection the following statements of Eleanora Knopf (1931, p. 7) may be quoted: "The existence of diaphthoresis implies that the rock in question has undergone, since the imprint of the earlier metamorphism (in this case hornfelsing), an active deformation of the sort to produce inner differential movements, that in some way . . . promote a molecular interchange and rearrangement that results in diaphthoresis." "If adjustment to the new pressure-temperature field is to take place the instigating force or trigger of the reaction must be furnished by a strong differential movement of the constituent parts before or together with the diaphthoresis."

In view of the above statements it is of special significance that the chlorite-hornfelses appear to attain a maximum development in the vicinity of the great shear-zone already referred to, along the line of the middle part of the Cascade and the Jackson Valleys. The diaphthoresis of the original biotite-hornfelses is therefore believed to have been instigated by shearing movements which affected these rocks at a late stage in the metamorphic cycle, subsequently to the hornfelsing, and which were especially powerful along the Cascade-Jackson Valley shear-zone.

(7.) *Biotite-andalusite-hornfels:* Andalusite is extremely rare in the metamorphic rocks of the Cascade-Arawata area, and in the previous paper cited (Turner, 1930a, p. 179) was recorded in only one specimen, a banded gneiss (No. 1212) of the hornfelsic paragneiss group. A quartz-biotite-oligoclase-hornfels (No. 1343), of which this mineral appears to have originally been a constituent, has since been collected from a boulder in Laschelles Creek, Cascade Valley.

This rock is a fine-grained grey hornfels consisting of quartz 50%, acid oligoclase 25%, biotite 20%, together with about 5% of secondary sericite, and accessory iron-ore, apatite, and epidote. The grains of quartz and oligoclase are mostly about 0.3 mm. in diameter, but there are also interstitial smaller grains resulting from incipient crushing. The biotite resembles that of the basic amphibole-schists in its strong pleochroism from pale yellow to very deep greenish brown, a sharp contrast with the reddish brown biotite which is almost universal in the biotite-hornfelses. The flakes are also unusually small (0.05 mm. to 0.1 mm. wide), and some show the first stages of alteration to deep green chlorite. Finely fibrous sericite occurs as sharply defined prismatic pseudomorphs reaching 1 mm. in length, with numerous rounded inclusions of quartz. This last feature, together with the prismatic outline, suggest that the original mineral might well have been andalusite, especially in view of the well-known tendency for this mineral to be replaced by " shimmer-aggregates " consisting largely of white mica. The alteration was probably brought about by retrogressive metamorphism, to which the partial replacement of biotite by chlorite and slight sericitisation of the oligoclase are no doubt also due.

(8.) *Hornfelsic Paragneisses:* The hornfelsic paragneisses are best developed *in situ* in the steep gorge of the stream which drains south-westward into Martyr Creek just below the ford where the track crosses that stream, 1½ miles above its junction with the Cascade River. Specimens 1208, 1349, and 1355 are from this locality. Boulders of this type are also plentiful in the bed of Colin Creek, which drains the north-western face of the Hope-Blue River Range, and are occasionally met with among the gravels brought down by Laschelles Creek.

Four characteristic features render these rocks conspicuous in the field, and equally distinctive when examined beneath the microscope. Though massive and compact, they always show very regular sharply-defined banding, due to alternation of fine and coarse texture, or differences in mineralogical composition of adjacent bands. Individual layers of the banded gneiss vary from 1 mm. to 100 mm. in thickness, but the thickness of a particular type of band remains fairly constant in any one specimen. The second characteristic feature is a general lack of schistosity due to more or less granoblastic texture, so that the rock breaks beneath the hammer in much the same fashion as a normal hornfels. In some instances, however (e.g., No. 1349), there may be marked fissility due to a tendency towards parallel orientation of the flakes of biotite and muscovite, in which case there is gradual transition towards micaceous schists, such as No. 1209 previously described (Turner, 1930b, pp. 177, 178). The third peculiarity of the hornfelsic paragneisses is a constant tendency for the biotite to crystallise as large usually unoriented porphyroblasts about 1 mm. or 2 mm. in diameter, especially in those bands which appear macroscopically to possess a coarse texture. Typically these large biotites enclose numerous inclusions of quartz, feldspar, and occasionally muscovite, and thus exhibit perfect sieve-structure. Finally muscovite is usually abundant in small well-formed flakes which only occasionally show parallel orientation.

The most abundant minerals are quartz, biotite, and muscovite, with variable but usually minor quantities of acid plagioclase, and accessory apatite, brown tourmaline, and sometimes magnetite. Andalusite is moderately plentiful in one case (Nos. 1211, 1212). As in all the typical rocks of the Quartzo-feldspathic Group, quartz and feldspar combined normally predominate over the micas, though particular bands of otherwise quartzo-feldspathic rocks may often contain very plentiful biotite and muscovite. With increasing development of these mica-rich bands, such rocks show gradual transition into the banded mica-schists of the Micaceous Group.

No. 1208 may be taken as a typical example of these banded paragneisses. The bands, alternately coarse and fine, are about 30 mm. in thickness, and are very sharply defined. In the fine bands (No. 1208a) the composition is quartz 40%, untwinned acid oligoclase 25%, biotite 25%, and muscovite 10%, with brown tourmaline and apatite as plentiful accessories. The quartz, feldspar, and muscovite constitute a mosaic of unoriented grains and flakes averaging about 0.2 mm. or 0.3 mm. in diameter. Ragged porphyroblasts of deep brown strongly pleochroic biotite (0.5 mm. to 1 mm.) occur throughout, and often show incipient sieve-structure due to the presence of included grains of quartz and less commonly flakes of muscovite. These porphyroblasts exhibit some degree of uniform arrangement parallel to the banding, in marked contrast with the totally unoriented condition of the surrounding crystals of muscovite. The coarser bands (No. 1208b) are surprisingly similar to the finer layers, the essential difference being the greater size of the biotite porphyroblasts, which now reach 1.5 mm. in diameter, and have very perfect sieve-structure. The surrounding mosaic is identical with that of the finer bands, except that quartz and muscovite are more plentiful while feldspar is present to the extent of about 5% or 10% only. Throughout the whole rock the effects of stress may be seen in the undulose extinction of grains of quartz and feldspar, and occasional distortion of crystals of biotite.

No. 1349 (Pl. 27, Fig. 7), representing a thick, fissile, coarse band collected a few yards distant from the specimen just described, is a closely similar rock. Most of the crystals of both biotite and muscovite, however, are arranged in approximately parallel position, with the 001 cleavage parallel to the direction of banding, thus producing the marked fissility already noted. An interesting textural feature, which indeed is commonly observable in the hornfelsic gneisses of the porphyroblastic type, is the equidimensional form assumed by the large biotites, which completely lack any trace of the normal flattening parallel to 001 (Pl. 27, Fig. 7). The small crystals of muscovite are nevertheless normal in this respect, and are noticeably elongated at right angles to the vertical crystallographic axis.

No. 1345 (boulder, Laschelles Creek) was collected from a coarse-grained non-schistose band which proved on sectioning to be highly micaceous, the assemblage of minerals being biotite 35%, muscovite 40%, quartz 15%, and acid oligoclase 10%. The biotite has the usual intense pleochroism from pale yellow to deep reddish brown, and occurs as large porphyroblasts 1 mm. or 1.5 mm. in diameter, enclosing numerous rounded grains of quartz and feldspar and very rarely flakes of muscovite (Pl. 27, Fig. 8). The surrounding groundmass is a mosaic of small unoriented crystals (about 0.05 mm.) of muscovite, quartz, and feldspar. Occasional grains of magnetite and epidote are associated with the biotite.

In a closely similar rock (S.W. 30, p. 217, Auckland University College collection) from the same locality the crystals of biotite are partially or completely replaced by pale green delessitic chlorite with small inclusions of sphene or sometimes of epidote. An unusual feature is the presence of a number of large unoriented porphyroblasts of chlorite with sieve-structure. It is distinctly pleochroic from rather pale green (parallel to X and Y) to almost colourless (Z), with relatively high refractive index (slightly higher than that of the biotite), very weak double refraction, strong dispersion, and frequently developed polysynthetic twinning. The crystals are elongated negatively, the optic sign is positive, and the optic axial angle is small. Rounded inclusions of quartz are numerous, and in each crystal are almost entirely restricted to a central hour-glass-shaped zone, the long axis of which is parallel to 001, much as described and figured by Simpson (1915, p. 74) in the case of chloritoid from Yampi Sound, Western Australia. The mineral thus closely resembles chloritoid, from which it differs only in its too low refractive index and weak absorption tints.

No. 1355 (boulder, Martyr Ford) is a very regularly banded rock consisting of alternating dark bands 0.5 mm. to 1 mm. in thickness and light-coloured bands from 2 mm. to 5 mm. thick. The average composition of the rock is quartz 50%, biotite 25%, oligoclase 15%, and muscovite 10%, with tourmaline and apatite as accessories. The oligoclase is of medium composition, about $Ab_{80}An_{20}$, and occurs in usually untwinned grains often partly replaced by sericite. Complete or partial alteration of biotite to delessite and subsidiary magnetite, as a result of retrogressive metamorphism at a late stage, may frequently be observed, the process being confined to irregular patches which bear no relation to the banding. The usual porphyroblastic development of biotite is totally lacking. In the lighter bands the four main constituents build up a granoblastic mosaic of unoriented grains in which biotite is present to the extent of about 10%, but in the darker bands the proportion of biotite rises to between 50% and 60% of the total composition, and the flakes are relatively large (0.5 mm. to 1 mm. in diameter). The distinctive features of this rock, which is a widely distributed type, are the unusually thin bands, complete lack of orientation of any of the constituents, and absence of porphyroblastic biotite with sieve-structure.

In considering the origin of the hornfelsic paragneisses, the prominent and regular banding combined with total lack of schistosity, or at most only moderate fissility, requires explanation. The banding appears comparable with the well-known colour-banding of the Moine Gneisses of Scotland, which is invariably commented upon in the numerous descriptions of those rocks in various memoirs of the Scottish Geological Survey. This feature of the Moine rocks is due to concentration of biotite or sometimes magnetite in particular layers, and has been taken by most writers on the subject (e.g., Read, 1926, p. 113) as indicative of a sedimentary origin for the rocks in question. Garnetiferous sedimentary gneisses, which are regularly banded on a coarse scale due to differences in composition of the original strata, have been described from the pre-Cambrian rocks of North America by several writers (e.g., Adams, 1895, p. 64; Adams and Barlow, 1910, pp. 173-191; Bruce and Matheson, 1930, pp. 119-132). More recently Tilley (1921, pp. 251-259) has given a comprehensive account of certain regularly banded garnetiferous paragneisses from South Australia, in some types of which the individual bands are less than ⅛in. in thickness. Commenting upon the origin of this feature Dr. Tilley states that it is "essentially a structure arising from initial differences of composition in the original sediments" (Tilley, 1921, p. 252).

By analogy it is therefore concluded that the banded structure of the Cascade Valley rocks is the direct result of variation in composition and texture throughout an initially finely stratified series of sediments. This assumption explains such petrological features as the restriction of andalusite in Nos. 1211 and 1212 to one set of bands, which doubtless represent laminae originally relatively rich in argillaceous material.

The textural features of the gneisses of this group plainly indicate that the dominating agency which controlled their crystallisation was high temperature, which was doubtless due, judging from the mineralogical similarities between the gneisses and associated biotite-hornfelses, to the same granite invasion which was also responsible for the hornfelsing of the latter rocks. As a result of localised stress in addition to high temperature, some degree of schistosity was imposed upon the gneisses in certain instances.

Local chloritisation of biotite and sericitisation of plagioclase, accompanied by minor development of strain effects, are attributed to incipient retrogressive metamorphism at a later stage.

(9.) *Composite Gneisses:* Under this heading are included certain coarse-grained, usually well-foliated rocks, which have originated as a contact phase of the sedimentary hornfelses, schists, and paragneisses, as a result of widespread invasion of these rocks by numerous small dykes of granite and granite-pegmatite. The term is applied only to rocks the structure and chemical composition of which have been considerably modified by accession of material introduced from the intrusive veins.

In the south-west portion of the map gneisses of this type are plentifully developed as narrow fringing bands, bordering the pegmatite veins which here invade hornfelses and hornfelsic paragneisses. In spite of their frequent development their total volume is relatively small in comparison with that of the normal invaded rock, since the individual bands of composite gneiss are usually only 5 cm. to 25 cm. in thickness. They are especially well shown, however, along the track at the south end of the bridge across the gorge of Martyr Creek, where bands of coarse gneiss several feet in width have been formed along the pegmatite-hornfels contacts. Narrow bands of gneiss derived from the biotite-hornfelses are also well exposed about one mile south-west of this locality, and again at intervals along the southern bank of the Arawata River for a distance of over one mile westward from the Jackson-Arawata confluence. These rocks have also been developed by contact alteration of the hornfelsic paragneisses in localities where the latter have suffered invasion by pegmatites.

In all the above cases restriction of the composite gneisses to the immediate vicinity of the intrusive dykes indicates clearly that their formation was governed by intrusion of pegmatites into rocks already completely recrystallised (as hornfelses or hornfelsic paragneisses) under high-temperature conditions. The field relations necessitate that the period of pegmatitic injection and gneiss formation was subsequent to the period of hornfelsing.

In the northern portion of the map gneisses of somewhat similar type are abundantly developed on the eastern flank of a heavily bushed knoll about one mile south of Mr J. Cron's homestead near the mouth of the Haast River, and again at Big Bluff on the south side of the Haast Valley, some six miles inland. The gneisses in this area are not confined to narrow bands bordering pegmatite intrusions, but constitute an extensive mass of rocks, which appear to have originated by very intense dynamo-thermal metamorphism of quartzo-feldspathic sediments, aided to a minor extent by widespread permeation by magmatic solutions, probably during the period of pegmatite injection. The rocks in question are relatively well foliated compared with the hornfelsic rocks further south, and this fact perhaps accounts for their much more complete permeation in the manner indicated above. The mineralogical changes induced by the pegmatitic fluids are not nearly so intense as in the gneisses from the southern portion of the map, and the amount of introduced material cannot be large. Eastward from Big Bluff there is perfect transition from gneisses showing minor effects of pegmatite injection, to the unmodified quartz-plagioclase-biotite-schists which occur so plentifully along the southern bank of the Haast from this point to the Landsborough.

Numerous descriptions of more or less closely similar gneisses of composite origin are to be found in the literature dealing with metamorphic rocks, but the nomenclature of such rocks is by no means uniform. K. Sugi (1930, pp. 75-96) uses the term " injection-rocks " to cover a variety of gneisses of this type from the Tsukuba district of Japan, where sediments of the Chichibu Series have been invaded and strongly metamorphosed by a granite batholith. This writer (Sugi, 1930, pp. 75, 76) states that two types of injection, not always clearly separable, have played an important part in the genesis of these rocks, namely, lit-par-lit injection, and impregnation by magmatic material without resultant banding. On the other hand, contact gneisses of similar origin, in which recrystallisation was accompanied by thorough permeation by magmatic solutions, have recently been described by C. M. Tattam (1929, pp. 17, 18) as " schistose hornfelses."

In the rocks at present under consideration the dominant genetic process appears to have been a thorough permeation of the whole rock by magmatic solutions under conditions of intense metamorphism, rather than lit-par-lit injection of individual layers of granitic material, though at the actual pegmatite-gneiss contacts this latter process has certainly operated to a minor extent. It is therefore proposed to include the rocks in question under the general heading of " composite gneisses "—a term which indicates origin by admixture of sedimentary and igneous material, without implying whether the introduction of magmatic matter was effected by general impregnation or by actual injection of definite layers. According to Holmes (1920, p. 66) this expression was introduced by Professor Grenville Cole in 1902 to include " gneisses produced by the intimate association, with or without molecular intermixture, of two different materials, the one (generally a granitic magma) having been injected into the other." Composite gneisses as defined above would therefore include both purely lit-par-lit gneisses (e.g., Cole, 1916) and also such rocks as the gneisses here described.

The composite gneisses of South Westland are coarse grained, foliated rocks in which quartz, biotite, plagioclase (acid oligoclase to medium andesine), and muscovite are the essential constituents. Either orthoclase or microcline may be present in small amounts in a few instances, while sillimanite is developed in some of the coarser-grained rocks, where the influence of pegmatitic solutions has been particularly potent. Apatite is constantly present, and may even rise to about 2% of the total composition of some specimens, while tourmaline, magnetite, and less commonly sphene or zircon are the usual accessories. Marked parallelism of the micas is a conspicuous feature of the gneisses of this group. Another highly characteristic textural feature is the development of myrmekitic intergrowths of plagioclase and quartz, while similar intergrowths of quartz with muscovite (Pl. 27, Fig. 5) and rarely biotite (Pl. 26, Fig. 4) are perfectly displayed in sections representing specimens collected from the immediate vicinity of pegmatite contacts. The effects of retrogressive metamorphism subsequent to the main crystallisation are seen in partial sericitisation of feldspar and chloritisation of biotite, accompanied by such cataclastic features as undulose extinction in quartz grains, partial granulation of quartz and feldspar, bending of cleavage-laminae in the micas, and development of microcline-structure in orthoclase.

No. 1278 (bushed knoll, one mile south of Mr J. Cron's homestead, near mouth of Haast River). Macroscopically this is a moderately coarse-grained gneiss with rather poorly developed banding and foliation, and having the general appearance of a granite-gneiss. In section, however, it is seen to consist of feldspar 40%, quartz 20%, biotite 20%, muscovite 20%, and occasional large irregular grains of apatite. The feldspar is entirely plagioclase, with the optical properties of acid andesine approximately $Ab_{67}An_{33}$, and frequently shows albite twinning. It occurs in large crystals from 0.5 mm. to 1 mm. in diameter, which in some parts of the section have been reduced by crushing to masses of angular grains of much smaller size. The grains of quartz are highly irregular, and vary from 0.1 mm. to 1 mm. in width, the usual mode of occurrence being as aggregates of small grains showing sutured or mosaic texture, which have evidently originated by crushing and recrystallisation of larger individuals. Strongly pleochroic deep reddish-brown to pale yellow biotite and colourless muscovite occur in xenoblastic flakes from 0.5 mm. to 1.5 mm. in length, often much twisted and frayed as a result of shearing (Pl. 26, Fig. 3). Incipient alteration of biotite to epidote, or to chlorite and included sphene, may occasionally be observed.

No. 1279, from the same locality, is a closely similar though somewhat coarser rock, in which quartz is more plentiful and muscovite much less abundant than in No. 1278. The feldspar is entirely plagioclase with the composition of medium andesine $Ab_{60}An_{40}$, and occurs in large partially sericitised grains which show only slight signs of crushing. The quartz, on the other hand, is in considerable-sized interstitial masses of angular or sutured grains, occupying the spaces between the feldspathic parts of the section. Stout prisms of apatite about 0.5 mm. long are abundant, while zircon and finely granular magnetite are less plentiful accessories.

No. 1280 (Big Bluff, Haast Valley) is macroscopically similar to the two preceding specimens, except that the micas show more pronounced parallelism and the foliation is consequently more conspicuous. The minerals present are quartz 20%, feldspar 35%, biotite 15%, muscovite 30%, and magnetite 0.5%, with plentiful apatite and tourmaline and rare zircon as accessory constituents. The quartz is in small, extremely irregular grains, which usually show undulose extinction, and are sometimes diablastically enclosed by porphyroblasts of feldspar. The latter mineral appears to be acid oligoclase, and occurs as xenoblastic crystals of small size, rarely showing albite twinning, and also as shapeless porphyroblasts about 2 mm. in diameter, which often enclose rounded quartz grains. In some of these masses quartz and feldspar are intergrown on a fine scale, and constitute a true myrmekitic intergrowth, throughout which the minute vermicular inclusions of quartz extinguish simultaneously. Large ragged porphyroblasts of deep reddish-brown biotite and small xenoblastic flakes of muscovite are plentiful. Both micas often show the effects of shearing, and the biotite is frequently slightly chloritised. The tourmaline is in relatively large idioblastic prisms, which may be blue, brown, or sometimes blue with a brown border. The apatite is faintly but very distinctly pleochroic, from bluish (X) to a very pale green tint (Z), the absorption being weak $(X > Z)$.

No. 1281 (Big Bluff, Haast Valley) is of the same general type as the preceding specimen (No. 1280), but differs from the latter rock in the absence of porphyroblasts of plagioclase and biotite, and in the presence of orthoclase to the extent of about 5% of the total composition. This occurs as ragged interstitial masses from 0.2 mm. to 1 mm. in diameter, which usually enclose very numerous rounded grains of quartz and plagioclase, and which are conspicuous on account of their low refractive index and water-clear appearance. The plagioclase—medium oligoclase—is subordinate to quartz. It may be untwinned or sometimes twinned according to the albite law, and rarely is seen to form myrmekitic intergrowths with quartz. Though these intergrowths were sometimes observed at plagioclase-orthoclase junctions, while in one or two instances rounded inclusions of myrmekite are actually enclosed by orthoclase, the formation of myrmekite appears on the whole to be independent of proximity to orthoclase. The accessory minerals include abundant magnetite and minor epidote, apatite, sphene, and zircon.

The rocks from Big Bluff are in every way intermediate between the gneisses further west (Nos. 1278 and 1279), in which foliation is not pronounced and the feldspar is andesine, and the perfectly schistose, relatively fine-grained quartz-plagioclase-biotite-schists of Thomas Bluff (No. 1282) in which the feldspar is albite-oligoclase.

The development of thin bands of composite gneiss from biotite-hornfels adjacent to dykes of pegmatite 1 ft. to 5 ft. in width, may easily be observed at various points along the track on the southern bank of the Arawata River, between one mile and one and a-half miles west of the mouth of the Jackson. The following series of specimens from this locality exemplify successive stages in the development of gneiss from hornfels:—No. 1329, biotite-hornfels; No. 1330, fine-grained gneiss; No. 1331, coarse-grained gneiss; No. 1332, very coarse gneiss immediately adjacent to pegmatite margin.

No. 1329, which has already been described on p. 192, is a typical biotite-hornfels, consisting of a granoblastic mosaic of grains of quartz, biotite and albite (Ab_{93} to Ab_{95}) averaging 0.2 mm. in diameter, accompanied by a small quantity of muscovite in large porphyroblasts with sieve-structure.

No. 1330 differs from the adjacent hornfels mainly in the gneissic structure and considerably coarser grain-size, which is here approximately 0.5 mm. The constituents are quartz 30%, feldspar 40%, biotite 30%, muscovite 1%, and accessory apatite, sphene, magnetite, secondary epidote, and rarely zircon. The quartz occurs in small aggregates of sutured grains, the result of subsequent recrystallisation of larger grains under stress during retrogressive metamorphism. The feldspar is albite-oligoclase approximately $Ab_{90}An_{10}$, and is in the form of somewhat sericitised xenoblastic grains which quite often are twinned according to the albite law. The deep reddish-brown biotite in places appears to be undergoing replacement by muscovite along the cracks. Porphyroblastic muscovite is absent.

No. 1331 macroscopically is a typical coarse-grained gneiss rich in large crystals of micas, and containing light-coloured veinlets of quartz and feldspar about 3 mm. in width, which give the rock a foliated appearance and appear to be a direct product of igneous injection. The section represents one of the more micaceous bands, and consists of quartz 40%, feldspar 25%, muscovite 25%, biotite 10%, magnetite 1%, abundant apatite, and sphene, occasional zircon, and secondary epidote as less plentiful accessories. The grain-size is notably coarser than in the previous section, and varies from 0.3 mm. to 3 mm. The quartz constantly shows undulose extinction, and occurs either in large irregular grains about 1 mm. in width or else in broken-down aggregates of sutured granules. The large untwinned crystals of feldspar prove to be acid oligoclase, and are often considerably altered to sericite. Reddish-brown biotite forms large ragged flakes, which sometimes contain small zircons surrounded by dark pleochroic haloes, while stout xenoblastic grains of apatite are plentiful. In comparison with the previous two sections the most striking mineralogical feature is the presence of very plentiful fibrous muscovite in highly irregular masses and streaks, some of which are continuous across the full width of the section. In some instances this mineral appears to have effected partial or complete replacement of biotite with simultaneous formation of magnetite, sphene, and epidote in small quantities. In others it appears to have formed at the expense of the feldspar, while in other cases again it has simply crystallised as interstitial masses between the quartz aggregates.

No. 1332 represents one of the quartzo-feldspathic bands in a coarse gneiss immediately adjacent to the margin of a pegmatite dyke. The essential minerals are quartz 60%, feldspar 25%, muscovite 10%, and biotite 5%. The texture is exceedingly coarse, the average grain-size of the principal minerals being 3 mm. to 5 mm. The feldspar occurs in large, highly irregular masses, which penetrate interstitially between the quartzes, and is always considerably altered to sericite. The refractive index is distinctly lower than that for the ordinary ray in quartz, and traces of multiple twinning indicate that it is probably albite-oligoclase. The presence of orthoclase is improbable, since in the gneisses of this group, potash feldspar is almost invariably water-clear and free from sericitisation. The large ragged flakes of deep brown biotite have in many cases suffered partial replacement by delessite, through which wisps of muscovite, granular sphene, and magnetite are scattered in small amounts. The muscovite occurs in masses of small, irregular twisted flakes, with sparsely distributed inclusions of chlorite, magnetite, sphene, and rarely vermicular quartz. The accessories include several large grains of apatite and occasional small crystals of zircon. The quartz is particularly coarse-grained, and shows very clearly the effects of retrogressive metamorphism subsequent to the main crystallisation. The large crystals show marked undulose extinction, and are traversed by innumerable cracks, while in many instances they have undergone partial recrystallisation under shearing stress, so that clear areas of small interlocking sutured grains have been developed either along the periphery of the parent crystal or in some cases enclosed deep within it. Absence of cracks in these secondary areas indicates that the recrystallisation occurred subsequently to the shattering and cracking of the large individuals. In a recent account of the phenomena of retrogressive metamorphism, Eleanor Knopf (1931) gives an instructive description of the textural criteria by which phyllonites (phyllite-mylonites) may be recognised, and makes the following statement, which is of interest in its bearing upon the origin of the textural peculiarities of the quartz grains in the section described above: "Particularly characteristic of phyllonites is the development of quartz lenses or nests of quartz grains that result from the breaking down of larger quartz individuals" (Knopf, 1931, p. 18). In specimen No. 1332 this breaking down process has not proceeded beyond the initial stages.

At the south-western end of the bridge which spans the gorge of Martyr Creek at its upper end, the metamorphic effects of pegmatite intrusions upon the surrounding biotite-hornfelses attain a maximum intensity, and bands of very coarse grey gneiss several feet in width here border the intrusive dykes. In the resultant rock the development of closely spaced, thin streaks, and discontinuous bands rich in biotite has given rise to a most pronounced gneissic structure, which is accentuated by marked parallelism of the mica flakes. The crystals of biotite increase in size and abundance as the pegmatite margin is approached, and the actual contact itself is marked by special abundance of both biotite and muscovite in flakes which sometimes attain from 1 cm. to 5 cm. in width. In the immediate vicinity of the pegmatite masses the gneiss contains well-defined veinlets and lenses of quartz and feldspar, which conform to the foliation and vary from 1 cm. to 5 cm. in thickness, while in several specimens lenticular masses of pure feldspar as much as 5 cm. thick in crystalline continuity throughout were noted. Quartz-feldspar bands of this type are obviously the product of injection of igneous material from the adjacent pegmatites.

The surrounding hornfels into which these gneisses imperceptibly pass is typified by Nos. 1200 and 1201 (north-east end, Martyr Bridge), which are relatively coarse-grained granoblastic rocks, the mineral composition of which is quartz 50%, acid oligoclase 25% to 30%, biotite (partly chloritised) 15% to 20%, coarsely porphyroblastic muscovite 2%, and accessory apatite, brown tourmaline, magnetite, and secondary sphene. The grains of the three principal constituents average 0.5 mm. in diameter.

No. 1337 is typical of a number of sections which were cut from specimens of coarse grey gneiss about 1 ft. to 2 ft. distant from pegmatite contacts. It differs from the surrounding hornfels mainly in the strongly gneissic structure and coarser grain, both of which are strikingly apparent in the hand-specimen, but the mineral composition proves to be surprisingly similar, being quartz 45%, acid oligoclase 30%, biotite 20% to 25%, muscovite 2%, with iron ore and abundant coarse apatite as accessories. As in the hornfels, both quartz and feldspar show undulose extinction. The plagioclase rather frequently is twinned after the albite law. The deep red-brown biotites are arranged parallel to the foliation, and sometimes contain marginal inclusions of sagenetic rutile.

No. 1338 (south-west end, Martyr Bridge) represents the very coarse mica-rich contact phase developed at the actual contact between pegmatite and gneiss. Two sections were cut and examined, the average mineral composition being quartz 20%, feldspar 15%, biotite 15%-20%, muscovite 40%, sillimanite 5%, apatite 2%, iron ore 1%. The texture is very coarse, the average grain-size of the four main constituents being 2 mm. to 3 mm. The bulk of the quartz occurs in irregular interlocking grains of large size, with marked undulose extinction and often containing lines of minute dark inclusions. It also very commonly takes the form of perfectly developed vermicular inclusions intergrown with plagioclase (myrmekite), muscovite (Pl. 27, Fig. 5), or even biotite (Pl. 26, Fig. 4). Such inclusions are often in optical continuity over areas 2 mm. or more in diameter, in which they need not necessarily be restricted to one particular enclosing crystal, nor even to crystals of one particular mineral. In several instances vermicular quartz of a myrmekitic intergrowth was observed to be optically continuous with that of an adjacent intergrowth of quartz and muscovite, while occasionally an individual vermicular body of quartz may even be enclosed partly in muscovite and partly in the adjoining plagioclase. The feldspar includes both orthoclase and acid oligoclase, the former predominating. The orthoclase is very coarsely crystalline, faintly dusted with kaolin, and sometimes shows patchy incipient development of microcline twinning, especially in strained and shattered crystals with strongly undulose extinction. Much of the orthoclase is traversed by irregular veinlets and patches of muscovite which has formed along the cracks (Pl. 27, Fig. 6), and in this way may often have replaced more than half of the original crystal. Oligoclase is in coarse clear crystals which nearly always contain abundant vermicular inclusions of intergrown quartz—a perfect example of myrmekitic intergrowth. Though the myrmekite may sometimes be adjacent to or even enclosed in crystals of potash feldspar, elsewhere it is in contact with crystals of quartz or mica, and its development thus appears to be entirely independent of the presence of orthoclase. The most abundant constituent of the rock is muscovite, which may occur as large ragged crystals some of which appear to have been formed at the expense of potash feldspar, and also as streaks and patches of fibrous muscovite which certainly replace orthoclase or microcline. Intergrowths of muscovite and quartz, throughout which the quartz inclusions are optically continuous, are exceedingly common. Sometimes the quartz is in the form of curving and twisted vermicular bodies of relatively large size (0.4 mm. × 0.1 mm.), comparable with those of the myrmekite described above. Elsewhere it takes the form of closely packed rectilinear inclusions (1 mm. × 0.01 mm.) arranged parallel to the cleavage of the intergrown muscovite. Fine-grained regular intergrowths of this last type not uncommonly fringe large crystals of muscovite devoid of inclusions, especially where the latter lie adjacent to partially replaced crystals of orthoclase or microcline. The biotite is very strongly pleochroic (X = very pale brownish yellow, Y = Z = very deep reddish-brown), and in rare instances appears to have undergone partial replacement by muscovite. Intergrowths of biotite and fairly coarse vermicular quartz are not common, but occasionally constitute a conspicuous irregular fringe around biotite crystals without inclusions (Pl. 26, Fig. 4). The biotite of the central crystal is always in optical continuity with that of the bordering intergrowth, while the quartz inclusions of the latter are elongated parallel to the cleavage of the enclosing biotite. Sillimanite is somewhat sporadically distributed through the rock, but is often very plentiful in the coarse mica-rich areas. It is in idioblastic slender prisms about 0.5 mm. × 0.05 mm., which are usually grouped in uniformly parallel or sometimes felted aggregates in close association with crystals of biotite or muscovite. Less commonly smaller groups of parallel prisms lie along the margins of the quartz or feldspar crystals, or, more rarely still, scattered crystals of sillimanite may actually be enclosed within grains of these minerals. Several clear instances were noted in which masses of prismatic sillimanite have partially replaced both biotite and muscovite, small ragged remnants of which still persist throughout the replacing felt of sillimanite prisms, much as described by Tattam (1929, pp. 19, 24) in gneisses from North-east Victoria. In other cases the crystals of mica fray out terminally into a fringe of parallel prisms of sillimanite, a phenomenon which seems to be not uncommon in composite gneisses of this type (e.g., see Sugi, 1930, p. 78; Adams and Barlow, 1910, p. 133). Very coarse grains of apatite, which may reach 3 mm. in diameter, are fairly plentiful. Epidote occurs as very rare yellowish grains derived from the biotite, while fairly coarse magnetite has sometimes been formed as a secondary product during replacement of biotite by sillimanite. As compared with the adjacent grey gneiss (e.g., No. 1337) the main features of the contact-gneiss described above are very coarse grain, abundance of muscovite, presence of sillimanite and orthoclase, and development of intergrowths of quartz with plagioclase, muscovite, or biotite on a very perfect scale.

Nos. 1335, 1202, and 1203, from the southern end of Martyr Bridge, are also typical examples of the coarse contact phase of the gneiss of this locality.

No. 1335 represents a band richer in quartz and feldspar than No. 1338, and consists of quartz 25%, feldspar 40%, biotite 15%, muscovite 20%, sillimanite 1%, with accessory quantities of magnetite, coarse apatite, and sphene. Orthoclase is absent, all the feldspar being acid oligoclase (about $Ab_{85}An_{15}$), which often shows albite twinning. Sillimanite is not so well developed as in the previous section. It normally occurs as swarms of acicular prisms enclosed in muscovite or as fringes of parallel needles fraying out from the borders of some of the biotite crystals, though in rare instances it may be enclosed by quartz or plagioclase. Myrmekite and quartz-muscovite intergrowths are very perfectly and plentifully developed, while rather indefinite intergrowths of quartz and biotite are much less frequent. In other respects the section closely resembles the preceding one (No. 1338).

A description of Nos. 1202 and 1203 has already been given (Turner, 1930a, pp. 175-176). They are essentially similar to Nos. 1335 and 1338 described above, but differ in several important respects. Intergrowths are practically absent, muscovite is not nearly so plentiful as in the previous specimens, while sillimanite is more abundant. Orthoclase appears to be absent, but plagioclase (oligoclase-andesine, $Ab_{70}An_{30}$) is abundant in slightly altered, often well-twinned crystals.

The hornfelsic paragneisses, which outcrop in the gorge of the minor tributary which drains into Martyr Creek about one mile and a-half above its junction with the Cascade River, have also been invaded by numerous small dykes of pegmatite and veins of nearly pure quartz. These intrusions have never affected the invaded rocks sufficiently to develop definite bands of composite gneiss, but their metamorphic effects, though confined to very narrow marginal zones, are nevertheless distinct and somewhat comparable with the much more complete alteration displayed in the other areas considered. The contact between hornfelsic gneiss and a tourmaline-pegmatite is shown in section No. 1222 (Turner, 1930a, pp. 177, 181-182).

With reference to the origin of the composite gneisses the following features are significant, and may be discussed at this stage:—

(a.) The field occurrence. The composite gneisses usually occur as marginal bands along the contacts between hornfelses or hornfelsic paragneisses, and the swarm of pegmatite veins which invade them. In the northern part of the map, however, extensive masses of composite gneiss veined with pegmatite occupy considerable areas near the sea coast, and merge gradually eastward into the quartz-biotite-plagioclase schists of the Haast Valley, where pegmatites are absent. The field relations alone therefore clearly indicate that the recrystallisation of the composite gneisses into their present condition was due to the metamorphic influence of the invading pegmatites upon the invaded hornfelses, paragneisses, and schists. The increase in temperature resulting from such intrusion cannot have been great, for the invading bodies themselves were of only small magnitude; but percolating magmatic fluids thoroughly permeating rocks which had already attained a high temperature, as a result of recent uprise of a subjacent batholith, would certainly be potent agents capable of bringing about complete recrystallisation and introducing new material of magmatic origin. This general permeation appears to have been of much greater importance than actual lit-par-lit injection, which is by no means common, and is restricted to the immediate vicinity of some of the larger dykes.

The importance of large-scale impregnation and " soaking " of the surrounding rocks during batholithic invasion is well known, and has recently been emphasised by Fenner (1914, pp. 697-699; 718-721), who draws attention to the conclusions deduced in this connection by Lacroix and Michel-Levy from observation of contact phenomena in the Pyrenees. In his recent account of the injection rocks of the Tsukuba district of Japan, Sugi (1930, pp. 77, 101-102) also stresses the importance of igneous impregnation in the genesis of this type of rock.

In the Haast-Cascade area the magmatic impregnation responsible for the formation of the composite gneisses was connected with the pegmatitic phase of igneous intrusion, not with the main uprise of granite magma which evidently preceded it and was responsible for the initial hornfelsing.

(b.) Gneissic texture. The composite gneisses all exhibit well-developed gneissic texture, dependent upon the arrangement of crystals of biotite, and less commonly muscovite, parallel to the pegmatite-gneiss contacts. The dykes of pegmatite themselves display a marked tendency to parallelism in any given locality, so that the whole mass might often be described as a lit-par-lit injection gneiss on a very coarse scale. It follows, therefore, that the intrusion of the pegmatite and the attendant metamorphic alteration of the adjacent rocks must have taken place under powerful directed stress.

(c.) Presence of orthoclase or microcline. Except in rare instances potash feldspar is absent from the unmodified hornfelses, schists, and paragneisses of the district. On the other hand, microcline or orthoclase, though by no means universal, may often be noteworthy constituents of the composite gneisses, especially in the coarser phases adjoining pegmatite contacts. It appears highly probable, therefore, that the potash feldspar of these rocks has been introduced by potash-bearing fluids from the invading pegmatites, especially in view of the fact that microcline or orthoclase are usually plentiful in these latter rocks (Turner, 1930a, pp. 181-182).

(d.) Typically muscovite, is much more prominent in the composite gneisses than in the parent rocks, and there is further a marked tendency for this mineral to be especially abundant, along with equally plentiful biotite, in the highly micaceous contact phase which usually is developed along the pegmatite margins. While much of the coarse muscovite appears to be primary, in other cases aggregates of fibrous muscovite seem to have partially or entirely replaced crystals of other minerals, notably orthoclase, plagioclase, and biotite. Much of the muscovite is thus probably of magmatic origin, and, like the potash feldspar, has formed under the influence of potassic pegmatitic fluids.

It has already been pointed out that some of the invaded hornfelses (e.g., Nos. 1218 and 1342) contain muscovite in two totally distinct habits—small clear-cut flakes scattered through the granoblastic mosaic, and large ragged porphyroblasts sieved through and through with quartz inclusions. It is suggested, therefore, that the porphyroblastic muscovite of the hornfelses like that of the composite gneisses owes its potash content to percolating magmatic fluids, a suggestion which is strongly supported by the almost universal presence of associated microcline in small amounts in hornfelses of this type.

(e.) Apatite and tourmaline are almost universally distributed in accessory amounts through all the metamorphic rocks of Southern Westland, and are doubtless due largely to emanations from subjacent masses of granite. Very coarse apatite of undoubted pegmatitic origin is especially plentiful in many of the composite gneisses, while in one instance (No. 1222) coarse idioblastic tourmaline has been developed in a similar manner at the contact between hornfelsic paragneiss and a tourmaline-pegmatite.

(f.) The composition of the plagioclase. In the composite gneisses the feldspar is mainly plagioclase, ranging from acid or medium oligoclase in the majority of cases to acid andesine or even andesine of medium composition. The chemical composition of the plagioclase is thus found to correspond moderately closely with that of the parent rocks. It is well established that the feldspars of the plagioclase series are very sensitive to changes in conditions of metamorphism, and that while albite is the stable member under low-grade metamorphic conditions, anorthite enters increasingly into the composition as the grade of metamorphism becomes higher. It therefore appears that the conditions of temperature and pressure which obtained during the period of pegmatite injection were not greatly different from those which prevailed during the preceding hornfelsing phase of metamorphism, since the composition of the plagioclase was much the same in each case.

In most cases the plagioclase of the pegmatites corresponds closely in composition with that of the adjacent gneiss, the limits of variation in the former case being $Ab_{90}An_{10}$ and $Ab_{67}An_{33}$. It is therefore possible that in certain instances the plagioclase of the invaded hornfels may have been modified to conform with that of the intrusive pegmatite, by local reaction with pegmatitic fluids during crystallisation of the resultant composite gneiss. Such reaction is difficult to demonstrate, since the plagioclase of both the hornfelses and the pegmatites must have been of approximately the same composition in the first place. It has already been shown, however, that potash feldspar has been introduced into many of the composite gneisses, while the coarsest gneisses from Martyr Bridge contain large masses of plagioclase sometimes 5 cm. or more in diameter, which could have crystallised only from pegmatitic solutions, or as a result of metamorphic diffusion.

(g.) Development of sillimanite. The sillimanite of the composite gneisses is strictly confined to the highly altered mica-rich gneiss immediately adjacent to pegmatite contacts, and it may therefore reasonably be inferred that one of the conditions essential for its development was thorough permeation of the gneiss by pegmatitic fluids. A further significant feature is that the sillimanite is very frequently intimately associated with biotite or muscovite, the former of which it appears actually to replace in certain instances. It may here be noted that Marshall (1907, p. 500) and Speight (1910, p. 261) have described a gneiss from Dusky Sound, West Southland, in which needles of sillimanite frequently crowd the plates of muscovite much as in the Cascade Valley gneisses. Association of sillimanite with biotite in highly metamorphosed rocks in the vicinity of granitic or sometimes basic plutonic masses appears to be a frequent occurrence, and has been described in greater or less detail by many writers on metamorphic petrology (e.g., Barrow, 1893, p. 338, Pl. XVI, Fig. 2; Watt, 1914, p. 279; Greenly, 1919, p. 136; Read, 1923, pp. 152, 153, 154; Ghosh, 1927, p. 305, Pl. VII, Fig. 11; Tattam, 1929, pp. 17, 19; Sugi, 1930, p. 78). Muscovite and sillimanite often show a similar relation (e.g., Gardiner, 1890, p. 576; Adams and Barlow, 1910, p. 133; Thomas, 1925, p. 53; Sugi, 1930, p. 78), while Bailey (1925, p. 52) and Thomas (1925, p. 54), in discussing the metamorphic effects of the Ross of Mull granite, stress the importance of reaction between muscovite and quartz, as giving rise to the sillimanite which is so characteristic of the inner zone of the contact aureole.

In his recent account of the metamorphic rocks of North-east Victoria, Tattam (1929, pp. 17, 19) describes replacement of biotite by sillimanite in " schistose hornfelses " and in xenoliths enclosed in granite gneiss. With reference to this reaction he later makes the following statement (Tattam, 1929, p. 45) : " This phenomenon occurs in schistose sedimentary material, either in direct contact with or close to magmatic solutions. Biotite gradually disappears, while sillimanite of approximately the same volume takes its place. The process is not one of simple decomposition, since biotite could not supply sufficient alumina to form the sillimanite, and there is no concomitant precipitation of iron oxides or hypersthene. Biotite probably goes into solution, and it may lose some alumina which augments the main supply used in building up sillimanite. Most of the alumina required for that purpose must come from some other source, possibly from muscovite, and if this assumption is correct alkali must leave the system. If the phenomenon has been rightly interpreted, a general reshuffling of material must have occurred, and the changes are brought about not by simple chemical decomposition, but by differences in dynamic physical equilibrium in different parts of the rock, the chemical constituents forming minerals which are stable under the various conditions."

In the rocks described by Tattam and the sillimanite-gneisses of Martyr Bridge it therefore seems that sillimanite has been developed at the expense of biotite, and that magmatic fluids have played an essential part in bringing about this reaction. In the

Martyr Bridge rock, moreover, there is evidence of similar replacement of muscovite by sillimanite. In this latter connection it is perhaps possible that some of the potash feldspar present in these gneisses may have originated along with sillimanite by the breaking down of muscovite in the presence of siliceous solutions, as pictured by Bailey (1925, p. 52) in the case of the aureole surrounding the Ross of Mull granite. However, the exact nature of the mechanism by which the micas have given rise to sillimanite in the gneisses of Martyr Bridge still remains obscure.

In discussing the action of granitic liquid upon xenoliths of argillaceous sediment, N. L. Bowen (1922, pp. 561, 562) has stated that an intermediate product of the reaction might be sillimanite, which, however, would later be made over into mica if complete reaction between liquid and xenolith were allowed to take place. In the present instance it is difficult to explain the presence of sillimanite on Bowen's hypothesis, for the petrographic relationship of sillimanite to mica in these rocks is such that the former mineral must have crystallised subsequently to the development of coarse micas already alluded to. In any case the presence of sillimanite in the composite gneisses indicates conclusively that the pegmatites were injected under conditions of very intense metamorphism.

(h.) Presence of " graphic " intergrowths. One of the most characteristic features of the coarser-grained composite gneisses adjacent to pegmatite contacts is the presence of " graphic " intergrowths of plagioclase and quartz, muscovite and quartz, or, less commonly, biotite and quartz. The most widespread of these are typical myrmekitic intergrowths of plagioclase and highly vermicular quartz.

According to Holmes (1920, p. 164) the term myrmekite was introduced in 1899 by Sederholm to include intergrowths of " plagioclase and vermicular quartz, generally replacing potash feldspars, formed during the later or paulopost stages of consolidation or during a subsequent period of plutonic activity." Later writers (e.g., Becke, 1908; Tilley, 1921a, pp. 87, 88; Sugi, 1930, p. 39; Read, 1931, p. 149) have stressed the fact that myrmekite usually develops where crystals of plagioclase are in direct contact with orthoclase or microcline, and it is thus generally held to be a product of replacement of potash feldspar by acid plagioclase. According to this view (Sederholm, 1916; Tilley, 1921a, p. 88) the formation of myrmekite in granitic rocks is a special phase of albitisation.

Sugi (1930, pp. 40, 66, 67) nevertheless describes several cases where the myrmekite cannot have originated in this way, and shows that in these particular instances the intergrowth has probably been produced by partial replacement of plagioclase by quartz.

It has already been shown that in the composite gneisses of the Haast-Cascade area, development of myrmekite is independent of the presence or proximity of potash feldspar, for intergrowths of this type are commonly found in rocks from which orthoclase and microcline are both completely absent. The most perfect development is attained in rocks which also contain plentiful quartz-muscovite or quartz-biotite intergrowths, and it therefore appears that all three have a common origin. Moreover, the prevalence of these phenomena in the most highly altered gneisses immediately adjoining the dykes of pegmatite clearly indicates that they have originated by the action of pegmatitic fluids upon the invaded rocks.

A brief survey of some of the more important literature dealing with contact metamorphism reveals the fact that micrographic intergrowths of all kinds appear to be highly characteristic of rocks formed near igneous contacts, as a result of incomplete reaction between liquid magma or magmatic fluids and invaded rocks or xenoliths. These include not only myrmekitic intergrowths of plagioclase and quartz (e.g., Watt, 1914, pp. 280, 283; Collins, 1917, pp. 59-62), but also such associations as biotite-quartz, biotite-feldspar, biotite-cordierite (Watt, 1914, pp. 282, 284), quartz-orthoclase, quartz-tourmaline, quartz-hornblende, hypersthene-plagioclase-magnetite (Read, 1923a, pp. 463, 466, 472, 478), corundum-biotite, and corundum-sillimanite (Ghosh, 1927, p. 305). In the cases cited above the micrographic textures are seen sometimes in the altered xenoliths or invaded rock, and sometimes in the contaminated igneous rock itself. Fenner (1926, pp. 737, 753), in discussing the origin of graphic intergrowths of quartz and feldspar, has recently drawn attention to the conclusion of Coleman (1907, p. 774) and Collins (1917, p. 62) that such textures may be considered as diagnostic criteria of rocks which have originated by reaction between magma and country rock.

In view of the above facts it is concluded that the intergrowths described in the present paper originated during the later stages of the pegmatitic phase of metamorphism, by partial replacement by quartz of original plagioclase, muscovite, or biotite, large crystals of which now act as hosts to the graphic or vermicular quartz inclusions. This type of origin has already been demonstrated by Sugi (1930, pp. 40, 66, 67) for some myrmekitic intergrowths, and by other writers (e.g., Schaller, 1925, p. 20) for graphically intergrown quartz and orthoclase.

(i.) Retrogressive metamorphic effects. The mechanical effects of retrogressive metamorphism are very pronounced, and include shattering and recrystallisation of quartz and feldspar, twisting of micas and bending of feldspar twin lamellae, and development of undulose extinction in various minerals. Orthoclase has frequently inverted to microcline under the influence of stress, while much of the albite twinning seen in the plagioclase is probably to be attributed to the same cause (compare Alling, 1921, pp. 209, 210). The purely chemical effects, on the other hand, are not as conspicuous as in the finer-grained hornfelses.

(10.) *Origin of Quartzo-Feldspathic Schists, Gneisses, etc.:* Although the quartzo-feldspathic group of schists, gneisses, etc., includes rocks of widely different metamorphic facies, their mineral composition indicates certain persistent chemical features which stamp them as having originated in all cases from a common parent rock. Quartz and sodic plagioclase always predominate, while potash feldspar is entirely lacking except in a few cases where there is reason to believe that it has been introduced by pegmatitic fluids. Chlorite, white mica, and epidote are usually moderately plentiful in rocks of low metamorphic grade, while red-brown biotite, minor muscovite, and small amounts of epidote or clinozoisite characterise the rocks which have suffered more intense metamorphism. The rocks thus fall into the Group of Plagioclase-gneisses in Grubenmann's chemical classification (Grubenmann, 1910, p. 179).

The mineralogical characteristics outlined above suggest derivation from sediments consisting originally of detrital quartz, plagioclase, and fairly plentiful ferromagnesian silicates. Sediments of this nature might have originated in the first place as quartz sands admixed with basic tuffaceous material, or, more likely, as " ferromagnesian sands " (Van Hise, 1904, p. 877) formed by rapid disintegration of igneous rocks of basic and intermediate composition. It is significant that upon cementation such sands would give rise to greywacke, a rock which is universally abundant in the older rock systems of New Zealand.

MICACEOUS SCHISTS.

The micaceous members of the metamorphic series include those rocks in which the micas biotite and muscovite, together with chlorites, predominate over combined quartz and feldspar. With increase in the latter constituents they grade into various members of the quartzo-feldspathic group. The micaceous schists do not constitute a distinct stratigraphic unit, but for the most part occur as bands of minor importance intercalated among the quartzo-feldspathic schists, gneisses, etc.

(1.) *Muscovite-chlorite-quartz-albite-schists:* Of the numerous specimens which consist mainly of the quartz-albite-muscovite-chlorite association, which is so typical of the lower grades of metamorphism in this area, only one, No. 1302, contains sufficient muscovite and chlorite to warrant classification among the micaceous schists. This specimen was collected by Mr C. R. Bentham from near the Main Divide at the head of the Wilkin Valley, about 20 or 25 miles southwest of Haast Pass.

Macroscopically the rock is a lustrous pale greenish grey schist with perfect foliation, obviously rich in mica. The constituent minerals include muscovite 40%, chlorite 25%, quartz 20%, feldspar 10%, epidote 5%, and accessory amounts of sphene, magnetite, and apatite. Ragged flakes of muscovite and chlorite about 0.5 mm. in length are arranged parallel to the foliation, giving a thoroughly lepidoblastic texture to the rock. The muscovite has an unusually small optic axial angle, which, judging from the interference figure, cannot be much above 10°. The chlorite is delessite similar to that recorded in the quartz-albite-chlorite-schists, with distinct pleochroism from pale greenish yellow (X) to deep green (Y and Z). The grains of quartz are highly irregular, frequently sutured, and vary from 0.05 mm. to 0.5 mm. in diameter. Those of feldspar are of similar size, water-clear, and untwinned, and have the optical properties of almost pure albite. Epidote is scattered plentifully throughout the whole section in pale yellow strongly birefringent prisms and granules, about 0.1 mm. in length. Sphene in colourless rounded granules is an abundant accessory, while there are also a number of large irregular grains of apatite and magnetite.

The essential difference between specimen No. 1302 and the quartz-albite-chlorite schists is that muscovite is much more plentiful than in the latter rocks, while quartz and albite are correspondingly less abundant. Whereas the presence of much muscovite indicates a noteworthy amount of argillaceous matter in the parent sediment, the persistence of the chlorite-albite-epidote association also points to the presence of basic igneous material in some quantity. The initial sediment thus appears to have been a somewhat argillaceous band in the series of sands and silts of greywacke composition, of which the schists, gneisses, and hornfelses of the quartzo-feldspathic group are the highly metamorphosed equivalents.

(2.) *Foliated Muscovite-biotite-quartz-schists:* The dominant minerals in these rocks are muscovite and biotite, the former in small irregular flakes and the latter as larger, sometimes porphyroblastic crystals, which may be sieved with inclusions of quartz. Quartz usually constitutes from 20% to 30% of the rock, but feldspar seems to be absent. Crystals of both micas show a considerable degree of parallelism, thus imparting to the rock a distinct and characteristic foliation.

Foliated muscovite-biotite-quartz-schists are represented by only two specimens, Nos. 1209 and 1210, which were collected from the south-western part of the map, and have already been described in a previous paper (Turner, 1930a, pp. 177, 178).

(3.) *Hornfelsic Biotite-muscovite-schists:* So far the hornfelsic mica-schists are known only as rather rare boulders in the gravels of Laschelles Creek. They are fine-grained, brownish, imperfectly foliated rocks of almost hornfelsic aspect, usually mottled with large knots or single porphyroblasts of white mica. Biotite and muscovite are the dominant constituents, and are usually accompanied by quartz and feldspar (sodic plagioclase or microcline), which typically rank as essential components. The commonest accessories are tourmaline, magnetite, and apatite, while in one specimen (No. 1463) the tourmaline is present in such large quantities that the rock may be classified as a tourmaline-mica-schist. In another specimen (No. 1339) porphyroblastic chlorite accompanies the two micas, but is in quite subordinate proportions. The four examples described below are representative varieties of the hornfelsic mica-schists.

No. 1339 is a dark brown fine-grained rock mottled with numerous irregular patches of muscovite from 10 mm. to 20 mm. in length. The foliation is only poorly developed. The constituent minerals are biotite 40%, muscovite 25%, quartz 20%, feldspar 15%, chlorite 0.5%, and accessory tourmaline, magnetite, apatite, and sphene. The texture is distinctly porphyroblastic, with numerous large muscovites and much less plentiful smaller porphyroblasts of chlorite set in a groundmass of biotite, quartz, feldspar, and fine muscovite. The feldspar is untwinned, and appears to be medium oligoclase, about $Ab_{80}An_{20}$ to $Ab_{76}An_{24}$. The biotite is intensely pleochroic, from pale yellow to deep sepia brown, and occurs in small ragged flakes showing some degree of parallelism. Muscovite occurs both as small flakes throughout the groundmass and as large highly-irregular porphyroblasts and knots of coarse crystals, sieved through with numerous rounded inclusions of quartz and rarer grains of biotite or magnetite. The chlorite is a pale green variety identical with that which has already been described in connection with specimen S.W. 30 (p. 199), but lacks the characteristic polysynthetic twinning displayed in the latter section. It takes the form of small clear-cut porphyroblasts about 1 mm. in length, enclosing abundant rounded inclusions of quartz and ragged ones of iron ore. Small idioblastic prisms of brown tourmaline and grains of magnetite are plentiful, and are accompanied by occasional grains of apatite and sphene.

No. 1340 is macroscopically very similar to No. 1339, but contains neither chlorite nor feldspar, and lacks the development of coarse muscovite which is so characteristic of the previous specimen.

No. 1463 is a fine-grained brown hornfelsic schist spotted with coarse knots of white mica, and closely resembling No. 1339 in hand-specimen, except that the foliation is even less distinct than in the latter specimen. The rock is remarkable for the great abundance of tourmaline, the mineral composition being biotite 30% to 40%, muscovite 40%, tourmaline 20% to 25%, feldspar 1%, quartz 2%, and accessory iron ore and apatite. The biotite is mostly in unoriented deep red-brown semi-porphyroblastic crystals (about 0.5 mm. $\times$ 0.2 mm.), but may be considerably coarser in the immediate vicinity of the muscovite knots, which are often fringed by discontinuous borders consisting almost entirely of these larger biotites. Tiny flakes of muscovite 0.1 mm. in diameter are very plentiful, while the same mineral builds coarsely crystalline porphyroblastic knots enclosing numerous granules of brown tourmaline. The tourmaline never takes the form of large crystals, but occurs as innumerable small, stout idioblastic prisms (0.05 mm. to 0.4 mm. in length) or rounded grains scattered throughout the whole section. It is the usual brown type with strong pleochroism from very pale yellow (X) to golden brown, sometimes faintly tinged with blue (Z). This curious rock may be classed as a tourmaline-mica-schist.

No. 1344 is a greyish-brown schist with very plentiful rounded porphyroblasts of silvery muscovite 3 mm. to 5 mm. in diameter uniformly distributed across the broken surface, giving the hand-specimen a most distinctive appearance. The section consists mainly of biotite, muscovite, and microcline in approximately equal proportions, together with quartz and albite-oligoclase, which together make up 10% to 15% of the rock. The accessory constituents are magnetite, apatite, sphene, and secondary epidote. Deep reddish-brown biotite occurs as rather small unoriented flakes without inclusions. The muscovite, on the other hand, builds large ragged porphyroblasts flattened parallel to the foliation planes, and sieved with plentiful rounded grains of quartz and occasional small crystals of biotite, though microcline is never enclosed in this manner. Microcline, with the usual " grid-iron " twinning, is developed as clear crystals about 0.5 mm. to 0.8 mm. in diameter, which always enclose small granules of quartz, magnetite, and muscovite. The plagioclase lacks such inclusions, and is often much altered to sericite. The rock is unique among the specimens collected from the Haast-Cascade area on account of its high microcline content, and may be classed as a microcline-mica-schist.

The predominance of biotite and fine-grained muscovite in the hornfelsic mica-schists points to derivation from initial pelitic sediments. Recrystallisation of this sediment into its present condition appears to have been controlled mainly by high temperature, probably aided by considerable hydrostatic pressure, but accompanied by only minor directed stress, this latter factor being responsible for the present imperfect foliation of the rocks under consideration.

During recrystallisation the original sediment appears to have been modified in composition by magmatic fluids, to the action of which the formation of porphyroblastic muscovite, microcline, and tourmaline is attributable. Development of porphyroblasts of muscovite under the influence of magmatic fluids has been noted by Tattam (1929, p. 17) in the case of certain of the " schistose hornfelses " of Victoria, and a similar origin has already been suggested, earlier in this paper, for the coarse muscovite of the composite gneisses and quartzo-feldspathic hornfelses. It is probable, too, that the abundant microcline of specimen No. 1344 has been similarly introduced from magmatic sources, since potash feldspar is only rarely a constituent of the other metamorphic rocks of this area, and is present only in rocks which have undergone thorough permeation by igneous emanations. Introduction of tourmaline may have preceded the development of coarse muscovite, since in specimen No. 1463 (where tourmaline is very plentiful) small idioblastic crystals are frequently enclosed in the large knots of muscovite.

The field relations of the hornfelsic mica-schists are unknown, and it is therefore impossible to state definitely whether their recrystallisation took place during the hornfelsing stage of the metamorphic cycle or the subsequent period of pegmatitic injection. In the writer's opinion, however, the petrographic evidence lends support to the first of these alternatives.

ALBITE-EPIDOTE-SCHISTS.

The albite-epidote-schists are represented by only two specimens, Nos. 1284 and 1310, in both of which albite is the dominant constituent, and is accompanied by very plentiful epidote, which makes up 20% or 25% of the total composition of the rock, the third essential component being quartz. While these schists resemble the rocks of the quartzo-feldspathic group, in that quartz and feldspar together constitute 60% to 80% of the rock, they differ in the great abundance of epidote and unimportant development or even absence of chlorite, muscovite, and biotite.

No. 1284 (boulder, Mule Valley, three miles north of Haast Pass) is a pale green fine-grained homogeneous schist with perfectly developed foliation. The mineral composition is albite 35% to 40%, epidote 25%, quartz 20%, actinolite 5% to 10%, chlorite 7%, calcite 1%, and accessory pale greenish mica, magnetite, and sphene. The average grain-size of the essential constituents is about 0.1 mm., though in the more feldspathic areas the grains of albite and quartz are a little larger than this. The feldspar is almost pure albite ($Ab_{98}An_2$) in water-clear untwinned interlocking granules. The epidote is aggregated into clusters of small xenoblastic grains with strong pleochroism in greenish and yellowish tints. The birefringence as determined by comparison with that of quartz is about 0.04, so that the mineral is an iron-rich epidote containing about 28% of the $HCa_2Fe_3Si_3O_{13}$ molecule (Winchell, 1927, p. 355). The chlorite is a pale greenish pennine with very low birefringence, and shows anomalous yellowish brown interference tints. Very slender prisms and needles of pale green actinolite about 0.3 mm. to 0.5 mm. in length are plentiful and freely penetrate the other minerals present, especially some of the larger crystals of albite. There are a number of scattered grains of calcite, which often enwrap rounded grains of quartz. The only mica present is a distinctly pleochroic colourless to pale green variety which may be phlogopite, and which occurs in rather rare flakes of small size. A similar pale mica has recently been mentioned by Dr. F. C. Phillips (1930, p. 244) in his description of the Green Beds of the Scottish Dalradian, where it is sometimes an important constituent of schists of the chlorite zone.

No. 1310 was collected from a boulder in the bed of the Jackson River, a quarter of a mile above its junction with the Arawata. It is a highly fissile white to pale greenish schist dotted plentifully with tiny bright grains of magnetite (tested with a magnet). The rock consists of albite 60%, epidote 20%, quartz 15% to 20%, chlorite 3%, biotite 1%, and magnetite 1%. These minerals build up a mosaic of small grains (0.2 mm. in average dimension), among which somewhat larger albites and well-shaped crystals of magnetite occasionally tend to porphyroblastic development. The albite is water-clear, usually untwinned, but sometimes shows either simple or multiple twinning. The optical properties indicate that the anorthite content does not exceed 5%. Subidioblastic stout prisms of yellow epidote are plentiful, the high birefringence (0.045) showing it to be an iron-rich variety containing about 30% of $HCa_2Fe_3Si_3O_{13}$. Chlorite, though not abundant, is conspicuous on account of its unusually strong absorption. It is apparently a ferruginous delessite, uniaxial, negative, poorly birefringent, and strongly pleochroic, from light brownish yellow (X) to deep green (Y and Z). Biotite is less plentiful than chlorite (with which it is often interlaminated), and shows striking pleochroism from pale yellowish brown to very deep green—almost black. There is also a very small quantity of colourless to pale green mica similar to that of the preceding section. It is confined entirely to very narrow rims which partially or completely surround the porphyroblasts of magnetite. This curious feature recalls somewhat similar structures described by Brammall

(1921, pp. 213, 214, 222) in certain phyllites from Bolivia. In these latter rocks porphyroblasts of ilmenite have been built up during reconstitution of the chloritic constituents of the rock, and later have become ensheathed in narrow selvages of transversely disposed fibres and prisms of muscovite and quartz. It is suggested (Brammall, 1921, p. 222) that as a result of tension caused by shrinkage of the groundmass during the reconstitution process, the porphyroblasts of ilmenite became detached from the surrounding matrix, and the spaces so formed were later filled in by the quartz and muscovite which now constitute the surrounding selvages. In the present specimen (No. 1310), there appears to be but little evidence either in support of or against such a mode of origin. It is certainly difficult to imagine how such a mineral as phlogopite or muscovite could arise by any process involving reaction between magnetite and surrounding albite, while the sharply cut boundaries of the magnetite crystals themselves point to absence of any such reaction. It should be noted, however, that whereas in the Bolivian rocks the transverse disposition of the prisms of quartz and muscovite is taken by Brammall as being indicative of secondary origin, in the present specimen the selvages do not show this feature, but are built up of tiny flakes of mica arranged parallel to the margins of the central magnetite grains.

From a genetic point of view the oustanding petrographic features of the albite-epidote-schists are unusual abundance of albite and epidote combined with almost complete absence of micas. The association of albite and epidote conclusively points to plagioclase of intermediate composition as the main source of both these minerals, though the presence of small amounts of chlorite indicates that the original rock may have contained minor quantities of pyroxene or amphibole, the lime contact of which may now be represented by a small proportion of the epidote. The highly ferruginous nature of the latter mineral also suggests the probable presence of femic minerals in the parent rock. It therefore seems probable that the initial rock of which the albite-epidote-schists are the metamorphic equivalent consisted largely of intermediate plagioclase, accompanied by a noteworthy amount of quartz and small quantities of iron oxides and ferromagnesian silicates. Dacites, dacite-tuffs, and highly feldspathic sands are rocks whose mineral composition might agree with that outlined above. The relatively large proportion of quartz, however, appears to preclude derivation from dacitic rocks. On the other hand, origin by metamorphism of a highly feldspathic sand is strongly supported by the field association with an extensive series of metamorphic rocks which are themselves the completely recrystallised and reconstituted equivalents of grits and silts of greywacke composition containing plentiful plagioclase. Scarcity of micas in the albite-epidote-schists points to absence of argillaceous material from this initial sediment.

FERRUGINOUS SCHISTS.

The ferruginous schists are represented by a single specimen of garnetiferous quartz-magnetite-haematite-schist obtained from a boulder in the bed of the Jackson River, 10 miles above its junction with the Arawata. The bulk of the rock is a finely laminated schist, consisting of very thin regular layers alternately quartzose and rich in iron ore. Careful testing with a magnet shows that the latter is largely magnetite in the form of minute shining grains, though the presence of haematite in some layers is shown by the red colour of the powdered mineral. There are also irregular porphyroblasts of magnetite as much as 2 mm. in length, elongated parallel to the schistosity. There is a single band, from 2 cm. to 3 cm. in thickness, which is most conspicuous on account of an abundant development of exceedingly coarse porphyroblastic masses of magnetite from 10 mm. to 15 mm. in diameter. These are set in a light-coloured pinkish matrix throughout which aggregates of finely prismatic green amphibole are interwoven.

Section No. 1317 (Pl. 28, Fig. 12) was cut from the fine-grained portion of the specimen, and consists of quartz 60%, iron ores 35%, amphibole 4%, and garnet 1%. The quartz forms a mosaic of interlocking equidimensional grains (0.1 mm. to 0.3 mm. in diameter), often with well-developed sutured texture. Iron ores, with a bright steely glitter in reflected light, are very plentiful, and vary in form from individual grains 0.1 mm. in diameter to elongated granular aggregates about 1.5 mm. × 0.4 mm. disposed parallel to the foliation. Though magnetite is plentiful, much of the iron ore is haematite, the grains of which appear blood-red at the margins when viewed under high power magnification. In a duplicate section, however, haematite is completely lacking, and magnetite is correspondingly more abundant. Slender prisms of pale bluish-green to colourless actinolite are present throughout, but tend to be concentrated in the magnetite-rich layers. The only remaining constituent is pale yellowish garnet, which occurs in minute grains and idioblastic crystals 0.01 mm. to 0.02 mm. in diameter, which are especially numerous in the iron-rich bands.

Section No. 1316 represents the coarse layer alluded to above. The composition is magnetite 25%, garnet 50%, amphibole 20%, and quartz 5%, though some parts of this band contain a considerably higher percentage of quartz than appears in the section. The large porphyroblasts of magnetite are set in an almost opaque matrix of very finely granular, yellowish brown garnet throughout which are interspersed clear patches and streaks of prismatic pale bluish green amphibole. The quartz is present as irregular grains of small size. In view of Tilley's (1926, 1926a) observations upon the significance of the presence of manganese in garnet, a chemical qualitative test for this metal was carried out on garnet separated from this rock. Abundant manganese was indicated.

The parent rock from which this curious schist originated can only have been a quartz-magnetite sandstone, containing also a minor proportion of aluminous ferromagnesian silicates now represented by garnet and actinolite. From the complete absence of albite, epidote, and micas in the schist it may reasonably be inferred that clastic plagioclase and argillaceous matter were totally lacking in this parent sediment. The rock thus differs widely from the other types so far described in this paper, and is therefore placed alone in a separate class as a ferruginous schist.

Green Schists.

The green schists are well foliated rocks which are conspicuous in the hand-specimen by reason of their distinctive light to dark green colour. Microscopically they are characterised by abundant development of chlorite, epidote, or amphibole, associated with less though still important amounts of sodic plagioclase and quartz. Chlorite and epidote are the dominant femic minerals of the lower metamorphic grades, while deep blue-green amphibole and less commonly biotite are distinctive of rocks which have suffered more intense metamorphism. Magnetite and sphene are constantly present as accessory constituents.

(1.) *Chlorite-epidote-albite-schists:* The chlorite-epidote-albite-schists are represented by one specimen collected from a boulder in the Haast Valley, and by a number of boulders and pebbles in the bed of the Jackson River. These latter have probably been brought down from the belt of low-grade metamorphic rocks (quartz-albite-chlorite-schists) which is drained by the upper part of the Jackson River, east of the peridotite belt.

The members of this group vary considerably in composition, but usually contain both chlorite (pennine) and epidote in abundance, though in extreme cases either mineral may be almost absent. These two characteristic minerals are invariably accompanied by plentiful, often porphyroblastic albite and minor quartz, while grains of both magnetite and sphene are usually numerous. In some specimens small quantities of calcite suggest transition towards the chlorite-calcite-epidote-schists described in the next section.

No. 1314 (boulders, upper ford, Jackson River) consists of epidote 45%, chlorite 25%, muscovite 10% to 15%, quartz 10%, albite 5%, sphene 1%, magnetite 1%, and accessory apatite. Though calcite was not seen in the section, its presence as a minor constituent was determined by testing the hand-specimen with dilute acid. Highly birefringent, pleochroic ferruginous epidote is unusually plentiful, and takes the form of xenoblastic grains and idioblastic prisms averaging 0.2 mm., but sometimes reaching as much as 1 mm. in length. The chlorite is deep green to yellowish green pennine, in coarse irregular pleochroic flakes which give a positive biaxial interference figure, though the optic axial angle is apparently small. Ragged wisps of muscovite sometimes interlaminated with chlorite are conspicuous, while rounded grains and wedge-shaped crystals of sphene 0.1 mm. to 0.2 mm. in diameter are relatively abundant. The latter are easily distinguished from epidote by their higher refringence and birefringence, positive sign, and much smaller optic axial angle. Quartz occurs as clear patches about 1 mm. across, composed of interlocking sutured grains of small size, as well as in isolated grains scattered through the chlorite-epidote-muscovite matrix. Undulose extinction is often pronounced.

No. 1319 (boulder, lower ford, Jackson River) is a deep green fine-grained rock containing abundant small flakes of chlorite clearly visible in the hand-specimen. The rock may be regarded as an extreme member of the chlorite-epidote-albite-schists in which epidote is nearly absent, the constituent minerals being chlorite 40% to 50%, feldspar 30% to 40%, quartz 10%, calcite 3%, sphene 3%, iron ore 2%, amphibole 1% to 2%, and accessory apatite and epidote. As is usual in this group of schists, the chlorite is a strongly pleochroic pennine (X = Y = deep green; Z = pale yellowish) with very low birefringence and strong dispersion, which combine to give yellowish brown and purplish interference tints when the section is viewed between crossed nicols. It is positive and definitely biaxial, but the optic axial angle is small. The feldspar is almost pure albite in clear, usually untwinned grains 0.4 mm. to 0.8 mm. in diameter, which may sometimes contain sparsely scattered inclusions of epidote, chlorite, amphibole, fine magnetite, or rarely sphene. It is accompanied by smaller irregular grains of quartz with slightly undulose extinction. The calcite takes the form of highly xenoblastic crystals of relatively large size, usually without inclusions, but sometimes enclosing swarms of amphibole needles. Small colourless grains of sphene are very abundant, and yield good positive biaxial interference figures showing strong dispersion of the optic axes. It is intimately associated with irregular granules of iron ore—presumably ilmenite—with which it often appears to build composite aggregates. These are almost invariably enclosed within flakes of chlorite, which are often crowded with numerous inclusions of this nature (Pl. 28, Fig. 10), suggesting origin from original titaniferous augite. Isolated needles and tufts of pale green to colourless actinolite are constantly present in small amount and often penetrate the other constituents.

Nos. 1347 and 1348 are specimens collected from a single boulder of coarse-grained green chlorite-schist in the bed of Laschelles Creek. In section it is an unusually coarsely crystalline somewhat feldspathic schist of variable composition, the chief constituents (an average of four sections) being chlorite 15% to 20%, epidote 15%, feldspar 40% to 50%, muscovite 10% to 20%, sphene 2% to 5%, and iron ore 2%, together with actinolite, tourmaline, rutile, and apatite as plentiful accessories. The feldspar is almost pure albite in the form of large untwinned xenoblastic crystals, in which shearing subsequent to crystallisation has often produced marked undulose extinction, or even partial recrystallisation of the albite into a mosaic of small interlocking grains. Inclusions of epidote and iron ore are often extremely plentiful, and are sometimes accompanied by locally abundant grains of sphene, needles of rutile or actinolite, or prisms of blue tourmaline. Inclusions of this type frequently show no sign of regular arrangement, but in some parts of the section they are elongated parallel to one another and disposed in regular, usually curved strings which show marked parallelism over limited areas of the section. Rounded grains of quartz (0.05 mm.) and small flakes of chlorite are also enclosed occasionally in the large albite crystals. The chlorite is a strongly pleochroic delessite (X = yellowish; Z = deep green), giving purplish red anomalous interference tints between crossed nicols. It occurs in relatively coarse flakes about 1 mm. in diameter, which typically are interlaminated with ragged flakes of muscovite of similar size. In contrast with the albite these chlorite-muscovite patches are usually almost devoid of inclusions, while the masses of pure chlorite contain relatively few included grains of epidote. Highly ferruginous epidote with a birefringence of 0.038 to 0.040 is consistently plentiful in all the sections examined, and takes the form of small granules and prisms about 0.2 mm. long, enclosed in the more coarsely crystalline minerals, especially in albite. It is sometimes accompanied by scattered small needles of pale green actinolite. Magnetite occurs as plentiful xenoblastic grains enclosed in the large feldspars, as well as in the form of irregularly distributed porphyroblastic octahedra 1 mm. to 5 mm. in diameter. Coarse grains of apatite are present in accessory amount. An unusual feature shown by this rock is local abundance of sphene, tourmaline, and rutile either separately or sometimes associated with one another. The rutile takes the form of very slender yellow needles, always enclosed in albite. In some crystals of the latter they are extremely numerous, while in adjacent grains of feldspar or chlorite they are entirely lacking. The distribution of sphene and tourmaline is also far from uniform. These two minerals are concentrated, either independently or in close mutual association, in irregular sinuous streaks not more than 0.5 mm. in width, which may extend for between 5 mm. and 10 mm. across the section, and which appear to represent lines along which pneumatolytic vapours have penetrated the schist. These streaks are continuous through feldspar and chlorite alike, and their course seems to bear no relation to the present texture. Furthermore, in cases where streaks of this type cross feldspars which have suffered partial recrystallisation under shearing stress, their trend is in no way influenced by zones of secondary granulation so produced. It appears, therefore, that the tourmaline-rich and sphene-rich streaks originated at an early stage of metamorphism before the present texture had been developed. The tourmaline itself is strongly pleochroic, from very pale yellowish violet to deep greenish blue, and occurs in small, idioblastic, often parallel prisms, which are practically confined to the streaks described above. Sphene, on the other hand, though especially concentrated along bands of this type, is also abundant as inclusions in chlorite and albite throughout all the sections examined. The exact source of this interesting rock is unknown. The metamorphic grade is much lower than that of the hornfelses and associated rocks of the area drained by Laschelles Creek, and it is highly probable, therefore, that the boulder from which the specimens were collected was not derived from the hornfels area of Laschelles Creek, but was washed from the late Pliocene conglomerates which underlie the moraines of the Cascade Plateau.

(2.) *Chlorite-calcite-albite-epidote-schists:* The rocks grouped under this heading are represented by specimens collected from boulders in the bed of the Jackson River and its eastern tributaries. As in the case of the chlorite-epidote-albite-schists the grade of metamorphism is low, and it is therefore surmised that all these rocks have been derived from minor bands of green schists intercalated among the low-grade quartzo-feldspathic schists along the range east of the Jackson River, beyond the eastern limit of the zone of quartz-plagioclase-biotite-schists.

The essential feature of the schists of this type is the presence of plentiful calcite accompanying the usual chlorite-epidote-albite association so characteristic of green schists of low metamorphic grade. Albite is more plentiful and epidote distinctly less abundant than in the chlorite-epidote-albite-schists just described. The percentage of epidote is usually about 5% to 15%, but in certain instances (e.g., No. 1320) this mineral is almost totally absent. Chlorite is always plentiful, and may be either positive pennine or negative delessite, while sphene and magnetite are characteristic accessory constituents. Two typical specimens are described below:—

No. 1313 (plentiful boulders, Turnley Creek, Jackson Valley). Macroscopically the rock is a light green silky chloritic schist with numerous small porphyroblastic knots of calcite and feldspar about 1 mm. in diameter, which impart to the hand-specimen a distinctive granular appearance. As seen in section the constituents are chlorite 25%, calcite 25%, albite 30%, epidote 15%, quartz 5%, and accessory sphene and apatite. The feldspar is almost pure albite, with an extinction angle of 22° measured from X to the 001 cleavage in sections perpendicular to the acute bisectrix Z. It occurs in large untwinned or in rare cases simply twinned porphyroblasts with more or less rounded outlines, which usually enclose numerous elongated grains of epidote accompanied by minor sphene and chlorite. In many instances these inclusions are arranged in regular parallel strings cutting through the porphyroblasts without any relation to the direction of elongation of the latter. The texture thus approaches the perfect helicitic texture displayed by certain other members of the Green Schist group (e.g., No. 1291) described later in this paper, and is closely similar to that of a chlorite-epidote-albite-schist from the start area described and figured by Dr Tilley (Tilley, 1923, p. 84; Pl. X, Fig. 1). Large irregular porphyroblasts of calcite sometimes as much as 3 mm. in diameter are very plentiful (Pl. 28, Fig. 9). This mineral is almost universally twinned, and usually encloses scattered inclusions of epidote, chlorite, and albite. These large crystals of calcite and albite are set in an enwrapping matrix which consists of fairly coarsely crystalline, pale green faintly pleochroic pennine, and small granules of colourless epidote, albite, and quartz.

No. 1318 (numerous boulders, upper ford, Jackson River). Macroscopically the rock is an even-grained deep green schist, in which dark chloritic layers 3 mm. in thickness alternate regularly with thin white laminae 0.5 mm. to 1 mm. thick, in which calcite is a prominent constituent. The whole rock is sparsely dotted with octahedra of magnetite from 1 mm. to 8 mm. in diameter. A section cut parallel to the foliation from one of the white bands consists of calcite 40%, albite 30%, quartz 15%, chlorite 10%, epidote 5%, magnetite 1%, and accessory sphene. Porphyroblastic texture is not developed, and the albite, the composition of which approximates to $Ab_{93}An_7$, is usually devoid of inclusions. Calcite is so plentiful in some parts of the section that it forms a coarsely crystalline continuous matrix, in which scattered rounded crystals of albite (about 0.3 mm.) and clear patches of granular quartz and albite are enclosed. Deep green, almost isotropic, chlorite and strongly pleochroic yellow epidote tend to be associated with one another, and are often accompanied by small granules of pale sphene.

(3.) *Biotite-calcite-albite-epidote-schist:* This rock is known from a single specimen, No. 1326, collected from a boulder near the mouth of the Jackson River. It is a coarse-grained dark green schist, in which biotite, chlorite, and porphyroblastic white feldspar and calcite are all plainly visible to the unaided eye. The constituent minerals are biotite 25%, calcite 20%, feldspar 25%, epidote 15%, chlorite 10%, quartz 5%, actinolite 1%, and accessory apatite and sphene. The feldspar is albite (Ab_{90} to Ab_{95}), and occurs as rounded crystals from 2 mm. to 5 mm. in diameter, which rarely show traces of albite twinning. They enclose numerous unoriented grains of yellowish epidote, parallel acicular prisms of actinolite, flakes of chlorite, and rarely grains of quartz or calcite. Since biotite is never thus included by the large albites, it may be inferred that the latter ceased to grow prior to the period when the biotite commenced to form. Large highly irregular crystals of calcite, often enclosing scattered granules of epidote, are numerous, and nearly always show lamellar twinning. The biotite is in coarse flakes with strong pleochroism from light yellowish to deep golden brown, and lacks the characteristic red-brown tint so frequently observed in that of the quartzo-feldspathic schists and gneisses. The chlorite is pennine, strongly pleochroic, from light yellow (Z) to deep green (X and Y), uniaxial, optically positive, and poorly birefringent (about 0.004). Epidote is plentiful throughout the whole section. The iron content of this mineral varies from moderately high to low, often within the limits of a single crystal. There is also a small proportion of actinolite in small acicular prisms with faint pleochroism from light yellow (X) to pale blue-green (Z). Quartz is a minor constituent only, and appears as small clear grains without inclusions. Coarse grains of apatite (0.2 mm. to 0.5 mm.) are fairly plentiful, while sphene is a minor accessory.

The rock is somewhat similar to the porphyroblastic chlorite-calcite-albite-epidote-schist No. 1313, from which it differs mainly in the presence of abundant biotite and in the more calcic composition of the plagioclase, pointing to a distinctly higher grade of metamorphism. Further, it is evident from the presence of biotite in No. 1326 that this rock and No. 1313 are chemically by no means identical, for the low-grade equivalent of the former rock must have contained muscovite to supply the necessary potash for the later development of biotite. In this respect chemical affinities are shown with muscovite-bearing chlorite-epidote-albite-schists such as No. 1314, which differ, however, in containing no calcite.

(4.) *Amphibole-plagioclase-epidote-schists:* Amphibole schists of this group are by no means common, and have so far been collected from stream boulders only. Very numerous boulders of this nature were observed in the beds of Douglas Creek, Haast Valley, and the small creek which drains into the Haast from the west about one mile below the Burke confluence. It is therefore probable that the rocks occur *in situ* in association with normal quartz-plagioclase-biotite-schists along the range in the vicinity of Mount Defiant and Pivot Peak, where both these streams have their headwaters. Similar boulders were obtained from the Jackson River and its tributary, Turnley Creek, and have doubtless been derived from a source among the quartz-plagioclase-biotite-schists which flank the Jackson Valley on the south-east.

The amphibole-plagioclase-epidote-schists are compact, highly fissile rocks, which are easily distinguished in hand-specimen by their deep green colour. Blue-green amphibole is always an essential constituent, and is constantly accompanied by abundant sodic plagioclase and a less but still important amount of epidote. Slight variations in chemical composition and metamorphic grade have produced corresponding variations in the mineral assemblages developed in different specimens. Thus biotite and chlorite may sometimes be sufficiently plentiful to rank as essentials. Quartz is always present as a minor constituent, while calcite, magnetite, and sphene are common accessories.

No. 1287 (boulders, Douglas Creek, Haast Valley) is typical of the highest grade of metamorphism attained by the amphibole-schists of the Haast-Cascade area. The constituents are amphibole 50%, feldspar 20%, epidote 7% to 10%, biotite and chlorite 10%, iron ore 5% to 10%, quartz 5%, and accessory apatite. The amphibole occurs in very slender prismatic crystals 0.5 mm. to 1 mm. in length (Pl. 28, Fig. 11), which show marked parallelism and impart a coarsely nematoblastic texture to the rock. The feldspar is acid oligoclase, $Ab_{88}An_{12}$, and takes the form of rarely twinned interstitial grains about 0.2 mm. in diameter scattered among the prisms of amphibole. It usually shows pronounced undulose extinction. Small grains of epidote and black iron ore (about 0.05 mm.) are plentiful, and frequently are enclosed within the larger crystals of plagioclase. The epidote is pale yellow or colourless, faintly pleochroic, and has only moderate birefringence (about 0.016). This latter property indicates a clinozoisite content of about 90%, so that the composition lies on the boundary between clinozoisite and pistacite as defined by Winchell (1927, pp. 354 to 356). Deep yellowish brown, strongly pleochroic biotite occurs in highly irregular flakes 0.3 mm. in diameter, which are often interwoven with masses of amphibole prisms, while associated with the biotite is a minor amount of pale green pennine. Clear grains of quartz are sparsely distributed throughout the section, and there are also several large xenoblastic crystals of apatite. The amphibole is a strikingly pleochroic variety with strong absorption, according to the following scheme:—

X = light yellowish.
Y = deep olive green.
Z = deep greenish blue.
$X < Y < Z$, Y and Z being nearly equal.

The extinction angle measured from Z to the vertical axis in the clinopinacoidal section is about 15°, the optical sign is negative, and the birefringence is approximately 0.020. Amphibole, with a deep blue or greenish blue tint for light vibrating parallel to Z, appears to be very characteristic of amphibole-schists and amphibolites of high metamorphic grade (e.g., compare Collins, 1917, p. 32; Stillwell, 1918, p. 38; Hunter, 1925, p. 33; Phillips, 1930, p. 246). The authorities quoted above all refer to the mineral simply as hornblende, though Stillwell (1918, p. 38) suggests that the blue colour is due to admixture of the glaucophane molecule. The optical properties of the Westland amphibole are identical with those of the mineral which J. P. Smith (1907, p. 190) described from the glaucophane-schists of California under the name "carinthine." In his recent chemical survey of the hornblende group, Kunitz (1930) groups the amphiboles into seven distinct isomorphous series, the first four of which (anthophyllite-cummingtonite, tremolite-actinolite, glaucophane-riebeckite, and glaucophane-actinolite) are characteristically developed in metamorphic rocks. The remaining three groups (green hornblendes, syntagmatitic hornblendes, and alkali-iron-amphiboles) are confined to igneous rocks. In view of its distinctive blue Z tint, relatively low extinction angle, and acicular habit it seems probable that the amphibole now under consideration would belong to the glaucophane-actinolite series of Kunitz (1930, p. 202) rather than to his group of igneous green hornblendes. Furthermore, Blasdale's analysis of the Californian "carinthine" (Smith, 1907, p. 191) clearly indicates that this mineral belongs to the actinolite end of the actinolite-glaucophane series. The deep blue tint referred to cannot be taken as an indication that the glaucophane molecule enters extensively into the composition of this amphibole, for Kunitz himself observes (Kunitz, 1930, p. 201) that blue-green tints are by no means confined to highly sodic amphiboles, and are due not to the presence of unusually high soda, but rather to iron in the ferric condition. Murgoci (1906, pp. 371, 372) has also observed that whereas the soda content may control the shade of colour exhibited by amphiboles of this type, the depth of the tint is determined by the Fe_2O_3 content. The green schists of the Haast and Jackson Valleys contain amphiboles which show every gradation from almost colourless or pale green actinolite (e.g., No. 1319), through varieties with slightly deeper absorption and a pale bluish green Z tint (e.g., No. 1326), to the striking blue-green amphibole just described. Furthermore, the series outlined above corresponds closely with regularly increasing metamorphic grade, as will be shown in a later section.

No. 1312 (boulders, Turnley Creek, Jackson Valley) is of the same general type as the previous section, but differs in that it contains more quartz and feldspar, less amphibole, and very little biotite. The composition is amphibole 30%, feldspar 30%, epidote 20%, quartz 15%, and chlorite 3%, with magnetite, biotite, sphene, and apatite in accessory quantities. The texture is nematoblastic, due to development of parallel prisms of amphibole (1 mm. × 0.1 mm.). The latter is almost identical with the blue-green amphibole of specimen No. 1287, but the absorption is slightly less intense, and the extinction angle (Z to c) appears to be about 18°. The feldspar is albite-oligoclase approximating to $Ab_{90}An_{10}$. Biotite is almost absent, being limited to two or three small flakes with deep brown absorption, but strongly pleochroic delessitic chlorite (X = pale greenish yellow, Z = deep green) is somewhat more plentiful. In the section magnetite is represented only by rather rare grains of moderate size, but in the hand-specimen it is conspicuously developed as idioblastic octahedra several millimetres in diameter.

No. 1291 (boulder, creek one mile below Burke confluence, Haast Valley). Macroscopically the rock is a deep green schist in which conspicuous flakes of dark biotite and white porphyroblasts of feldspar are plainly visible to the unaided eye. The component minerals are amphibole 10%, albite-oligoclase 35%, epidote 15%, biotite 15%, chlorite 10%, quartz 10%, and calcite 5%. The texture is porphyroblastic due to the development of large crystals of untwinned albite-oligoclase averaging 2 mm. × 1 mm. These helicitically enclose strings of elongated epidote granules (sometimes accompanied by needles of amphibole) which show perfect parallelism in any particular porphyroblast, and often extend beyond the limits of the feldspar crystal into the adjacent chlorite-amphibole matrix or into a second feldspar individual. The orientation of these lines of inclusions is unrelated to the direction of elongation of the enclosing feldspar, and though their trend is more or less constant over restricted areas it is by no means uniform throughout the section as a whole. Where they approach the opposite sides of a porphyroblast the strings of epidote are usually distinctly bent in opposite directions. A further conspicuous feature is a uniform tendency for the lines of included material to be concentrated towards the centre of the crystal with respect to a direction at right angles to their trend. The biotite is in ragged crystals about 0.5 mm. to 1 mm. in width with intense pleochroism from light yellowish to very deep greenish brown. Deep green nearly isotropic chlorite is also fairly plentiful, and in some places appears to be undergoing conversion into biotite. In other parts of the section swarms of slender prisms of blue-green amphibole identical with that of section No. 1287 have developed in parallel position through the chlorite, and seem to have been derived from it. Idioblastic prisms and rounded grains of poorly ferriferous epidote are very numerous, both as inclusions in the feldspars, and associated abundantly with the other femic constituents. There are several rather large twinned xenoblastic grains of calcite containing sparsely distributed inclusions of amphibole, magnetite, and epidote. Clear grains of sphene, sometimes enclosed in the albite porphyroblasts, are moderately plentiful, while less common accessories are magnetite and apatite. The striking helicitic structure shown by the large feldspars deserves some further comment. It is rather imperfectly approached in the chlorite-calcite-albite-epidote-schist No. 1313, and also in certain of the chlorite-albite-epidote-schists described by Dr. Tilley (1923, p. 84, Pl. 10, Fig. 1) from the Start area of Devon. Bailey (1923), in an account of the albite-schists of the south-east highlands of Scotland, has fully discussed structures exactly comparable with that shown by the present rock. He concludes that strings of epidote, oriented parallel to the schistosity of an early stage of metamorphism, have later become enclosed in growing porphyroblasts of albite, and that the latter have subsequently been subjected to mechanical rotation while still in the " living " state, as a result of shearing at a late stage (Bailey, 1923, p. 328). The twisting of the strings of epidote where they emerge from the enclosing porphyroblast has thus the same significance as the spiral structure of " snowball " garnets, in contrast with " rodded " structures which may result when porphyroblastic albite or garnet are subjected to shearing after they have ceased to grow. The helicitic texture of the rock from the Haast Valley may thus reasonably be taken to indicate that the process of metamorphism in this area has not been simple, but has involved at least three successive stages, in which formation of strings of epidote, growth of porphyroblastic feldspars, and finally mechanical rotation of the latter have respectively taken place.

S.W. 19 (Auckland University College collection) is a dark green schist collected from a boulder near the mouth of the Jackson River. It consists of amphibole 10% to 15%, albite-oligoclase 25%, epidote 35%, chlorite 20%, quartz 2% to 5%, biotite 1%, sphene 1%, and magnetite 1%. In section the rock has a most distinctive appearance, due to development of conspicuous large crystals of zoned epidote (1 mm. $\times$ 0.5 mm.), in addition to porphyroblastic feldspar and magnetite. Typically each epidote crystal contains a sharply defined core of yellow, highly ferruginous epidote, with a birefringence of 0.040 to 0.045, pointing to a composition of about 30% $HCa_2Fe_3Si_3O_{13}$ and a ferric oxide content of about 15% (Winchell, 1927, p. 355). These cores are often simply twinned and nearly always show idioblastic outlines, whereas the surrounding outer zone is universally xenoblastic in outline and is never twinned. The outer zone consists of clear colourless or pale yellow clinozoisite with a very wide optic axial angle and a birefringence not greater than 0.010, so that the mineral contains about 7% of the $HCa_2Fe_3Si_3O_{13}$ molecule, corresponding to a ferric oxide content of 3.3%. In addition to these compound crystals there are abundant small granules of yellow ferriferous epidote 0.1 mm. in width, and rare small porphyroblasts of clinozoisite without zoned structure. The amphibole occurs in sheaves of acicular prisms about 0.5 mm. in length. The pleochroic scheme is much the same as for the blue-green amphibole of the previous sections, but the absorption is less intense and the extinction angle is about 20°. The chlorite is a delessitic type, and occasionally shows transition into greenish brown biotite. Rounded grains of pale yellow sphene are very plentiful, usually in close association with the femic minerals.

(5.) *Origin of the Green Schists:* The less metamorphosed members of the green schist group of South Westland are closely similar to, though not identical with, the chlorite-schists of Central Otago, which occur as beds and lenses of usually minor extent, intercalated among the quartz-muscovite-schists which constitute the Maniototo Series (Park, 1906, p. 15; 1908, p. 25; 1909, p. 56).

According to Professor Park, the chlorite-schists of Central Otago originated by metamorphism of basic volcanic rocks. Finlayson (1908, pp. 75, 76) concluded from petrographical examination and chemical analyses that the chlorite-schists of Gibbston and the Dunstan Range are "altered flows or sheets of basic igneous rocks, contemporaneous with the associated mica-schists of sedimentary origin." More recently Professor Benson (1928, p. 57) has pointed out that while some of the chlorite-schists are sharply bounded bands which may represent lava-flows, others merge into the adjacent mica-schists, and have probably been derived from beds of basic tuff.

Petrographically the green schists of Otago and South Westland closely resemble those of well-known areas such as Anglesey, the Start area of Devon, the Scottish Highlands, and the Alps of Switzerland, where origin from basic tuffs or effusive rocks has been clearly demonstrated by detailed chemical and petrographic investigations.

If a close comparison is made with the rocks of the Start area it is clear that the green schists of the Haast and Jackson Valleys approach most closely those rocks which are grouped by Tilley (1923, p. 188) as "schists of composite origin." According to this writer (Tilley, 1923, pp. 188, 189) these composite schists are probably the metamorphosed equivalents of basic tuffs, and are distinguished from the essentially igneous green schists of the district by their variable composition and the presence of muscovite and quartz, which mark a transition towards the associated quartz-mica-schists of sedimentary origin. The green schists of Westland and Otago often contain either muscovite or biotite, the latter being developed only where the grade of metamorphism is relatively high, while granular quartz is always present to the extent of 5% or 10%.

The Westland schists also show a close resemblance to isogradic melanocratic members of the green bed group of the Scottish Dalradian. Dr. F. C. Phillips (1930, p. 240) concludes from recent investigation of these beds that though "they are readily seen, at least in the lower grades, to be of sedimentary origin, yet they possess distinctive chemical characteristics most readily explained by fairly direct derivation from basic igneous rocks, and deposition without much admixed material."

The present writer therefore suggests that the green schists of the Haast and Jackson Valleys have originated by metamorphism of tuffs of basic composition. A possibility that must not be overlooked, however, is that they may represent beds of sandstone or grit derived directly from the rapid disintegration of basic igneous rocks much as suggested by Dr. Phillips in the case of the Scottish green beds.

"Riebeckite"-Schist.

Schists carrying a considerable amount of deep blue amphibole close to riebeckite are represented by numerous large boulders in the bed of Douglas Creek, about five miles below the Clarke Hut, Haast Valley. These masses cannot have travelled any great distance, and have doubtless been derived from beds of schist associated with the green amphibole-schists and quartz-plagioclase-biotite-schists of Douglas Creek.

No. 1285 is a typical specimen. Macroscopically it is a blue, highly fissile, finely laminated schist, composed of thin layers alternately rich in light-coloured and femic constituents. Numerous small grains of pyrite are clearly visible in the hand-specimen. The composition (average of three thin sections) is albite 50%, quartz 20%, blue amphibole 10%, biotite 10%, epidote 5%, secondary muscovite 5%, and accessory calcite, apatite, magnetite, and pyrite. The albite, which approximates in composition to $Ab_{94}An_6$, occurs in small grains from 0.1 mm. to 0.2 mm., accompanied by occasional larger crystals, some of which reach 1 mm. in diameter. In some parts of the sections it has suffered partial replacement by innumerable tiny flakes of white mica, but in other areas the albite is water-clear and unaltered. Sericitisation of the albite is especially marked in parts of the sections where biotite is plentiful, and has sometimes resulted in almost complete replacement of the feldspar by dense finely felted masses of white mica. The biotite is pleochroic from pale green to dull greenish brown, and occurs either in irregular patches from 0.3 mm. to 2 mm. in diameter, or as plentiful tiny flakes scattered through the albite. Some layers of the rock consist almost entirely of coarse biotite and sericitised feldspar. The grains of quartz are always of small size, and occasionally may be diablastically enclosed by some of the larger albites. Subidioblastic small prisms of green highly ferriferous epidote occur abundantly throughout the section, frequently in close association with the amphibole. The latter mineral occurs in small slender prisms 0.2 mm. in length, often aggregated together in tufts. It is strongly pleochroic, according to the following scheme:—

X = deep indigo blue.
Y = deep lavender blue.
Z = pale greenish yellow.

The absorption is $X > Y > Z$, X and Y being strong and nearly equal, while Z is weak. The elongation is negative, the maximum extinction angle (X to c) in vertical sections being 12°. The optic axial angle is fairly small, the optic sign is negative, and the plane of the optic axes is parallel to the clinopinacoid, as in most amphiboles. The birefringence is approximately 0.015 as determined with a quartz wedge in clinopinacoid sections, but sections parallel to the orthopinacoid show very weak double refraction. There is strong dispersion of the bisectrices which renders exact determination of extinction angles a difficult matter. Though it is obvious that the mineral must belong to Kunitz's riebeckite-glaucophane series (Kunitz, 1930, pp. 196-200), which includes glaucophane, crossite, riebeckite, and crocidolite, the optical properties described above nevertheless do not correspond exactly with those of any recognised member of the amphibole group. It resembles glaucophane only in its blue colour, while it differs markedly from crossite in pleochroism, elongation, and orientation of the optic axial plane. It resembles riebeckite in the characteristic negative elongation, the position of the optic axial plane, the strong dispersion and the deep blue absorption tint for light vibrating parallel to X. The mineral nevertheless differs distinctly from riebeckite in its higher birefringence, larger extinction angle, and weaker absorption, as well as in the details of the pleochroic scheme. It is somewhat difficult to compare the amphibole under consideration with crocidolite, since the properties of the latter mineral are rather obscure, but it certainly lacks the typical fibrous habit of crocidolite. According to Murgoci (1906, pp. 369-370) the pleochroism and absorption of crocidolite resemble those of riebeckite, the optical character is positive, and the extinction angle (X to c) = 10° to 21°. Iddings (1906, p. 344) and Dana (1922, p. 493) both stress the fact that the extinction angle is high (18° to 20°), and Dana quotes the birefringence as 0.025, the optic sign being positive. Winchell (1927, p. 208), however, regards crocidolite merely as a fibrous variety of riebeckite, while a recent analysis of South African crocidolite made by Kunitz (1930, p. 198) shows that the composition is very close to that of riebeckite, but grades slightly towards that of crossite. It seems from the above that the amphibole under consideration definitely differs from crocidolite in having lower birefringence, small extinction angle, and negative optical sign, as well as in habit and pleochroism. Phemister (1926, pp. 32-35) has recently given a detailed account of a blue amphibole which occurs in alkali-syenites of the Loch Ailsh district of Scotland, and whose properties are almost identical with the blue amphibole from the Haast Valley. The pleochroic scheme (X = Prussian blue, Y = violet, Z = straw yellow) corresponds well with that quoted above for the amphibole of section No. 1285, but the absorption is quoted as $X < Y < Z$—the exact reverse of the present case. From the very nature of the tints quoted it would seem, however, that this is probably a misprint for $X > Y > Z$. Further, the elongation of Phemister's amphibole is given as negative (the extinction angle X to c being 1.5° to 14°), and, judging from the pleochroism displayed by other amphiboles, it is highly unlikely that this mineral would show minimum absorption for light vibrating parallel to the length of the crystal. Phemister (1926, p. 34) classes his amphibole as a member of the riebeckite-katophorite series close to riebeckite. The present writer, following Kunitz's classification, prefers to regard the amphibole of the Haast Valley schist as a member of the riebeckite-glaucophane series intermediate between riebeckite and crossite. It will be sufficient to refer to it in this paper as "riebeckite."

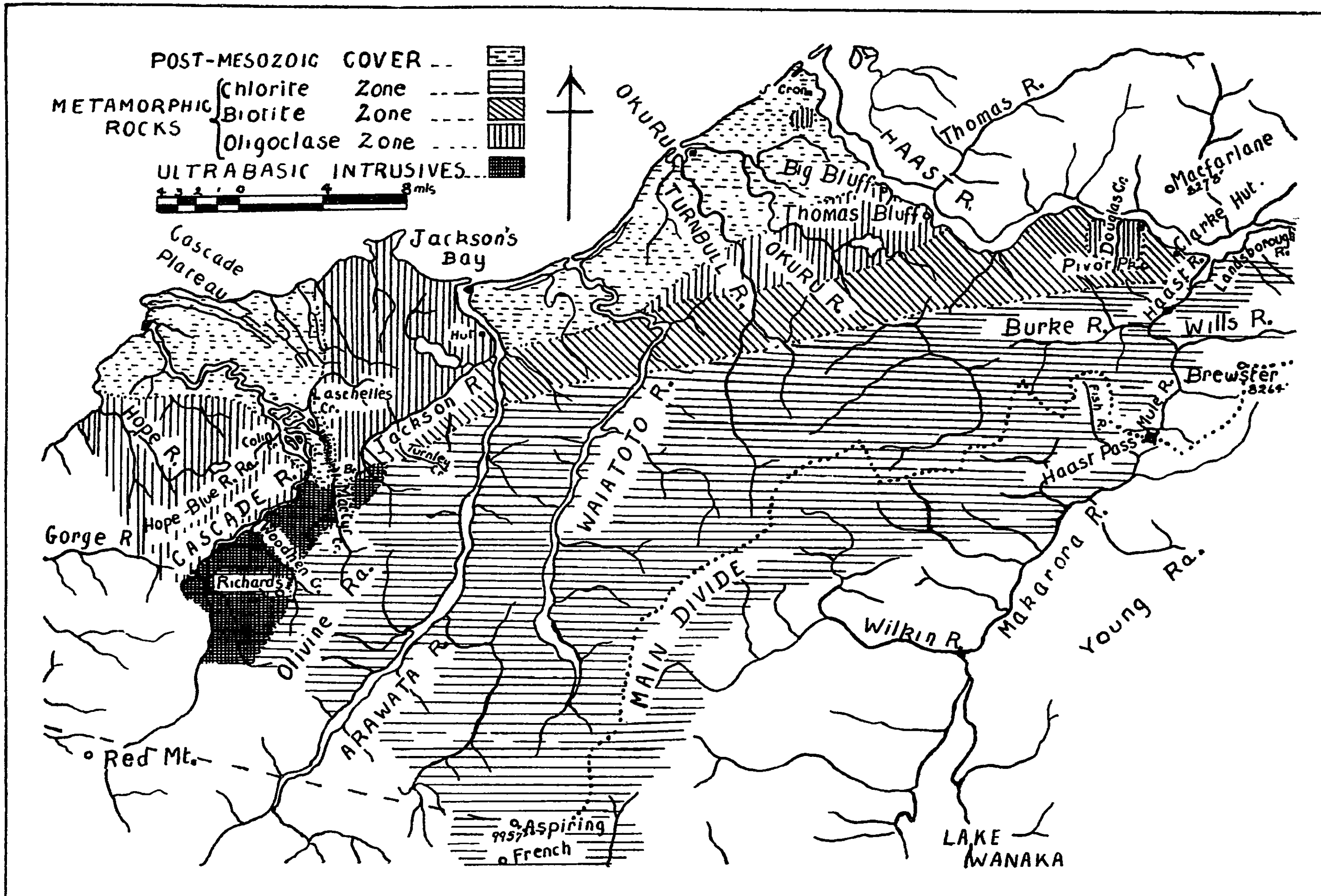
In his recent paper on the hornblende group, Kunitz (1930) includes the minerals of the riebeckite-glaucophane series among the amphiboles, which characteristically crystallise in metamorphic rocks. While glaucophane, crossite, and crocidolite are all typical metamorphic minerals, the end member riebeckite usually occurs in igneous rocks. Murgoci (1905, p. 143) quotes instances where Lacroix and others have described as riebeckite fibrous blue amphiboles from crystalline schists, but nevertheless suggests that these should probably be referred to crocidolite and states that in general riebeckite is not found in genuine schists. It is therefore of interest to note that the " riebeckite " of the Haast Valley schist is undoubtedly a product of metamorphism, and is paragenetically associated with albite, quartz, biotite, and epidote—a typical metamorphic assemblage*.

The development of " riebeckite," instead of the greenish blue amphibole of the normal amphibole-schists, requires explanation, and may be due to some peculiarity in chemical or mineralogical composition of the rock in question, or to some special conditions of metamorphism. Apart from the presence of " riebeckite " itself, and the fact that the feldspar is more sodic than that of the associated rocks, there is nothing to suggest that specimen No. 1285 is especially rich in either soda or iron in comparison with the associated green amphibole-schists, so that the actual chemical composition of the rock does not appear to have been the controlling factor. In the green amphibole-schists the characteristic blue-green amphibole seems to have been generated largely from chlorite, probably as a result of interaction with epidote or sometimes calcite (compare Tilley, 1923, pp. 187, 197). On the other hand, chlorite is quite absent from the " riebeckite "-schist, though its former presence, together with muscovite, may be inferred from the presence of plentiful biotite. The " riebeckite " appears almost certainly to have been formed at the expense of the highly ferruginous epidote with which it is always associated, possibly by reaction with the surrounding albite (compare Phillips, 1930, p. 252).

According to Murgoci (1905, pp. 143, 144) the conditions essential for the formation of riebeckite in igneous rocks are pressure and long-continued action of pneumatolytic vapours. Similarly Phemister (1926, pp. 34, 35) finds, in the case of the alkali-syenites of Loch Ailsh, that while some of the " riebeckite " of these rocks is primary, a great deal of it has been formed from aegirine-augite by the action of mineralising solutions, probably prior to complete consolidation of the rock. In the " riebeckite "-schist of the Haast Valley local sericitisation of albite and the presence of widely disseminated grains of pyrite and coarse apatite all point to pneumatolytic action during the later stages of metamorphism. Whereas tourmaline and apatite are constantly present and sometimes abundant in the quartz-plagioclase-biotite-schists and green amphibole-schists of this locality, pyrite

* A riebeckite-bearing schist of sedimentary origin has been described by W. E. Tarasenko ("On Some Crystalline Schists in the Krivoy-Rog Ore-bearing District," *Acta Universitatis Voronegiensis*, Voronezh, vol. 1, pp. 265-289, 1925).

is absent from these rocks, and the feldspars are typically clear and unaltered. It is thus apparent that the " riebeckite "-schist has been subjected to special pneumatolytic conditions which have not affected the associated rocks, and which may therefore constitute the essential factor upon which crystallisation of " riebeckite " instead of blue-green amphibole is dependent. The source of the mineralising vapours doubtless lies in the subjacent mass of granite, which from other considerations appears to underlie this particular area at no great depth.



Map showing the distribution of the metamorphic rocks and ultrabasic intrusives of Southern Westland.

FIG. 1.—*Quartz-albite-chlorite-schist (No. 1304)*, with abundant prismatic epidote and patches of dusty magnetite.

FIG. 2.—*Quartz-oligoclase-biotite-schist (No. 1288)*, showing irregular porphyroblasts of biotite, prisms of clinozoisite and colourless quartz and plagioclase.

FIG. 3.—*Coarse-grained gneiss (No. 1278)*, with plentiful biotite and muscovite, quartz, and andesine.

FIG. 4.—*Intergrowth of vermicular quartz and biotite in coarse-grained composite gneiss (No. 1338a)*, Note also the partial replacement of the large crystal of feldspar by sericitic mica.

All magnifications 37 diameters.

FIG. 5.—*Intergrowth of quartz and muscovite in coarse-grained composite gneiss (No. 1338a).*

FIG. 6.—*Coarse-grained gneiss (No. 1338a),* showing development of sericite along cracks traversing coarse plagioclase. The highly irregular crystal interstitial to the feldspar is quartz.

FIG. 7.—*Porphyroblastic hornfelsic paragneiss (No. 1349),* showing large crystals of biotite sieved with small inclusions of quartz and muscovite.

FIG. 8.—*Micaceous band in porphyroblastic hornfelsic paragneiss (No. 1345).* Large sieved crystals of biotite are enclosed in a fine-grained groundmass of muscovite and quartz.

All magnifications 37 diameters.

Fig. 9.—*Chlorite-calcite-albite-epidote-schist (No. 1313)*, showing coarse calcite, abundant chlorite, and irregular clear grains of albite with dark inclusions of epidote.

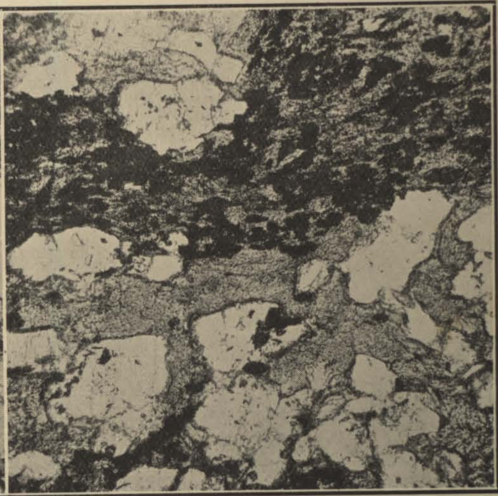


Fig. 10.—*Chlorite-albite-schist (No. 1319)*. Note the abundant dark inclusions (consisting of granular sphene and iron ore) enclosed in some of the chlorite areas.

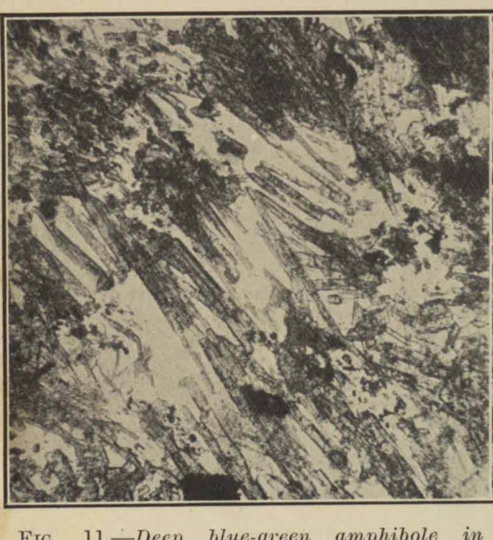


Fig. 11.—*Deep blue-green amphibole in amphibole-schist (No. 1287)*.

Fig. 12.—*Magnetite-haematite-schist (No. 1317)*.

All magnifications 37 diameters.