THE TERTIARY GEOLOGY
OF THE AREA AROUND
IHANGARUA JUNCTION

A thesis presented for the
degree of Master of Science with Honours in Geology
in the University of Canterbury,
Christchurch, New Zealand

by

T. D. Phillips,
1963.
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MAP AND SECTION

(In pocket at end)

Geologic map of area around Inangahua Junction 1:31,680 (two inches to one mile) and geologic cross section AB.
Frontispiece. Suspension bridge, Berlins, Quartz porphyry with greywacke xenoliths outcrops on both sides of the Buller River at this point.
Fig. 1. Portion of West Coast of South Island showing N.Z.M.S.1 sheet districts and Inangahua Junction area.
SECTION I - INTRODUCTION

INTRODUCTION

The area mapped covers about 60 square miles and comprises most of the northeast portion of N.Z.M.S.1 sheet S.31 (Buller) and part of the extreme west of sheet S.32 (Murchison) (fig.1). It is centred on the township of Inangahua Junction which is situated near the junction of the Inangahua and Buller Rivers. The rivers are bordered by alluvial flats and terraces covered with a thin veneer of glacial outwash gravels. Tributary streams, particularly those from the east, have deeply dissected the terraces. The ground rises steadily to the east towards the Brunner Range (4,000 ft.) and to the west towards the rugged country of the Lower Buller Gorge region and the northern end of the Paparoa Range.

Bush still covers 80-85% of the area, farming, mainly dairying, being confined to the flats bordering the rivers. The main settlement is Inangahua Junction (population c.250) which actually consists of three settlements. Two of these lie on the western side of the Inangahua River, one around the railway station, and one around the Post Office and hotel. The third and largest, known as Inangahua Camp (fig.2), is situated on the eastern side of the river and contains the Ministry of Works camp, school, store, and garage, etc. Roads are confined to the settled areas, but sawmill tracks, State Forest Service and N. Z. Electricity Department roads provide relatively easy access to some of the bushed areas.
Fig. 2. View looking east from Rosemount. Settlement of Inangahua Camp in foreground, Brunner Range in background. The Inangahua River (lower right) joins the Buller just to the left of the photo.  
(Photo: W. Inwood).
FIELD WORK

Most of the mapping was done using N. Z. Lands & Survey Department vertical air photos, grid references being given in terms of the grid on N.Z.M.S.1 sheets S.31 Buller and S.32 Murchison, 1944 editions. The air photo scale was approximately 3 miles to the inch, and data plotted on them was transferred to a base map on a scale of 2 miles to the inch enlarged from the 1:63,360 topographic sheets.

Since the investigation was primarily concerned with the stratigraphy of the Tertiary rocks, the pre-Tertiary basement rocks and the Pleistocene deposits were not examined in detail. Field work was carried out at intervals between March and November, 1962.

ACKNOWLEDGEMENTS

Thanks are due to Drs. M. Gage, W. D. Sevon and A. E. Cockbain for helpful criticism and advice; to Messrs. A. King, Inangahua Junction, and P. L. M. Bain, Rokeby, Mid-Canterbury (formerly of Inangahua Junction), for assistance with accommodation; to Mr. D. J. Jones for help and advice on technical matters and for taking the photomicrograph (fig.5); and to Mr. W. Inwood for the loan of colour transparencies from which the colour illustrations (figs.2 and 10) were processed.
PREVIOUS WORK

Brief geologic descriptions of the area were given by several writers in the latter part of the last century, but in general these were only incidental remarks in descriptions of much larger areas. McKay (1877, pp.101-2) mentions the area in the course of a description of a fossil collecting trip on the West Coast, and describes collecting fossils at Landing, at "Christies" (near Inangahua Junction) and at Inangahua Junction itself. Later (1883) he described the geology in an account of the Reefton area which was illustrated with a black and white map on which he failed to differentiate between the mudstones and siltstones above and below the Cobden Limestone. In a report mainly concerned with gold prospects, McKay (1897) gives the area brief mention, while on the coloured map that accompanied the report, all formations from Hawks Crag Breccia to "Blue Bottom" were mapped together.

The most complete account of the area is by Henderson (1917) in the Geological Survey Bulletin on the Reefton Subdivision, the Inangahua area being covered by the coloured geologic map of the Inangahua Survey District. Henderson failed to notice any difference between Ohika Beds and Lower Tertiary Coal Measures and hence mapped them together in his "Miocene" Camaru Series. He visualized the structure as a sequence of gently dipping strata interrupted by several strike faults aligned more or less parallel to the Inangahua River, but the positions where he placed these faults are now interpreted as the axes of anticlines and synclines.
Gage & Wellman (1944) discussed most of the coal mines in operation in the area, confining their remarks mainly to the coal measures. Wellman (1950) in a paper on the Ohika Beds pointed out errors in earlier mapping in which Ohika Beds and Brunner Coal Measures were mapped together, and also illustrated the geology of the western part of the Inangahua area with a map and listed the formations present in a column. D.S.I.R. Coal Survey Reports by Suggate (1949) and Suggate & Wellman (1949) describe areas to the north and south of the Inangahua area, while the map of Beck, Reed & Willett (1958) adjoins it to the west.
SECTION II - STRATIGRAPHY

(a) OUTLINE OF STRATIGRAPHY

The basement rocks of the area consist of Precambrian grey-wacke, Jurassic Ohika Beds, and quartz porphyry and granite of uncertain age. These are unconformably overlain by Tertiary strata deposited during a complete cycle from transgression to regression of the sea, and range from coal measures at the base, through mudstone, limestone, more mudstone, etc., and back to coal measures at the top of the sequence. Fig.3 illustrates the succession and the formations mapped, while the table compares the different classifications that have been employed for the Tertiary rocks of the area. East of the Inangahua River, the strata are folded into a syncline and an anticline and then are faulted against Waiuta Group greywacke by the Lyell Fault which truncates the sequence within the Rough Creek Coal Measures so that higher beds, although formerly present, do not now outcrop in the area. Although the sequence extends north across the Buller River, it is interrupted there by the Inangahua Fault, but probably continues north of this to link up with the synclinal strata mapped in the Pensini Creek area by Suggate (1949). The anticline plunges to the south, resulting in progressively older rocks being exposed northward, and in the occurrence of limestone and coal measures in Flaxbush and Little Flaxbush Creeks, immediately to the north of the area mapped.
<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (ft)</th>
<th>Lithology</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rough Creek Coal Measures</td>
<td>5,700</td>
<td>Fault</td>
<td>Sands, gravels, etc., with interbedded lignite seams</td>
</tr>
<tr>
<td>Inangahua Formation</td>
<td>2,300</td>
<td>R/Z</td>
<td>Mudstone, siltstone and sandstone with concretionary bands</td>
</tr>
<tr>
<td>Cobden Limestone</td>
<td>1,500</td>
<td></td>
<td>Hard impure limestone, sandy near base</td>
</tr>
<tr>
<td>Buller Mudstone</td>
<td>1,000</td>
<td></td>
<td>Dark massive mudstone grading up into calcareous siltstone</td>
</tr>
<tr>
<td>Brunner Coal Measures</td>
<td>80</td>
<td></td>
<td>Dark siltstone and coal</td>
</tr>
</tbody>
</table>

Greywacke, quartz porphyry, etc.

Fig. 3. Generalized stratigraphic column for Inangahua area compiled from observations west of Inangahua Junction and from Rough Creek. Scale: 1,000 ft. to 1 in.
## COMPARISON OF CLASSIFICATIONS OF TERTIARY STRATA OF THE INANGAHUA AREA

<table>
<thead>
<tr>
<th>Lithology</th>
<th>McKay (1883)</th>
<th>Henderson (1917)</th>
<th>Wellman (1950)</th>
<th>Present Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conglomerate, sandstone, mudstone and lignite</td>
<td>Conglomerates</td>
<td>Deltaic sandstone, claystone and conglomerate</td>
<td>Upper Coal Measures</td>
<td>Rough Creek Coal Measures</td>
</tr>
<tr>
<td>Massive sandstone, siltstone and mudstone</td>
<td>Dark marly strata</td>
<td>Marine sandstone and claystone (Blue Bottom)</td>
<td>Blue Bottom</td>
<td>Inangahua Formation</td>
</tr>
<tr>
<td>Limestone and hard calcareous sandstone</td>
<td>Cobden Limestone</td>
<td>Limestone, calcareous grit, sandstone and claystone (Cobden Limestone)</td>
<td>Cobden Limestone</td>
<td>Cobden Limestone</td>
</tr>
<tr>
<td>Dark massive mudstone and calcareous siltstone</td>
<td>Dark marly strata</td>
<td>No separate unit 1</td>
<td>Port Elizabeth 2</td>
<td>Buller Mudstone</td>
</tr>
<tr>
<td>Sandstone, siltstone, and coal</td>
<td>Breccias, grits and coal</td>
<td>Littoral conglomerates, grits, sandstones, and shales</td>
<td>Kaiata Mudstone</td>
<td>Brunner Beds</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Brunner Coal Measures</td>
<td></td>
</tr>
</tbody>
</table>

1. Included in the underlying unit
2. Probably intended to be Port Elizabeth Mudstone
The beds in the west, i.e. the Brunner Coal Measures, Buller Mudstone and Cobden Limestone, can also be traced north across the Buller River, where they link up with similar strata in the area of the Buller Coalfield.

The strata represent part of the sequence of Tertiary rocks that once covered most of Westland and western Nelson, and as such, can be lithologically correlated in a general manner with many of the remaining outcrops in that area. Variations in lithology and facies make new stratigraphic names necessary in some cases, while in others, e.g. the limestone, an existing name can be satisfactorily applied.
(b) PRE-TERTIARY STRATIGRAPHY

GREENLAND AND WAIUTA GROUPS

Greenland Group greywacke outcrops in the bed of the Buller River on the south bank from about a quarter of a mile to a mile downstream from its junction with the Inangahua, and extends across the river into the hills to the north. It also forms the basement rock of the Tertiary strata to the north of Rahui, but its full extent in this area is not known due to the lack of outcrops. Greywacke correlated with the Waiuta Group occurs to the east of the major fault bounding the Brunner Range in the headwaters of Brown and Rough Creeks and extends east until replaced by intrusive granite.

In most outcrops, the rock is a hard, grey or greenish grey sandstone (commonly termed greywacke), generally fine-grained, and often showing incipient schistosity, in all exposures exhibiting several joint systems, most being filled with secondary quartz.

The degree of weathering of an outcrop is a valuable criterion for determining how close it lies to the unconformity between the top of the greywacke and the base of the Tertiary strata. Immediately beneath this surface, the rock is very crumbly and soft, is weathered orange throughout, and brown clay accompanies the remaining rock fragments. With decrease in weathering, this zone passes down into another where, although the rock is still homogeneous, an orange weathered fringe penetrates well into the rock.
from each crack, so that it is practically impossible to get an unweathered specimen from this zone. The weathering decreases downwards, the orange-stained fringe along each crack becoming progressively narrower until it fades out and the rock as a whole becomes unweathered.

The western exposures of greywacke are correlated with the Greenland Group because they link up with greywacke mapped as belonging to that group by Beck, Reed & Willett (1958) to the west of the Inangahua area, while the greywacke to the east is correlated with the Waiuta Group because it links up with Waiuta Group greywacke mapped in the Reefton Subdivision by Suggate (1957). The two groups are differentiated on account of persistent differences in regional strike, but true bedding was so rarely visible in outcrops seen in the area that it was not possible to get dip and strike values that would correctly indicate the attitude of the strata and not just the attitude of whatever joint system happened to be dominant at that particular locality. Hence, correlation was made as outlined above.

**QUARTZ PORPHYRY**

Quartz and granite porphyry occur on both sides of the Buller River in the vicinity of the Berlins suspension bridge and outcrop along the railway line to the east and west. Microgranite, which appears to be a lateral variant of the quartz porphyry, occurs where the Mackley River enters its gorge, about a mile upstream
from where it joins the Buller, and also on both sides of the Buller River immediately downstream from its junction with the Inangahua.

On both sides of the river near the suspension bridge, the rock contains numerous xenoliths of angular and subrounded greywacke, many over 6 in. and some over 12 in. in length, giving it the appearance of a breccia. Prominent phenocrysts of quartz and feldspar also occur, making it a true quartz porphyry. To the northeast, along the railway line towards Rahui, the xenoliths and phenocrysts decrease in size and abundance, finally becoming absent altogether, with the result that the outcrops near Rahui have the characteristics of a microgranite. Petrographic descriptions are given by Morgan & Bertram (1915, p.107).

The depth of weathering of the porphyry beneath the unconformably overlying Tertiary strata can be clearly seen in a road cutting about three quarters of a mile east of Berlins. At the top, the xenoliths are soft and easily broken by hand, while the matrix is completely kaolinized, this zone extending down about 20 feet with the effect of the weathering gradually becoming less severe. Below this is a zone 20-30 feet thick in which the xenoliths are still hard but the matrix is soft and orange-stained. This differential weathering is probably due to the smaller amount of feldspar in the greywacke than in the porphyry.

The exact age of the intrusions is unknown, but Beck, Reed & Willett (1958) suggest that since there appears to have been
no great interval of time between the intrusion of the quartz porphyry and the deposition of the Ohika Beds, the age is possibly Jurassic.

GRANITE

Granite forming the main mass of the Brunner Range to the east of the Inangahua area is probably a southward extension of the Karamea Granite of Grindley (1961). The streams were not traversed far enough into their headwaters for outcrops of granite to be seen, and the boundary on the map is taken from the map of the Inangahua Survey District by Henderson (1917). Petrographic descriptions of the rock are given by Morgan & Bartrum (1917, pp.100-101).

OHlKA BEDS

Ohika beds underlie the Tertiary coal measures near Berlins on the western margin of the area, the two being separated by a major unconformity that has been discussed in detail by Wellman (1950). The lithology varies, but comprises mainly sandstone, shale, and conglomerate. The age is given as Middle Jurassic or slightly older by Couper (1960) as the result of study of a microfloral sample from a thin coal seam on the north side of the Buller River about a mile downstream from the suspension bridge (grid ref. S.31/303606).
Name: The term Brunner Coal measures has been retained for the coal bearing strata near Berlins on account of the fact that they occupy a similar stratigraphic position to the type Brunner Coal Measures in the Greymouth Coalfield, i.e. directly beneath the first sediments deposited by the Lower Tertiary marine transgression. Other coal measures occur in similar stratigraphic positions at various localities between the Buller and Greymouth areas. For these reasons there is little need to erect a new stratigraphic name for the coal measures at Berlins. As used in this account, the term includes all those beds between the base of the Tertiary sequence and the lowest bed of the Buller Mudstone.

Distribution: Brunner Coal Measures occur along the western side of the area from Berlin's Bluff to the Buller River, and extend across the river north of Rahui almost to the Mackley River. Although coal measures outcrop in Rahui Creek about half a mile from the Mackley River, they could not be found in the river itself, but there is an obscured interval of 10-15 yards in the exposures between outcrops of granite and Buller Mudstone on both sides of the river just downstream from where it enters its gorge. However, if coal measures were present in this gap, they could be expected to be of high enough rank to support a bank, but instead their place is taken by slumped gravels, probably due to the
weathered top of the granite having been eroded away. This is true for both sides of the river. Thus it appears that the coal measures thin out and disappear between Rahui Creek and the Mackley River. At the other localities where the contact of basement rock and overlying Tertiary strata are exposed, in the reach of the Buller immediately downstream from its junction with the Inangahua, coal measures are absent, the mudstone being separated from basement by thin quartz sandstone and grit. The largest and economically the most important area of coal measures is that lying between Berlin's Bluff and the Buller River, since those in the vicinity of Rahui are thinner and more disturbed.

**Lithology:** Due to the variable conditions under which the coal measures were laid down, the lithology varies greatly from place to place, as does the total thickness of coal measures and the thickness of coal. The sequence at Heaphy's Mine, grid ref. approximately S.31/316577, is as follows:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buller Mudstone</td>
<td>ft.</td>
</tr>
<tr>
<td>Dark brown-grey micaceous mudstone</td>
<td>100+</td>
</tr>
<tr>
<td>Dark massive carbonaceous micaceous muddy siltstone</td>
<td>c.30</td>
</tr>
<tr>
<td>Brunner Coal Measures</td>
<td></td>
</tr>
<tr>
<td>Grey carbonaceous micaceous banded siltstone</td>
<td>10</td>
</tr>
<tr>
<td>Dark carbonaceous shale</td>
<td>6</td>
</tr>
<tr>
<td>Coal</td>
<td>30</td>
</tr>
</tbody>
</table>

(Lower beds not exposed).
Although basement is not exposed here, from the fact that the coal is underlain by fireclay, it seems likely that weathered basement, probably Ohaka Beds, if not directly below, is not far beneath the base of the coal seam. Cross bedding occurs in the banded siltstone, the bands, both in frequency and in width, decreasing upwards. This bed is actually the basal marine bed in the locality since marine fossils occur in it. Although none was found during an examination of the mine area, which however, has been considerably disturbed by bulldozing in connection with opencast mining, a fragment of a crinoid stem collected by Mr. L. Heaphy has been presented to the University of Canterbury Geology Department, (collection UCM.203 - see Appendix).

At Burley's Mine on the Buller Gorge Road, the sequence is:

Buller Mudstone  ft.
Dark brown-grey micaceous mudstone ............... 50+
Brunner Coal Measures
Dark very carbonaceous mudstone .......... 10
Quartz sandstone and grit with carbonaceous streaks
and thin interbedded shale bands .......... 16
Light soft carbonaceous sulphurous fissile shale ..... 9
Coal, top 12 inches weathered ............... 18
Carbonaceous quartz sandstone and grit ......... 2

Unconformity
Quartz porphyry (top 50 ft. weathered).

At the old Rahui Mine on the north side of the Buller River, now completely overgrown with blackberry, Gage & Wellman (1944)
reported that the coal (10-12 feet thick) directly underlay mudstone, and was separated from basement by 30-40 feet of sandstone. Only one outcrop of coal measures was seen in Rahui Creek, and this comprised approximately 12 inches of coal overlain by carbonaceous, friable, quartz sand and underlain by hard, creamy-white quartz sandstone.

It can thus be seen that there is a general decrease in the thickness of the coal in a northerly direction, from 30 ft. at Heaphy's Mine, to 25 ft. at the abandoned opencast working part way between Heaphy's Mine and the Buller Gorge road, to 18 ft. at Burley's Mine, to 12 ft. at the old Rahui Mine, and thinning to 1 ft. in Rahui Creek. This assumes that only one seam of coal is involved. In the case of the areas where coal is, or has been, mined, there is no doubt about this, since only one seam is known, but the relationship of the outcrop in Rahui Creek is more problematical. However, the absence of coal measures in the Mackley River suggests that it could well represent the most northerly extension of the main seam.

Although small faults are known to exist in the coal measures, the structure within the fault blocks is simple. Two faults bound the area being worked at Heaphy's Mine, and another bounded the area worked at the old Glen Crag Mine, next to Burley's Mine on the Buller Gorge road. A further fault must exist here since coal measures, comprising 12 inches of coal (top not exposed) underlain by fireclay and whitish claystone, outcrop in a small creek by the
main road, dipping northwest, while 10-15 yards up the creek, micaceous siltstone outcrops, dipping east. Since this relationship cannot be explained by folding, a fault must occur.

Despite the occurrence of marine fossils in siltstone above the coal at Heaphy's Mine, this bed is included in the Brunner Coal Measures since the base of the massive mudstone of the Buller Mudstone makes a more distinctive, mappable horizon. The maximum thickness of Brunner Coal Measures known in the area is approximately 50 ft. at Heaphy's Mine.

**Relation to Underlying Rocks:** The Brunner Coal Measures rest with angular unconformity on quartz porphyry, Ohika Beds, and Greenland Group depending on the locality. The unconformity between them and the Ohika Beds has been discussed in detail by Wellman (1950), but the only contact seen was the fault contact at Heaphy's Mine. The unconformity on the quartz porphyry is clearly exposed on the Buller Gorge road about a quarter of a mile east of the suspension bridge, grid ref. S.31/323603, where coal is separated from deeply weathered quartz porphyry by 2 ft. of quartz sandstone.

**Age and Correlation:** The exact age-range of the coal measures is unknown, but by assuming that the immediately overlying marine beds are only slightly younger than the top of the coal measures, the age arrived at is Bortonian. Suggate (1950) has discussed the age and distribution of the quartzose coal measures of the West Coast and Western Nelson, showing that the age decreases
from south to north, those in the Buller Gorge having correlatives of the same age at Westport, Reefton, and in the Murchison area.

**Conditions of Deposition:** The coal measures represent deposits laid down immediately prior to transgression by the sea over older basement rocks, and as such, encompass terrestrial and swamp deposits, and probably also, those of estuarine and littoral environments. During the Cretaceous, a peneplain formed over the older rocks, on which continual re-working and chemical weathering of the sediments took place (Suggate 1950). Tectonic movements preceding the Lower Tertiary transgression, but probably of the same origin as those causing it, warped the surface of the peneplain causing undrained hollows to form in which accumulation of peat took place that was subsequently metamorphosed by depth of burial to coal. The limited total thickness of coal measures and the fairly rapid variation in coal thickness in the Berlins area shows that the area involved in the down-warping was not large. Marine transgression then took place, resulting in re-sorting of the sediments above the coal followed by deposition of marine strata.

**Economic Geology:** Two coal mines are currently in operation at Berlins. Heaphy's Mine, situated beside Felix Creek, is reached by a side road off the main Inangahua-Westport road. It is worked by opencast methods, with the overburden being stripped off with bulldozers, after which the coal is removed from the face with explosives, then sluiced down a flume to the bins by means of a high-pressure jet of water (fig.4). Production from the mine in 1962 totalled 12,988 tons of coal.
Fig. 4. Heaphy's Mine, Berlins, showing hydraulic method of opencast working. The coal is sluiced down a flume (lower right), which passes through a tunnel beneath the camera point, before reaching the bins.
Burley's, or Paines' Mine is situated beside the Buller Gorge road near Berlins. Although formerly an opencast mine, it is now worked by underground methods, with the coal loosened at the face being sluiced down a flume within the mine and out to the bins in the manner of Heaphy's Mine. Coal produced in 1962 amounted to 2,475 tons.

**BULLER MUDSTONE**

*Name:* The name is taken from the Buller River and was considered the most appropriate of those available since the most accessible exposures of the formation occur along the road down the Buller Valley, west of the junction of the Inangahua River.

*Definition:* The Buller Mudstone is defined as the mudstone and siltstone lying between the base of the Tertiary marine sequence and the Cobden Limestone of the Inangahua area. The base of the massive mudstone is taken as the lower boundary while the upper is placed at the base of the hard calcareous sandstone which forms the lower part of the Cobden Limestone.

The type section is the roadside exposures from about three-quarters of a mile to a mile and a half west of the junction of the Inangahua River with the Buller, grid ref. S.31/394522 to S.31/380618. The name is given to strata that previously have been loosely referred to as Kaiata Mudstone, but while this name is suitable for the lithology of the base of the formation in most localities, it cannot be satisfactorily applied to the formation as a whole. There is no correlative of the Omotumotu Beds of the
Greymouth area, and in its upper part of the formation grades into beds that have been correlated with the Fort Elizabeth Mudstone by Wellman (1950). However, the contact with the underlying beds is gradational, and the strata are best included in a single unit.

The definition excludes the thin marine beds that have been included in the Brunner Coal Measures, but algal limestone, and glauconitic and quartz sandstone exposed at the junction of the Buller and Inangahua Rivers are included, for reasons given below.

**Distribution:** Buller Mudstone extends from the base of the prominent scarp that forms the boundary of the Cobden Limestone on the southern side of the Buller River valley north across the river to the gorge of the Mackley River and around the limestone remnant that lies between it and Welshman Creek. The western boundary is the Brunner Coal Measures near Berlins, and to the east it is cut off by the Inangahua Fault.

**Lithology:** Typically the formation consists of moderately hard brown-grey micaceous mudstone passing up into blue-grey calcareous siltstone that becomes more calcareous upward until it grades into, or is replaced by, Cobden Limestone. Angular quartz and feldspar grains predominate, while mica, principally muscovite, is common throughout, except in some of the muddy beds near the base of the formation. Brown biotite makes its appearance in the upper part, while pale green-yellow and yellow-brown biotite was noted in residues of microfaunal samples collected from almost immediately below the base of the limestone. Although glauconite is present in small quantities in some of the siltier samples from the
upper part of the formation, a sample taken from the massive mudstone above the coal measures at Heaphy's Mine area contained abundant rounded grains. Thin carbonaceous streaks occur locally near the base of the formation.

Small, calcareous, pyritic concretions, principally spheroidal (up to 2 inches in diameter), but also nodular and tabular, are abundant near the base of the formation. While the latter are oriented parallel to the bedding of the rock, the spheroidal and nodular forms are randomly distributed throughout and not concentrated on particular bedding planes.

In most outcrops the mudstone is massive with no bedding discernable, but in the blue-grey calcareous upper part, some slight banding does make its appearance. The thickness of the formation ranges from about 350-400 feet in the vicinity of "Whitecliffs" to approximately 1,000 ft. near Berlins. In the former case, the boundary with the limestone is obscured, while in the latter, dense bush prevented measurement and the thickness quoted is that derived from interpretation of geologic cross sections.

Included with the beds mapped as mudstone is a sequence at the junction of the Buller and Inangahua Rivers, grid ref. S.31/402612, in which quartzose and glauconitic sandstone underlies the mudstone. This was not mapped separately as the area involved was too small to show on anything but a very large-scale map. The sequence is:
Dark brown micaceous mudstone ........................................ 50+ ft.
Hard dark fine-grained sandstone ......................................... 2 ft.
Hard light-grey coarse-grained glauconitic sandstone ........... 12½ ft.
Hard grey fine-grained sandstone, bands of algal limestone c.1 ft. thick in lower 10 ft. .................. 17 ft.
Yellow-orange weathered shale ............................................ 2½ ft.
Pinkish and creamy quartzose sandstone ............................... 12 ft.

Unconformity

Microgranite, top 10 ft. deeply leached and rotten.

Coal has been reported as outcropping at the edge of the Buller River directly opposite the above sequence (W. Inwood pers. comm.), in a locality now inaccessible due to overgrowth of blackberry and gorse and possibly obscured by gravels. Since the details of this outcrop are unknown, it is mapped with Buller Mudstone on the northwestern side of the Inangahua Fault. Approximately one mile to the west, and about 300 yards from the farm known as "Whitecliffs", marine beds below the mudstone and Brunner Coal Measures are absent, and the following sequence is exposed on the roadside, grid ref. S.31/390625:

Yellow and yellow-orange quartzose sands and grits ................ c.6 ft. (base not exposed)

Unconformity

Greywacke, top 5-10 ft. deeply weathered.
In general, the mudstone is distinguishable from finer-grained sediments of the Inangahua Formation, which at times it somewhat resembles, by its much darker colour and by the fact that the outcrops of mudstone, particularly in the lower portion, weather to a dark orange-brown colour, probably on account of its high iron content, while mudstones of the Inangahua Formation remain a very dark grey.

Relation to Underlying Rocks: In the Berlins coal mining area, the strata overlying the coal either pass up directly into massive mudstone, or a bed of very micaceous siltstone intervenes, as at Heaphy's Mine. This bed has been included in the Buller Mudstone. The relationship of these beds is conformable, the beds forming a continuous sequence from non-marine to marine deposition. In the bed of the Mackley River, the mudstone apparently rests directly on granite without the intervention of coal measures, while on the Buller Gorge road, near "Whitecliffs", it is separated from greywacke by a maximum of 6 ft. of grit, then at the junction of the Inangahua and Buller Rivers, it passes down into sandstone and algal limestone resting unconformably on granite.

Palaeontology: Macrofossils are rare in the mudstone, and even in those localities where they are found, they are scattered, poorly preserved, and fragile, and hence are difficult to collect. The only locality from which macrofossils were recovered was on the north bank of the Buller River, from an outcrop just above water level, about 1½ miles below the junction of the Inangahua.
The fauna, UCM.201 (University of Canterbury macrofossil collection number - see Appendix) comprised:

Mollusca
- *Baryspira* (Gracilispira) *morgani* (Allan)
- *Proximitra amorica* (Suter)
- *Dentalium solidum* (Hutton)

Coelenterata
- *Notocyathus* (Paradeltocyathus) *pedicellatus* (Tennison-Woods)
- *Stephanocyathus* (Odontocyathus) *tatei* (Dennant).

The corals were identified by Dr. D. F. Squires, Smithsonian Institution, U. S. A. Complete pelecypod valves and turritellids also occur in the same matrix, but proved too fragile for collection.

The fauna and flora of the algal limestone, UCF.406 (University of Canterbury microfaunal sample number - see Appendix), from the junction of the Inangahua and Buller Rivers, is significant in view of the information it yields on the palaeoecology of the formation. As far as can be ascertained from available literature, the algae belong to the genus *Archaeolithothamnion*, a genus that was particularly common in the Eocene, with the possibility that other genera are also present. Associated with it are rare gastropods and pelecypods and a moderate number of Foraminifera. Some of the limestone was dissolved in acetic acid, and examination of the residue disclosed abundant echinoid spines and fragments of plates, along with the partially dissolved tests of Foraminifera and rare Ostracoda. Of the Foraminifera, the most common is *Asterigerina cf. cyclopus* Dorrean, a species that is not uncommon in beds of the
same age and suitable lithology elsewhere on the West Coast. The other species did not survive the acid treatment and could not be identified in thin section.

The microfaunas of the formation show a gradation from arenaceous, shallow-water forms at the base, to calcareous, deeper water faunas at the top. Basal faunas, such as UCF.400, from beside the Buller Gorge road near "Whitecliffs" (full details of localities are listed in the Appendix), are characterized by large specimens of the arenaceous Foraminifera *Ammodiscus* and *Cyclammina*, along with some smaller species too badly preserved for identification. Although Akers (1954, p.149) has suggested that the genus *Cyclammina* could be an indicator of bathyal depths, Finlay (1945, p.361) has noted its dominance in a sample from the base of the Kaiata Mudstone at Garden Gully, near Blackball. This is obviously not a bathyal fauna since it comes from immediately above poorly fossiliferous (sublittoral?) sandstone overlying basement, and underlies mudstone with rich faunas indicative of depths probably less than 400 ft. Furthermore, these faunas contain specimens of *Cyclammina* identical with those of the basal fauna. Hence, the Garden Gully occurrence of *Cyclammina* is very probably shallow water, showing that the Inangahua occurrences in similar deposits, although apparently anomalous with regard to the general depth indications of the genus, are not unique.

The arenaceous faunas of the type discussed above grade up into faunas containing increasing numbers of calcareous forms.
Fig. 5. Algal Limestone, junction of Inangahua and Buller Rivers, grid ref. S.31/402612. Thin section cut parallel to the length of the algal stems and showing their mesh-like appearance. x 90.

(Photomicrograph: D. J. Jones).
Typical of these is UCF.401, from a road cutting about 2 miles east of Berlins, which included:

- **Gaudryina** sp.
- **Cyclammina** sp. (common)
- **Quinqueloculina** sp. (common)
- **Robulus** sp.
- **Vaginulina** sp.
- **Sigmoidella** sp.
- **Rectuvigerina bortotara** (Finlay) (rare)
- **Bolivina** sp.
- **Cassidulina** sp.
- **Gyroidinoides scrobiculatus** (Finlay)
- **Anomalinoides semiteres** (Finlay)
- **Cibicides semiperforatus** Hornibrook.

Associated with these are rare pelagic Foraminifera, rare Ostracoda, and abundant echinoderm spines.

From a slightly higher stratigraphic level, the microfauna (UCF.402) of the matrix of the macrofossil collection listed earlier, UCM.201, from the Buller River bank, included:

- **Textularia** sp.
- **Gaudryina reussi** (Stache)
- **Arenodosaria antipoda** (Stache)
- **Schenckielia levis** (Finlay)
- **Cyclammina** sp.
- **Quinqueloculina** sp.
Robulus sp.
Dentalina sp.
Cassidulina sp. (common)
Gyroidinoides zelandica (Finlay) (common)
Anomalinoides sp.
Cibicides semiperforatus Hornibrook (common)

Also occurring are rare pelagic Foraminifera.

Although the lack of a continuous section through the formation made it impossible to sample a complete sequence of beds, it is probable that faunas similar to the above pass up into faunas similar to UCF.403, 404, 405, from siltstone beneath the Cobden Limestone, Buller Gorge road. In these, the Foraminifera are badly preserved and are not common, probably due to solution and recrystallization of the calcite preceding the phase of limestone deposition. The following were identified:

Lenticulina sp.
Rectuvigerina postprandia (Finlay)
Cassidulina sp.
Sphaeroidina sp.
Rotaliatina sulcigera (Stache)
Anomalinoides sp.
Cibicides sp.

Pelagic Foraminifera (not identified), mostly poorly preserved, occur in slightly greater numbers than lower down in the formation, but they are still rare.
The most important feature of the microfaunas is the gradual change from completely arenaceous faunas at the base of the formation, through mixed calcareous and arenaceous faunas, to solely calcareous faunas at the top, corresponding to a change from sublittoral to open-sea environments.

**Age and Correlation:** The age of the formation ranges from Kaiatan to Runangan. The only significant macrofossil from the point of view of dating is *Baryspira* (*Gracilispira*) *morgani* (Allan) which ranges from Bortonian to Kaiatan, but the microfaunas show the formation to be no older than Kaiatan. Species making their last appearance in the Bortonian are absent, and the occurrence of *Gaudryina reussi* (Stache) and *Asterigerina cf. cyclops* Dorreen, both of which make their first appearance in the Kaiatan, confirms a Kaiatan age for the base. The upper age limit is governed by the occurrence of *Rectuigerina postprandia* (Finlay) which is restricted to the Runangan.

The Buller Mudstone can be correlated with similar strata in Westland and Southwest Nelson between the Greymouth and Buller areas, all of which have been loosely termed Kaiata Mudstone on account of their general lithologic similarity to the type Kaiata Mudstone of the Greymouth area, but of which they are not necessarily exact lithologic or time correlatives.

**Conditions of Deposition and Palaeoecology:** The sediments of the Buller Mudstone were deposited following a marine transgression and range from shallow-water littoral and sublittoral sediments deposited in areas of restricted water circulation at
the base, to open-sea, relatively deep-water sediments at the top. Combined with the increasing depth of deposition of the sediments there was a change in their nature, resulting in the mudstone at the base of the formation grading up into calcareous siltstone and sandy siltstone at the top.

The occurrence together of arenaceous Foraminifera, carbonaceous material, and calcareous pyritic concretions in the basal portion of the mudstone indicates that deposition began in an environment of restricted water circulation, probably in localized basins or embayments. This suggestion is supported by the fine grain size of the sediment, since coarser grades could be expected in areas of more vigorous water movement. Furthermore, the absence of shellbeds, or even scattered macrofossils near the base of the mudstone is an indication that special environmental conditions prevailed, since their occurrence is general in most shallow-water deposits. Weeks (1953, 1957) has suggested that carbonate concretions form in environments of restricted water circulation due to the pH of the water being too low for normal carbonate deposition, the alkalinity required for precipitation of the carbonate coming from ammonia formed by the decomposition of nitrogenous organic matter. Whether or not this applies to the base of the Buller Mudstone is open to question, but the necessary requirements (restricted water circulation; organic material) were certainly present. Furthermore, although the absence of calcareous fossils can be explained by normal leaching processes, the continued presence of carbonate concretions remains an anomaly. In the area where
the algal limestone was forming, the restricted water circulation had little effect while the water was shallow, allowing a diversified flora and fauna to develop, but deepening of the sea resulted in the bottom water becoming partially stagnant and limited the scope of the fauna to arenaceous Foraminifera.

The flora and fauna of the algal limestone is important in considering environments and ecology for the lower part of the mudstone. Johnson (1963) states that present species of Archaeolithothamnion occur in tropical or sub-tropical waters at depths of 40-200 ft. and that available evidence suggests that past species occurred in similar environments. Cushman (1948) states that Asterigerina is often abundant on coral reefs and in warm, shallow waters, and that Amphistegina, a close relative, is very abundant in similar conditions and is very probably limited to around 180 ft. It is therefore very likely that deposition of the limestone took place at a depth of between about 50 and 150 ft. in warm, clear tropical or sub-tropical waters.

This phase of shallow-water sedimentation was followed by further submergence of the land and the merging of local basins, bringing open-sea conditions and an influx of calcareous Foraminifera. Apart from the change in character of the microfaunas, the attainment of more normal conditions is also shown by the occurrence of macrofossils, including solitary corals, along with some of these richer foraminiferal faunas. The increase in depth of deposition is shown by the decrease in abundance of Quinqueloculina, a genus generally confined to depths of less than 300 ft., between faunas
such as UCF.401 and UCF.402. The decrease in abundance of cidarid spines between these faunas supports the suggestion of increasing depth, since echinoids generally also prefer water shallower than 300 ft. (Vella, 1962, p.28, fig.2). Rare ostracods were found in UCF.401 but none in UCF.402, again suggesting an increase in depth between the two.

For sample UCF.401, the occurrence of rare Ostracoda, cidarid spines, the genera Quinqueloculina, Cibicides, and Cassidulina (rare), the ratio of arenaceous to calcareous benthonic Foraminifera of about 1:4, and the rare occurrence of pelagic forms, suggests that the sediments were deposited within the depth range of the outer part of the continental shelf, i.e. at a depth of the order of 200-300 ft., using the figures given by Phleger (1960, p.259). The Foraminifera define a depth range of 200-400 ft., since Quinqueloculina is generally confined to depths less than 400 ft. while Cibicides and Cassidulina become increasingly abundant below 200 ft., depth distributions being taken from Vella (op. cit.) and Phleger (op. cit.). However, the other factors stated above serve to restrict the depth to the 200-300 ft. range.

The association of corals and molluscs with microfauna UCF.402 allows a more complete palaeoecological study of this part of the formation to be made. The evidence of the corals indicates that the bottom temperature was around 50 deg.F., since the temperature ranges of the corals are (Squires, 1958, p.22):

Notocyathus (Paradeltocyathus) : 48-74 deg.F.
Stephanocyathus (Odontocyathus) : 40-50 deg.F.
Although the microfauna is basically the same as UCF.401, the lack of ostracods, scarcity of cidarid spines, and the more abundant occurrence of Robulus (a deep water indicator), along with common Cibicides and Cassidulina, indicate an increase in depth, probably to within the range 250-400 ft. Despite the fact that this represents an increase in depth over that for UCF.401, there was no change in the conditions of deposition of the sediment, since both faunas occur in similar massive mudstones. Although these depths fall within the depth-range of the present-day continental shelf, evidence for the existence of such a feature at this time is lacking. Instead, the area formed part of a relatively large depression of the sea floor in which deposition of mudstone was taking place.

Towards the end of Kaiatan or early in Runangan times, this depression became full, bringing the sea floor within the range of wave and current action. This caused a coarsening of the Runangan sediments due to winnowing-out of the finer grades, and also resulted in the appearance of faint bedding in the hitherto massive formation. Paralleling the grain-size increase is an increase in calcium carbonate content, foreshadowing the succeeding period of carbonate sedimentation. The absence of macrofossils and the poor preservation of the microfaunas from the upper, coarser, part of the formation is probably due to recrystallization of calcite from their shells during diagenesis, possibly accompanied by some post-depositional leaching, rather than to unfavourable environmental conditions.
Name: As originally used, the name was applied to limestone at Cobden, near Greymouth. However, it is used here for the limestone and hard calcareous sandstone of the Inangahua area because it occupies a similar stratigraphic position to that further south, i.e. between a correlative of the Port Elizabeth Mudstone and beds previously referred to as Blue Bottom, and because it is of approximately the same age. For these reasons there is little need to erect a new stratigraphic name.

Distribution: Cobden Limestone covers a relatively large area on the western side of the Inangahua River, from Landing in the south to the valley of the Buller River in the north, where the northern edge forms a prominent scarp extending from Berlins Bluff to Inangahua Junction. More limestone occurs on the northern side of the Buller River, between the valley of the Mackley River and Welshman Creek, and extends northward from here out of the area mapped, again bounded by a prominent scarp.

Lithology: The lack of a section exposing a complete sequence through the limestone, combined with the lateral variation in lithology that occurs, makes description of the formation difficult. In the vicinity of "Whitecliffs", the basal bed is a hard, massively bedded, calcareous sandstone, more than 20 ft. thick, which is overlain by lensoid beds of thin-bedded and graded-bedded sandstone alternating irregularly with massive sandstone, all highly calcareous. These are overlain in turn by hard creamy
limestone. Thin layers of soft, calcareous siltstone occur inter-bedded with the calcareous sandstones. Beds above the creamy limestone are not exposed, due partly to removal by erosion and partly to lack of suitable outcrops.

However, higher strata are exposed in Hard Creek, at Oweka in the Inangahua Valley. The lowest bed with known stratigraphic relations that is exposed is a soft, grey, calcareous siltstone, overlain by 15-20 ft. of thick-bedded calcareous sandstone, which is overlain in turn by fine-grained, massive, argillaceous limestone. Outcrops in the bed of Hard Creek show that the bedded sandstone is cross-bedded at low angles on a moderately large scale. The contact with the overlying Inangahua Formation is not exposed in Hard Creek, the nearest approach to it being at Landing, where the highest limestone exposed at the combined road and rail bridge, just up-river from the contact, is fine-grained, with whole and fragmentary macrofossils.

In the absence of clear contacts in suitable places, the total thickness of the limestone is hard to estimate, but it is probably in the vicinity of 1,500 ft. in the Berlin's Bluff area, and thinning to approximately 1,000 ft. in the area immediately west of Inangahua Junction. This eastward thinning is in accordance with the observations of Suggate (1949) for the area near Lyell, and also in accordance with the eastward thinning of the Buller Mudstone.

In order to assess the general purity of the limestone, in view of the interest of residents of the area in limestone for
calcium carbide production, samples from various localities were dissolved in hydrochloric acid and the percentage residue calculated, with the following results:

<table>
<thead>
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<th>Locality</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Residue</td>
<td>23.7</td>
<td>22.4</td>
<td>51.4</td>
<td>63.3</td>
</tr>
<tr>
<td>Grade</td>
<td>clay</td>
<td>silt</td>
<td>silt</td>
<td>sand</td>
</tr>
</tbody>
</table>

1. Hard Creek, at old track crossing, S.31/354577
2. Side of track, above Buller Gorge road, S.31/385626
3. Same locality, bottom of track, S.31/385626

The above figures show the low purity throughout, since the samples range from the top (1) to the base (4). These results also show a decrease in the grain size of the residues from bottom to top, a fact in accordance with field observations. The residues consisted mainly of subrounded grains of quartz, with, in the case of (2), rare sand-size rounded quartz grains amongst and silt-sized remainder. Mica, mainly muscovite, is present in variable quantities, with biotite present in (3) and (4), i.e. near the base of the formation.

A notable feature of the limestone is the occurrence of a conglomeratic band set in hard, creamy, calcareous, coarse, arkosic sandstone, exposed at the foot of the cliff overlooking the Buller River, near "Whitecliffs", grid ref. S.31/390624. The conglomerate forms a band of up to 15 ft. in thickness, thinning-out away from this maximum, and comprises angular and subrounded boulders of granite and greywacke, with the latter predominating, up to 15
Fig. 6. Boulders in Cobden Limestone, base of limestone bluffs above Buller Gorge road, near "Whitecliffs".
inches in length and about 9 inches in diameter (fig. 6). No pre-
ferred orientation or bedding was seen, while both size and quan-
tity of coarse elastic material decrease upward, forming, in ef-
fect, a graded bed. Current bedding occurs in some of the coarse
sandstone beds both above and below, but no unconformity could be
detected between them and the rubble band. Hence it is concluded
that the conglomerate forms part of a continuous sedimentary se-
quence.

Both small and large-scale cross-bedding occurs within the
limestone. The thin-bedded calcareous sandstone near the base of
the formation in the Buller Gorge is cross-bedded at low angles;
it occurs again in the limestone in the lower reaches of Herd
Creek; while large-scale, low-angle cross bedding can be seen in
the cliffs overlooking the Buller Gorge road just before it turns
to cross Walker's Flat (fig. 7). At this locality, the beds in the
upper part of the cliff have an angular discordance of 5-10 degrees
with those underneath, but the absence of any obvious erosional
break between the two sets of beds suggests that the feature is
cross bedding, and not an angular unconformity.

In the section beside the Buller Gorge road about half a mile
southwest of "Whitecliffs", grid ref. S.31/383622, soft calcareous
sandstone which grades up into the hard calcareous sandstone that
forms the base of the Cobden Limestone in this locality, rests with
angular discordance of 10-15 degrees on the top of the Buller
Mudstone. This appears to be an entirely local phenomenon since
it extends over only 200-300 yards of road cutting, and does not
Fig. 7. Limestone bluffs above Buller Gorge road, showing angular relationship of beds. Walkers Flat in background.
extend back as far as the head of the small creek which runs down to the river at this point. The main cause appears to be local slumping of the sediments before they became consolidated, with the unconformity marking the scoured surface. Although contorted bedding is absent, the upper surface of the siltstone has inclined borings which point down the slope, and small pieces of siltstone are caught up in the sandstone immediately above the contact. The Foraminifera indicate that there is also no appreciable time gap between the beds above and below the contact. However, the presence of small amounts of glauconite in the sediments above the scoured surface suggests that there may have been a temporary slowing down of the rate of sedimentation. Following the slump, the beds above were deposed with the initial dip of the scoured surface, resulting in the angular discordance.

Relation to Underlying Rocks: Apart from the case described above where slumping has occurred, the contact with the underlying Buller Mudstone is conformable, being either transitional, where the gradual increase in calcium carbonate content in the underlying siltstones produces a gradual increase in the induration of the sediment, or abrupt, where the calcium carbonate content has either been increased abruptly, or been caused to recrystallize by some means. The most accessible contacts are along the Buller Gorge road below "Whitecliffs", where it is transitional in the road cuttings and abrupt at the head of the small creek which crosses the road at grid ref. S.31/382619.
Palaeontology: Macrophossils are rare in the Cobden Limestone of the Inangahua area, and where present proved impossible to extract whole. Complete shells occur in the topmost portion of the limestone as exposed on the river bank at the combined road and rail bridge at Landing, while rare, poorly preserved specimens occur on bedding planes in the alternating calcareous sandstone and limestone southwest of "Whitecliffs". Gastropods and fragmentary brachiopods were noted. Fucoidal markings, dubiously organic in origin, also occur. The only foraminiferal sample with a useful fauna was UCF.407, from grey calcareous siltstone above Hard Creek. The fauna was not well preserved, but included:

- Robulus sp.
- Hofkeruva sp.
- Bolivina sp.
- Gyroidinoides zelandica (Finlay)
- Elphidium spp.
- Notorotalia sp.
- Discorotalia tenuissima (Karrer)
- Cibicides sp.

Pelagic Foraminifera (not identified) also occur.

Age and Correlation: The age of the limestone ranges from Whaingaroan to Waitakian. No internal evidence of age was found, and that given above is taken from Wellman (1950), based on N. Z. Geological Survey studies. The age-range is limited by the occurrence of Runangan sediments below and Otaian sediments above the formation.
The Cobden Limestone of the Inangahua area is correlated with similar limestones occurring in the Grey-Inangahua depression, and in the coastal belt from Greymouth to Cape Foulwind. Although the lithology is variable, they are all of about the same age and occupy similar stratigraphic positions.

Conditions of Deposition: The Cobden Limestone was deposited as an off-shore type of detrital carbonate deposit at relatively shallow depths and probably in warm seas. In the lower portion, calcareous sandstone predominates, showing that land was not far off, by-passing of the finer grain sizes of sediment resulting in the coarse grain size of the rock. The cross bedding that also occurs in this portion is another indication that the sedimentary environment was an active one. A further indication of the nature of the environment is given by the alternation of lenticles up to 9 inches thick of bedded and non-bedded sandstone (the former showing signs of graded bedding) near the base of the formation as exposed beside the old mill track near "Whitecliffs". These provide evidence of quiet conditions resulting in the deposition of the thin, bedded lenses of sandstone, alternating with more agitated conditions resulting in the formation of the more extensive massive beds.

The origin of the conglomerate in the limestone is obscure, but available evidence suggests that the boulders accumulated elsewhere, either as a lag deposit on a remnant of the former land, or as a result of tectonic activity, and were moved into their final position by a large slump. The upward decrease in size of the
boulders making up the deposit possibly arises from the greater velocity attained by the larger boulders and their sinking into the soft bottom sediment to greater depths than those of cobble and pebble size.

As sedimentation continued, the grain size of the clastic material decreased giving rise to fine-grained argillaceous limestone in the upper part of the formation. This was probably due to a decrease in the rate of sediment supply caused by slowing-down of the rate of erosion on land, and increasing distance from the shoreline due to continuing submergence. The depth of deposition also increased towards the end of the phase of sedimentation. The fauna of sample UCF.407, which includes Notorotalia and Elphidium, common indicators of relatively shallow waters, shows that the water at this stage was within the depth-range of the continental shelf, and probably less than 200 ft. However, a thin section made from fine-grained limestone from near the top of the formation showed a fauna composed mainly of pelagic Foraminifera, suggesting that the water was now too deep for abundant benthonic forms and that land was even more distant. The clay content of the limestone sample from Hard Creek (23.7%) indicates that erosion was still continuing on the distant land, and thus suggests that not all of the former land of the region was submerged during the Lower Tertiary transgression.
INANGAHUA FORMATION

Name: The name Inangahua Formation is given to the mudstone, siltstone, and sandstone lying above the Cobden Limestone in the Inangahua area that has previously been loosely referred to as "Blue Bottom". The name is taken from the Inangahua River along which the formation outcrops at numerous points.

Definition: The Inangahua Formation is here defined as the mudstone, siltstone, and sandstone lying between the Cobden Limestone in the Inangahua area and the non-marine sequence forming the Rough Creek Coal Measures. The lower boundary is taken as the top of the highest limestone bed of the Cobden Limestone, and the upper as the top of the highest marine bed of the Inangahua Formation. Thus, tongues of non-marine strata occurring below this level (discussed later under Rough Creek Formation), are included in the Inangahua Formation. The type section is the exposure in Rough Creek extending from the first contact with the Rough Creek Coal Measures, grid ref. S.31/413555, downstream to the road bridge. Supplementary information on the lower portion of the formation can be gained from the exposures at Inangahua Junction, on the roadside north from the hotel, and at the Inangahua River bridge.

Distribution: The formation covers a wide area on both sides of the Inangahua River, from Landing to its junction with the Buller, and also occurs on the north side of the Buller River in the area opposite the mouth of Dee Creek. It extends continuously
up Ram, Dee, and Brown Creeks until replaced by Rough Creek Coal Measures, but in Rough Creek, synclinal folding has caused repetition of the upper portion, giving two transitions from marine to non-marine sediments, separated from each other by Rough Creek Coal Measures filling in the centre of the syncline.

**Lithology:** The strata comprising the formation include moderately hard and hard blue-grey siltstone and darker mudstone, and also light sandstone, all generally massive in character, but with bedding sometimes visible in the coarser beds. Concretionary bands occur throughout. Usually these are completely massive in nature, but some show parallel bedding, while extremely contorted bedding is preserved in others. They are well developed on Dee Hill, where calcareous sandstone forming bluffs facing east appears to increase in cementation laterally to the extent that, where the strata are intercepted by the Buller River, grid ref. S.31/427613, they take the form of closely-space concretionary bands interbedded with soft calcareous sandstone.

The sediment is composed principally of angular and subrounded grains of quartz and feldspar. These are generally accompanied by mica, usually muscovite, but brown biotite often occurs with it, while chlorite occurs sporadically in small amounts. Rare grains of glauconite were noted in some samples. The lower part of the formation is very calcareous, but the proportion rapidly declines, until, in most of the higher beds (those on Dee Hill are one exception), the slight effervescence that occurs with acid is probably caused by reaction with Foraminifera.
<table>
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<td></td>
<td></td>
<td>Sandstone and siltstone with intercalating non-marine beds</td>
</tr>
<tr>
<td>Ph-a</td>
<td>411</td>
<td></td>
<td></td>
<td>Massive mudstone, scattered macrofossils</td>
</tr>
<tr>
<td>Ph-a</td>
<td>41C</td>
<td></td>
<td></td>
<td>Siltstone, some beds calcareous</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Massive mudstone with concretionary bands</td>
</tr>
<tr>
<td>Inangahua Formation</td>
<td>409</td>
<td></td>
<td></td>
<td>Thick-bedded sandstone and siltstone</td>
</tr>
<tr>
<td></td>
<td>408</td>
<td></td>
<td></td>
<td>Moderately calcareous siltstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Massive calcareous mudstone</td>
</tr>
</tbody>
</table>

Fig. 8. Generalized stratigraphic column for Inangahua Formation. Compiled from observations near Inangahua Junction and in Rough and Dee Creeks. Scale: 600 ft. to 1 in.
Although massive siltstone is probably the dominant rock type of the formation, considerable thicknesses of sandstone and mudstone also occur. Many of the outcrops along the Inangahua River are sandy, while local coarseing occurs at several other localities, one cast noted in Rough Creek comprising a bed of current-bedded sandstone approximately 2 ft. thick with massive muddy siltstone lying above and below. In the upper portion also, there is a general coarsening that has been noted in all sections examined. This phase is characterized by massive coarse sandstone with very little clay content, alternating with thin beds of massive mudstone and siltstone. These sandstone beds are often orange-stained, probably due to percolating water from the present-day overlying streams having its high iron content oxidised by the atmosphere, and filtered out by the strata, since their very low clay content renders them very porous. Carbonaceous streaks occur in Rough Creek half a mile upstream from the road bridge, and they are locally common on Dee Hill below the calcareous sandstone, where a 6 in. layer of thin-bedded carbonaceous sandstone was also noted.

Towards the top of the formation, the grain size decreases until the rock is a dark, micaceous mudstone containing scattered and fragmentary macrofossils. This passes up into bedded sandstone and siltstone, slightly lighter in colour and of unknown thickness. Interfingering of marine and non-marine sediments occurs in the remaining 350 ft. (approximately) of the formation. The final marine bed is 5 ft. of littoral sandstone exhibiting swash and rill marks.
and containing scattered shell fragments, overlain by 12 in. of carbonaceous sandstone and quartz grit which is taken as the base of the Rough Creek Coal Measures (fig. 9). This is the sequence in Rough Creek where the best exposures of the transition are situated, but similar sequences occur in Brown and Dee Creeks. The generalized stratigraphic column (fig. 8) illustrates the variation in lithology described above.

On account of the folding and changes of strike direction that occur within the formation, the thickness is difficult to estimate accurately, but it appears to be at least 2,300 ft., of which probably 1,500 ft. are represented in the Rough Creek section.

Relation to Underlying Rocks: Although the contact with the Cobden Limestone was not seen, it is assumed to be conformable. It occurs in the river bank downstream from the combined road and rail bridge at Landing, but a boat would be required to examine it here; it is obscured in Hard Creek at Oweka, and in the vicinity of Inangahua Junction, faulting occurs. The lowest bed of the formation that was seen outcrops in a gully west of Inangahua Junction, grid ref. S.31/389958, and comprised hard, very calcareous mudstone that broke down with difficulty to yield Foraminifera of Otaian age.

Palaeontology: Although macrofossils occur in several outcrops of the formation, they proved very fragile and practically impossible to extract whole. From Gorgy Creek, about 100 yards from its junction with Rough Creek, the following collection (UCM.202) was made:
<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inangahua</td>
<td>Light brown gritty sand</td>
<td>5' Frable quartz sand (top not exposed)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1'6&quot; Moderately hard carbonaceous sandstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3' Soft, moderately carbonaceous sand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1'6&quot; Moderately hard carbonaceous sandstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1&quot; Impure lignite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5'6&quot; Light brown gritty sand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9' Fine sandy gravel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7' Obscured</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1' Carbonaceous sandstone and quartz grit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4' Grey sandstone with shell fragments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5' Hard calcareous (concretionary) sandstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50' Blue-grey siltstone and sandstone</td>
</tr>
</tbody>
</table>

Fig. 9. Stratigraphic column showing sequence through transition from marine Inangahua Formation sediments to non-marine sediments of the Rough Creek Coal Measures. Rough Creek, grid ref. S.51/443550. Scale: 10 ft. to 1 in.
Mollusca  Polinices huttoni  von Hering
Dentalium sp.

Other macrofossils, including turritellids, also occur sporadically in the mudstone at this locality but proved too fragile for collection.

Good microfaunas are confined to the mudstones, those from coarser rock types being very poor in numbers and in preservation. Since the beds are very porous, this could be due to post-depositional leaching of the faunas, but could also be due to winnowing-out of part of the benthonic population by current action while sorting of the sediments was taking place.

The fauna from the lowest stratigraphic level mounted for reference was UCF.408, from beside the Buller Gorge road, approximately 30 chains north of the Junction Hotel. It included:

Haeuslerella hectori  Finlay
Spiroloculina novozelandica  Cushman and Todd
Robulus gyroscapulus  (Stache)
Lenticulina mammilligera  (Karrer)
Vaginulina sp.
Nodosaria spp.
Lagenonodosaria sp.
Virgulina schreibersiana  Czjzek
Uvigerina canariensis  d'Orbigny
Hofkeruva (Trigonouva) zeaecuminata  Vella
Rectuvigerina reensis  (Finlay)
Bolivina sp.

Schaeroidina bulloides d'Orbigny

Gyroidinoides zelandica (Finlay)

Globigerina bulloides d'Orbigny

G. cf. cineroensis Bolli

G. apertura Cushman

Globoquadrina dehiscens (Chapman, Parr and Collins)

Anomalainoides sp.

Cibicides novozelandicus (Karrer)

C. perforatus (Karrer).

Despite the number of benthonic species represented, pelagic Foraminifera comprise more than 90% of the individuals in the sample. Succeeding this sample stratigraphically is UCF.409, from the road cutting at the northeast end of the Inangahua River bridge.

The fauna, which was not well preserved, included:

Haeuslerella rukeuriensis Parr

Siphotextularia awamoana Finlay

S. cf. subcylindrica Finlay

Robulus sp.

Dentalina sp.

Hofkeruva sp.

Bolivina sp.

Plectofrondicularia parri Finlay

Gyroidinoides sp.

Cibicides spp.
Pelagic Foraminifera (not identified) and rare Ostracoda also occur. Specimens of benthonic Foraminifera make up approximately 50% of the sample.

The best preserved fauna studied in detail was UCF.410, from dark mudstone, Dee Creek, the first outcrop above the old mill site. The following species occur:

- *Textularia miozea* Finlay
- *Quinqueloculina* sp.
- *Robulus gyroscalurus* (Stache)
- *Vaginulina elegans* d'Orbigny
- *Dentalina soluta* Reuss
- *Nodosaria filiformis* d'Orbigny
- *Lagenododosaria scalaris* (Batsch)
- *Palmula taranakia* Finlay
- *Virgulina schreibersiana* Czjzek
- *Hofkeruva (Trigonouva) miozea* (Finlay)
- *H. (T.) zeacuminata* Vella
- *Trifarina bradyi* Cushman
- *Bolivina lapsus* Finlay
- *Sphaeroidina bulloides* d'Orbigny
- *Pullenia bulloides* (d'Orbigny)
- *Plectofrondicularia marri* Finlay
- *Discopulvinulina bertheloti* (d'Orbigny)
- *Laticarinina halophora* (Stache)
- *Gyroidinoides zelandica* Finlay
Globigerina cf. ciperoensis  Bolli

g. semivera  Hornibrook

Notorotalia spinosa  Chapman

Anomalinaoides subnonionoides (Finlay)

Cibicides molestus  Hornibrook.

Ostracoda, minute Mollusca, and common spines and broken plates of echinoderms also occur.

A sample from near the top of the formation, UCF.411, from dark mudstone, Gorgy Creek, the matrix of the macrofossil collection recorded above, included:

Robulus gyroscalprus  (Stache)

Nodosaria spp.

Lagenonodosaria scalaris  (Batsch)

Bolivina lapsus  Finlay

Sphaeroidina bulloides  d'Orbigny

Plectofrondicularia parri  Finlay

Notorotalia spinosa  (Chapman)

Cibicides molestus  Hornibrook.

Also rare pelagic Foraminifera (not identified) and rare echinoid spines.

The highest sample from the formation that provided an identifiable fauna was UCF.412, from siltstone, Rough Creek, about 200 yards downstream from the contact with Rough Creek Coal Measures. Foraminifera identified were:
Ostracoda are relatively common in this sample compared with others from the formation.

Although a general sequence from off-shore, dominantly pelagic, to near-shore faunas is shown by the above samples, some of the un-mounted samples examined were inconsistent with it, probably due to fluctuations in the depth of water caused by variations in the rates of sediment supply and down-warping.

Age and Correlation: Judged from its foraminiferal faunas, the age of the formation ranges from Otaian to Hutchinsonian or Awamoaan. Despite the occurrence in fauna UCF.408 of several Foraminifera that first appear in the Waitakian, e.g. Haeuslerella hectori Finlay, it is definitely Otaian because of the occurrence of rare damaged specimens of Spiroloculina novozelandica Cushman and Todd. This is confirmed by the occurrence of better preserved specimens in an unmounted sample taken from the same series of outcrops and about 50 yards from UCF.408. Sample UCF.409 is Hutchinsonian from the occurrence of Haeuslerella pukeuriensis Parr and Plectofrondicularia parri Finlay, both of which make their first appearance in that stage. The remaining samples, UCF.410, 411, 412, can only be dated as Hutchinsonian-Awamoaan, due to the lack of species indicating one or other of those stages. The upper age limit is governed by the occurrence of Notorotalia spinosa.
(Chapman), which is replaced by \textit{N. wilsoni} Hornibrook in the Altonian Stage.

The Inangahua Formation is a restricted correlative of strata usually termed "Blue Bottom", a rather ill-defined formation (Suggate, in Fleming, 1959, p.47) occurring principally in the Greymouth area, where all stages from Otaian to Waitotaran have been recognized, but also reported further south, and also in the Reefton area. Previously the upper boundary of the "Blue Bottom" has been undefined, and has either been drawn at the top of the marine sequence, or somewhere between the non-marine sequence and the Old Man Gravels. However, in this account, the non-marine part has been separated out as a separate formation.

\textbf{Conditions of Deposition:} The sediments of the Inangahua Formation were deposited during a period of increased tectonic activity following the period of relative tectonic quiet that marked the maximum extent of the marine transgression of Landon times. Although a general sequence from deep to shallow-water sediments can be demonstrated, it is not straightforward, due to periods of shallowing followed by deepening again prior to the general emergence, which itself is characterized by interfingering of marine and non-marine sediments.

The highly calcareous nature of the lowest sediments, the Otaian portion, as exposed near Inangahua Junction, combined with a content of pelagic Foraminifera of over 80%, and the occurrence together of the genera \textit{Uvigerina} (as \textit{Hofkeruva}), \textit{Bolivina},
Cibicides, Robulus, and Haeuslerella, shows that they were deposited well away from the shoreline beyond the continental shelf, possibly at a depth approaching 1,000 ft. The moderate clay content indicates that an increase in the rate of erosion on land had taken place, probably due partly to an increase in the relief of the existing land and partly to new areas of land being brought above sea level. These factors resulted in an increase in the rate of sedimentation, and thus brought to an end the carbonate sedimentation of Landon times.

This was followed by a rapid increase in the supply of clastic material, resulting in the deposition of over 1,000 ft. of coarse-grained sediment, probably Hutchinsonian in age, and now occupying the centre of the Inangahua valley from Landing to the Buller River. Since the beds are well sorted, the predominance of sandstone is probably due in part to by-passing and winnowing-out of the finer grades by current action, as well as to rapidity of sedimentation.

The sandstone with thin bands and streaks of carbonaceous material that occurs in Rough Creek, and again (although probably not the same bed) near the top of Dee Hill by the Buller River, is evidence for shoaling towards the end of the period of deposition of these coarser sediments. This was probably due to sedimentation exceeding subsidence, with consequent shallowing of the water. The foraminiferal faunas from above and below these occurrences show that they were not near-shore deposits, suggesting either that the sea was shallow enough for carbonaceous particles suspended in the
near-surface waters to be caught on the sea-bed, or that the
shoaling extended back to the land, with the same result.

Following this phase, further submergence and possibly some
warping of the sea floor changed the sedimentary environment from
an outer shelf "high" to a depressed area, allowing the accumulation
of several hundred feet of mudstone preceding emergence. The occurrence of pelagic/berthonic foraminiferal ratio of over 80% in some
samples examined indicates that land was still distant. Succeeding
microfaunas show a gradual decrease in the depth of deposition of
the sediments, foreshadowing the general emergence that later oc-
curred. The sequence of faunas, UCF.410, 411, 412, illustrates this
gradual shallowing.

The occurrence together of the genera Quinqueloculina,
Notocralia, Robulus, Uvigerina (as Haskaevra), and Cibicidoides in
UCF.410, along with fragments of echinoid plates and spines,
Ostracoda, and minute Mollusca, taken in conjunction with the mas-
sive nature of the sediment, suggests deposition on the outer part
of the continental shelf or the upper part of the continental
slope. The depth of deposition is thus in the range of about 200-
1,000 ft., but is more likely to be towards the shallower end of
this range, say 200-600 ft., when the occurrence of shallow water
indicators such as Quinqueloculina, echinoderms, and Ostracoda, is
balanced against the occurrence of indicators of deeper water
(300+ ft.) such as Robulus, Uvigerina, and Haeuslerella.

Shallowing is indicated by the next fauna in the sequence,
UCF.411, since it is associated with scattered macrofossils and
contains only rare pelagic Foraminifera. This decrease in depth is probably the reason for the reduced scope of the fauna. The most common components of UCF.412, which succeeds it stratigraphically, are Elphidium and Notorotalia, which along with the more common occurrence of Ostracods and scattered macrofossils, indicate deposition within the depth range of the inner continental shelf, i.e. 60-200 ft. (Phleger, 1960, p.259), and probably towards the deeper end of this range, since the bedded and well-sorted sandstone that overlies is more indicative of the shallower end of the range.

The lack of well-developed shell-beds in this part of the formation suggests that shallowing and emergence took place rapidly, probably due not only to uplift, but also to sediment filling the depositional area and hastening the withdrawal of the sea. However, the general emergence was interrupted by slight regression of the sea resulting in interfingering of the strata at the top of the formation with non-marine strata of the Rough Creek Coal Measures.

ROUGH CREEK COAL MEASURES

**Name:** The name is taken from Rough Creek where the type section of the formation is situated and in which the best exposures occur. The succession of non-marine strata and coal measures to which the name is given has previously been unnamed, either being considered part of the undefined "Blue Bottom" or loosely termed "Upper Coal Measures".
**Definition:** The Rough Creek Coal Measures are here defined as all the non-marine strata lying above the Inangahua Formation in the Inangahua area. The top of the highest marine bed of the Inangahua Formation is taken as the boundary between the formations. The upper boundary cannot be defined from outcrops in this area since higher beds are cut off by the Lyell Fault which bounds the Brunner Range. Further south, in Coal Creek, and in the Fletcher Creek area, both Waitotaran littoral marine beds and terrestrial Nukumaruan Old Man Gravels occur. Further field work in these areas is needed before the top of the formation can be accurately defined, but it is tentatively placed at the base of the Waitotaran marine beds.

The type section is taken as the exposures in Rough Creek, upstream from the second contact with the Inangahua Formation, grid ref. S.31/442550. The sequence through the transition is illustrated by fig. 9 (p.50). Despite the fact that the formation is not exposed continuously in this creek, it is the most complete and most accessible section available. Although interfingering between marine and non-marine strata occurs here and elsewhere, the tongues of non-marine beds are best mapped with the Inangahua Formation.

**Distribution:** Beds referable to this formation occur in the upper reaches of all creeks from Brown Creek in the south to Dee Creek in the north, while a tongue extends from the main area of it across the middle reaches of Rough Creek in the centre of the Inangahua Syncline.
Lithology: Due to its non-marine origin the lithology of the formation varies greatly from place to place, and the discontinuity of exposures makes it impossible to trace from creek to creek any bed which may actually persist between them. Because of this, only a general description of the lithology is given below, most of the remarks apply to strata that outcrop in Rough Creek.

The sediments making up the formation include creamy-white, pink, and grey quartz sands, moderately hard sandstone, blue-grey mudstone, quartz grits, gravels, conglomerates, and lignite seams. The grey quartz sands often include layers of quartz grit or fine rounded gravel suggesting a fluvial origin for them. The mudstones are generally massive in character, with little indication of bedding, but some are laminated, the laminations usually being parallel, but cross bedding also occurs.

Both cemented and uncemented conglomerates are represented, those without cement being usually finer and cleaner than their indurated counterparts. Greywacke pebbles are dominant, but granite pebbles are also common, while pebbles of schist and Tertiary mudstone occur in some, set in a sandy matrix. Thin coal seams occur sporadically throughout, particularly in the lower portion. In general they are only 12-18 inches thick, but Henderson (1917, p.217) reported a 20 ft. seam in Camp Creek. The rank of the coal, along with the rank of the sediments in general, decreases upwards in the formation. Along with this decrease in rank is an upward
decrease in the purity of the coal, so that the thin seams near the top of the formation are little more than impure lignite.

All the sediments are very micaceous, with muscovite the most common variety, and most are also carbonaceous, the carbonaceous material being concentrated into thin layers and streaks as well as being disseminated throughout the rest of the sediment. Those beds that have obviously been deposited under fluviatile conditions generally only contain this material in definite layers. Stem impressions are common beneath some of the carbonaceous bands but no leaf impressions were seen, despite reports of them by Henderson (1917, p.94, 218).

The interfingered of marine and non-marine sediments below the base of the formation proper has already been mentioned briefly. In Rough Creek, the exposed portion of a tongue of non-marine strata comprised approximately 12 inches of impure, sandy lignite, overlain by 9 inches of blue-grey mudstone, overlain in turn by 12 inches (at least) of carbonaceous mudstone. In Brown Creek also, non-marine beds attributable to interfingered of the formations are well exposed, due to flattening of the dip of the strata.

The highest outcrop of non-marine strata in Rough Creek, grid ref. S.32/452528, comprises the following sequence of mudstone, sands and gravels, and muddy lignites (higher beds not exposed):
<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark, muddy impure lignite</td>
<td>2 ft.</td>
</tr>
<tr>
<td>Blue-grey mudstone, lower 6 ft. finely but irregularly laminated. Upper part massive and coarser (muddy silt)</td>
<td>12</td>
</tr>
<tr>
<td>Blue-grey mudstone with indistinct laminations inter-bedded with dark, very carbonaceous mudstone</td>
<td>6</td>
</tr>
<tr>
<td>Coarse, micaceous, quartzose sands, grits, and fine gravels, with interbedded carbonaceous silts and impure lignites</td>
<td>50</td>
</tr>
<tr>
<td>Blue-grey, yellow-orange weathering mudstone, thin-bedded and irregularly laminated; small scale cross-bedding. Occasional lumps of coalified wood or derived coal near top. Gritty layer at base</td>
<td>20</td>
</tr>
<tr>
<td>Dark carbonaceous micaceous mudstone and siltstone, and impure lignite</td>
<td>10</td>
</tr>
<tr>
<td>Blue-grey thin-bedded and irregularly laminated mudstone; carbonaceous streaks in lower part</td>
<td>250+</td>
</tr>
</tbody>
</table>

(Base not exposed).

In the outcrop, the laminations in the lower 6 ft. of the upper mudstone have the appearance of varves, but microscopic examination of them showed graded bedding to be absent and that the laminations are due solely to size-sorting, thin layers of fine silt alternating irregularly with thicker layers of clay. The remainder of the strata also provide no evidence of a glacial origin since deposits reminiscent of it are absent, the beds suggesting a mixture of lake, swamp, and fluviatile environments. Thus, the possibility of climatic factors controlling the formation of the laminations appears remote.

Due to the incompleteness of the exposures and the gradually increasing dip to the east, the thickness of the formation is
difficult to estimate accurately, but in Rough Creek, it is probably of the order of 5,700 ft.

**Relation to Underlying Rocks:** In all sections examined, the relationship of the formation to the underlying Inangahua Formation is conformable, with interfingering of sediments, as noted above, taking place. In no case was there any obvious sign of erosion of the marine sediments prior to the deposition of the non-marine strata.

**Age and Correlation:** In the absence of accurately dated pollen samples, the age-range of the formation cannot definitely be stated, but would appear to range from Hutchinsonian or Awamoan at the base to Waitotaran at the top, the extreme limits being governed by the occurrence of marine beds of these ages at the bottom and top respectively. Couper (1960) gives the age of the only plant microfossil sample examined to that date, S.31/621, from near Coal Creek, grid ref. S.31/38321, as Southland Series, with stage dating not possible. Thus, although internal evidence of age is lacking, it is obvious that the age of the formation ranges through the Southland and Taranaki Series and into the lower part of the Wanganui Series.

The formation can be correlated with similar non-marine beds in the Reefton area (Suggate, 1957, p.54), but correlatives further to the south may not exist, since marine sedimentation continued in the Greymouth area at least until Kapitean time. To the north, the Longford Formation of the Murchison area is probably a correlative since it occupies a similar stratigraphic position and is of approximately the same age.
Conditions of Deposition: The sediments of the Rough Creek Coal Measures were deposited in lake, swamp, and fluvial environments on a low-lying coastal plain following the elevation of the land above sea level and the ending of marine sedimentation. As mentioned under the previous formation, the withdrawal of the sea was probably caused by a combination of tectonic uplift and filling up of the depositional area with sediment derived from newly risen land areas, but following emergence, the tectonic uplift factor probably decreased in importance, allowing the Inangahua area to remain tectonically low with respect to nearby areas, and hence to continue to receive sediment.

The initially rapid uplift resulted in the strata near the base of the formation containing a greater proportion of fluvial sediments (sands and gravels) than the upper portion, which has a greater proportion of lake sediments (silts and muds). However, this distinction may be more apparent than real, caused by the location and number of outcrops in each case.

Throughout the time that the formation was being deposited, swamps, and probably shallow lakes formed which received organic matter that was subsequently converted into low-rank coal in both areally and stratigraphically discontinuous bodies. The dominance of greywacke over granite pebbles in the conglomerates suggests that at that time the area of granite exposed to erosion was less than the area of greywacke, a reversal of the present situation. The large flakes of mica that occur in some of the sediments suggest that they have not been transported far, but it is not possible to
state a definite source for them. However, Suggate (1957, p.24) suggests that equivalent sediments of the Reefton area were derived from existing areas of land that had been reduced to relatively low relief by the Pliocene, and this probably was the case for the Inangahua area also. The Paparoa, Brunner, and Victoria Ranges rose later, during the Pleistocene.
(d) PLEISTOCENE AND RECENT DEPOSITS

Although this account is primarily concerned with the Tertiary strata and deposits of the above ages were not investigated in detail, an outline of their occurrence in the Inangahua area is given below.

The oldest Pleistocene deposits comprise the high (c.1,100 ft.) terraces on the north bank of the Buller River north of Inangahua Junction (see fig.10) which link up to the northeast with similar high-level terraces near Lyell (e.g. Manuka Flat). Down-river, near Berlin, there is a flattening of a spur below Trig. AB which probably indicates another correlative. Because they are the highest of the terrace remnants of the area, and because of the greater depth of weathering of the gravels (as exposed in slips), they can probably be correlated with the Porika Glaciation.

Further terrace remnants, probably caused by the succeeding glaciations, occur at lower levels ranging from approximately 100 ft. above the present river level to more than 500 ft. in height. Exposures in cliff faces indicate that they are not true outwash terraces, they are too far from the source of the glacial sediments to be of this type, but are bedrock terraces covered with a thin veneer of glacial gravels. This is also illustrated by the fact that a well put down for water at the Inangahua Junction school, which is situated on a terrace approximately 100 ft. above the
Fig. 10. Inangahua area viewed from the Brunner Range. The Inangahua River (centre) flows from left to right of the photograph and joins the Buller River to the right of centre. Arrow indicates 1,100 ft. high terrace on north side of Buller River opposite Inangahua Junction. (Photo: W. Inwood).
river, passed through only 16 ft. of gravels before striking the Tertiary mudstone.

Recent river deposits are composed mainly of granite and greywacke boulders in a proportion of approximately 60% granite to 40% greywacke. In some cases these appear to be only a thin capping on bedrock, as along the Inangahua River and the unnamed flat beside the Buller River south of Mt. Courtney, but in other cases, as at Inangahua Junction itself, and Walkers Flat, the alluvial deposits appear to be deeper than present river level. A well sunk on Walkers Flat, away from the river but only a few feet above river level, was put down to a depth of 28 ft. but failed to strike bedrock, suggesting that the thickness of gravel persists away from the present course of the river.
SECTION III - STRUCTURE

STRUCTURE

The structure of the area consists basically of easterly dipping Tertiary strata, the sequence truncated in the east by the Lyell Fault, and folded into a syncline, the Inangahua Syncline, and an anticline, the Glasgow Anticline, to the east of the Inangahua River. A major fault, the Inangahua Fault, occurs in the vicinity of Inangahua Junction, while minor faulting occurs in the Brunner Coal Measures near Berlins. These faults are not of sufficient importance to warrant naming. The names of the structural features, with the exception of the Inangahua Fault (previously unnamed), are taken from the 1:250,000 geological map covering the area (Bowen, in press). Details of the structural features are given below.

Inangahua Fault: This fault runs in a roughly NE-SW direction near Inangahua Junction and brings mudstone of the Inangahua Formation of Otaian age into contact with Buller Mudstone of Kaiatan age. Although its extension into heavily bushed country on the northern side of the Buller River has not been traced, it appears possible that the coal measures mapped by Henderson in Thomson Creek may be correlatives of the Rough Creek Coal Measures rather than of the Brunner Coal Measures of the Berlins area as Henderson believed, although he mapped them as part of his "Miocene" Oamaru Series. To the southwest, the fault appears to fade out in
the area to the northwest of Oweka, since there is no evidence of faulting in the Hard Creek section.

A feature possibly attributable to the fault is the susceptibility to slumping of the hillside above the Buller Gorge road between the Junction Hotel and the corner where it turns down the Buller River. Slump scars are common on the slope, and movement of the hillside has necessitated protective work along the side of the road. Since there is no evidence elsewhere in the area of Tertiary mudstone slumping in this manner, in fact, banks several tens of feet in height can be maintained, it seems likely that movement on the fault has shattered the mudstone just enough to render it prone to slumping but not enough to allow it to be quickly eroded away. There is no evidence for lateral movement on the fault.

**Lyell Fault:** This is the major fault of the area, extending beyond it to the north and south. Throughout its length, Tertiary sediments are faulted against older rocks (greywacke and granite) of the Brunner Range. Details of the fault to the north are unknown, while to the south it appears that the movement must be taken up by splinter faults within the older rocks of the Brunner Range since Suggate (1957) has mapped a sedimentary contact between Tertiary rocks and greywacke in the northern part of the Reefton Sheet.

**Inangahua Syncline:** This syncline crosses the Buller River near the mouth of Dee Creek and Rough Creek near the second bridge
on the road up the creek, but is not visible in Brown Creek. However, it is probably represented there by an observed flattening of the dip of the strata. North of the Buller River it is probably cut off by the Inangahua Fault.

**Glasgow Anticline:** This feature extends south from the vicinity of Lyell and fades out between Rough and Brown Creeks, probably because of interplay between the anticline, the Inangahua Syncline, and the Lyell Fault. As the anticline is traced northward beyond the Inangahua area, progressively older beds are exposed due to its southward plunge.

**Courtney Syncline:** This syncline extends southwards across the Buller River from the area of limestone near Mt. Courtney, from which it takes its name, to be cut off by the Inangahua Fault north of Oweka. No southward extension on the other side of this fault has been observed, but such an extension could be obscured by recent gravel in the area between Landing and Oweka.
BY THE END OF THE CRETACEOUS OR EARLY IN THE TERTIARY, PROLONGED EROSION AND CHEMICAL WEATHERING HAD REDUCED THE RELIEF OF THE ROCKS OF THE INANGAHUA AREA (GREYWACKE, QUARTZ PORPHYRY, GRANITE, AND OHIKA BEDS) TO THAT OF A PENEPLAIN. DURING EARLY TERTIARY TIMES, TECTONIC MOVEMENTS WERE INITIATED WHICH EVENTUALLY LED TO MARINE TRANSGRESSION. HOWEVER, AT THAT TIME THE MOVEMENTS WERE CONFINED TO WARPING OF THE PENEPLAIN, RESULTING IN SOME CASES IN THE FORMATION OF UNDRAINED HOLLONS. PEAT SWAMPS AND LAKES OCCUPIED THE CENTRES OF THESE, WITH THE CONTINUING DOWN-WARPING ALLOWING THE DEPOSITION IN THEM OF VARYING THICKNESSES OF SEDIMENTS WHICH NOW COMPOSE THE BRUNNER COAL MEASURES.

THUS, IMMEDIATELY PRIOR TO TRANSGRESSION, THE AREA COMPRISED A SURFACE OF OLD ROCKS HAVING SLIGHT RELIEF, COVERED WITH TERRESTRIAL SEDIMENTS THAT WERE THICKEST AND GENERALLY INCLUDED COAL SEAMS IN THE HOLLONS, AND WERE PROBABLY THIN AND QUARTZOSE ON THE HIGHER AREAS FROM WHICH, IN MANY CASES, THEY WERE ERODED DURING THE MARINE TRANSGRESSION.

NEAR BERLINS, MARINE SEDIMENTATION CONFORMABLY FOLLOWED THE NON-MARINE, WHILE IN THE AREA ABOUT THE JUNCTION OF THE INANGAHUA AND BULLER RIVERS, SHALLOW SEA COVERED GRANITE AND GREYWACKE, AND RELATIVELY CLEAR WATER AND WARM TEMPERATURES ALLOWED CALCAREOUS ALGAE TO FLOURISH BRIEFLY. THICKNESS VARIATIONS IN THE BASAL
Fig. 11. Stratigraphic columns showing variation in thickness of basal Tertiary sediments.
Datum: base of mudstone. Scale: 20 ft. to 1 in.
Tertiary (fig. 11) suggest that in the vicinity of "Whitecliffs", a ridge of basement greywacke stood above the water at this stage, either as an island or as a peninsula, with deposition of carbonaceous shallow-water sediments taking place to the west and strata including algal limestone to the east. As the transgression progressed, this land gradually submerged, with the thin coal measures that probably covered it being slowly eroded by the sea, the absence of a basal conglomerate, or a conglomerate in nearby exposures of Buller Mudstone, suggests that the terrestrial sediments that capped it were fine-grained, probably clays resulting from the prolonged weathering of the greywacke.

With the submergence of this barrier, the basins of deposition in the Berlin and Inangahua areas merged, but the exclusively arenaceous foraminiferal faunas that occur in the basal portion of the mudstone show that for a time the area as a whole remained part of a larger embayment which restricted water circulation, resulting in the limited microfauna, the carbonaceous streaks, and the calcareous, pyritic concretions. Further deepening of the sea resulted in a gradual increase in the number of calcareous Foraminifera, the occurrence of scattered macrofossils, including solitary corals, and the attainment of more normal open-sea conditions.

Throughout the time that the Buller Mudstone was being deposited, the relief on land remained low, resulting in the building-up of 400 ft. of fine-grained sediment in the area near Inangahua.
Junction and approximately 1,000 ft. near Berlins, the westward thickening indicating that the remaining land lay to the east. The coarser sediments of Runangan age indicate that by this time the basin of deposition had been filled up to the level where winnowing of the sediments could take place, the quieter conditions allowing carbonate sedimentation to increase in importance. This began in Runangan times, in the final stages of deposition of the Buller Mudstone and reached its peak in Landon times when the thick calcareous sediments that now comprise the Cobden Limestone were laid down. During this time, the gradual decrease in the rate of deposition of clastic sediment continued, resulting in an upward increase in purity in the limestone. Isolated occurrences of macrofossils show that local shallowing occurred at times, but in general, the microfossils show that the depth of water was beyond the optimum for macrofaunas, being somewhere in the depth range of the outer continental shelf.

Towards the end of Landon times, tectonic movements raised above sea-level new areas of land which provided a new source of sediment for the area, and these same movements lowered the sea floor in the Inangahua area to form part of a trough which was progressively filled with sediment in Pareora times. Otaian sedimentation was characterized by the rapid decline and ending of the carbonate sedimentation of Landon times and a gradual increase in the depth of water and the rate of sediment supply. By Hutchinsonian times, deposition had almost overtaken subsidence, resulting in a
considerable thickness of well-sorted shelf sandstones. However, further deepening and shallowing of the water took place at intervals until finally, in late Hutchinsonian or Awamoan times, the area rose above the sea, probably as a result of a combination of uplift and sedimentation causing rapid withdrawal of the sea.

Throughout Southland, Taranaki, and early Wanganui times, the area remained a swampy coastal plain, still below base level despite its emergence, allowing deposition of several thousand feet of non-marine sediments to take place. The low-lying nature of the plain resulted in the formation of peat swamps and lakes in which layers of carbonaceous material accumulated that was subsequently converted into low-rank coal interbedded with sands and gravels, etc. of fluviatile origin.

The area remaining tectonically low until after the period of time represented by the sediments of the Rough Creek Coal Measures in the Inangahua area. This is shown by the fact that it was possible for shallow sea to encroach briefly on the land in Waitotaran times, the beds deposited containing littoral and brackish water mollusca. Following this, deposition of the terrestrial Old Man Gravels began, consequent on the uplift of the present-day mountains by the Kaikoura orogenic movement.
For clarity, some of the more important facts and conclusions arrived at are set out below:

1. Brunner Coal Measures did not form a uniformly thick blanket over the area. They were probably only a few feet thick on the higher areas of the peneplain.

2. Deposition of Buller Mudstone followed conformably in an environment of restricted water circulation (probably in a series of shallow bays), with initially, an island or peninsula separating the Inangahua and Berlins areas.

3. Continued transgression progressively removed the restrictions on water circulation while the amount of clastic sediment deposited decreased, so that, by the Runangan, carbonate sedimentation was beginning to take place. The remaining land lay to the east and was of low relief.

4. Even so, a remnant of land, or alternatively a high area of sea floor, must have remained nearby to be the source of the boulders in the Cobden limestone near "Whitecliffs".

5. The topography of the surviving land was progressively reduced during Landon times resulting in an upward increase in purity in the limestone.

6. Sediment supply increased during Pareora times, depth increasing initially, shallowing to a level where sorting of sediments
could take place, and then fluctuating somewhat before the final shallowing and emergence.

7. The sediments of the Inangahua Formation are entirely shelf sediments. No evidence of redeposition was seen.

8. Sediments of the Rough Creek Coal Measures follow conformably on those of the Inangahua Formation and represent deposits on a low-lying coastal plain. No evidence for a major unconformity was observed in the coal measures, so it is assumed that the sediments are the products of a continuous period of deposition covering the entire Southland and Taranaki Series, and the Lower Wanganui Series.

9. A much larger area of greywacke was exposed to erosion at this time than at present, resulting in greywacke pebbles predominating over granite pebbles in the conglomerates, the reverse of the present-day situation.
REFERENCES


APPENDIX: SAMPLE LOCALITIES

The following table gives details of sample numbers and localities. Descriptions of the localities are listed separately.

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1. University of Canterbury microfaunal sample number.
2. University of Canterbury macrofossil collection number.
3. N. Z. Fossil Record Form number. Prefixed S.31/.
4. All grid references refer to the grid on the 1944 provisional edition of sheet S.31 (Buller).
5. I Inangahua Formation  Bm Buller Mudstone
   C Cobden Limestone  Bcm Brunner Coal Measures.

6. The ages quoted are those of the microfossils.

Descriptions of localities:

400 Above Buller Gorge road, 300 yards east of "Whitecliffs".
401 Road cutting, Buller Gorge, where road descends to Walkers
   Flat, c.2 miles east of Berlins.
402 North bank, Buller River, c.1 1/2 miles down from the junction
   of the Inangahua. Just above water level.
403 Roadside, Buller Gorge road, below angular unconformity.
404 Same locality, above angular unconformity and 3 ft. above
   403.
405 Same locality, above angular unconformity and 10 ft. to right
   of 404.
406 Junction of Buller and Inangahua Rivers. Just above water
   level.
407 Hard Creek, cliff face above bend in old track.
408 Roadside, Buller Gorge road, c.500 yards north of the Junction
   Hotel.
409 Road cutting, northeast end of Inangahua River Bridge,
   Inangahua Camp.
410 Dee Creek, right bank, first outcrop above old mill site.
411 Gorgy Creek, 100 yards upstream from its junction with Rough
   Creek.
Rough Creek, left bank, c. 200 yards downstream from contact between Inangahua Formation and Rough Creek Coal Measures. Massive siltstone 2 ft. below bedded sandstone.
