# The Metamorphic and Ultrabasic Rocks of the Lower Cascade Valley, South Westland.

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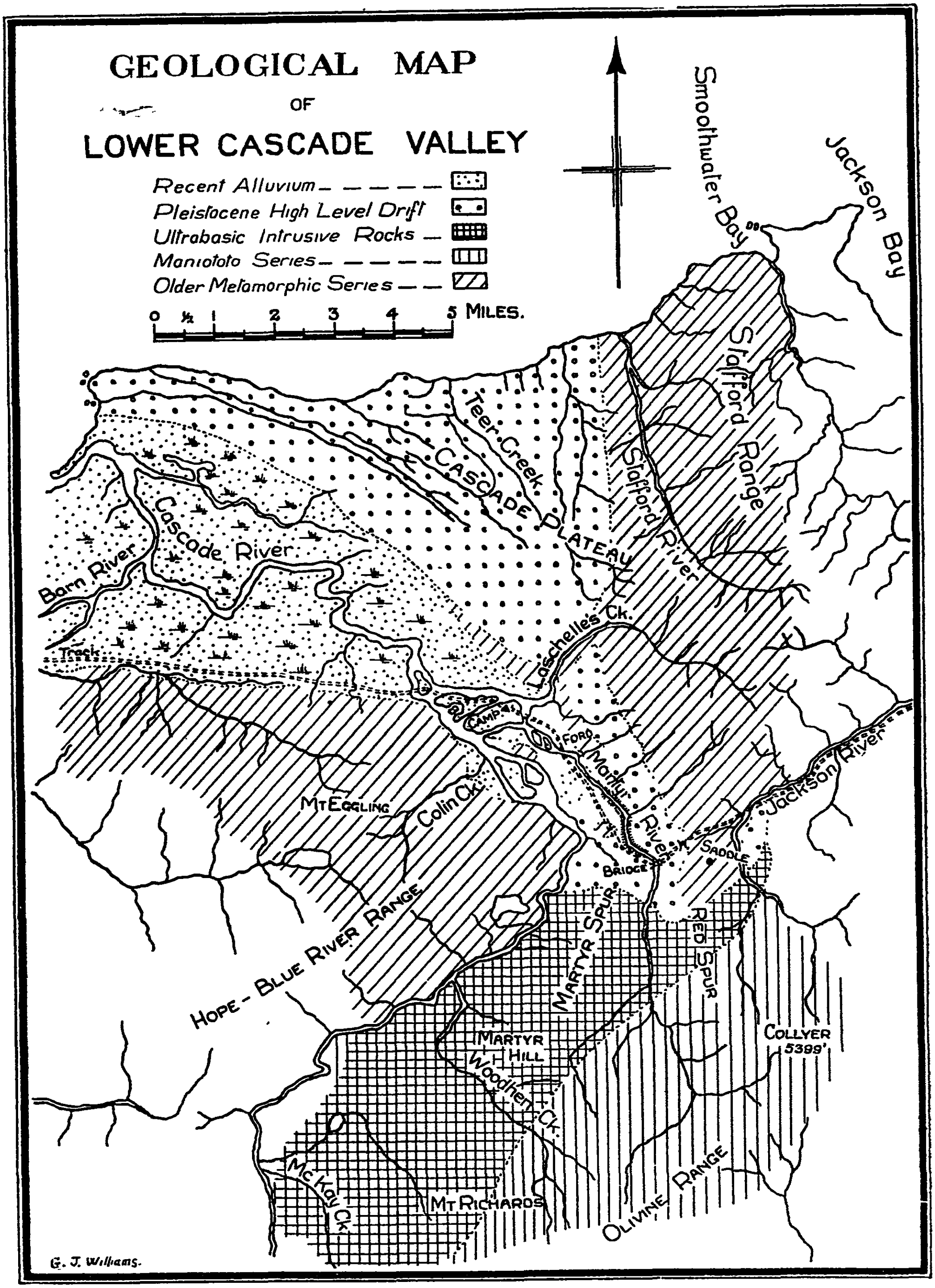
## INTRODUCTION.

THE area to be described embraces about fifty or sixty square miles of country in the vicinity of the lower part of the Cascade Valley, South Westland, and includes parts of the Cascade Plateau and the Hope-Blue River Range, and the western slopes of the northern portion of the Olivine Range.

In January and February, 1929, the writer, accompanied by Mr. W. E. La Roche of Auckland, and Mr. G. J. Williams of Dunedin, visited this region, the greater part of the expenses incurred being met by a Government research grant from the New Zealand Institute.

The route followed lies from Makarora at the head of Lake Wanaka, over the Haast Pass, down the valley of the Haast to the coast and thence ten miles southward to the isolated settlement of Okuru. From Okuru the track follows down the coast across the Waiatoto and Arawata rivers, up the Jackson from its junction with the Arawata to the low saddle which leads into the valley of Martyr Creek, and so into the lower part of the Cascade Valley. Here a camp was established in the excellent hut belonging to Nolan



GEOLOGICAL MAP
OF
LOWER CASCADE VALLEY
Recent Alluvium
Pleistocene High Level Drift
Ultrabasic Intrusive Rocks
Maniototo Series
Older Metamorphic Series
0 ½ 1 2 3 4 5 MILES.
Smoothwater Bay
Jackson Bay
Stafford Range
Stafford River
Teer Creek
Cascade Plateau
Cascade River
Barn River
Track
Laschelle's Ck.
Camp
Ford
Martyr River
Jackson River
Saddle
Bridge
Mt Eggling
Colin Ck.
Hope - Blue River Range
Martyr Spur
Red Spur
Collyer 5399'
Martyr Hill
Woodhen Ck.
McKay Ck.
Mt Richards
Olivine Range
G. J. Williams.

Brothers of Okuru, and subsequent field work was carried out from this as a base. The total distance from Makarora is about 110 miles, which can be covered in four days of actual travelling (whether riding or walking). The track is on the whole good, but considerable difficulty may be experienced if the large rivers such as the Haast, Arawata and Waiatoto, or the smaller, though scarcely less formidable torrents, such as the Jackson and Martyr should be in flood.

The writer's party was unfortunate in encountering particularly bad weather; and heavy floods, combined with fog, rain and snow on the high country rendered it impossible to carry out detailed field work, and considerably limited the area that was geologically explored. It is hoped, however, that further exploration work at some future date will make possible a more detailed account of the field occurrence. The present paper is concerned chiefly with the petrological features of the rocks obtained. The discussion of the complex physiography observed is deferred to a later occasion.

The writer's sincere thanks are due to his two companions Messrs. La Roche and Williams, to Mr. P. Nolan of Okuru and his bushmen, for their generous hospitality and assistance, to Professor J. A. Bartrum of Auckland for help in connection with photomicrographic work, and especially to Professor W. N. Benson of Otago University for his advice and valuable assistance in the preparation of this paper.

## Previous Work.

The earliest report is that by Cox (1877), who described briefly the small area of Tertiary rocks in the vicinity of what was then the settlement of Jackson's Bay.

In the same year there also appeared a brief report by Mr. D. Macfarlane, then Government Agent at Jackson's Bay (Macfarlane, 1877), on the geology of the valleys of the Jackson and Cascade, in which a large belt of ultrabasic intrusive rocks was described and accurately mapped. In an accompanying note by Hector (1877) identifications of the rocks collected by Macfarlane were given.

In 1886, Professor Park, then geologist in the Government Geological Survey, carried out an extensive exploration of the rugged and still almost unknown country which lies between the upper reaches of the Dart and the head of the Cascade Valley. In this report (Park, 1887), an account is given of the southern portion of the peridotite instusion, where it attains its maximum development in the vicinity of Red Mountain.

Ulrich (1890), published an account of the ultrabasic rocks of Red Mountain and the Cascade River, in connection with the occurrence therein of the new iron-nickel alloy awaruite which had recently been described by Skey (1886). This account and the map accompanying it, were based on specimens received from various prospectors, and especially upon information supplied by Mr. R. Paulin, who for many months was engaged in prospecting and exploration along the whole length of the peridotite belt. Unfortunately, however, the geological features shown on the northern part of this map—representing the area dealt with in the present paper—have proved to be incorrect in many instances.

## SYNOPSIS OF GEOLOGY.

The oldest rocks in the area appear to be a series of intensely metamorphosed sediments, represented by gneisses, schists and hornfelses, invaded by innumerable dykes and veins of granite - pegmatite and granite. These rocks, which will henceforward be referred to as the Older Metamorphics Series, are developed extensively on both sides of the lower portion of the Cascade Valley, in the Hope-Blue River Range on the south, and to the north in the bush covered ranges which lie between the Cascade Plateau and the valley of the Jackson.

Corrugated quartz-mica-schists, petrologically identical with the schists of Central Otago (Maniototo Series of Park), form the crest of the Olivine Range along the Cascade-Arawata Watershed, on the eastern border of the map. For reasons which will appear later, these are considered possibly to be younger than the rocks of the Older Metamorphic Series, and they are here correlated with the Central Otago schists with which, indeed, they are almost certainly continuous across the dividing range. It has recently been shown (Marwick, 1925) that these latter rocks are not younger than Carboniferous, and possibly extend far back into the Palaeozoic.

Serpentines and peridotites and associated dyke-rocks form a north-east and south-west trending belt, which lies along the lower slopes and spurs of the western flank of the Olivine Range, between the Older Metamorphic Rocks on the north-west and the schists which form the summit of the Olivine Range on the south-east. These intrusive rocks appear to be younger than either of the series of metamorphic rocks, and are possibly to be regarded as of Early Cretaceous age.

Limestone, marls, sandstones and conglomerates of Middle Tertiary age have been described by Cox (1877) as occurring near the old (now abandoned) settlement of Jackson's Bay, where they constitute a small patch lying unconformable upon the ancient basement rocks. Park (1887) mentions similar small remnants of a former Tertiary cover at Big Bay, some 35 miles south, but as neither of these occurrences was examined by the present writer the rocks of this series will not here be considered further.

The youngest rocks in the area are those of Pleistocene and Recent age, including drift material and alluvium, which are developed extensively for a distance ten miles inland from the mouth of the Cascade, and on the Cascade Plateau immediately north of this.

The downward sequence may, then, be summed up as follows:

(5) Alluvial, glacial and fluvioglacial detritus (Recent and Pleistocene).
(4) Limestones, marls, sandstones and conglomerates (mid-Tertiary).
(3) Peridotites, serpentines and accompanying dyke rocks (? Early Cretaceous).
(2) Schists of the Maniototo Series (Palaeozoic).
(1) Older Metamorphic Series (? Pre-Maniototo).

## The Older Metamorphic Series.

### *Distribution.*

The rocks of the Older Metamorphic Series are developed extensively on both sides of the lower part of the Cascade River, where it flows north-west to the sea.

From the fact that all the boulders in the bed of Colin Creek, which drains the north-eastern slope of the Hope-Blue River Range, consist of rocks of this type, it is inferred that they make up at least the northern end of the range, though the whole of this area was mapped by Ulrich (1890) as peridotite. These hills moreover are heavily bushed (a fact which in itself points to the absence of much peridotite), and owing to the difficulty of fording the Cascade, which was almost constantly in flood, they were not examined in detail. From observations made from the western slopes of the Olivine Range it appears certain, however, that the metamorphic rocks continue for a considerable distance up the north-western side of the Cascade River, which here flows north-east along the junction with the peridotite mass. This accords with Macfarlane's map (1877) on which the north-western boundary of the ultrabasic rocks is marked by the Cascade River along the whole of the north-easterly portion of its course from McKay Creek down to the point where it turns abruptly through 90° and flows north-west to the sea.

On the north-east side of the Lower Cascade, banded gneisses are well exposed in the steep sides of the gorges cut by Laschelles Creek and the small creeks which drain into the Martyr, between this and the ford across the latter stream. Similar rocks appear to underlie the whole of the vast mass of alluvial and morainic material which mantles the Cascade Plateau, and probably extend at least as far north as Jackson's Bay. The precipitous gorge of the Martyr River has also been carved in cemented stratified conglomerates overlying the Older Metamorphic Rocks. These latter appear in the lower part of the walls of the gorge, as well as at the south end of the bridge which spans it, where coarse biotite-sillimanite-gneisses and large veins of granite-pegmatite are very clearly exposed. Isolated masses of grey quartz-biotite-gneiss invaded by numerous veins of pegmatite outcrop prominently from beneath the mantle of Pleistocene conglomerate at a number of points along the track between the Martyr Bridge and the ford about three miles downstream.

The rocks of the Older Metamorphic Series were traced through the bush which covers the western ends of Martyr Spur and Red Spur to their termination against the peridotite mass. The actual junction is well below the bush line and was not therefore observed.

The northern limit of the gneissic rocks was not determined owing to the unfavourable weather conditions experienced along the route from the Arawata to the Cascade Hut, but such observations as could be made suggest that these rocks probably extend as far north as the Arawata.

*Petrography.*

(1.) *The Gneisses, Schists and Hornfelses.*

Gneisses of the older series are exposed abundantly along the track on both sides of the bridge across the gorge of the Martyr. Numbers 1200 and 1201 are fine-grained compact gneisses with no trace of banding, light green in colour, showing in the hand specimen numerous cleavage faces of small feldspar and mica crystals. In thin section they consist essentially of quartz 50%*, feldspar 25% to 30%, biotite and chlorite 15% to 20%, and a little muscovite. The quartz is in highly irregular interlocking grains averaging 0.5 mm. to 1 mm. in diameter, frequently elongated in directions parallel to one another, and invariably showing pronounced undulose extinction (Fig. 4). The feldspar is largely andesine with subordinate orthoclase, both considerably altered to kaolin, in grains reaching 1 mm., in average dimension. The biotite is reddish brown, strongly pleochroic, in flakes of similar size scattered evenly throughout the rock. In number 1200 it is almost completely replaced by a green almost isotropic chlorite; but in number 1201 the two minerals are present in equal proportions, the biotite occurring as a central unaltered core surrounded by a border of chlorite, though in a less altered part of the section chlorite is practically absent. Muscovite is present in sparse, large, ragged flakes up to 2 mm. in length, and often contains rounded grains of included quartz. Apatite is an abundant accessory in small prisms and rounded grains, while a few very small short prisms of brown tourmaline and tiny patches of magnetite were also noted.

Numbers 1202 (Fig. 1) and 1203 represent a coarse gneiss developed at the southern end of the bridge adjacent to small invading dykes of pegmatite. In hand specimen the rock is irregularly banded, and is seen to consist of layers a few millimetres thick, rich in brown biotite, alternating with lensoid bands of quartz and white feldspar, averaging 5 mm. in thickness, which appear to have been introduced from the adjacent pegmatites. In one instance a single mass of feldspar, 50 mm. through and in crystalline continuity throughout, was observed occurring in this way. At the junction with the pegmatite the gneiss is especially rich in coarse biotite. In thin section the rock is seen to consist of quartz 40%, feldspar 25%, biotite 20%, muscovite 5%, and sillimanite 5% to 10%, with accessory apatite and magnetite. The quartz occurs in large clear interlocking grains about 2 mm. in diameter, with marked undulose extinction. The feldspar is oligoclase-andesine, possibly accompanied by a small amount of orthoclase, in irregular grains of the same order of size as the quartz, slightly clouded by kaolin, and sometimes containing as inclusions rounded grains of quartz. Twinning according to the albite law is common, but may be quite absent, while pericline twins are rare. Biotite occurs as large, ragged or subidioblastic crystals up to 3 mm. in length showing very strong pleochroism from pale yellowish brown to very deep reddish brown. It

*Unless otherwise stated the percentages given are rough estimates based upon microscopic inspection.

is usually quite fresh, except in part of one section (number 1202) where there is incipient alteration to chlorite. Muscovite occurs sparingly in large irregular flakes, often with bent cleavage lamellae and undulose extinction. Sillimanite occurs plentifully in long, slender, transparent prismatic crystals which reach up to 2 mm. in length, usually in aggregates of parallel individuals. It may be distinguished easily by its high refractive index, moderately high double refraction (giving bright interference tints), straight extinction, positive elongation and well defined cross fracture. It occurs scattered through crystals of biotite, or of quartz, or very frequently along the margins of crystals of biotite. In some parts of the section (Fig. 16) aggregates of parallel prisms of sillimanite have apparently replaced almost completely crystals of biotite, remnants of which still persist throughout rendering the whole mass pleochroic in pale brownish tints. Similar replacement of biotite by sillimanite has recently been described by C. M. Tattam (1929) in schists and gneisses from north-east Victoria. In other instances, however, the boundary between biotite and sillimanite is sharp, while in many parts of the section the prisms of sillimanite are enclosed by quartz or feldspar and are obviously unrelated to biotite. Apatite is present in large crystals (1 mm. × 0.2 mm.) included in the quartz, feldspar or biotite, while accessory magnetite is also present, especially as inclusions in the biotite.

Specimens collected from beside the track about one mile south of the bridge* consist of a fine-grained compact banded grey or greenish gneiss very similar to that already described from the vicinity of the bridge (numbers 1200-1201). The constituent minerals are quartz 45%, feldspar 30 % (including variable but approximately equal proportions of andesine and orthoclase), biotite, or chlorite derived from it, 20%, muscovite 5%, together with magnetite, apatite and small prisms of brown tourmaline as constant accessories. The biotite of the fresh rock (numbers 1204 and 1205) is deep reddish brown and shows no sign of alteration while the feldspar is only slightly kaolinised (Fig. 2); but in some apparently altered specimens, especially in the finer phases of the rock, the biotite may be replaced partially (Number 1206) or completely (Number 1207) by chlorite which imparts a greenish colour to the hand specimen, while the feldspars in such cases show considerable alteration to kaolin. Muscovite is not plentiful and occurs in rare rather large, ragged crystals, which frequently enclose rounded inclusions of quartz. Though the grain becomes considerably coarser where close to the contacts between the gneiss and the numerous dykes and veins of pegmatite which here invade it, they never approach in coarseness the banded gneisses (such as Numbers 1202 and 1203) which have been described above from near Martyr Bridge.

Sections 1208, 1208a and 1208b represent a regularly banded, very compact gneiss which occurs abundantly *in situ* in the sides of the steep gorge which has been cut by the small creek which drains

*The gneiss of this locality is so crowded with veins of pegmatite that the whole mass might be described as a "lit-par-lit" gneiss.

southward into the Martyr just below the ford across the latter stream. The bands, alternately coarse and fine, are about 30 mm. or more in thickness and are very sharply defined. The fine bands (Number 1208a) consist of quartz 40%, feldspar 25%, biotite 25%, muscovite 10%, and accessory tourmaline and apatite. Quartz is present as interlocking clear allotriomorphic grains, with undulose extinction, averaging 0.2 mm. in diameter. The feldspar is in untwinned grains of similar size, and may be distinguished from quartz by its definitely lower refractive index, and by the slightly clouded appearance of the crystals. Such interference figures as could be obtained in spite of strain effects indicate that the mineral is positive, and on this account, and since the refractive index appears to be only slightly lower than Canada Balsam, it is probable that the feldspar is oligoclase-albite rather than orthoclase. Biotite is plentiful in large, pleochroic, deep sepia brown crystals (0.5 mm. to 1 mm.) which have a marked tendency towards sieve-structure due to rounded inclusions of quartz and less commonly crystals of muscovite. Muscovite, in small idioblastic flakes up to 0.3 mm. in length, is scattered abundantly through the rock, usually between the crystals of the other minerals. The optic axial angle is small, and basal sections show undulose extinction and quite low order interference tints between crossed nicols. Whereas the crystals of biotite are oriented parallel to the banding of the rock, those of muscovite show no approach to parallel orientation. Tourmaline, with marked pleochroism from pale yellowish to deep brown tints, is an abundant accessory mineral, occurring in stout prisms or rounded grains which may reach 0.3 mm. in length, while similar crystals of apatite are also plentiful. In section 1208b cut from a coarse band in the same rock the mineral composition is similar to that just given for the finer band, except that feldspar is present to the extent of only about 5%, the quartz being correspondingly increased to over 50%, while muscovite is slightly more plentiful. Crystals of biotite are larger (1.5 mm.) and show very perfect sieve-structure (Fig. 3) where they enclose numerous rounded grains of quartz and sometimes small crystals of muscovite. In two cases the cleavage lamellae show bending and distortion due to pressure. Muscovite, tourmaline and apatite are developed much as in the finer phases of the gneiss. In section Number 1222 the contact of the gneiss with a vein of tourmaline-pegmatite is shown. The line of separation is definite and sharp, but the gneiss immediately bordering the pegmatite is especially rich in small flakes of muscovite arranged parallel to the contact, while there are several large idioblastic crystals of brown tourmaline about 2 mm. in length showing perfect sieve-structure with numerous inclusions of quartz. Some of the biotite has been converted to pennine pseudomorphs, but some remains unaltered.

Muscovite-biotite-quartz-schist (Numbers 1209, 1209a) is well exposed in the small island in the Cascade River a mile or so above its junction with the Martyr. The rock is compact, but the predominance of the micas over quartz gives it a well marked schistosity unusual in the rocks of this series, while veins of secondary quartz are frequent. A section at right angles to the schistosity shows small plates of muscovite making up 50% of the rock, clear quartz 20% (in grains from 0.1 to 0.2 mm.) scattered through the felt of muscovite crystals, and about 30% deep brown biotite in large crystals about 1 mm. × 0.5 mm., in some of which sieve-structure is visible. Apatite and brown tourmaline occur as accessories.

The rocks forming the north-eastern face of the Hope-Blue River Range are represented only by specimens collected from boulders in the bed of Colin Creek (Numbers 1210, 1210a, 1211, 1212, 1213, 1213a). Sections 1210 and 1210a were cut from a rather fine-grained quartz-biotite-muscovite-schist which is much less coherent than is usual in the rocks of this series. It consists of fine bands two or three millimeters in thickness alternately rich in quartz and in micas. Quartz with undulose extinction, deep brown biotite and muscovite are present in equal proportions, but crystals of biotite are much larger than those of the other minerals and show a tendency towards imperfect sieve-structure. As in nearly all the rocks of this type the muscovite is in small crystals 0.5 mm. × 0.05 mm., and has only a small optic axial angle, so that between crossed nicols basal sections show interference tints considerably lower than do the grains of quartz. Brown tourmaline, and to a less extent apatite, are abundant accessories as small prisms.

Numbers 1213 and 1213a (Fig. 16) represent the fine and coarse phases respectively of a compact banded gneiss, consisting of alternatively coarse and fine sharply defined bands which average from 7 cms. to 10 cms. in thickness. In the finer bands quartz (60%) and biotite (25%) make up the bulk of the rock, in crystals of variable size ranging from 0.1 to 0.7 mm. Small crystals of muscovite, partially kaolinised, occur to the extent of about 15%, while grains of epidote, prisms of brown tourmaline and apatite, and a little magnetite are present as accessories. In the coarser phase the same minerals are developed. Biotite is raised to 35% and occurs in large porphyroblasts 1 mm. long, strongly pleochroic in light yellowish to deep reddish and sepia browns, almost uniaxial, with well developed sieve-structure due to numerous inclusions of rounded quartz grains and of rare idioblastic muscovites. These are set in a fine mosaic—much finer and more even-grained than in the "fine" band described above—consisting of even-sized crystals and grains about 1 mm. in diameter of muscovite and quartz in the proportion of 2 : 1. The quartz has only a tendency towards undulose extinction.

Sections 1211 and 1212 were taken from a compact gneiss with very distinct alternating fine and coarse bands a few millimeters in thickness. The average composition of the finer bands is esssentially quartz 40% to 50%, feldspar 15%, and biotite 25% and muscovite in very variable proportions, usually from 5% to 15%. The quartz and feldspar are in small irregular grains averaging 0.1 mm. in diameter. All the feldspar is untwinned with a refractive index less than that of Canada Balsam, but the fact that the optical sign is sometimes positive and sometimes negative indicates the presence of both albite and orthoclase. The biotite is in ragged sepia brown crystals a little larger than the surrounding grains of quartz and feldspar; it is sometimes partially altered to greenish biotite and chlorite, and often shows incipient sieve-structure. In the coarser bands quartz, feldspar and muscovite are developed much as in the finer phase of the gneiss, except that the latter mineral is usually more plentiful and the feldspar less abundant. The biotite, however, as well as being more plentiful is very much coarser, and occurs in large oriented diablastic porphyroblasts about 1 mm. × 0.5 mm., with numerous rounded inclusions of quartz. Andalusite is constantly present to the extent of about 10% in the coarser bands only, in large diablastic masses up to about 1 mm. or 2 mm., in diameter, enclosing almost an equal amount of quartz in rounded grains (Fig. 5). The high refractive index (higher than that of the biotite), fairly low birefringence (slightly greater than that of quartz), straight extinction parallel to a poorly marked cleavage, and negative elongation all agree perfectly with the normal properties of andalusite though it was not possible to obtain distinctive interference figures in convergent light. Some sections show the characteristic partial alteration of the mineral to muscovite. Throughout the whole rock brown tourmaline is an abundant accessory, together with prisms of apatite and grains of magnetite and rarer epidote.

Number 1214, cut from a pebble which was collected at the ford across the Cascade River immediately below its junction with the Martyr, is a lightcoloured greyish green hornfels in which quartz (60%), kaolinised feldspar (30%) and partially chloritised biotite (10%) are the chief constituents. Much of the quartz is in large ragged porphyroblastic grains about 0.7 mm. in diameter, set in a matrix consisting of much smaller grains of quartz and the other minerals. The biotite is mostly in small irregular deep brown flakes without inclusions, a large proportion being altered to pennine and other chloritic products. Small masses of kaolin, probably representing original feldspar, are abundant, while apatite and magnetite are present as accessories, along with rare grains of epidote which usually occur associated with the chloritised biotite. The section contains a single knot about 1 mm. × 1.5 mm., consisting of about six crystals of a mineral which is identified somewhat doubtfully as prismatine, the whole being fringed with a biotite (Fig. 6). The mineral is transparent, almost colourless but with a slightly yellowish tint, non-pleochroic, with high refractive index (probably between 1.65 and 1.70), and fairly high double refraction (about 0.016). The crystals are prismatic with negative elongation parallel to a single well marked cleavage, with reference to which there is a straight extinction. There are rare small inclusions of magnetite. Unfortunately definite interference figures in convergent light could not be obtained. The distinctly negative elongation distinguishes the mineral definitely from orthorhombic amphibole or pyroxene as well as from sillimanite. The double refraction appears slightly too strong for prismatine, the birefringence of which is about .013, though Winchell (1927, p. 250) comments upon the variability of the optical properties of this mineral.

Hornfelsic rocks also occur abundantly in the boulders of Laschelles Creek and among the detrital material of the Cascade

Plateau, from which many of the boulders in Laschelles Creek were themselves derived. Since the bulk of the boulders of the Plateau consist of dunite which appears originally to have been brought from the middle and upper parts of the Cascade Valley, it is probable that much of the hornfels, too, has been derived from rather distinct localities.

Many of these rocks resemble in appearance and composition the finer types of quartz-biotite-gneiss which outcrop near the Martyr Bridge and along the track a mile or so south of this. They are finer in grain, however, and exhibit no trace of schistosity (Fig. 7). A common type is a brownish hornfels (Numbers 1215 and 1216, Laschelles Creek) consisting of quartz 60%, small ragged flakes of brown biotite 25%, and the remainder of the rock small grains of muscovite, possibly with a little basic plagioclase. Abundant apatite and less plentiful epidote and magnetite are accessories. Number 1217 (Cascade Plateau) is a similar rock with, in addition to the above minerals, a small amount of green hornblende and twinned basic labradorite in grains about 0.1 mm. in diameter. A greenish grey hornfels (Number 1218) from Laschelles Creek consists largely of small crystals of quartz and chloritised biotite together with aggregates of kaolin representing original feldspar. The biotite is almost completely replaced by chlorite in which fine sagenitic needles of rutile are perfectly developed. Muscovite occurs in rather large clear crystals with numerous inclusions of quartz, while there is also about 5% of clear microcline in well twinned masses up to 0.5 mm., occurring interstitially among the grains of quartz.

From the descriptions given above it will be seen that the majority of the rocks of the Older Metamorphic Series are fine-grained gneisses and hornfelsic rocks with little or no trace of schistosity, in which quartz makes up 50% of the rock and biotite is always abundant, while muscovite and feldspar are also consistently present in considerable amount. The feldspar is usually plagioclase ranging from albite to andesine together with a less amount of orthoclase, though in one case a small amount of basic labradorite and in another microcline were observed. In rare instances andalusite (Number 1213) or sillimanite (Numbers 1202 and 1203) may be present in some quantity, but in the majority of the rocks examined there was no trace of these minerals. The constant presence of accessory brown tourmaline and apatite, in idioblastic prisms is a characteristic feature.

The texture of the rocks is normally granoblastic, though in some of the banded gneisses the crystals of biotite are much larger than those of the other minerals present, and show more or less marked parallel orientation and perfectly developed sieve-structure. In two specimens (Numbers 1209 and 1210) the rocks are distinctly schistose, these two sections being especially rich in muscovite, which is present to the complete exclusion of feldspar, as well as having the usual complement of biotite.

(2.) *The Pegmatites.*

Wherever the gneisses and schists of the Older Metamorphic Series were examined *in situ,* they were found to be invaded by numerous dykes and veins of white pegmatite and granite, ranging from an inch to two or three feet in width, and conforming to the foliation of the invaded rocks.

Specimens taken from alongside the track about one mile south of Martyr Bridge are holocrystalline granitoid rocks consisting essentially of quartz 20%, feldspar about 70%, and muscovite and biotite in varying but never very large amount. The quartz is in allotriomorphic often interstitial grains with pronounced undulose extinction, and is sometimes present as sparse rounded grains included in crystals of feldspar. The feldspars are microcline, oligoclase-albite and orthoclase in very variable proportions, the last named mineral never being very abundant. The microcline, which in some cases (e.g. Number 1219) may make up nearly 50% of the whole rock, is in clear unweathered allotriomorphic masses—often interstitial—with perfectly developed gridiron twinning (Fig. 8). The plagioclase is considerably altered to kaolin, so that it is not always easy to compare the refractive index with that of Canada Balsam. The refraction is generally definitely less than that of the balsam, however, and the mineral is always optically positive, while the extinction angle measured with reference to the twinning plane is about 10°. In many cases twinning is either absent or only indefinitely shown. In some specimens (e.g. Number 1220) this mineral makes up 60% or more of the rock. The biotite is deep reddish brown and strongly pleochroic and in some sections shows partial alteration to chlorite, while the muscovite is always in large flakes, often with bent cleavage laminae. Neither mineral is ever present in greater quantity than 5% or 7%. Apatite in stout prisms is sometimes abundant, while magnetite, epidote, zircon, and in one case (Number 1220) very long slender needles of rutile may also be present as accessories.

Number 1221, cut from a large vein of pegmatite invading coarse gneiss at the south end of Martyr Bridge, differs considerably from those described above. Quartz, in large allotriomorphic crystals ranging up to 2 mm., and showing undulose extinction, makes up 30% to 35% of the rock. Nearly all the feldspar is andesine with bent twin-lamellae, while there is also a small amount of orthoclase, both minerals being somewhat altered to kaolin. Partially chloritised reddish brown biotite (3%), muscovite (5%) in ragged flakes often with included quartz, and clear golden brown to very pale brown idiomorphic tourmaline (5%) in crystals reaching 3 mm. in length are the remaining essential constituents of the rock. Rare apatite, needles of rutile, and secondary iron ores associated with the chloritised biotite are present in accessory amount. The rock shows evidence of considerable crushing in the partial granulation of much of the quartz and some of the feldspar, in the undulose extinction of the quartz and in frequent bending of the plagioclase twin-lamellae.

Number 1222, from a vein invading the banded gneiss in the gorge of the creek draining into the Martyr just below the ford, consists mainly of quartz 30%, oligoclase-albite 50%, and orthoclase 10%. Tourmaline is abundant in large idiomorphic prisms usually blue in the central part and brown round the margins, or else in small brown prisms. Muscovite occurs in flakes ranging up to 2 mm., while accessory apatite is present in small prisms. Biotite is absent. The only evidence of straining is the slightly undulose extinction of the quartz grains.

Number 1223 (Fig. 9) from a boulder in the Martyr River at the ford, is a different type of rock, consisting of orthoclase 80%, quartz 15%, a small amount of oligoclase, a little muscovite and rare small flakes of chlorite pseudomorphous after biotite. The rock has been severely crushed and large strained and shattered feldspar and quartz crystals alike are set in a much crushed matrix of the same minerals which constitutes 20% of the rock.

The rocks described above may be summed up as a series of granite-pegmatites consisting chiefly of feldspar and quartz with only a small percentage of ferro-magnesian silicates in the form of either biotite or tourmaline. The feldspar is normally a mixture of potash-feldspar (orthoclase or microcline or both) and highly sodic plagioclase in very variable proportions, either mineral being sometimes dominant almost to the exclusion of the other. In one case (Number 1221) andesine is the dominant feldspar and the rock approaches a granodiorite-pegmatite in composition. Strain structures are sometimes very pronounced.

*Origin.*—From the summary given on page 174 it will be seen that the rocks of the Older Metamorphic Series are fairly uniform in composition and fall into Grubenmann's group of "alkali-feldspar gneisses." The rocks belonging to the biotite-rich families of this group are usually derived, according to Grubenmann 1910, pp. 147, 153), from the metamorphism of granites and syenites, or less commonly of sediments such as arkoses, breccias, and clays, of similar composition. Several lines of evidence sugggest, however, that the rocks considered in this paper were originally sedimentary rather than igneous. Chemical analyses have not been made, but the mineralogical composition indicates the high silica, relatively high iron and magnesium, and low calcium content characteristic of the sedimentary gneisses of this type (Grubenmann *loc. cit.*, p. 147). The abundance of both micas also points in this direction for Grubenmann (*loc. cit.*, p. 153) also notes that the meso-gneisses of this group are specially rich in micas when of sedimentary origin. Further the occasional occurrence of andalusite or sillimanite in some quantity indicates the excess of aluminium which is such a characteristic feature of the more pelitic types of sedimentary gneiss. Finally the clear cut nature of the junction between adjacent fine and coarse layers in banded rocks such as Number 1208 and Number 1213 suggests differences in texture and composition in original sedimentary strata, while the universal absence of all traces of blastogranitic structure in the thin sections seems also to preclude the possibility of igneous origin. It seems probable therefore that the rocks of the Oder Metamorphic Series are the result of metamorphism of sedimentary strata which probably consisted originally of impure feldspathic sandstones.

The coarse grain size and completely recrystallised state of the constituent minerals, the prevalence of granoblastic structure, the universal abundance of deep reddish brown biotite and the invariable absence in the unaltered rock of chlorite, epidote or zoisite, all indicate that the rocks of the Older Metamorphic Series have attained a high grade of metamorphism and belong either to the meso- or middle zone or to the kata- or deepest zone of Grubenmann (*loc. cit.*, pp. 80, 81). Features indicative of the lowest zone are the granoblastic and hornfels structure of many of the rocks, the perfect development of sieve-structure in the larger crystals of biotite, and the occurrence of sillimanite and prismatine. The last two minerals are, however, rare in the rocks of this series, and their presence may be explained (see below) as the result of contact action due to the invasion of the series by granite-pegmatites. On the other hand, the occasional development of marked schistosity (Numbers 1209 and 1210) and the frequent presence of abundant muscovite which often constitutes 20% and in one case even makes up 50% of the whole rock, are features both of which are characteristic of the middle zone. The absence of garnet is not of any great significance in the rocks of this group (Grubenmann, *loc. cit.*, pp. 144, 149). It is probable, therefore, that the majority of the rocks of this series should be classed in the lower part of Grubenmann's middle zone in the family of meso-mica-alkalifeldspar–gneisses.

It seems certain, also, that the granite pegmatites which everywhere invade the rocks of the Older Metamorphic Series as innumerable small dykes and veins have had a not inconsiderable influence upon the invaded rocks. This effect is especially pronounced in the coarse sillimanite-gneiss of Martyr Bridge, which undoubtedly owes its large grain-size and peculiarities of mineralogical composition to complete recrystallisation of the normal quartz-biotite-feldspar-gneiss (into which it merges in the course of a few feet) in the presence of igneous material from the adjacent pegmatites, which has thoroughly permeated the surrounding rocks. Part at any rate of the sillimanite seems to have been formed by the replacement of coarse biotite, much as has been described by Tattam (1929, pp. 19, 45) in certain of the metamorphic rocks of north-eastern Victoria, where "the phenomenon occurs in schistose sedimentary material either in direct contact with or close to magmatic solutions." Probably much of the coarse muscovite and very coarse oligoclase-andesine of the Martyr Bridge gneiss is also due to recrystallisation of the original rock while thoroughly permeated by igneous solutions derived from the pegmatite. In other cases, e.g. one mile south of Martyr Bridge, the mica is coarsest and most plentiful near the contact with pegmatite veins. The universal presence of idioblastic brown tourmaline and of apatite throughout all of the Older Metamorphic Rocks would also suggest that these minerals have been formed under the influence of magmatic emanations from the pegmatites penetrating through the gneiss. The pegmatites themselves carry abundant brown tourmaline in many cases, and the surrounding rocks then appear to be specially rich in tourmaline near the contacts. Finally the occurrence of undoubted andalusite in one rock is also evidence of contact action, and probably is the result of high temperature induced in the vicinity of a mass of pegmatite.

The effects of retrogressive metamorphism at a later stage in the history of the area are to be seen in the tendency for biotite to give place to chlorite in some of the rocks, the frequent undulose extinction in crystals of quartz and feldspar in both gneisses and pegmatites, and occasional bending of biotite and muscovite laminae. That the chlorite has developed from biotite and not *vice versa* is definitely shown by the presence of webs of sagenitic rutile in the chlorite, representing titanium in the original biotite, by the frequent occurrence of borders of chlorite surrounding cores of unaltered biotite, and by the obviously pseudomorphous nature of much of the chlorite. Cataclastic structures in many of the pegmatites themselves show that the whole series including both pegmatites and gneisses suffered severe pressure in the upper zone of metamorphism, subsequently to the intrusion of the pegmatites.

The rocks of the Older Metamorphic Series may be said, then, to owe their present constitution and structure to three causes, of which the first is the most important. These are:—

(1.) Intense dynamo-thermal metamorphism of original quartzo-feldspathic sediments under conditions characteristic of the lower part of Grubenmann's middle zone.

(2.) Closely associated with the above and probably approximately contemporaneous with it, is a phase marked by the invasion of the series by granitic pegmatites with the development of local coarse sillimanite- or andalusite-gneiss accompanied by the dissemination of tourmaline and perhaps apatite through the whole series. These pegmatites seem to indicate the presence of a subjacent mass of granite, not as yet exposed by erosion.

(3.) At a subsequent stage, retrogressive metamorphism in the epi- or upper zone has resulted in such mineralogical changes as the alteration of biotite to chlorite and the production of occasional small quantities of epidote from a similar source. Other effects are the development of marked cataclastic structures in some of the pegmatites and the undulose extinction and rare bent cleavage laminae in the quartz and micas of many of the gneisses.

*Structure and Age.*—Cox (1877, p. 44), states that along the coast line north of the Jackson's Bay settlement (i.e. immediately south of the present Jackson's Bay landing) the auriferous slates appear, overlaid by mica schists, the whole striking north-east and dipping north-west at an angle of from 60° to 70°. Macfarlane (1877, p. 30) notes that the "micaceous sandstones" exposed in the gorge of the Martyr dip north-west at 35°, and that the "slates and sandstones" of the Barn Bay Range (Hope-Blue River Range) dip west at 30°. The rocks mentioned above by Macfarlane are in reality gneisses and schists of the Older Metamorphic Series, and it is quite probable that Cox's "slates" and "schists" may also belong here. The present writer observed a steep north-westerly dip in the

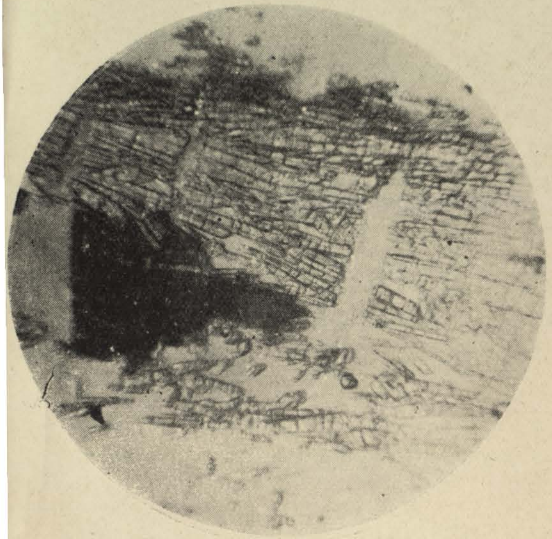


FIG. 1.

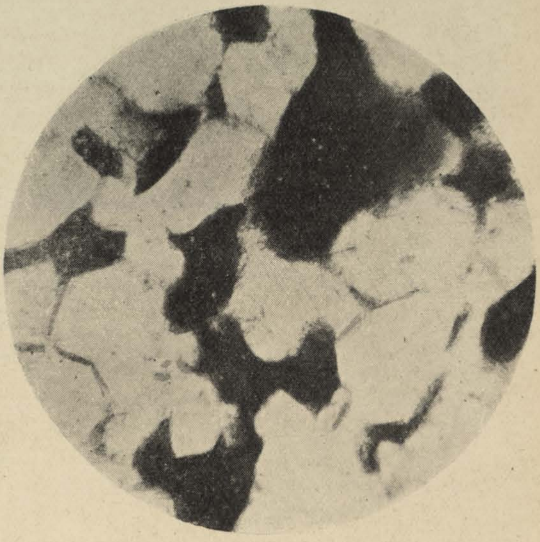


FIG. 2.

FIG. 1.—Sillimanite-gneiss from Martyr Bridge (No. 1202), showing sillimanite, biotite and clear quartz. (Polarised light). Magnification, 45 diams.

FIG. 2.—Fine gneiss one mile south of Martyr Bridge (No. 1205), showing deep brown biotite, slightly altered feldspar, clear quartz and a small crystal of apatite. (Polarised light). Magnification, 45 diams.

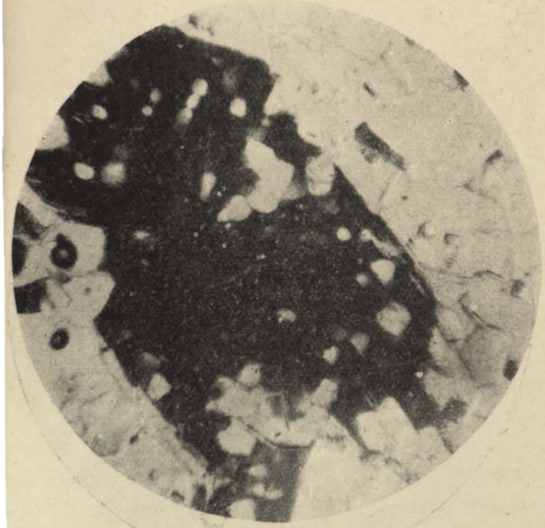


FIG. 3.

FIG. 4.

FIG. 3.—Banded gneiss (No. 1208b), showing large crystals of biotite with sieve-structure, and smaller grains of quartz and plates of muscovite. (Polarised light). Magnification, 45 diams.

FIG. 4.—Fine-grained gneiss from Martyr Bridge (No. 1200), showing quartz with undulose extinction, altered feldspar (speckled) a single large crystal of muscovite enclosing some quartz, and adjacent to it a small crystal of chloritised biotite. (Crossed Nicols). Magnification, 45 diams.

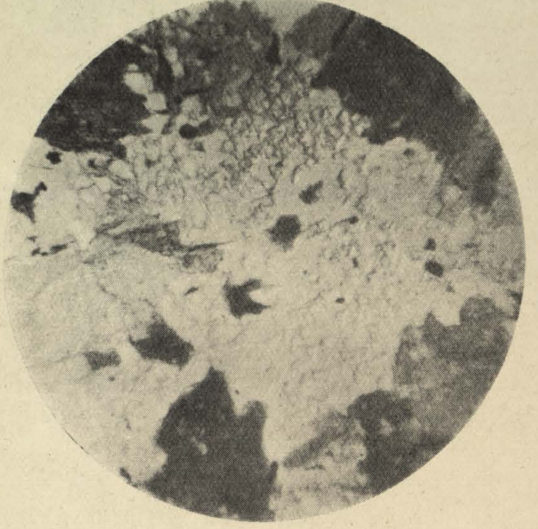


FIG. 5.

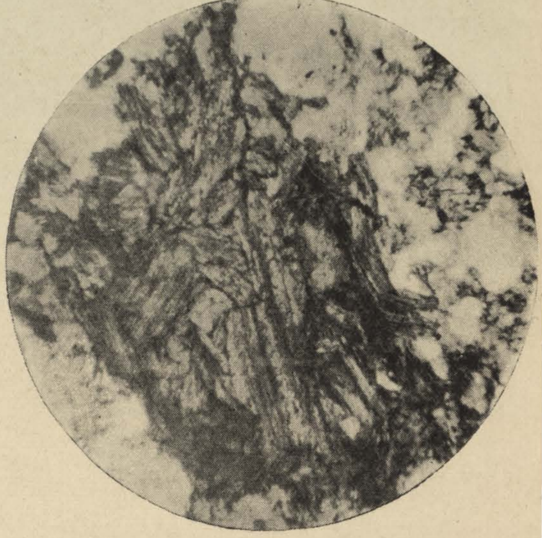


FIG. 6.

FIG. 5.—Banded andalusite-gneiss (No. 1211), showing brown biotite (dark) and andalusite (with high refractive index) enclosing quartz grains to give sieve-structure. (Polarised light). Magnification, 45 diams.

FIG. 6.—Knot of crystals of prismatine fringed with biotite, surrounded by clear quartz and decomposed feldspar in hornfels (No. 1214) from Cascade River Ford. (Polarised light). Magnification, 45 diams.

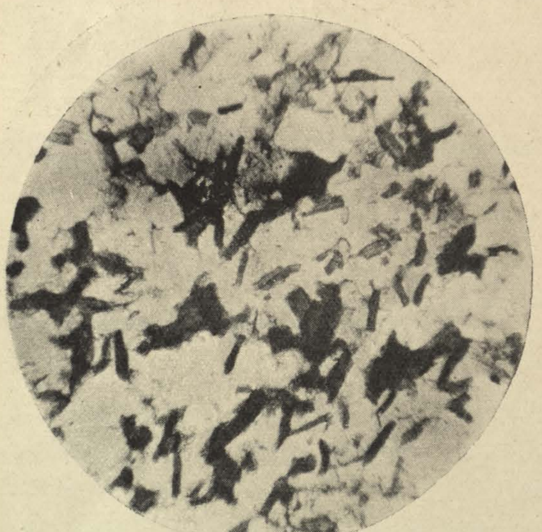


FIG. 7.

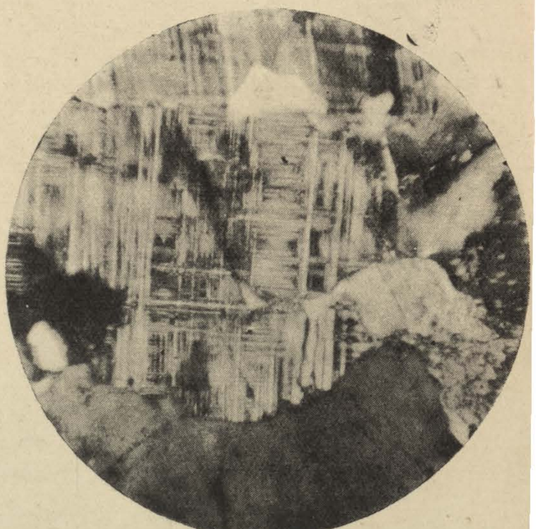


FIG. 8.

FIG. 7.—Biotite-quartz-muscovite-gneiss (No. 1217), Cascade Plateau. Polarised light). Magnification, 45 diams.

FIG. 8.—Pegmatite (No. 1219) from one mile south of Martyr Bridge, showing microcline, quartz and one crystal of muscovite (speckled). (Crossed Nicols.) Magnification, 45 diams.

FIG. 9.

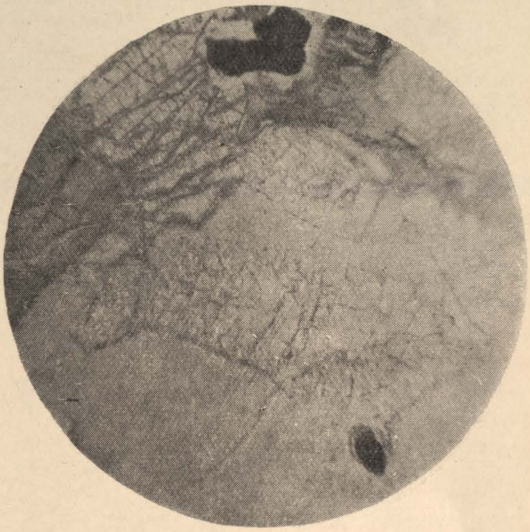


FIG. 10.

FIG. 9.—Pegmatite (No. 1223), showing broken feldspar set in a matrix of fine crushed feldspar and quartz. (Crossed Nicols). Magnification, 45 diams.

FIG. 10.—Wehrlite (No. 1225), Red Spur. Clear shattered olivine is seen passing into antigorite (clear, with low relief), while a small grey crystal of clouded augite and two black grains of chromite are also shown. (Polarised light). Magnification, 45 diams.

FIG. 11.

FIG. 12.

FIG. 11.—The same as Fig. 10, with Nicols crossed. Magnification, 45 diams.

FIG. 12.—Serpentine (No. 1244), showing typical antigorite. (Crossed Nicols). Magnification, 45 diams.

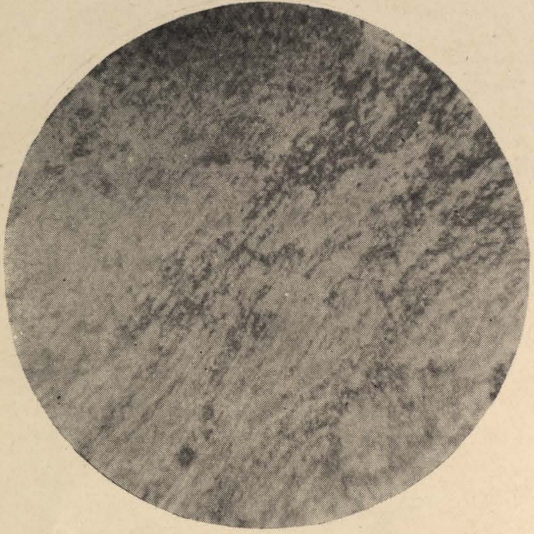


FIG. 13.

FIG. 14.

FIG. 13.—(No. 1249). Talc (light) and fine antigorite (dark) replacing original enstatite. (Crossed Nicols). Magnification, 45 diams.

FIG. 14.—Albite-quartz vein (No. 1255), showing a large crystal of partially kaolinised albite set in crushed quartz and albite. (Crossed Nicols). Magnification, 45 diams.

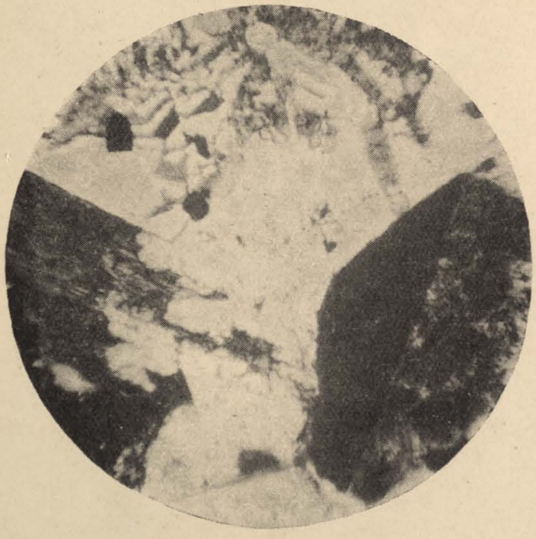


FIG. 15.

FIG. 16.

FIG. 15.—Dioritic rock (No. 1263), showing feldspar, twinned hornblende and a micrographic intergrowth of quartz and feldspar. (Crossed Nicols). Magnification, 45 diams.

FIG. 16.—Biotite-quartz-sillimanite-gneiss (No. 1201). (Polarised light). Magnification, 45 diams.

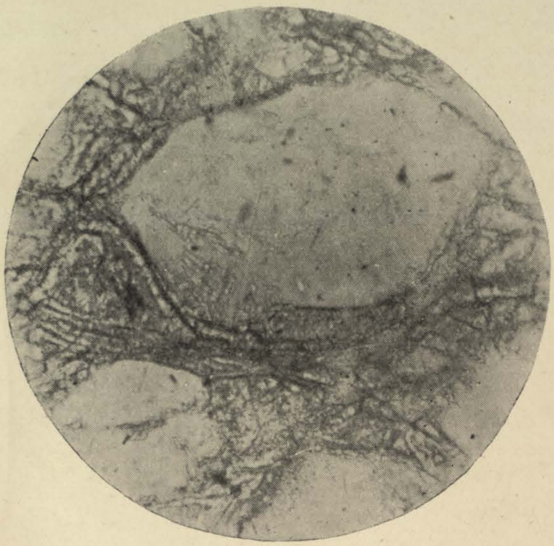


FIG. 17.

FIG. 18.

FIG. 17.—Clear plates of antigorite, surrounded by grains and prisms of monoclinic pyroxene (high refractive index). (Polarised light). Magnification, 85 diams.

FIG. 18.—The same as Fig. 17, with Nicols crossed. Magnification, 85 diams.

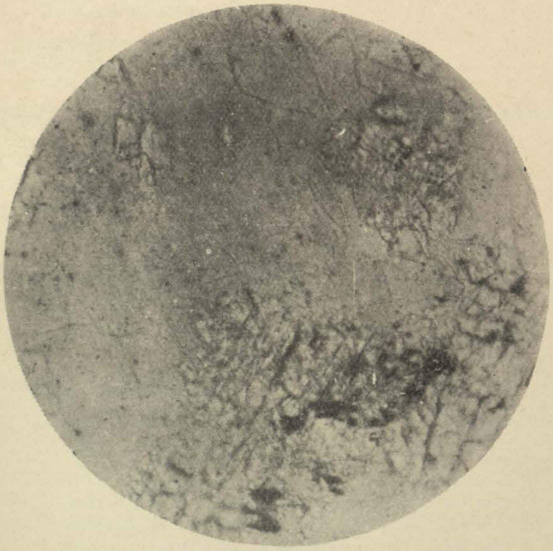


FIG. 19.

FIG. 20.

FIG. 19.—Pyroxenite (No. 1261), showing pyroxene passing into antigorite. (Polarised light). Magnification, 85 diams.

FIG. 20.—The same as Fig. 19, with Nicols crossed. Magnification, 85 diams.

rocks a mile or so south of Martyr Bridge, and again in the gorge of the small stream which joins the Martyr not far below the ford. In the island in the Cascade River, a mile above its junction with the Martyr the strike is north and south and the rocks dip steeply to the west. The facts available indicate, then, that the strike of the rocks of the Older Metamorphic Series varies from north-east in the northern portion of the district mapped to north in the southern portion while the dip is always westerly, usually at high angles.

Until further field work has been done, no attempt will be made to give a definite age to the rocks of the Older Metamorphic Series, or to correlate or compare them with the schists and gneisses described by Morgan (1908) from northern Westland, or those of Fiordland described by Marshall (1907) Speight (1910) and Park (1921). It is sufficient to state that for reasons given in the next section they are believed possibly to antedate the schsits of Central Otago.

## THE MANIOTOTO SERIES.

Quartz - muscovite - schists and chlorite - schists outcrop continuously west of the peridotite belt, along the crest of the Olivine Range in the area here mapped, and appear to extend along the summit of the range many miles southward. These rocks have not yet been examined in sufficient detail for a full description to be given, but they appear to be identical lithologically with the schists of Central Otago, and indeed are almost certainly continuous with these across the main dividing range. Consequently they are here grouped in the Maniototo Series of Park (e.g. 1921). These consist in the main of quartz-muscovite-schists of indubitably sedimentary origin, together with less common chlorite- or sometimes hornblende-schists probably representating original basic igneous material. They probably owe their present condition to extensive dynamic metamorphism and have the mineral composition and structures typical of Grubenmann's upper metamorphic zone (Benson 1921, p. 27). As already stated, these rocks have recently been shown to be at least pre-Permian in age, and probably extend far back into the Palaeozoic.

The only specimen collected by the writer was a soft green schist (Number 1224) from just east of the peridotite-schist junction, on the spur leading up to the Olivine Range between Woodhen Creek and the upper part of the Martyr Stream. In section the rock is seen to be typically schistose, with bands consisting chiefly of granular albite with small amounts of orthoclase and quartz, alternating with layers which consist almost entirely of epidote and chlorite. The albite is in clear usually untwinned irregularly granular crystals, the refractive index of which is always less than that of Canada Balsam, while interference figures always indicate that the crystals are biaxial and positive. The epidote is evidently rich in iron, while the chlorite is deep green, distinctly pleochroic and almost isotropic. There is a little zoisite and several large crystals of apatite in the bands rich in ferromagnesian minerals. The average grain size of the rock is from 0.1 mm. to 0.3 mm.

The relation of these schists to the rocks of the Older Metamorphic Series has not been observed, for in the area here mapped the two series are separated by the intervening belt of peridotites and serpentines. However, the great difference in metamorphic grade between the two groups, and the abundance of pegmatites in the Older Rocks and their complete absence, as far as was observed, in the schists of the Olivine Range, both suggest that the two series are distinct and it is on this assumption that the name Older Metamorphic Series has been put forward for the gneisses and schists west of the peridotite belt. It is possible, however, that these latter rocks are merely the deep-seated much more strongly metamorphised equivalent of the Maniototo schists of the Olivine Range.

## The Peridotite Series.

### *Distribution.*

Peridotites and serpentines are developed along the north-western flank of the Olivine Range from the valley of the Jackson to the southern limit of the district mapped. They form the northern end of a great mass of similar rocks, which extends for twenty miles south-west to the Red Mountain and Red Hill Range where they attain their maximum. In the area here mapped the intrusion is bounded on the north-west by the Cascade River, which marks the junction with the rocks of the Older Metamorphic Series. In the vicinity of Mt. Richards the width is about three or four miles but from this point north-eastwards it narrows off and eventually thins out and disappears completely on the north-eastern side of the Upper Jackson Valley. The trend of the peridotite belt is north-east.

Vegetation is practically absent above about 1500 ft., and in some parts the rocks descend in steep slopes of broken angular talus right down to the valley floors. This absence of vegetation, combined with the characteristic brick-red colour of the weathered rock surface, renders the peridotite belt a very striking feature in the field.

Numerous specimens were collected at frequent intervals along the crests of Red Spur, Martyr Spur and Martyr Hill, and also from the bed of the torrent which descends from Martyr Hill into the rugged and precipitous gorge of Woodhen Creek. Other specimens were obtained from the drift which builds up the Cascade Plateau, and from similar cemented drift along the track between the Martyr Ford and the saddle leading over into the Jackson Valley. This drift material represents debris brought down from the full length of the peridotite belt by the ancestral Cascade River and by the glacier which occupied its valley in Pleistocene times.

In addition, the writer has examined sections cut from about a dozen specimens which were collected some years ago by Mr. G. Moir, M.Sc., from the Red Mountain itself, some twenty miles south of the area here described, and presented by him to the Geology Department of the Otago University. The writer wishes to extend his best thanks to Mr. Moir for the trouble taken by him in collecting and carrying out specimens from this wild and remote region.

## *Petrography.*

### (1.) *Peridotites and Serpentines.*

The rocks collected *in situ* from the flanks of the Olivine Range are mainly wehrlites and dunites with less common lherzolites, nearly always partially serpentinised, usually fine-grained, and dark greenish grey in colour. Those specimens in which serpentinisation is far advanced break with the fine flaky or somewhat splintery fracture characteristic of antigorite rocks.

Though a large number of sections were examined, no trace of regular gradation in mineralogical composition or in degree of serpentinisation across the intrusive mass could be observed. Red Spur and Martyr Spur consist mainly of wehrlite, with some dunite, both of which may occasionally contain small amounts of enstatite, while dunite is developed in abundance on the southern flank of Martyr Spur where it falls away into the precipitous gorge of Woodhen Creek. Numerous dykes of pyroxenite and other rocks of a hypabyssal nature invade the main formation throughout, but these will be considered separately under (2).

Evidence of shattering is always prominent and in some places, e.g. in the gorge of Woodhen Creek, below Mt. Richards, there are zones of intense crushing and slickensiding. Chrysotile veinlets, usually about 5 mm. but sometimes reaching 20 mm. in width, are very numerous along the fracture lines throughout the whole peridotite formation.

Boulders of chromite occur in a number of places on the slopes of Martyr Spur, but no masses of any great size were seen *in situ.*

Descriptions of typical rocks are given as follows:—Number 1225 (Red Spur). The rock is an altered wehrlite which consisted originally of olivine about 75%, and diallage 25%, with minor amounts of chromite. The olivine has been much shattered and about three-quarters or more of it has been converted to colourless antigorite (Figs. 10, 11) plates and blades of which project radially inward from the cracks into central cores of still fresh olivine. In parts of the section all the olivine has thus been replaced by parallel, tufted and sometimes interwoven crystals of antigorite, but the positions of the cracks in the original olivine are still marked by fine lines of extremely minute dark particles, probably of magnetite. This latter mineral, as usually is the case in rocks of this area, is never developed in any quantity, as a result of the change from olivine to antigorite. The pyroxene occurs in rather irregular crystals from 1 mm. to 2 mm. in diameter, which sometimes enclose poikilitically smaller masses of olivine. It is always altered to a semiopaque brownish product which appears white in reflected light, though the polarisation tints of the pyroxene still show through when it is viewed between crossed nicols. Complete extinction of any one crystal cannot be obtained, but the extinction angle measured upon those small fragments of the mass which are clearest and least altered as seen under high magnification, indicates that the original pyroxene was monoclinic. Alteration of aluminous pyroxene in this way is a constant feature in the rocks of this area. Small amounts of antigorite may also be developed along the cleavage cracks of the altered pyroxene, while a considerable quantity of secondary magnetite is often produced, especially round the borders of the pyroxene crystals.

Number 1226 (Red Spur). Thus is a much altered lherzolitic rock which probably consisted originally of olivine 80%, augite 10% and enstatite 10%, with a small amount of accessory chromite. The olivine shows perfectly developed mesh structure the cracks being sharply defined by a semiopaque mixture of fine talc (?) and a very little magnetite dust. The intervening grains have been replaced almost completely by blades of antigorite between which the residual remnants of olivine, though small, are clearly visible under high magnification. The aluminous pyroxene is partly clear, but in most cases has been altered to the usual almost opaque white replacing product. Orthorhombic pyroxene was not definitely determined, but there are a number of patches of coarse strongly birefringent talc with numerous grains of secondary magnetite throughout, and in view of the distinctive types of alteration constantly shown by the augite and the olivine respectively, it is thought probable that the talc-magnetite aggregates represent an iron-bearing enstatite in the original rock.

Number 1227 (Martyr Spur, half-mile below the bush line). The rock is a serpentinised dunite showing perfect mesh structure. The meshes consist of normal chrysotile serpentine spotted with strings of magnetite grains, but the enclosed cores of olivine have been converted largely to flakes of antigorite between which tiny remnants of olivine still persist.

Number 1228 (Martyr Spur, quarter-mile below the bush line). This is a partially serpentinised wehrlite very similar to Number 1225 from Red Spur.

Number 1229 (Martyr Spur, just below the bush line). Nearly 70% of the rock consists of a fine lattice of clear antigorite crystals which seem to have been derived largely from pyroxene, though probably to a minor extent also from olivine, small residuals of which occur throughout. The former mineral is mostly augite, but includes also a small proportion of enstatite, and occurs in crystals which may reach 1 mm. in length. Some of this augite has been altered to the usual brown dusty aggregate, but mostly it is in fairly clear ragged remnants and small cleavage fragments obviously in the process of being converted directly into antigorite. Secondary magnetite is fairly abundant.

Number 1230 (Martyr Spur at the bush line). In hand specimen this is a homogeneous, fine-grained, dark green serpentine with well marked flaky fracture. The section is clear and transparent and consists almost entirely of antigorite, with a little secondary magnetite and a small percentage of dusty brown opaque material representing aluminous pyroxene. In a number of places in the section there are remnants of what have been crystals of bastite showing a striking transition to antigorite into which they are now more than half converted.

Number 1231 (Martyr Spur, one quarter-mile above the bush line). This is a serpentinised dunite consisting almost entirely of altered olivine with about 5% brown opaque altered augite.

Number 1232 (Crest of Martyr Spur half-a-mile above the bush line). This is a fine-grained grey rock which in section proves to be a-half serpentinised wehrlite consisting originally of 70% olivine, 25% augite, two or three small crystals of enstatite and accessory chromite. As usual the olivine is shattered and shows perfectly the transition to antigorite, blades of which not only project radially inwards from the cracks, but also stab in every direction through all parts of the olivine grains. The crystals of monoclinic pyroxene show the usual alteration to brownish almost opaque aggregates white in reflected light, with fringing rims of dusty magnetite, but the enstatite on the other hand is unaltered except for the presence of a narrow border of fine magnetite.

Number 1233 (Martyr Hill, twenty-five yards from the eastern boundary of the peridotite mass). The rock is a wehrlite similar to the section previously described except that it is less altered. Antigorite needles are only just starting to form through the olivine, while the pyroxene, though partially altered in the usual way, is still sufficiently clear to show the extinction angle. So that it may definitely be determined as monoclinic. Strings of secondary magnetite occur along the cracks on the pyroxene and to a less extent in the olivine also. Enstatite is absent, but chromite is present in accessory amount.

Numbers 1234 and 1235 (Upper part of creek draining the southern side of Martyr Hill). The rock is a banded dunite consisting entirely of olivine and chromite, the latter being present in amounts ranging from 15% to 30% of the whole rock. In hand specimen the olivine appears fresh and clear, but high magnification beneath the microscope reveals incipient alteration to antigorite, while two or three veinlets of chrysotile occupy major cracks. The rock merges into a perfectly fresh clear dunite carrying about 2% chromite, which continues in abundance down the creek to the bottom of the gorge of Woodhen Creek. In this rock (Number 1236) needles of antigorite are very rare, though the olivine is much crushed.

The specimens collected by Mr. Moir from the vicinity of the Red Mountain include several representing the normal peridotite as well as a number of interesting dyke rocks which invade the main intrusion and will be described in the next section.

Number 1237 (western margin of Red Mountain intrusion, east of Awarua Bay). This is a greenish partially serpentinised wehrlite consisting originally of olivine (about 80%) and augite (about 20%) with some accessory magnetite. The main constituent is antigorite, through which are scattered small remnants and cleavage prisms of olivine with feathery margins where they pass into antigorite. The olivine grains show undulose extinction but lack the shattering which is such a constant feature of the rocks previously described. The pyroxene is altered to the usual brownish decomposition product. Number 1238 (Red Mountain) is a yellowish dunite which in section appears quite fresh. There is a small amount of chromite, and in the hand specimen a single crystal of bright green chrome-diopside was observed, similar to that which is developed in some of the dykes of pyroxenite and was described by Ulrich (1890) from this area.

The Pleistocene drift which covers the whole of the Cascade Plateau consists very largely of huge boulders of peridotite which probably include material brought from along the full length of the Cascade Valley. The prevailing rock type (e.g. Numbers 1239, 1240 and 1241, from Laschelles Creek) is a fresh clear green dunite in which darker grains of pyroxene are present to the extent of about 5% or 10% so that the rock may approach to harzburgite in composition. The olivine is much crushed and has undulose extinction, but it is either quite fresh or exhibits merely the incipient stages of alteration to antigorite. The pyroxene is enstatite, usually almost clear and transparent, and sometimes shows bent cleavage lamellae. A small amount of chromite also is present. Number 1242 (from drift beside the track one quarter mile above the ford across the Martyr) is a rather similar looking rock, which on sectioning is found to contain about 15% much altered augite and about 85% olivine which in places has been converted to antigorite. This may be classed as a wehrlite.

Number 1243 (Boulder from Martyr Ford) is a fine-grained green serpentine which consists mainly of fine antigorite together with a few crystals of basite about 1 mm. in length. There is abundant secondary magnetite and a few small patches of secondary carbonate.

Number 1244 (from drift between Jackson Saddle and Martyr Bridge) is a green semitranslucent serpentine which breaks with the characteristic splintery fracture of antigorite, and resembles nephrite but for its inferior hardness (about 5 to 5½). In thin section 90% of the rock is seen to consist of fine blades of antigorite (Fig. 12) about 0.1 mm. to 0.2 mm. long, showing most perfectly the "thorn structure" of Bonney. About 5% of the rock consists of a very pale green mineral with similar structure, sometimes distinctly pleochroic with absorption $X < Z$. The crystals are elongated parallel to Z. The refractive index is slightly higher than that of antigorite, but the birefringence is distinctly greater (about 0.02) giving interference tints as high as red of the first order when the antigorite gives only greys and whites. Convergent light tests show that the mineral is biaxial and positive, with a small optic axial angle. This latter character and the higher double refraction distinguish it definitely from antigorite. The mineral appears to lie between chrysotile and xylotilite, and may be identified as an iron-bearing chrysotile or iron-poor xylotilite. Bastite also occurs in rather small amounts (about 5%) and appears in ordinary light as patches having slightly lower refractive index than the surrounding mass of antigorite crystals. The mineral shows a negative biaxial interference figure. Under high power the bastite is seen to be in the process of being converted to antigorite, needles and blades of which are forming in all directions throughout every crystal of bastite. Similar replacement of bastite has been described and figured by Benson (1914, pp. 674, 675) from serpentines in New South Wales.

(2.) *Dykes invading the Peridotites.*

Dykes and veins of pyroxenite, usually only a few inches in thickness, occur abundantly invading the peridotite mass along the whole of its extent. Similar rocks are represented among the specimens collected by Mr. Moir from Red Mountain district, and were found also as small dykes and veins traversing the dunite and wehrlite of large boulders, among the drift material of the Cascade Plateau. The abundance of these dykes probably accounts for the statement made by Ulrich (1890) who in describing the Red Mountain mass notes that "the olivine and enstatite vary much in relative proportions; while in some specimens the former greatly predominates over the latter, in others the reverse is the case." Professor Ulrich was working on specimens collected by prospectors and others; but recently obtained field evidence shows clearly that peridotites with a high olivine content constitute the main intrusive mass and that pyroxenites are minor features only.

The pyroxenites of the Olivine Range consist essentially of augite and enstatite in varying proportions, the former usually dominant, and occasionally there may be a little olivine. Many of these rocks show the effects of intense alteration which has followed along lines entirely different from those shown by the peridotites, in which conversion of olivine to antigorite, augite to a brown opaque decomposition product, and enstatite to bastite or antigorite are such constant features. Typical pyroxenites in various stages of alteration are described below:—

Number 1245 (Martyr Spur half a mile above the bush line). Dillage in subidiomorphic crystals about 2 mm. long, occasionally showing Schiller structure and always unaltered except for a slight dusting of brownish material, makes up 80% of the rock, while there are also one or two clear crystals of enstatite. The remainder consists of clear interstitial patches of antigorite, which enwrap the pyroxene and probably represent original olivine, small grains of which still remain in the surrounding mass of antigorite laths.

In Number 1246 (boulder, Cascade Plateau) over 95% of the rock is pyroxene, enstatite greatly predominating over augite, while a very little olivine and a few grains of chromite also are present. All the minerals are quite fresh. Number 1247 (Red Mountain) is also an undecomposed enstatite-rich type, which contains also about 25% of augite and a small amount of chrome-diopside. The latter mineral is brilliant emerald green in hand specimen but pale green and transparent in section. As noted by Marshall (1906, pp. 564, 565), Ulrich (1890) did not examine this latter mineral in section but identified it provisionally as enstatite. Marshall, however, definitely determined as chrome-diopside a similar mineral from the lherzolite of Cow Saddle, some twenty-five miles south of Red Mountain, and suggested that the green pyroxene from this latter locality would prove to be the same mineral.

Number 1261 (Red Mountain mass, east of Awarua Bay) is a dark green slickensided serpentine which breaks with a flaky "antigorite" fracture. The rock appears originally to have been a pyroxenite but is now more than half converted to antigorite.

Augite and enstatite are both present, but the former mineral greatly predominates over the latter. Both pyroxenes originally occurred as large crystals reaching 3 mm. in length, which are now much broken down and in many parts of the section are represented only by aggregates of small clear cleavage prisms and grains. The transition of both pyroxenes to antigorite is perfectly shown (Figs. 19, 20). Magnetite is present in accessory amounts both as a primary mineral, and also as strings thrown out along the cleavage planes of the altered pyroxene.

Number 1248 (Martyr Spur, one-third of a mile above the bush line). In hand specimen this is a greyish serpentinous rock in which small crystals of pyroxene are visible. The greater part of the rock consists of small plates of pennine with characteristic greenish grey anomolous interference tints, interspersed with less plentiful blades of antigorite and numerous small remnants of clear monoclinic pyroxene. In some parts of the section small grains (0.05 mm.) of deep red garnet are scattered in small amount through the aggregates of pennine and antigorite, usually in the vicinity of grains of magnetite. Apparently the rock consisted in the first place largely of aluminous pyroxene, which has since been altered to pennine, and a little antigorite, garnet and magnetite, through which small cleavage prisms and grains of residual pyroxene still remain in small proportions. Between these aggregates are also present smaller patches of clear felted antigorite, probably pseudomorphous after enstatite or olivine, though no trace of either mineral remains.

Number 1249 (Martyr Spur, three-quarters of a mile above the bush line). In hand specimen this is a coarse-grained rock in which abundant grey serpentinised pyroxene together with large crystals of green chlorite, bright unweathered magnetite and one crystal of reddish-brown garnet were determined. Apparently both monoclinic and orthorhombic pyroxenes were present in abundance in the unaltered rock. The former is now represented by a very fine felt of antigorite in which cleavage prisms of the original mineral still persist in one or two places in the section. The enstatite has been replaced completely by a mixture of coarse talc and finer antigorite (Fig. 13). Sometimes almost the whole of the pseudomorph consists of talc, while in other cases alternating bands of talc and fine antigorite have formed parallel to the cleavage of the original enstatite. About 5% of the rock consists of antigorite pseudomorphous after olivine. Though this mineral is completely replaced, its former presence is indicated by the characteristic curved cracks which are now defined by strings of magnetite dust. There are several very large crystals of magnetite, but neither the garnet nor the chlorite seen in the hand specimen were observed in the section.

Number 1250 (Martyr Spur, a-quarter of a mile above the bush line). The main constituent is augite (60% of the rock) the crystals of which are considerably dusted with brown decomposition products but are still definitely determinable. Pennine in clear subidiomorphic crystals about 1 mm. in diameter showing the usual greyish-green interference tint, occurs between the crystals of augite from which it seems to have been derived. Red garnet in granular masses up to 0.2 mm. long is usually to be found associated with the pennine, but may occur in the pyroxene as well. Secondary magnetite is also fairly plentiful. In other parts of the section large crystals of augite pass into a frayed mass of small prismatic crystals of colourless diopside associated with which are small amounts of garnet, pennine and magnetite. The transition from augite to diopside is sometimes perfectly shown under high magnification. There are also several crystals, ranging up to 2 mm. in length, of a striking pale golden yellow mineral which is probably an iron-rich or titaniferous variety of olivine. There is strong pleochroism with X = golden yellow and Z = almost colourless or very faint yellow. The extinction is straight parallel to a distinct prismatic cleavage, which is the Z direction of the crystal. In several cases crystals were found to consist of three or four twinned individuals. The refractive index is fairly high and the birefringence is about equal to that of the augite. Convergent light tests indicate that the mineral is biaxial with an optic angle near 90°, so that the sign could not be determined.

Number 1251 (Red Spur). Relatively clear monoclinic pyroxene in crystals one or two millimetres long makes up 30% or 40% of the rock and passes gradually into a finely crystalline mass of pennine with greyish-green interference tints, through which residual grains and small cleavage prisms of the original pyroxene are scattered plentifully in some parts of the slide. In other parts, fine pennine has been developed in well defined bands along the cleavage cracks of the pyroxene crystals. There are also present numerous sharply bounded areas about 1 mm. to 2 mm. in length, which consist largely of granular reddish brown material much of which shows up white in reflected light. Some of this substance appears under high magnification to be translucent and is probably much altered sphene partially coated with leucoxene. Included among the grains are small amounts of pennine and serpentine.

Number 1252 (Gorge of Woodhen Creek). The specimen was collected from the great mass of crushed and slickensided green serpentinous rock which outcrops at the junction of the creek draining the south side of Martyr Hill with Woodhen Creek. Veins of chrysotile are abundant in the hand specimen. The rock appears to have consisted originally almost entirely of monoclinic pyroxene which is still present in considerable quantity. Much of the mineral has been converted to antigorite which now occurs in rounded flakes which may reach 0.5 mm. in diameter and which clearly show a definitely negative optical sign. In some crystals this alteration has taken place along the cleavage cracks of the pyroxene. Throughout most of the section, however, an unusual type of mesh structure has been developed on a very perfect scale (Figs. 17, 18). The rounded plates of antigorite referred to above are separated from one another by a meshwork built up of grains and prismatic fragments of clear transparent monoclinic pyroxene which at first sight appears from its very mode of occurrence to be secondary in origin. Careful inspection, however, reveals that this interstitial pyroxene is similar to and apparently continuous with the undoubtedly primary pyroxene, which in other portions of the slide shows normal alteration to antigorite along the cleavage planes as already noted. It is suggested therefore that the curious mesh effect has arisen by the alteration of pyroxene to antigorite, crystals of which, in growing outward from points within the pyroxene crystals, have gradually replaced the latter mineral to a large extent, leaving borders of shattered residual pyroxene separating adjacent plates and masses of antigorite from one another. A further complication has been introduced by subsequent shearing and shattering of the whole rock, after which microscopic veins of chrysotile have been formed along the cracks so produced. In some parts chrysotile appears to have replaced completely the previously formed antigorite so that there are large patches of normal chrysotile serpentine enclosing grains of residual pyroxene, which lie adjacent to the aggregates of antigorite and pyroxene just described. Pressure effects are seen in the universal undulose extinction of the antigorite and in pronounced bending of some of the veins of chrysotile.

Number 1253 (Boulder, Martyr Ford). The rock is a green serpentine which seems originally to have consisted almost entirely of clear transparent monoclinic pyroxene, half of which is now converted to chrysotile serpentine. The transition is perfectly shown. In some parts of the section there is a tendency for the serpentine to show rough antigorite structure, and it is possible that this mineral has been developed in small amount from the chrysotile as a result of pressure. A single large crystal of bastite was noted, while there are also several veinlets of talc running through the mesh of chrysotile. A small amount of secondary magnetite is present in some parts of the section.

Although recorded by Ulrich (1890) from the Red Mountain area, dykes of normal gabbro-pegmatite were not found at all in the district described in the present paper. Dykes of light-coloured rocks were occasionally met with, however, and microscopic examination shows that these vary considerably in composition.

Number 1254 (Martyr Spur). The specimen was obtained from a dyke of hard white rock several feet in width, which cuts the peridotite mass and outcrops on the crest of Martyr Spur just where the heavy bush gives way to subalpine scrub. The rock is much altered, and under low magnification appears to consist largely of semiopaque white material interspersed with clear irregular patches of finely felted antigorite which constitute 15% of the section. There are also one or two large crystals of unaltered diopside the margins of which feather out into the antigorite. Under high power, the white almost opaque mass is seen to consist largely of colourless grossularite in very small clear grains, intimately associated with which are slender prisms of secondary pyroxene and laths of antigorite. Most of this pyroxene is enstatite, but diopside is also present. There is a small quantity of secondary magnetite and also what appear to be residual altered grains of original pyroxene in some parts of the section. The rock is clearly allied to the garnet-pyroxene rocks of the peridotite belt of Nelson, to which Marshall (1911) gave the name, rodingite. Benson (1918, p. 686) noted very similar rocks in the Great Serpentine Belt of New South Wales. One of these he describes as consisting entirely of garnet containing lakelets of antigorite which represent original pyroxene, and he notes at the same time that the garnet has encroached considerably upon the pyroxene boundary. In a recent paper Grange (1927, pp. 162-163) mentions the frequent presence of diopside, zoisite and prehnite in the Nelson rocks, but apparently secondary enstatite, though so abundant in the rock just described, is absent both from the rodingites of Nelson and the similar garnetiferous rocks from New South Wales.

Number 1255. The specimen was obtained from a narrow dyke of hard even-grained white rock which cuts the peridotite mass about half-way down the gorge of the creek flowing from the southern slopes of Martyr Hill into Woodhen Creek. The rock consists almost entirely of albite and quartz in equal proportions. The albite occurs in tabular crystals about 3 mm. in length, and is much crushed and shattered into smaller angular fragments in many parts of the slide. Much of it is untwinned, though albite twins were seen in several instances, but the low refractive index and definitely positive optical character in every case allow the mineral to be determined with certainty. The large crystals of albite are set in a matrix (Fig. 14) which consists almost entirely of much crushed quartz in irregular grains ranging from 0.05 mm. to 0.5 mm., which show undulose extinction between crossed nicols. Epidote occurs in strings of small grains along the junctions between the large feldspars and the surrounding mass of quartz grains, and in several places is developed as veinlets along cracks. Benson (1918, p. 691) has described similar rocks from dykes cutting the peridotite of the Great Serpentine Belt of New South Wales. The writer has been fortunate enough to have had the opportunity of examining Professor Benson's sections, one of which (M.B. 230) is almost identical with the rock just described.

Number 1256 (Boulder, Martyr Ford). In hand specimen the rock is white with ill-defined bands of a light brownish tint. In section the most conspicuous mineral is tremolite, which occurs in clear prismatic crystals (0.5 mm. × 0.1 mm.) and ragged torn flakes of similar size, which are set in a very fine crushed matrix consisting of tremolite, antigorite and a small amount of a clear mineral with refractive index less than that of Canada Balsam—probably albite. The prisms of tremolite frequently show simple twinning. There are also a few small crystals of augite and several grains of magnetite in the process of being converted to limonite. The rock probably represents an extremely crushed and altered gabbroid dyke-rock originally very rich in pyroxene.

Number 1257 (Boulder, Martyr Ford). In hand specimen this is a whitish or light grey homogeneous fine-grained rock with a flaky fracture. Under low magnification, the section is seen to consist for the most part of a finely granular almost opaque white matrix through which are streaked irregularly drawn out patches of clear transparent material which make up about one-fifth of the rock. Under high power the white semiopaque matrix appears to be made up almost entirely of granular pleochroic yellowish-green epidote, intermixed with much less abundant, fine, transparent grains which are probably albite and quartz. One or two tiny crystals of brown hornblende and a little zoisite were also noted. The clear lenses and streaks consist mainly of albite or oligoclase-albite intermixed with smaller amounts of finely granular quartz. The albite is water-clear and sometimes shows polysynthetic twinning. In one or two cases crystals ranging up to 1 mm. in length were observed, but usually the mineral is in small interlocking grains. In hand specimen the rock closely resembles specimens of "white gabbro" or gabbro-granulite collected by Professor W. N. Benson from Carrick Luz in the Lizard district of Cornwall, and described by Flett and Hill (1912, pp. 87-90). In these, however, the pyroxene is granulated and often converted wholly or partially to amphibole while the feldspar either goes over to saussurite or is simply crushed; but in Number 1257 described above there has been interaction between the augite and plagioclase, which have ultimately been altered to epidote, albite and a little quartz—a reaction involving loss of magnesium.

Number 1258. The specimen was collected by Mr. Moir from a dyke in the peridotite near the summit of Red Mountain. About half the rock consists of large idiomorphic crystals of hornblende (about 1.5 mm. × 1 mm.), yellowish to brownish green in colour, which sometimes is simply twinned. These are set in a fine granular mass the main constitutent of which is zoisite showing strong Prussian blue interference tints, together with minor quantities of albite and quartz. Sometimes the interstitial albite is in crystalline continuity throughout patches as much as .25 mm. in diameter, the twinning lamellae also being continuous across this distance. There is a small amount of rather indefinite chlorite, while a single crystal of tremolite, bordered with brown hornblende, was observed. The rock probably represents a gabbroid dyke, in which the augite has been converted to hornblende and the labradorite to zoisite and albite. Recrystallisation must, however, have been very complete since the hornblende now shows no trace of secondary origin.

Number 1259 (Dyke, Red Mountain). This also is a much altered dyke rock consisting mainly of hornblende and altered feldspar in equal proportions. The hornblende is in large ragged prismatic crystals, often showing bent cleavage lamellae, and a curious pinkish brown in colour. The pleochroism is strong (absorption $Z > Y > X$), the extinction angle is 18°, the elongation is positive and the optical sign negative. In parts of the section the hornblende passes into tufted groups of slender prisms of tremolite. The feldspar is intensely altered to an almost opaque white aggregate which appears to be largely zoisite and quartz. Secondary epidote and clear quartz occur in small veinlets occupying cracks.

Number 1260 (Vein in peridotite, Red Mountain). This is an interesting rock which in hand specimen is very hard, finely granular, irregularly streaked and pinkish in colour. It consists almost entirely of clear unaltered monoclinic pyroxene (probably diopside) in crystals ranging up to 2 mm. and a slightly less amount of pale pink faintly pleochroic vesuvianite. The latter mineral may easily be distinguished by its colour, high refractive index, very low double refraction giving an anomolous greyish green interference tint, distinct prismatic cleavage parallel to which there is straight extinction, uniaxial negative interference figure and negative elongation parallel to the vertical axis. In some cases it has formed as borders round crystals of diopside, while in others it appears to be enclosed by that mineral. Veinlets of zoisite 0.2 mm. wide cut the section sharply in one place. In another section (Number 1260a) of the same rock, streaks consisting almost entirely of aggregated prisms and grains of diopside were noted, while about 1% of the rock consists of green pennine scattered in small patches throughout the main mass of pyroxene and vesuvianite. Grange (1927, p. 163) mentions the occurrence of vesuvianite in the fine-grained "rodingites" of Nelson, and calls attention to the presence of grossularite, diopside and vesuvianite in veins described by Graham (1917) from the serpentines of Quebec.

### *Discussion of Alteration Phenomena.*

The peridotites, pyroxenites and other rocks of the ultrabasic intrusive series nearly all exhibit in greater or less degree the effects of various types of alteration which seem to have followed closely upon the intrusion of the mass, apparently largely as the result of hydrothermal processes. Partial serpentinisation is undoubtedly the most widely developed of these changes in the main peridotite mass. Usually olivine, enstatite and less commonly monoclinic pyroxene show a direct transition to antigorite, while most of the aluminous pyroxene has become coated with a cloudy brownish or white decomposition product which sometimes renders the mineral almost opaque. This latter phenomenon has been noted by Bartrum and Turner (1929) in the peridotites of the North Cape area. Occasionally bastite has first been formed from enstatite, and chrysotile from olivine, while at a later stage both bastite and chrysotile show partial or complete replacement by antigorite much as described by Benson (1914, pp. 674, 675) from New South Wales serpentines. When this transformation is complete, the original parallel structure of the bastite and mesh structure of the chrysotile are indicated only by strings of magnetite dust seen in ordinary polarised light, while between crossed nicols the whole mass shows up as a uniform aggregate of antigorite, with perfectly developed "thorn" structure.

This universal abundance of antigorite and absence of chrysotile other than in veinlets of more recent development, is conclusive evidence, according to Harker (1919, p 87), that the process of serpentinisation took place under considerable shearing stress. This conclusion is amply supported by the invariable shattering of peridotites and serpentines alike and by frequently observed undulose extinction in crystals of olivine, pyroxene and antigorite.

The hypabyssal rocks which invade the main peridotite mass show in many cases mineral transformations which are considerably more diverse, but are still indicative of accompanying pressure and shearing stress. Olivine, if present, is always altered partially or wholly to antigorite. The enstatite is usually altered to the same mineral just as in the normal peridotites, but sometimes it has been replaced by talc, a mixture of talc and antigorite, or rarely by bastite. The augite is frequently converted into pennine, with which grains of garnet or prisms of diopside may be associated. Sometimes it is altered to antigorite or to tremolite with subordinate antigorite, while rarely it may be decomposed to the opaque brownish substance which is so commonly met with in the wehrlites of the main intrusion. In one case the conversion of augite to diopside was observed.

In some specimens representing very much sheared and altered gabbroid rocks, there has been fairly complete reaction between the original constituent minerals with the production of a new association in which stress minerals are often predominant. In this way hornblende-zoisite rocks such as Numbers 1258 and 1259, epidote-albite rocks such as Number 1257 and one rock (Number 1256) consisting almost entirely of tremolite with subordinate antigorite and a little albite, have been produced.

In yet other cases, rocks containing in quantity one of the heavy lime-aluminium silicates grossularite and vesuvianite have been formed. Doubtless the grossularite has originated in a similar way to that of the "rodingites" and related rocks of Nelson in which according to Benson (1926, p. 43) it is a secondary mineral which has been formed under the influence of concentrated magmatic water. Grange (1927, p. 160) expresses a similar idea in these words: ". . . . the rocks containing diallage are really altered gabbros, the prehnite and grossularite being secondary after feldspar. The dense white rocks consist of grossularite and diopside and are probably veins formed by solutions which have taken lime, magnesia, and a little alumina from the pyroxene." In the present case (Number 1254) the rock now consists largely of grossularite, enstatite and antigorite, which have been formed probably by the alteration, by magmatic water under pressure, of a rock consisting originally of diallage and some basic plagioclase. The change involved may perhaps be expressed by the following equation in which the variable alumina of the diallage has been neglected.

$$\underset{\text{(Anorthite)}}{Ca\,Al_2\,Si_2\,O_8} + \underset{\text{(Diallage)}}{2Ca\,Mg\,(Si\,O_3)_2}$$

$$= \underset{\text{(Grossularite)}}{Ca_3\,Al_2\,(Si\,O_4)} + \underset{\text{(Enstatite)}}{2Mg\,Si\,O_3} + Si\,O_2$$

Since the whole transformation is brought about in the presence of water, the production of antigorite in addition to enstatite, and the removal of the extra molecule of silica and of any albite derived from the plagioclase is readily explained.

Graham (1917, pp. 174 - 177) has described grossularite-vesuvianite- and diopside-bearing veins from the serpentines of Quebec, and considers that they originated from the residue of a granitic magma, rich in silica and volatile constituents, which became enriched in lime and alumina dissolved from the pyroxene of the invaded peridotites and pyroxenites. It seems probable, in the absence of any such invading granites from the present peridotite mass, that the vesuvianite-diopside veins of Red Mountain (Numbers 1260, 1260a) have originated in a similar way to the grossularite-enstatite rock of Martyr Spur, from the reassortment of molecules already present in pyroxene-rich gabbros and peridotites, without any addition of material, other than water, from external sources.

### *Tectonic Conditions and Date of Intrusion.*

Professor Park in his report of 1887 suggested that the peridotites of Red Mountain had risen up along a great fault plane separating the Maniototo Schists of Central Otago on the east from rocks on the west which were identified by him as the Te Anau Series. In the present area two strong lines of evidence also lead to the conclusion that the intrusion has been effected along a major fault line. In the first place the middle part of the Cascade Valley which marks the north-western margin of the intrusive mass, has a definitely north-east trend which is continued, across a very low saddle, in the valley of the Jackson, which follows this direction for about ten miles to its junction with the Arawata River. The general trend of the whole peridotite belt is also north-east and accords well with the north-easterly fault lines developed throughout Westland. In the second place the rocks on the landward side of the intrusion are the quartz-muscovite-schists of the Maniototo Series, while those on the seaward side are the strongly metamorphosed gneisses of the Older Metamorphic Series. The regular perpendicular junction of the peridotite mass and the schists of the Olivine Range, as displayed in the valleys of Martyr and Woodhen Creeks, also support this conclusion. The rocks on either side of the Jackson Valley have not yet been examined and compared.

The age of the peridotites of the Cascade Valley–Red Mountain belt is not definitely known, except for the fact that they must certainly post-date the schists of the Maniototo Series. It is probable, however, that they may be correlated more or less closely with the other peridotites of the South Island, i.e. with the intrusions of Nelson, Hokitika district, Cow Saddle (Western Otago) and Milford Sound. Most recent workers believe that these invaded the overlying strata in Early Cretaceous times during the great post-Hokonui folding movement.

It seems then that the peridotite mass rose up along a plane of shearing at an early stage in this orogeny, and that the subsequent partial serpentinisation and other mineralogical transformations took place immediately after, under conditions of considerable stress, during the later stages of folding. This view is in accordance with the generalisations advanced by Benson (1926) on the tectonic conditions accompanying the intrusion of ultrabasic rocks.

## The Dioritic Rocks.

Dioritic rocks of unknown age are represented fairly abundantly among the boulders in Laschelles Creek and in the small creek draining into Martyr Creek just below the ford across the latter stream. Number 1262 from the former locality and Number 1263 from the latter are closely similar rocks consisting essentially of equal quantities of hornblende and feldspar. The hornblende is brown, strongly pleochroic, sometimes simply twinned, and occurs in idiomorphic crystals 3 mm. long by 1 mm. wide. It is sometimes slightly altered to chlorite. The feldspar is so decomposed that it is impossible in most cases to determine what variety is present, except that in Number 1262 a small proportion of it appears to have been orthoclase. Quartz is present to the extent of 5% to 10%, intergrown in perfect micropegmatitic fashion with the feldspar (Fig. 15), as well as in isolated grains. Coarse apatite in slender prisms ranging up to 2 mm. in length is very abundant while pyrite and magnetite are both plentiful, the former showing alteration to haematite. The rocks may be classed as micropegmatitic quartz-hornblende-porphyrites.

Number 1264 is a very coarse diorite-pegmatite from boulders in the Cascade River just below its junction with the Martyr. Hornblende in pale green idiomorphic prisms 3 mm. to 4 cms. in length makes up to 40% of the rock, while the remainder consists of white very altered feldspar which is sometimes recognisable as andesine. Very coarse apatite prisms are sparsely present.

## Pleistocene and Recent Accumulations.*

Pleistocene conglomerates and drift material outcrop over wide areas in the vicinity of the Lower Cascade Valley, especially over the great uplifted area known as the Cascade Plateau, while the Cascade River is itself bordered by wide flats of Recent alluvium and swamp accumulations along the last ten miles of its course. The origin of the Cascade Plateau and other curious physiographic features of the area will be discussed in a later paper when further field work has been carried out.

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*Recent field work shows that much of the detrital material underlying the Cascade Plateau is probably Late Pliocene, though the surface is for the most part mantled with Pleistocene moraines.

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