Art. XV.—*The Geology of the Quartz Veins of the Otago Goldfields.*

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Communicated by Dr. Marshall.

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Introduction.

The accompanying paper contains the results of investigations into the geology of the veins of the Otago Goldfield. The area is a large one, and the paper is not exhaustive, but the different types of veins have been examined, and the features of every group described and discussed. As most of the mines are now closed down, the district is not an ideal one for studying vein-phenomena, and it is to be regretted that the work was not undertaken many years ago, when Bullendale, Bendigo, and the O.P.Q. workings were accessible.

I wish to acknowledge my great indebtedness to Professor Park, Dr. Marshall, and Mr. D. B. Waters, of the Otago School of Mines, for much help and advice, both in the field and in the laboratory; and to Mr. A. O. Bishop, of Skipper's, and Mr. R. Mollineaux, of Barewood, who gave me great facilities in examining their mines.

General Description of the District.

The Otago Goldfield, as far as veins are concerned, embraces an area of nearly 10,000 square miles, stretching from Lake Wakatipu on the west to the sea-coast on the east, and from Cardrona in the north to Lawrence in the south. This district is drained chiefly by the Clutha and Taieri Rivers, and also by the smaller Shag River.

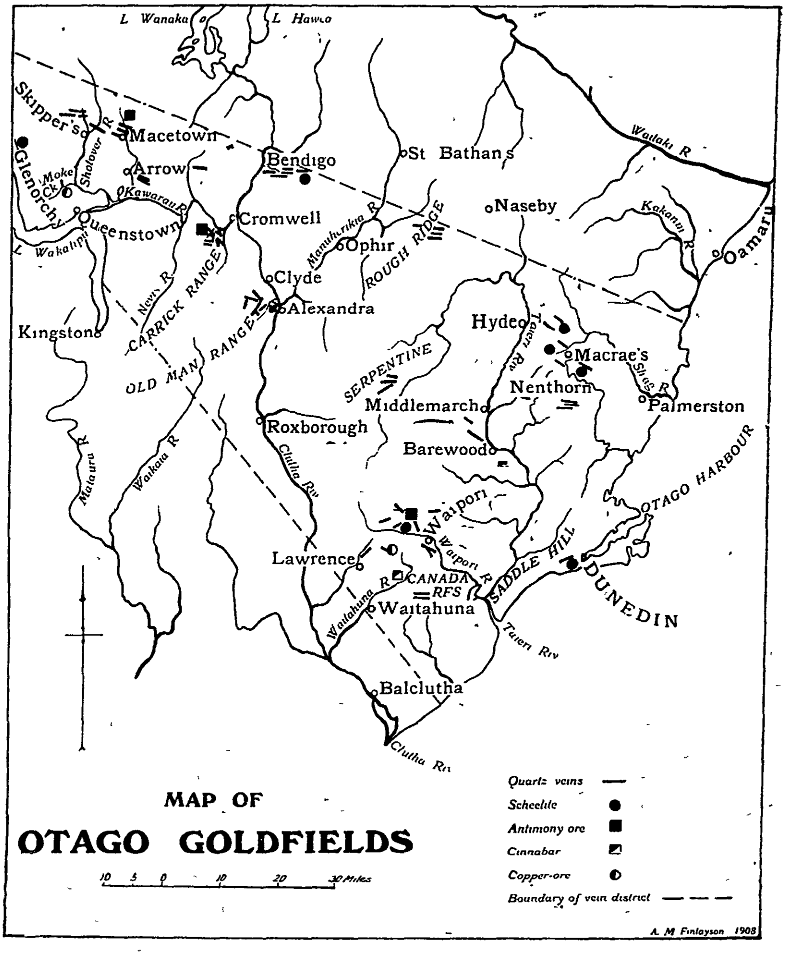
The country is mountainous, the various ranges running for the most part approximately north-east and south-west, or at right angles to the course of the Kawarau River, while the tributary streams flow between and parallel to the ranges. This disposition is described and discussed by Dr. Marshall in his "Geography of New Zealand."* Professor Park claims that the ranges of Central Otago are block mountains.†

The climate of the inland districts is much hotter in summer and colder in winter than on the east coast, but the rainfall is generally low. For this reason the hills and valleys are practically barren of vegetation, being clothed only in tussock. Dearth of water and absence of timber are serious hindrances to mining in some parts of the field.

The goldfield has no centre of population, but comprises a number of towns which grew up in the roaring days of alluvial mining, for which the district is chiefly noted. The principal towns are situated on the Clutha River, or in its drainage-basin, and stand as fingerposts indicating the

* Marshall, "Geography of New Zealand" (Whitcombe and Tombs, 1905), p. 102.
† Park, Bull. No. 2, N.Z.G.S., 1906, p. 7; Bull. No. 5, N.Z.G.S., 1908, p. 9.

march of the pioneer diggers from the coast inland. Communication, which in the early days was difficult, is now good, the most remote mining districts being connected by coach and rail with Dunedin.



PREVIOUS GEOLOGICAL WORK.

The geology of the district has been the subject of a good deal of notice, and a complete bibliography is given in Bulletins Nos. 2 and 5, N.Z. Geological Survey (New Series). The quartz veins have, however, not been much studied, the chief works being by Ulrich, Rickard, and Park. The following list includes all work written on the Otago veins:—

McKay, Alexander—

"Carrick Antimony Lodes," Geol. Explorations, 1882, p. 80.
"Antimony on Barewood Run," Geol. Explorations, 1890, p. 54.
"Quartz Reefs at Nenthorn," Geol. Explorations, 1890, p. 50.

Park, James—
"Green's Reef, Ophir," Geol. Explorations, 1888, p. 17.
"White's Reef, Old Man Range," Geol. Explorations, 1888, p. 32.
Alexandra Antimony Lode," Geol. Explorations, 1888, p. 33.
"Economic Geology of the Alexandra Sheet," Bull. No. 2, N.Z.G.S., 1906, p. 21.

Rickard, T. A.—
"Goldfields of Otago," Trans. Am. Inst. Min. Eng., vol. xxi, p. 411.

Rowe, W. E.—
"Antimony Lode at Hindon," Geol. Explorations, 1879–80, p. 153.
"Antimony Lode, Waipori," Geol. Explorations, 1879–80, p. 155.
"Waitahuna Copper Lode," Geol. Explorations, 1879–80, p. 156.

Ulrich, G. H. F.—
"Goldfields of Otago": Dunedin, 1875.
"Handbook of New Zealand Mines," 1887, 1906.

Geology of the Goldfield.

(*a.*) *Geological Formations.*

The main formation of the goldfields and the country rock of the veins is a foliated schist of considerable thickness. It varies locally, but for the most part it is a mica-schist, more or less *quartzose*, and only submetamorphic in its upper portions.

The schists have been described by Hutton as forming an anticline whose axis runs south-east from Lake Wakatipu to Dunedin, with a syncline on either side of it.* Along the axis of the anticline, where denudation has been most active, are exposed the lowest and most metamorphic beds, while younger and semialtered slates and phyllites are preserved in the adjacent synclines. As we pass north-east or south-west we come on younger rocks (conglomerates and greywackes), and finally reach fossiliferous beds at Kurow in the north-east, and in the Hokonui Hills in the south-west. The former have been classed as Permo-carboniferous,† and the latter as Triassic and Jurassic.‡ The age of the schists has as yet been little more than guessed at, and no systematic attempt has been made to ascertain their relation to the above fossiliferous beds. The quartz veins are confined to the schistose rocks, but this is evidently an effect of the distribution of the fissuring-force, and not due to a different age of rocks. It will be sufficient at present to regard the gold-bearing series as of middle and upper Palæozoic age.

The schists are traversed by a number of structural faults, running for the most at right angles to the axes of the folds described by Hutton, or north-east and south-west. The faults have been mapped by McKay,§ and described later by Park.‖ It is open to question, however, if they are so dominant and easily traced as these writers claim. This much seems evident—namely, that the schists are much faulted, and that the faults have roughly the direction stated.

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* Hutton, "Geology of Otago," 1875, p. 30.
† Park, "Permo-carboniferous Rocks at Mount Mary," Trans. N.Z. Inst., vol. xxxvi, p. 447.
‡ Hector, "Outline of New Zealand Geology" (Wellington, 1886), p. 83.
§ McKay, "Older Auriferous Drifts of Central Otago" (Wellington, 1897), p. 107.
‖ Park, Bulls. 2 and 5, N.Z.G.S., 1906, 1908

For a goldfield, the district is poor in igneous intrusions. An outcrop of actinolite-schist near Ophir is probably a metamorphosed dyke.* There are, at Gibbston and Moke Creek, outcrops of serpentine-talc rock, representing magnesian intrusives of doubtful age.† Finally, there is the important middle Tertiary series of volcanic rocks developed especially round Dunedin, and along the east coast as far north as Oamaru and inland to Macrae's.‡ The rugged and little-known district between the lakes and sounds doubtless contains extensive igneous intrusions, as judged from pebbles picked up in the Clutha and Kawarau Rivers.

The next formation, chiefly developed along the coast, is the Tertiary limestone series of New Zealand, seen as a small patch at Bob's Cone, near Queenstown, where it has been preserved from denudation by being involved in a fault-line in the schists.

Then follow the Pliocene auriferous gravels and cements, shales, and sands, which fill the valleys of the goldfield (formerly old lake-basins), and finally the Pleistocene river and lake terraces, for the most part auriferous.

(*b.*) *Geological History.*

As far as we know at present, sedimentation was continuous, with minor breaks, from the middle Palæozoic, and perhaps earlier, till near the end of the Jurassic period. During this extended time a vast thickness of sediments was deposited. Then followed, throughout the South Island, the main upheaval of all these older beds, accompanied by the intrusion of an important belt of granitic rocks, which can be traced from Nelson, through Westland, and probably through western Otago, down to Preservation Inlet and Stewart Island. At the same time the metamorphism and alpine folding of the older rocks was mainly effected.

With elevation, denudation became active, and the younger Mesozoic beds were removed from the central portions of Otago, where the uplift was greatest.

Subsidence followed in the early Tertiary, and a series of coals and limestones was deposited, the sea extending far into the interior. Then followed elevation, accompanied by faulting and volcanic activity. Denudation at the same time almost entirely removed the Tertiary deposits, and the present drainage-system of Otago was inaugurated. Subsequent movements are not quite clear, but there probably occurred a Pliocene depression, during which the deposits of the Central Otago lake-basins were laid down, followed by a late Pliocene and early Pleistocene elevation, accompanied by glacial extension, and then a subsidence, with retreat of the glaciers.

THE VEINS.

With some exceptions, the veins are small, rarely exceeding 2 ft. or 3 ft. in width. The filling is largely crushed and altered rock, accompanied in the smaller ones by veins and stringers of quartz, and in the larger by lenses or blocks of quartz, varying in size.

The predominant ore is gold, with very little silver (fineness, 960), accompanied by auriferous pyrite. Other minerals are scheelite and stibnite, which are common, and sometimes constitute the dominant ore; also galena, bournonite, and zincblende, which are rare.

* Park, Bull. No. 2, N.Z.G.S., 1906, p. 41.
† Finlayson, "Notes on the Otago Schists," Trans. N.Z. Inst., 1907, p. 76.
‡ Marshall, "Geology of Dunedin," Quart. Journ. Geol. Soc., vol. lxii, p. 422.

There are, in addition, two small copper-veins and one cinnabar-vein.

The veins may be divided into groups according to their locality and characteristics, as follows: (1) Glenorchy, (2) Skipper's and Macetown, (3) Carrick Range, (4) Bendigo, (5) Macrae's, (6) Waipori, (7) Barewood, (8) copper-veins, (9) cinnabar-vein, (10) barren reefs and fault-fractures.

(1.) *Glenorchy Veins.*

The chief vein in this district is a scheelite-bearing vein, which I have described in a previous paper.*

(2.) *Skipper's and Macetown Veins.*

The veins of this district are mineralised shear-zones rather than fissure-veins. The country rock is a soft, finely laminated mica-schist, traversed by broad belts of fracturing. Along these belts the rock is sheeted or divided by several parallel fissures, the intervening schist being crushed and contorted, and more or less altered. These planes of fracture served as channels for the mineralising solutions, which caused the formation of segregated lenses or blocks of quartz. These blocks are of varying size and value. The gold is mostly fine and free, and the adjacent shattered schist or lode-formation is impregnated with pyrite.

The Shotover, or Nugget and Cornish, Vein.—The country rock strikes north and south, and dips to the west at from 30° to 45°. The vein, striking north-west and dipping south-west at about 60°, crosses the Shotover River about two miles above Skipper's Point. At the river-bank there are two veins, the eastern and the western, about 100 ft. apart. These two merge into one a short distance up the hill, and the single fissure-line has been traced across the ranges for some miles to the north-west. On the south-east side of the river the two outcrops are distinctly seen, but only the eastern has been traced for any distance. This runs over the dividing-range, apparently in line with the Premier reef of Macetown.

The vein is typical of its class, two main fractures constituting respectively the hanging and foot walls, with a parallel sheeting of the intervening belt by subordinate fractures. In the western reef four blocks of quartz have been stoped out. At the junction of the two veins a large block (the No. 1) was stoped for a depth of 250 ft. below the surface. The blocks are generally lens-shaped, and limited on all sides. They are generally bounded by thin clay partings or selvages, but not infrequently these are absent, and there

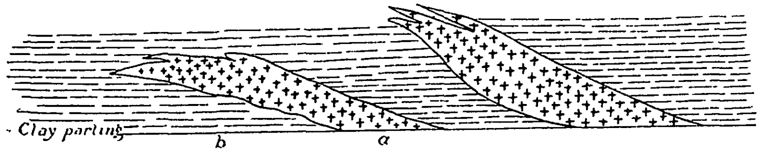

FIG. 1.

a. Quartz shoot. *b.* Vein-formation of crushed schist.

is a gradual transition from quartz to lode formation. In such cases the quartz "makes" gradually out of the lode-formation, and passes over to a parting or wall, where it wedges out (fig. 1).

* Finlayson, "Scheelite-deposits of Otago," Trans. N.Z. Inst., 1907, p. 110.

The lode-formation varies in width from 8 ft. to 20 ft., and has generally defined walls with tough clay casings. The value of quartz varies from 5 dwt. to 20 dwt. per ton. The gold is fine, hackly, and free, the extraction being about 80 per cent. by mill amalgamation. The pyrite is auriferous, but not by any means rich enough to warrant the treatment of the pyritic lode-formation, as some promoters would have us believe.

In places, more especially near the surface, the lode-formation contains bands of a soapy yellowish-grey rock, especially near quartz, and devoid of pyrites.

The following analyses indicate the normal mode of alteration :—

	1.	2.	3.	4.
H_2O	2·06	2·48	2·13	+ 0·07
SiO_2	53·05	54·12	46·30	— 6·75
Al_2O_3	10·31	11·94	10·31	..
Fe_2O_3	9·74	5·63	4·83	— 4·91
FeO	8·60	6·54	5·60	— 3·00
CaO	5·17	3·93	3·37	— 1·80
MgO	0·72	1·65	1·41	+ 0·60
K_2O	4·74	4·73	4·05	— 0·69
Na_2O	2·90	4·31	3·69	+ 0·79
MnO	0·51	0·22	0·18	— 0·33
TiO_2	1·06	0·39	0·32	— 0·74
CO_2	1·15	1·51	1·30	+ 0·15
FeS_2	...	3·43	2·94	+ 2·94
	100·01	100·88	86·43	+ 4·64
				— 18·22
				—13·58

1. Unaltered country rock.
2. Altered lode-formation.
3. Altered lode-formation, recalculated on a basis of constant alumina.
4. Gains and losses of altered rock.

These figures show—(1) that a good deal of replacement has occurred in connection with the segregation of quartz; (2) that the type of rock-alteration may be regarded as partial sericitization.

The following analyses indicate the nature of the yellowish altered rock :—

	1.	2.	3.	4.
H_2O	2·06	2·60	1·56	— 0·50
SiO_2	53·05	46·90	28·14	—24·91
Al_2O_3	10·31	16·46	10·31	..
Fe_2O_3	9·74	6·67	4·00	— 5·74
FeO	8·60	7·26	4·35	— 4·25
CaO	5·17	7·45	4·47	— 0·70
MgO	0·72	1·97	1·18	+ 0·46
K_2O	4·74	4·07	2·44	— 2·30
Na_2O	2·90	2·08	1·25	— 1·65
MnO	0·51	0·23	0·14	— 0·37
TiO_2	1·06	0·27	0·16	— 0·90
CO_2	1·15	3·98	2·19	+ 1·04
FeS_2	..	..	..	..
	100·01	99·94	60·19	+ 1·50
				—41·32
				—39·82

1. Country rock.
2. Yellow rock.
3. Yellow rock, recalculated with constant alumina.
4. Gains and losses.

It is evident from these figures that this altered rock is a kaolinized variety of the normal lode-formation. The bleaching and the total removal of pyrite are probably due to the secondary processes of descending surface waters, accompanied by the formation of kaolin.

Present mine-workings have not yet shown what factors regulate the occurrence of the quartz blocks. It is probable, however, that they are connected with some local structural features. The No. 1 block, for instance, occurred where the two reefs junction.

A common occurrence of gold in this and other veins of the district is as fine "paint" coating the clay selvages. This is probably due to processes of secondary enrichment, the clay partings acting as a filter to the gold-bearing solutions. In other words, this seems to be an instance of adsorption—the process recently studied by Kohler.*

Microscopically the quartz occurs in coarse granules, with patches of fine-grained quartz studded with pyrite crystals. Such patches evidently indicate portions where replacement has occurred.

Other Veins.—The Invincible, fifteen miles up the Rees Valley from Glenorchy; the extensive group of veins round Macetown; some veins near Arrowtown; and the Bullendale or Phœnix vein, up Skipper's Creek, as well as other smaller veins in the Shotover Basin, all belong to this type, and have the same characteristics.

(3.) *Veins of the Carrick Range.*

The northern flank of the Carrick Range, overlooking the Bannockburn Flat, is intersected by a complicated system of small veins, striking in various directions. The country rock is a mica-schist of varying type, striking north and south, and dipping to the east. The eastern flank of the range is bounded by a well-marked fault, which passes near the veins and drags down the schist with it, the rock along the fault-line standing almost vertically.

The veins, which are irregular and considerably disturbed, vary in width from 18 in. to 3 ft., and the filling consists of mullock or highly crushed schist, impregnated with pyrite, and traversed by stringers of gold-bearing quartz. Ulrich referred the irregularities of the veins to disturbances caused by the intrusion of supposed dykes of "hornstone-porphyry."† As I have shown elsewhere,‡ these dykes do not exist, and both Hutton and Ulrich made a peculiar mistake in failing to identify the horny silicified gossan of some of the vein-outcrops.

The map of the Carrick Range veins shows the interesting system the individual members of which have been described in detail in Bulletin No. 5, N.Z. Geological Survey. They fall naturally into four groups—the Caledonian, Carricktown, Young Australia, and Antimony groups.

1. *The Caledonian Group.*—The veins of this group, the most northerly of all, occupy a radiating group of fissures, varying in strike from north and south to north-west and south-east. They dip at high angles.

2. *Carricktown Group.*—These veins, which occur near old Carricktown, also form a similar radiating group, opening out, however, towards the north and west, whereas those of the Caledonian group spread out to the south and east.

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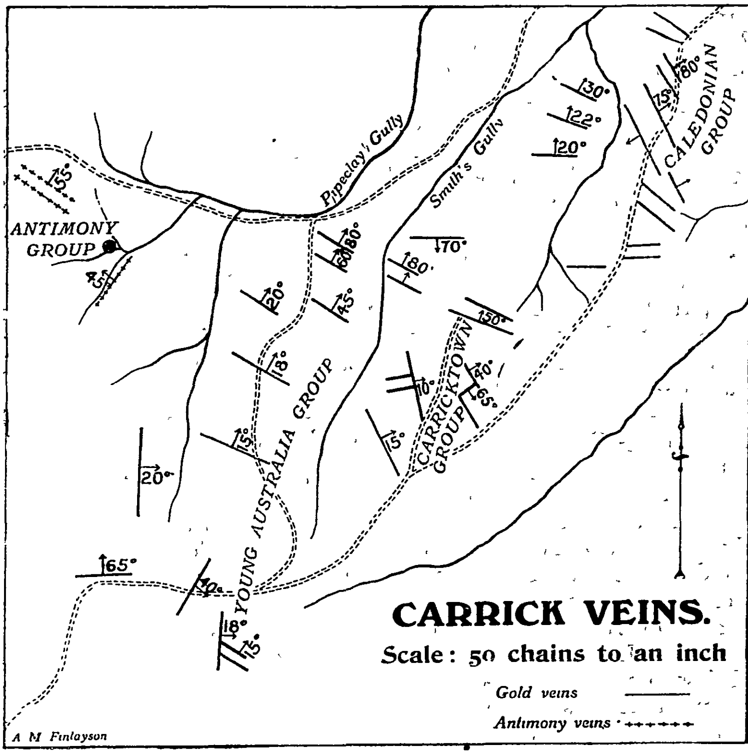
* E. Kohler, "Zeitschrift fur Praktische Geologie," 1903, p. 49.
† Hutton and Ulrich, "Geology of Otago," 1875, p. 162.
‡ Finlayson, "Notes on the Otago Schists," Trans. N.Z. Inst., 1907, p. 72.

3. *Young Australia Group.* — This comprises a number of flat-dipping veins lying for the most part to the south of the last group, and crossing the country rock both in strike and dip. They occur only on the higher slopes of the range, having evidently been denuded off the lower parts. The Border Chief, Heart of Midlothian, and Vale of Avoca veins, lying on the high spur west of the Caledonian group, are also members of this group, the ridge not having been sufficiently denuded to remove them.

4. *Antimony Group.* — The veins of this group are similar in character to the others, but they carry bunches of stibnite besides being auriferous. They occur in a scattered group on the summit of the range, to the west of and distinct from the other groups.



The Fissure-system.—The somewhat complicated system seems to be best interpreted as follows: There have been two sets of radiating fissures formed—the Caledonian and the Carricktown. Their formation was doubtless due to torsional stress, and the features of these groups are very well reproduced by Daubrée's experiments on the fracturing of glass by torsional effects.* There has also been a shearing movement, which resulted in the formation of the flat-lying fissures of the Young Australia group. To this movement are probably due many of the disturbances in the other veins, such as the peculiar horizontal displacements which have affected some of the veins.

* Daubrée, "Géologie Expérimentale," 1879, p. 306.

The fault-lines in all the veins are gold-bearing, and often carry thin stringers of quartz. Unless this is due to secondary enrichment, the filling of the fissures must have extended over a considerable period of time. The order of movement seems to have been: (1) Formation of radiating fissures; (2) formation of flat fissures or shear-planes, with disturbance of the radiating fissures; (3) final adjustment of the fissured area, with faulting of the flat fissures. In other words, the evidence seems to indicate that the formation of the radiating fissures was the cause of all the movements which followed, these latter being due to forces called into play to readjust the strain on the fissured area.

The formation of the fault on the east flank of the range, which was subsequent to and independent of these local movements, also doubtless disturbed the veins, but it is not possible to say to what extent.

Localisation of Ores.—A striking feature is the occurrence of the antimony-ore limited to the extreme west of the fissured area, no more than a trace of antimony being found in the sulphide minerals of the other veins. This is evidently due to processes of ore-segregation beneath.

Gold.—In the oxidized zone, which extends to a depth of about 60 ft., the gold is free and easily extracted, and from a comparison of the very high values which have been obtained on the surface with the much lower value of the unoxidized ore it is evident that an immense amount of secondary enrichment has taken place.

The unoxidized ore is impregnated with a sulphide having by analysis the empirical formula $FeAs_2S_3$, evidently a mixture of iron and arsenical pyrites. J. S. Maclaurin recently made a series of extraction tests on samples of quartz from the Carrick Range,* with the following results: Fire assay—Gold, 17 dwt. 8 gr. per ton; silver, 3 dwt. 3 gr. per ton. "No gold was visible in the stone, but panning-off showed a little free gold." Amalgamation—Extraction, 55 per cent. Chlorination without previous roasting, 33 per cent. Cyanidation, 62·7 to 72·3 per cent. Cyanidation with subsequent amalgamation, 91·3 to 96·4 per cent.

These results indicate that the gold is largely associated with sulphides, partly as a coating, most of which amalgamation would remove, and partly involved in the sulphides, which explains the small extraction from unroasted ore by chlorination. With a lens a little free gold can always be seen in the quartz, and much more coating the sulphides in irregular strings.

Stibnite.—This is highly crystalline, often shows a marked comb-structure parallel with the vein-walls, and is rather quartzose and low-grade. It occurs in bunches easily freed from the soft lode-formation (at least, in the oxidized parts), but requires much dressing to make it marketable.

Similar Groups of Veins.—The Old Man Range, near Alexandra, carries on its flanks a number of small veins similar in character to those of the Carrick Range. White's reef is the best-known. It is significant that a small antimony-vein occurs at Alexandra, thus completing the parallel between the two groups of veins.

(4.) *The Bendigo Veins.*

The veins of Bendigo lie on the north-west flank of the Dunstan Range, three miles from the Clutha River. The country rock is a firm and highly plicated quartz-mica-schist, lying almost horizontally. The veins, which are small and narrow, occupy a series of well-defined parallel fissures running

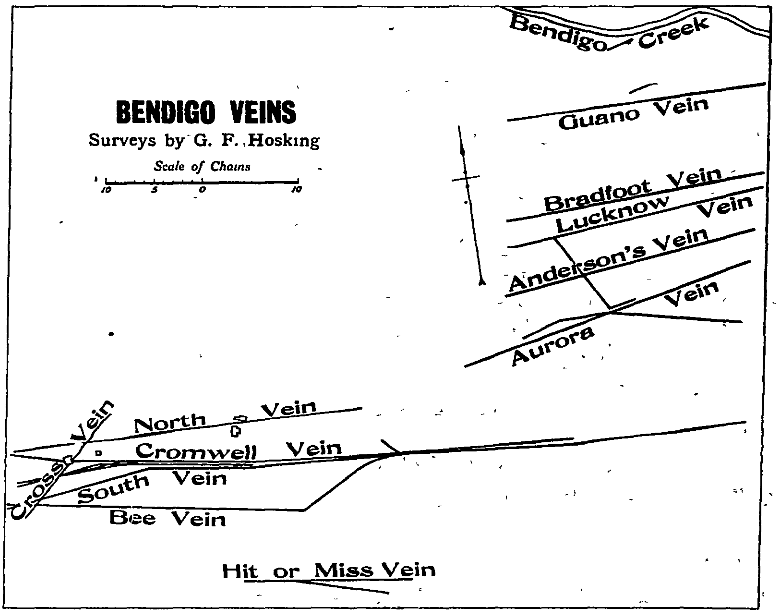
* Government Mines Report (Wellington, 1905), p. 9.

east and west, and standing almost vertically. These are well shown on the plan, and it will be seen that there is also a subordinate series of diagonal veins crossing them.

The lode-matter consists of crushed and altered schist, impregnated with pyrites and traversed by defined and continuous seams of quartz, which may run on either or both walls, occasionally occupying the whole width of the vein, with frequent splits and branch stringers. The quartz seams often show a very fine comb-structure.

In the upper levels the ore was oxidized, and extraordinary values were frequently obtained from small patches near the surface. In depth the ore is reported to be refractory, and sulphides—pyrite, galena, and blende—become prominent.

The individual veins have been described in detail in Bulletin No. 5, N.Z. Geological Survey. The group also includes the Alta scheelite-vein, which lies about three miles to the east of the main group. This seems another instance of the segregation of ores.



The System of Fissures.—The Bendigo group illustrates the sheeting of rock by fissures, discussed many years ago by Emmons in his "Structural Relations of Ore-deposits."* It is also noteworthy that the best ore was largely obtained from the neighbourhood of intersections with the cross-fissures—an instance of ore-shoots at intersections. The minor cross-veins, in fact, besides being payably auriferous, served as reliable indicators. At the intersections a mutual displacement frequently occurred—a phenomenon characteristic of crossing fissures, even when formed simultaneously.

The cross-veins are doubtless the result of shearing stresses set up in the rock at the time of formation of the main fissures, the compound fissure-lines being opened in such directions as would best relieve the strain.

* Emmons, "Structural Relations of Ore-deposits," Trans. Amer. Inst. Min. Eng., vol. xvi, p. 821.

The Vein-filling.—The quartz shows throughout a distinct banding, parallel to the vein-walls. The crystal-axes of the quartz are distinctly seen at right angles to the banding, and frequently very fine cavities with comb-structure are to be seen (Plate II, 1*a*). Brecciation is common, the quartz cementing fragments of country rock impregnated with pyrites, and indicating that movement occurred subsequently to the first mineralisation of the fissures (Plate II, 1*b*).

Chemical tests and microscopic examination of the sulphides show that the habit and association of the gold is very similar to that of the Carrick Range. The quartz, according to Ulrich and to the statements of miners, occurs in shoots dipping east along the strike of the veins. This is a matter which cannot be investigated at present, as the old workings are all closed.

The very high values which have been picked up near the grass on several of the veins are evidently the result of prolonged secondary enrichment.

Microscopically the ore is seen to be banded in alternate lines of coarse and fine granules, and carries also bunches of fine granular quartz thickly studded with pyrite crystals (Plate II, 2.)

Professor Park calls the Bendigo veins "immature replacement lodes,"* but the highly drusy and crustified nature of the quartz frequently observed argues rather for fissure-filling, and is a decided argument against Professor Park's theory.

The deepest workings in Otago were on this group, the Cromwell shaft having been sunk to a depth of 500 ft.

Other Veins allied to the Bendigo Veins.—The Conroy's Gully vein, near Alexandra, is similar to these or to the Carrick veins. The group of small east-and-west veins at Rough Ridge, now almost forgotten, are very similar to the Bendigo type.† Lastly, the Nenthorn group,‡ east of the Taieri Gorge, whose exploitation lasted for a period of two years, from 1889 to 1891, may be put under this heading. They comprise a similar set of narrow parallel veins, striking east and west, and dipping either north or south at a steep angle.

(5.) *Veins of Macrae's District.*

These are an important group of scheelite-veins, which I described in a previous paper.§ They are typical bedded or segregated veins, being the only group of this nature in Otago.

(6.) *Veins of Waipori and Southern Districts.*

Ulrich has described four of these veins—the O.P.Q., Canada, Gabriel's Gully, and Saddle Hill veins.‖ He states that they are characterized by shoots or blocks of quartz which "show an endlong dip in strike." The feature, he says, "may be considered as an oblique banded structure on the large scale," the banding being marked by alternate blocks of quartz and mullock. He also remarks that the gold occurs in shoots in the quartz blocks, in the centre or on either wall.

The O.P.Q. (Otago Pioneer Quartz-mining Company's), or Shetland, Vein.—This vein, near Waipori Township, strikes at about 160°, and dips eastward at an angle of 56°. The country rock is a slaty quartz-schist, striking north-

* Park, Bull. No. 5, N.Z.G.S., 1908, p. 63.
† Ulrich, "Geology of Otago," 1875, p. 229.
‡ McKay, Rep. N.Z. Geol. Explorations, 1890, p. 50.
§ Finlayson, "Scheelite-deposits of Otago," Trans. N.Z. Inst., 1907, p. 112.
‖ Ulrich, "Geology of Otago," 1875, pp. 159, 191.

east and dipping south-east at an angle between 10° and 25°. The walls are fairly defined with seams of gouge, and the vein has been opened up for nearly two miles along the strike, but the workings are now inaccessible. Its thickness varies; in places it is no more than 2 ft., but the average distance between walls is about 10 ft. The rusty quartz from near the surface was in patches extremely rich, while the deepest levels (200 ft.) averaged from 7 dwt. to 12 dwt. per ton. The quartz is, in general, seamy, and distinctly banded by parallel streaks of pyritic matter. The quartz shoots may occupy the whole width of the vein or only a short width on either wall. The dip of the shoots is regular and characteristic, although they generally wedge out in lens fashion when followed down, to make again on the same track at a greater depth.

Microscopically the quartz is mostly fine-grained, with occasional coarse granules enclosed in it, giving a pseudo-porphyritic structure. Frequent strings and veins of calcite are present, and the mass of fine-granular quartz is crowded with pyrite. Evidently the quartz is very largely a result of replacement, and the very distinct banding occasionally seen is best explained as due to progressive replacement of sheeted rock by ore.

In general the vein bears strong resemblances in structure to those of Skipper's and Macetown. A fuller description is given by Mr. T. A. Rickard in a very graphic article.*

Canton Vein.—This is similar to the last. It lies close to that one, and strikes in a direction to join it, the probable junction lying in a gravel-filled basin. These two veins in their field-relations may be compared with the two branches of the Nugget and Cornish vein.

Bella Vein.—This lies four miles from Waipori Township, in Long Gully, a branch of the Waipori River. It strikes east and west, and stands almost vertically. It has fairly defined walls, and varies from 3 ft. to 5 ft. in thickness. Where exploited, it consisted at the surface of a shoot of payable quartz from wall to wall. This block was stoped out for a depth of 50 ft., when it ran over to one wall and wedged out, although the width between walls was maintained. The vein carries a little scheelite, which is found in some quantity in several little-known veins in this district.

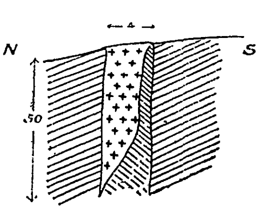


FIG 2.—SECTION OF BELLA VEIN.

Cox's Vein.—This lies on the flanks of the Lammerlaw Range, about four miles from Waipori in a northerly direction. On the line of fissure,

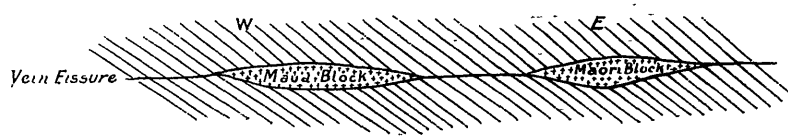


FIG. 3.—SKETCH-PLAN OF COX'S VEIN.

which strikes about east and west, and stands vertically, two shoots of stone were opened out on the surface, dignified by the names "Maori" and "Maud," with a contraction of the fissure between them.

* Rickard, "Goldfields of Otago," Trans. Amer. Inst. Min. Eng., vol. xxi, p. 416.

On the Burnt Range and Lammerlaw Range there are a number of small veins or leaders, some carrying good gold. Their strike is for the most part east and west, and they dip in either direction, with varying underlie. They show similar characters to the O.P.Q.—namely, the occurrence of lenses of quartz in the fissure-zone. The smaller veins, however, carry generally a stronger and more continuous body of quartz than the larger.

Waipori Antimony-vein.—This occurs on the right bank of Stony Creek, nine miles above the township. It has a strike of 105°, and a northerly dip of about 45°. The outcrop has been proved for half a mile. The vein is from 3 ft. to 4 ft. wide, and consists of quartz seamed with mullock, and poor in gold. It carries frequent bunches of quartzose stibnite. At one spot a pocket of scheelite was found and extracted, and gypsum was found where the scheelite and stibnite were intermingled. This is no doubt a secondary product, formed by the oxidation of sulphur and combination with the lime of the scheelite.

The veins at Gabriel's Gully, near Lawrence; at Table Hill, near Milton; and at Saddle Hill, near Dunedin, described by Ulrich in 1875, are now all closed down.

(7.) *The Barewood Claim.*

This is the best-known vein in the Taieri Gorge district, which includes several veins prospected at Hindon, Matarae, and elsewhere.

The country rock is a quartz-mica-schist, lying almost horizontally. The vein strikes north-west and south-east, and dips north-east at an angle of about 60°. It is worked by an underlay shaft, which cuts the vein at a depth of 130 ft. At 180 ft. and 240 ft. crosscuts open up Nos. 2 and 3 levels, while a winze from No. 3 level has been sunk for a further distance of 30 ft. This is one of the few veins now being worked on the goldfield. It averages from 4 ft. to 5 ft. in width, but widens out to 15 ft. in the upper levels. It is composed of solid quartz throughout, divided by subordinate clay heads or partings parallel to the well-defined walls. The foot-wall is uninterrupted, but the hanging-wall carries small leaders (from 6 in. to 12 in. wide), which wedge out a short distance up. These leaders generally carry good gold.

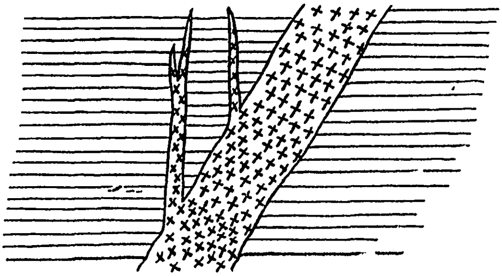


FIG. 4.—HANGING-WALL LEADERS AT BAREWOOD.

Slickensides are often well developed, generally on the hanging-wall. In places the quartz adjoining the walls, and also the adjacent wall-rock, are highly brecciated. This has been seen on both walls in No. 3 level, and on the hanging-wall in No. 1, while it is absent in No. 2.

Horizontal Distribution of Gold.—The gold, so far as workings have disclosed, is uniformly distributed along the strike, and shows as yet no tendency to occur in localised shoots.

Vertical Distribution of Gold.—The present depth of workings has disclosed an interesting variation in value from the No. 3 level winze to the surface. The accompanying section shows the values at different points, taking the average value through the whole cross-section of the vein :—

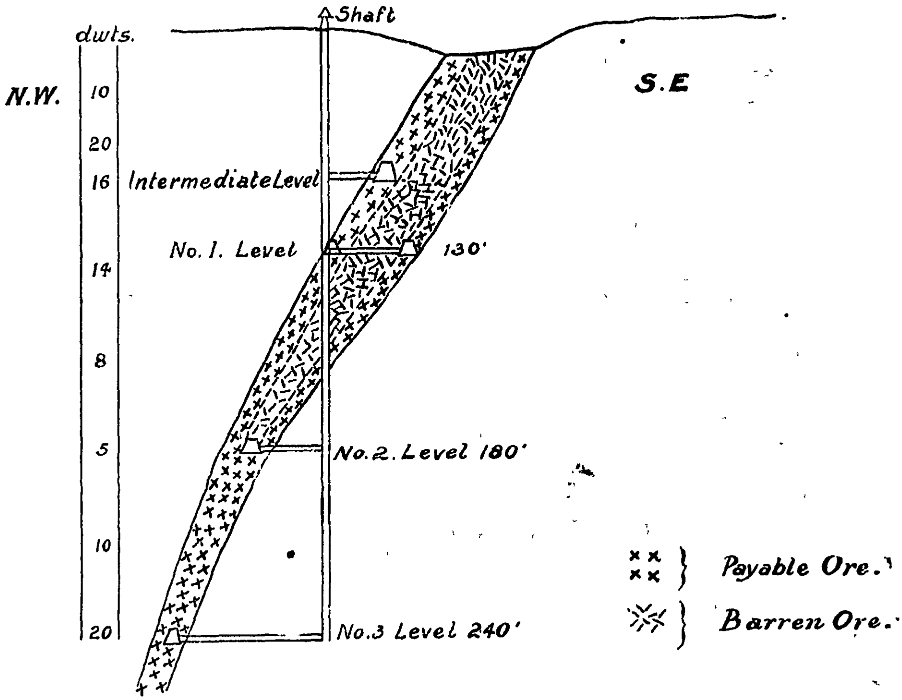


FIG. 5.—CROSS-SECTION OF BAREWOOD VEIN.

From the surface to a depth of 50 ft. the value rose from ½ oz. to 1 oz. per ton. From here to the intermediate level the value fell to 16 dwt., and then more slowly, till at three stopes below No. 1 level it was 14 dwt. From here to No. 2 level the mean value became very low—approximately, 5 dwt. Between Nos. 2 and 3 there was an equally rapid rise, and at No. 3 it varies from ½ oz. to over 1 oz. per ton, while at the foot of the winze the assay value is uniformly over 1 oz., and rich specimen-stone, particularly the brecciated variety, may be picked up showing much coarse gold. It is peculiar also that at this point the gold is often dark in colour and rusty.

At No. 3 level, below it, and for some distance above it, the gold is pretty evenly distributed across the vein. Rising to No. 2 level, a barren block of glassy quartz comes in, and the seamy gold-bearing quartz is pushed over to the two walls, and divided by clay partings from the barren centre block, which corresponds practically to a "horse" of country rock. This block wedges out when followed in either direction along the strike, and it also has an easterly pitch or dip along the strike of the vein. Both these features may be seen on the accompanying plan of the workings, where it will be observed that in each level the foot-wall and hanging-wall seams have been driven on, leaving the centre block intact.

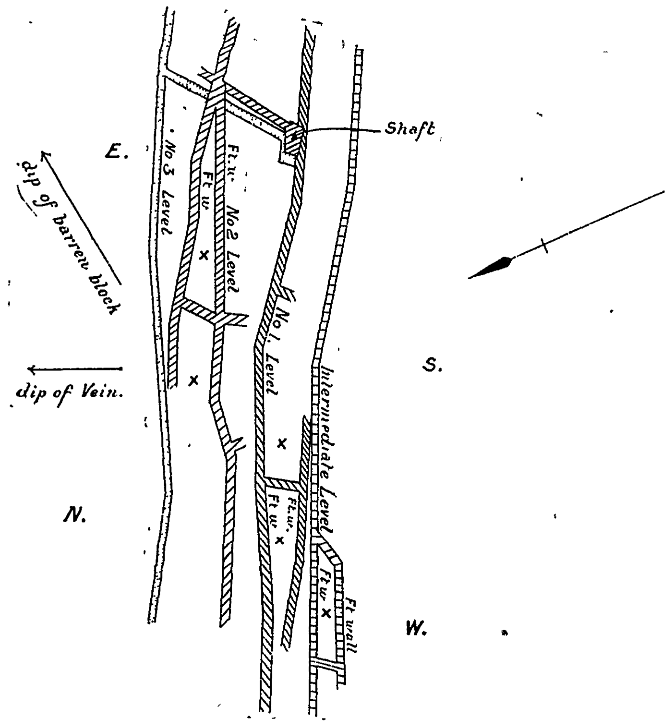


FIG. 6.—MINE-PLAN, BAREWOOD.
X Barren block.

Thus in the wider portion of the vein the gold has been deposited in two shoots along the walls. The gold-bearing quartz differs from the barren "dog's-tooth" quartz in being seamed and mottled with pyritic mullock, and under the microscope is finer in grain. These facts point to a certain amount of replacement along the walls, while the barren block has been formed by simple deposition in an enlarged fissure.

In places in Nos. 2 and 3 levels there occur peculiar siliceous concretions (Plate II, 3), cavernous and irregular in form, with a fine chalcedonic banding. They are dark, and coated thickly with very fine pyrites. In appearance they suggest "clinkers" in coal, or fossil forms.

Associated Minerals.—The dominant sulphide is pyrite, in fine crystals and grains. It is absent in the clear glassy quartz, and thickly distributed in the auriferous quartz. In the No. 3 level there was found within the vein, and near the hanging-wall, a narrow cavity containing a cluster of large stalactites of pyrite. Stibnite, galena, and scheelite occur occasionally. The only one of importance is stibnite, which is becoming common in the deeper levels.

Habit of the Gold.—The gold is largely free, the assay value of pyrite being low. It is probable, however, that at a greater depth the ore will become refractory.

Alteration of the Wall-rock.—The country rock is little altered, except for about 2 ft. from the vein-walls, where the alteration is considerable, the rock being soft and "mullocky." There is, further, frequently found on the walls a type of greasy yellowish rock, devoid of pyrite, and very similar to the corresponding rock described above in the Nugget and Cornish Mine. It accompanies the brecciated ore, the payable seams being well developed in No. 3 level and the winze.

The following analyses indicate the alteration of the normal rock:—

	1.	2.	3.	4.
H_2O	1·68	2·11	1·58	— 0·10
SiO_2	62·02	65·30	48·97	—13·05
Al_2O_3	11·15	14·70	11·15	..
Fe_2O_3	5·58	4·12	3·09	— 2·49
FeO	7·26	2·41	1·80	— 5·46
CaO	6·11	3·76	2·82	— 3·29
MgO	0·65	0·79	0·60	— 0·05
K_2O	1·71	1·28	0·96	— 0·75
Na_2O	3·34	2·05	1·54	— 1·80
MnO	0·17	0·21	0·15	— 0·02
TiO_2	1·01	0·37	0·27	— 0·74
FeS_2	..	3·82	2·85	+ 2·85
	100·68	100·92	75·78	+ 2·85 —27·75 —24·90

1. Unaltered rock.
2. Altered rock.
3. Altered rock, recalculated on a basis of constant alumina.
4. Gains and losses.

The alteration in this case is more intense than at Skipper's, although more local, and the loss of material greater. It is, however, of a similar nature—namely, sericitic.

Analyses made of the yellowish or bleached variety of wall-rock show that, like that at Skipper's, it is a kaolinized type of the ordinary sericitic rock, evidently formed by the action of descending waters.

Ore-shoots of Primary Origin.—The characteristic hanging-wall and foot-wall seams described above doubtless originated during the primary deposition of the gold, through the influence of the wall-rock.

Ore-shoots of Secondary Origin—Secondary Sulphide Enrichment.—A number of facts indicate that the No. 3 level winze has encountered a zone of enriched sulphides (pyrite and stibnite). These are as follows: (1.) The occurrence of the gold in the free state, and its frequent rusty colour. (2.) The occurrence of stalactites of pyrites. (3.) The peculiar siliceous concretions, probably due to solution and redeposition by subsequent leaching processes. (4.) The brecciation, signifying subsequent movement, would give readier access to descending solutions. (5.) The kaolinization and bleaching of the yellowish wall-rock, and the absence of pyrite in it, are evidently due to descending surface waters, and it is notable that it occurs associated with the brecciated ore and with the richest seams. (6.) Finally, the impoverishment in the upper levels, supported by the above data, points to the work of secondary enrichment, which has largely leached the gold out of the upper levels and redeposited it with sulphides in the zone now being opened up. It is probable that when this zone is passed through the ore will become lower grade and refractory, as at Bendigo and on the Carrick Range.

(8.) *Copper-veins.*

There are two veins in the district carrying auriferous chalcopyrite—one at Moke Creek, near Queenstown, and one in Reedy Creek, near Waitahuna. I examined the outcrop of the Moke Creek vein, but little can be seen, and no information of importance was obtained. The ore is low grade, and the veins are small and of uncertain ore-content. Under the microscope there is seen to be a good deal of carbonate in the gangue (Plate II, 4). Ulrich described both these veins in 1875, and Rowe later described the Waitahuna vein (see Bibliography).

(9.) *Cinnabar-vein.*

One cinnabar-vein has been located—namely, the Waitahuna vein, in a gully at the foot of the Waitahuna Hills, half-way between Berwick and Waipori. The vein is a small one, filled with pyritic mullock, which carries bunches and veins of very high-grade cinnabar. The mineral is highly crystalline in the frequent small cavities, the crystal form being prismatic with rhombohedral terminations (r, $10\bar{1}1$).

Cinnabar is frequently found in the alluvial gravels throughout the Waipori district, and there is no doubt that there are other veins of this mineral in the neighbourhood. Such veins might escape detection owing to their small size, and to the soft and perishable nature of the vein-filling. The country is, moreover, unfavourable for the prospecting of such veins, being largely worn down into rolling foothills covered with tussock.

A good deal of alluvial cinnabar has also been found in the Nevis and Nokomai district, and a vein doubtless exists there also, although none has yet been found.

(10.) *Fault-fractures and Barren Quartz Reefs.*

The occurrences described under this head have, as far as can be seen, no economic value.

Fault-fractures.—The faults and crush-zones which extend through the goldfield are occasionally mineralised, and carry a few grains or more of gold to the ton. One of these occurs about three miles to the east of Bendigo, running about north-west and south-east.* In several places on the line of the fault prospecting-work has been carried on, and a little payable work done, but the irregular and very low-grade nature of the formation caused operations to be soon suspended. The workings disclose a belt of crushed schist traversed by small irregular veins of quartz.

Green's reef, at Ophir, described by Ulrich† and by Park,‡ is another instance of this type. Some years ago it gave a good return to its sole prospector. The occurrence of gold at Green's reef is cited by McKay as an instance of the occurrence of free gold in the schist.§

Ulrich has suggested that these "lode-formations" will, if developed, lead to a simple defined vein in depth.|| It is much more probable that

* Park, Bull. No. 5, N.Z.G.S., p. 56.
† "Handbook of New Zealand Mines," 1887, p 75.
‡ Park, Bull. No. 2, N.Z.G.S., p. 29.
§ McKay, "Gold-deposits of New Zealand" (Wellington, 1903), p. 67.
|| Ulrich, "Geology of Otago," 1875, p. 185.

they will peter out altogether, and certainly their gold-content will not justify sinking on the outcrop. That they have had their indirect value, however, is undoubted, and they must have helped in some measure to supply the alluvial gold of the drifts.

Barren Reefs, or Buck Reefs.—These are peculiar types, and correspond to similar occurrences on the Hauraki goldfields, in California, and in a great many other vein districts. In Otago they consist of very wide, massive, bold outcrops of "hungry" glassy quartz, often traceable for considerable distances. They are practically barren, devoid of pyrite, and composed of quartz throughout.

A typical buck reef occurs near the Hawksburn Homestead, six miles south of Bannockburn. Several occur at Quartz Reef Point, on the Clutha River, four miles above Cromwell. Another occurs at Nenthorn, and another in the Nokomai district. An interesting buck reef occurs near Waipori, on the road to the Waipori antimony-vein. Where it outcrops it consists of 2 ft. of quartz, much of which is in very fine pseudomorphs after calcite, and preserves excellently the rhombohedral cleavage. It is, however, not proved that this is a buck reef, as no tests have been made of the quartz.

GENERAL OBSERVATIONS ON THE VEINS.

(1.) *The Vein-fissures.*

Nature of the Fissures.—The fissures which carry the veins of Otago vary greatly in nature, according to the physical character of the particular zone of schist through which they pass. Where the schist is resistant and quartzose the fissures are simple, being narrow and defined, as at the Carrick and Bendigo; where the rock is softer the fissures are compound, ill-defined, and longer, and become shear-zones of some width, as at Skipper's and Macetown. Finally, at Macrae's the shear-zones follow the foliation-bedding planes, so that here we have a group of bedded or segregated veins. Thus the division of the veins into groups, first used by Ulrich, is made possible by the above fact—the varying nature of the schist and the consequent varying nature of the veins in different localities.

Professor Park speaks of the vein-type at Bendigo as a twin fissure containing a band of schist between.* I can see no evidence of this, and I regard such a vein as a single fissure filled by quartz, except where portions of country rock have been detached from the walls of the fissure by subordinate cracks, giving the quartz vein a varying thickness.

Orientation.—The mean strike of the gold-bearing fissures is west and east, or slightly to the north of west, although locally the strike varies through all points of the compass, as on the Carrick Range.

Distribution.—The local distribution of fissures as shown on the map is in part more apparent than real, for there is no doubt that the whole goldfield is traversed by veins, even in localities where they have not been located. This is due in part to the absence of prospecting in less inviting districts, and in part to the fact that veins might readily be overlooked in tussocky country where shoots or blocks of quartz did not happen to outcrop. Nevertheless, there is evidence of a localisation of fissures into more or less defined groups. This is probably due to local factors, such as the nature or previous disturbance of the schist, which aided or retarded the fissuring-forces.

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* Park, Bull. No. 5, N.Z.G.S., 1908, p. 63.

It is noticeable that the vein-bearing district spreads out in a fan from the head of Lake Wakatipu to Macrae's in the north and Lawrence in the south. This fan encloses all the known auriferous veins of Otago, although it must be remembered that veins exist at Preservation Inlet, in the far south-west, and also probably in the Longwood Range, in Southland. Nevertheless, the fact remains that the gold-veins of Otago proper are contained within the area indicated.

Origin.—The fissures are evidently due to compression-forces, as they have all the typical features of compression veins, described by Emmons. For the cause of this compression there are two alternatives: (1.) It may have been caused by a tectonic force acting from west to east and south-east, with its greatest intensity at the head of Lake Wakatipu, in the near vicinity of the belt of igneous rocks which were intruded during the Jurassic mountain-formation. Such a compression movement would conceivably extend its area of effect as suggested by the above "fan," and would gradually diminish in intensity as it passed towards the coast. This would be favourable to the formation of bedded shear-zones, as seen at Macrae's. (2.) It may have been caused, as Professor Park claims,* by local intrusions of igneous rocks which did not reach the surface. As against this view, it is strange that none of the intrusives are to be seen exposed. The evidence is not yet sufficient to decide which view is the correct one, but from a consideration of the gold-bearing veins throughout the South Island there is strong evidence for concluding that the fissures were formed during adjustment of the strains set up by the alpine folding at the end of the Jurassic.

Age.—On this view the fissuring is Post-Jurassic, and probably occurred during subordinate earth-movements following on the main extensive folding. They may be regarded as of Cretaceous or early Tertiary age.

The fault-fissures are much younger, being, from geological considerations, of late Pliocene or even younger date.

(2.) *The Vein-formation.*

The vein-formation varies, as has been seen, according to the nature of the fissures, and all gradations may be traced from quartz-filled fissures to replacement veins. The typical quartz vein is seen at Barewood; Bendigo is also a good instance of fissure-filling. At Skipper's, Waipori, and Macrae's, replacement has been the chief process.

The characteristic metasomatic alteration, as revealed by analysis, is sericitization of the wall-rock, accompanied by a reduction of specific gravity and a decrease in volume. A calculation of the constituents of the altered rock at Barewood shows that about 33 per cent. of sericite is present. As regards changes in constituents, the altered rock shows generally a considerable loss in silica, greatest in the case of veins which carry segregated quartz (Macrae's), in iron and titanium, in the earths and in the alkalies. The added constituents are generally sulphur and carbon-dioxide. The nature of the metasomation is somewhat similar to that of the Freiberg gneiss, examined by Scheerer and Stelzner.†

Ore-shoots.—Nearly all those veins which have been reported to contain ore-shoots are now unworked, and I was unable to investigate the subject. It is therefore inadvisable to speculate or make statements based on rumour and on records of doubtful value.

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* Park, Bull. No. 5, N.Z.G.S., 1908, p. 63.
† Beckweed, "Nature of Ore-deposits," 1905, p. 397.

Changes of Primary Ore-content in Depth.—The deeper workings appear to show that in most cases the gold in depth becomes largely involved with sulphides, the free gold diminishing in proportion. The metal is still largely free at Barewood, but this appears due to secondary enrichment, and primary or unleached ores in Otago are all probably refractory.

In regard to variations in the sulphides at different depths, the data are either unreliable or too meagre to indicate anything.

Paragenesis. — The following are the known cases of paragenesis in Otago: (1) Gold, iron-pyrites; (2) gold, iron-pyrites, stibnite; (3) gold, iron-pyrites, stibnite, galena; (4) gold, iron-pyrites, galena, zincblende; (5) gold, iron-pyrites, bournonite, zincblende; (6) gold, iron-pyrites, scheelite; (7) gold, iron-pyrites, scheelite, stibnite; (8) gold, iron-pyrites, scheelite, stibnite, galena; (9) gold, iron-pyrites, cinnabar; (10) gold, iron-pyrites, copper-pyrites.

(3.) *Subsequent Changes in the Veins.*

1. *Movement along the Fissure-walls.* — Subsequent movement of the fissures is shown by the frequently brecciated ore, but there is nothing to indicate enrichment by uprising thermal waters during the movement.

2. *Secondary Sulphide Enrichment.* — Gossan enrichment is best seen at Bendigo and the Carrick, and illustrated by the manner in which workings were largely confined to the oxidized zone. The phenomenally rich patches of ore recovered near the surface in the early days are further evidence.

The occurrence of film or paint gold on clay selvages, as at Skipper's, is another proof of enrichment, and the yellow kaolinic wall-rock seen here and at Barewood is no doubt due to the same cause.

A zone of enriched sulphides occurs, as discussed above, at Barewood, and probably in other veins as well.

3. *Denudation.* — During the frequently recurring periods of elevation since the vein-formation denudation would be active, and the upper enriched portions of the veins would be continually shorn off, the gold going to supply the alluvial wealth of Otago, for which the district is more justly famed. A consideration of the relative amounts of vein and alluvial gold obtained in Otago shows that the value of the veins has been largely indirect. Denudation has, indeed, gone on to such an extent that the Otago veins must be considered as practically vein-roots, and when it is possible to calculate the amount of denudation that has taken place we will have a legitimate field for speculating on the depth to which the veins will be payable.

4. *The Source of Alluvial Gold.* — The early diggers in Otago, as in all other goldfields, maintained that the alluvial gold was derived from quartz veins. Messrs. McKay* and Rickard,† however, claim that the quartz veins are insufficient in quality and quantity to have supplied the gold, and they maintain that the gold has been derived mainly from the schist. In another paper I have pointed out that the occurrence of gold in the schist is an unproven hypothesis.‡ Further, after a careful study of the great number of veins which exist, and of the prolonged enrichment and enormous denudation which have taken place since the veins were formed, I have come to the conclusion that the early diggers held the correct view—that the quartz veins were a sufficient source of supply, and that no other source supplied any appreciable quantity.

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* McKay, "Gold-deposits of New Zealand" (Wellington, 1903), p. 67.

† Rickard, "Goldfields of Otago," Trans. Amer. Inst. Min. Eng., vol. xxi, p. 442.

‡ Finlayson, "Notes on the Otago Schists," Trans. N.Z. Inst., 1907, p. 77.

(4.) *Genesis of the Veins.*

In the light of present views in regard to the genesis of ore-deposits, we must conceive that the vein-fissures when formed gave access to thermal waters charged with precious metals, which rose from a magma beneath, wherein rock-differentiation and ore-segregation had taken place.

The universal occurrence of gold and pyrites, and the very frequent presence of antimony-ore and scheelite, indicate a pretty uniform degree of segregation beneath. The isolated occurrences of copper-ore and cinnabar are no doubt due to some local segregations at points beneath.

Fault-fractures.—These were formed at a much later date, probably when thermal magmatic waters had ceased their activity. Moreover, being gravity faults, they would not extend to such a depth as compression fractures, even allowing for a reduced thickness of the schists due to denudation.

Buck Reefs.—The explanation of these occurrences is difficult. Their presence in so many gold-bearing districts would lead us to infer that they have been formed by similar processes to the gold-veins, and probably at the same time. The quartz appears to have been deposited in a wide fissure, or at least in a fissure which widened as it was being filled, while the solutions were either of meteoric origin or had been robbed of their metallic content some distance below the present surface. It is even possible that the solutions were barren of metals, and that these buck reefs illustrate the extreme siliceous product of magmatic differentiation in a portion of the magma where the conditions were not favourable to the segregation of ores.

(5.) *Future Prospects of the Goldfield.*

The history and development of quartz-mining in Otago have been sketched by Mr. Robert Mackintosh, who has also some observations on the future prospects of the district.* The following matters may be emphasized from the standpoint of economic geology:—

1. Timber is scarce all over the field, while water and fuel are also often at a premium. These factors are obstacles in the way of extensive working.
2. The small size of the veins, and the fact that the ore is frequently refractory and low-grade, are also objectionable features.
3. The uncertain occurrence of quartz blocks in the larger veins, and their uncertain quality when found, entail extensive development, and the returns from such workings are not likely to be highly remunerative.
4. Finally, in consideration of the fact that the veins are practically roots, and that the ore is almost certain to be low grade after a depth of about 300 ft., deep sinking is less likely to be successful than development along the strike. There is no doubt that a great deal of payable ore still exists in undeveloped portions of the veins, and that the jūdicious exploitation of the upper levels would maintain the field for some years to come.

EXPLANATION OF PLATE II.

Fig. 1. Comby quartz (*a*), and brecciated quartz (*b*), from the Cromwell vein, Bendigo.
Fig. 2. Vein-quartz, Bendigo. The photo shows the association of coarse and fine granules. Magnified 27 diameters.
Fig. 3. A siliceous concretion from the No. 2 level, Barewood, formed evidently during secondary enrichment by meteoric circulation.
Fig. 4. Chalcopyrite, from Moke Creek. The photo shows some ore (opaque) in a gangue of quartz and twinned calcite. Magnified 27 diameters.

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* R. Mackintosh, "Mineral Resources of New Zealand," *N.Z. Mines Record*, 16th Jan., 1907.