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Department of Scientific and Industrial Research.

GEOLOGICAL MEMOIRS.

MEMOIR No. 1.

THE GEOLOGY OF THE MALVERN HILLS.


With a Section on the Physical and Chemical Properties of the Clays and Sands, by S. PAGE, B.Sc.

WITH MAP AND SECTIONS, PANORAMIC SKETCHES, AND PHOTOGRAPHS.

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# CONTENTS

A. Introductory .................................................. 1

B. General Physiography of the Area ...................... 1

C. Stratigraphy .................................................. 3
   I. Pre-Senonian ............................................. 4
      (a) Triassic Sedimentary and Volcanics, and Lower Jurassic Sedimentary ...... 4
      (b) Upper Jurassic or Lower Cretaceous Volcanics ................................ 12
         (i) Rhyolites ........................................... 14
         (ii) Andesites .......................................... 16
   II. Senonian .................................................. 17
      (a) Coal-measures ....................................... 17
         (i) Hororata-Glentunnel-Sheffield Area ............................ 34
         (ii) Outliers .......................................... 34
            Cordy's Flat, Hart's, St. Helena, Phillips Saddle, Rookwood, Hawkins Valley, Kowai Valley, High Peak, Acheron, Rakaia Gorge.
      (b) Age of the Beds ..................................... 44
   III. Post-Senonian ........................................... 44
      (a) Igneous Rocks—Effusives and Intrusives ............................ 46
      (b) Post-Tertiary—Gravels, &c.................................. 52

D. Economic Geology ........................................... 53
   (a) Coals ................................................... 53
   (b) Clays and Sands ........................................ 56
   (c) Building-stone ......................................... 67
   (d) Metalliferous Minerals .................................. 68

E. Bibliography ............................................... 69

Index ........................................................ 71
THE GEOLOGY OF THE MALVERN HILLS.

A. INTRODUCTORY.

In the early days of geological work in New Zealand the Malvern Hills district attracted considerable attention, chiefly, perhaps, since it promised to provide a considerable amount of coal for a region deficient in fuel, but also because it furnished points of purely scientific interest. The latter were fully recognized by Dr. von Haast, who was then Provincial Geologist for Canterbury, and he spent much time and trouble in attempting to elucidate its geological features and to determine the precise economic possibilities of the area. Although this work was done fifty years ago, it is surprising how well it has stood the test of time. The records of his work are to be found in his reports to the Provincial Government, and also in the earlier reports of the New Zealand Geological Survey. In addition to Haast's pioneer work, special mention must be made of that done by Captain Hutton when he was on the Survey and later, and also of that by S. Herbert Cox. The accounts given by these early geologists still furnish the basis of subsequent work, and I must personally express my indebtedness to them for suggestions so numerous that it is impossible to mention them further. Quite recently most important paleontological work has been carried out by Woods and Trechmann, and many points connected with the chemical aspects of the coal problem have been thoroughly dealt with by Evans. The fact that the latest account of the area was given by S. H. Cox in 1884—that is, forty years ago—has prompted me to redescribe it in the light of more modern knowledge, and hence the following account.

B. GENERAL PHYSIOGRAPHY.

For the purpose of this paper the area called the Malvern Hills will be considered as that lying to the south-east of Big Ben Range, and forming the basin of the Upper Selwyn and its tributaries, the Hawkins, Wairere, and the Hororata. Since the main matter for consideration is concerned with the nature and stratigraphy of the Cretaceous coal-measures occurring in the district, there are three other areas which must naturally be considered with it—viz., the outliers at Benmore, the Acheron, and Rakaia Gorge.

As has been explained in a previous paper (Speight, 1924), the main surface features of the area arise from fault-movements which have affected a peneplain developed out of Trias-Jura rocks covered with a thin veneer of weak Cretaceous beds. These movements have resulted in the formation of a series of subparallel more or less continuous ridges, with intervening strips, whose orientation has determined initially the directions of the main streams. Commencing from the north-west, these faulted strips are as follows:

1. The Benmore Area, with a possible continuation on the line of the Acheron Valley. South-east of this lies the mass of the Big Ben Range, a long even-topped ridge, rising to 5,436 ft. in Benmore, with lower foothills farther south-east. Then follows

2. The High Peak Area, occupying a portion of the Upper Hawkins basin and reaching north-east across the Upper Hawkins. South-east of this extends a well-defined ridge, of which the following are the chief features, commencing from the south-west end of the range: Round Top (2,917 ft.), Snowy Peak (2,983 ft.), High Peak (3,367 ft.), Four Point Range (2,414 ft.), Flagpole Hill (2,393 ft.), and the Black Hills (2,364 ft.). The Selwyn has cut its gorge between the last two of these. (See panoramas.)

1—Geol. Mem. No. 1.
3. The Kowai Area, bounded on the south by the Russell Range (3,986 ft.), which forms a kind of splinter connecting the foothills of Big Ben with the north-east end of the Round Top—Flagpole—Black Hills ridge.

4. The Rockwood Area, occupying the upper valley of the Hororata and lying between Snowy Peak, High Peak, and a ridge extending south-west from Pullwool Peak (2,404 ft.).

5. Cordy’s Flat Area, which lies between the Four Point Range—Flagpole Hill—Black Hills ridge and the broken ridge of which Mount Misery (1,910 ft.) and the Cairn Range (1,534 ft.) are segments. This area perhaps extends across Pig Saddle (Knight’s Saddle) to the west of Abner’s Head and on to the north-east under Russell’s Flat, where it is masked by recent river-gravels, except at the northern corner, close to the Township of Springfield.

The following streams are associated with these strips of country:

(1) Macfarlane’s Stream, which runs north-east to the Upper Kowai, behind Big Ben, and probably the Acheron, which discharges south-west to the Rakai.

(2) The Upper Selwyn, which runs north-east and receives the greater part of its water from the south-east slopes of Big Ben.

(3) The Kowai, in its middle and lower course, running north-east to the Waimakariri.

(4) The Upper Hororata, which runs almost south past the Rockwood Station.

(5) The Glendore Stream, which runs north-east past Mount Misery to join the Selwyn near Whitecliffs.

While attributing the major outstanding surface features of the area to faulting, it should be noted that the deformational movements did not in all cases result in rupture, but rather warping. In the north-east, especially in the vicinity of Abner’s Head and the Black Hills, also on the northern flank of the Cairn Range, this is most marked. Stripped surfaces occur here in such a perfect condition that it is reasonable to infer not only the former presence of covering beds, but also their dip and strike from the slope of these surfaces. This may seem somewhat doubtful evidence, but when one sees remnants of the covering beds associated with such surfaces, and then again the surfaces without the covering beds, the conclusions drawn therefrom are hardly as far-fetched as persons unacquainted with the locality might imagine. As a result of observations on these I have concluded that the faulting movements lost somewhat of their intensity and graded into folds in the north-east part of the area, although there is certainly evidence that some faulting existed there. The association of faults with folds is a characteristic feature of many parts of the submontane area of New Zealand, and it may have been characteristic of the montane area, but we cannot say, since the covering beds, from whose position inferences may most readily be drawn, have been stripped away almost completely.

The only streams that have been powerful enough to break across the ridges which bound them on the south-east are the Selwyn and Hawkins, the former aided, no doubt, by the interference of the glaciers coming from the direction of the Rakaia Valley; otherwise the drainage has been in a north-easterly or a south-westerly direction. In the area occupied definitely by the coal-measures the control of structure on the directions of the subordinate streams is very marked.

There is decided evidence of glaciation in the High Peak Valley and on the western part of the area under consideration. Not only did the Rakaia Glacier cover the plains in the vicinity of the point where it issued on to them with morainic and fluvio-morainic material, but there is undoubted proof that the ice-stream crossed the Rockwood Range at two points—viz., at Middle Saddle, which lies between High Peak and Snowy Peak, and also between Snowy Peak and Round Top. This conclusion is based not only on the smoothed landscape features, but on the fact that massive blocks of greywacke up to 20 tons in weight occur in many parts of the range, resting on a surface consisting of andesite or of rhyolite. It is likely that the whole of the western end of this range was covered with glacier-ice, and, if so, it must have cascaded over into the low country between Rockwood and the Point, and possibly may have filled the Rockwood Valley, since the ridge extending westward from Pullwool Peak shows features attributable to glaciation; and, besides, on the flat country south-east of this there are huge blocks of rhyolite—one of which weighs 80 tons—whose presence in the position in which they occur can only be due to the action of ice.

In general, it may be stated that the ice extended from the direction of the Rakaia River to the line of the Hororata River, since all the intervening country is covered with material of glacial origin—i.e., occasional large travelled blocks, heaps of fluvio-glacial drift, and in certain parts a tenacious clay with subangular and rounded pebbles which may belong to ground moraine. Some of the stones it contains show markings which suggest ice-scratches, but this has not definitely been established.
Whether the Rakaia ice extended beyond the line of the Hororata River is doubtful, but the down country between the Glenroy Saddle and Rockwood is covered with a thick veneer of gravel, composed mostly of greywacke but occasionally containing rhyolite, some of the stones being up to 4 ft. in diameter, suggesting either glacial action or the presence of very powerful streams issuing from an ice front in close proximity. All over the down country which is characteristic of the area where the coal occurs in greatest abundance is a heavy coating of this gravel up to 70 ft. in thickness, and perhaps more. This materially interferes with prospecting, except by boring and actual mining operations. The surface of the ground where this lies exhibits a remarkable uniform level surface, which the present streams have dissected, cutting down into it for a depth which varies from 70 ft. to 375 ft., the greater depth being, as a rule, characteristic of the surface adjacent to the greywacke and rhyolite substratum in the north-west part of the area.

This dissection has reached an early mature stage, so that, while the tributary valleys are wide, with very flat floors, large undissected remnants of the original surface still persist. The Selwyn River still runs on a very steep gradient, but it is so clogged with shingle that it is an aggrading stream, and this aggradation has resulted in the ponding-back of tributaries such as the Glendore, Wairere, and Waianianiuwa, and the formation of extensive swamps on their floors. The Wairere Swamp, once known as the Thousand Acre Swamp, has now been drained and converted into good pastoral country.

The glacial features of the northern part of the area present some difficulty. As far as I can see, there is no evidence whatsoever that ice ever came through the Selwyn Gorge, but in the vicinity of Springfield and Sheffield and on the northern slopes of the Abner's Head Range there occurs in places a deposit formed of large subangular blocks of greywacke up to 5 ft. in length, whose origin can hardly be credited to any other action than that of glaciers. The largest deposit is that fringing the northern base of Abner's Head for a distance of at least a mile. It apparently rests on gravels of a series older than those at present being laid down in the river-beds. This occurrence is apparently separated by a depression from the other deposits on the flanks of the range, and, if glacial, it is either a lateral moraine or a terminal one. Analogous to this is the deposit forming Little Racecourse Hill, in the vicinity of the Sheffield Railway-station. The size of the boulders suggests that this hill is formed from moraine or from fluvio-morainic material laid down quite close to the terminal face of a glacier. Similar hills near Springfield may have been formed in the same way.

Farther up the Hawkins Valley, on the spurs of the Black Hills, there are coarse breccias possibly attributable to glaciation. Their location suggests that they were due to a glacier which came from the direction of the Upper Hawkins past the Dalethorpe Homestead. If this is so, then it may have been a distributary from the main Rakaia glacier, which came down the High Peak Valley and crossed the low divide—this is practically non-existent as a divide—into the Hawkins basin. I can see no difficulty in this explanation, and it is certainly as satisfactory as to attribute the deposits to the former extended Waimakariri glacier. All the same, the conclusion that these deposits are glacial is based only on the shape, size, and position of the boulders, unsupported by other evidence, and so I cannot view it as entirely convincing. No doubt large rivers issuing from the face of the ancient glacier have swept away a good deal of the old moraines and have left mere remnants, so that perhaps the absence of other evidence, such as the occurrence of crescentic heaps of angular material across the old front of the glacier, &c., is not so remarkable—in fact, it is what might have been expected. If the deposits are glacial, then the ice must have extended either from the direction of the Hawkins or from the Waimakariri nearly as far as Sheffield.

C. STRATIGRAPHY.

Note.—In order to illustrate the general stratigraphical relations of the different beds that occur in the area, a geological map is given, as well as sections—three in number—oriented across the general grain of the country, approximately parallel to the dip. No further references to these will be made in the text, but a number of smaller sections illustrative of limited areas are given, and these will be referred to as necessity arises. In the case of sections passing through the Triassic greywackes, &c., it should be pointed out that in that part of the sections the representation of the dip of the beds is largely diagrammatic, and not intended to show their true relationship, since the beds have been subjected to folding movements, the precise effect of which has not as yet been determined.
I. PRE-SENONIAN ROCKS.

(a) TRIASSIC AND JURASSIC.  

Although the chief reason for this paper concerns the coal-measures, some reference should be made to the basement rocks of the area. These are best developed in the ridge which divides the High Peak area from the main area where the coal-measures occur. At the western end of this ridge the rocks are exclusively volcanics—rhyolites and andesites; while towards the north-east sedimentaries are developed and form the Four Point Range, Flagpole Hill, the Black Hills, the Cairn Range, and the ridge of which Abner's Head is the dominant feature. There is also a small inlier in the creek running from the Brockley Coal-mine, and another in the Hororata River near Glenroy. 

The rocks include greywackes, slaty shales, carbonaceous shales, sandstones, conglomerates, and interstratified beds of diabase ash and related volcanics. Whether the whole series is part of one conformable set of beds is a matter of opinion, but I am persuaded that two separate series occur. There are differences in lithological character, and also differences in strike and dip within small areas between beds which show divergence in lithological character; and, further—and this seems most important—over wide areas there are conglomerates containing greywacke pebbles indicating something more than an interformational unconformity between the two sets of beds. 

The greater part of the underlying series consists of greywacke of a normal type, but interstratified with it are slaty shales, and again jasperoid rocks or reddish shales which owe their distinctive colour to ferric oxide. Some of these are of extremely fine grain. The strike of these beds is north-east and south-west, but local variations about this mean are frequent; and the dip is usually high, often vertical. In no place have I seen these beds with a flat dip, so that this arrangement implies either an enormous thickness of the beds or that they are involved in isoclinal folds with closely appressed limbs inclined at high angles. I think that the latter alternative is the correct one; but no definite repetition of the beds has been determined up to the present, although the occurrence of ash-beds on parallel lines does suggest it; all the same, I quite expect that definite repeated horizons will be made out in the future. 

The best section through these beds is given by the gorge of the Selwyn River, which cuts across the strike almost at right angles. The direction of the beds in the gorge controls to some extent the course of the river, in that the longer reaches are generally parallel with the strike, and the shorter reaches across it; but the general effect is that the river cuts across the beds. The strike in this part of the area is more to the east than generally, being usually between east-north-east and east, so that the line of the range from Flagpole Hill to Abner's Head is approximately that of the strike of the beds. Almost invariably they dip at high angles, from 70° to vertical; very rarely the angle is as low as 40°, and then it appears to be quite local and in close proximity to some dislocation or deformation of the beds. In the lower part of the gorge the dip is to the north, but near the upper end, close to the old copper-drives, the dip is to the south, but at very high angles—in fact, it is hard to say at times whether it is to the south or not. As the ash-beds are to some extent involved in this southerly dip, the question of their repetition in this section of the gorge was considered carefully; but there is no sign of it in the position in which they would occur were this change in direction of dip due to acute folding of the same beds, so that I am inclined to think that the southerly direction of dip is merely due to slight overturning of the beds without repetition. 

In the section through the gorge there is definite evidence of faulting, of the presence of crush-belts (the latter sometimes associated with local variations in dip and strike), and of a frequent waviness in the stratification. 

The same general features of these beds appear to occur on Abner's Head, where the strike is approximately the same and the dips high; but in a quarry on the road over to the saddle to the east of this hill the dip is definitely low, being about 40°. 

I have referred briefly to the ash-bed in the upper end of the gorge. There is another, which occurs on the line of Middle Creek, just north of Steventon, whose continuation to the east is masked by later deposits, if, indeed, it does extend farther in that direction. Detailed reference will be made to these ash-beds later, but they have some bearing on the question of the thickness of the greywacke beds with which they are interstratified, since it is possible that their occurrence on two lines may be due to isoclinal folding. If this is assumed to be the case, and it is not due to the occurrence of exactly analogous beds at two horizons separated by thousands of feet of sediments, then some indication of the thickness of the beds involved in these folds may be gained from a consideration of the separation of these lines of outcrops. These are approximately 12,000 ft. apart measured across the strike, and, as the dip of the beds is generally at high angles, the thickness will be approximately half that distance—that is, between 5,000 ft. and 6,000 ft. This calculation may be somewhat unsatisfactory, seeing that it depends on the supposition that the two belts of ash-beds are really the same, but it is the only estimate of the thickness of the beds belonging to the greywacke series that I have been able to suggest.
1. Greywackes.
2. Jurassic: Conglomerate with Shales.
3. Rhyolites.
5. Basic Intrusions & Flowers.

SECTION No. 2. FROM SELWYN R. ACROSS LIMESTONE SADDLE, STEVENSIE & HARPER HILLS.

Selwyn R. (Upper)
Moraize Cover
Four Point Range Marble & Ash
Cleaching's Gully
Bas. Dyke
Rhy. Dykes
Glendore Valley
Jul. Eagle
Pullwood Pk.
Bas. Dyke
Coal Seam
Sill
Glendore Creek
Fault
Stevenson
Coal Sill
Monro's Creek
Mt Misery
Coal Seams
Selwyn Rapid Beds
Surveyor's Gully
Dyke
Basalt Cap
perhaps a sill
Selwyn R.
Harper Hills
Wairere Creek
Harper Hills
Wairere Valley
Harper Hills

SECTION No. 3. FROM SELWYN R. ACROSS OYSTER HILL, HARPER HILLS.

Selwyn R. (Upper)
Fault
Ja. Goglem
Limestone
Saddle
Marble & Ash
Middle Creek
Marble & Ash
Marble
Ash Beds
Black Hills
Sill
Hart's Coalfield
Fault
Cairn Range
Plant Fossils

SECTION No. 1. FROM THE BLACK HILLS ACROSS HART'S COALFIELD TO HARPER HILLS.

Coal Seams
Selwyn Rapid Beds
Surveyor's Gully
Dyke
Basalt Cap
perhaps a sill
Selwyn R.
Harpers
Hills
Coal Seams
Selwyn Rapid Beds
Surveyor's Gully
Dyke
Basalt Cap
perhaps a sill
Selwyn R.
Harper Hills
Wairere Creek
Harper Hills
Wairere Valley
Harper Hills
The relationship of the greywackes to the overlying beds in typical localities will now be considered.

The first case is that occurring on the western end of the Cairn Range, immediately at the back of Captain Woodcock's house. The greywackes here have a north and south strike, with a vertical dip; but immediately north-east of this there are conglomerates containing greywacke pebbles, striking north-east and dipping south-east. Farther on the pebbles become finer, the beds retaining the same strike and dip, but are succeeded by shales, with plant-remains, dipping north-west. In this section the Cairn Range probably has the form of an anticline with a flanking syncline to the north-west, and the north-west limb of the anticline is the most clearly exposed; still, the covering of soil and surface slip renders the precise stratigraphy difficult to determine. This locality is interesting as being the spot which furnished the plant fossils described by Arber (1917, p. 11).

The lowest beds exposed on the face of the hill are conglomerates, but at the spot where the plant fossils occur most plentifully, which is near the crest of the hill, the following sequence is exposed in ascending order:—

1. Conglomerates with pebbles of greywacke.
2. Sandstone, brownish, with calcite veinlets.
3. Carbonaceous shales, 12 ft.
4. Sandy shales with impressions of leaves and stems of trees—the most prolific plant horizon, and the one from which nearly all the plant fossils described by Arber were obtained.
5. Brownish, hard, indurated sandstone.

At various points on the hillside similar beds appear, the succession of shales and sandstones being repeated several times—probably at least four times. At several points short adits have been driven on the carbonaceous layers in the hopes of finding payable coal, but without success. Wherever the beds are clearly visible conglomerates form the lowest member.

They strike east-north-east and dip north-west at angles of from 10° to 15°; but on the sides and head of the gully which comes from the north-west corner of the Cairn Range there is a reversal of dip, but only the uppermost beds of the northerly wing of the syncline are exposed, and these consist of a soft somewhat friable sandstone, like a freestone, composed of loosely cemented quartz-grains. In these beds Haast found the fossil fern Polypodium Hochstetteri Ung. = Cladophlebis australis (Morris). Arber considered the underlying plant-beds containing this fossil as probably Lower Jurassic, but it also occurs fossil in beds of Neocomian age (loc. cit., p. 18) at Waikato Heads, Auckland. However, the general suite of fossils suggests a Lower Jurassic age, and as there is no apparent unconformity they are without doubt all of that age.

The country to the east of this, towards the head of Bush Gully and along the southern flank of the Cairn Range, was carefully examined in order to see how far these Jurassic beds extend. (See Section No. 5.) The crest of the range appears to be of normal greywacke, but it is flanked to the south for some distance by beds which belong to the Jurassic Series. Just above the bush there is a sandstone similar to that on the end of the range facing the Selwyn, with occasional narrow beds of bright coal and of carbonaceous shale, while on the east side of the gully is a fine conglomerate with greywacke pebbles, dipping to the north (?). On the spur west of the bush there is a conglomerate composed of greywacke pebbles closely resembling the other Jurassic conglomerates in appearance, which strikes N. 55° E. and dips south-easterly at an angle of 45°. A little farther down the spur is a rhyolite-bearing conglomerate striking slightly more to the east and with the same dip. The practical accordance in the dip and strike of the two beds, in spite of the lithological resemblance to the Jurassic conglomerates, makes me conclude that they belong to the same series, and that therefore the greywacke conglomerate should be assigned to the Senonian Series. The absence of the rhyolite constituent is not, after all, so remarkable, since a greywacke or similar land must have been in close proximity to the area when the beds were laid down. If, however, the bed belongs to the Jurassic Series, then an anticline must flank the syncline to the south; and there is some indication of this farther east, for on a spur to the east of the bush the sandstone is well developed and perhaps bent up into an anticline whose axis strikes east-north-east and west-south-west, flanked by a syncline to the north whose northern limb rests on greywacke. This cannot be stated for certain, since exposures giving undoubted indications of dip and strike are impossible to get owing to the covering of soil, surface debris, and tangled scrub. I have therefore given the section (No. 1) on the supposition that there is no flanking anticline.

The beds extend to the east along the southern flank of the Cairn Range, forming a stripped surface on which the Senonian coal-measures rest at an angle approximately accordant with that of the stripped surface. The Jurassic beds apparently extend as well along the northern side of the range for some distance from its western end, since sandstone with carbonaceous shale outcrops in some of the gullies running north from the main ridge. Where observed, these latter beds dip to the south, and apparently form the northern wing of the syncline as developed on the end of the range facing the Selwyn River.
On the western side of the Selwyn River, opposite the end of the Cairn Range, on what is called the Manuka Range, there is a notable development of these beds, practically in the same alignment if due allowance be made for the shift of the outcrops owing to the Cairn Range–Misery Fault. In a slip at the bottom of a small creek coming from the range there lies on the basement beds of normal greywacke, as exposed on the end of the range near the river, the following sequence in ascending order:

1. Compact sandstone with plant-stems.
2. Argillite, much weathered and crumbly.
4. Argillite with ferruginous concretions.

Some distance above this stratigraphically the following occur:

5. Fine sandy conglomerate.
6. Coarse incoherent sandstone and conglomerate, containing greywacke pebbles, striking E. 10° N. and with a northerly dip.
7. Greywacke conglomerate.

The ridge is capped with these beds for some distance to the west, and in places they extend well down the southern face near to the level of the flat occupied by Middle Creek. (See Section No. 4, p. 19.) On the northern face they extend right down to the bed of Manuka Creek, which follows along the southern base of Flagpole Hill from Hill’s Saddle. They then cross the creek and continue up its northern bank for about half a mile, where the continuation is lost in tangled scrub and cannot be followed till the face of the hill is burnt. In the bed of the creek are outcrops of shaly coal, bright in colour, like those of the Cairn Range. These beds have a northerly dip—in some places very steep—and they are apparently interstratified with greywacke, since this occurs above them along the flanks of Flagpole Hill and also below them along the southern side of Manuka Creek. In no place was I able to examine a contact in order to determine their precise stratigraphical relations.

On the southern face of Manuka Range, just opposite a plantation on a ridge to the south, is a small gully coming down from the crest of the range. At the mouth of this gully, on both sides, occurs greywacke full of quartz veinlets and having an east and west strike—i.e., along the line of Middle Creek—and a steep, almost vertical, dip. On the western side of the gully, and also in its bed, are slaty shales with nearly the same strike and a dip to the south at high angles. On the eastern side of the gully the conglomerates are very well developed, with a thickness exceeding 200 ft. They strike south-east and dip north-east at an angle of 55°. They thus cross the line of the greywacke which is in close proximity, and apparently overlie the slaty shales which belong to the greywacke series. The conglomerates not occurring to the west of the gully on the same line as the shales. The total thickness of the conglomerate on Manuka Range in all probability approaches, if it does not exceed, 500 ft., and it apparently disappears within a distance of half a mile when traced along the strike. The general stratigraphical relations of the bed in this locality suggest the presence of a break.

To the west of Hill’s Saddle, at the head of Manuka Creek, there is another occurrence of these conglomerates. On the flanks of the Four Point Range facing the High Peak Valley they extend for half a mile, and show a thickness of between 200 ft. and 300 ft. Their lithological character is similar to that of the other occurrences, and they show heavy bands of conglomerate, with interstratified layers of sandstone, and shaly coal, this latter facies being more developed in the lower levels; but coaly material does occur interstratified even in the heavy conglomerate layers. Mr. H. Robb has shown me some specimens of plant fossils which he recently found in shaly beds between the conglomerates in this locality, and they are no doubt of the same age as the Cairn Range beds. The fossils collected include *Cladophlebis australis*, *Elatocladus conferta*, and *Coniopteris (?) hymenophylloides*. The beds strike north-east and south-west at this spot, and dip south-east at fairly steep angles, those observed being in the neighbourhood of 45°. They thus form a anticline with the beds in Manuka Creek. The folding, however, is not so pronounced as that of the associated greywackes. The crest of the ridge immediately above this occurrence is composed of greywackes and slaty shales with the same strike and apparently vertical dip, but immediately to the west of it and approximately in the same line ash-beds occur which strike in a northerly direction and dip west. The strike of these swings round to the west of the saddle, so that the disagreement in direction of the conglomerates and the ash-beds can hardly be used as an absolute test for unconformity; but no trace whatsoever of the great thickness of conglomerate occurs immediately to the west on the line of the beds, although its presence should easily be detected on the steep rocky face of the range if it did continue. The sudden termination of the beds points to unconformity, since the disappearance of a heavy band of conglomerate and its passage into ash-beds or normal greywacke in a distance of a hundred yards or so along the strike is hard to explain if the beds be part of a conformable series. It is, of course, just possible, but hardly likely. There is, of course, the possibility that the contact between the con-
glomerates and the greywacke series is a fault contact. The main evidence, therefore, from this locality of the presence of a structural break is based on the lithological character of the conglomerate.

Similar beds are found near the crest of Rocky Ridge above the marble quarry, on the western side of Boundary Creek above the rhyolite gorge, and on the north-east side of Pullwood Peak, overlying cherts and associated beds in the first two cases and normal greywacke in the last, but overlain in all cases by basalt, which is probably intrusive, as will be shown later. These occurrences dip at moderate angles, as distinct from the steep dip of the beds over which they lie. However, this is not to be taken as a definite proof of unconformity, since the conglomerate beds are involved to some extent in the movements which have affected the greywackes, and in the general absence of fossils the demonstration of their precise relations is a somewhat uncertain task.

The conglomerates at Cairn Range and Manuka Range have been referred to by Jobberns (1925, pp. 214–28), and his descriptions apply generally. The constituent pebbles appear to be in all cases almost entirely normal greywacke, and there occur also a fair number of pebbles of that type which exhibit veins of quartz freely, a type which was considered by S. H. Cox to be typical of the oldest members of the greywacke series and classified by him as of Carboniferous age (1884, pp. 24–25). Among the pebbles are a few of granite and also an occasional one of jasper. In some cases the pebbles are thoroughly well rounded, as if they had come from some distance or had suffered prolonged attrition; but a reasonable percentage of them are subangular, at times even angular, and thus could not have occurred. The largest noted did not exceed 8 in. in length. There is a matrix of finer-grained material of the same nature as the pebbles.

Associated with the conglomerates and plant-beds of Cairn Range and of Manuka Creek are thin beds of bright shining coal. They are rarely more than a couple of inches thick, but they have been prospected freely in the hopes that it might turn into something of commercial value, but unfortunately without success. An analysis made in the Chemical Laboratory (by Mr. W. G. Hughson) of a sample from one of the layers from Manuka Creek gave the following result:—

<table>
<thead>
<tr>
<th></th>
<th>Per Cent.</th>
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<tr>
<td>Mechanical moisture</td>
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<tr>
<td>Ash (inorganic residue)</td>
<td>. . . . . .</td>
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<tr>
<td>Volatile matter</td>
<td>. . . . . .</td>
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<tr>
<td>Fixed carbon</td>
<td>. . . . . .</td>
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This result is somewhat surprising, since the hand-specimen suggests a coal of better quality and with more fixed carbon.

Similar coals occur in narrow seams in and near the bush in Bush Gully, on the south side of Cairn Range.

The presence of such a widely distributed conglomerate with greywacke pebbles closely resembling the rocks adjacent thereto implies an unconformity between the conglomerates and the parent rocks. The stratigraphical evidence in support of this is not convincing by itself, although there is nothing against the contention. The differences in strike of the beds behind Captain Woodcock’s house, also the fact that if the direction of the conglomerate bed on the southern flank of the Manuka Range is continued for a few chains in its apparently regular direction it will be found to be underlain by greywacke and to be abutting against greywacke with apparently different strike, also the features of the conglomerate lying to the west of Hill’s Saddle, and the apparent discrepancy of the dip of the beds on Rocky Ridge and Pullwood Peak, are all to some extent in favour of the contention, and support the inference drawn from the nature of the constituent pebbles of the conglomerate, that a definite stratigraphical break occurs, and that the greywacke belongs to an earlier series and the conglomerate to a later one.

This set of beds in which conglomerates are somewhat important members is evidently widely spread in the Canterbury area. S. H. Cox refers to it in the gorge of the North Ashburton, where he assigns it to a later age than the Maitai greywackes, and considers it overlies the latter unconformably. It also occurs in the Pudding Stone Valley, a tributary of the Upper Rangitata ; near Lake Coleridge; and in the middle gorge of the Hurunui, just above Kihelson. The latter occurrence has some definite bearing on the age of the beds in the Malvern region, for it is interstratified with finer-grained beds containing calcareous concretions. A little while since an ammonite was discovered in the bed of the river not far from this occurrence with a similar matrix to these concretions, and this has been classified by Marshall (1924, pp. 615–16) as of Jurassic age, a fact which is not inconsistent with the determination of the conglomerates in the Malvern Hills as belonging to that period.

Similar beds with Jurassic plant fossils also occur on the south-eastern slopes of Benmore, across the Upper Selwyn River, and it is possible that they may be traced over considerable areas of the mountain region of Canterbury. For example, I myself have seen in the valley of the Pudding Hill Stream, a tributary of the North Ashburton, similar plant-beds, and not far distant from them similar conglomerates which probably belong to the same series.
The age of the greywackes is determined as probably Lower Triassic from the similarity in their lithological character to the beds in Mount Torlesse and elsewhere containing the annelid Teredoliana mackayi and other Lower Triassic fossils. I have not observed the annelid-tubes in any rocks of the Malvern Hills proper, but they occur in greywackes at the upper end of Rakanui Gorge, which is in close proximity. Thus we have a greywacke series of Lower Triassic age, and a conglomerate with sandstone and shaly beds containing plant fossils of Rhaetic or, according to Arber, more probably of Lower Jurassic age, if we can rely on plant fossils alone as a criterion for the determination of age. In this case it is all we have to rely on.

If this be definitely established it implies two periods of deformation in the formation of the Southern Alps. The pebbles in the widespread conglomerate imply that land of some elevation composed of greywacke was in existence when the conglomerate beds were laid down. Therefore some deformational movements in the alpine area had taken place in later Triassic times, by which the land was raised above sea-level. There is no evidence from the area as to whether these movements were merely uplift or attended with folding, but judging from the differing intensity of folding exhibited in the greywackes and the conglomerates it is a reasonable inference that some folding had taken place before the great revolutionary movements at the end of the Jurassic or in the early Cretaceous.

The matter of the names to be assigned to these two series remains to be settled. Marshall's name, Maikai, cannot be applied to both, but it may perhaps be applied to the underlying Triassic Series, although Morgan has perhaps more appropriately called these beds Hokonui. I would suggest the name Wanakaepa, the Maori name for the Selwyn River, since the set of beds is typically developed in the valley of the Selwyn not only in the Malvern Hills proper, but also in the valley of the Upper Selwyn in the foothills on the south-eastern flanks of Benmore.

**Triassic Volcanics—Lavas and Ash-beds.**

A most important point to be considered now is the relation of the ash-beds to these two series—viz., to which of the two they ought to be assigned. These volcanics are best developed along a belt of country running north-east from the High Peak Saddle, through the Four Point Range, towards the head of Manukau Creek, a definite band following along the south side of the creek that runs just north of the Steventon Homestead and crossing on to the southern face of the Manuka Range, where outcrops occur in fairly close proximity to the Steventon Coal-mine. Another band occurs on the north side of Flagpole Hill, crossing the Selwyn near the upper end of the gorge, continuing over a low saddle to the east, and entering the valley of the Hawkins.

These beds consist of ash, with occasional flows of solid rock of basic composition. They were called diabase ash by Haast and by S. H. Cox, a name which may still be applied to them with propriety. Hutton has called rocks from the same belt leucophyres (1888, pp 271-74). The ash-beds themselves are much altered, very largely owing to the formation of a considerable amount of epidote, a secondary product derived from the F.M. minerals and perhaps the basic feldspars present. They are associated with a crystalline limestone known as marble, and cherty beds stained by iron oxides and occasionally by manganese oxide. Interstratified with these are fine-grained detrital rocks in which grains of feldspar are important constituents. No definite fossils have been found in the ash in this district, but impressions suggestive of the form of Monotis were observed near the marble-quarry on the High Peak Saddle. However, Monotis and other associated forms have been reported as occurring to the north-west of Mount Thomas in ash-beds extending north-east from the Ashley Gorge towards the Okuku, whose relations are similar to those in the Malvern area.

The marble is of a finely crystalline variety, sometimes decidedly siliceous. It forms irregular-shaped, disconnected masses. The place where it is best developed is at Adams Quarry, to the east of the Selwyn, where it has been worked at intervals for many years as a source of high-grade lime for building purposes.

This bed of marble strikes north-east and south-west, and has a high, almost vertical, dip. The breadth of the bed is somewhat narrow, and does not exceed a chain at most. It is much faulted, most of the faults being strike faults, reversed at times, showing slickensided surfaces and frequent brecciation. It occurs in ash, probably as separate overlapping lenses, and the ash becomes subchisistose along fault-lines.

The most extensive development of the ash-beds and the associated rocks occurs on the High Peak Saddle. Here we have ash with irregular masses of marble, one of which has been worked, but abandoned many years ago. The marble here is pinkish in colour, much jointed, and occurs in three or more detached masses of no great size, the largest being not more than 2 chains in length. Analyses of these are given in Bulletin 52 of the N.Z. Geological Survey (p. 239), which show the samples to be a fairly pure limestone.
Overlying these beds are siliceous rocks stained with iron oxide and manganese oxide, lying in a broad belt to the south-east several chains—perhaps half a mile—in width. These continue down nearly to the rocky gorge of Boundary Creek; but below the old camp-site at the bend occurs a bed of diabase with veins of calcite and crystals of pyrites freely showing, which no doubt belongs to the diabase-ash series, although it may perhaps be intrusive. This is succeeded again, before the gorge is reached, by normal greywacke, and then the succession is obscured by the rhyolites of Rocky Ridge and Pullwool Peak. Just above the gorge is an occurrence of intrusive basalt, which will be referred to later. This overlaps a small occurrence of greywacke conglomerate of probable Jurassic age, referred to previously (p. 8). Small masses of marble also occur in the siliceous rocks between this point and the quarry, evidently on a parallel line, but the beds are twisted about in a remarkable way and their true alignment is difficult to determine precisely.

This remark also applies to an occurrence of marble in similar beds at the head of the valley leading down to Cleathing's old homestead. It may be on the same line as the deposit at the quarry or on a parallel line, though the first hypothesis is probably correct. This occurrence of marble strikes north-east, and occurs in siliceous rock stained black with manganese oxide associated with rock pink with the manganese silicate (rhomboide). The beds can be traced right down into the gully on a line running to the south-east of the highest point on the Four Point Range.

Stains of malachite have been observed on some of the siliceous rocks of the locality, and one of the cherty layers was definitely prospected for gold. This occurs on the face of the hill above the old camp. It strikes E. 30° S. and has a vertical dip, thus simulating a reef in appearance; but in close proximity there are hard siliceous rocks with veins of quartz interstratified with slaty greywacke which strike east-north-east and west-south-west, and dip south-south-east at high angles. The strike of the greywacke to the south-east of this band is definitely determined from observations on the road over the saddle, and shows an east-and-west direction, which is maintained on the hill called Golgotha, forming the ridge between the two branches of the Glendore Valley. The general arrangement of the ash-beds in this locality indicates that they are interstratified with the greywacke, and thus they represent interbedded sheets and ash-beds of the same date as the greywackes—that is, they are probably Lower Triassic.

There appears to be some break in the continuity of the ash-beds and the associated marble, since the next outcrops of the latter occur on the northerly face of the range near Limestone Saddle—that is, the saddle at the head of Middle Creek, which is about half a mile to the west of Hill's Saddle. Marble also occurs in ash-beds near the crest of the ridge at the head of Middle Creek, and also along its southern side in a narrow belt which crosses the creek lower down, so that pieces of marble can be picked up at the foot of Manuka Range just opposite to the coal-mine.

The ash-beds are usually greemish in tint, but the diabase is frequently reddish. They are apparently interstratified with the greywacke, and the strike of the beds is the same. Along the south side of Middle Creek this is approximately east and west, whereas at the head of the gully near the saddle it is almost at right angles to this direction, being north-north-west and south-south-east; but the general line in a north-east and south-west direction is resumed immediately to the west of the saddle, where isolated masses of marble occur in the ash. I could not make out for certain whether this disagreement in strike is due to a local bending of the beds south of the saddle or due to the incoming of another layer of ash at a slightly different angle. The latter seems more probable.

The diabase beds in Selwyn Gorge are not on the same line with the beds following along Four Point Range. They may be at a different horizon, but they may be at the same horizon as the result of folding. In the vicinity of Hill's Saddle the beds are anticlinal, and the southern and western faces of Flaggpole Hill show that they are part of the limb of a fold with a general dip to the north, so the latter supposition may be the correct one. In the gorge the strike is north-east and south-west, and the dip is almost vertical. The green colour of the beds suggested to prospectors the possibility of copper, and two or more drives were put in, with a negative result. The ash-beds are interstratified with greywacke. Siliceous rocks also occur, sometimes as definite beds of jasperoid material, and again as jasper in the ash; occasionally it is whitish in colour, resembling the reef worked on the High Peak Saddle.

It may be interesting in this connection to report the occurrence of marble in the Thirteen Mile Bush on the southern face of Big Ben Range. This and the occurrence of plant fossils of Jurassic age, kindly collected and lent to me by H. Robb, suggest that other lines of marble and associated beds occur to the north-west of the lines already definitely known in the Malvern Hills proper. I have seen none of these, since my examination of this part of the country has been very meagre, and the country is extremely difficult, owing to the covering of bush and its general roughness.

The ash-beds can be traced north-east through Adams Quarry, across the low saddle behind the quarry, and along the northern face of the Black Hills, on the south-east side of a valley tributary to the Hawkins. They form a broad band on the same line as the marble-beds, and extend across the ridge leading down to Mr. Smith's house and on to the next ridge a little above the valley-floor.
They occur over several hundred feet in altitude, but their precise limits are difficult to locate. The main band is bounded on the south-east side by greywackes, and there are small subordinate strips higher up the ridge parallel to the main band. The rock varies in the hand-specimen, but frequently shows tints of dark green, lighter green, and with a yellowish tinge, and reddish and greenish quartzose layers, sometimes stained with manganese dioxide, similar to those in the country to the south-west on the High Peak Saddle, frequently occur parallel to the ash-beds. The strike of the diabase, as well as of the associated greywackes and argillites, is north-east and south-west, with a dip to the south-east at high angles. It is possible that other bands may occur south-east of the one just referred to, more on the strike of those occurring in the Four Point Range.

The solid material of the ash-beds, no doubt belonging to contemporaneous flows, is generally light yellowish-green in the hand-specimen, sometimes a dark green. Under the microscope it proves to be a diabase of moderately fine texture. The feldspar is in the form of laths, of fairly uniform length, averaging about 0·3 mm., and oriented irregularly to the augite, which shows a subophitic relationship. It has an index higher than balsam, and an extinction angle corresponding generally to that of an anorthosite, and it frequently shows a denticulate border of more acid facies. Phenocrysts do not occur.

There is much augite present, greenish-grey in colour, and usually showing signs of decomposition. Epidote is a notable constituent, as well as a stain of chloritic material which specially colours the alteration-products occurring in cavities and veins. The yellowish-green tint that the rock frequently exhibits is no doubt due to the presence of the epidote and chlorite. In some of the less-altered varieties olivine appears, but in the altered forms it does not show as a separate entity. Calcite and quartz—notably the former—occur frequently in veins and cavities, and also ilmenite in grains with denticulate borders and in broken comb-like forms.

The ash under the microscope appears to be composed of fragments of the same variety of rock, augite being the dominant constituent of the grains. Epidote occurs very freely, as well as calcite. These forms pass gradually into the marble, with an increase of the calcite constituent; but transitional forms have always a percentage of epidote. Some of the marbles show a fair proportion of quartz; but then, again, some are practically pure calcite. I have seen nothing in the evidence to suggest that the marble is an alteration-product of the ash, and represents the accumulation of the calcium constituent of the feldspar and altered augite of the diabase, seeing that the large quantity of epidote accounts quite satisfactorily for what has disappeared. It seems to me more probable that the marble represents the calcareous constituent of a calcareous tuff laid down on a sea-bottom contemporaneously with the deposition of the ash.

Although it seems reasonable that all the diabase material is either ash or flow, some rocks remarkably like it in general appearance may be due to subsequent intrusions. This remark applies specially to the occurrences at the head of Boundary Creek, above the rhyolite gorge, though I think it more likely that they, too, are merely interbedded sheets like those associated with the ash farther to the north-west.

One or two of these diabases show decided relationship to spilites, and their association with jasperoid rocks is interesting in view of the frequent occurrence of the two types in conjunction. The general texture answers to the description of spilites, but the feldspar is hardly sodic enough, being not more acid than oligoclase, with an index of refraction practically equivalent to that of balsam, and an extinction angle corresponding to an oligoclase. Although some of the mineralogical characters indicate a relationship to spilites, the rocks are not so completely decomposed as is the case with typical spilites, and the feldspars are singularly fresh, unaltered, and do not show the characteristic terminations of spilitic feldspars. More work is therefore necessary in this connection before the spilitic character is definitely established.

The general occurrence of manganese oxide forming a stain on the rocks in the vicinity of these ash-beds is a matter of some interest. Hutton considered that the presence of manganese in the greywacke might be taken as indicating that they were a deep-sea deposit, a conclusion he had come to on other grounds. It appears to me, however, that the manganese may be traced to the volcanic rocks themselves. In the analysis cited by Hutton (1888, p. 273) the percentage of manganese oxide present is given as 0·73, and the concentration of this amount from decomposed ash and lava in the surrounding rocks would account for the small amount they contain without necessitating the assumption that the manganese represents the nodules characteristic of abyssal marine deposits.

It will be seen from the descriptions of these localities that the ash-beds are interstratified with the greywacke, and therefore it may reasonably be assumed that the two sets of beds belong to the same age—that is, they are Lower Triassic. This conclusion is confirmed as far as the ash-beds are concerned by the occurrence of Monotis, &c., in beds of similar lithological character at Mount Thomas. There are, therefore, two main series of Lower to Middle Mesozoic age—(1) Greywackes and ash-beds with occasional interbedded sheets of diabase of Lower Triassic age; and (2) conglomerates, shales, sandstones, with plant fossils of Rhaetic or Lower Jurassic age.
In addition to the ash-beds and associated diabase, which are contemporaneous volcanics, there are igneous rocks of later date intrusive into the above-mentioned series.

One instance of these is no doubt connected with the rhyolites to be referred to later. Two dykes of this rock occur near the end of Cleathing's Road with a N. 30° E. strike, so that they appear to have originated from somewhere near Rocky Peak, as if it was the centre of disturbance. The more easterly of these crosses the ridge between the two tributaries of the Glendore Stream which come from the south-east slopes of the Four Point Range, and it can be traced as far as the High Peak Road, where it is exposed in a cutting. Then followed to the north-east it apparently turns in direction till its alignment is almost north-east and south-west, being directed almost to the saddle over which the road passes. The second dyke can be followed across the ridge down into the western gully, but it is not known farther south-west for certain, although it may also cross the road, since at the spot where it should do so is a collection of rhyolite boulders but no rock in position. Another rhyolite dyke occurs on the western side of Ahner's Head, which I found some years ago but have not been able to locate again. On the northern face of the same hill there is an outcrop of rhyolite, evidenced by the occurrence of numerous boulders of rhyolite over an area of a few square yards; but this could not be traced in the surrounding greywacke, nor could the actual contacts be seen in order to determine whether or not they were from an intrusion.

Another rhyolite dyke occurs in greywacke in the creek coming from the Brockley Mine, south-east of the main adit, and this also can be traced south-west through the rhyolitic knob between this creek and the headwaters of Wairere Creek, and it may continue on to the north-western face of the ridge determined by the sill behind the Glenroy Mine. But, of course, all these occurrences are connected genetically with the rhyolite igneous rocks to be referred to later.

Besides these acidic rocks, there are intrusive into the greywacke a number of basic dykes. One of these occurs north-west of the rhyolite dykes near Cleathing's, running almost parallel with them. This crosses the ridge just referred to; and a dyke does occur on the High Peak Road, very much weathered, and about a foot in width, which may be a continuation of the dyke in that direction. Another basic dyke occurs on the southern side of the Cairn Range, and other basic rocks, probably intrusive, along the junction of the rhyolites and the pre-existing sedimentaries near the crest of the range from Pullwool Peak to the rocky ridge east of High Peak. The special occurrences of this are—

1. North-east of Pullwool Peak;
2. Near Hood's Bush, on the north-east slope of Rocky Peak;
3. On both sides of Boundary Creek, above the rhyolite gorge; and
4. On the actual crest of the ridge south of the marble-quarry. The first, third, and last of these overlie the Lower Jurassic conglomerate, and the second apparently overlies greywacke, though the conglomerate may be there too. Nos. (3) and (4) were known to Haast, and he considered them as belonging to the andesites so well developed farther west. This would be their proper position according to his ideas of the sequence of volcanic rocks in the area, seeing that he considered them effusive and not intrusive—viz., they were overlying the greywackes and underlying the rhyolites. They are, however, judging more from their microscopic features than their field relations, which are somewhat obscure, not so much related to the andesites as to the basic rocks, which are certainly intrusive into the Senonian beds. I should therefore consider them as of a later date than the andesites.

(b) JURA-CRETACEOUS VOLCANICS.

Andesites and Rhyolites: their Field Relations.

In addition to the diabase-flows and ash-beds of Triassic age, there are two series of pre-Senonian volcanics. One of these is a hypersthene-augite andesite, and the other a garnetiferous mica rhyolite. The former consists of flows and clastics, while the latter occurs in several facies ranging from what is practically a quartz-porphyry to a pitchstone, the last-named probably occurring as dykes, though in some cases they may be merely a chilled facies of the ordinary rhyolite and not intrusive. In addition, there are clastic rocks associated with the flows. Both Haast (1872, pp. 12-18) and S. H. Cox (1884, pp. 36-41) considered the andesite to be older than the rhyolite, although it plainly rests on the rhyolite at Round Top, near the Point Station, where the flows of andesite clearly dip to the north-west, with the rhyolite lying under them, both on the south-east and the north-west flank of the hills. The same relation occurs elsewhere along the Rockwood Range. Although this is so, S. H. Cox was convinced that the andesites were the older of the two, and he explained their anomalous position by suggesting that the thick masses of rhyolite forming the hills in its vicinity were built up by a process of endogenous growth; that the thickness of the mass was increased by growth from within; that the andesites were bodily lifted at the same time, and hence their present singular position. This conclusion as to the relative age of the two rocks has been questioned, as far as the Rakia Gorge is concerned, by P. T. Cox (1925, pp. 100-1). He concludes that in that locality, at all events, the rhyolite antedates the andesite, while he thinks that the evidence from Mount Somers, where similar series occur, points to a reversal of the sequence in that district.
The whole question presents serious difficulties. On the eastern margin of the exposed andesite near the summit of Middle Saddle—a depression in the Rockwood Range crossed by a distributary ice-stream at the time of the maximum ice-flood—and also lower down the slopes to the north, there is some evidence that the rhyolite is the more recent of the two. Here an outlier of fragmental rhyolitic breccia or agglomerate several acres in extent and 50 ft. thick apparently rests on andesite, and if this could be definitely substantiated it would appear to settle the relative ages of the two series as far as this locality is concerned. But on the southern side of the saddle in close proximity, round the head of the western branch of Rockwood Creek, and, of course, farther south-west, the andesite is certainly on top of the rhyolite. The patch of rhyolitic breccia may, after all, be an inlier, and owe its appearance to the denudation of the somewhat thin cover of andesite which masks the rhyolite in the vicinity of the saddle. This probably explains the presence of the inlier of pitchstone and pitchstone breccia surrounded by andesite at the head of Washpen Creek, near the saddle, just north of Round Top. Near the Switching Station at the western end of the Rockwood Range, at the point where an adit was driven on the contact of the andesite and rhyolite in the hopes of striking copper in payable quantity, the andesite rests on the decomposed surface of the underlying rhyolite, and suggests that the andesites were poured over an old land-surface of rhyolite. Therefore we have the following alternatives:

(1) The andesite is the younger of the two—as it apparently is, judging from its general position on top.

(2) It is the older of the two, and owes its position to (a) being lifted up by the process of endogenous growth of the rhyolite as suggested by Cox; or (b) the rhyolite being part of a large intrusive mass which has lifted the andesite in a manner somewhat similar to (a); or (c) faulting, the andesite having been thrust over the rhyolite, the overthrusting in the neighbourhood of the Switching Station having come from the north-west, the last-named supposition being supported to some extent by definite evidence of faulting of this kind on approximately the line of contact of the two volcanics in the neighbourhood of Rakaia Gorge. All the same, a belt of rhyolite fringes the andesite along the greater part of the north-west flank of the Rockwood Range, and so this explanation will hardly apply.

In the neighbouring Mount Somers district, where similar series of andesite and rhyolite exist, the andesite appears to be the older of the two.

The chief reasons for this conclusion are:

(1) The rhyolite does actually lie above the andesite on the northern side of Mount Somers at the head of Chapman's Creek.

(2) Fragments of andesite are found in a pitchstone breccia.

(3) Apparent intrusions of rhyolite are found in andesite.

(4) There occur patches of rhyolite which were in apparent continuity at one time but are now separated as outliers of the parent mass as the result of erosion.

These reasons are, on the face, apparently conclusive as to the rhyolite being subsequent to the andesite; but at Rakaia Gorge itself, as pointed out by P. T. Cox, it is difficult to explain the relations on any other assumption than that the order is reversed. It does not seem at all likely that there are two andesites in the Rockwood Range, one older and the other younger than the rhyolite, since andesite occurs in unbroken continuity from Middle Saddle right to the south-west end of the range.

There are one or two occurrences of volcanic rock, especially those near the Rockwood Homestead, which no doubt prompted both Haast and S. H. Cox to suggest the order of eruption that they did. Two of these lie north of the homestead, and there may well be others hidden by the scrub. They were considered by Haast to be andesites like those of the general run of the rocks. This conclusion is supported by microscopic evidence. As far as can be seen, these rocks rest on rhyolite; there is a good exposure in a creek about a mile north of the house showing this clearly, but in one place at least the andesite rests on rhyolite with rhyolite exposed on the hillside just above it. This may be due to erosion of a thin veneer of andesite, and the rhyolite may be an inlier. This occurrence of andesite can be connected up by blocks lying on the surface and traced to the west into the bush, and on to the end of the spur coming down between the two branches of Rockwood Creek.

There is also a peculiar occurrence of andesite at the base of the hill just where Washpen Creek emerges on to the plain, in close proximity to Mr. Stone's house. Here it is exposed over a few square chains, and its position is difficult to explain. This and the occurrence just mentioned may be intrusive, or the remnant of a covering veneer of andesite (supposing the andesites to be younger than the rhyolites), or they may be outliers of an older andesite exposed by the erosion of a veneer...
of rhyolite. Their peculiar position at various levels may be due to faulting. In the present state of our knowledge the proper explanation cannot be selected from these possibilities.

A somewhat important point which has bearing on the relations of these beds is the general irregularity of the upper surface of the rhyolite on the south-eastern flank of the Rockwood Range. No actual contacts are exposed, but it is very clear that the surface of the rhyolite shows irregularities in elevation amounting at times to several hundred feet. This is clearly seen, since its upper surface forms a distinct shelf or shoulder along the length of the range in this section. It does seem unlikely that if the rhyolite is intrusive its form should be so irregular. Of course, the irregularity might be the result of subsequent faulting on lines generally across the range; but it is much more probable that this feature is due to the fact that the rhyolite was eroded before the andesites were poured over it, and that these filled up gullies and valleys resulting from such erosion, and hence the irregular contact. The occurrences of breccia on the top of Middle Saddle and at the head of Washpen Creek would thus be parts of the underlying rhyolite surface exposed as the result of erosion. This seems to be a probable explanation of its existence. Breccias are, no doubt, at times connected with intrusions, but the area exposed in this case seems somewhat against its being the result of intrusion, and it is more probably an ordinary volcanic breccia formed normally as the result of explosive action on or near the surface.

Another problem is presented by the occurrences on the end of the spur on the opposite side of the river from the Rockwood Homestead. Igneous rocks appear along the river-bank as it skirts the spur, and these are dolerites of the usual type, containing much titaniferous augite, often ophitically intergrown, and titaniferous magnetite or ilmenite. All outcrops apparently belong to the same mass, but on the up-stream side of the spur, and in apparent continuity with the doleritic facies, there is a more acid one, still with ophitic patches, but much weathered. There is an occasional development of the decomposed material in the doleritic facies, so that they may be variations of the same dolerite. An undoubted andesite, similar to the other andesites of the area, does occur in the vicinity of the point, but its field relations are uncertain.

The whole question thus presents serious difficulties, and, as I have not sufficient opportunity at present to decide the case one way or the other to my complete satisfaction, I have left the solution of the problem to Mr. S. J. H. Sylvester, a student who has been of the utmost assistance to me in many ways, in the confident anticipation that he will do his best to come to a correct conclusion. All the same, my present opinion is that the rhyolites are the older of the two rocks.

The actual age of the two series cannot, in the light of what we now know, be stated more definitely than that they are subsequent to the Lower Jurassic conglomerates and plant-beds, and are anterior to the Senonian coal-measures. If due weight be given to the definite unconformities which exist both below and above these volcanics, it seems reasonable that they be assigned either to the Upper Jurassic or Lower Cretaceous, and their origin is probably connected genetically with the revolutionary movements which resulted in the formation of the Southern Alps. If this can be determined precisely, then it will throw considerable light on the actual date of these volcanics.

(i) Rhyolites.

The rhyolites of the area are specially developed on the northern and southern flanks of the Rockwood Range, the former strip extending from near the south-west extremity to High Peak, and the latter from Rakaia Gorge (see P. T. Cox, 1925, pp. 95-97), past the Point Station to just behind Rockwood Homestead, when this strip junctions with the first and continues north-east, forming the highest part of the ridge in the elevations known as Rocky Peak and Pullwool Peak. The last named is divided from a further occurrence to the east, known as Mount Misery, by the saddle called Yorkie's Pass. The rhyolite rests either directly on the Trias-Jura beds, as at High Peak, Rocky Peak, Pullwool Peak, and Mount Misery, or with the doubtful intervention of the andesites as referred to previously. From Pullwood Peak a ridge extends to the south-west on the east side of the valley of the Upper Hororata, and on the south-east flank of Mount Misery there is an extension onwards, which is marked by a fine old beech-tree growing on an almost bare outcrop of rhyolite in position.

There are, besides, one or two occurrences of rhyolitic dykes separated from the main mass, as near Cleathing's old homestead, and on the northern and western flanks of Abner's Head and in the valley of the Wairere. These instances of dykes are quite apart from the pitchstones associated with the main mass of rhyolite.

The rhyolite and associated pitchstones are characterized by the presence of mica and garnet. They have been described, as far as the Rakaia Gorge area is concerned, by P. T. Cox, and these occurrences may be taken as typical of the area. The texture of the rock varies from a glass up to that of a quartz-porphyry, and there is the granite variety noted by Haast (1873, p. 18; 1879, p. 268) and Hurton (1885, p. 113) occurring near the headwaters of Rockwood Creek.
Although pitchstones are usually supposed to occur as dykes, there are good reasons, as noted both by Haast (1879, pp. 287-89) and P. T. Cox (1925, pp. 99-100), that some of the dyke-like masses are dykes only in appearance, and their glassy texture is due to circumstances which promoted the consolidation of flows without crystallization of the groundmass. If, however, a large proportion of the rhyolites were extruded endogenously, as suggested by S. H. Cox (1885, pp. 36-40), these pitchstones are practically intrusions, and they represent portions of the liquid rock which took on the glassy form while other exhibited a moderate amount of crystallization of the groundmass.

The most important areas of pitchstones are the following: (1) The inlier near the head of Wash Pen Creek; (2) the dyke-like mass marking the shelf on the south-eastern facing of the Round Top - Snowy Peak ridge—this may be part of one occurrence or formed of disjointed and disconnected members; (3) another dyke-like mass running from the western face of High Peak across the northerly branch of Rockwood Creek; and (4) the occurrence on the south-west side of Pullwool Peak. Although these are said to be dyke-like, I am not certain that they are actually dykes. Besides these, there are numerous small areas in the rhyolite where pitchstone is exposed. A number of these are indicated on the map.

The pitchstone occurs frequently in situations close to the contact of the rhyolite and andesite—for example, at the head of Wash Pen Creek, where there is an inlier of the following in ascending series: (1) Rhyolite, (2) pitchstone, (3) pitchstone and rhyolitic clastics, (4) andesite. The same sequence occurs on the shelf between the two branches of Rockwood Creek, and a similar series also occurs in the Mount Somers area, but in reversed order, the andesite being apparently the oldest member. All the same, pitchstone also occurs freely apart from this association, so that it cannot be looked on as an intermediate facies between the rhyolite and andesite, although the intermediate character of the analysis may suggest it. In the occurrence on Pullwool Peak, which is not obviously connected with andesitic outcrops, and is therefore either intrusive or a special facies of the rhyolite, there are numerous included fragments of an altered sedimentary (hornfels), occasional fragments of granite, and also of an andesite of different appearance from the ordinary hypersthene andesite of the area. This suggests that there may be an older andesite present, not outcrops of which are visible. Chalcedonic and calcite amygdaloids also occur in the pitchstone.

An interesting feature of the rhyolites is the frequent occurrence of slickensided surfaces over considerable lengths without any definite evidence of faulting. The surfaces so affected sometimes extend for only a few yards and then disappear without any sign of rock-movement. Occasionally they occur over a length of several chains at least, notably alongside the so-called pitchstone dykes. They seem to indicate movements in the rhyolite when it was on the point of consolidation at a time when the neighbouring masses were able to accommodate themselves to the strain without showing rupture.

The facies of the rhyolite called by Haast a syenitic granite-porphry, and called by Hutton a granite was sought for, but not found. However, slides made from the specimen used by Hutton show that this granite is almost certainly a pegmatitic facies of the rock. It is characterized by a graphic intergrowth of quartz and feldspar, like that shown by a pegmatite, and, in addition, the mineral considered by Hutton at Daintree's suggestion to be prehnite is a pleochroic mineral, in radiating groups which is almost certainly biotite. It is not tourmaline. I did not detect any garnet in the granite facies of this rock, although this mineral does occur in the rhyolite attached to the specimen. The only thing we found in our search that suggested a relationship to the specimen was pieces of rock with veinlets composed of somewhat coarse feldspar intergrown with quartz. It is possible that Haast's find might be something similar on a larger scale, and, if so, the chance of finding the rock in position is really somewhat slender.

The rhyolite occurring between Brockley Creek and the western branch of Wairere Creek presents some peculiarities. In the hand-spicemter of feldspar are plainly visible, as well as occasional inclusions of calcite stained with iron oxide. Under the microscope the rock is seen to be composed of phenocrysts of andesine up to 3 mm. in length, frequently untwinned but with higher index of refraction than that of balsam, and usually stained with oxide of iron; occasional quartz; while the base is composed of micrographic intergrowths of quartz and feldspar like that of some of the rhyolites of Gebbie's Pass. In it are also numerous flecks of biotite, occasional grains of zircon, and needles of apatite. This rock is evidently a rhyolite, but different in character from any rhyolite with which I am acquainted occurring in the area.

This rock is somewhat similar to one occurring on the ridge south of the Wairere and on the same line. It is composed of phenocrysts of andesine and occasional quartz in a groundmass composed of quartz and feldspar, the latter showing, as a rule, a higher index of refraction than that of balsam, though some has a lower index. Some of the feldspar is in laths which are twinned and have the extinction angle of oligoclase. Much biotite in pleochroic flakes occurs, and numerous grains and aggregations of iron oxides, which are no doubt derived from it. The field relations of this occurrence are entirely problematical, since the slides were made from blocks lying on the surface.
The analyses here given, made by Mr. Seelye, of the Dominion Laboratory, give an idea of the chemical composition of the rhyolites as well as of the andesites to be referred to later.

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No. 1. Rhyolite. I. 3. 2. 3. Tehamose. Brockley Creek.
No. 4. Andesite. II. 4. 3. 4. Andose. Middle Saddle.
No. 5. Andesite. II. 4. 2. 3. Dacose. Outcrop north-west of Rockwood Homestead.
No. 4 (re-calculated). II. 4. 2. 3. Dacose. As the analysis of this rock contains more than 2 per cent. of calcite, the norm has been re-calculated on a basis of the absence of calcite.

A comparison of these analyses with those of other local rhyolites—e.g., those given by P. T. Cox (1926, p. 98) and by Speight (Records of the Cant. Mus., vol. 2, p. 79, 1922)—indicates that these rocks are slightly more basic than the rhyolites of Rakaia Gorge and Gebbie’s Pass, but not so basic as the pitchstones cited by P. T. Cox from the former locality. The similarity in composition of the pitchstone from Rockwood with the associated rhyolites is worthy of note.

(ii) Andesites.

These andesites are usually grey in the hand-specimen, with porphyritic feldspars freely showing, and they very frequently contain amygdaoids of quartz and chalcedony, the latter showing a range of colour characteristic of such forms of silica. The texture of the rock as disclosed in sections varies considerably. Phenocrysts of plagioclase are very prominent, and occupy a considerable portion of the field. The groundmass ranges from a somewhat coarse pilotaxitic down to a hyalopilitic texture, in which glass dominates the other constituents. The feldspar phenocrysts range from a basic-andesine
to a medium-labradorite, an acid-labradorite being the most common type. Both augite and hypersthene appear in all slides. The feldspar laths of the groundmass are an andesine-labradorite, and in the coarser varieties there is a fair amount of pyroxene between the mesh of feldspars. Ilmenite in stumpy laths with denticulate margin is a very notable constituent of some slides, and very occasionally there is a little olivine present. Amygdaloids of quartz and chaledony of varying colours are frequent, usually filling cavities, but at times forming a mere fringe to their outside margins, and calcite amygdaloids also occur at times. The composition of an andesite occurring at the Rakaia Gorge is given in an analysis cited by P. T. Cox (1925, p. 98), and two analyses of typical rocks are given in the table on page 16. The high percentage of silica in No. 5 is no doubt due to the presence of some amount of amygdaloidal quartz or chaledony.

II. SENONIAN.

(a) COAL-MEASURES.

(See Sections Nos. 1 to 8.)

These beds are developed best in the fringe round the base of the greywacke and rhyolite hills extending from the Hororata River, through Glentunnel and South Malvern, to the Hawkins River near Sheffield. There are, in addition, outliers separated from the main area as the result of faulting on a major scale. It will be best, however, to take the beds in the undisturbed area and deal with their features first, and then consider the isolated patches in detail.

The general sequence of beds belonging to the Senonian Series is as follows, commencing from the base:

1. *Clays, sands, and conglomerates* with thin layers of coal and shale. The clays are at times almost sufficiently refractory to be called fireclays, and the conglomerates are generally characterized by rhyolite pebbles which are extremely well rounded. The sands and clays also frequently show a rhyolitic origin. The sands are frequently cemented by iron oxide, and form well-defined harder bands.

2. *Clays, shales, and coal-seams.*—This is the most prolific horizon for coal, since nearly all seams that yielded good returns have been located about this stratigraphical level. Seeing that these beds are typically developed near Glentunnel, where also most coal has been obtained, the chief coal-horizon will be referred to hereafter, in accordance with Morgan's suggestion (1920, p. 11), as the Glentunnel horizon.

3. *Sands, frequently concretionary,* the cementing-material being at times iron oxide and at others calcium carbonate, while occasionally both these substances occur. They are associated in places with fossil shells, which enable the age of the beds to be definitely determined. The most noted places for fossils are the Selwyn Rapids, Oyster Hill and Gully, and Hall’s Creek, near Mount Pleasant. The sands contain at times large calcareous concretions (septaria), with occasional shells, notably *Conchothyra parasitica.* They are glauconitic in their upper levels and are at times interstratified with clay.

4. The uppermost horizons of the sequence are more decidedly sandy, whitish quartz sands being common.

The total thickness varies, but in the Glentunnel area, where it is probably thickest, it is approximately 5,000 ft. The general strike of the beds is north-east and south-west, and the dip south-east at angles of between 10° and 20°, though occasionally it is as high as 40°.

Associated with these sedimentaries are basic igneous rocks—dolerites and basalts—some of which are flows with pyroclastic material, and others are intrusive in the form of both dykes and sills.

After this general description, different parts of the area will be taken in detail, and the sector near Glentunnel will be considered first, since more is known about it than any other.

(i) HORORATA—GLENTUNNEL—SHEFFIELD AREA.

Glentunnel AREA.

Coal was found here by Haast in 1870, though it had been known earlier in other parts of the district. At Glentunnel it has been worked continuously till now, so that, as the result of drives and bores, in addition to the evidence furnished by natural sections, a fairly accurate idea of the structure and sequence of the beds in its vicinity can be arrived at. Natural sections are furnished by the steep sides of Surveyor’s Gully, where the Homebush Mine is located, for this has cut right across the strike somewhat deeply into the down country beneath which the coal-measures lie. All the same, numerous gaps occur in the recorded sequence since the surface is covered by gravel-beds, and by soil and slip
material, so that in some parts no exposures of the underlying beds are visible. Although igneous rocks do occur, they do not interfere with the sedimentaries to any marked extent. Faulting is on a small scale, and fault-lines can only be determined by the evidence from drives, and not from any surface manifestations.

The section up the gully discloses the following sequence: Starting from the mouth, there occurs on the east side a sheet of dolerite, a small remnant of which lies on the western side of the gully. Whether or not this sheet is a flow or a sill it is impossible to say with the evidence at one's disposal, since no contact could be seen. The sheet forms the edge of the downs between Glentunnel and Coalgate, judging from exposures in the gullies which have been incised in their margin, and it extends back for nearly a mile at a maximum and forms the topmost layer on the south side of two gullies with apparently north-east and south-west alignment, one running east and the other south-west to Surveyor's Gully. Although this sheet is only exposed in a few places where the gullies have cut deep, yet it is fairly evident that it forms a capping under the soil covering of the downs over a considerable area.

It evidently lies on sands, as these are exposed on a point on the tram-line some 10 chains from the works, where they are penetrated by a basaltic dyke running in an east-south-east and west-north-west direction. This dyke has been quarried for road-metal alongside the tram-line and can be traced on the other side of the gully, where it forms a well-defined ridge. Alongside it the sands have been indurated and formed into a compact, rusty-coloured mass, while a few feet away they are rendered a chocolate brown, and seen to contain relatively large grains of sandstone.

The sands penetrated by this dyke have weathered to a brownish colour, and are probably slightly glauconitic in an unweathered condition; but there was no exposure of definite character to allow this being determined. They are underlain by clays and then by sands judging from the limited exposures farther up the gully. The latter are first seen clearly in an old drive 50 chains from the works. The strike is here north 25° east, with a south-easterly dip of 22°. The beds seen in the drive are—

1. Rusty brown sands;
2. greenish-grey sands, slightly glauconitic; and
3. dark-grey sandy clays.

About 50 chains farther on is a sandy cliff on the east side of the gully. The sands are in some cases almost pure-white in colour—e.g., in a small shallow drive—but usually they are yellowish or brown, and at times consolidated into thick irregular beds of ferruginous sandstone; two, if not more, of these are exposed on the face of the cliff. The hard bands determine the line of the scarp edge of the ridge extending north-east in the direction of Oyster Gully.

As the exposure in Oyster Gully is in close proximity to the Surveyor's Gully section, it may be considered here, especially as it serves to fill a gap where there are no outcrops in the latter section. In Oyster Gully there is a high sand-cliff on the north-east side of the gully, where sands of lightish-brown colour are exposed, their thickness being from 100 ft. to 150 ft. Capping these is the oyster-bed from which the gully is named. This is over 2 ft. thick, and composed almost entirely of black-oyster shells (Ostrea dichotoma); but a small number of lamellibranchs also occur, as well as fragments of belemnites. This oyster-bed apparently stands here in the same stratigraphical relation to the coal-measures as it does in other parts of the North Canterbury district—e.g., at Waipara and Weka Pass, and in the Trelissick Basin. Thin seams of coal occur in Oyster Gully under the sands beneath the shell-bed. This is apparently the oyster-bed referred to by Woods (1917, p. 15, first part par. 3), but there is no doubt that this bed is higher in the sequence than the seams of Deans coal-mine.

Reverting to the sequence as it is found in Surveyor's Gully, it is found that about 10 chains on from the sandstone bluff is the mouth of the drive whence most of the coal from the Homebush Mine has been won. Several seams occur here, the thickest being 7 ft.; also overlying this is another seam 3 ft. 6 in. thick; associated with them are beds of shale and sandy clay. The strike of these beds is N. 23° E., and the dip S.E. 13° S. at an angle of 20°. The shales associated with the coal frequently contain crushed stems of wood, sometimes of between 3 ft. and 4 ft. in length, and of from 2 in. to 3 in. wide. Above the coal-seam is frequently a layer called by the miners of the district "corduroy," which consists of roughly laminated argillaceous sands, the laminae being of two distinct colours of very light and dark grey material.

About 7 chains farther on from the mouth of the coal-drive is the drive whence the pipeclay and also the so-called "gannister" is obtained (see analyses, page 62). The latter is a white sandy clay, extremely variable in quality and amount. The supply from the drive is almost exhausted. The gannister outcrops in an excavation on the western side of the gully, where it appears as a whitish sandy clay, some parts very sandy, striking N. 15° E., and dipping easterly at an angle of 10°. Both strike and dip are somewhat variable, and there is a considerable irregularity in bedding. It underlies the pipeclay seam in the drive, but in the excavation it is interstratified with fireclay seams in thin bands, and also with shale and coaly material. There are as well irregular concretionary ferruginous sandstone layers, and the whole exposure here is capped unconformably with gravels composed of greywacke pebbles such as occur on the neighbouring downs. Pipeclay is also obtained in a tributary gully to the west on the same horizon, and below that is a deposit which supplies fireclay.
SECTION FLAGPOLE HILL ACROSS
N° 9, MANGA RANGE.
--- Length about 1 Mile ---

1 Greywacke 2 Conglomerate 2a Shales

SECTION FROM CAIRN RANGE ACROSS BUSH GULLY
N° 5 --- Length 2/3 Mile ---

1 Greywacke, 2 Jurassic Sandstones & Shales, 4 Coal Measures with Conglomerates.

SECTION FROM PULLWOOL PK. ACROSS
GLENROY MINE
--- Length 1½ Miles ---

1 Greywacke 2 Rhyolite 3 Coal Measures 4 Basic Intrusions 5 Gravels

SECTION ALONG BROCKLEY CREEK
N° 7 --- Length ½ Mile ---

1 Greywacke 2 Rhyolite 3 Coal Measures 4 Basic Dykes 5 Gravels

On a parallel line a little to the S.W. Coal Measures rest on Rhyolite and the Greywacke does not outcrop.

SECTION ACROSS ACHERON COALFIELD
N° 8. --- Length 200 Yards ---

1 Greywacke 2 Clay, Foreclays, Shales, etc. 5 Lower Basic Sill
2 Basic Sill 6 Dolerite Sill
3 Coal Seam 7 Terrace Gravels

W. 6

Small Sill

Big Sill

Cool Seam

RIVER

Acheron R.
This section may be continued north across the ridge which divides Surveyor’s Gully from Bush Gully. The latter runs in an easterly direction along the line of strike of the beds. On the southern side of the valley are exposures of sands, frequently cemented in layers with oxide of iron, whereas lower down in the sequence are massive bands of conglomerate, the pebbles being formed of rhyolite, greywacke, and occasional pieces of chalcedony, their source being no doubt the rhyolite hills of the neighbourhood. All the same, the percentage of rhyolite is much above what would occur had the pebbles come from the present exposures of that rock, even allowing for a difference in relief of the land as compared with that now existing.

These hard layers of conglomerate are very persistent, and determine the positions of ridges and shelves parallel to the course of the valley. They cross the stream lower down, and form a low flanking buttress to the Cairn Range (see section No. 5). In the bed of the creek below the lowest bed of conglomerate occurs a massive band of fireclay, and in the bush which gives its name to the gully are thin beds of coal, sandy shales and clays, sands, and occasional beds of rhyolite conglomerate, which can be traced up the flank of the range for a considerable distance. These sands are rhyolitic in origin, and frequently contain crushed and partially carbonized stems of trees. There is an exposure of greywacke conglomerate below the rhyolite conglomerate, and this may possibly belong to the Jurassic beds, but relying on the fact that its dip and strike are practically accordant with the Senonian beds, it seems best to place it here. These conglomerates with rhyolite continue south-west, and form well-defined outcrops at the western end of Bush Gully, and across the ridge at its head towards Whitecliffs, where they appear again on the face fronting the Selwyn river.

The principal workings of the Homebush Mine are on the eastern side of Surveyor’s Gully, about three-quarters of a mile from the Glentunnel Township. The main seam here was 7 ft. thick. This was worked for about 40 chains along the strike and about 8 chains to the dip and 9 chains to the rise, but it got thin when followed along the strike to the N.R., and developed stone in the dip. About 3 ft. above this there was a seam 3½ ft. thick, and about 40 ft. higher was a seam, known as the “Engine” Seam, 5 ft. thick. This developed stone both in the direction of the dip and along the strike, but it was followed to the dip for about 3 chains, and 8 chains to the rise, and along the strike approximately 30 chains. Unfortunately, this took fire spontaneously and was temporarily abandoned, but it probably contains the largest reserve of unworked coal in the locality. These seams are disturbed by three distinct faults, which will be referred to directly. In addition, there was another seam 4½ ft. below the 7 ft. seam, but this got stony on following it both to the north-east and to the south-west along the strike. The beds between it and the overlying seam consist of clays and shales.

On the western side of the gully the following seams were encountered. The uppermost seam worked, called the “Coronation” Seam, was 4 ft. thick where worked, but proved unsatisfactory along the strike owing to the appearance of stone, and it also thinned out to the dip. About 20 ft. below this occurred another seam, 4 ft. thick; but this was not encountered in a bore sunk 2 chains to the north-west, so it must be of limited extent. Then came what was called the “Smithy” Seam, 3½ ft. 6 in. to 3 ft. 10 in. in thickness. This was worked to the dip and became stony. This seam was probably the same as the 3½ ft. seam on the opposite side of the gully, just above the 7 ft. seam, and below it is a small 20 in. - 24 in. seam, which may pass into the 7 ft. seam, since this does not appear to the western side of gully, except possibly divided into two smaller ones. Another 3½ ft. seam was worked here as well, which varied in distance below the “Smithy” Seam. At the Smithy it was 20 ft. below, but when followed to the south-west they closed up till they were only 1 ft. apart, so that it is possible that this and the overlying “Smithy” Seam may represent a splitting of the 7 ft. seam on the eastern side of the gully, the small seam lying between the two perhaps belonging to the same bed.

Some of the small seams are noteworthy on account of their containing considerable quantities of ambrute, or fossil gum. This is met with occasionally in the thicker seams, usually near the lower margin.

By the kindness of Mr. John Deans I have been permitted to use the logs of the bores put down in the country to the south-west of the mine in order to determine whether or not there were payable seams in that direction. Unfortunately, no payable seams were located, but the nature of the country associated with the coal-seams is described so well by them that I have given a number of them in full. They show the presence of sands, sandy clays, and shales in rapidly alternating sequence, and numerous small seams of coal, none exceeding 3 ft. in thickness.

A most striking feature of the log of the bore is the great thickness of gravel met with in most of them—in one case over 100 ft. ; and this occurs not only on the summit of the flat area to the south-west of the mine, but also along the flanks of the gullies. The widespread distribution of this drift material over the whole area, even as far as Glenroy, has been noted already.

In the log of one bore (No. 9), located near the top of the gully leading down to Sheath’s Coal—an old mine on the bank of the Selwyn River, about a mile south-west of the Homebush Mine—4 ft. of dolerite was passed through. This is what might have been expected, since the dolerite is exposed on the point of the spur near Glentunnel; but, of course, outcrops on the down country between the mine and Sheath’s Coal are completely masked by the covering of gravel.
**RECORDS OF BORES AT HOMEBOUR.**

No. 1 Bore (100 yds. above little bridge on tram-line opposite big gully on the west).

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No. 2 Bore (400 yds. south-south-west of No. 1, half-way up the gully).

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No. 3 Bore (on top of hill to west of the gully and sand-pit).

Shingle to 75 ft.

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Bore No. 4 (39 chains west-south-west of the mine, 11 chains from No. 3).

<table>
<thead>
<tr>
<th></th>
<th>ft.</th>
<th>in.</th>
<th>ft.</th>
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<tr>
<td>Coal</td>
<td>1 3</td>
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<td>No. 5 Bore (on downs between the Homestead Mine and Selewyn River, on the east side of gully above Sheath's mine south-west of No. 4).</td>
<td>ft. in.</td>
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<td>Blue gravel</td>
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<td>Light-brown clay</td>
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<td>Clay and coal</td>
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<td>0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>4 9</td>
<td>0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light clay</td>
<td>1 3</td>
<td>0 0</td>
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<tr>
<td>Clay</td>
<td>7 6</td>
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</tr>
<tr>
<td>Ironstone</td>
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<td>0 0</td>
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<td></td>
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<tr>
<td>Coal</td>
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<td>0 0</td>
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<td>Sandstone</td>
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<td>0 0</td>
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<td>0 0</td>
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<tr>
<td>Sandstone</td>
<td>0 6</td>
<td>0 0</td>
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<td>Dirty coal</td>
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<td>0 0</td>
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<td></td>
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<td>Grey sandstone</td>
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<td></td>
<td></td>
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<tr>
<td>Clay and coal</td>
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<td>0 0</td>
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<tr>
<td>Clay</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Light clay</td>
<td>3 9</td>
<td>0 0</td>
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<td></td>
</tr>
<tr>
<td>Coal and clay</td>
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<td>0 0</td>
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</tr>
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<td>Sandstone</td>
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<td>0 0</td>
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<tr>
<td>Shale</td>
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<td>0 0</td>
<td></td>
<td></td>
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<tr>
<td>Light clay</td>
<td>7 6</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sandstone</td>
<td>4 6</td>
<td>0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal and clay</td>
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<td>0 0</td>
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<td></td>
<td></td>
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<tr>
<td>Shale</td>
<td>3 6</td>
<td>0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey sandstone</td>
<td>7 0</td>
<td>0 0</td>
<td></td>
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</table>
continued to the dip the coal passed into a mushy condition, but when followed to the rise the coal doubled in thickness for about 20 ft., then gradually but fairly quickly reverted to its normal thickness.

For a fault, striking E. 10° N., which had a downthrow to the north of 2 ft. 6 in. To the west of the main workings there was also another disturbance, which ran N. 10° W., and exhibited some peculiarities. For a length of about 4 ft. the seam of coal was upthrust for 4 ft., and when this disturbance was continued to the dip the coal passed into a mushy condition, but when followed to the rise the coal doubled in thickness for about 20 ft., then gradually but fairly quickly reverted to its normal thickness.

The area mined showed the presence of at least three faults, which, however, do not show any decided regularity in arrangement.

The first fault met with in the drives ran N. 30° W., and showed an upthrow of 18 in. to the north-east. It was followed by a fault which ran north-west and crossed the first near the outcrop. This fault had a downthrow of 6 ft. to the north-east. The next fault farther north-east was oriented west-north-west and east-south-east, and had a downthrow to the north of 6 ft. Farther to the north there was another fault, striking E. 10° N., which had a downthrow to the north of 2 ft. 6 in. To the west of the main workings there was also another disturbance, which ran N. 10° E., and exhibited some peculiarities. For a length of about 4 ft. the seam of coal was upthrust for 4 ft., and when this disturbance was continued to the dip the coal passed into a mushy condition, but when followed to the rise the coal doubled in thickness for about 20 ft., then gradually but fairly quickly reverted to its normal thickness.

The area mined showed the presence of at least three faults, which, however, do not show any decided regularity in arrangement.

The first fault met with in the drives ran N. 30° W., and showed an upthrow of 18 in. to the north-east. It was followed by a fault which ran north-west and crossed the first near the outcrop. This fault had a downthrow of 6 ft. to the north-east. The next fault farther north-east was oriented west-north-west and east-south-east, and had a downthrow to the north of 6 ft. Farther to the north there was another fault, striking E. 10° N., which had a downthrow to the north of 2 ft. 6 in. To the west of the main workings there was also another disturbance, which ran N. 10° E., and exhibited some peculiarities. For a length of about 4 ft. the seam of coal was upthrust for 4 ft., and when this disturbance was continued to the dip the coal passed into a mushy condition, but when followed to the rise the coal doubled in thickness for about 20 ft., then gradually but fairly quickly reverted to its normal thickness.

The area mined showed the presence of at least three faults, which, however, do not show any decided regularity in arrangement.

The first fault met with in the drives ran N. 30° W., and showed an upthrow of 18 in. to the north-east. It was followed by a fault which ran north-west and crossed the first near the outcrop. This fault had a downthrow of 6 ft. to the north-east. The next fault farther north-east was oriented west-north-west and east-south-east, and had a downthrow to the north of 6 ft. Farther to the north there was another fault, striking E. 10° N., which had a downthrow to the north of 2 ft. 6 in. To the west of the main workings there was also another disturbance, which ran N. 10° E., and exhibited some peculiarities. For a length of about 4 ft. the seam of coal was upthrust for 4 ft., and when this disturbance was continued to the dip the coal passed into a mushy condition, but when followed to the rise the coal doubled in thickness for about 20 ft., then gradually but fairly quickly reverted to its normal thickness.

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The first fault met with in the drives ran N. 30° W., and showed an upthrow of 18 in. to the north-east. It was followed by a fault which ran north-west and crossed the first near the outcrop. This fault had a downthrow of 6 ft. to the north-east. The next fault farther north-east was oriented west-north-west and east-south-east, and had a downthrow to the north of 6 ft. Farther to the north there was another fault, striking E. 10° N., which had a downthrow to the north of 2 ft. 6 in. To the west of the main workings there was also another disturbance, which ran N. 10° E., and exhibited some peculiarities. For a length of about 4 ft. the seam of coal was upthrust for 4 ft., and when this disturbance was continued to the dip the coal passed into a mushy condition, but when followed to the rise the coal doubled in thickness for about 20 ft., then gradually but fairly quickly reverted to its normal thickness.

No. 6 Bore (north-west of No. 4, in gully going up from smithy).

<table>
<thead>
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<th>ft. in.</th>
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<tr>
<td>Surface clay</td>
<td>6 0</td>
<td>Sandy clay</td>
<td>18 0</td>
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<tr>
<td>Brown gravel</td>
<td>109 0</td>
<td>Clay and bands of coal</td>
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<tr>
<td>Blue gravel</td>
<td>8 0</td>
<td>Sandy clay</td>
<td>14 0</td>
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<td>Light and dark clay</td>
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<tr>
<td>Coal</td>
<td>1 0</td>
<td>Sandy clay</td>
<td>1 0</td>
</tr>
<tr>
<td>Clay</td>
<td>1 0</td>
<td>Dark shale</td>
<td>1 0</td>
</tr>
<tr>
<td>Coal</td>
<td>0 9</td>
<td>Sandstone</td>
<td>3 0</td>
</tr>
<tr>
<td>Clay</td>
<td>3 9</td>
<td>Dark shale</td>
<td>2 0</td>
</tr>
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<td>Coal</td>
<td>0 6</td>
<td>Sandy clay</td>
<td>2 0</td>
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<tr>
<td>Light clay</td>
<td>2 0</td>
<td>Dark shale</td>
<td>1 0</td>
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<tr>
<td>Brown clay</td>
<td>7 3</td>
<td>Sandy clay</td>
<td>2 0</td>
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<tr>
<td>Clay and coal</td>
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<td>20 0</td>
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<tr>
<td>Sandy clay</td>
<td>21 6</td>
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<td>Grey sandstone</td>
<td>4 6</td>
<td>—— 207 0</td>
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No. 7 Bore (on side nearer Sheath’s Row than No. 5).

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<td>Surface clay</td>
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<td>Coal</td>
<td>0 6</td>
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<td>0 9</td>
<td>Coal and clay</td>
<td>2 0</td>
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<tr>
<td>Brown clay</td>
<td>7 6</td>
<td>Dirty coal</td>
<td>1 0</td>
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<tr>
<td>Coal</td>
<td>1 3</td>
<td>Sandy clay</td>
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</tr>
<tr>
<td>—— 200 0</td>
<td>—— 200 0</td>
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<tr>
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<td>—— 483 0</td>
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<tr>
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No. 9 Bore (near the top of the second gully on the east side of Sheath’s Row, 15 chains from No. 5).

<table>
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<th>ft. in.</th>
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<td>Dolerite</td>
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<td>Blue gravel</td>
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<td>Sandstone with shells</td>
<td>6 0</td>
</tr>
<tr>
<td>Green sandstone</td>
<td>7 0</td>
<td>Grey sandstone</td>
<td>2 0</td>
</tr>
<tr>
<td>Grey sandstone</td>
<td>13 6</td>
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<td>9 0</td>
</tr>
<tr>
<td>Brown sandstone</td>
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<td>Soft sandstone</td>
<td>67 0</td>
</tr>
<tr>
<td>Concretion</td>
<td>1 3</td>
<td>—— 236 0</td>
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Note.—The positions of the above-mentioned bores and also the details concerning the mine were kindly supplied by Mr. D. Kane. The precise positions of some of these bores, especially Nos. 6 and 7, are somewhat uncertain and the logs cannot be used for the determination of such factors as dip, &c.—R.S.
Opposite Glentunnel, on the other side of the Selwyn River, lies the long ridge known as the Harper Hills. Between this ridge and the mouth of Surveyor's Gully, and also between it and Oyster Hill, there are no exposures for fully half a mile, the basement beds being masked by the modern gravels of the Selwyn River and by those of the lower part of Wairere Creek. But on the north-west, facing scarp-slope of the Harper Hills clays are exposed, succeeded by white sands, slightly argillaceous in places, also at times very white in colour, but at higher levels stained by oxide of iron. These are succeeded by a whitish bed, which may be volcanic ash, and then by the pyroclastics and lavas which cap the hills for their whole length from the Selwyn River at Coalgate Bridge nearly to the Glenroy Saddle.

No doubt the sequence is somewhat similar between the downs near Glentunnel in the direction of the Homebush ridge or Deans Range, which is merely the extension northwards of the Harper Hills, across the gap cut by the Selwyn River between Coalgate and the Homebush Homestead.

**Section at Whitecliffs.**

The lowest part of this section consists of sands exposed in the bed of the Selwyn, upstream from the cliff, and resting unconformably on the greywackes. They show a number of small faults, which appear down at water-level. The next exposure is a bed of sandstone 4 ft. to 5 ft. in thickness, and this is followed by bands of sandstone interstratified with fireclays, and then by another bed of sandstone. At the bend of the road are fireclays, poor in quality, and then obscurity till the cliff itself is reached. The lower beds exposed here are cemented bands of sandstone from 4 in. to 12 in. in thickness, rapidly alternating with shales and fireclays. The sandstone layers are frequently stained with iron oxide. This part of the sequence, which is clearly exposed, is about 40 ft. thick. Then follows a massive bed of rhyolitic conglomerate composed of irregular layers of coarser material interstratified with finer material. On the whole, the top appears finer than the bottom. There are three distinct layers of coarser material in one place and two in others, the irregularity indicating a rapidly-changing current during deposition. The bed is about 25 ft. thick, but varies slightly, being thicker at the base of the cliff, and it rests with interformational unconformity on the underlying shales and fireclays, a frequent feature when coarse conglomerates rest on sands and clays in the same formation. The conglomerate is succeeded by 12 ft. to 15 ft. of interstratified layers of shales and sandstone, the former being occasionally carbonaceous, while the topmost layer of all consists of about 3 ft. of sandstone. Owing to the precipitous nature of the face of the cliff, it was found impossible to get precise accounts of the different layers. The gaps are partly supplied by exposures in the bed of the Selwyn, either just opposite the cliff or near the bridge. A little distance up the Selwyn is a thick bank of sandstone, which is probably the same as one of the beds farther up-stream, the change in strike to be referred to presently allowing the same bed to cross the river twice. This bed strikes N. 15° E., and dips east at an angle of 60°. It is composed of rhyolitic material, and is coarse enough to be called a grit. It also contains fragments of coaly substance in small lenses and irregular masses, with imprints of tree-stems, some of these showing woody structure. It is succeeded by layers of sandy shale, at times carbonaceous, and also by fireclays, with the same strike and dip as the hard band for about a couple of chains down-stream, and then shales again appear, but lying very flat.

At the bridge the beds consist of sandstones and sandy shales like those just referred to, but the strike is north and south, and the dip east at an angle of 40°. A little farther down-stream, behind the engine-shed, the strike is north-north-west, the dip being still high, and the beds consisting of sandy shales with hard sandstone lenses and rounded masses in the planes of stratification. The structure of the beds in the neighbourhood of the cliff is thus synclinal, the axis running approximately north-west, with a pitch to the south-east. The north-eastern wing of this syncline is the more complete of the two; in fact, the south-western wing is almost obscured by slip, but sufficient exposures exist to show the arrangement clearly, and the swing-round of the beds in the river noted previously confirms this. The south-west limb is the more highly inclined of the two; in fact, near the axis, where a certain amount of crushing has taken place, the dip is almost vertical, and the dislocation is accompanied by a number of small faults, the south-west limb being upthrown relative to the north-east.

This syncline is continued in a southerly direction along the edge of the downs to near the South Malvern Station, when the succession and arrangement of the beds are as described previously, but what its precise relation is to the rhyolite conglomerates occurring on the north and north-east face of Mount Misery is not clear. It is unlikely that faulting has taken place—in fact, there is no decided evidence of it—and the more reasonable supposition appears to be that the syncline is succeeded on the west by an antiform which is covered up by the alluvial deposits to the west of the Selwyn, and this is succeeded again by another syncline whose western wing rests on the eastern flanks of Mount Misery. The upturning of the western limb of the syncline can hardly be an effect due to proximity.
to a fault-line, since the area of disturbed inclination is too broad, and the gradual swing-round of the beds not exactly what might be expected in such a case. All the same, this movement may have been attended with faulting as a secondary feature.

On the hillside behind the South Malvern Railway-station, south-east of Whitecliffs and west of the Homebush Mine, there was once great activity, mostly in the direction of obtaining supplies of clay and so-called "gannister." Numerous drives were put in and several pits opened to supply the adjacent pottery-works. The chief outcrops show that the material was connected with rhyolite originally. There was a heavy band of conglomerate with rhyolite pebbles, and under this lay the gannister-beds, then fireclay (sample taken), and then a small coal-seam 2 ft. thick. These beds had a north-west and south-east strike, and a dip into the hills in an easterly direction at moderate angles. Further south, but above the conglomerate, was another bed of gannister. Towards the north, in the direction of Whitecliffs, occasional thin seams of coal were found under the conglomerate, and on Farr's Road a clay-pit was worked for fireclay. In the present exposures the clay is much stained with oxide of iron, and of no special value. It is reported that below the floor of the pit, now fallen in, there was an excellent seam of fireclay.

At the lower end of the road is a gannister-pit, used at the present time, where there is a hard bed of weathered rhyolitic material, coarse grained like a grit, and very hard and compact. This overlies another bed of hard rhyolitic conglomerate. These beds apparently dip to the north-west, and this step being taken.

At about 100 ft. higher in the stratigraphical sequence than Sheath's Row, but the operations were discontinued many years ago, and the only traces of the workings are the heaps of spoil between the road and the river-terrace.

About 100 ft. higher in the stratigraphical sequence than Sheath's coal are the beds occurring in the well-known locality called the Selwyn Rapids. At this point, which is situated about one-third of a mile above the bridge over the river at Glentunnel, the bed of the stream is crossed by a series of hard layers of concretionary calcareous sandstone, some 30 ft. thick in all, dipping south-east —i.e., down-stream—at an angle of 20°. The fossils are fairly numerous, though difficult to extract without the aid of explosives. The following genera have been recorded from the locality by Woods (1917, pp. 16–17), by Trechmann (1917, pp. 394–395 and 337–42), and by Wileckens (1922), who revised Trechmann's nomenclature: *Pectunculus seymuressis*, *Pecten* (Camptonectes) *hectori*, *Pinnia* sp., *Adare bentonicus*, *Lucina causterburyensis*, *Tellina* sp. cf. *Larullieri* (d'Oorb.), *Tellina* sp., *Callista thomsoni*, *Cassalia* sp., *Dosina* sp., *Cardium* sp., *Panopea maieronesssis*, *Delphinula* aff., *Natiana seymuressia*, *Natia inquata*, *Scalaria pascific*, *Archeges haustianus*, *Perissopora nova selandica*, *Conchothyla parvatica*, *Protodolium speighti*, *Tudicina ex. aff. turrida* O. Wilc., *Cryptothyris sulcata*, *Dentation monganinum*, *Dentilium* sp., *Turritellia* sp., *Chrysostoma seymuressis*, *Aloria otteri*, *Aplustrum seymuressi*, *Holodiscus (Kosmatoliter) genunatus*, *Belennites* sp.

Wileckens has recently (1924, pp. 539–40) identified *Lahilliia* cf. leusa* Wilc., a form related to one occurring in the Upper Senonian beds of South Patagonia, as being existent among the fossils collected by McKay in 1886 from the Selwyn Rapids beds.

These beds pass up into greensands, and into greyish and greenish sands with large calcareous concretions containing fragments of shells, notably *Conchothyla parvatica*, also fragments of saurian bones. They are the equivalent of similar beds above the oyster-bed in the Waipara district, and are probably equivalent to the saurian beds and concretionary greensands at Amuri Bluff. The large concretions are well exposed in a small gully coming in from the downs on the east below the rapids. At this point they are about 135 ft. higher stratigraphically than the beds exposed at the rapids.

It will be appropriate here to mention the beds occurring at Oyster Hill, a low ridge about half a mile to the south of the river, but slightly off alignment with the general strike of the beds at the river. This bed consists of sandstone with shells of *Ostrea* and other lamellibranchs, and, no doubt, corresponding stratigraphically with the similar bed in Oyster Gully above the coal. Small seams of coal have been worked to the west of the ridge in the same stratigraphical position as the seams at the Homebush Coal-mine—that is, below the oyster-bed. In fact, I can say definitely that I know of no coal-seam in this area which occurs higher in the series than the oyster-bed; they are all below it.

The beds here have a fairly steep dip, and this, with the departure from the true alignment of the beds at the rapids, suggests that the country between—now completely masked with terrace and present-river gravels—has experienced some deformation or dislocation. This may be either of faulting, in which case the fault would follow the general direction of the river, with a downthrow to the north, assuming it is a normal fault, or there exists a fold on the same general line as that near
26

the Whitecliffs Railway-station which gradually peters out down-stream but has not quite reached
vanishing-point by the time the Selwyn Rapids are reached.

A number of fossils have been collected from this bed, as recorded by Woods (loc. cit., pp. 16-17)
and Wilckens (loc. cit., pp. 26-27). They comprise the following: *Trigonia pseudocucumisata,
*T. hanetiana, Ostrea sp. cf. dichotoma Bayle, *Pecten* (Camptonectes) hectori, *Lucina canterburiensis* ?,
*Dosinia* sp. 1, *Panopea malvernensis*, *Conchothyra parasitica*, *Hoploparia* 1.

**Bush Gully to Sheffield.**

The coal horizon extends north-east from the Homebush Mine along the ridge on the south side
of Bush Gully towards its junction with the Waianainiwha, and considerable workings occur near
the mouth of that gully. At one place a seam 18 ft. thick was exposed, but on following it to
the north-east a band of stone in the coal increased in thickness, and the seam caught fire and
was abandoned. A small amount of coal is being won at the present time from smaller associated
seams, the following sequence occurring:—

1. Coal-seam, 3 ft. thick.
3. Coal-seam, 5 ft., on fire. This seam has thinned considerably from where it was first worked,
   the exposure being 18 ft. thick.
4. Sands, clays, &c., 50 ft.
5. Coal-seam, 6 ft., but with two partings of stone; not worked.
6. Clay, 2 ft.
7. Coal-seam, 3 ft.
8. Clays and sands, 35 ft.
9. Fireclay, 6 ft.
10. Coal-seam, 5½ ft., with stone band about 1 ft. interstratified, and a stone band at bottom
    —about 4 ft. of workable coal.

The succeeding beds cannot be determined, owing to the covering of surface material, but they
no doubt pass up into the sandy beds encountered in Oyster Gully. Between this spot and Surveyor’s
Gully a number of prospecting-adits have been driven in the hillside in order to pick up, if possible,
a payable seam of coal; but the largest seam encountered was only about 3 ft. thick, and that apparently
did not warrant opening out. All the same, the thickness of seams varies rapidly along the strike,
so that an unpromising seam may turn out well, just as a promising seam may thin out and disappear
when traced away from the outcrop or exposure in a prospecting shaft or drive. The seams also
apparently thin out when traced to the dip; but such seams may increase in thickness again. They
have not been followed sufficiently far to find out whether this is so or not. The following are the
logs of two bores sunk on the northern side of Bush Gully, approximately on the line of the coal:—

**No. 1 Bore, Bush Gully.**

<table>
<thead>
<tr>
<th>Ft. in.</th>
<th>Ft. in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface clay</td>
<td>8 0</td>
</tr>
<tr>
<td>Blue clay and gravel</td>
<td>11 0</td>
</tr>
<tr>
<td>Conglomerate</td>
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<td>Brown sandstone</td>
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<tr>
<td>Coal</td>
<td>0 9</td>
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<tr>
<td>Yellow sandy clay</td>
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</tr>
<tr>
<td>Grey sandstone</td>
<td>6 0</td>
</tr>
<tr>
<td>Grey sandstone with clay partings</td>
<td>3 0</td>
</tr>
<tr>
<td>Light-brown clay</td>
<td>18 6</td>
</tr>
<tr>
<td>Coal</td>
<td>1 0</td>
</tr>
<tr>
<td>Brown clay</td>
<td>2 6</td>
</tr>
<tr>
<td>Grey sandstone</td>
<td>4 0</td>
</tr>
<tr>
<td>Brown clay</td>
<td>1 0</td>
</tr>
<tr>
<td>Coal</td>
<td>2 9</td>
</tr>
<tr>
<td>Brown clay and coal</td>
<td>1 0</td>
</tr>
<tr>
<td>Brown sandy clay</td>
<td>15 3</td>
</tr>
<tr>
<td>Brown clay</td>
<td>2 0</td>
</tr>
<tr>
<td>Brown clay</td>
<td>3 0</td>
</tr>
<tr>
<td>Brown clay</td>
<td>5 6</td>
</tr>
<tr>
<td>Grey sandstone (gave 2 gal. water per minute)</td>
<td>10 6</td>
</tr>
<tr>
<td>—</td>
<td>108 0</td>
</tr>
<tr>
<td>Sandy clay</td>
<td>7 0</td>
</tr>
<tr>
<td>Soft grey sandstone</td>
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<tr>
<td>Sandy clay</td>
<td>9 0</td>
</tr>
<tr>
<td>Concretion</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Brown clay</td>
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</tr>
<tr>
<td>Dirty coal</td>
<td>2 6</td>
</tr>
</tbody>
</table>

**No. 2 Bore, Bush Gully.**

<table>
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<tr>
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<tbody>
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<td>5 3</td>
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<td>2 0</td>
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<tr>
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<td>4 0</td>
</tr>
<tr>
<td>Brown sandy clay</td>
<td>13 6</td>
</tr>
<tr>
<td>Coal</td>
<td>2 6</td>
</tr>
<tr>
<td>Brown clay</td>
<td>1 0</td>
</tr>
<tr>
<td>Dirty coal</td>
<td>2 0</td>
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<td>1 9</td>
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<tr>
<td>Brown clay</td>
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<tr>
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<tr>
<td>Stone</td>
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</tr>
<tr>
<td>Dirty coal</td>
<td>1 6</td>
</tr>
<tr>
<td>Brown clay</td>
<td>9 6</td>
</tr>
<tr>
<td>Brown clay</td>
<td>306 0</td>
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FIG. 1.—Stripped Surface of Greywacke on the Southern Slope of Abner's Head.
Cairn Range and Flagpole Hill in the distance.

FIG. 2.—Lower Part of Stripped Surface Leading up to Abner's Head.
Cairn Range in the distance on the left, Jimmy's Knob in the centre middle distance: the landscape on the left formed from coal-measures resting on greywacke. This is almost a continuation of Fig. 1.
A hard concretionary band determines the ridge running south-west from near the coal-mine to the head of Oyster Gully, and this continues on to the same bed in Surveyor’s Gully at a higher stratigraphical level than the coal horizon. On the opposite side of the gully on the southern flank of Cairn Range is the continuation of the beds described previously as occurring in the bush at the head of this valley. They follow along the southern side of a tributary valley coming in from the north-east, the line of this valley following practically the junction of the Senonian and Cairn Range beds. The former continue to the north-east along the western side of the Waianianiwha Valley, covering a triangular patch of ground of considerable size between the road and the south-eastern angle of the Cairn Range. Where these beds abut on the flanks of this range they have a dip of approximately 20°—i.e., parallel to the stripped surface which forms its south-eastern face.

The arrangement of beds occurring in Bush Gully continues north-east for some distance, but when the eastern end of the Cairn Range is reached there is a slight change in the direction of the strike, which becomes more east and west and follows the line of a small stream which rises on the eastern end of the range and joins the Waianianiwha about half a mile from the forking of the roads. The stream for a considerable part of its course is practically on the strike of the beds, which rest at an angle of about 25° on a surface of greywacke.

The lowest bed exposed consists of a conglomerate composed of pebbles of rhyolite, pitchstone, and greywacke in a fine-grained matrix; then sandy shales, sometimes micaceous, but stained rusty or ochreous-brown, very well laminated, and with layers of carbonaceous material; succeeded by a heavy band of ferruginous sandstone and by a rhyolitic grit. The last-named may be a continuation of the sandstone, but it is difficult to determine the point exactly owing to the limited and discontinuous exposures afforded by the locality. In one or two places these beds had been driven on in the hopes of striking coal, but the result was disappointing. In any case, the horizon is too low to expect to get payable seams.

The former extension of these beds across the Waianianiwha Valley is indicated by the well-preserved stripped surface on the south side of Jimmy’s Knob, and farther on they occur under the veneer of soil and link up with the coal-measures occurring near Sheffield. This is not the only line on which they occur. The southern face of Abner’s Head and its westerly extension presents a beautifully preserved stripped surface, especially towards its eastern end, where it has been but recently uncovered, and this landscape feature is preserved on the northern side of the Waianianiwha Valley, towards Pig Saddle (see Plate No. 1 and the sketch facing page 2). This suggests the presence of a line of fault following along the northern face of the Cairn Range behind Jimmy’s Knob.

The conclusion as to its origin deduced from the landscape form is confirmed by the presence on the south side of the valley, about three-quarters of a mile from the junction of the roads, of an outlier of coal-measures. This forms a very narrow strip, about half a mile in length, striking east and west and dipping south at low angles, of beds comprising ferruginous shales, sandy clays, and concretionary calcareous sandstone. These have certainly been faulted down from their true position. Further, there is an extension of the main development of measures in the valley behind Jimmy’s Knob, along which the road from Sheffield follows, as if a splinter had been dragged down at the end of a diminishing strike-fault. The valley of the small stream along which the road passes has been determined by the line of fault, and the stream now follows approximately the contact of the weaker overlying beds and the subjacent greywackes on the north side of the road. This fault-line would follow along the north side of the Cairn Range, junctioning with the Mount Misery—Cairn Range fault, but on following the line farther north-east past Jimmy’s Knob it petered out and the covering beds belonging to the Abner’s Head, and the Jimmy’s Knob stripped surfaces gradually merge into one another before they reach Sheffield.
Further west, south of the occurrence of sandstones and shales just referred to, there is a valley running east and west whose conditions suggest that the main fault following along this valley had subsidiary faults alongside it; but there is no remnant of coal-measures here to confirm an inference drawn from surface features.

Other remnants of the covering beds may occur higher up the valley, but the veneer of gravels masks the surface, especially where the valley expands towards the west, so that there is no obvious connecting-link between the outliers just referred to and the Hart’s coal area, concerning which more detail will be given later.

From the south-east face of Jimmy’s Knob the beds are continuous over the ridge into the watershed of the Hawkins River, but few exposures occur owing to the gentle flowing outlines and the covering of high-level river-gravels similar to those occurring near Glentunnel and elsewhere. There are exposures of ferruginous sands and concretionary ferruginous sandstone in a small valley leading down past Mr. Douglas Duans’s house, and judging from the occurrence of rock-fragments lying on the surface the latter bed continues north-north-west along the line of the gully towards the saddle from which a small valley leads down towards Sheffield. Nearly all the country to the east is masked with gravels.

From the saddle the coal-measures continue round the end of the eastern extension of the Abner’s Head ridge in the direction of the Hawkins River, lapping the lower slopes and gradually getting lower as the beds are followed west, so that they apparently peter out or become invisible about half-way between the Sheffield and the Annat crossings of the river. Right down on the greywacke the beds consist of a conglomerate in somewhat massive layers, the pebbles being almost entirely of greywacke—I recognized no others in this sector, although they occur elsewhere to the west—and they are sub-angular in shape, which indicates that they had not come from far. These conglomerate beds dip in accordance with the slope of the underlying surface of greywacke, and in places form only a thin veneer, so that it is likely that occurrences have not been detected, and that these Cretaceous beds extend farther west than is at present apparent.

Over these lie beds more definitely rhyolitic in origin. These are well developed along both sides of the valley leading down to the bridge over the river near Sheffield, and they have been worked as sources of clay in one or two places. One of these is on the eastern side of the road, but the most extensive workings lie to the west.

At Bradshaw’s (Austin’s) clay-pit the beds consist of sand, slightly argillaceous, evidently of rhyolitic origin, succeeded in a downward direction by shale 20 ft. or more in thickness; dark sandy shale, 2 ft.; alternating layers of clay and sandy clay, 6 ft.; sand, slightly argillaceous, at bottom of drive (sample taken); and, underneath, various seams, 3 ft. to 4 ft. in thickness, interstratified with clays, 9 ft. (John quarryman). These beds dip 1 in 12 to the south-east and underlie the coal-seams formerly worked. They cannot be far above the greywacke surface on which these beds have been laid down.

In the older workings, now fallen in, there appear at higher stratigraphical levels than the present drive alternations of sands, pure clays, clays with very fine sand. Some of the bands are stained with iron oxide, sometimes in sufficient quantity to cement them into hard layers, and then again this iron oxide tends to segregate till it forms an almost pure limonite; the clays form a minor proportion of the material. On some of the layers there is an efflorescence of alum. The sands show themselves to be composed of quartz-grains, but there is a considerable amount of interstitial material which is either feldspar or material derived from the decomposition of feldspar, and indicates that these beds had a dominantly rhyolitic origin.

The coal-seams occurring above these rhyolitic clays were worked as far back as 1861, and an account of them is given by Haast (1872, pp. 39-40). They were all small, the largest 2 ft. 8 in. thick, the six others ranging from 2 ft. down to 11 in. They were separated by beds of fireclay and micaceous shales. The upper set dipped south-east at an angle of 19°, while the lower dipped east-south-east at about the same angle. Lindop (1887, pp. 19-20) mentions two seams—one 4 ft. thick with a band of fireclay in the middle up to 3 ft. thick, and another seam 20 in. thick. He says that the dip was east; but a good many of Lindop’s observations as to direction were very rough, so that Haast’s record is more probably correct. For many years there has been no work carried on, except in the most casual manner, and the drives have fallen in, so that they cannot now be examined.

**South Side of the Selwyn River.**

On the south-west side of the Selwyn River the stratigraphical series is very similar to that up Surveyor’s Gully, the most characteristic features being the occurrence in a bed of sandstone of oyster and other shells at Oyster Hill (referred to above), the paucity of coal-seams at the Glentunnel horizon, and the great development of the beds derived from rhyolite between this horizon and Mount Misery. Sections of this are furnished by two creeks coming from the slopes of this mountain, the more...
northerly one, Munro’s Creek, which runs past the old Mount Misery Homestead, once owned by Mr. George Harper, giving the following sequence, which is fairly complete in its lower parts, the beds, in descending order:

1. Argillaceous earthy shales, at mouth of the creek, dipping south-east 5° to 10°.
2. Concretionary sandstones.
3. After an interval of a few chains,—
   b. Fine sandy conglomerate.
   c. Ferruginous shales with indistinct plant-remains.
4. Just below the site of the old homestead is—
   a. Rhyolite conglomerate, 35 ft. thick, and dipping south-east at an angle of 20°, a dip which is maintained to the base of the section.
   b. Coaly shale with thick masses of conglomerate, and below this a succession of hard resistant conglomerate beds alternating with soft sandy shales.
   c. No contact with the rhyolite is visible. Low down in the series, close to the rhyolite, is the best show of coal, but it is neither pure enough nor thick enough to work. Numerous coaly masses occur in the conglomerate which point to drift material as their origin.

The main branch of the next creek farther south-west comes direct from Mount Misery, but it receives two tributaries on its right bank which come from the vicinity of the lone beech-tree, which is such a characteristic feature of the landscape on this side of the mountain. The tree is growing on solid rhyolite, and from it runs a rhyolite ridge in a north-east direction between the two tributaries. On the outside of the one farthest south-east the rhyolitic sedimentaries are developed, the stream flowing along the junction of the original and the derived rocks. Streams also run down across the strike of the beds from the neighbourhood of the tree towards the Wairere Valley, cutting at right angles the low scarp ridge formed by the sandstone on the line of the beds at Oyster Hill.

The rhyolitic clastic material consists of conglomerates, occasionally very coarse in texture, with a fine-grained matrix, the rounded boulders of rhyolite ranging up to 10 in. in diameter, inter-stratified with layers of finer material, usually very white in colour but sometimes stained with oxide or iron, which forms the cementing-material of some of the finer more consolidated layers. The strike is north-east and south-west, and the dip south-east at angles of approximately 15°. In the main stream, right against the slopes of Mount Misery, is a rhyolitic breccia, also containing rounded pebbles of the same material, resting unconformably on a surface of solid rhyolite inclined towards the mountain, but not showing any decided planes by which its dip could be determined. This appears to be a clastic bed lying right down at the base of the series, resting on an old Cretaceous surface still maintaining certain irregularities which had not been completely reduced when deposition of the Cretaceous sediments commenced.

No payable coal has been found in this locality, although several drives have been put in—one into solid rhyolite. Why it was done is uncertain, except that there was a little carbonaceous shale outcropping on the summit of a spur immediately over the point where the drive was made.

**The Brockley-Glenroy Area.**

This area forms the south-west portion of the Malvern Hills coalfield, and occupies the down country to the south-east of Pullwood Peak and its outlying rhyolite spurs. It is drained by tributaries of the Hororata, and also by the headwaters of the Wairere Stream, which runs north-east to join the Selwyn opposite Glentunnel. Throughout this area outcrops are rare, and occur only in the beds of streams, but there has been considerable mining activity in the past, and some records exist of the beds cut in the old drives; most of them have fallen in or are otherwise impracticable at present.

The general succession of beds appears to be similar to that in the Glentunnel area. Starting at the base, resting unconformably on the rhyolites of Pullwood and the south-westerly spurs of Mount Misery there is the following general sequence (see Sections 6 and 7):

1. Rhyolite conglomerates, grits, and sands, with occasional beds of coal and fireclay.
2. The main coal horizon, with seams of fireclay, sand, shale, &c., corresponding to the Glentunnel horizon.
3. Sands and clays, the former occasionally concretionary and at times calcareous, with well-developed beds of black oyster lying over the coal as in Oyster Gully. Some beds at this level show a resemblance to the Selwyn Rapid beds, as occurring in the Selwyn River at the typical locality.
4. Sandy beds, with clays in relatively small proportion.

The whole is capped unconformably by gravel-beds which mask the surface of the country and prevent its complete examination. The beds are penetrated by intrusions of basalt, dolerite, &c., which have produced important changes in the strata associated with them.
The lowest beds of this series are developed on a line running north-east from the Hororata River along the flanks of Pullwool Peak to Yorkie's Saddle, which they cross, and thus connect after a very slight break—perhaps with none at all—with the coal area north-west of Mount Misery, to be described hereafter. In general, the coal is best developed between the rhyolite and a massive dolerite dyke which has changed the character of the coal materially. The coal was mined at numerous points between the dyke and the rhyolite, and was found in almost all cases to dip at high angles to the north-west, the change in dip being partly due to the dislocation and deformation produced by a wedge-shaped intrusion (see Sections 6 and 7), although it is possible that the contact with the rhyolites may be a fault contact, since the same dip inward into the hill occurs in places where no dyke is visible. This would apparently imply that the fault was an overthrust from the north-west. The evidence for this becomes more decided as the beds are traced along the strike towards the Hororata River.

In some cases the drives were put in from the land surface between the dyke and the rhyolite, but others penetrated the dolerite as well. One of the most determined workings was made at the head of Brockley Creek, where the dyke was cut by the drive, and the following record of the beds encountered is given by Evans (1899, p. 558):—

1. Dolerite, about 300 ft.
2. Fireclay (so called), 7 ft. 10 in.
3. Greystone, 5 ft. 7 in.
4. Plumbago, 4 ft. 6 in.
5. Anthracite, 2 ft. 6 in.
6. Ordinary coal-measures, about 130 ft.
8. Measures, 12 ft.

The drive continued beyond this point, but owing to a fall in the tunnel no coal could be taken from the inner end.

Dr. Evans in this paper notes the effect of the dyke on the siliceous clays, baking them into porcellanites, and also the alteration of the brown coal into plumago and anthracites.

Some time after this drive was put out of commission another was driven at a higher level. The dyke was thinner at this level, and the coal-seams were cut more readily. An examination of the beds cut in the drive led me to conclude that as a result of the intrusion the beds between it and Pullwool had been bent up into an anticline, so that the same seam or seams were cut twice in the drive, one near the dyke and the other farther away. As a result it became possible to note the effect of the dyke on the seam near it and farther away, and to see the progressive decline in metamorphic effect depending on distance. Near the dyke the brown coal has been converted into an anthracite or mineral coke, while farther away the coal could be described as an altered brown coal. Quite close to the dyke one of the thin seams has been converted into graphite, and a little farther away the clay has been burnt and hardened into a prismatic porcellanite by the dyke. This drive fell in many years ago and cannot be examined, but the record of the sequence in my notebook is as follows:

(a) Dyke, 6 ft. thick, cut 20 yards from entrance to the drive.
(b) Altered sandy shale, 18 ft., converted into porcellanite, with graphitic facies on the edge next to the dyke. The porcellanite shows prismatic jointing as an effect of heat.
(c) Main anthracite seam, 4 ft., striking E. 10° N., changing to east-north-east; dip vertical.
(d) Shales slightly altered, with anthracite 10 in., and altered coal 10 in.; with southerly dip.
(e) Same altered coal, 10 in., with northerly dip of 30°, on the other wing of the anticline.
(f) Sandy clays, thickness ?, with northerly dip.
(g) Altered brown coal (the "Brockley" Seam), 3 ft. 4 in., with northerly dip.

When the record of this drive is compared with the one given by Evans it will be recognized how much thicker the dolerite intrusion is in the lower level. It is therefore wedge-shaped in form, and the forcing-up of this mass would thus account for the position of the measure between it and the rhyolites of Pullwool Peak. The conditions of other drives more to the south-west are referred to by Cox (1883, pp. 57-58) and by Lindop (1886, p. 17), specially the latter, who refers to the two seams—viz., the anthracite near the dyke and the altered coal from 33 ft. to 45 ft. farther off—and also to the fact that in one the drives there is a reversal of dip of the coal-seams similar to that recorded in the drive examined by myself, which probably confirms my conclusion as regards the anticlinal arrangement.

The coal-measures extend as a continually narrowing band to the north-east right to the summit of the pass on the north-western side of Mount Misery, where for a distance of about a mile they rest...
on their western edge on greywacke. This is inferred from the presence of "gannister" beds in a creek coming from the west and crossing the track about half a mile from the summit of the pass, as well as from blocks of concretionary ironstone lying on the surface; and this evidence is supported by the form of the pass itself, where a well-defined ledge occurs which merges into that where the coal occurs farther south-west near the Brockley Mine. In all probability the basaltic intrusion continues nearly up to this point, since on the line of the dyke there occur in places numerous pebbles of basalt, continuing right up against the western slopes of Mount Misery. However, no rock of this nature was seen in position north-east of that recorded in the drives, but it does definitely outcrop in several places when traced to the south-west.

The sedimentary beds associated with the coal are those mentioned in the records of the drives, and overlying them in places are concretionary sandstones and material derived from rhyolite. These continue, judging from the presence of a well-defined buttress to the rhyolites along the south-western extension of Pulwood Peak, right to the Hororata River above its greywacke gorge, and above the junction of the river with Washpen Creek. The coal was formerly worked on the south side of the river a little above water-level, but the workings have fallen in. I was told by the miner who formerly worked the coal that it was an ordinary lignite, and lay very flat, dipping south-east 1 in 4, but that it was difficult to work and the amount of coal extending to the rise was negligible. An attempt has recently been made, but unsuccessfully, to work the coal on the north side of the river at this point. The beds here consist of fireclays, ordinary clays, and starchy sandy clays (corduroy), passing up into rhyolite conglomerate, and with them are associated irregular seams of coal. All are much contorted and dislocated, dipping at high angles to the north-west, and the coal is crushed and changed, but whether this is the result of pressure due to faulting or due to an intrusion is difficult to say. Since the old miner said that the coal in immediate proximity on the other side of the river was a lignite, in all probability the change was due to faulting. Basic rocks, probably intrusions, do occur close by, and they may have been responsible for the change, but it is difficult to understand why they did not change the lignite to which they are in close proximity.

These coal-measures can be traced along the hillside in a north-easterly direction, so that this horizon corresponds with that at Brockley, and the intrusions belong probably to the occurrences developed at Brockley.

Coal-measures also occur round the corner of the hill towards Rockwood, but they have been much disturbed by slip, and may belong to beds occurring in the vicinity of the Rockwood Homestead, and not to the Brockley line. The whole occurrence is not promising for the existence of thick seams of coal, and is very similar to that occurring at the same horizon—that is, close down on the basement here—elsewhere in the field.

Lower down the Hororata, opposite its junction with Washpen Creek, occurs a small inlier of greywacke, the beds striking north-east and south-west and with a vertical dip. On the greywacke rests a coarse conglomerate dipping south-east 12°, the pebbles being composed chiefly of greywacke, with occasional rhyolite, and rare andesite. Where this really belongs appears to me uncertain. It may represent a basal bed of the Cretaceous Series, or it may be an upper bed, or perhaps it may even be a part of the veneer of gravel which covers the down country and locally shows a tilt, and would therefore be the equivalent of the Kowai gravels of North Canterbury.

A few chains farther down-stream the river has cut through beds of the coal-measures of an horizon corresponding with the Glentunnel beds. In the bed of the river and on its steep banks are exposed carbonaceous shales with at least one seam of coal, 3 ft. 6 in. thick, and lower down still are sands with concretions and fragments of shells of the Selwyn Rapids horizon. Haast reports the presence of several genera, but I have not had an opportunity to collect here. The exposure is, however, very limited in area, since river-gravels mask the surface, and as there is little coal above water-level, it has not been worked. About a mile north-east of this outcrop, in a gully eroded in the downs, is a seam 8 ft. to 10 ft. thick which has been worked for several years and still gives excellent promise (see Section 6). This is known as the Glenroy coal area. The coal is obtained by means of a level drive, 3 chains in length, running across the beds in the direction of the rise, from which a level has been driven for 30 chains north-east along the strike, and then there is another level parallel to the main one running for the same distance and 8 yards from it. A considerable quantity of coal has been taken from this area, above the main level. No development or prospecting work has been done in the direction of the dip, and the coal still maintains its character at the end of the 30-chain level, so that a very large amount of coal, some hundreds of thousands of tons, is still available, especially as there is promise that the seam extends considerably farther along the strike to the north-east.

One feature of this mine proved disappointing. It was supposed that the coal would continue up from the main level almost to the surface of the ground; but there was a covering of gravel 30 ft. thick, as is disclosed in a ventilating-shaft, so that the conditions closely resemble those obtaining on the downs near the Homebush Mine.
The coal is a lignite, and is, as a rule, very solid, but the drive is crossed in many places by narrow bands of crushed material which appear to be connected with the joint system, as well as by belts where the coal is crushed and useless for present commercial purposes, the latter, no doubt, connected with fault-systems.

The main geological features of the locality are as follows: The strike of the beds is N. 60° E. and the general dip 25° to 30°. In the entrance drive the following succession of beds is encountered from the main coal-seam, in ascending order:

- Coal, 8 ft. thick, dipping south-east 13°-15°.
- Sandy clay
- Fireclay, thin seam
- Coal, 1 ft.
- Sandy clay
- Fireclay, 18 in.
- Coal, 3 ft.
- Loose sand, 10 ft.

"Corduroy" measures with thin seams of coal, 150 ft.

In the level to the north-east the thickness of the coal is 10 ft. 6 in. with a fireclay above it 16 in. thick, and then a fireclay a 3 ft. seam of coal with sandy roof, as in the entrance drive. The beds are regularly running 20 chains north-east, and was discontinued in that direction owing to meeting with gravel, no doubt part of the heavy coating which caps the downs in the neighbourhood. The estimated thickness of the gravel roof at the end of the level approaches 100 ft. A beginning has been made to extract the coal in the pillars to the rise.

The floor of the seam is not level, but interfered with by rolls, which usually show little faulting. Undoubted faults of small throw do exist, and in the top level there is a strike fault (precise direction N. 65° E.) with an upthrow of 4 ft. to the north-west, the throw taking place in two steps each of 2 ft. about 3 ft. apart, with a slight roll between them. Between this and the main level there is another strike fault with an upthrow of 15 in. to the north-west.

The joint-system of this coal-seam merits special reference. Towards the entrance to the level the coal is intersected by planes whose directions run N. 10° W., along which the coal is crushed. The direction is not constant even here, since it swings round at times till it runs N. 30° W., and occasionally it swings farther still. Although these are associated with broken coal, there is apparently no displacement. The dominant joints (i.e., "backs" of miners) are parallel to these bands, and these are sometimes exceedingly well defined with bright lustrous surfaces, which are as a rule plane, but somewhat curved. Another set of joints has developed at right angles to these.

Farther in the level the direction of these planes changes more across the seam till it is at times at right angles to the strike. The perfection of the jointing is maintained, as well as its orientation, parallel to the planes along which crushing has taken place. I had thought that the change in the nature of the coal along those joints might have been due to the effect of water soaking in from the surface along a fairly easy path, but there is no sign of decomposition of the neighbouring coal, and most of the joints are clearly and definitely cut. The whole circumstance suggests inapparent movement as the cause of the crushed bands, and from the association of these with definite joint surfaces, it is credible that the latter owe their presence to the same cause. The variability of direction is against their being attributed to some telluric cause, which has affected in a regular way wide areas in other parts of the world, as has been suggested by some authorities. In the Homebush Mine the jointing is very regular, the backs running north and south, and the ends at right angles thereto—that is east and west. In this mine they have no relation to the faults. In the year 1922 I circularized some of the mines in the South Island as to the nature and direction of the jointing, but got variable answers. From the Reefton Coal Co.'s mine at Reefton, Knight's mine at Nightcaps, the Blackball Mine, and the Kaitangata Mine, the jointing was variable, and showed little or no relation to the strike of the seams or to the faulting; but in the Millerton Colliery it runs regularly north and south, except in the faulted areas, where it is parallel to the faults. In the Linton Coal-mine, Ohai, the directions are—backs are E. 12° S., and the ends N. 14° W., the direction of the former being at right angles to the strike; also, in this mine no extensive faults have been met with, but steps are crossed regularly running parallel with the strike. The mine-manager of this mine remarks that the field is very regular, and that all rise places are directed by the backs, and the bearing all through the mine is uniform.

The horizon of the Glenroy coal when followed north-east coincides with that of seams in the adjacent Wairere Creek, about a mile away, where a seam fully 4 ft. in thickness is exposed. I understand that one reason for the abandonment of this seam was the large amount of sulphur that it contained. The beds on this line are affected by a dolerite sill which appears on the slopes of the downs south of the creek, crosses it at a picturesque waterfall, and continues for over half a mile in
a direction N. 55° E. and ends in all probability; but another sill occurs a few feet away to the south-east, offsetting the original sill by that distance—it may be a splinter of the main sill—and this continues for another quarter of a mile into the creek west of Hall's Creek. In this creek a waterfall is formed, where a dyke 12 ft to 15 ft. through crosses, but its orientation is somewhat different, being E. 5° N.

The first-mentioned sill has been cut by a drive in several places, but some of these are not now negotiable; in one which could be entered the sill was 20 ft. thick, and it may be thicker elsewhere. In addition to these intrusives, there is another sill about half-way between the Glenroy Mine and the Old Brockley Mine, forming a prominent ridge, and this may continue on the same line, since a sill 8 ft. to 10 ft. thick of similar lithological character is found in the creek coming from the main Brockley Mine, this I have called for convenience Brockley Creek (see Section No. 7). Associated with this sill at higher levels stratigraphically are sands and fireclays, but below it is an interesting greywacke outcrop. This is exposed in the bed of the creek for about 10 chains, and it no doubt extends for a considerable distance to the north-east under the covering of soil; and it also extends to the south-west, where it is covered with rhyolite in position. This rhyolite is penetrated by a rhyolite dyke, which appears also cutting the greywacke in the creek and strikes north-east. The greywackes and associated slaty shales strike variously north-east and north. The overlying rhyolite covers a considerable area to the south-west, extending as far as Wairere Creek, judging by the boulders on the surface; and the occurrence of rhyolitic boulders closely associated with the Glenroy sill suggests that the rhyolite, and therefore in all probability the greywackes, continue south-west at but little depth, and thus the latter junctions under a thin cover of soil with the inlier of greywacke in the Hororata.

All along the line of the first-mentioned sills and the dyke old workings occur, the drives being put in through the sills, as a rule, in order to cut an altered coal-seam on the under side. It has been assumed that the igneous rocks are sills and not flows, although there is no positive evidence owing to the covering of soil and surface debris of the presence of altered rocks above them; but their isolated position without attendant tuff beds, the texture of the rock, and the fact that undoubted basic intrusions of similar lithological character do occur in the vicinity makes it advisable to regard them as sills and not flows. Their effect on the associated lignite was noted by Cox (1883, p. 57).

In Wairere Creek the coal-measures exposed consist of rhyolitic material, gannister beds, sandy shales with streaks of carbonaceous matter and carbonized stems, dipping south-east at an angle of 30°—i.e., parallel with the sill. Near the track to the Old Brockley Mine the sequence, exposed on the surface and in the drive which was entered, is as follows: Conglomeracy iron-stained sandstone exposed in thick masses on the hillside, clays, sill 20 ft. thick, then altered coal, beyond which the drive had fallen in. Cox (1883, p. 58), says there are two seams here—one 4 ft. and the other 2 ft. dipping towards the flat, the former an altered coal and the latter an anthracite. Cox does not say which is nearest to the volcanic rock, but one may infer that the thin seam is, judging from the degree of change as recorded in the analysis.

In the creek farther north crossed by the dyke considerable amount of working must have been carried on, judging by the size of the spoil-heaps, but there can have been little to show for it all. Below the dyke are yellowish ochreous sands interstratified with dark carbonaceous sandy shales and then sands continuing to the dyke, in contact with which the beds are changed to a white sandy pum, while about 3 chains above the dyke is an exposure of fireclay, 15 ft. to 20 ft. thick. The workings along this line are evidently all of them in proximity to the Homebush horizon.

Higher in the sequence the beds consist of sands, stained yellowish brown with oxide of iron; greyish sands; and sandy clays; but the exposures are rare, and the complete series cannot be made out. Occasionally hard concretionary bands of sandstone determine the position of weak scarp ridges in this sector of the field. In general the main Wairere Creek and its tributaries cut across these at right angles, as in the case of the sills, and the subsequent streams develop with marked persistence in the direction of the strike in the soft beds interstratified with these hard beds.

I have considered the possibility that the repetition of the coal-bearing horizons in the Brockley-Glenroy area may be due to strike-faulting, and have decided against it. There does not appear to be any break in the sequence in the country to the east of the Glenroy Mine, at the head of Wairere Creek; though the wide severance of the outcrop and the coming-in of the greywacke between the two outcrops in the Hororata and of the rhyolite and greywacke in Brockley Creek is suggestive that some dislocation may have taken place, increasing in amount on going south-west, as the separation is greater in the Hororata than near Brockley. I prefer, however, to regard the apparent separation as due to the effect of denudation on the thin veneer of coal-measures, which has removed in one place a portion of the cover and allowed of the basement beds appearing as an inlier (see Sections 6 and 7). There is no reason, therefore, to discard the conclusion that coal occurs at two levels—viz., one at the
Glentunnel level and the other near the base of the series—the occurrence of coal in Brockley Creek close down to the greywacke at the upper level being due to the gradual overlapping by the upper levels of the lower members of the series.

The strike of all these beds is north-east and south-west approximately, and the dip south-east at angles of about 15°, and this direction is preserved as they approach Mount Misery from the south-west and follow along the south side of Hall’s Creek, where they are decidedly calcareous and contain numerous oyster and other shells. The topmost beds of this part of the sequence are the more calcareous, and resemble the beds in the Selwyn Rapids. On following the line north-east they pass into the non-calcareous cemented sands which finally connect up with the shell-beds of Oyster Hill. However, on the side of the stream which rises in Yorkie’s Pass and follows round the flanks of Mount Misery there is a markedly calcareous band, really a sandy limestone, lying between the creek and the rhyolites, dipping at high angles to the north-west and then swinging round till it dips west, and finally merges into the normal direction, the stream following along the strike the whole way and thus swinging from a south-west direction, through south, to south-east, and on to north-east till it breaks through the hard band in the direction of the dip and enters the flat area of the Wairere Valley, formerly known as the Thousand Acre Swamp.

On the end of the spur running south-west from the shoulder of Mount Misery a marked band of black oyster occurs towards the upper part of the calcareous bed, and this has formed a good deal of calcareous tufa owing to springs at the point where the bed attains its greatest western extension. Under this calcareous band are ferruginous sandstones, sandy clays, and whitish shales, occurring on a spur reaching into a loop of the stream; and on the hillside above there are clays with poor seams of coal (prospected in one place), and under this again a hard calcareous sandstone, which exhibits the same swing-round as the overlying more calcareous bed. This sandstone apparently forms the face of the shelf running round the southern flank between Hall’s Creek and the mountain, extends for some distance to the north-east, where its position is obscured by soil, &c., and no doubt merges into the normal arrangement of the area.

This arrangement can be best explained by supposing that the fault which runs along the northern side of Mount Misery continues through Yorkie’s Saddle. The calcareous beds have been broken and dragged down along a line of fault, so that when they first occur to the south-west of the saddle they are in juxtaposition with the lower beds of the coal-measure series; but the throw gets less and less on following their line south-west, and the fault is replaced by a fold which gradually flattens out and disappears.

(ii) OUTLIERS.

Having dealt with the main occurrence of Cretaceous beds, attention may now be given to the various outliers of this age.

Cordy’s Flat and Associated Outliers North-west of the Cairn Range—Mount Misery Fault.

These have been dealt with by Jobberns (1925, p. 214) as the result of work done a year or two ago. With regard to the Hart’s and the St. Helens or Levick’s area (now known as Sutherland’s) little more need be said than to record the succession, but in the case of the Steventon area the recent development of the coal-mine has yielded further information. This mine has been developed by a dip drive, from which levels were driven north-east and south-west, and a considerable quantity of coal won from the seam, 14 ft. thick, dipping south-east 30°. Unfortunately, creep set in, and the mine has become dangerous, so a new drive has been commenced to cut across the measures away from the disturbed portion. As explained by Jobberns (loc. cit., pp. 221–23), the coal-seams have been modified by a dolerite intrusion, and the progressive effect of such a heated mass on adjacent coal-seams, by which an ordinary lignite has been converted into an “altered coal” or into an anthracite, has been noted by Evans (1924, p. 214).

When the former workings were practically abandoned the main level had been driven 7 chains to the north-east and 5 chains to the south-west. Two seams of workable coal were encountered, but only the one farthest from the intrusions was worked. In this drive three faults were encountered, the two nearer the outcrop being reversed faults with upthrow to the south-east, and the last with the upthrow on the north-west, the throws being 6 ft., 7 ft., and 8 ft. respectively, and their direction runs a little east of the strike and parallel to the “backs” of the coal. Associated with the faulting are slight sympathetic changes in the angle of dip of the seam.

The sequence of beds in the locality cannot be made out completely, since there are very few exposures, but a considerable portion can be filled in from the records of drives and shafts sunk for
prospecting purposes. At the base of the series there is a clay-pit near the gate of Mr. Starky's (the owner of the property) garden, in which the basal beds may be seen. These consist of the following:

1. Greywacke, exposed in the bed of the creek near the gate below the house.
2. Sandstone, red and highly ferruginous.
3. Sandy clays, with ferruginous concretions, laminated light and dark—i.e., corduroy—and weathering whiter, containing pieces of coal substance.
4. Fireclay, typically hard, with concretions of ferruginous sandstone containing excellent imprints of leaves, and with pieces of coaly substance.
5. Sandy shales, with flattened stems of trees, grey in colour, and with small lenses of coal; pyrites concretions occur in the coal.
7. Fireclay, with pieces of coal.
8. Light-coloured clays.

Then follows a considerable distance where there are no exposures, but on the ridge opposite the plantation and yards there is a ferruginous sandstone overlying burnt shale. A shallow shaft was sunk here, but there is no sign of igneous rock in it to account for the change, and so any intrusion must lie above the shale; there is, however, no outcrop on the surface in proximity to the shaft. In another shaft farther south-east a white sand was encountered, and above this measures with coal. Beyond the line of outcrop yet another shaft was sunk, and 12 ft. of dolerite encountered lying over shales containing thin seams of altered coal, one of which, 4 in. in thickness, was right against the dolerite, and then after 8 ft. of sandy shale was a seam of altered coal 2 ft. 6 in. thick, then 6 ft. of sandy shales 6 in. of carbonaceous shale, 4 in. of slightly altered coal, 6 ft. of sandy clay, followed by 14 ft. of coal, the big seam lying about 22 ft. below the dolerite. The occurrence of these seams in an old adit, put in over fifty years ago, and their progressive alteration by the dolerite are dealt with by Jobberns (loc. cit., pp. 221-23), and their change in composition by Evans (1924, p. 214, table). Evans (1927, pp. 137-58) has also given a very interesting account of the microstructure of the apparently unaltered coal, and the microstructure and composition of the coal altered by the dolerite. I have also referred to the presence of pebbles of quartz in this coal (1925, pp. 327-29), but this matter has been dealt with much more satisfactorily by Evans (loc. cit.). The total thickness of the beds from the greywacke to the mouth of the drive amounts to at least 700 ft.

The actual horizon at which this coal occurs is not certain, but judging from the stratigraphical relations of the beds at Hart's, which are on a line with the Steventon coal, it seems reasonable to think that it corresponds to the Glentunnel horizon. Jobberns has dealt with this point adequately, and has come to the conclusion that Haast had no foundation for thinking that there were two definite coal-bearing horizons in the area, one with unaltered and the other with altered coal, the Steventon area belonging to the latter, its position, apparently, so far below the Glentunnel coal stratigraphically being due to the downthrowing of the area as a result of the Cairn Range-Mount Misery fault.

In a shaft recently sunk some chains away to the north-east the following succession was met with:

- Clay, 20 ft.
- Clay and fragments of rock, 4 ft. 6 in.
- Gravel, 18 ft.
- Dolerite, 18 ft. 6 in.
- Coal, altered and of excellent quality, 2 ft. 10 in.
- Measures, 4 ft.
- Black coal, 6 in.
- Measures, 2 ft. 6 in.
- Black coal, 10 in.
- Measures, 7 ft.
- Brown coal, 2 ft.

Total depth of the shaft, about 80 ft.

Relying on these results, a drive from the surface was put in in order to strike the coal and follow it down to the dip, but at the time of my last visit this had been temporarily abandoned. The large seam in the main drive was probably cut in this drive. Although working has ceased for the present, the area appears to me most promising and worthy of detailed examination, since no doubt a considerable amount of workable coal still remains in the ground.

The analyses of two of the seams were kindly furnished me by Dr. W. P. Evans. These are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Water</th>
<th>Fixed Carbon</th>
<th>Volatile Matter</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>From seam in contact with dolerite</td>
<td>...</td>
<td>11·9</td>
<td>32·1</td>
<td>31·5</td>
</tr>
<tr>
<td>From seam distant about 12 ft.</td>
<td>...</td>
<td>19·2</td>
<td>32·8</td>
<td>35·0</td>
</tr>
</tbody>
</table>
Hart's Coal.

Hart's coal area lies on the north-west side of the Cairn Range, between it and the Selwyn River, and is no doubt connected with the Steventon area, but the connection is masked with river-gravels, soil, and surface clay. At one time it produced a fair amount of altered coal, but on penetrating farther away from a dolerite intrusion the coal passed into an unaltered variety and working was discontinued.

The lowest beds of the series are exposed on the left bank of the Selwyn River, on the up-stream side of the road to Sheffield, where rhyolitic sandstones and argillaceous beds with thin layers of impure carbonaceous material rest unconformably on a weathered surface of greywacke. The succeeding beds, in ascending order, are obscured for some distance down-stream, but the outcrops become clearer near the old workings on the other side of the road, on the face fronting the river. All the drives have now fallen in, but the following record of beds has been obtained from outcrops. The series is in ascending order, running from north-west to south-east, in the direction of the dip of the beds.

1. Sill, thickness uncertain.
2. Whitish sandy shales, baked, 7 ft., containing imprints of tree-stems.
3. Greyish sandy shale, 6 in.
4. Whitish-grey sandy shale, less changed than No. 2, 2 ft.
5. Interbedded carbonaceous shales and greyish argillaceous sandstone, 2 ft.
6. Black carbonaceous shale, altered, 2 in.
7. Dark-grey sandy shales, 5 ft.
8. Altered coal, 1 ft.
9. Dark-grey sandy shales, 6 ft.
10. Altered coal, 6 in.
11. Sandy shales, lighter-coloured in their middle portions, in places distinctly sandy and stained by iron oxide, 5 ft.
12. Dark carbonaceous shale, 6 in.
13. Light- and dark-grey sandy shales ("corduroy"), 5 ft.
15. Carbonaceous shales, 10 ft.
17. Carbonaceous shale, 2 ft.
18. Altered coal, 1 ft.
19. Fireclay, thickness?

These beds strike N. 15° E., and dip easterly 5°. Farther up the river the strike is more north-easterly, and the dip south-easterly 20°.

The section continues upward with shales and small altered coal-seams of uncertain thickness. The surface is then obscured by slip material and old spoil-heaps, as well as by covering of soil; but seams of 20 in. and 4 ft. thickness are reported, the former of altered coal, and the latter the main seam worked.

In the spoil-heaps there are fragments of altered coal, as well as altered sandy shale (porcellanite), the alteration being almost certainly due to a sill and not to a dyke.

I have been informed by Mr. Leeming, an old miner, who put in several of the drives, that the working was discontinued owing to a sudden inrush of water, which necessitated the abandonment of tools and equipment. According to his statement, there is a considerable quantity of good coal left in the ground. Farther on the sequence is resumed with—

12. White quartz sands, streaked and stained with iron oxide, striking north-east and dipping south-east 30°, about 300 ft.
13. Calcareous sandstone, slightly glauconitic, striking N. 40° E., dipping south-east 30°. This bed caps the ridge above the sand.
15. Calcareous sandstone, with a lower band consisting almost entirely of shell-remains, notably Conchothrya parasitica, exposed in the gully immediately below the Cairn Range.

These beds no doubt continue north-east along the strike for a considerable distance, but the surface is completely masked by gravels, which cover the country in the direction of the upper waters of the Waiananiwha Valley. The bed of sands, No. 12, has been used extensively as a source of material for moulding and other purposes.
St. Helens or Leviick's (= Sutherland's).

This area forms a somewhat narrow strip between the base of Mount Misery and the road running up the Glendore Valley, the position of the measures being easily recognized by the shelf they form at the base of the rhyolites. The area has been worked for many years, and still yields a small quantity of coal. As far as can be made out, the seams consist of the following, starting from the bottom:

1. Coal, 6 ft. to 8 ft. thick, the workings being abandoned owing to an inrush of sand and water, with pieces of coal.
2. Clays and sands, 40 ft.
3. Coal, 5 ft. 6 in. to 4 ft. thick, but only seen in one part of the area.
4. Wilson's seam, 5 ft. thick, worked at 124 ft., 160 ft., and 200 ft. from the surface in an old dip drive.
5. Sands and clays, 4 ft., with a band of poor fireclay, 15 in.
6. So-called "stone" coal, 5 ft. thick, but carrying a band of stone which varies in thickness from almost nothing to 2 ft.

All these beds dip at an angle of 30° and thin out to the dip. They have been worked for a distance of 5 chains at most, when no doubt they reach the vicinity of the fault which bounds the area to the south-east.

S. H. Cox (1884, pp. 33-34) records the presence of a dyke near the line of these seams, but no outcrops have been found on the surface, though I have been told by Mr. Leeming that it was cut in a bore. Perhaps this is an extension in a south-westerly direction of the sill or sills occurring at Steventon and Hart's. Judging from the position of the beds and having due regard to the dip, it is reasonable to infer that some disturbance such as folding or faulting—probably the latter—occurs under the flat between the two areas. This might represent a subsidiary fault parallel to the main Mount Misery fault, with a downthrow to the north-west. The record from the Steventon Mine shows that some such dislocations have taken place, but those recognized are not of such a magnitude to account for the discrepancy in levels that actually exists. If this subsidiary fault exists, it would be located practically on the line of the Glendore Stream.

This area continues towards the south-west over Yorkie's Saddle, where rhyolite conglomerates and concretionary ferruginous sandstone are exposed in places between the branch of the Glendore Stream coming from the saddle and the north-west flank of Mount Misery. The west side of the tributary creek is formed of greywacke.

An interesting section is exposed in a clay-pit recently opened up by H. Robb in this locality. The following sequence is shown on the south-east side of the valley, resting on greywacke, but with the actual contact obscured:

1. Rhyolite conglomerate, with fragments of chalcedonic quartz; then, after a break—
2. Fireclay, 6 ft.
3. Fireclay, 2 ft., divided from No. 2 by a dark band.
5. Fireclay, grey in colour, 6 ft.
6. Fireclay, 2 ft.
7. White clay, 6 in.
8. Fireclay, 6 ft.

The lower layers of fireclay contain ironstone concretions which include beautifully preserved impressions of dicotyledonous leaves, similar to those in the Steventon clay-pit—in fact, the situation of the two pits, which are in the very lowest members of the coal-measures, are closely analogous. Robb's pit also shows beautiful strike-faulting on a small scale, and, as it is situated right alongside the main Mount Misery fault, the faulting shown in the pit is no doubt connected in some way with the major dislocation.

This occurrence of coal-measures is part of the narrow strip extending across Yorkie's Saddle, and serves to connect up the areas behind Mount Misery with those of the Brockley area at the head of Hall's Creek. A small basic intrusion occurs in rhyolite in the bed of the creek a few chains above the clay-pit.

Phillips Saddle.

An interesting outlier occurs near the track leading over Phillips Saddle from Whitecliffs to Rockwood. Exposures are, however, very limited, and the observations made are suggestive rather than definite. A drive was put in on the northern flank of Pullwool Peak above the track, and the spoil-heaps therefrom show the presence of an inferior coal with fragments of dolerite. In the bed of the creek leading from the saddle there are exposures of black carbonaceous shales with pebbles of rhyolite, no doubt indicating the presence of other beds belonging to the series. These apparently rest on rhyolite. Pieces of excellent anthracite up to 9 in. in diameter have also been picked up in
the creek (fide H. Robb), so there must be a seam of some thickness of altered coal in the area, though whether this is due to the presence of an intrusion or to pressure attendant on faulting is not clear. Basic intrusions do occur in the coal-measures, in the rhyolite above them, and also along the junction of the rhyolite and greywacke to the west of the gully. Some of the beds, too, show slickensides, and thus indicate faulting.

These beds can be traced discontinuously through the saddle towards the south-west, and they no doubt junction with the outlier in the Hororata River. On the saddle itself the dip is to the south-east, and the boundary of the area in that direction must be a fault which connects with the main Rockwood fault. It may be that the north-west side of the saddle represents a fault-scarp as well, but I am more inclined to think that it is part of a stripped surface inclined at a somewhat steep angle.

This area extends to the west of the gully, since in a cultivated paddock above the High Peak Road are fragments of ferruginous sandstone like that occurring in the measures, and associated with this is a capping of basalt. Again, farther west still on the road is a very small exposure of rhyolitic conglomerate with carbonaceous fragments. These occurrences suggest that a considerable area of the outlier may lie to the west in the angle between the gully and the road. In this part of the area the coal-measures rest on greywacke. There is also some indication, judging from the shape of a shelf on the hillside, that they extend to the east for some distance round the face of Pullwool Peak.

**Rockwood.**

A very interesting outlier of the Cretaceous beds lies in the basin formed by the headwaters of the Hororata River in the vicinity of the Rockwood Station. They lie between the Rockwood Range and the spur running south-west from Pullwool Peak. Starting from the upper part of this area, these beds are first met with some chains below the junction of the creeks coming from Phillips Saddle and Rocky Gully, where there are carbonaceous shales with crushed stems of trees interstratified with rhyolitic grits, striking north-east and south-west, and dipping south-east 20°. In the first creek coming in on the south side the measures were traced up nearly half a mile, showing the same strike as before, but with the dip gradually increasing to 45°. The dip is then reversed, with a north-north-east strike, the inclination gradually getting steeper till the underlying rhyolite is reached. The beds consist of carbonaceous shales, fireclays, sands, and rhyolite grit. The upturning of these beds is probably associated with the movement on the downthrow side of the fault which extends along the flank of the spur from Pullwool Peak.

This synclinal arrangement continues for some distance down the creek, but above the plantation near the homestead the coal-measures dip south-east, and then rhyolite appears cutting off these beds from similar areas down-stream. The structure of the measures is here synclinal, with the axis of the syncline pitching south and showing a fault of small throw, with overthrusting from the south-east and some crushing. Just below the plantation only the south-east wing of the anticline is exposed, and the beds apparently dip to the west under a bank covered with soil, &c., and thus the north-west wing is hidden, if it really exists. The following is the general sequence, in ascending order:

1. Rhyolite sands and conglomerates.
2. Sands, with crushed stems of trees.
3. Carbonaceous shales.
5. Sandy clays, 15 ft. to 17 ft.
6. Lignite, 10 in.
7. Sandy clay, 5 ft.
8. Carbonaceous shale, 15 in.
10. Sands, sandy clays, and shales alternating for about 5 ft.
11. Coal, 2 ft., at the fault.

Immediately west of this there is a reversal of dip, the beds consisting of coals, whitish sands, white sandy clays, and fireclays.

Farther down-stream the beds dip west at very high angles or are actually vertical, and then again there is an easterly dip of 60° by the sandy shales against the rhyolite, with a fault contact. Farther down-stream two beds of impure lignite, striking north and south, and dipping west 70°, occur, separated by sandy clay; and farther down-stream still is a hard band, with amygdaloids of silice, running along the hillside and getting higher in an up-stream direction. On the point of the spur there is a big slip, referred to under the Glenroy heading, where shales and sandy clays occur dipping into the hill to the south-east. The whole of this occurrence indicates considerable dislocation and variation in strike and dip, which might occur along a fault-line.
The coal-measures occurring near Sheffield probably extend discontinuously along the northern flank of Abner's Head. The form of the lower slopes and the characteristic stripped surface leading up to the base of the dome-shaped mass which crowns the hill are suggestive that this is the case. Positive proof of this exists in a conglomerate which is exposed in places along this face, and specially about half-way up the slope immediately north of Abner's Head itself. This bed, 25 ft. to 30 ft. thick, is composed chiefly of subangular greywacke pebbles up to 6 in. in length, but well-rounded rhyolitic material also forms an important constituent. The shape of the latter pebbles suggests that they have travelled for a considerable distance; and, indeed, the nearest mass of rhyolite, apart from the small occurrence mentioned on page 14, is at Mount Misery, some five miles away in a straight line. If they have come from that direction the form of the surface and the direction of stream-valleys must have been far different from that obtaining now. The subangular greywacke constituent could have been derived from the immediate vicinity of the bed. The dip is to the north, in general agreement with the slope of the stripped surface. In a line with this occurrence there are a number of knobs, which no doubt indicate the continuation of the bed, about half a mile to the west. The overlying beds are not exposed, owing to the complete covering of soil, but exposures on tracks, &c., give some indication that the soil is similar to that derived from coal-measure clays and sands in other parts of the field. The base of this deposit is fringed for about a mile along the foot of the hills with a strip composed almost entirely of greywacke boulders, which range up to 5 ft. in length. These are in all probability of glacial origin, and represent an old terminal or lateral moraine of a glacier which impinged against the Abner's Head Range from the direction either of the Waimakariri or of the Rakaia by way of the Hawkins Valley, past the Dalethorpe Homestead. The fact that it is almost entirely of coarse material indicates that it is morainic and not fluviomarginal in character. This is, of course, of Pleistocene age, and not connected with the Cretaceous beds, but it appeared convenient to mention the occurrence in this connection.

(i) Pig Saddle Outlier.

Undoubted coal-measures outcrop on Pig Saddle, which is the low place in the ridge running west from Abner's Head to the Black Hills. This small occurrence has been known for many years, since it is first referred to by S. H. Cox (1884, p. 21). Some small amount of prospecting-work was done in the early days, and quite recently another half-hearted attempt has been made to determine its possibilities. On the southern side of the saddle, just east of the road, a dip drive has been put in, but with unsatisfactory results. A coal-seam about 18 in. thick, lying almost down on the greywacke, was followed in the direction of the dip for over a chain. The props had been taken away at the time of my visit and portions of the roof had fallen, so a complete examination was not advisable. The strike of the seam is about east and west, and the dip to the north at angles of between 15° and 17°. Sandy clays of rhyolitic origin overlie the coal, and these contain streaks and lenses of coaly substance, while a few feet higher is a layer of concretionary ironstone which determines the edge of a weak escarpment stretching in an easterly direction along the flanks of the Abner's Head Range. A small quantity of coal was obtained from the drive, but it was apparently very broken, although the quality of the coal substance showed it to he a somewhat superior brown variety. The rocks exposed on the saddle to the south are entirely of greywacke.

A few chains higher up the road, towards the crest of the saddle—that is, to the north—is an outcrop of carbonaceous shales, sands, and whitish sandy shales with ironstone nodules, the first-named containing thin seams of coal. This has the same strike and dip as the beds lower down in the series. The patch extends to the west side of the road, and similar beds underlie the downs to the east over an area which may be 100 acres in extent, and perhaps more. There is perhaps a gap, and then a recurrence of the same beds in down country about a mile in a direct line to the east.

The northerly dip of these beds suggests that under the gravel which covers Russell Flat the coal-measures lie with a synclinal arrangement and connect up with the patch of coal-measures dipping east in the vicinity of Springfield. Even if this is the case, and a coalfield of some extent does occur, its position below water-level would render it expensive to work and unprofitable under present circumstances.

(ii) Springfield.

A small patch of coal-measures underlies the volcanic hill immediately south of the Township of Springfield, and rests on the Trias-Jura rocks of the eastern end of the Russell Range. Exposures are practically absent, and for this reason the area escaped notice for a considerable period after other places had been exploited. At the present time clays are obtained from adits driven along the strike and from surface workings on the northern side of the hill, and one of the old drives is being used to extract pillars of coal left when the major working was abandoned. This drive is on the western side of the ridge, and it shows a seam of altered coal, somewhat crushed, and probably 2 ft. 6 in. to 3 ft. in thickness.
The best account of the strata is that furnished by the logs of the bores and the records of the shafts sunk by the Springfield Colliery Co., which worked the area in the "eighties" of last century. Unfortunately, the shafts have now fallen in. The information available at the time of working is given by S. H. Cox (1884, pp. 19-22 and 1887, pp. 22-23), and there are further remarks by Lindop (1887, pp. 25-27). The records of the bores show a thickness of about 200 ft. of coal-measures, consisting of sands and clays with thin seams of coal, the thickest being about 5 ft. 6 in., and there are two other workable seams 4 ft. thick. Cox mentions that there was a seam of 9 ft. 6 in. in the shaft, and concludes that it represented a union of two other seams, but Lindop does not mention this at all. These beds dip east 1 in 4 — i.e., 15°. The estimate of the amount of coal in this area according to both Cox and Lindop is in the vicinity of 14,000,000 tons, an exceedingly optimistic estimate. Coal-mining was abandoned in this area in the early "nineties," except for minor operations in a casual way.

There are one or two points of special interest in connection with this occurrence beyond what has been said by Cox and Lindop. First of all, there is the presence of the mass of dolerite over a considerable area. It is exposed along the crest of the low hill near the workings, and is also recorded in No. 2 bore as being 187 ft. thick, with an additional 11 ft. separated from the main mass by 1 ft. of clay, so that its total thickness approximates 200 ft. There is no positive evidence on which to base a definite conclusion as to whether the igneous rock is a flow or an intrusion, but the coarseness of the rock and the absence of ash-beds and other fragmentary material suggest that it is probably intrusive, and it is thus analogous to the igneous masses occurring elsewhere in the field. Further, if altered coal was found above the igneous rock on the north-east face of the ridge, and if that were correct it would settle the question for certain. The clip of the dolerite is practically consideráble area.

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A matter of interest in connection with the Springfield outlier was the prediction that coal of payable nature might be found in the basement beds under the coal-measures. This was made by S. H. Cox (1884, pp. 21-22), and was based on the report that a coal-seam had been found in the older Mesozoic beds near Dalethorpe, and that, as these beds were considered to form a syncline through the eastern end of the Russell Range, the same beds should appear on the eastern limb near Springfield. Had Cox actually seen the outlier of coal-measures near Dalethorpe I do not think that he would have endorsed this opinion. Small seams of carbonaceous matter do occur in Jurassic beds, such as those at the Cairn Range, but there is nothing to suggest that they contain payable coal, and the occurrence near Dalethorpe is only another of the small outliers of Cretaceous beds which the area furnishes in so many places.

This patch occurs on the south-west side of the Russell Range, in a tributary valley coming in on the north side of the Hawkins. It is a small outlier, forming a narrow strip faulted down against greywacke, and not in greywacke. The beds strike north-east and south-west, and dip south-east at varying angles; in a shallow drive where the beds are apparently undisturbed the dip is 20°, but it is frequently higher—a difference owing, no doubt, to slumping of the surface. The coal occurs in sandy shales, and is underlain by sandy clays, which are frequently ferruginous, sometimes becoming a definite ferruginous sandstone, and the whole rests directly on greywacke, but the precise nature of the contact cannot be made out owing to the slips. The patch extends along the hillside for about half a mile, but it is nowhere more than a few chains in breadth, being widest at the end nearest the Hawkins River. A considerable amount of prospecting has been carried out, but, of course, the result proved disappointing.

The coal met with in a shallow drive, and coming from a seam about 2 ft. thick, is a brown coal of fair quality, but pieces of an altered variety were picked up in the spoil-heaps in other parts of the area. By the kindness of Dr. Denham, of the Chemical Laboratory, Canterbury College, I obtained a couple of partial analyses of these two varieties. The former gave volatile matter and moisture, 60-4 per cent.; fixed carbon, 30-7 per cent.; ash, 2-9 per cent. — while the latter gave volatile matter and moisture, 56-5 per cent.; fixed carbon, 55-8 per cent.; ash, 20 per cent. The latter thus shows decided chemical properties indicating that it had been altered. I examined the locality thoroughly in order to account for the change, but could find no trace on the surface of the presence of igneous rocks, so if they occur their development must be slight. It is possible, however, that the alteration may be the result of the pressure attendant on the faulting.

No doubt this area was once of much greater extent, since stripped surfaces occur in the vicinity. There is also a characteristic rounding of the outliers of the greywackes, suggesting the result of glaciation; and there is apparently no reason why a distributary from the main Rakias glacier, coming down the High Peak Valley, has not been responsible for this landscape feature.
KOWAI VALLEY OUTLIERS.

(i) KOWAI BRIDGE.

This is a small outlier occurring at the southern approach to the Kowai Bridge, on the West Coast Road, and is referred to by Haast (1863, and 1872, pp. 36–38) as the Kowai coal. Some prospecting-work was done on this in the "sixties," but it yielded no satisfactory result. The drives have now fallen in, and the most interesting product of the spoil-heaps is a dolerite which does not outcrop on the surface. Only for a few chains on the bank of the river alongside the road-cutting can anything be seen, and the stratigraphy is most confused. Haast (1872, plate) gives a record of the beds cut in the drive, consisting of shales and coal apparently altered by a dolerite intrusion, 30 ft. thick; between the last and the greywacke lies a very narrow band of much-altered coal with polygonal structure. Haast also gives a section along the river-bank, but it shows no more than can be seen at present. At the western end of the section is the rhyolite conglomerate, and then about 8 chains to the east is an appearance of altered coal. At the present time the coal exposed in the road is much crushed, and its appearance suggests other alteration than that merely due to an intrusion. It must be close alongside the Kowai fault, and therefore the change may be in part due to crushing. The presence of the rhyolite pebbles so far away from the parent rock is somewhat remarkable. The form of the landscape must have been entirely different when the beds were laid down from what exists at present, in order to give a conglomerate composed almost entirely of rhyolite material, considering the close proximity of greywacke of pre-Cretaceous age.

Haast was very disappointed with the result of the workings in this place, and considered that a coalfield of considerable extent might have been located had boring been carried out in the river-flat. A recent washout of the river-bank has disclosed the presence of sedimentaries, probably of Cretaceous age; but if any great area of coal exists it must be beneath the level of the Kowai, and therefore difficult to work profitably. The presence of Cretaceous beds in the banks of the Waimakariri above the junction with the Kowai, on the line of the beds just referred to, supports to some extent Haast’s contention, but, unfortunately, no coal appears on the banks of the larger river to encourage the hope that an extensive field does exist. In all probability the great part has been removed by erosion, the only remnants being such as the occurrence just referred to, and the presence of a stripped surface on the hills to the north of the Kowai which indicates its former extension in that direction.

(ii) BEMMORE.

This outlier has been fully dealt with by Haast (1872, pp. 41–46) and by myself (1924, pp. 619–26), and I have nothing further to add to what has been said already.

HIGH PEAK OUTLIERS.

These lie in the valley of the Upper Selwyn, and owe their position and also their preservation to having been faulted down, the line of fault extending along the northern flank of the Rockwood Range from its western end, across the Selwyn River at its right-angle turn above the gorge, and on the Russell Range where the Dalethropë outlier is situated. The end of this fault is probably located at the distinct saddle in the range about two miles west of the Springfield Township. The fault is, no doubt, double for a part of its length, notably that section north-east of the junction of Copper Cliff Creek with the Selwyn River, for there is a beautifully developed stripped surface to the north of the river and also another at a higher level to the south of the river, the divergence between the two increasing on following them to the north-east. This would furnish an excellent example of a splintered fault-scarp such as has been described by Cotton from Otago (Trans. N.Z. Inst., vol. 51, p. 282, 1919). The position of these faults has been indicated in my former paper (loc. cit., pp. 619–26 and map).

The coal-measures form three very small remnants, a somewhat severe glaciation being responsible for the removal of the greater part of the covering sheet. They are as follows: (1) Just west of the High Peak Homestead, at the bottom of the ascent to Middle Saddle; (2) about a mile below the homestead, near the junction of Copper Cliff Creek and the Selwyn, and extending north-east therefrom up the next creek; (3) about two miles farther north-east still, in the basin of the creek coming from the north-west slope of Flagpole Hill.

Some exploration work has been done in the case of the first and third of these outliers, but this only served to prove that the coal did not exist in commercial quantity. In the case of the second of these outliers occur the clearest exposures, and it will be best to take it first.

The section is seen most clearly in the vicinity of the junction of Copper Cliff Creek with the Selwyn. On the banks of the river are clear exposures of greyish sands, succeeded by greensands, whity-grey sands, bright greensands, greensands burnt brown by a sill, and then a sill, or in all probability a double sill, with interstratified sandstone beds. The strike is along the river, practically east-north-east and west-south-west, and the dip to the south at low angles. The beds extend upstream from the junction of Copper Cliff Creek, but they are soon covered with surface debris and by
marginal material. S. H. Cox reports this occurrence across the river to the north, but I have not examined the place. In one part underlying this there is a definite deposit of laminated glacial silt, like that in the Rakaia Gorge described by Cox (1925, pp. 105-7) and Speight (1926, pp. 55-81), and in the fluvioglacial material are fragments of coal and of the large black oyster (Ostrea dichotoma) such as occurs over the coal-beds in other parts of the Malvern area. The oysters were not seen in position, but the containing bed no doubt exists in close proximity underneath. The glacial succession here is as follows: (1) Fluvioglacial beds with scratched stones; (2) stream deposit; (3) glacial silts, laminated or "varved"; (4) moraine. The last-named covers the surface fairly completely and masks the coal-measures, so that the complete sequence cannot be seen.

On the northern side of the sill the burnt sandstones are upturned as if they had been pulled up on the downthrow side of a fault. The sill is probably very thin, judging from the breadth of the surface of the ground covered with blocks. It exhibits a coarse-grained as well as a fine-grained facies, the change at times being abrupt, and again gradual. This rock shows distinct relationship to the tectonic facies of the sill in Rakaia Gorge as described by P. T. Cox (pp. 104-5). The sill apparently spreads out or is exposed for a much greater breadth on going east, but it reaches and crosses the next creek and continues along the crest of the ridge in greywacke. This creek discharges into the Selwyn through a gorge cut in greywacke. In the western branch of it boulder-clay is developed towards the top, but in the eastern branch there are coal-beds striking N. 65° E. and dipping to the south, the coal being poor in quality, and fireclays, all much faulted by faults running north-east and south-west generally. The boulder-clay probably continues into this branch as well. There does not appear to be any possibility that coal exists in commercial quantity in this area.

In the area west of the homestead the beds exposed consist of sands, concretionary in their higher levels, striking north-east, the best exposures being on the south side of the stream. On the north side in greywacke, is a sill, 20 ft. to 25 ft. thick, much weathered, and striking north. This sill appears on the south side of the stream higher up. The greywacke is altered by it to a porcellanite. There is a thin capping of coal-measures on the top of the terrace to the north, where there are shales, sands, rhyolitic-gravel beds, with impure lignite. Some exploration work must have been done in the early days to test the possibility of the measures, judging from old shafts which appear in places, but apparently they led to nothing. This area is apparently cut off from the main one by a bar of greywacke, which must reach down to the vicinity of the homestead from a spur of High Peak.

On going down-stream from the saddle immediately east of the middle area ferruginous concretionary sands first appear after about a mile. These lie close down on greywacke. On the eastern side of this outlier, well exposed in the tributary of the Selwyn coming from Flagpole Hill, are coal-beds with shales, sandy clays, and sands. These strike north-east and dip south-east. They are intruded on the east side of the creek by a sill apparently running north, and near the top of the area there is a dyke—perhaps there are two—with the same strike. Boulders of basalt also occur along the bank of the creek to the north-west of the area, but the bed was not observed in position; it must, however, be in close contact with them, and judging from the distribution of the boulders on the surface it is probably parallel to the trend of the creek. The remains of old workings occur, but all the drives have fallen in.

There seems to be little possibility of either coal or clay occurring in this area in commercial quantity, since the outliers are of limited extent, are thin, and form only discontinuous veeners on the greywacke. The general lithology of the beds and the presence of the oyster-fragments show that they must be correlated stratigraphically with the Senonian beds of the other part of the area.

Acheron. (See Section 8.)

A most interesting outlier occurs in the Acheron River about a mile above the bridge by which the main road to Lake Coleridge crosses the stream. The river has here cut right through the coalmeasures, but most of the area lies on the right bank. Here there is the following sequence:

1. Greywacke.
2. Sandy carbonaceous shales, about 25 ft., with seams of altered coal, one of which is about 4 ft. thick.
3. Fireclays, grey in colour, and altered close to the sill which lies above.
4. Fine-grained basaltic sill, 2 ft. thick.
5. Fireclays and sandy clays, grey in colour and slightly altered.
Then follows a part obscured by slip and surface debris, but succeeded by—
6. White sandy shales.
7. Altered more and more into porcellanite.
8. Massive sill, about 25 ft. thick, much decomposed on the surface, and showing columnar structure. This lies from 36 ft. to 40 ft. above the coal.
9. Gravels and morainic deposits, covering the coal-measures unconformably.
These beds have a westerly dip at low angles, about 10°. The total thickness of the exposure is
about 70 ft., and the length along the river-bank about 350 ft.

Round a turn in the river up-stream there are other exposures in the bank. At a little distance
above the greywacke is a dark-grey sandstone, then a seam of altered coal 2 ft. thick, then a few feet
of shales, and then another seam which has been worked to a slight extent. Outcrops of the measures
also occur farther up-stream still, but their relations, owing to the covering of gravel, are obscure.
The sill overlies these beds at the upper end of the exposure, and, no doubt, occurs parallel to the bank
of the river under the gravels.

The coal-measures extend to the south side of the river, where trial drives were put in but
abandoned quickly; the coal they obtained was the altered variety, as disclosed by the spoil-heaps.
Fragments of fine-grained basalt are to be found here as well, showing that the drive cut an intrusion.

About three-quarters of a mile up-stream there is a massive intrusion of dolerite in greywacke.
This is wedge-shaped in form, and crosses the river almost at right angles. A similar rock is met with
higher up the river on both banks, but whether it is a separate intrusion or only a part of the one just
referred to is uncertain. If the former is the case, then the general orientation of the intrusions is
approximately parallel to the general trend of the stream, the smaller intrusions lower down and also
some others farther up-stream still being apparently offshoots from the main mass; but the irregularity
of arrangement and of their form renders it impossible to make a definite statement in the present
state of my knowledge of the field relations of the various occurrences.

The massive intrusion farthest up-stream contains a definite gabbroid facies, which is merely a
coarser variety of the dolerite. There are, as well, light-coloured veins, up to 6 in. in thickness, taking
somewhat irregular courses through the rock. These are apparently of a more syenitic facies of the
rock, similar to those described by Cox at Rakaia Gorge (1925, pp. 104-5). Amygdaloids of natrolite
also occur in this rock. The whole circumstances of this interesting locality merit further examination,
and it would form an excellent subject for a thesis.

At one time a fair amount of coal was obtained from the seam which outcrops farthest down-
stream, but the workings are now abandoned. They lie just above the water-level, and dip beneath
it. It was also worked at a point a few chains away on the south side of the river. In the mine the
coal had been completely coked, and exhibited good columnar structure. At all places where coal is
exposed it is of the altered variety, a change due entirely to the intrusions. When I first examined
the spot the thin 2 ft. sill was not showing, and the metamorphism of the coal was attributed to the
heat and pressure caused by the massive sill; but a recent slip disclosed the thin one, and no doubt
this is the main reason for the change.

Owing to the masking of the surface with gravels and moraine, it is impossible with the evidence
at one's disposal to say how far the patch extends, but it was no doubt much more widely distributed,
since there are remnants of the overlying limestone and other beds on the opposite side of the Rakaia
at Redcliff Gully, as well as in the valley of the Harper, not only just above the road-crossing but
farther up towards the head of the stream. These are mere remnants of a widespread veneer of
Cretaceous and overlying Tertiary beds.

Rakaia Gorge.

This outlier has been fully dealt with by P. T. Cox (1925, pp. 91-111), and further reference to it
here is unnecessary.

Just above the Glenroy Bridge over the Hororata there is a small exposure, about 5 chains in length,
of marls, sandy clays, with occasional layers of fine conglomerate, striking north-east and south-west,
and dipping south-east at moderate angles, whose position is uncertain. It may belong to the
Curiosity Shop beds, which occur in the Rakaia about three miles away, or may represent higher
members of the coal-measure series—probably the former. The beds most developed are argillaceous
sands, occasionally calcareous, yellowish and also at times greenish in colour. The interstratified
layers of conglomerate are very fine grained, and contain thoroughly decomposed pebbles, probably
volcanic in origin. In some parts of the sequence there are angular fragments of calcareous material
included in the clays, as well as nodular masses up to 3 in. in diameter, lined inside with calcareous material, but occasionally containing needles of gypsum. This occurrence is surrounded entirely by river-gravels, and is only to be seen in the actual bed of the stream.

The whole of the Senonian sequence points to the beds having been laid down under estuarine or shallow-water conditions. The greatest depth obtaining in the area probably occurred at the time of the deposition of the greensand, just after the laying-down of the Rapids beds. From these higher it is probable that shoaling took place. One special feature might be noted: viz., the fact that the conglomerates do not as a rule occur right at the base of the series, but at some distance—in some cases hundreds of feet—above the basement of greywacke and its associated rocks. To the north of Abner’s Head conglomerates do undoubtedly lie right down on the greywacke, or with a very slight thickness—a few feet at most—of intervening finer-grained material. From this it may be inferred that in general the deposition of the estuarine beds as they now appear did not take place in close proximity to a shore-line, but at some distance away from it. Although the conglomerates are now separated from the basement beds, it seems reasonably certain that when they were laid down they extended till they were in close contact with the old land-surface, and this junction would occur some distance away from the point where the beds now outcrop, and this would also imply a small angular discordance with the surface of the peneplain on which they were laid down. At Abner’s Head the bed of conglomerate has not been separated from its parent land by erosion, but still retains the position it had when it was on an old shore-line or near it. This statement as to the presence of the conglomerates implying the presence of a shore-line in close proximity is made with all due regard to the fact that conglomerates sometimes are deposited off shore, and that finer sediments are at times laid down between them and the actual shore-line.

(b) AGE OF THE BEDS, ETC.

From the foregoing descriptions it will be seen that the critical locality for the determination of the age of the beds is that near Glentunnel, which includes the Selwyn Rapids beds and the oyster-beds at Oyster Hill and Oyster Gully. The marine fossils listed on page 25 show that these horizons belong to the Senonian age. The succession of beds and their correlation with similar series at Waipara and Amuri Bluff as given by Wilckens (1920, p. 261) seem to me to be satisfactory, provided some slight modifications are made. His succession is as follows:

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Amuri limestone</td>
<td>Amuri limestone</td>
<td>Loose sands and volcanic tuffs.</td>
</tr>
<tr>
<td>Teredo limestone (upper)</td>
<td>Teredo limestone</td>
<td></td>
</tr>
<tr>
<td>(a) Greensand</td>
<td>Greensand</td>
<td></td>
</tr>
<tr>
<td>Grey sandstone</td>
<td>Grey sandstone</td>
<td></td>
</tr>
<tr>
<td>Teredo limestone (lower)</td>
<td>Teredo limestone</td>
<td></td>
</tr>
<tr>
<td>(b) Greensand with concretions</td>
<td>Greensand with concretions</td>
<td></td>
</tr>
<tr>
<td>(a) Saurian beds</td>
<td>Saurian beds</td>
<td>Saurian beds without fossils.</td>
</tr>
<tr>
<td>(b) Black grit (upper)</td>
<td>Black grit (upper)</td>
<td>Selwyn Rapids beds.</td>
</tr>
<tr>
<td>Greensand</td>
<td>Greensand</td>
<td>Ostrea beds.</td>
</tr>
<tr>
<td>Grey sand</td>
<td>Grey sand</td>
<td></td>
</tr>
<tr>
<td>Black grit (lower)</td>
<td>Black grit (lower)</td>
<td></td>
</tr>
<tr>
<td>(a) Calcareous conglomerate</td>
<td>Calcareous conglomerate</td>
<td>Quartz sand and conglomerate with</td>
</tr>
<tr>
<td>Lower or wood</td>
<td>Lower or wood</td>
<td>coal-shears.</td>
</tr>
<tr>
<td>Sand</td>
<td>Sand</td>
<td>Great discordance.</td>
</tr>
</tbody>
</table>

The points in the above table concerning which I should like to make observations are—

1. Saurian beds with saurian bones do occur at Malvern in the Selwyn at a higher stratigraphical horizon than what are called the Selwyn Rapids beds.

2. Greensands with concretions are also developed in their anticipated stratigraphical position.

3. Above these are sands which apparently pass up from the concretionary greensands without a break, but which cannot, owing to the absence of fossils, be correlated definitely with any particular horizon at the Waipara or elsewhere. They may be equivalent to Thomson’s Waipara greensands of that locality.

4. I do not consider that there is any definite evidence for the inclusion of the volcanic tuffs in the Cretaceous sequence—i.e., presuming that Wilckens refers to the pyroclastic material of the Harper Hills, which is probably of much later age, possibly late Tertiary.
The limestone members of the sequence are entirely absent from the visible beds of the Malvern area, but they may occur under the gravels of the plains to the east and south-east of the hills. Limestones do occur at the Curiosity Shop on the Rakaia, but these are much higher stratigraphically, a remark which also applies to the limestone at Redcliff Gully opposite the Coleridge Power-station. Some of the marls at the latter place underlying the limestone may possibly be the equivalent of the Amuri limestone, just as they are in the Treleisstock Basin.

The amended series which I should like to propose for the sequence developed in this district would be as follows:

1. Lower and Middle Mesozoic sedimentaries and volcanics, the sedimentaries most probably divisible into two series—(a) Lower Triassic and (b) Lower Jurassic—separated by an unconformity.
   Great unconformity.
2. Conglomerates, sands, fireclays, and clays with thin seams of coal.
3. Sands, fireclays, and clays with coal-seams thicker than in the case of No. 2 and commercially exploitable—the Glentunnel horizon of Morgan; 2 and 3 conformable, and 3 passing up without apparent break into—
   4. Ostrea beds, composed chiefly of a grit with oyster and other molluscan forms, including belemnites.
   5. Selwyn Rapids beds, a concretionary calcareous sandstone, with molluscan remains—the chief fossil horizon.
   6. Saurian beds, with saurian remains contained in concretionary sands.
   7. Greensands and greyish sands with concretions, and some shell-remains—the main Conchothysa horizon.
   8. Sands and clays, capped unconformably with basaltic lava-flows and pyroclastic material.

It will be seen that the Malvern Hills beds fall within Thomson's Piripauan Series as it is developed at the Waipara and Amuri Bluff.

The evidence as to the age of these beds as deduced from plant fossils is not so satisfactory. Ettingshausen (1891, p. 240) considered that the plant fossils submitted to him from the Malvern Hills were Tertiary in age, but this determination is so much at variance with that based on the marine forms that it is open to suspicion. Ettingshausen identified the following species as present: Atrucaria haastii, Dammara oweni, Myrica proxima, Quercus lischotoides, Fagus lendenfeldi, Planera australis, Cissophyllum malvernican. I do not know precisely where these specimens were obtained, but I suspect they came from the vicinity of the Homebush Mine, in the higher part of Surveyor's Gully.

Dr. Marie Stopes (1914, pp. 347-49) has redescribed one of the specimens of wood, to which Ettingshausen gave the name of Araucaria haastii, under the name Araucarioxylon nomine sedinante, assigns its age to Cretaceous (Mid-Cretaceous ?), and further mentions that "the well-defined growth-rings in an Araucarian of Cretaceous age in this region is of special interest because it affords evidence which is strongly presumptive of well-marked seasons." According to Dr. Stopes, there is not sufficient evidence to connect this wood with the leaf-impressions described by Ettingshausen under the name of Araucaria haastii.

There is a reference by Chapman (1918, p. 13) to the occurrence of the shark Odonotaspis inexcusa at White Rock, Malvern Hills, and Morgan (loc. cit., p. 38) also mentions Neidiana margarites as occurring at the same locality, though I can find no mention of the latter in Chapman's report. Since the latter fossil is given as of Miocene and Pliocene age, and there is no locality at Malvern known as White Rock, although there is one known as Whitecliffs, it is most probable that a mistake has been made in labelling the place of origin of the specimen, especially as there are two other well-known localities in Canterbury undoubtedly called Whiterock which have furnished Tertiary fossils.

Another point of interest in connection with these beds is the source of sediments of which they are composed. There do not appear to be any critical minerals in the sands or clays which may be used for this purpose, except the two micas, biotite and muscovite. There are no rocks at present exposed which could furnish the latter constituent. It might possibly come from the greywackes, since they contain a small percentage of muscovite; but this small percentage when subject to a reduction proportional to that when the greywacke was formed from granite or other similar rock would not furnish sufficient to account for the amount of the clays and fireclays. It was probably derived from some other source.
The noteworthy rhyolitic constituent of the conglomerates below the Glentunnel horizon points to the presence of a rhyolitic land which furnished a large proportion of the sediments. In some cases, even when the beds rest on greywacke, the percentage of material to be traced to the rhyolite is so great that it seems extremely unlikely that a land-surface even approximating in form to the present could have furnished it. This has been pointed out by P. T. Cox in connection with the Rakaia Gorge beds, and it applies also, though perhaps not so strongly, to those in the Malvern Hills proper. If the land-surface and the direction of movement of the sediments were those of the present time, the great majority of the sediments should be of greywacke origin; but they are rhyolitic, and this suggests that there was an almost pure rhyolite land surface somewhere near the area. The distribution, too, of the rhyolite pebbles on a basement of greywacke also requires some such different direction of movement. This might be explained by supposing the surface lay to the east and south-east and is now buried up by the gravels of the plains.

When one considers the almost purely greywacke composition of the Jurassic conglomerates in comparison with the notable rhyolitic composition of the Senonian conglomerates, even when they both rest on greywacke, it must be clearly recognized that the form of the land-surface and the direction of the currents or rivers which transported the material must have been entirely different in each case.

III. POST-SENONIAN.

(a) IGNEOUS ROCKS.

The igneous rocks associated with the Senonian beds consist of both intrusives and extrusives. The only definite evidence of age is that the intrusives must be post-Senonian, while the volcanics rest on a denuded surface of Senonian rocks and they must also be post-Senonian. There is nothing further, except the similarity in lithological character to volcanics occurring elsewhere in Canterbury—e.g., at Timaru, at Geraldine, and in the Oxford district at Burnt Hill, View Hill, &c. The Timaru occurrence is certainly as late as Pliocene, and the Oxford occurrences are post-Awamoan—that is, post-Miocene—in age. So, judging from lithological similarity—a somewhat unsafe guide, all the same—it is probable that the Malvern extrusives date from the latter part of the Tertiary era and belong to the Upper Miocene or Lower Pliocene period.

The value of this section of the report has been materially increased by the series of analyses of selected rocks kindly made by the Dominion Laboratory, and they will be cited here, as being the most convenient place to give them initially. References will be made to them subsequently as circumstances demand.

**Analyses of Post-Senonian Igneous Rocks, Malvern Hills.**

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<td>7.15</td>
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<td>Magnesia</td>
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<tr>
<td>Chromium trioxide</td>
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<td>Vanadium trioxide</td>
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<td>Strontia</td>
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<tr>
<td>Barium</td>
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<td>0.06</td>
<td>Trace</td>
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<td>Trace</td>
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Total: 100-30 99-87 100-27 100-21 100-13 99-95
# Norms.

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<td>(5-00)</td>
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</table>

No. 3. Dolerite. IV. 1. 3. 1. 2. Whirinosa, Sill, Ashburton River.
No. 4. Basalt. III(II). 4(5). 34. 44. Tenlakos, Sill, Station Creek, High Peak.
No. 6. Dolerite. II. 5. 3. 4. Andose. From Hororata River, just above Mr. Levice's old coal-drive.
No. 7. No. 6, recalculated. II. 5. 3. 4. Andose.

The analyst remarks that in view of the high percentage of water in No. 3 and of CO₂ in No. 4 the classification of these two rocks under the C.I.P.W. system is of doubtful value. No. 6 also contained so much calcite that the norm has been recalculated on its absence.

The only major occurrence of volcanic rock as distinct from intrusions, with the possible exception of that at Springfield, is that which caps the Harper Hills and the Homebush ridge, as noted above. This extends for some twelve miles in length, but the outcrop has a somewhat narrow breadth, nowhere exceeding a mile. There are probably two flows, separated by a layer of clastic material, and underlain in the neighbourhood of Coalgate by a breccia with a maximum thickness of 50 ft. This breccia apparently thins out when followed towards the south-west. It is best developed near the Coalgate Bridge over the Selwyn. Here it forms a bluff, which was known to Haast as the Palagonite Bluff, although palagonite is not specially apparent. The material is mostly fragmentary, of small size, rarely exceeding 3 in. in diameter, included in a finer matrix. The source both of the flows and the clastics is uncertain. There is apparently no centre from which they could have come, the only possibility being that the material might have been derived from one or more of the dykes, of which there is a fair number in the country to the north-west of the ridge. The conditions might therefore approximate more or less to those of a fissure eruption. The possibility of the occurrence being a sill was considered, but the presence of the thick mass of fragmentary material rather negatives this hypothesis, although fragmentary matter is sometimes associated with sills and there are differences in character which point to another origin. There is, unfortunately, no outcrop which shows the contact of the solid rock with overlying sediments by which the question can be definitely settled, but, on the whole, the evidence suggests that they have been poured out on the surface, and perhaps have never been covered up at all except by gravel deposits of very late date. Contacts exposed on the Harper Hills show the presence of subjacent layers of porcellanite or indurated sandstone.

In the hand-specimen the rock is greyish in colour and very vesicular. Under the microscope the phenocrysts are olivine, which occur up to 2 mm. in length; augite up to 1.2 mm. The groundmass is holocrystalline, moderately coarse in texture, and is composed of laths of labradorite from 0.28 mm. to 5.3 mm. in length, averaging 0.35 mm.; grains of greyish to slightly purplish augite; olivine in small grains; and secondary ilmenite in characteristic skeletal forms apparently derived from small crystals of titaniferous magnetite; also a mineral with the form, cleavage, slight pleochroism, and extinction of hypersthene. There is much calcite present, as well as a colourless isotropic mineral, both filling cavities. The texture of the rock corresponds to that of an anameline. The occurrence on the Homebush ridge is somewhat similar, but in my sections there is still more calcite present. The former rock is referred to by Hutton (1889, p. 148). Its chemical composition is given in the list of analyses on page 46; this presents no features calling for special comment.

The occurrence of hypersthene, similar in character to that in the rocks near Oxford and at Timaru, is somewhat interesting, as suggesting a common genetic origin, and perhaps a similarity in time for these rocks.
Sections made from fragments in the breccia at Coalgate show that some of the material is of andesitic character. One slide of this class also shows numerous rounded fragments of quartz, included in an andesitic matrix, which itself exhibits no signs of brecciation. It is thus apparently of different origin from the lava-flows which associated with it, and, after all, there may be little genetic connection between the two.

The intrusions are much more interesting. In every occurrence of an outlier of the Senonian coal-measures, with the exception of those on Pig Saddle and in the upper valley of the Waianianuiwa, there is an occurrence of intrusive rocks, which has been responsible for the alteration of the coal-seams. These occur at Hart's, Steventon, Phillips Saddle, Rockwood, Springfield, Kowai, Benmore, High Peak, Rakaia Gorge, Acheron; and, further, there are intrusions in the main area of coal-measures near Glentunnel (on the downs on both sides of Surveyor's Gully and near the Selwyn Bridge), at Brockley, and at Glenroy. A special point to consider in this connection is the relation of these isolated occurrences to the faulting. Are the isolated occurrences of intrusives part of one great sheet which was intruded anterior to the faulting, and which has been broken into isolated remnants as the result of the faulting, or are these occurrences more or less independent manifestations, perhaps genetically connected with the faulting?

The former supposition would require a thin and widely distributed sheet, now mostly removed by denudation—a possible but not a probable contingency; whereas the latter is the more likely, especially as some of the intrusions, notably those at High Peak, Rakaia Gorge, and the Acheron, are somewhat alkaline in character, and are perhaps illustrations of the associations of such rocks with faulted areas.

These intrusives are, with one exception, all basic in character, and usually moderately coarse in texture, so that they should be called dolerites. There is a gabbroid facies at the Acheron, and in one or two cases the rocks are fine-grained and should be called basalts.

There is a similarity in lithological character in most of the dolerites. They are usually even-grained, consisting of feldspar and augite in subequal proportions, and olivine in less amount. The first is usually labradorite, the augite is markedly titaniferous, and the olivine frequently changed to a greenish slightly pleochroic alteration-product. In some few cases there are porphyritic feldspars, and then ophitic structure is beautifully developed in the groundmass.

The occurrences near Glentunnel are all dolerites. They form a capping to the downs near the township, and also occur as dykes at the bridge and near the mouth of Surveyor's Gully, one being traced on to the western side of the gully about a quarter of a mile above its mouth. The capping of the downs is probably intrusive. I considered the possibility that it might be a part of the capping of the Harper Hills, which had been faulted down; but if such had occurred the Senonian beds should show some signs of dislocation of equal magnitude, and this does not appear, the beds being apparently undisturbed in stratification. However, exposures are few and far between, and the covering of soil over the capping of the downs prevents its field relations from being definitely determined. All the same, I think it is an intrusion of sill-like form.

The dykes in this locality have been dealt with to some extent by Captain Hutton (1889, p. 148). He mentions examples near the bridge and just north of the township. The former of these is probably part of the intrusion capping the downs more to the north-east. In section the latter shows phenocrysts of labradorite and olivine in a somewhat fine-grained base, which consists of purplish feldspar, arranged subophitically to the feldspar of the groundmass; labradorite laths; grains of olivine; and skeletal crystals of ilmenite. There is besides a greenish decomposition-product probably derived from the olivine, but occasionally bordering the augite.

The dyke which crosses the gully higher up, and is best developed on the western side, is similar in character, but it contains unwinned feldspar phenocrysts which exhibit zonal structure with the outside fringe of higher index than the middle, with inclusions of augite microlites parallel to the margin, and with the kernel exhibiting the water-mark characters of anorthoclase. In every case that I could observe the kernel had a higher index of refraction than balsam. The mineral, too, is optically positive, and therefore andesine or labradorite. The feldspar of the base is labradorite.

The rock of the downs is much coarser in texture, ophitic relationships of the labradorite to the augite being common; the olivine is partly or completely serpentinized, and there is much ilmenite. This rock is entirely different from that which caps the Harper Hills, and exhibits the general features of the undoubted intrusives of the area, so it is probably a sill, and not a flow connected with the volcanics of the Harper Hills and Homebush ridge.

There are several occurrences of intrusives in the Brockley area. The first of these is the main Brockley dyke. This is coarser than the general run of the intrusives considered up to date, but not so basic. There is much feldspar (acid-labradorite), up to 0·7 mm in length; very faintly purplish-grey augite, up to 3·5 mm in length; olivine in small amount; ilmenite in skeletal crystals; some quartz in cavities; biotite in small amount; an occasional grain of zircon; and a yellowish-brown alteration-product. On a line with this dyke, but lying in the surface, there is a rock of similar character but coarser in texture and much more subject to weathering.
About three-quarters of a mile to the south-east of this intrusion is another series, sills or dykes, which probably form splinters on the line of some main intrusion. They are first of all developed in the middle branch of Wairere Creek, where there is a waterfall formed by the dyke crossing the stream. This occurrence is decidedly basic. There is much augite; considerable olivine altered into serpentinous products; labradorite; ilmenite and a chaledonic alteration-product in cavities, usually stained green.

The sill on the same line to the south-west is finer-grained but still holocrystalline, composed of olivine phenocrysts, up to 1 mm. in length, sometimes quite fresh; augite phenocrysts, greyish in colour, occurring at times in aggregations—both contained in a groundmass of labradorite laths; greyish, occasionally greenish, grains of augite; skeletal crystals of ilmenite; much calcite in cavities; greenish alteration-products, probably after olivine; and leucoxene derived from the titanium-bearing minerals. These two intrusions are so different from the Brookley dyke that it is very unlikely they were part of the same intrusion, and this difference diminishes greatly the possibility of faulting being cited to explain the occurrence of coal at two horizons in this locality.

Besides these dolerites in the Brookley area there is an igneous rock which forms a ridge parallel to the Glenroy Coal-mine and to the north-west of it, and extends, discontinuously, to the north-east to the main branch of Wairere Creek, and probably still farther into Brookley Creek, where there is an outcrop of similar rock. It may be a flow, but is more probably an intrusion. In the hand-specimen the rock is very close-grained, almost flinty, in texture, and shows well-developed flow-lines. In section the latter are very clear indeed, and there are a few phenocrysts of labradorite, and occasional augite and olivine, with grains of titaniferous magnetite. The groundmass is very fine, and is composed chiefly of glass in which are very small microlites of augite and dust of magnetite. There are inclusions of foreign material, one being a grit composed mostly of quartz, and another being an andesite closely resembling the pre-Senonian andesites of the area. These inclusions are frequently drawn out so as to lie almost parallel to the flow-lines.

The analysis of this rock (No. 2, page 46) is that of an andesite, but I cannot help thinking that the acid character is rather due to the presence of the inclusions and that the rock is really a basalt modified by material which it has picked up. However, in view of the analysis, I have called it an andesite. If it is really an andesite it is one in which olivine is a definite constituent. The fineness of the rock as a whole, particularly as regards the groundmass, would demand that reliance should be placed on the chemical composition in determining its species, but the presence of the inclusions renders this criterion illusory.

An occurrence of basic rocks occurs on the point of the ridge just east of the Rockwood Homestead on both sides of the Hororata River. Analysis No. 6, page 46, is of a specimen from here. In all the slides there are purplish augites, sometimes bordered with green; titaniferous magnetite; olivine in grains and aggregations of crystals; laths of labradorite, with ophitic arrangement to the augite; titaniferous magnetite and secondary ilmenite; and occasional apatite. There is a green alteration-product from olivine, and also at times a greenish-grey mineral with high polarization colours and moderate extinction angle occurring in minute laths, which is probably serpentine-augite. Phenocrysts of labradorite occur at times, with a zonal banding of less acid feldspar and inclusions of augite microlites. Although there is no field evidence that this occurrence is intrusive, the microscopic properties of the rock and its resemblance to other intrusives are fairly strong evidence that it is so. There is a facies of this rock much more andesitic in character which is subject to the action of weathering agents, the two facies being apparently continuous and not belonging to different occurrences, as far as can be seen.

This concludes the description of the occurrences of igneous rocks associated with the main development of the coal-measures. There remains those associated with the outliers. The first of these to consider is that at Springfield, which is probably a sill. Hutton (1899, p. 147) described this rock as an augite dolerite, and my examination generally confirms his conclusions. The feldspar is a basic-labradorite; the augite is greenish-grey to slightly purplish in colour; ilmenite occurs in skeletal crystals; there are very occasional grains of unaltered olivine, and much carbonate in my slides. The groundmass is holocrystalline, the feldspars being about 0·3 mm. to 0·4 mm. in length, but there are frequent micro-phenocrysts of feldspar which reach to 2 mm. in length.

The intrusion at Kowai Bridge is much altered. The olivine has been almost entirely changed to serpentinous products; augite occurs in crystals up to 2 mm. in length; the feldspar is almost entirely replaced by secondary alteration-products; there is a small quantity of reddish-brown biotite; and a general decomposition-product, brownish-green in colour, stains a considerable part of the slide—this is in all probability serpentinous material stained with chlorite, &c. According to the German usage, this rock would be called a diabase.

The occurrences at Benmore have been dealt with by the present author (1924, pp. 619--26), and those at Hart's and Steventon by Jobberns (1925, p. 229), while those at the head of the Glendore Valley will be taken after the High Peak occurrences.
The most interesting occurrences of these basic rocks are those at Rakaia Gorge, the Acheron River, and at High Peak, all of which show a general family resemblance. The great sill at Rakaia Gorge has been described by P. T. Cox (1925, pp. 104–5), and he has pointed out its teschenitic relations, as well as the presence of a gabbroid facies and an alkaline syenitic facies associated with it. The sill at the Acheron shows a faint teschenitic relationship and also a gabbroid facies. The ordinary rock exhibits in the hand-specimen a dark-grey colour and a tendency to rapid weathering, by which it takes on the appearance of a greenish granular incoherent mass. Amygdaloids of natrolite occasionally occur. Under the microscope the rock is seen to be composed of a holocrystalline aggregate of the following minerals, labradorite, up to 3 mm. in length, usually more or less altered, and sometimes bordered with a feldspar of more sodic character with an index of refraction lower than balsam; occasional orthoclase; augite, up to 5 mm. in length, purplish in colour as a rule, and slightly pleochroic, but occasionally greenish, the former passing at times into uralitic brownish hornblende; in the gabbroid facies it takes on diallagic structure; olivine very sparingly in the unaltered form, but probably represented by aggregates, in which small grains of the mineral are included; occasional brownish hornblende; reddish-brown flakes of mica; titaniferous magnetite with leucoxene, and also secondary ilmenite in skeletal forms; needles of apatite; natrolite in radiating bundles of fibres, and polarization colours about those of quartz and a very low index of refraction, giving a rough surface to the mineral in the slide. In addition to these minerals, there is probably a very little nepheline, and also occasional analcite, from which the natrolite is derived in some cases, although in others it is apparently derived from feldspar. There is also a considerable amount of decomposition-product, brownish or yellowish-green in colour, some of which is chlorite, and in some cases much carbonate in cavities and occupying the spaces between the other minerals; there is also occasional secondary quartz. It is not clear what mineral has furnished these alteration-products, but occasional grains of olivine included in them suggest that it represents this mineral, seeing also that such alteration-products are derivable from olivine.

There is a considerable variation in the amount of the feldspars in different slides; in some cases it forms by far the most important constituent, and then again it is of minor importance. There is a wide range of coarseness, some of the slides showing a rock with the texture of an ordinary dolerite and others distinctly gabbroid, the essential composition of the different facies being substantially the same. I have not come across any form corresponding with the syenitic variation of the Rakaia sill described by Hutton as occurring here (1889, pp. 145–46) is merely a coarser version of the gabbro described by Cox (1926, pp. 104–5); but the analysis (No. 3, p. 46) hardly bears this out. The sample submitted for analysis was one, in which natrolite was not obvious, taken from the main mass of the sill near the coal-mine, but it was found especially difficult to get a piece even slightly weathered and of average composition. I can only regard the disagreement of the analysis as compared with the results of the microscopic examination of the general run of the rock as being due to the sample submitted for analysis being more deeply decomposed than it appeared from casual inspection, a fair proportion of the material of the feldspars and related minerals having been removed in solution. As the analysis stands, it certainly suggests that this piece of the rock has a picroitic relationship. (Cf. Analyses cited by Washington: “Petrology of the Hawaiian Islands,” Amer. Jour. Sci., vol. 6, 1923, pp. 346–47.) This is, of course, perfectly possible, considering the variability shown by the rocks from the same occurrence throughout the area. There is the case of the sill at the Rakaia, and variability is also extremely well shown by the intrusions in the neighbouring area at High Peak.

A rock analogous to the Acheron sill occurs in this area, about a couple of miles to the east of the homestead, as a single or perhaps a double sill. This exhibits a finer and a coarser-grained facies, sometimes grading into one another and again at times showing well-defined differentiation, but the coarse facies never being as coarse as that at the Acheron. The minerals present are the same but exhibit more definitely alkaline characters, the augite is more titaniferous and occasionally shows a greenish fringe, and, in addition to the analcite and natrolite, nepheline is definitely present.

One sample of the rock is porphyritic, with phenocrysts of labradorite; much olivine in grains; and augite; in a holocrystalline groundmass, where the augite is grouped in agglomerations of small purplish grains, and the feldspars as laths occupying adjacent areas, the two minerals being in general separated. There are large skeletal crystals of titaniferous magnetite and patches of analcite, and the feldspars of the groundmass consist of plagioclases, some higher than balsam as well as some lower than balsam, the latter with an extinction angle of albite. The coarser varieties appear to be more acid, and to contain more analcite, natrolite, and orthoclase feldspar.
A very interesting differentiate of this magma occurs as a dyke or sill about half a mile south-west of the homestead. This is really a fine-grained syenite. The texture in holocrystalline, moderately fine and even-grained. The main mass of the rock consists of orthoclase associated with a plagioclase of lower index of refraction than balsam. The pyroxene is a purplish augite edged with aegerine-augite, or aegerine-augite itself. There are skeletal crystals of titaniferous magnetite, small flakes of reddish-brown hornblende and mica, analcite, natrolite, and nepheline in small amount. The rock is therefore an alkaline syenite analogous to that occurring as a differentiate in the sill at Rakia Gorge.

The analysis (No. 4, p. 46) was of a sample of the rock selected from the outcrop as being of average character, but neither the analysis nor the microscopic examination shows any decided alkaline features. The norm contains 8-35 per cent. of quartz, but the total percentage of normative feldspars and related minerals does not bring it as high as the critical value required by Washington for the basalts. There is a fair content of calcite and also of titanium oxide as disclosed by the analysis.

The microscopical examination of the rock shows it to be even-grained in texture, and composed essentially of feldspar and quartz, the individual crystals ranging in length on the average from 0.5 mm. to 0.8 mm. The feldspar is labradorite, and no other variety of lower index of refraction than balsam could be detected. The feldspar is generally fresh, but occasionally decayed. The augite is greyish in colour, sometimes very slightly purplish and with an occasional fringe of green. It is moulded on the feldspar and sometimes encloses it ophitically. There are occasional small rounded crystals of olivine in an unaltered condition, and much secondary ilmenite in skeletal forms and grains. There is also a considerable amount of secondary calcite and other alteration-material in patches, though what the original mineral was is not clear. All of it seems to have a higher index of refraction than balsam. The only suggestion of an alkaline character is the very occasional slight green fringe to the purplish augites. It is possible, therefore, that this occurrence may be quite distinct from that with the teschenitic affinities, and more work will have to be done on the locality before the question can be definitely settled.

A dolerite of fairly acid composition but containing olivine occurs in the most easterly patch of coal-measures in this area. It does not, however, show any definite alkaline characters like other intrusions of the locality; but it is possible that portions of the rock may do so, although I have not come across them.

Another series of intrusions of related rocks occurs along the northern border of the rhyolites extending from Rocky Ridge to Pullwool Peak. Outcrops occur at the summit of the ridge above the marble-quarry, just above the gorge of Boundary Creek, in Hood's Bush on the eastern face of Rocky Peak, and on the eastern side of Pullwool Peak. From the position of these occurrences they might be considered as flows belonging to a series anterior to the rhyolites, and therefore more or less contemporaneous with the andesites, since no contact is clearly exposed; but the general character of the rocks as shown by the microscope indicates that they are probably intrusives, and their position may be explained by their having forced their way along the contact of the rhyolites and the underlying sedimentaries, this being a line of crustal weakness, and they thus would date from the time of the other intrusives posterior to the coal-measures, which they resemble lithologically.

They all show a close resemblance, with a characteristic doleritic texture, ophitic structure being at times beautifully developed, and the augites being, as a rule, purplish in colour, bordered at times by a fringe of green. An interesting occurrence is that in Hood's Bush. This rock is dark-grey in the hand-specimen, with feldspar phenocrysts plainly showing. Under the microscope the feldspars prove to be labradorite and are up to 3 mm. in length, and they show definite zonal structure, with inclusions of aegerine-augite arranged parallel to the margins. The augite phenocrysts are purplish in colour and markedly pleochroic. The augites of the groundmass are of two kinds—one purple and slightly pleochroic, and the other an aegerine-augite. Sometimes the purple variety is bordered by the aegerine variety. The former shows an ophitic relationship to the feldspars of the groundmass, which are of labradorite. Olivine occurs in grains, either fresh or altered into a green pleochroic decomposition-product with light polarization colour. There is a considerable quantity of titaniferous magnetite in squarish grains, as well as secondary ilmenite in skeletal forms. Flecks of brownish mica occur sparingly. Analcite is also a constituent, showing high relief; also small grains of a mineral of low polarization colour and index of refraction near that of balsam, which probably corresponds to nepheline.

The rock on the east side of Pullwool Peak is much more acidic in composition than the rock just referred to, in that there is much less augite and olivine present, but the structure is at times most beautifully ophitic, and the greenish margin to the purplish augite is not so pronounced.

The specimens, however, from the head of Boundary Creek closely resemble those from Hood's Bush. Analcite occurs interstitially, and there is the same green pleochroic alteration-product of olivine and pleochroic greenish aegerine-augite. One phenocryst of feldspar 6 mm. in length had a border more basic than the core of the crystal which was proved definitely to be labradorite, although it showed no twinning. Analysis No. 5 on page 46 gives the composition of this rock. Judging by
the amount of normative feldspar it would just come within Washington's criterion for an andesite, although the rock is definitely basaltic in character. The small amount of nepheline in the norm—viz., 1·70—bears out the conclusion as to the moderately alkaline nature of the rock based on the microscopical examination.

Another occurrence of basic rock lies on the opposite side of the gully in which is Hood's Bush, associated with the small outlier of coal-measures to the north-west of Pullwool Peak. This is the most basic of any of the rocks encountered. In the hand-specimen it is dark-grey in colour, somewhat coarse in texture, and liable to disintegration. In section it is holocrystalline, and shows phenocrysts of olivine in a somewhat coarsely crystalline groundmass. The olivine occurs in rounded grains, and occasionally in well-developed crystals up to 2·5 mm. in length; it is much stained and seamed with iron oxides, but is at times quite fresh. The groundmass consists of augites, greyish to purplish in colour, up to 0·5 mm. in length, and also a form which shows a green tint and pleochroic; laths of labradorite; titaniferous magnetite; and a quantity of secondary ilmenite. There is a small quantity of an isotropic mineral filling cavities. This rock is entirely different from any of the others occurring in the vicinity, or, in fact, from any I have met with in the area, notably for the large proportion of olivine that it contains.

I am informed by H. Robb that lying on the rhyolite above the spot where this specimen came from are frequent blocks of a dolerite, much decomposed, and from which crystals of olivine can readily be extracted. He says that boulders of a similar dolerite are frequent along the northern face of Pullwool Peak, though he has never seen the rock in position. It no doubt occurs as an intrusion, and from his description it must contain a constituent more readily decomposable than olivine, which is certainly suggestive of the presence of a mineral which weathered very readily indeed. This conclusion has recently been confirmed by the discovery of the rock in position as an intrusion in rhyolite at a higher level up the hill. The inclusions are a fibrous zeolite, in all probability natrolite.

A basic intrusion also occurs in the gully in rhyolite a few chains above Robb's clay-pit.

(b) POST-TERTIARY — GRAVELS, ETC.

The only sedimentary rocks posterior to the coal-measures are the gravels which cap the downs over wide areas, and also the terrace and river-beds gravels of the present streams. The former are best developed near Sheffield, on the outer fringe of the downs stretching south therefrom; on the downs on both sides of the Selwyn River near Whitecliffs and Glentunnel; near Hart's Coal-mine, on the saddle between the Selwyn and the upper waters of the Waianianihia; and on the downs between the Hororata River and the Upper Waierere near Glenroy, also south of the Hororata River near Rockwood. Fragments occur in other places, such as near the Steventon Mine and on the northern flanks of Abner's Head. This capping is quite thick in places—at times over 100 ft., as is disclosed by the logs of the bores between the Homebush Mine and the Selwyn River. As these gravels contain no fossils, they cannot be definitely correlated with the gravels of the Mount Grey downs; but some of them were certainly antecedent to the glacier-advance, as moraine covers them at times. Occasionally they show well-developed stratification, as in the Hororata River near the greywacke gorge, and in the Hawkins near Waddington. It is probable that the gravels of Racecourse Hill belong here.

Their upper surface is remarkable for its evenness and generally accordant level, between 250 ft. and 350 ft. above the level of the present bed of the Selwyn; and the isolated occurrences no doubt formed remnants of a surface analogous to that of the present plains, which fringed the hills in pre-glacial times. It is possible that some of these gravels are glacial and post-glacial, and represent the fans of streams which issued from the ice front while the ice was advancing and again while it was retreating.

The present streams have incised their beds into this surface, a circumstance perhaps attributable to uplift of the land, or perhaps to other causes, such as variation in the supply of waste, which have exerted a profound influence on the terrace development in the valleys of the Canterbury rivers.

The question of the location of the morainic deposits of the area has been dealt with generally in connection with the particular localities described earlier in this article, and also treated very fully and efficiently for the Rakaia Gorge area by Haast (1879, pp. 386–90) and by P. T. Cox (1925, pp. 108–9). There are two points to note specially concerning these deposits:—

(i) There is positive evidence that ice crossed the Rockwood Range at its western end near Round Top, and also by way of Middle Saddle—evidence based on the smoothing of the landscape and on the presence of large blocks of greywacke lying stranded on the surface of Mesozoic volcanics and of a boulder-clay containing striated stones on the northern slopes of the ridge leading to the saddle. This implies that the ice-stream was at least 2,000 ft. thick at the outlet of the Rakaia Valley on to the plains, an estimate which is supported by the glacial shelves on the flanks of Mount Hutt.
on the south side of the Rakaia. But there may have been some change in the height of the range owing to faulting since Pleistocene times—a supposition partly supported by the observation of P. T. Cox in the Rakaia Gorge, where rhyolites have been thrust over glacial silts in reversed faults. Unless the height of the Rockwood Range has changed appreciably since the glacier-advance, it implies that this great thickness of ice cascaded over the range near Rockwood, and thinned out and disappeared within a distance of two miles from the foot of the range—a supposition which appears to be hardly probable. Traces of moraine, as distinct from fluvio-moraine, do not occur at a greater distance than that from the base of the hills near Rockwood. The peculiar ridge about half a mile west of the homestead is apparently composed of large angular blocks of greywacke and rhyolite, and is therefore probably morainic.

The thinning-out and disappearance of the ice is possible within such a short distance, but it does not appear probable; while an increase in the height of the Rockwood Range since the glacier-advance would serve to solve the problem, especially as there is distinct evidence of faulting in the neighbourhood of such a kind as would produce the suggested effect.

(ii) The next point, as emphasized by P. T. Cox, is that there is distinct evidence in the Rakaia Gorge of two periods of glacier-advance, and this is supported by similar evidence from the valley of the Upper Selwyn near the High Peak Station.

D. ECONOMIC GEOLOGY.

(a) COAL.

The most important economic product of the area has up to the present been coal, and this is likely to continue for a considerable time—in fact, till the area approaches exhaustion, when the clays may be the most important output. The quantity raised up to the present is approximately 800,000 tons. Although the quantity in reserve cannot be predicted with any certainty, it is probable that the amount capable of being mined profitably existing now in the ground does not exceed the amount already raised.

The nature of the coal is disclosed by the numerous analyses published by the Colonial and Dominion Laboratories, and also in the different papers published by Dr. W. P. Evans (1899, 1924, and 1927). It is not maintained that all of these analyses are of the same value, for owing to the advance in methods and the adoption of a standard system the analyses conducted by later analysts are more likely to be not only more complete but also more comparable. The fractions under the headings of F.C. and V.M. of the earlier cases are likely to be different from the results obtained from the same seam in a recent analysis; still, the sum of these taken in conjunction with the sulphur should allow of some measure of comparison being made, and therefore I have thought it wise to include all published analyses in this list if reference is made to a definite locality or to a particular seam. It is hardly worth while to include analyses when the locality of origin is merely given as “Malvern Hills.” The following is the list:

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Homestead

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<td>30-46</td>
<td>39-34</td>
<td>28-16</td>
<td>5-14</td>
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</tbody>
</table>

Church Reserve (— Shrew’s Coal), Selwyn River

<table>
<thead>
<tr>
<th>F.C.</th>
<th>V.M.</th>
<th>Water</th>
<th>Ash</th>
<th>Sulphur</th>
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<tbody>
<tr>
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**JESON'S (= SHEFFIELD).**

<table>
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<tr>
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<th>37-55</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Col. Lab., 1871.</td>
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**GLENROY.**

<table>
<thead>
<tr>
<th>59-90</th>
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<tr>
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</tr>
<tr>
<td>63-20</td>
<td>23-60</td>
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<td>10-00</td>
<td>Col. Lab., 1879. Lower portion, 44 ft. seam.</td>
</tr>
<tr>
<td>61-90</td>
<td>26-80</td>
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<td>10-40</td>
<td>Col. Lab., 1879. Williamson's seam.</td>
</tr>
<tr>
<td>68-00</td>
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<td>16-60</td>
<td>11-00</td>
<td>Col. Lab., 1879. South heading.</td>
</tr>
<tr>
<td>55-90</td>
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<td>9-60</td>
<td>Col. Lab., 1879. Main drive north.</td>
</tr>
<tr>
<td>50-60</td>
<td>33-80</td>
<td>7-80</td>
<td>2-80</td>
<td>Col. Lab., 1879. Main drive east.</td>
</tr>
<tr>
<td>41-90</td>
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<td>26-04</td>
<td>5-19</td>
<td>Col. Lab., 1882. Top.</td>
</tr>
<tr>
<td>38-60</td>
<td>33-06</td>
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<td>5-03</td>
<td>Col. Lab., 1882. Bottom.</td>
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<tr>
<td>34-34</td>
<td>35-13</td>
<td>23-88</td>
<td>6-25</td>
<td>0-45 Col. Lab., 1907.</td>
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<tr>
<td>31-40</td>
<td>41-70</td>
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<td>12-90</td>
<td>4-40 Dom. Lab., 1919.</td>
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<tr>
<td>34-37</td>
<td>57-72</td>
<td>20-10</td>
<td>7-81</td>
<td>0-42 W. P. Evans, 1899.</td>
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**SPRINGFIELD.**

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<th>12-69</th>
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<tr>
<td>38-40</td>
<td>12-00</td>
<td>23-40</td>
<td>26-20</td>
<td>W. P. Evans. 12 ft. above sill.</td>
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**COTY'S FLAT AREA.**

**Hart's.**

<table>
<thead>
<tr>
<th>67-42</th>
<th>16-95</th>
<th>2-12</th>
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<td>2-94</td>
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<td>40-30</td>
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<td>22-90</td>
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<td>0-45 W. P. Evans, 1924. Approx. 16 ft. from sill.</td>
</tr>
<tr>
<td>37-10</td>
<td>28-30</td>
<td>18-64</td>
<td>16-03</td>
<td>0-57 W. P. Evans, 1924. Approx. 12 ft. from sill.</td>
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<tr>
<td>66-30</td>
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<td>3-30</td>
<td>17-20</td>
<td>1-44 W. P. Evans, 1925. Contact with runner.</td>
</tr>
<tr>
<td>49-90</td>
<td>31-50</td>
<td>11-20</td>
<td>14-70</td>
<td>W. P. Evans, 1925. Personal communication. Contact with dolerite.</td>
</tr>
<tr>
<td>32-30</td>
<td>35-00</td>
<td>19-20</td>
<td>13-00</td>
<td>W. P. Evans, 1925. Personal communication. 12 ft. from dolerite.</td>
</tr>
<tr>
<td>30-10</td>
<td>31-50</td>
<td>11-90</td>
<td>14-70</td>
<td>W. P. Evans. Personal communication.</td>
</tr>
<tr>
<td>32-30</td>
<td>35-00</td>
<td>19-20</td>
<td>13-00</td>
<td>W. P. Evans. Personal communication.</td>
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**Levick's (= S. Helen's or Sutherland's).**

<table>
<thead>
<tr>
<th>31-40</th>
<th>37-40</th>
<th>27-06</th>
<th>3-25</th>
<th>0-52 W. P. Evans, 1899.</th>
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**BROCKLEY.**

<table>
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<tr>
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<td>4-89</td>
<td>39-00</td>
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</tr>
<tr>
<td>53-29</td>
<td>32-94</td>
<td>12-65</td>
<td>2-02</td>
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</tr>
<tr>
<td>52-10</td>
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<td>31-20</td>
<td>12-22</td>
<td>1-40</td>
<td>0-49</td>
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<tr>
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<td>2-95</td>
<td>5-05</td>
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<td>34-00</td>
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<td>17-42</td>
<td>0-80</td>
<td>0-60</td>
</tr>
<tr>
<td>48-00</td>
<td>37-96</td>
<td>12-22</td>
<td>1-22</td>
<td>0-55 W. P. Evans, 1899. Altered brown coal, old working.</td>
</tr>
</tbody>
</table>
The list of analyses shows that the ordinary coal is a lignite or brown coal of no special excellence, but still most useful for household purposes. However, the relative importance of this type of coal must not be judged from the number of analyses of such coal catalogued, since the occurrence of an altered coal of improved quality usually resulted in a number of analyses being made owing to the interest it aroused. A large number of the records are therefore of altered coals and those approaching anthracites or mineral cokes. Some of these show at times little or no volatile matter. The whole series exhibits a relatively high percentage of ash, which, of course, diminishes the calorific value of the coals substantially. The highest percentage of water noted is in the case of the Glenroy coal—viz., 37.55 per cent.—and this specimen was taken directly from the mine and had not been exposed in any way to rain or atmospheric moisture. Some of the small seams in Bush Gully show a surface approximating to that of a cannel, but no analyses of these are available.

The varying chemical composition of the altered coals has been discussed by Evans, and their alteration can in every case be attributed to the action of intrusions. The degree of alteration diminishes as a rule as distance from an intrusion increases, whether considered along the seam or across the measures, for the same seam may in one place be an ordinary lignite and in another an altered coal or even an anthracite. The distance away from the intrusion at which alteration occurs is somewhat striking, amounting in some cases to over 100 ft., so that a great thickness of beds of low conductivity is not able to mask the effect of heat. Of course, a notable proportion of the alteration may, as Evans points out, be credited to the pressure induced by the mechanical effect resulting from the intrusion of masses of igneous rock.

The falling-off in the extent of alteration is not always dependent on the distance from the intrusion, the action appearing at times to be selective, so that seams near by may be little altered, while others at a distance are substantially changed. Such anomalies may admit of simple explanation: for example, the marked alteration of the Acheron coal was somewhat difficult to explain when only the big sill was looked on as the source of the change, whereas a chance slip in the bank of the river disclosed a small sill close to the coal, which was certainly the chief modifying agency. There are other cases which no doubt can be explained in some such simple way, but in some a solution of the problem is not immediately forthcoming. It may be that at times pressure is a more important agent of change than the heat, and this may affect the beds at some distance from the intrusion rather than those in close proximity.

Bituminous coal has been reported from various localities, but I have seen none. However, some of the analyses in the above list might quite well belong to a coal of that variety. I think, all the same, that such cases are merely stages in the progressive alteration of a seam from lignite to

<table>
<thead>
<tr>
<th>P.C.</th>
<th>V.M.</th>
<th>Water</th>
<th>Ash.</th>
<th>Sulphur</th>
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<td>68.30</td>
<td>14.70</td>
<td>3.90</td>
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**Rakaia Gorge.**

- Col. Lab., 1868.
- Col. Lab., 1883. Outcrops on Rakaia River, upper seam.
- Col. Lab., 1883. Outcrops on Rakaia River, lower seam.
- W. P. Evans, personal communication, 1925. 10 ft. below sill.
- W. P. Evans, personal communication, 1925. Lowest altered, near water-level.

**Kowar Bridge.**

- Col. Lab., 1871.
- Col. Lab., 1871.
- Col. Lab., 1871.
- Col. Lab., 1871.

**Big Ben.**

- Col. Lab., 1871.

**Acheron.**

- Col. Lab., 1871.
- Dom. Lab., 1912.
- Dom. Lab., 1912.
- W. P. Evans, 1924.

- 37.55 per cent. —and this specimen was taken directly from the mine and had not been exposed in any way to rain or atmospheric moisture. Some of the small seams in Bush Gully show a surface approximating to that of a cannel, but no analyses of these are available.

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The falling-off in the extent of alteration is not always dependent on the distance from the intrusion, the action appearing at times to be selective, so that seams near by may be little altered, while others at a distance are substantially changed. Such anomalies may admit of simple explanation: for example, the marked alteration of the Acheron coal was somewhat difficult to explain when only the big sill was looked on as the source of the change, whereas a chance slip in the bank of the river disclosed a small sill close to the coal, which was certainly the chief modifying agency. There are other cases which no doubt can be explained in some such simple way, but in some a solution of the problem is not immediately forthcoming. It may be that at times pressure is a more important agent of change than the heat, and this may affect the beds at some distance from the intrusion rather than those in close proximity.

Bituminous coal has been reported from various localities, but I have seen none. However, some of the analyses in the above list might quite well belong to a coal of that variety. I think, all the same, that such cases are merely stages in the progressive alteration of a seam from lignite to
igneous rocks had the power to alter the coal materially, extensive exploratory work was carried out on nearly all of the small occurrences of better-grade coal in order to see if thick seams existed, but in all cases the grade of the coal fell off and anthracites passed into ordinary lignites at a reasonable distance from the intrusions. The disappointed prospectors in most cases abandoned their work when the coal reverted to the ordinary form. This is the history of most of these operations.

As far as the mode of deposition of the coal is concerned, there seems to be no evidence to support the theory that the vegetation grew on the spot where the coal was formed; rather, all the circumstances point to its having been formed from drift material, and that the conditions of deposit were similar to those of the sands and clays associated with it.

It has been pointed out already that the prolific horizon is one just under the Selwyn Rapids and oyster-beds or their stratigraphical equivalent—i.e., the Glentunnel horizon of Morgan. This is the level at which occur the most valuable seams at Bush Gully, Springfield, Glenroy, Hart’s, and Steventon. The occurrence at the last two places is not, as Haast suggested, due to the presence of an older set of measures with altered coal, but it may be attributed to the faulting-down of the area. Although coal does occur below the Glentunnel horizon, the seams are thin as a rule, though the quality may be slightly better. With the possible exception of the seams in the bush in Bush Gully and at Brockley, coal is not found near the base of the Senonian beds, and in no case at a higher level than the Selwyn Rapids and the oyster horizon. It is thus practically restricted to a somewhat narrow belt in a definite stratigraphical position.

On this line the seams are not continuous. There are long sections where none appear, either on the surface or as the result of investigation by exploratory drives. The most prolific sections are those in the immediate vicinity of Glentunnel near the Homebush Mine, near Glenroy, and in the faulted outliers in the Cordy’s Flat area. Even in these parts the beds are not continuous; they are lenticular in shape when traced along the strike, either disappearing entirely or passing into stone. The lenses overlap to some extent. They also thin out or become stony when followed to the dip. Whether they increase in thickness again is not known, since following them in that direction would prove expensive, and with entirely problematical results. No doubt their continuation in that direction could be easily proved by bores, but even if seams of reasonable thickness were located they would in all probability not pay to work owing to difficulties in the way of mining.

The area along the strike in the vicinity of the Homebush Mine has been fairly extensively bored to the depth at which coal was likely to occur, but with disappointing results. The most promising parts of the field appear to me to be those near Glenroy, where there is a likely extension of payable seams through the ridge into the upper part of the basin of Wairere Creek, and especially the Steventon area, where there is a possibility that the coal lives for some distance down to the dip, and a certainty that it continues along the strike in the direction of the Hart’s area. There is also a possibility that a considerable area of coal exists near the old Hart’s Mine in the direction of the upper valley of the Wainianiniwha. The surface of the country is masked here by gravel deposits, but the extent of payable coal could easily be determined by boring.

The other areas where coal has been mined do not promise any reasonable amount of payable coal, with the possible exception of the area near Springfield. These predictions are made, of course, under present conditions of the demand and supply of coal from other fields. When these latter show signs of exhaustion some of the seams and some of the areas in the Malvern Hills not payable now may be exploited profitably, and specially will this be the case if steps be taken to use the coal on proper lines and not according to the wasteful methods obtaining at present. Considering the conditions of the field, it would be foolish to attempt to give an estimate of the amount of coal available therein, but, making allowance for all known factors, it appears unlikely that the future yield will exceed what has been obtained up to the present, unless exploratory work in the direction of the dip reveals unexpected and more promising conditions.

(6) CLAYS AND SANDS.

The clays of the Malvern Hills are considered an important potential source of wealth, and their true capabilities should therefore be carefully estimated. They have already been used extensively in the manufacture of drainpipes, firebricks, &c., as well as ordinary building-bricks, the principal manufactory being located at Glentunnel, known as the Homebush Brick and Tile Works. This was formerly controlled by the Deans Estate, but recently it was disposed of to Messrs. McSkimming, of Otago, who have had wide experience in the treatment of similar clays. Clay has also been obtained from several other places—e.g., Steventon, Whitecliffs, Sheffield, and Springfield—and sent
to Christchurch brickyards to be treated there. Although some of the clays are called fireclays, none of those tried or tested exhibits high-enough refractory properties to merit this designation. Their physical and chemical characters will be dealt with by Mr. Page later in this report, and I will confine my remarks as far as possible to their geological features and their occurrence in the field.

The horizons at which clays of any value are encountered are (1) near the base of the coal-measure series, and (2) about the Glentunnel coal horizon. The former occurs just above the greywacke basement, and the latter in conjunction with the most prolific horizon for coal. Between the two are the levels at which conglomerates are the dominant stratigraphical features. The clays belonging to the lower horizon become more sandy at higher levels before they pass into conglomerates, and above these beds there are layers of not completely decomposed material of the same origin as the conglomerates, passing into highly siliceous clays, the so-called "gannister," sometimes interstratified with clays of a normal-type, before they pass up into the clays associated with the coal. These lie both above and below the coal, sometimes interstratified with the seams, but in no case have I seen conditions which suggest that the clays are "under-clays" in the sense in which that word is frequently used. The fairly high percentage of alkalis in some of these clays, such as that given by Nos. 3 and 9 in the list of analyses, also supports the contention that they are not under-clays. As a general rule, the best clays are at the Glentunnel horizon, and not near the base of the series.

A feature of these clays as they occur is the extreme variability in the nature of the deposit both along the strike and across it. Patches of good clay peter out at times in a few yards. The higher-grade clays are extremely irregular in disposition, and this is likely to be a factor of extreme importance in devising methods for utilizing the resources of the area satisfactorily. Unfortunately, few deposits occur on the surface, the thick covering of gravel which masks extensive areas, and also the usual covering of soil over areas not so masked, render it extremely difficult to locate the deposits. They will, in general, have to be mined in the same way as coal, and this makes their exploitation a matter of difficulty and expense. The pit at Steventon appears to me the one where this disability does not exist to any great extent. There does not seem to be any method which might be advantageously employed in locating good patches. Boring appears to be unsatisfactory in practice when such friable and soft material has to be dealt with, unless carried out with extreme care, and the only hope appears to be the chance striking of payable deposits or of coming across them while coal-seams are being exploited. As the best clay occurs in close association with coal-seams, as at Glentunnel and Glenroy, this appears to be the most promising method of locating good deposits. Therefore it is clear that the coal-mining and the clay industries are closely associated when the probability of success is estimated, especially as coal is an essential for carrying on the latter.

A microscopical examination of the residues obtained by Mr. Page and also of samples in bulk gives some indication of the origin of the clays. The chief constituent of the concentrates is quartz. This is what might have been expected. The size of the grains varies from a general average of the larger grains of 0.5 mm. diameter down to the finest fragments; usually they are about 0.2 mm. in diameter. There is a certain amount of feldspar of lower index of refraction than that of balsam, some of it showing polysynthetic twinning; therefore there is an acidic plagioclase present in addition to the orthoclase. There is also some feldspar with higher index than balsam, and repeatedly twinned, but I cannot say anything further about this than that it is a moderately basic variety. The flakes of feldspar at times show little sign of alteration, but again they are completely kaolinized. Their size is about that of the average quartz-grain or a little smaller. Biotite occurs freely, and also muscovite, though some of the latter may, after all, be merely bleached biotite. There is a considerable amount of kaolinite in definite crystals, and also clay substance which coats the grains of quartz and feldspar and renders them more or less opaque. The analytical results show the presence of a fair amount of titanium dioxide, and this necessitates the presence of some titanium mineral, probably ilmenite or leucoxene. The latter was not seen, but it is possible that some of the dull grains with higher index of refraction than balsam are, after all, leucoxene. Very occasional grains of augite and of zircon also occur.

It will be seen that the residues as obtained by Mr. Page come within the fraction called "fine sand" in a recent paper by F. P. Grout, entitled "Relation and Composition of Clays" (Bull. Geol. Soc. of America, vol. 38, pp. 391-415), and also bears out the statement contained therein that the fractions included under "fine sand" are dominantly composed of quartz.

The only possible sources of the clay as far as can be seen are the Triassic and Jurassic sedimentaries and the Jurassic and Cretaceous volcanics—i.e., andesites and rhyolites. By far the greater part of the conglomerates of the coal-measure series consists of material derived from the rhyolites, and it is therefore reasonable to infer a similar origin for the interstratified and associated finer-grained sediments. The presence of biotite, an important constituent of the rhyolites, supports this view; but I have not come across any garnet either in the clays or sands, as might have been expected if this were the source of supply. The feldspar also shows that it belongs to species occurring freely in the rhyolites. The sand associated with the clays contains an occasional crystal of augite, suggesting 5—Geol. Mem. No. 1.
more basic volcanics as furnishing a part of the material, so that some of the more basic feldspars of the clay may well have been derived from the same source. No doubt some material was derived from greywackes and associated sedimentaries, and these might furnish a part of the muscovite contained in the clay, since this mineral does occur in the form of shreds in the greywacke.

The "gannister," wherever it occurs, is obviously of rhyolitic origin, and there are forms of this where the rhyolitic material has not been completely decomposed, which indicates an intermediate material between the rhyolites and the clay.

It has been pointed out by P. T. Cox that it is probable that the rhyolitic conglomerate at Rakaia Gorge derived its material from the east, and not from the west; and the same may be true of the rhyolitic sedimentaries of the Malvern Hills, as has been pointed out previously (p. 46). If this is so, then the comparative poverty of the clays in greywackes and andesites is explained, since it came from areas where those rocks were but slightly developed, or, if developed, were masked by rhyolites.

At both horizons where clay occurs it is marked by extreme fineness of grain. There is no coarse material present, and the largest grain of quartz measured did not exceed 1 mm. in diameter. The material must, therefore, have been laid down in very still water, while the conglomerates intermediate must have been deposited where waves or currents were stronger. Seeing that the materials are so fine, it is not remarkable that the decomposition of some of the feldspars is usually complete. This completeness perhaps indicates also that the climate of the area was moist, a condition no doubt favourable for the growth of the forests which formed the coal-seams.

**REPORT ON THE EXAMINATION OF A NUMBER OF CLAYS FROM THE FOOTHILLS IN THE SPRINGFIELD AND NEIGHBOURING DISTRICTS.**

**By S. Page.**

**General.**—The value of clays from the constructional side lies in their peculiar physical properties. With water they form plastic masses, sticky and impervious, readily shaped, and with strength and toughness enough to retain fairly elaborate forms while still wet. On exposure to air the mechanically held water dries out almost completely, the mass contracts more or less and becomes stiff and fairly strong, though usually still soft enough to be scratched with the finger-nail. Both strength and hardness vary a good deal and are retained indefinitely in the absence of water. In the sun-dried bricks of Mesopotamia both are considerable.

Heated to 500° or 600° C., chemically combined water is lost, commonly without contraction; the strength and hardness increase and are retained on wetting. However, alternate wetting and drying, with ordinary climatic temperature-changes, bring about slow breaking-down to a soft powder, more or less hydrated again, corresponding more or less to the weathering of natural shales. At about 900° to 1000° C. contraction sets in again with ordinary clays, the strength and hardness increasing till the burnt material can no longer be scratched with a knife and is said to be "steel-hard." This product is apparently permanent—at least, to all ordinary conditions of the earth's crust.

Usually clays, whether formed where found, residual clays, or removed by and deposited again from water (transported clays), contain a variety of matter in addition to the true clay—sand, lime, mica, feldspar, iron oxides, &c. All of these affect the physical properties. Finely divided silica, ferrous oxide, and silicates containing potash or soda either melt easily or interact with each other and with the clay substance to form more or less easily fusible compounds. Hence impure clays at and above 1000° C. may have the solid dehydrated clay-particles cemented together by the viscous fused material which fills the pores, causing shrinkage and greatly increased strength. Higher temperatures and larger proportions of fusible material allow this action to proceed until the pores are mostly filled and the product is impervious to water—e.g., stoneware. Hence the potter's definition, "Vitrifiable clays are those which are impervious to water after being fired." China clays are so free from fluxes that they remain completely porous at the highest kiln-temperatures and do not vitrify.

The volume-changes on heating are the net results of a number of actions. As the fluxes melt, the liquid produced draws the unfused particles closer and closer together and dissolves some of them, resulting in decrease of porosity and in shrinkage. On the other hand, fusion of feldspar and mica gives an increase of volume—about 6 per cent. with mica; while the forms of silica stable at high temperatures have about 14 per cent. greater volume than the low-temperature forms. Also, the general effect of temperature-rise on solids is expansion; hence in the burning of clays contraction extends up to vitrification, and beyond that the mass expands and porosity increases—the overfiring stage. The amount of shrinkage increases with the water content of the plastic stage and the porosity (in vitrifiable clays), and is decreased by uncombined silica, which expands throughout, though irregularly; hence the shrinkage varies greatly, ranging from under 4 per cent. to over 20 per cent.

If resistance to high temperature is required, as in firebricks, the purer the clay the better. Highly refractory clays are usually comparatively pure. Even in such clays plasticity, shrinkage, and mechanical strength are by no means constant. Friend ("Inorganic Chemistry," vol. 3, p. 103)
says, "Chemically, clays are impure complex alumino-silicic acids, the characteristics of a clay being dependent upon the particular acid present, on its state of hydration, and the impurities associated with it." The plasticity and binding-power so characteristic of clay are dependent also upon the mechanical condition.

Dr. Armstrong ("Chemistry of the Twentieth Century") says, "Clays stirred about with water break down into their natural state of fine subdivision, which the potter cannot alter." These fine particles are less than 0.002 mm. (1/150,000 in.) in diameter, and are probably much the smallest solid particles found commonly in inorganic nature—small enough to show Brownian movement, and perhaps on that account to remain long in water suspension. "Washed china clay, English, consists of particles ranging from 0.03 mm. down to 0.006 mm. (1/17,500 in.)" (Friend, "Inorganic Chemistry," p. 77.) About 0.1 per cent. each of sodium silicate and sodium carbonate added to a stiff clay suspends the clay, destroys its viscosity, and makes it thin and fluid enough to be pumped through 1 in. pipes. Run into plaster moulds, which absorb the water and the alkalies, the clay remains in suspension. The dispersing action of an acid or a salt causes a frequently visible flocculation, the new aggregates being large enough to settle and leave a clear liquid. Alkalies and sodium silicate in minute amounts reverse the action, setting the minute individual particles free and sending them into suspension again.

"Alkalies deflocculate clay, intensifying its stickiness and impermeability, and causing it to remain suspended in water for long periods. Acids and salts added to puddled clay cause temporary loss of (a) plasticity, (b) tendency to go into suspension, (c) impermeability." ("Second Report, Colloid Chemistry," p. 77.) About 0.1 per cent. each of sodium silicate and sodium carbonate added to a stiff plastic mass containing 20-25 per cent. water deflocculates the clay, destroys its viscosity, and makes it thin and fluid enough to be pumped through 1 in. pipes. Run into plaster moulds, which absorb the water and the alkalies, the clay solidifies. Clay castings thus made are denser and stronger than articles made from the same clay in plastic state. The impurities in clays are mostly less colloidal and less sensitive to alkalies; hence such a clay emulsion, diluted, allows the flocculated and coarse impurities to settle out, while the deflocculated clay remains in suspension. The dispersing action of alkalies on clay is well illustrated in the great artesian system of north-east Australia. Much of the artesian water, although obtainable in acid districts, is useless for irrigation, as it is alkaline, and therefore destroys the granularity essential to fertile soil, causing it to pack close and hard.

Clays are conveniently classified according to their behaviour to heat. Refractory clays, according to Mellor, are such as do not soften below 150° C. Refractory clays burning white are further classified as china or ball clays, while those which develop colour, being valueless in fine pottery, constitute the fireclays. Mellor divides fireclays into three grades—(1) low, softening between 1600° and 1750° C.; (2) medium, softening between 1650° and 1750° C.; and (3) high-grade, softening above 1750° C. The Institute of Gas Engineers defines two grades only—No. 1, where no softening occurs below segercone 30 (1670° C.), and No. 2, where softening occurs above cone 20 (1680° C.) but below cone 30. Fireclays are mostly associated with coal-seams, and are usually much compacted, or even hardened into shales by long-continued pressure, possibly assisted by deflocculating agents. This dense character, however, is lost on working up.

Firebricks have to stand very severe conditions of service. Not only must they retain strength at high temperatures, but they are subjected to sudden and violent temperature-changes, to the direct action of flames oxidizing and reducing, to the chemical action of vapourized substances and flue-dusts, and to the more severe chemical action of molten slags, acidic or basic.

Dense compact structure, as given by highly plastic clays, or clays worked under pressure or deflocculated by alkalies, tends to give strength, but is also greatly liable to crack under rapid heating or cooling. Open porous structure, as obtained by admixture with grog (highly burnt and pulverized clay or brick) or with organic material (as sawdust, which burns out and leaves cavities),
resists cracking, but is weak. The character of clay products can be considerably affected by addition of refractory materials. Those used are—

1. Grog (highly burnt fine clay or firebrick mixtures).
2. Alumina (as bauxite, a hydrated alumina oxide; melting-point, above 2000°F.).
3. Magnesia.
5. Silica (melting-point—quartz, 1600°–1750°F.; tridymite, about 1625°).

In American firebricks there is usually found a large proportion of very coarse grains, ranging from 1 mm. to 5 mm. diam. (¼ in.), these grains being angular or rounded, and consisting of feldspar, quartz, clay, or grog.” (Weber, Trans. Am. Ceramic Soc., 1904.) New Zealand firebricks (West Coast) may contain quartz-fragments over ¼ in. in length. Grog is added in large amounts, to the limit that the plasticity of the clay will permit, as much as two parts grog to one of raw clay being not uncommon. This greatly reduces volume-changes during heating, but tends to reduce strength and does not much affect refactoriness. Carbon is used in the forms of graphite and retort carbon in amounts of from 25 to 50 per cent. of the mixture, and raises the softening-point materially. Silica is usually added in very coarse form, to offer the least possible surface. Finely divided silica comes into sufficiently great surface contact with the clay and the basic constituents, lime, and magnesia to chemically react and form more or less readily fusible compounds; hence coarse silica will raise, and fine silica reduce, the refractoriness of a given clay. Dr. H. Riss, New Jersey Geological Survey, found that New Jersey firebricks are reduced in fusing-point 4 or 5 cones (about 100°F.) by grinding to pass a 100-mesh sieve.

Fine siliceous material can be used satisfactorily only where it forms the main part of the mixture. Up to about 90 per cent. SiO₂ the fusion-point decreases as silica increases; from that point the fusion-temperature rapidly rises with increasing SiO₂ content. Commercial silica bricks contain only enough clay to act as a bond—up to 10 per cent. The refractoriness has been summed up as depending upon the total fluxes (the metals other than alumina), the silica percentage, and the coarseness of grain.

R. F. Weber (Trans. Am. Ceramic Society, 1904) says, “None of the American firebricks fusing above cone 30 (1670°F.) have over 60 per cent. silica, while in those fusing below this cone few have less than 60 per cent.” Silica may thus be a greater element in lowering refractory character than the bases usually considered as the fluxing agents in clays, the high-temperature forms, tridymite and cristobalite, being more chemically active than quartz. Of forty-four European firebricks examined by Weber, half withstood a temperature of 1670°F. and none failed below 1580°F.

The clays here reported upon were all associated with coal deposits and contain considerable amounts of impurities—whether initially present, added in transportation, or absorbed by the colloidal clay from percolating water there was not much evidence to show. Apart from carbonaceous matter, present in most, and in large amounts in some, the main residual matters seen after washing off the clay were very fine siliceous sand and fine scales of clark mica. The cracks and fissures were frequently lined with thin layers (films) of limonite in such fine state of division that it readily washed off with the clay. All were free from grit, nothing being retained on a 30-mesh screen.

In some of the deposits on hill-slopes the upper and surface layers contained much iron oxide, while the lower layers, particularly those below the coal, contained much less. This suggests recent contamination by downward percolation, the vegetable matter in the upper layers yielding dissolved ferrous compounds where waterlogged and air-free, and these draining down through the crevices and cracks in the clay-beds below. In these beds entangled or even occluded air might cause reoxidation and deposition. Most of the clays when dry held much occluded gas, and some after ignition again absorbed air considerably on exposure.

The heat tests were made upon briquettes 1½ x 1½ x ⅜ in. made in a plaster mould with hand-pressure. Upon the upper face were scratched two parallel lines, 1 in. apart, immediately after removal from the mould. The distance between these lines was used for determining the linear contraction.

All the samples, in the form of powder passing a 20-mesh screen, were mixed with water to uniform consistency, and moulded at once. No weathering or prolonged soaking was given. The harder and more compact samples tended to increase in plasticity on standing in the moist condition after working up. The briquettes were air-dried thoroughly and then heated—first, in an electric resistance oven at 650°C. as determined by the melting-point of aluminium; second, in a gas-fired furnace, natural draught, to 900°C., determined by a Cambridge Instrument Co.’s thermo-couple pyrometer; third, in a blast gas-furnace to temperatures which varied between 1350° and 1400°C., the temperature being found by a Ferri absorption pyrometer of the Cambridge Instrument Co.; fourth, in a crucible-steel furnace, fired with hard coke, chimney draught, up to 1500°C. temperature measured by absorption pyrometer. In each case the samples were kept two hours at or about the maximum temperature. All the clays were plastic enough for brickmaking. In the absence of any better method of measuring the plasticity, it is given in terms of the percentage of water added to the dry clay to give working consistency.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Melting Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina</td>
<td>2000°F</td>
</tr>
<tr>
<td>Magnesia</td>
<td>1625°F</td>
</tr>
<tr>
<td>Carbon</td>
<td>100°F</td>
</tr>
<tr>
<td>Silica</td>
<td>1600°–1750°F</td>
</tr>
</tbody>
</table>

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[Image of table]
Foreign material: 10 grammes of each sample were rubbed down with water in a porcelain basin, and the fine granular residue left on prolonged washing was dried, weighed, and reported as residual sandy matter. In all cases this was very fine. In a number the sand seemed to form the nucleus of larger granules, each particle being embedded in a firmly adherent clay coating. In no case was the mica so embedded; it was always strikingly clean and bright.

For briquette results see Table 1.

The outstanding feature of these tests is that most of the clays fail to reach the standard set for refractory clays for firebricks. Nos. 1, 10, 11, and 16 would class as No. 2, the lower grade in the gas engineers' system, softening between 1500° and 1670°, and in Mellor's system as the lowest of his three grades, softening between 1500° and 1650°. Further testing of these is desirable, but a suitable furnace for temperatures above 1500° C. was not available.

Next to refractoriness in firebricks shrinkage is most important. This is rather high in most. No. 5 is fairly low—0.6 to 2 per cent. total shrinkage; Nos. 8, 9, and 15 have 9 per cent.; the rest range from 12 to 15 per cent.—distinctly high. In the most refractory clays, Nos. 1, 10, 11, and 16, it is about 15 per cent. As these are all fairly plastic, additions of grog or quartz could be made sufficient to largely reduce contraction.

Chemical examination: Owing to the large variation in organic matter, the analyses were made on the freshly ignited samples, in order that the results might be more readily compared.

The clays are notably high in silica, none containing less than 67 per cent. The free silica is very finely divided. The clays leave no residue on a 30-mesh screen and very little on a 60-mesh; hence the free silica is very reactive, and is probably the main factor in the low softening point. As already noted, none of the highly refractory American firebricks tested by Weber has over 60 per cent. of silica, though some of them have an extremely high percentage of total fluxes. Fairie, in "Notes on Pottery Clays," gives the range of silica in British fireclays as from 43 to 68 per cent.

The amount of alumina is not high, lying between 17 and 27 per cent. In British fireclays it gives the range of silica in British fireclays as from 43 to 68 per cent.

Foreign material: The foreign minerals readily recognized by the naked eye are silica, limonite, and dark mica. Iron oxide, and the alkaline and alkaline earth metals, are commonly grouped as "total fluxes." Fe₂O₃, however, is infusible and inert in an oxidizing atmosphere until high temperatures are reached, and Ries showed in 1903 that titanic acid is an active flux, 2 to 3 per cent. added to a high-grade kaolin lowering its fusing-point two or three cone numbers. Weber "now generally recognized that TiO₂ is absent from few clays." In a reducing atmosphere the iron, as ferric oxide, becomes extremely active, readily forming very fusible compounds with the clay and silica. The "total fluxes" (metallic oxides other than alumina) here range from 3 to 7.5 per cent. It is usually considered desirable that the total should not exceed 4 per cent. Weber, however, quotes numerous cases of Continental fireclays with 6 per cent. of total fluxes fusing at and above cone 32 (about 1700° C.). He also shows that in American firebricks with a refractoriness of cone 30 or over the average flux content is about 8.6 per cent.—considerably higher than in the clays here dealt with.

It would appear that up to the present time a knowledge of the chemical composition is of little value in judging refractory character, the nature of the clay substance and the state of subdivision of the free silica are active factors. In these local clays the latter appears to be the controlling factor.

Tables showing the results of chemical analysis and of the briquette tests are appended.

### Table 1.—Composition.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
<th>9.</th>
<th>10.</th>
<th>11.</th>
<th>12.</th>
<th>13.</th>
<th>14.</th>
<th>15.</th>
<th>16.</th>
<th>17.</th>
<th>18.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica (SiO₂)</td>
<td>70-40</td>
<td>72-20</td>
<td>74-47</td>
<td>67-30</td>
<td>79-96</td>
<td>70-16</td>
<td>72-07</td>
<td>75-45</td>
<td>67-91</td>
<td>97-35</td>
<td>97-50</td>
<td>97-80</td>
<td>95-80</td>
<td>90-70</td>
<td>91-20</td>
<td>97-20</td>
<td>97-80</td>
<td></td>
</tr>
<tr>
<td>Alumina (Al₂O₃)</td>
<td>24-74</td>
<td>21-50</td>
<td>17-00</td>
<td>24-45</td>
<td>14-42</td>
<td>25-12</td>
<td>24-98</td>
<td>23-06</td>
<td>24-19</td>
<td>20-60</td>
<td>29-02</td>
<td>12-80</td>
<td>24-80</td>
<td>17-37</td>
<td>14-27</td>
<td>24-64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferric oxide (Fe₂O₃)</td>
<td>0.97</td>
<td>0.70</td>
<td>0.50</td>
<td>0.10</td>
<td>1.10</td>
<td>0.70</td>
<td>0.77</td>
<td>1.50</td>
<td>1.40</td>
<td>1.80</td>
<td>1.30</td>
<td>1.50</td>
<td>0.90</td>
<td>0.97</td>
<td>1.10</td>
<td>1.60</td>
<td>0.65</td>
<td>0.65</td>
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<tr>
<td>Titanium oxide (TiO₂)</td>
<td>0.57</td>
<td>0.37</td>
<td>0.24</td>
<td>0.10</td>
<td>1.10</td>
<td>0.10</td>
<td>0.87</td>
<td>0.72</td>
<td>0.40</td>
<td>0.00</td>
<td>0.78</td>
<td>0.54</td>
<td>0.65</td>
<td>0.76</td>
<td>0.83</td>
<td>0.86</td>
<td>0.89</td>
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<tr>
<td>Calcium oxide (CaO)</td>
<td>2.32</td>
<td>1.02</td>
<td>1.02</td>
<td>1.38</td>
<td>0.00</td>
<td>1.01</td>
<td>0.96</td>
<td>0.87</td>
<td>0.90</td>
<td>0.51</td>
<td>0.68</td>
<td>0.62</td>
<td>0.80</td>
<td>0.84</td>
<td>0.86</td>
<td>0.89</td>
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<tr>
<td>Magnesium oxide (MgO)</td>
<td>0.47</td>
<td>0.47</td>
<td>0.72</td>
<td>0.54</td>
<td>0.54</td>
<td>0.70</td>
<td>0.47</td>
<td>0.80</td>
<td>0.40</td>
<td>1.10</td>
<td>0.47</td>
<td>0.47</td>
<td>0.74</td>
<td>0.74</td>
<td>1.10</td>
<td>0.74</td>
<td>0.74</td>
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</tr>
<tr>
<td>Alkalies as Na₂O</td>
<td>1.27</td>
<td>1.37</td>
<td>2.96</td>
<td>1.37</td>
<td>0.94</td>
<td>1.64</td>
<td>0.44</td>
<td>0.94</td>
<td>0.94</td>
<td>0.74</td>
<td>Not</td>
<td>0.53</td>
<td>0.74</td>
<td>0.84</td>
<td>0.90</td>
<td>0.90</td>
<td></td>
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</tr>
</tbody>
</table>

| Loss on ignition (total) | 9-00 | 7-50 | 11-00 | 9-00 | 6-00 | 15-00 | 9-00 | 9-00 | 14-76 | 19-25 | 12-75 | 11-00 | 12-50 | 5-20 | 11-90 |
| Residual sandy matter | 3-70 | 10-70 | 6-10 | 1-85 | 35-50 | 2-70 | 9-70 | 11-30 | 7-00 | 0-20 | Not | 6-00 | 18-00 | 37-20 | 5-30 |

Note: The above analysis is based on the assumption that the total fluxes are active factors.
### Table 2.—Physical Tests.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water absorbed per cent. (plasticity)</td>
<td>23</td>
<td>25</td>
<td>25</td>
<td>21</td>
<td>18</td>
<td>25-26</td>
<td>21</td>
<td>18-19</td>
</tr>
<tr>
<td>Colour—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air-dry</td>
<td>Pale grey</td>
<td>Very pale buff</td>
<td>Grey</td>
<td>Greenish-grey</td>
<td>Grey</td>
<td>Very dark grey</td>
<td>Grey</td>
<td>Grey</td>
</tr>
<tr>
<td>Fired at 1400°</td>
<td>Darkish brown</td>
<td>Grey-brown</td>
<td>Thickly speckled brown on lighter grey</td>
<td>Brownish-grey</td>
<td>Grey-brown</td>
<td>Buff</td>
<td>Buff</td>
<td></td>
</tr>
<tr>
<td>Fired at 1500°</td>
<td>Little change.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General appearance—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired at 900°</td>
<td>Soft to knife hardened</td>
<td>Soft to knife hardened</td>
<td>Fairly hard</td>
<td>Fairly hard</td>
<td>Somewhat vitrified</td>
<td>Soft to knife hardened</td>
<td>Soft to knife hardened</td>
<td>Soft to knife hardened</td>
</tr>
<tr>
<td>Fired at 1350°-1400°</td>
<td>Vitrified, but retained shape completely</td>
<td>Vitrified, but retained shape completely</td>
<td>Vitrified, but retained shape completely</td>
<td>Vitrified, but retained shape completely</td>
<td>Vitrified, but retained shape completely</td>
<td>Vitrified, but retained shape completely</td>
<td>Vitrified, but retained shape completely</td>
<td>Vitrified, but retained shape completely</td>
</tr>
<tr>
<td>Fired at 1500°</td>
<td>No softening</td>
<td>Rounded up to ball</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear shrinkage (per cent.)—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 650°</td>
<td>No change.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 900°</td>
<td>No change.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 1350°-1400°</td>
<td>15.00</td>
<td>12.50</td>
<td>15.60</td>
<td>15.60</td>
<td>14.00</td>
<td>9.30</td>
<td>9.40</td>
<td>9.40</td>
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<tr>
<td>At 1500°</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Water absorbed per cent. (plasticity)</td>
<td>24</td>
<td>24</td>
<td>Not plastic</td>
<td>26.50</td>
<td>24</td>
<td>19-20</td>
<td>27</td>
<td>Sand</td>
<td>Sand</td>
</tr>
<tr>
<td>Colour—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air-dry</td>
<td>Dark grey</td>
<td>Dark grey</td>
<td>Grey</td>
<td>Dark grey</td>
<td>Light grey</td>
<td>Dark grey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired at 650°</td>
<td>Grey-white</td>
<td>Very pale white</td>
<td>Grey</td>
<td>Creamy-white</td>
<td>Grey-white</td>
<td>Dark brownish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired at 900°</td>
<td>Pale</td>
<td>Pale</td>
<td>Pale</td>
<td>Pale</td>
<td>Creamy-white</td>
<td>Dark white</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired at 1350°-1400°</td>
<td>Pale</td>
<td>Pale</td>
<td>Pale</td>
<td>Pale</td>
<td>Light brownish-grey</td>
<td>Light grey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired at 1500°</td>
<td>Little further change.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General appearance—</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired at 650°</td>
<td>Carbon all burnt out; no visible change in texture; variation in hardness slight; all cut by finger-nail.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired at 900°</td>
<td>Somewhat vitrified</td>
<td>Somewhat vitrified</td>
<td>Fairly hard</td>
<td>Soft to knife hardened</td>
<td>Soft to knife hardened</td>
<td>Soft to knife hardened</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired at 1350°-1400°</td>
<td>Vitrified, cracked</td>
<td>Vitrified, cracked</td>
<td>Vitrified, cracked</td>
<td>Vitrified, cracked</td>
<td>Vitrified, cracked</td>
<td>Vitrified, cracked</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fired at 1500°</td>
<td>No softening</td>
<td>No softening</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear shrinkage (per cent.)—</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air-dry</td>
<td>9.40</td>
<td>9.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 650°</td>
<td>No change.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 900°</td>
<td>15.60</td>
<td>15.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 1350°-1400°</td>
<td>15.60</td>
<td>Spongy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 1500°</td>
<td>18.70</td>
<td>15.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
List of Localities.

No. 1. Clay-pit, Steventon. (See page 35.)
No. 2. Clay-pit, King's, near Captain Woodcock's, Whitecliffs. The exposure consists of brownish clay and " corduroy," but very plastic. The beds dip the same way as those on the cliff near the station. There are coaly bands above (slipped) and probably below. The thickness of the beds is uncertain.
No. 3. "Corduroy" from clay-pit, Steventon. (See page 35.)
No. 4. Gully just north of Whitecliffs. Fireclay is exposed all up the northern side of this gully on the line of strike, in some cases with concretions of ironstone; thickness uncertain.
No. 5. From same gully, but south-west of No. 4.
No. 6. From old workings near road at cliff, Whitecliffs. These beds, as well as No. 4, are stratigraphically under the rhyolite conglomerate at the bluff, and are therefore very low in the series. The latter remark applies to No. 2 as well.
No. 7. Alum Creek, Avoca Mine.
No. 8. Old drive, Avoca Mine, on north side of Broken River. Included for purposes of comparison.
No. 9. From coal-mine, Bush Gully.
No. 10. Coal-mine, Glenroy, from entrance to drive. Layer, 18 in. thick, 9 ft. above large seam of coal.
No. 11. Coal-mine, Glenroy, from level in mine, 16 in. thick.
No. 15. Austin's drive, sandy clay. Nos. 13, 14, and 15 are from the same pit, sometimes known as Bradshaw's. The following succession is shown: Whitish, slightly argillaceous, rhyolitic sand; shale, 20 ft.; dark sandy shale, 2 ft.; alternations of clay and sandy clay, 6 ft.; sand at bottom of drive, sample taken 15; interstratified clays and sands, sample 13.
No. 16. Farr's Road, South Malvern. Stained with iron oxide, but seams free from this reported under the floor of the pit.
No. 17. Sand, Hart's. (See page 36.)

Possible Uses of the Clays.

All have too much colour to be suitable for paper-filling or for fine pottery. For stoneware they might answer if the contraction is not too great or the colour not too dark. For firebricks the bulk are not refractory enough; a few of the best might serve for medium or low-grade firebricks if the quantity and availability are sufficient. For drainpipes some are already in use, but the high contraction and relatively low softening temperature makes it difficult to keep the shape true in large sizes or considerable lengths.

On account of the manner in which these clays occur, in thin layers differing in quality and of comparatively small extent, with a variation of character even in a given layer, any extensive use would seem to be barred unless all the layers of any locality could be used together.

Practically all have a considerable range in firing-temperature above that at which they become hard and below softening. Heated to 1200° C. or thereabouts, most of them become hard and strong and nearly impervious to water, the colour remaining a light buff. It appears to me that in those localities in which the deposits are near the surface and readily available all the layers mixed together and hard-burnt would give a light-buff-coloured brick of good appearance, strong, nearly impervious to water, and quite permanent. As a building-brick this would be attractive in colour and in quality away beyond anything available in Christchurch at the present time. If delivered at a reasonable price, such bricks would probably be very largely used in Canterbury, or at least in Christchurch, where the building-bricks hitherto used are soft, very pervious to water, and of uncertain permanence.

With reference to the determination of the probable mineral composition of these clays as judged from the chemical analysis, I must, first of all, quote a statement made by F. F. Grout (loc. cit., p. 407). He says, "With so many disturbing factors it may be doubted whether a satisfactory mineral diagnosis can be made of the finest clays. While the chemical data may be fairly accurate determinations, the minerals are only rough estimates, but the abundance of fine clays in some deposits makes it desirable to assemble what information is available and make the best estimate possible."

In addition to the doubt cast on the value of such determinations in this statement, there are other reasons why an attempted solution in this case would be of little or no value and not worth the trouble it would necessitate. In the first place, the alkalies, reckoned as soda, would not enable a proper estimate to be made, seeing that the microscopical examination discloses a fair amount of orthoclase. Also, both muscovite and biotite, potash- and soda-bearing minerals, occur in conjunction with the feldspars in proportions I have been unable to determine. Lastly, a good deal of the loss on ignition really belongs to burned-off carbonaceous matter, and therefore this fraction cannot be entirely credited to water derived from kaolinite.

[Norm.—The magnesia content is explained by the presence of biotite, but the titanium probably occurs as leucopenne rather than as ilmenite, seeing that ferrous oxide does not appear either in Mr. Page's analyses or in those of the Dominion Laboratory, to be quoted directly. I saw no rutile in the slides which could also account for its presence.—R.S.]
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No. 11. Coal-mine, Glenny, from level in mine, 16 in. thick.
No. 12. “Gannister,” Farr’s Road, South Malvern.
No. 13. Austin’s drive, Sheffield, representing 4 ft. in depth. Composite sample.
No. 15. Austin’s drive, sandy clay. Nos. 13, 14, and 15 are from the same pit, sometimes known as Bradshaw’s. The following succession is shown: Whitish, slightly argillaceous, rhyolitic sand; shale, 20 ft.; dark sandy shale, 2 ft.; alternations of clay and sandy clay, 6 ft.; sand at bottom of drive, sample taken 15; interstratified clays and sands, sample 13.
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[Note.—The magnesia content is explained by the presence of biotite, but the titanium probably occurs as ilmenite rather than as ilmenite, seeing that ferrous oxide does not appear either in Mr. Page’s analyses or in those of the Dominion Laboratory, to be quoted directly. I saw no rutile in the slides which could also account for its presence.—R.S.]
By the kindness of the Dominion Analyst I have received permission to use certain analyses, &c., made in the Dominion Laboratory on sands and clays from the neighbourhood of Glentunnel, which fill a gap in the series made by Mr. Page. These are as follows:

1. Sand from sand-pit, Surveyor's Gully, a few chains below the mine.
2. "Gannister" from near the mine.
3. Fireclay, light in colour, from pit at slightly lower stratigraphical horizon than the coal-seams of the mine.
4. Pipeclay, light in colour, from pit at slightly lower stratigraphical horizon than the coal-seams of the mine.
5. Fireclay, dark in colour, from pit at slightly lower stratigraphical horizon than the coal-seams of the mine.

**Analyses.**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>90·93</td>
<td>77·38</td>
<td>58·08</td>
<td>60·18</td>
<td>57·58</td>
</tr>
<tr>
<td>Alumina</td>
<td>4·28</td>
<td>11·79</td>
<td>22·31</td>
<td>18·33</td>
<td>19·66</td>
</tr>
<tr>
<td>Iron oxide</td>
<td>1·04</td>
<td>1·52</td>
<td>1·72</td>
<td>3·80</td>
<td>1·44</td>
</tr>
<tr>
<td>Titanium dioxide</td>
<td>0·48</td>
<td>0·86</td>
<td>0·88</td>
<td>0·85</td>
<td></td>
</tr>
<tr>
<td>Lime</td>
<td>0·34</td>
<td>0·60</td>
<td>1·60</td>
<td>1·29</td>
<td>0·70</td>
</tr>
<tr>
<td>Magnesia</td>
<td>0·14</td>
<td>0·09</td>
<td>0·18</td>
<td>0·11</td>
<td>0·11</td>
</tr>
<tr>
<td>Potash</td>
<td>0·09</td>
<td>1·58</td>
<td>1·35</td>
<td>1·64</td>
<td>1·51</td>
</tr>
<tr>
<td>Soda</td>
<td>0·14</td>
<td>1·18</td>
<td>0·21</td>
<td>0·75</td>
<td>0·33</td>
</tr>
<tr>
<td>Water lost at 100 °C.</td>
<td>0·40</td>
<td>1·90</td>
<td>5·25</td>
<td>3·30</td>
<td>5·00</td>
</tr>
<tr>
<td>Combined water and organic matter</td>
<td>0·05</td>
<td>3·85</td>
<td>9·50</td>
<td>10·40</td>
<td>13·20</td>
</tr>
<tr>
<td>Totals</td>
<td>99·51</td>
<td>100·37</td>
<td>100·96</td>
<td>100·73</td>
<td>100·88</td>
</tr>
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Note.—In comparing these results with those given by Mr. Page it must be remembered that the percentages in the latter are those obtained from freshly ignited samples. When this is allowed for, the results show a closer approximation.—R. S.

Calculated from the analyses, the theoretical mineral composition of the samples 3, 4, and 5 would be—

<table>
<thead>
<tr>
<th></th>
<th>3. Per Cent.</th>
<th>4. Per Cent.</th>
<th>5. Per Cent.</th>
</tr>
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<tbody>
<tr>
<td>Feldspar</td>
<td>18·12</td>
<td>28·73</td>
<td>23·08</td>
</tr>
<tr>
<td>Quartz</td>
<td>28·73</td>
<td>32·15</td>
<td>32·15</td>
</tr>
<tr>
<td>Limonite</td>
<td>2·10</td>
<td>4·59</td>
<td>4·59</td>
</tr>
<tr>
<td>Clay substances and combined water</td>
<td>51·05</td>
<td>40·18</td>
<td>51·53</td>
</tr>
<tr>
<td></td>
<td>100·00</td>
<td>100·00</td>
<td>100·00</td>
</tr>
</tbody>
</table>

Small bricks and tiles made of samples 3, 4, and 5 were dried and baked. The total linear shrinkage was—

<table>
<thead>
<tr>
<th></th>
<th>3. Per Cent.</th>
<th>4. Per Cent.</th>
<th>5. Per Cent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>At 100 °C.</td>
<td>6·87</td>
<td>5·62</td>
<td>6·25</td>
</tr>
<tr>
<td>At 970 °C.</td>
<td>9·37</td>
<td>6·25</td>
<td>10·94</td>
</tr>
<tr>
<td>At 1140 °C.</td>
<td>10·94</td>
<td>6·25</td>
<td>9·37</td>
</tr>
<tr>
<td>At 1140 °C.</td>
<td>14·06</td>
<td>12·50</td>
<td>12·50</td>
</tr>
</tbody>
</table>

The samples are all easily moulded and give strong moulded articles.

No. 3.—At 970 °C. a white rather soft brick is obtained. At 1060 °C. the colour has changed to a yellowish-white. At 1140 °C. a very hard brick, not scratched with a file, is obtained; the shrinkage, however, is excessive and somewhat uneven; the appearance would indicate that the vitrifying-point had almost been reached.

No. 4.—At 970 °C. a white and moderately hard brick is produced. At 1060 °C. it changes in tint to a lighter pink. At 1140 °C. the brick produced is very hard, and the shrinkage is somewhat uneven. There are no signs of vitrification.

No. 5.—This is very similar in firing properties to No. 3, except that the shrinkage at 1140 °C. is not so great and is more uniform.

The following additional report on the clays from Robb's pit (see page 37), on the north-west side of Mount Misery, has also been kindly furnished by the Dominion Laboratory. The numbers
given are those supplied by Mr. Robb, and do not quite tally with those obtained when I examined the pit myself; however, they indicate clearly the nature of the clays.

No. 1. Light-coloured clay from 6 ft. seam. (= No. 3, page 37.)
No. 7. Light-coloured clay from 2 ft. 6 in. seam. (= No. 3, page 37.)
No. 6. Light-coloured clay from 9 in. seam. (= No. 5, page 37.)
No. 5. “Gannister” from 8 ft. seam.
No. 4. Grey clay from 6 ft. seam.
No. 3. Light-coloured clay from 2 ft. 6 in. seam. (= No. 7, page 37.)
No. 2. Light-coloured clay from 3 ft. seam. (= No. 6, page 37.)

Complete analyses were made of samples Nos. 1 and 2, and partial analysis of No. 5. Test bricks and tiles were made from clays Nos. 1, 2, 3, 4, 6, and 7, and burned at various temperatures.

Analyses.

<table>
<thead>
<tr>
<th></th>
<th>Silica (SiO₂)</th>
<th>Alumina (Al₂O₃)</th>
<th>Iron oxide (Fe₂O₃)</th>
<th>Magnesia (MgO)</th>
<th>Lime (CaO)</th>
<th>Sods (Na₂O)</th>
<th>Potash (K₂O)</th>
<th>Combined water and loss on ignition (H₂O +)</th>
<th>Moisture lost at 105°C. (H₂O −)</th>
<th>Titanium dioxide (TiO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>64·87</td>
<td>20·44</td>
<td>2·08</td>
<td>0·80</td>
<td>0·09</td>
<td>Nil</td>
<td>1·99</td>
<td>7·16</td>
<td>1·20</td>
<td>0·79</td>
</tr>
<tr>
<td>No. 2</td>
<td>66·97</td>
<td>20·65</td>
<td>1·20</td>
<td>0·23</td>
<td>0·09</td>
<td>Nil</td>
<td>0·44</td>
<td>7·97</td>
<td>1·52</td>
<td>0·77</td>
</tr>
</tbody>
</table>

Theoretical rational analysis, corresponding to a mineral composition, calculated from the clay dried at 105°C.:

<table>
<thead>
<tr>
<th></th>
<th>No. 1</th>
<th>No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscovite</td>
<td>17·20</td>
<td>3·81</td>
</tr>
<tr>
<td>Quartz</td>
<td>41·59</td>
<td>43·39</td>
</tr>
<tr>
<td>Limonite</td>
<td>2·36</td>
<td>1·36</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>35·84</td>
<td>49·42</td>
</tr>
<tr>
<td>Minor constituents</td>
<td>3·01</td>
<td>2·02</td>
</tr>
<tr>
<td>100·00</td>
<td>100·00</td>
<td></td>
</tr>
</tbody>
</table>

(Note.—In both these clays it was decided to calculate the potash to mica (K₂O, 3Al₂O₃, 6SiO₂·2H₂O). The reasons for this were that no soda and little lime is present, and these almost invariably are associated with potash feldspar. Also, as an examination of the analysis of No. 2 shows, the Fe₂O₃, MgO, and K₂O are the only components varying to any extent in the two samples, and this would point to a variation in mica content. Microscopically, no opaque feldspar was seen, and, though no mica was definitely identified, a yellowish-green decomposed mineral was very frequent and was possibly micaceous.)

Burning Tests.

No. 1.—This clay is of high plasticity, and moulds very well. It is fine-grained. At 100°C. the linear shrinkage is 4·7 per cent. At 1050°C. pale-pink bricks of very good shape are obtained; shrinkage, 6·3 per cent. At 1100°C. hard yellow bricks of good shape result; shrinkage, 9·4 per cent. At 1200°C. yellowish-grey vitrified bricks and tiles of very good shape and compact texture result; shrinkage, 9·4 per cent. At the highest temperature available in the wind-furnace (about 1580°C.) the shape is well maintained, though the edges have commenced to soften.

The clay is especially suitable for the manufacture of stoneware, electrical insulators, and as an ingredient of porcelain.

No. 2.—At 100°C. the linear shrinkage is 4·7 per cent. At 1200°C. dull white, hard, but not vitrified bricks of good shape result; shrinkage, 7·8 per cent. At 1580°C. a light-brown product of good shape is obtained; no sign of vitrification.

Since the clay withstands a temperature of 1580°C. without vitrifying, it complies with the British specifications for a second-grade fireclay. It would probably withstand a still higher temperature, but no means are available here for carrying out such a test. The clay is suitable for the manufacture of good second-grade firebricks.

(Note.—A comparison of the analyses of No. 1 and No. 2 explains clearly the difference in behaviour at high temperatures of the two samples. No. 2 is low in impurities such as muscovite, while No. 1 is relatively high in this component.)
No. 3.—This clay is highly plastic, and moulds well. At 100° C. the linear shrinkage is 4·7 per cent. At 1200° C. pale-yellow hard bricks are obtained; shrinkage, 7·8 per cent. At 1580° C. a light-brown product of good shape results. There is no sign of vitrification. This sample is suitable for the manufacture of second-grade firebricks.

No. 4.—This clay is highly plastic, and moulds well. At 100° C. the linear shrinkage is 4·7 per cent. At 1200° C. dull-white, hard, but not vitrified bricks and tiles are obtained; they broke into pieces in the furnace, possibly due to too sudden heating. At 1580° C. a light-brown product of good shape results; there is no sign of vitrification. This sample is suitable for the manufacture of second-grade firebricks.

No. 5.—This sample is a coarse-grained gannister. On washing, it was found to contain a certain amount of clay, which binds the particles loosely together. A partial analysis was made:—

<table>
<thead>
<tr>
<th>Component</th>
<th>Analysis</th>
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<tr>
<td>Silica (SiO₂)</td>
<td>80·3</td>
</tr>
<tr>
<td>Soda (Na₂O)</td>
<td>0·6</td>
</tr>
<tr>
<td>Potash (K₂O)</td>
<td>2·2</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>3·1</td>
</tr>
<tr>
<td>Undetermined (incl. clay), by difference</td>
<td>13·8</td>
</tr>
<tr>
<td>Total</td>
<td>100·0</td>
</tr>
</tbody>
</table>

In order to test the value of this sample as a refractory, it was moulded into a tile with the aid of 10 per cent. of a refractory clay; also, a tile was pressed out of the material without grinding. These were burned at 1200° C. In each case the material had fritted together, and the quartz had apparently changed its state, probably being partially changed to the lighter variety called cristobalite. This change was very noticeable in the case of the tile made without the addition of clay: this, instead of shrinking, actually swelled considerably.

A fragment broken off the sample was burned at 1580° C. in the wind-furnace. On examination, the product was found to be mostly in a fused condition, but the fragment was loose and had not run together.

In a Technological Paper of Bureau of Standards (No. 116), entitled "Silica Refractories," it is stated that, in general, the most satisfactory raw materials for the manufacture of silica refractories are those which contain not less than 97 per cent. of silica and not more than 0·40 per cent. of alkalies. The sample does not by any means comply with these specifications; the presence of refractory clay in a gannister would not be harmful, but the potash present indicates the probable presence of micaceous mineral.

Though when heated for a short time at 1580° C. there is no definite running-together of the material, yet this would very likely occur with prolonged heating, especially at a slightly higher temperature. The sample has not the qualities of a good refractory.

No. 6.—This clay is gritty and of very low plasticity. Examined microscopically, it appears to be full of angular particles, probably ferro-magnesian. It was possible to mould bricks, however. These were burned at various temperatures. At 100° C. the linear shrinkage is 3·6 per cent. At 1200° C. there is no sign of vitrification; the clay cracks badly, due to excessive shrinkage; shrinkage, 15·6 per cent. At 1580° C. a mottled white product results, but there is no sign of vitrification.

This clay is refractory, but owing to high shrinkage, low plasticity, and bad moulding properties is not suitable for the manufacture of refractory products. It could possibly be used in admixture with plastic fireclays.

No. 7.—This clay is of only moderate plasticity, but moulds fairly well. At 100° C. the linear shrinkage is 4·7 per cent. At 1200° C. the shape is fair; there is no sign of vitrification, but a few small cracks have developed; shrinkage, 7·8 per cent. At 1580° C. a light-brown product of good shape results; there is no sign of vitrification. This clay is suitable for the manufacture of second-grade firebricks.

NOTE.—Nos. 2, 3, 4, and 7 all appear to be similar in physical properties, and are all suitable for the manufacture of refractory products.

SANDS.

The sands usually occur above the coal horizon at a higher level than the clays, practically about that of the Selwyn Rapids beds. They also occur in places from this level upwards, especially near the top of the series under the Harper Hills basalt, but they are poorer in quality and much stained by oxide of iron.

At only two points have they been worked at all—near Hart's Coal-mine, and near the Homebush Mine in Surveyor's Gully. The general features appear to be the same in both places, but the former yields the purer material, being almost entirely composed of quartz-grains, with but a small amount
of stain resulting from iron oxide. In places the sand is almost white, with a minimum of stain, the coloration where it does occur having worked down what are apparently weak joint-planes or being distributed throughout the mass.

The two analyses, Nos. 18 and 19, are of sand from this place. They show a sand fairly high in silica, with a moderate percentage of iron oxide. Another analysis of sand from this place, made by Mr. R. O. Page, gave the following result: Silica, 95 per cent.; aluminas, 2.7 per cent.; iron oxide ($Fe_2O_3$), 1.1 per cent.; lime, 2.0 per cent.; volatile matter, 0.2 per cent.; total, 101.0. This was made from an average sample, and serves to confirm the results of the other analyses.

A separation of the sand by means of bromoform showed that it was practically free from heavy minerals, though I did come across one grain of augite in the microscopical examination. This shows that the grains are almost wholly of quartz, with very occasional fragments of feldspar present. The size of the grains shows little approximation to uniformity. The larger grains reach 0.5 mm. in diameter, but there is also a large proportion of smaller fragments, down to 0.02 mm. in diameter or even less, so it does not fulfil the requirements insisted on by Boswell ("Sands and Rocks used in Glassmaking," 1918, pp. 43-47) for a good glass sand, seeing that it does not exhibit the necessary uniformity of grade. In addition to the impurity of iron oxide, there are occasional grains of augite.

Mr. Page has kindly furnished the following results of the mechanical analyses of these sands, with comments thereon:

<table>
<thead>
<tr>
<th>Mechanical Examination Results.</th>
<th>No. 17</th>
<th>No. 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retained on a 60-mesh screen</td>
<td>40.00</td>
<td>45.00</td>
</tr>
<tr>
<td>Retained on a 100-mesh screen</td>
<td>55</td>
<td>45</td>
</tr>
<tr>
<td>Passed through 100-mesh screen</td>
<td>30</td>
<td>14</td>
</tr>
</tbody>
</table>

Cohesiveness quite appreciable, and somewhat greater in No. 17 than No. 18. Porosity: One hundred volumes of sand absorbed forty volumes of water or very slightly less in No. 17 and very slightly more in No. 18.

The two samples are from the same deposit, and differ little except in texture. No. 17 is finer in grain than No. 18, and contains twice as much fine dust. Both are nearly white, but the deposit furnishing them is considerably stained in parts with iron oxides in more or less vertical streaks. For glassmaking this would involve rejection of large portions; the range of grain-size also is greater than glassmakers consider desirable.

For silica brick with lime bonding the deposit would seem quite suitable, the parts most stained with iron being rejected. For foundry-work the sand has been tried in Christchurch at various times and the whiter portion found to be very suitable for light or fairly light steel castings, the cohesiveness required being easily obtained with small additions of binding-material, owing to the fineness of grain. For heavy steel work its permeability is too small, and for ordinary cast iron moulders prefer sands having much more natural cohesiveness.

The sand from near the Homebush Mine is not so pure. (See analysis No. 1 in the set made in the Dominion Laboratory.) The percentage of silica is lower, alumina and iron oxide higher. This, therefore, would be only suitable for poorer grades of glass. The percentage of alumina might, however, increase its suitability as a moulding-sand, though I do not know if it has been tried for that purpose.

There seems to be a very great quantity of sand available near Hart's Coal-mine, as the beds no doubt extend along the strike to the north-east for a considerable distance, and there is probably an available thickness of about 50 ft. of sand whose iron-oxide content is fairly low.

(c) BUILDING-STONE.

The only stone from the district which has been used for building-construction is, as far as I know, the dolerite of the Harper Hills. This is durable, dark grey in tint, moderately easy to work, and adaptable for monumental purposes as well as building. It has been used with success in a part of Christ's College, and also for the Anglican Church at Hororata. The stone in these cases was obtained from blocks which had rolled down the scarp facing the Wairere Valley, and, as far as I know, no stone was obtained from the rock in position. It is very like, not only in texture but also in appearance, some of that supplied from Melbourne, and as far as these two qualities are concerned there is no reason why it should not be used as a substitute for the Victorian stone; but it is doubtful if the Malvern stone occurs in large-enough blocks for it to be considered as an effective substitute for basalt courses, where large sizes are frequently demanded.

No doubt some of the layers of concretionary sandstone could be used for building, but their position in the middle of the coal-measure series, their narrow width, and their variability of texture, in addition to difficulties in the way of quarrying, are against any general use for building.

Some of the greywackes might be used, but the general shattered nature of the beds and the intractability of the stone itself militate against it being used, although some of the layers would furnish excellent road-metal.
The marble deposits hold out no promise of supplying any other building-material than lime. They are too variable in colour and composition, too fractured by joints, and too limited in extent to be considered seriously. Certain of the deposits, where the siliceous content is low, such as that at Adams's Quarry, give an excellent lime.

(d) METALLIFEROUS MINERALS.

The district is singularly deficient in metalliferous deposits of any value. A bed of clay-ironstone is reported by Haast (1872, p. 22) as occurring in the Hororata, but it cannot be of any extent. At times the iron content in the clays is concentrated into seams of limonite or into concretionary masses, but this has no commercial value. The red rocks on the High Peak Saddle owe their redness to a mere colouring of oxide, and as far as I know there is no concentration into definite beds containing any reasonable percentage of ore.

Manganese-ore occurs also on the High Peak Saddle and perhaps elsewhere, but the percentage of oxide is very low, probably not more than 2 per cent., the occurrence being practically a chert stained black by oxide derived in all probability from the diabase-ash beds which lie in close proximity and which contain a fairly high percentage of manganese oxide for a volcanic rock.

At one place in the same locality some exploration work was done on a vertical bed of white siliceous rock, in the hopes that it might contain gold and other metals, the prospectors thinking that it was a quartz reef. I believe it contained the merest traces of gold and silver—not more than might be expected from such a rock anywhere. Some prospecting for gold has been carried on in the Thirteen Mile Bush, on the south-eastern slope of the Big Ben Range, but it does not appear to have been successful. I have not seen the place, but I expect one of the jasperoid bands occurring frequently in the greywackes has been the cause of the bed being investigated, or some impregnation of metalliferous material has taken place along a crushed zone.

The diabase-ash beds have been prospected in several places for copper, it being considered that the green colouring was due to that mineral. Several drives were put in near the upper end of the Selwyn Gorge, but with disappointing results. An assay of material from this spot made by W. Skey and quoted by McKay (1886, p. 8) gave a percentage of 1.14 of copper from an ore consisting of carbonate and silicate of copper. Similar traces of copper can be obtained at other places on the line of these diabase-ash beds, usually as incrustations of the carbonate on siliceous rocks.

A drive was also put in on the western end of the Rockwood Range, at the junction of the rhyolite with the overlying andesite, the green facies of the rhyolite suggesting the presence of copper, but the result proved unsatisfactory.

I know of no other metalliferous mineral which may be considered as likely to occur within the area, so it appears reasonably certain that the chief mineral wealth consists almost entirely of the coal and associated clays and sands.

Before concluding, I have to express my acknowledgments to many people who have helped materially in the preparation of this report. Among the residents in the Malvern Hills district I wish to mention Messrs. John Deans, T. A. Phillips, C. Marsh, D. Kane, the Leeming Brothers, H. Robb, and especially Mr. George Starky, of Steventon. I have also to acknowledge the substantial help in its preparation given by Mr. S. Page; also that given by my students, Messrs. George Jobberns, P. T. Cox, and, above all, Mr. S. J. H. Sylvester, not only in the field but also in the laboratory. I have also to acknowledge with many thanks the most excellent analyses furnished by Mr. Seelye, of the Dominion Laboratory, through the kindly suggestion of Mr. Morgan, and also the assistance and advice given by Dr. W. P. Evans on many occasions and in many ways; and by Mr. W. F. Robinson, of the School of Engineering, Canterbury College, for his excellent panorama of the district.
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INDEX.

A.

Acheron coal, 42, 55.
Sills, 42, 50.
Adana Quarry, 10.
Analcite, 50, 51.
Andesite—
Age, 14.
Analyses, 16, 47.
Field relations, 12.
Petrology, 16, 49.

B.

Basic rocks—
Analyses, 46.
Field occurrence, 35 seq., 47 seq.
Petrology, 47 seq.
Benmore coal, 41, 46.
Bibliography, 69.
Brockley coal, 29, 54.
Alteration of, 30.
Dyke, 30.
Brockley fault, 30.
Building stone, 87.
Brockley coal, 29.
Conglomerates, 27.
Record of bores, 29.

C.

Cairn Range—
Beds, 6.
Conglomerates, 6, 8.
Plant fossils, 6.
Cairn Range—Mount Misery fault, 34, 35, 37.
Chapman, Frederick, 45.
Clays and sands, 56.
Clays—
Report by S. Page, 58.
Composition, 61.
Physical tests, 62.
Uses, 63.
Report by Dominion Analyst—
Analyses, 64.
Burning tests, 65.
Coal—
Age of, 44.
Alterations by intrusions, 30, 35, 36, 40, 41, 43.
Analyses, 33 seq.
Probable amount, 66.
Coal-measures—
Conglomerates, 17, 28, 29, 41, 46, &c.
General sequence, 17.
Occurrences at—
Acheron, 42.
Benmore, 41.
Brockley, 29.
Cordy's Flat, 34.
Dalethorpe, 40.
Glenroy, 31.
Glen tunnel, 17.
Hall's Creek, 34.
Hart's, 36.
Hawkes Valley, 39.
High Peak, 41.
Hororata River, 31.
Kowai Bridge, 41.

Coal-measures—continued.
Occurrences at—continued.
Levick's, 37.
Phillips Saddle, 37.
Pig Saddle, 39.
Rakaia Gorge, 43.
Rockwood, 38.
Selwyn River, south side, 28.
Sheffield, 28.
Springfield, 39.
St. Helens, 37.
Stevenson, 34.
Sutherland's, 37.
Waianamotuhia, 27.
Waikato Creek, 23.
Whitecliffs, 24.
Yorkie's Pass, 34, 37.

Conglomerates—
Jurassic, 6, 7, 8.
Senonian, 17, 28, 29, 41, 46, &c.
Cordy's Flat coal, 34, 54.
Alteration of, 35.
Cox, S. H., 12, 13, 33, &c.
Cox, P. T., 13, 14, 15, 17, 50, &c.

D.

Daintree, R., 15.
Dalethorpe coal, 40.
Diabase ash-beds, 9.
Relation to spilites, 11.
Dolerite, 47 seq., 51.
Dykes—
Basic, 12, 30, 33, 37.
Rhyolitic, 12, 14, 33.

Economic geology—
Coal, 53.
Clays and sands, 56.
Sands, 66.
Building stone, 67.
Metalliferous minerals, 68.
Ritingshausen, C. von, 45.
Evans, W. P., 30, 34, 35, 53 seq.

Faults, 23, 27, 28, 30, 33, 34, 35, 37, 38, &c.
Relations to intrusions, 48.
Folding, pre-Senonian, 9.

G.

Gabbro, 43, 50.
Gannister, 18, 25, 63, 66.
Glacial beds, 2, 63.
Glenroy coal, 31, 54.
Sill, 33.
Glenroy Bridge beds, 43.
Glen tunnel coal, 17.
Horizon, 17.
Intrusives, 18.
Sands, 64.
Granite, 15.
Gravels, post-Tertiary, 31, 52.
Greywacke, 4.
Haast, Julius von, 1 et passim.
Haast’s Creek coal, 34.
Harper Hills volcanics, 24, 46, 47.
Harper Hills coal, 35, 54.
Hawkins Valley coal, 39.
High Peak coal, 41.
Intrusives, 42, 50.
High Peak Saddle—Ash-beds, 9.
Hill’s coal, 35, 54.
Hill’s coal, 35, 54.
Homebush Mine, 18, 53.
Intrusives, 42, 50.
Intrusives, 40.
Intrusives, 40.
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