The Benmore Coal Area of the Malvern Hills.

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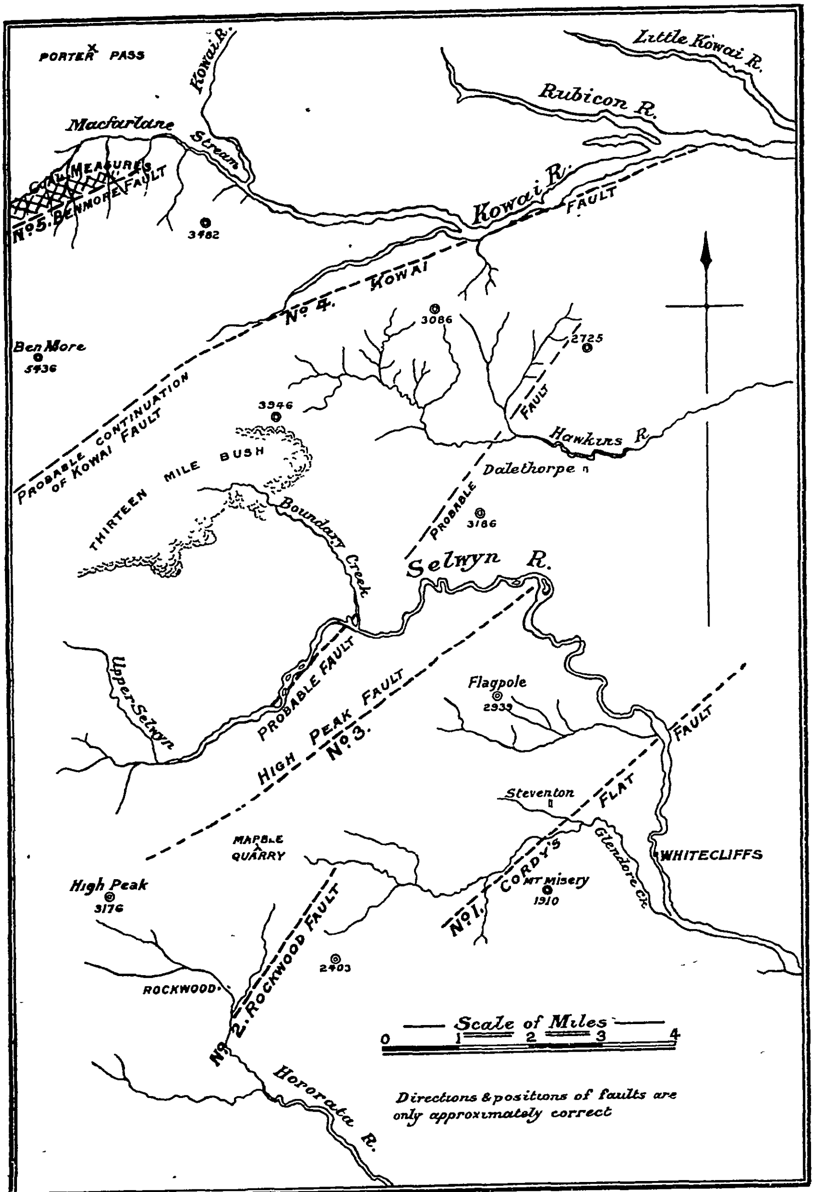
THE Benmore outlier of the Malvern Cretaceous series was described in some detail by Haast (*Report of the Geol. Explor. during 1871–72*, pp. 41–46, 1872), special attention being given to it, since it was looked on as a possible source of coal. Some development work was carried out, but it was soon discontinued, chiefly on account of the inaccessibility of the area, the poor character of the coal, and the probable amount available not warranting any further exploitation. Recent examinations of the area by the present author have revealed geological features of some interest, notably in their bearing on the origin of the present topography of the Malvern Hills and of the Southern Alps, and hence this brief account.

The extent of country covered by this outlier is about a mile in length, with a width varying from nothing at its two ends up to about half a mile in its widest part, which occurs near the middle of the area. The height above sea-level varies from about 2,000 ft. to just over 3,000 ft., so that it is one of the highest occurrences of coal-measures in the alpine region of the South Island. Some few are certainly higher, but they are by no means so extensive. It is located in the valley of Macfarlane Stream, which is a tributary of the Kowai River, and lies immediately south of Porter Pass (see map), in that gap which divides the Big Ben and Mount Torlesse Ranges, on a kind of shelf on the north side of Benmore, the highest point of the former range. This shelf has a general N.E.-S.W. trend, but it is divided from the valley of Macfarlane Stream for the north-eastern half of its length by a barrier of greywacke, the difference in elevation of the outlier above the bed of the stream at this end being about 800 ft. On following it towards the south-west the beds occur at stream-level, nearly all the drainage of the area converging to a point about half-way along its northern side. From the shelf just referred to the slopes of Benmore rise steeply for another 1,500 ft., the change in surface-features on passing from coal-measures to greywacke being most marked. The coal-measures rest unconformably on the greywackes, the slope of the basement beds being continued to the north-west as a well-preserved stripped surface, whereas on the south-east side the area is bounded by a fault whose features will be detailed later.

The chief tributaries of Macfarlane Stream rise in the northern slopes of Benmore, and run in approximately north-western directions in sub-parallel channels incised in their lower reaches into the easily eroded coal-measures. As these channels enable a clear insight to be obtained into the structure of the area, a description of the beds occurring in each will be given.

The extreme north-eastern end of the area consists of clays, sandy clays, and thin beds of lignite most of which is of low grade. This part is much disturbed by slip and covered with surface debris, so that it is impossible to obtain a definite idea of the relations of the various beds. The first clear section is obtained in the bed of the creek farthest north-east. This rises in Benmore and cuts the coal-measures—the upper portion almost on



Sketch Map of
MALVERN HILLS SHOWING MAIN FAULT LINES

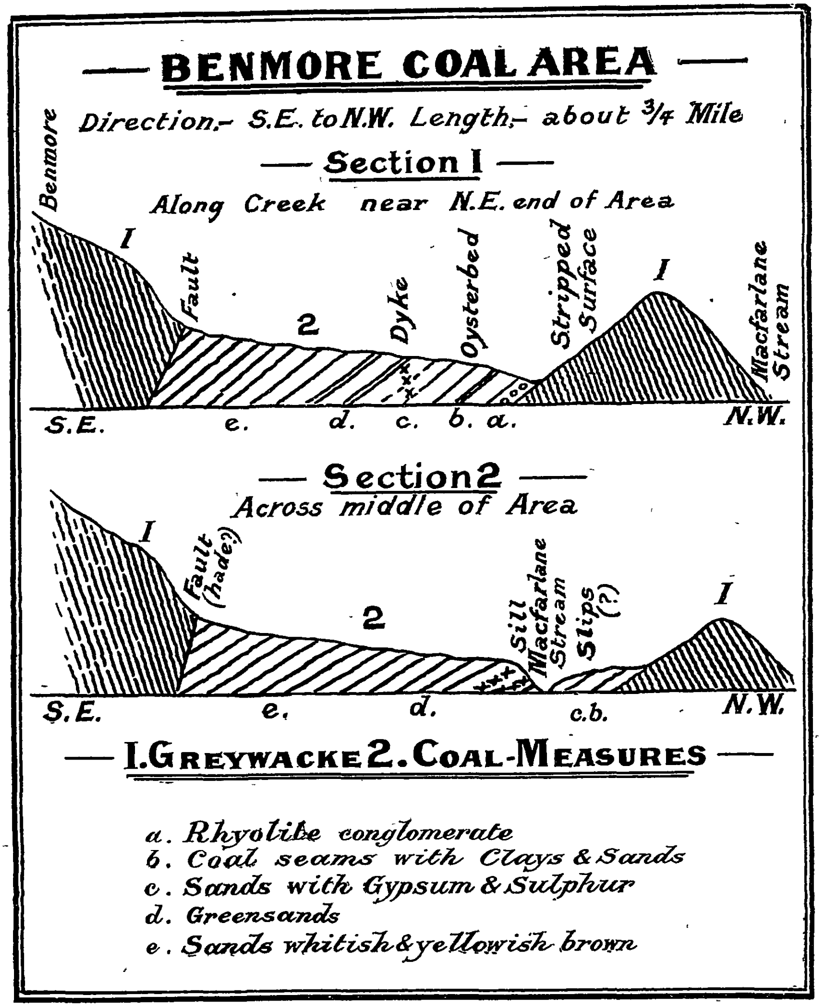
the line of strike, and the lower part more in the direction of the dip. Haast enumerates in detail the beds occurring in the lower part of the series, and the following is a summary of his record (see Section 1, although this is intended for the creek farther west) :—

1. Shales and porphyry conglomerate	60 ft. to 80 ft.
2. Bluish sandy clays	15 ft.
3. Brown coal	11 in.
4. Ferruginous and white quartzose sands alternating	11 ft.
5. Clays, shales, sandy clays, and brown coal in small seams	7 ft.
6. Brown coal, main seam	4 ft. 7 in.
7. Shales, clays, and sands, with occasional layers of brown coal	110 ft. (approx.)
8. Oyster-beds with intercalated clay	6 ft.
9. Sands and shales interstratified, the former yellowish-green or greyish weathering pink and brown, with smell of H_2S, and crystals of gypsum	60 ft.

The uppermost beds exposed in this creek strike N. 10° W., and dip south-west at angles approximating 20°, but the lower beds swing round till they strike more to the north-west. At the top of the exposure the beds are much disturbed, slickensided, crushed, and apparently overturned along a line of fault, as if the greywackes had been thrust against them from the south-east. The two important beds in the series are the porphyry conglomerate, about which more will be said later, and the oyster-bed, which contains *Ostrea dichotoma* like that in the Glentunnel area of the Malvern Hills, and definitely correlates the two occurrences as being of the same age.

The bed called by Haast a "porphyry conglomerate" is a conglomerate with a fine-grained matrix in which are pebbles of a rhyolite similar to that occurring on the ridge extending from Mount Misery, through the Rockwood Range, to Rakaia Gorge. The pebbles are small, the largest seen measuring about 2 in. in length, very well rounded, flattish, with characteristic shingle shape suggesting long wear on a beach. Allowing for the smaller size of the pebbles, the conglomerate is similar to that which occurs elsewhere in the Malvern Hills at the base of the Cretaceous series, notably at Rakaia Gorge, White Cliffs, and on the south-eastern slope of Mount Misery; and its occurrence at Benmore is somewhat remarkable, since the nearest rhyolites in position are in the neighbourhood of High Peak, on the Upper Selwyn, nine miles away in a straight line, whereas Mount Misery is twelve miles distant. A similar conglomerate occurs in the basin of the Kowai at the bridge over the river, where there is a small exposure of coal-measures, this being the nearest recorded occurrence of a bed similar to that occurring at Benmore. It should be noted, however, that Hutton mentions the occurrence of a pebble of rhyolite in a conglomerate in the coal-measures at Craigieburn, near Lake Pearson ("The Geology of the Trelissick or Broken River Basin, Selwyn County," *Trans. N.Z. Inst.*, vol. 19, pp. 398–99, 1887), and discusses its bearing on the form of the land when the beds were laid down. This pebble is in a collection at the Canterbury Museum, and Hutton's determination can be confirmed.

A few chains to the north-west of this creek is another coming in from the slopes of Benmore, but in this the sequence cannot be seen as clearly (see Section 1). The rhyolite conglomerate occurs at the base, resting on the greywacke, and this is succeeded by shales and sands with coal. After some intermission where the outcrops are quite hidden by surface accumulations, there are exposures on the western side of the gully which the stream has worn, consisting of concretionary sands, well bedded, with layers of harder and softer material interstratified with sandy shales; some of the harder layers contain numerous sharks' teeth. These beds strike N. 10° W., and dip to the west at angles of 15°. They are succeeded by



greensands, containing rounded concretions and hard concretionary layers of greensand, and these pass up into grey quartzose sands, light-green sands, and whitish sands, which close the sequence here. The topmost beds lie faulted against the greywacke, which has been pushed over the sands from the south-east. The fault-plane hades at an angle of 40°, and apparently runs north-east and south-west. The surface of the sand is indurated and much slickensided. It is impossible to determine the amount of the throw from the exposures.

On the western side of this gully three basic dykes occur. The most easterly of these is exposed in a face consisting of hard and soft sandstones. It is about 5 ft. wide, and strikes N. 5° E. A narrow band of altered material lies alongside the dyke. This appears to be the one referred to by Haast (*loc. cit.*, p. 45). Two other dykes also occur on the crest of the ridge dividing the basin of this creek from the next one lying to the west. These dykes may be part of one main intrusion, but as they appear on the surface they are quite distinct, and sands are exposed on the ground between them. One forms a small wall for a short distance, which runs N. 15° E., but the other is not defined where exposed, although the slopes to the westward are covered with detached blocks over a considerable area. They have both been intruded into sands.

The rock of which these dykes are formed is a very basic basalt. In a groundmass composed of feldspar laths, augite granules, and rather long individuals of magnetite with the skeletal outline of ilmenite, there are many phenocrysts of olivine and augite, the former predominating in number. Some of these show signs of serpentinization, but they are usually fresh and colourless, or with cracks stained with oxide of iron. They, as well as the augite, frequently form aggregations. The rock does not show any close relation to the teschenitic varieties which occur at High Peak and at Rakaia Gorge, but is more closely connected with the basic rocks of the other areas of the Malvern Hills.

The next creek to the west is the main source of Macfarlane Stream (see Section 2). On the north-west boundary of the outlier clays and shales with coal lie on the greywacke, but the country is much slipped. These beds are succeeded by sands and greensands, well exposed in a gully coming in from the north, and also in a tributary coming in from Benmore on the south. The line of the former has been determined by a basaltic intrusion. On its south-east side shales at times carbonaceous, sandy shales with gypsum crystals and greensands, and sands with concretionary bands are exposed, striking north-east and dipping south-east at angles of from 35° to 40°. In the tributary from Benmore there are sands of varying colour—grey, brown with oxdized iron, green with glauconite, and yellowish-white passing into white—all dipping south-east at an angle of 30°, the whole thickness of the coal-measures in this part of the area being approximately 1,500 ft. These sedimentaries are intruded by a massive basalt sill. Where exposed in Macfarlane Stream it is 50 ft. thick, but it thins out when traced along the gully to the north, and does not appear on the surface on the north-west boundary of the area. It can be traced across country to the west of the main creek, and appears in a creek coming from a saddle in the extreme south-west corner of the basin. Although Haast looked on this occurrence of igneous rock as a surface flow, there is little doubt that it is an intrusion in the form of a sill. The following points are of importance in this connection: (1.) The contacts of both the upper and lower surfaces are intrusive contacts, the beds both above and below the mass being affected by its heat. (2.) It is not parallel to the stratification, but crosses it at a small angle.

Haast evidently thought that all these igneous occurrences belonged to one great sheet, but the evidence clearly points to their discontinuity on the surface.

Where the tributary creek from Benmore crosses the boundary of the coal-measures there is decided evidence of faulting on a large scale. No actual contacts can be seen, owing to debris slopes coming from the greywacke, but on the line of the fault the greywacke is exposed some 250 ft. to 300 ft. vertically above the line to which the coal-measures reach in the bed of the creek, and the fault-plane is in consequence almost vertical, if not actually in a reversed position.

The chief tributary of Macfarlane Stream farther west follows the strike approximately, but in the gullies coming in from the flanks of Benmore the upper sand and greensand beds are exposed in places, and the position of the south-east boundary suggests the continuance of the fault-line to the south-west. The width of the coal-measures narrows gradually on tracing them south-west, but they extend almost to the crest of the saddle at the head of the creek. In this creek the sill mentioned previously occurs about 250 yards above the junction, strikes nearly due east, and dips south at an angle of 40°. It underlies light-green sands. Immediately up-stream from it a gully comes in from the south, in which are exposed greensands with rusty-brown stain, grey sands, sandy shales, passing up into greenish and greyish sands, which are brownish and yellowish near the fault-line. These beds dip south-east 50°.

No decided conclusion can be come to as to whether the area was glaciated or not. There is no reason why ice should not have invaded the head of the basin of Macfarlane Stream over the saddle which leads to the Rakaia Valley, especially as there is undoubted proof of the presence of glacier-ice lower down the Rakaia Valley having crossed ridges at a higher elevation than this saddle, and some of the features in the upper part of the basin can be attributed to ice-action. In the middle of the basin there are numerous large blocks of greywacke scattered over the surface, which suggest from their size and position that they have been carried by ice; but there is a possibility—perhaps a remote one—that they have been shed from the slopes of Benmore at a time antecedent to the dissection of the weak Cretaceous beds on which they now lie, and it is just possible, though not probable, that they have been transported by agencies other than ice.

The two special features of the area which have an interest not limited to the area itself are the occurrence of rhyolite conglomerate and also the positive evidence of faulting. With regard to the former, Hutton noted a difficulty, especially in the occurrence of the rhyolite pebbles at Craigieburn, and attributed its wide distribution to the action of a hypothetical river running from the Malvern Hills, past Benmore, through the Broken River basin, but he considered the form of the land-surface to be substantially the same as that at present existing. If, however, we take a more modern interpretation of the origin of the alpine region of Canterbury, with a stage during the middle Cretaceous after Jurassic folding, when it was reduced to a peneplain, then the features present no difficulty. The rhyolite pebbles have in that case travelled up a shore-line from their place of origin in the neighbourhood of the Misery–Rockwood ridge, or perhaps from farther out in the plains from an area of rhyolite now buried under Tertiary and Quaternary deposits.

When this peneplain, with its cover of sediments, was raised at the close of the Tertiary era the elevation was attended with faulting, and it is probable that this faulting continued down to a comparatively late recent date. In any case, this faulting is responsible for the major surface features of the Malvern Hills as they stand at present. From a study of the lie of the remnants of the Cretaceous coal-bearing beds which are preserved in the valleys in the heart of the Malvern Hills a well-defined series of subparallel faults may be inferred. These are as follow (see maps):—

(1.) *The faulted area where occurs the Cordy Flat Coalfield*, now being worked at Steventon. The fault-line runs along the northern flank of the Cairn Range, and continues in a south-west direction along the northern side of Mount Misery.

(2.) *The area about Rockwood Station,* whose position is determined by a fault which follows up the eastern side of the eastern branch of the Hororata River towards Phillips Saddle, and may be continued through it, since small patches of coal-measures occur on the north-eastern flank of Rocky Peak, and the form of the saddle suggests a structural origin.

(3.) *The Upper Selwyn basin,* which is faulted down along the north side of the Flagpole Range on a line running past High Peak. A splinter of this fault probably occurs a little to the north-west, and this continues to the north-east into the basin of the Hawkins River behind Dalethorpe, where the well-marked stripped surface indicates a former extension of the coal-measures into the upper basin of that stream, the only visible surviving remnant being a small patch on a tributary coming in from the north just west of the trig. marked 2725. The stripped surface of the Hawkins area is a continuation of that of the Upper Selwyn area, since there is no break between the basins of the two streams, and the upper Selwyn River may at one time have flowed into the Hawkins.

(4.) *The basin of the Kowai west of Springfield,* where the fault-line runs along the base of the Russell Range, the fault-line or fault-line scarp being strongly indicated by the series of faceted spurs fronting the Kowai River. The line of fault runs in close to the small patch of exposed coal-measures near the Kowai Bridge, which are crushed and much disturbed stratigraphically, while the hill slopes opposite on the lower spurs of Mount Torlesse are a stripped surface, which continues across the Waimakariri on to the downs behind the Woodstock Station, the greensands and underlying beds containing *Conchothyra* and *Trigonia,* and other shells exposed in the bed of the river near Otarama being a part of the beds which have been faulted down.

These problematical coal-measures have been covered up by the aggrading gravels brought down by the Kowai and its tributaries. An extension of this fault-line probably follows after a slight turn along the south-eastern flank of the Benmore Range. The marked break in the topography all along the range, and the similarity in the form of successive ridges as they abut against the sides of Benmore, are to be explained in this way, although there hardly appears to be sufficient evidence on which to base a positive statement of the existence of a fault. Its direction is nearly parallel with what may be regarded as definite fault-lines occurring in other parts of the area.

This suggested fault would necessitate a change of throw from the north-west to the south-east side of the fault, a reversal of displacement amounting to hundreds, if not to thousands, of feet. Such a change would be remarkable in a short distance. For these reasons the continuance of the Kowai fault along the south-eastern flank of the Benmore Range is somewhat doubtful.

(5.) *The Benmore area,* described previously. If the suggested explanation of the origin of this area be correct, it is probable that the gap between the Big Ben Range and Mount Torlesse, through which passes the West Coast Road over Porter Pass, has been determined by faulting, and also that this fault-line, or a closely related one, may cross the Rakaia River above the junction of the Acheron, and account for the position of the Redcliff limestone-beds, with their underlying sands, these limestone-beds representing a deeper-water deposit as the sea transgressed over the area during mid-Tertiary times after the coal-measures had been laid down. In my paper on Redcliff Gully (*Trans. N.Z. Inst.*, vol. 45, pp. 340–41, 1913) I had considered the possibility of the beds occurring there being connected with the limestones in the Broken River basin, and had decided against it. I do think, however, that they may be connected with the coal-measures of the Benmore area, and both may be remnants of a more widely distributed covering-sheet of Tertiary sediments.

The lines of fault indicated above are, with the exception of No. 2, thoroughly well authenticated, and No. 2 is probably correct. Their downthrow side lies to the north-west, but there is not sufficient evidence to show whether the faults are normal or reversed. The Benmore fault is certainly overthrust to the north-west, but faulting occurs at Rakaia Gorge where the overthrusting is to the south-east. Judging from the inclination of the beds and the separation of the outcrops of similar beds, the throw in certain cases amounts to thousands of feet, but with wide stretches, where no remnants of the covering beds occur, it is unsafe to determine throws from observations of dip and distance merely. Possible folding or change in the inclination of the strata forming the cover, even on a gentle scale, would render such calculations absolutely unreliable. A variation in the amount of vertical displacement along the line must also be expected.

This system of faulting on subparallel lines results in the Malvern Hills and the country behind them having a surface characterized by subparallel ridges, which have a general N.E.-S.W. trend, parallel to the main lines of fault. Some faults, such as No. 4, depart somewhat from this direction, and have an orientation more to the E.N.E.-W.S.W., and there is a correspondingly change in the line of the ridge associated with it.

On the north-west side of these ridges the slopes are generally steep and scarp-like, but on the south-east they are more gentle even where the covering beds have been stripped away. The maturity of the sculpture on these slopes varies considerably; in some cases the dissection of the surfaces has proceeded beyond the infancy stage, suggesting that either the original surface—*i.e.*, the Cretaceous peneplain—was quite uneven when the covering beds were laid down, or that after having been stripped they have been exposed to erosion for a considerable period. In other cases the stripped surfaces are almost as flat as the sides of a well-pitched tent, and suggest a recent uncovering. It should be mentioned also that the stream-directions are in many cases determined primarily by the fault-lines, for their dominant trend is between north-east and east-north-east —that is, parallel to the faults, and also at the same time parallel to the strike of the weaker Cretaceous sedimentaries which have occupied the angle formed by the successive down-dropping of parallel blocks.