The Geology of the Eastern Hokonui Hills, Southland, N.Z.

By W. A. Watters,
University of Otago

[*Read before the Otago Branch, November 14, 1950; received by the Editor November 30, 1950*]

Abstract

The Eastern Hokonui Hills, lying some four miles north-west of Gore, consist mainly of Mesozoic sediments dipping steeply to the south-west; their ages range from probably Lower or Middle Triassic to Middle Jurassic. Well-defined Upper Triassic and Lower Jurassic fossiliferous horizons are present. Several exposures of Tertiary rocks, continuous with those underlying the Southland Plain, occur on the eastern and south-eastern flanks of the hills, while a small outlier of lignite-bearing beds has been found in Otamita Valley. During the Pleistocene quartz-greywacke gravels were deposited over much of the low land surrounding the hills, which owe their present major outline to uplift and block-faulting at the end of the Tertiary Period.

Contents

Introduction

The area described in this paper, nearly fifty square miles, covers the most easterly portion of the Hokonui Hills, Southland, comprising part of the Waimumu and Hokonui Hundreds. On their northern and north-eastern sides the hills are bounded by the plains of Waimea and Mataura Rivers, while along the southern boundary the hill country is fringed by a broad strip of downland sloping gently toward the Southland Plain. The western boundary of the area mapped lies one and three-quarter miles west of Kelvin Peak, and runs due north to the Waimea Valley.

Much of the country is rugged, and in most places the hills rise steeply from the surrounding plain and downland, reaching a height of over 2,000 feet at East Peak and at the Ship Cone-Kelvin Peak ridge. The main plant covering is tussock with small areas of scrub, but to the south there are a few square miles of low forest, now part of the Croydon Scenic Reserve. The area is well roaded, and several tracks provide access to the open country above.

This account has been condensed from a degree thesis prepared at Otago University. The field work was carried out using photographic enlargements of portions of the provisional One Mile sheets, S.169

and S.170. Grid references, where given in the text, refer to one or other of these two sheets.

The writer wishes to express his appreciation of the help and interest freely given by Professor W. N. Benson and Mr. D. S. Coombs during the preparation of this paper. To Mr. D. McGregor, Gore, Mr. and Mrs. H. Hargest, Mandeville, and his parents go the writer's gratitude for assistance during the course of field work.

Previous Geological Work

In 1878, S. H. Cox and A. McKay, in their classic reports, described the geology of the Hokonui Hills, and laid a firm foundation for future work on the wide areas of Lower Mesozoic rocks in Southland. They divided the older rocks into 73 beds, grouped into 8 formations ranging in age from Lower Carboniferous to Lower Oolites. Tertiary deposits were also recognized. Their work, together with that of Park on certain Jurassic rocks in the Hokonui Hills (1887), and of McKay on the Waimea coal (1892), will be referred to later in more detail.

P. Marshall (1908) described fossil cephalopods from the hills near Mandeville, and C. T. Trechmann (1917) has given a full description of a Triassic fossiliferous section from Otamita Stream. This section, to which he assigned a Carnic and, in part, possibly Noric age, lies somewhat west of the area described herein. More recently, collections of conglomerate pebbles have been made and some observations recorded by officers of the Geological Survey (J. Healy, 1938).

Stratigraphy

The following outline shows the sequence of beds in the Eastern Hokonui Hills:

Recent	Gravels and silt	
Pleistocene	Unsorted greywacke gravel and quartz greywacke gravel	45 feet
Lower Tertiary	Mudstone, lignite, quartz gravel, Duntroonian glauconitic sandstone. One occurrence of basal quartz sandstone.	(?)
Jurassic	Coarse feldspathic sandstone and conglomerate	5,500 ,,
	Coarse sandstone, breccia, mudstone, conglomerate	3,800 ,,
Liassic	Siltstone and mudstone with *Otapiria* and possibly *Psiloceras*	1,100 ,,
Triassic		
Otapirian Stage Rhaetic	Mudstone, greywacke, feldspathic sandstone, conglomerate With *Rastelligera* and *Clavigera*	1,700 ,,
Otamitan Stage Carnic	Mudstone, greywacke, arkosic sandstone. With *Mytilus problematicus* Zitt.	1,350 ,,
Kaihikuan Stage Ladino-Carnic	Greywacke, conglomerate. With *Spiriferina, Mentzeliopsis, Daonella.*	2,500 ,,
Middle or Lower Triassic	Mudstone, greywacke, breccia, tuffaceous sandstone, vitric tuff, conglomerate Predominantly unfossiliferous.	11,500–12,000 ,,

Triassic System

[Note: The subdivision of the Triassic rocks has been based upon that of Dr. C. T. Trechmann (1917, pp. 167–170) and Mr. M. Ongley

(1939). Determination of rock types in the field has been supplemented by microscopic examination of representative thin sections.]

Middle Triassic? The beds tentatively classed as Middle Triassic form a strip up to 2½ miles in width, and outcrop over the northern and north-eastern portion of the hills. The oldest beds exposed occur along a low-lying strip north-west and south-east of the Otamita railway siding. Outcrops are few, and the rock is a fine-grained, well-bedded, dark blue-grey mudstone, similar in hand specimen and in the field to the mudstones occurring higher in the sequence. At one good exposure, in a railway cutting about one mile north-west of the Otamita siding, the rock has been contorted so that small drag folds and tiny faults are present. Here the strike is variable, often veering through 30° in the course of a few feet, but in the main it is parallel to that of the overlying beds, i.e. N.60°W. The base of the mudstone is covered by the gravels of the Mataura Valley. The thickness exposed along the line of the section (Plate 95) is 1,000 feet.

These beds are overlain by about 1,150 feet of hard, brown, tuffaceous siltstone and fine-grained sandstone In places, however, the rock becomes gritty and occasional thin bands and lenses of fine mudstone occur also Toward the northern part of the area of outcrop the coarser bands become more conspicuous and there stand out as small strike-ridges. The highest member of the siltstone is a hard, coarse grit, occasionally carrying a few pebbles. Along its outcrop there is often a distinct break of slope apparently controlled by the presence of this resistant band.

Immediately above the grit is a well-exposed band, 950 feet thick, of dark, blue-grey and green-grey mudstone and fine-grained siltstone. The rocks have always a characteristic crumbly appearance, resulting from numerous, closely spaced, curving joints. At two localities, a little north-west of Stony Creek, thin bands of zeolitic vitric tuff were noted interstratified among these sediments, toward the top of which there are numerous thin bands of coarse grit yielding spheroidally-weathered boulders.

Overlying these sediments is a hard, coarse, tuffaceous grit and gritty sandstone, about 300 feet in thickness, outcropping along a conspicuous strike-ridge. On the south-east end of this ridge, at a sharp craggy hill known locally as the "Three Sisters," the rock is a massive volcanic breccia from which a few indeterminate fossils were collected. These include two small, imperfect casts of brachiopod ventral beaks and a single, small, elongate lamellibranch. A tiny gasteropod, recalling *Pleurotomaria,* was seen, but could not be collected.

The succeeding beds, 1,600 feet thick, consist of very uniform mudstones and siltstones similar to those already described. Occasionally thin bands of coarse gritty rock occur interbedded in this mudstone, and yield lines of spheroidally-weathered boulders.

Above these sediments are about 280 feet of coarse, tuffaceous sandstone, dark brown or green-brown in colour, with occasional small pebbles. This is easily traced along an almost continuous strike-ridge for several miles Small, black, fragmentary plant remains were noted commonly in this bed.

Lying above this sandstone is a thick sequence of fine-grained greywackes and interbedded mudstone, and a few thin intercalated and usually discontinuous bands of coarse grit, or conglomerate, 300 yards north-east of East Peak. Good outcrops are frequent along the bed of Otamita Stream, where the thickness exposed is 2,100 feet. Approximately halfway through the sequence in Otamita Stream occurs a mudstone with abundant, fragmentary plant remains. Very similar plant-bearing rocks were seen at approximately the same horizon at other localities north-west and south-east of the stream.

The boundary for the succeeding beds has been drawn immediately below the conglomerate which forms the East Peak ridge. This is a hard massive rock with pebbles averaging an inch in diameter, although occasionally reaching 12 inches. As the bed is traced along the strike to the north-west, the pebbles become fewer and the rock passes into a pebbly sandstone, but in the Otamita Stream further west it is represented by a tough grit and breccia.

Above this conglomerate is a thick band mainly composed of hard blue-grey greywacke with interbedded mudstone. Thin intercalated bands of coarse tuffaceous grit and sandstone occur, and these often determine the presence of minor strike-ridges. The positions of the more conspicuous of these bands have been marked on the map (Plate 95) by lines of stippling. Apart from occasional black plant-fragments no fossils were observed. Near the summit of Grant's Bush track, 800 yards south-west of East Peak, there is a thin layer of hard, cherty, vitric tuff which was noted at several points along the strike for a distance of two miles. The beds exposed in Otamita Stream are predominantly fine-grained and are 4,600 feet thick.

The rocks so far described are in all between 11,500 and 12,000 feet thick. At no point was there evidence of angular unconformity between adjacent beds. Unfortunately, in the Eastern Hokonui Hills, their relation to underlying beds is unknown. In the area occur no outcrops of Clinton Permian greywacke similar to that described by Ongley (1939, p. 33), or to the coarse greywacke of Ram Hill, near Lumsden, noted by Healy (1938). Throughout this assemblage of sediments fossils, other than plant fragments, have been found at one locality only, and are too poorly preserved to be of use in age determination. But since it is overlain conformably by rocks having characteristic Kaihikuan fossils to which a Ladino-Carnic age has been given by Trechmann (1917), a Middle or possibly Lower Triassic age has been assigned to it.

Kaihikuan Stage. The lower boundary of the Kaihikuan Stage has been drawn immediately below a conglomerate forming two high bluffs overlooking Otamita Stream. Granite is represented among the pebbles which are of all sizes ranging up to a diameter of one foot. As the rock is traced along the strike to the south-east, the number of pebbles rapidly diminishes and the conglomerate grades to a hard, coarse grit containing locally small, angular and rounded pebbles up to ¼ inch in diameter. A small brachiopod referred to *Spiriferina fragilis* (Schlotheim) was found in this basal grit nearly one mile east of the Upper Waimumu Stream. The basal bed passes into fine-grained siltstones and mudstones with occasional bands of coarse grit. This Stage has a total thickness between 2,400 and 2,500 feet. Fossils were found in large numbers at several localities. Details of their occurrence are summarized in Table 1.

Locality	Otamita Stream	Otamita Stream	Waterfall Creek	Upper Waimumu Stream	Upper Waimumu Stream
Grid References (All on S. 169)	682496	686496	702488	736471	726478
Pleurotomaria sp.			X		
Daonella indica Bittner	X	X		X	
Halorella zealandica Trechmann	C	C	X	C	C
Dielasma sp. cf. *D. himalayana* Bitt.		X	X	X	
D. zealandica Trech.		X			
Spiriferina fragilis (Schlotheim)	X				
S. kaihikuana Trech.	C	C	C	X	
Mentzeliopsis spinosa Trech.	C	X	X		
Athyris kaihikuana (Trech.)			X		

TABLE 1—*Kaihikuan Fossils from Eastern Hokonui Hills*
("C" denotes commoner forms)

At three of these localities there were also found a number of small undetermined casts and impressions of lamellibranchs. The largest specimen observed measured 24 x 19 mm., and most showed a rounded ridge running from the beak region to the posterior ventral angle. They were doubtfully compared with species of *Anodontophora* described by Trechmann (1917). In the highest beds of this Stage scattered fragments of *Halobia* sp. occur rarely.

Otamitan Stage. No fossils characteristic of the Oretian Stage were found in the rocks lying between the fossiliferous Kaihikuan horizon and the fine-grained greywacke and mudstone containing *Mytilus problematicus* Zittel seen in Waimumu Stream and the Otamita Valley. What is assumed to be the lowest bed of the Otamitan rocks is a coarse, yellow, arkosic sandstone, about 150 feet thick, forming small bluffs and a line of huge boulders just above the bush-line at Waimumu Stream. It is overlain by hard, massive, grey, well-jointed mudstone and fine-grained greywacke outcropping along the bed of the same stream. Fossils were collected in place from the bed of the stream, about 300 feet above the base of the Stage, and from derived pebbles further downstream. These include (Grid reference, 732465, S.169):

Discophyllites sp.
?*Gonodon mellingi* Hauer (Wilckens, 1927, p. 28)
Halobia spp. (abundant)
Mytilus problematicus Zittel (abundant)
Anodontophora angulata Trechmann

To the north-west of this locality, in Waterfall Creek valley, the main rocks noted are hard, grey mudstones with some interbedded fine and coarse-grained greywacke. No fossils were found between Waimumu Stream and Otamita Valley, but in the latter a single band of hard greywacke, crowded with specimens of *Mytilus problematicus* Zitt., crosses the stream as a bar, about 200 yards downstream from its junction with Gordon Stream. The total thickness of the beds referred to this Stage is 1,350 feet.

Otapirian Stage No beds containing fossils, notably ***Monotis richmondiana*** (Zitt.), characteristic of the Noric Warepan Stage have been found in the present area. However, at several localities, beds have yielded fossils shown by Trechmann (1917) to be of Rhaetic age, and characteristic of the Otapirian Stage. In addition to these a number of forms were found, mostly of brachiopods, which have not yet been recognized in the New Zealand Mesozoic rocks.

This Stage, which has a total thickness of 1,700 feet, begins with a light-coloured, rather gritty, feldspathic sandstone. This passes upward abruptly to a fine-grained, grey greywacke, overlain by mudstone followed by hard, light grey sandstone. Overlying this in the lower part of Boundary Creek is a coarse conglomerate containing pebbles of acid plutonic rocks and a variety of volcanic rocks, including almost unaltered andesites This conglomerate outcrops about 1,270 feet above the base of the Stage. The overlying beds consist of well-bedded, fine-grained, grey and grey-green mudstones, often with closely-spaced joints. These fine-grained beds and the overlying Liassic beds are well displayed in road cuttings beside the road running from Waimumu Stream to Otamita Stream.

Details of occurrences of Otapirian fossils are given in Table 2.

Locality	Lower part of Coneburn Stream	Lower part of Boundary Creek	West branch of Waimumu Stream	West branch of Waimumu Stream*	Lower part of Gordon Stream
Grid References (All on S. 169)	678488	688483	729459	703473	658490
"Pleurotomaria" sp.	X				
Rastelligera spp.	X			X	C
Mentzelia sp. cf. *M. ampla* Bittner			X	X	
M. kawhiana Trechmann			X	X	
Clavigera bisulcata Thomson		X	X	C	
Rhynchonellids				X	

TABLE 2—*Otapirian Fossils from Eastern Hokonui Hills*
("C" denotes commoner forms)

JURASSIC SYSTEM

Reference to section GH on the map accompanying Cox's paper (1878) shows that the boundary between the Triassic and Jurassic lies close to that adopted during the present survey. In his description of the section GH (1878, p 35) he mentions no definite fossils, and it seems that, taking as his standard the subdivision of beds near the Bastion and Flag Hill, his correlation therewith of the strata in other areas was essentially based on lithological similarity. Although a considerable thickness of Jurassic rocks occurs in the south-west part of the present area, fossils were found only in the basal beds.

Lower Jurassic. Liassic. There is no observable lithological break between the Triassic and Jurassic. The dark friable mudstone containing Otapirian fossils can be followed into the Jurassic, where it has yielded Liassic fossils in a number of localities (Grid references, both on S.169, are 694472 and 701469) near the saddle between Boundary Creek and the west branch of Waimumu Stream. This fossiliferous bed is assumed to be the base of the Jurassic rocks. The commonest fossil is *Otapiria marshalli* (Trechmann), originally described by Dr. C. T. Trechmann (1923, p. 270) as *"Pseudomonotis" marshalli.* It was redescribed by Dr. J. Marwick (1935) as the type of a new genus *Otapiria* and later shown (Marwick, 1948) to be in all probability confined to the Lias, possibly ranging down as low as the top of the Hettangian.

At one locality, *Otapiria* is accompanied by rather rare, poorly preserved impressions of a small ammonite up to one inch in diameter. It is tentatively compared with *Psiloceras,* though the transverse ribs are more numerous and extend further toward the ventral margin than on the specimens from the junction of Taylor's Creek and Otapiri Stream, figured and described by Spath (in Trechmann, 1923). An incomplete broken cast of an undetermined ammonite, about 4½ inches in diameter, was found in dark friable mudstone beside the road running from Waimumu Stream to Otamita Stream (Grid reference, S.169, 726459).

Overlying this fossiliferous mudstone is a hard grey siltstone. The presumably Liassic beds, which are 1,100 feet thick, form part of the Bastion Series as mapped by Cox and McKay (1878). In view of the possible future discovery of other Liassic fossils [e.g. *Pseudaucella marshalli* (Trech.)] to the west of the present area the upper boundary of the Liassic beds is only tentatively indicated.

Jurassic Rocks overlying the Liassic Beds. A band of conglomerate occurs at several points along the strike a little south of the road from Waimumu Stream to Otamita Stream. Microscopic examination of sections cut from pebbles of this conglomerate shows that the commonest rocks present are acid types such as granophyre and microgranite. Overlying this conglomerate is a group of beds, about 3,800 feet thick, composed principally of massive, coarse-grained, yellow or yellow-brown sandstone with some interbedded grey-green mudstone. A good section is exposed on the north faces of Ship Cone and Kelvin Peak where the downward sequence includes coarse-grained sandstone, very coarse-grained dark-grey grit and light-coloured feldspathic sandstone. The coarse grit is exposed on two minor peaks to the north of Ship Cone and Kelvin Peak respectively.

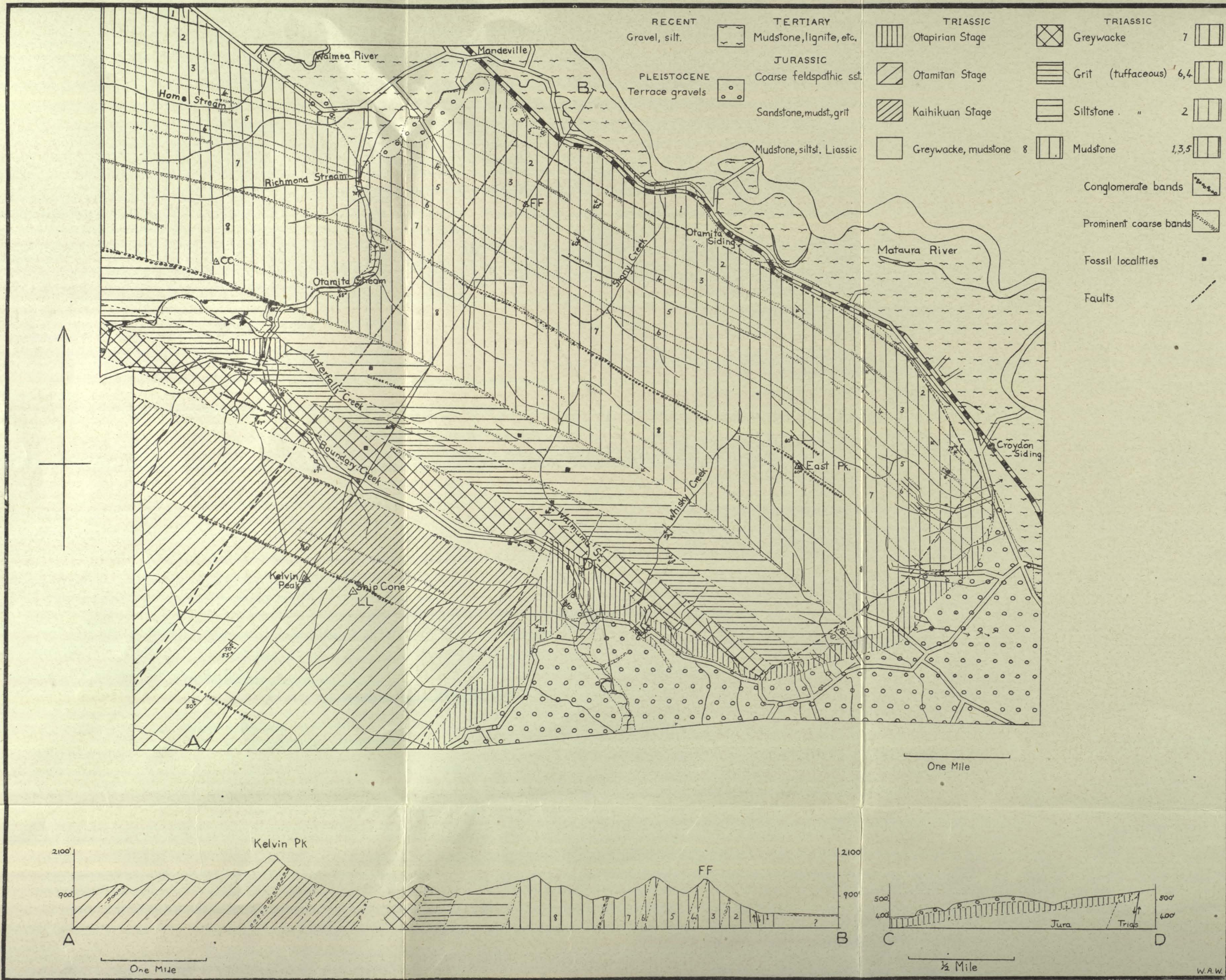
These beds are overlain by conglomerate, about 150 feet thick, forming low bluffs high on the northern slopes of Ship Cone and Kelvin Peak. The pebbles are up to about six inches across, and are in the main similar to those mentioned above. Ship Cone, Kelvin Peak and the lower hills to the south-west consist of coarse-grained, yellow to brown, feldspathic sandstone, about 5,500 feet thick, containing occasional thin bands of dark mudstone and a prominent band of conglomerate which is exposed along a ridge near the south-west corner of the area. In contrast to the sediments of the Triassic sequence, which are always hard and indurated, the Jurassic sandstones are rather friable, and fragments are easily crushed with a hammer. The only fossils found after considerable search were a few black plant fragments.

The beds overlying the Liassic rocks correspond to the Flag Hill, Putataka and Mataura Series as mapped by Cox (1878), but, as no fossils characteristic of these were found in the present area, it has not been practicable to subdivide the Jurassic rocks described herein except on their lithology. In his description of the Mesozoic section on the east bank of the Mataura River between Gore and Mataura, McKay (1881) mentions the difficulty of separating the different series there from one another. The total thickness of the Jurassic rocks in the eastern part of the Hokonui Hills is some 10,500 feet, a figure which is considerably larger than that of Cox and McKay. Their estimate (6,600 feet) was based on the closely studied exposures of Jurassic rocks near the Bastion and Flag Hill It appears that the thickness of the Jurassic sediments increases eastwards in the Hokonui Hills. It is interesting to note that the thickness of Jurassic rocks occurring on the east bank of the Mataura River, estimated from the section accompanying McKay's account (1881), is at least 11,000 feet. Mr. D. S. Coombs (1950) notes the eastward thickening of the Jurassic sediments between Taringatura Hills and the coastal section south-west of Nugget Point.

Notes on the Mesozoic Sequence. The total thickness of Mesozoic rocks in the Eastern Hokonui Hills is about 28,000 feet, a figure comparable with those detailed by Coombs (1950) for the Mesozoic sequences at other localities in Otago and Southland In the Triassic rocks the sediments are largely fine-grained, but the presence of numerous intercalated bands and lenses of sandstone and conglomerate suggests that deposition was mainly in shallow water. Fossils characteristic of the Oretian and Warepan Stages have not been found in the area here discussed. It is possible (1) that the fossils have been overlooked in the field, or (2) that these Stages are here represented by unfossiliferous sediments only, or (3) that sediments belonging to these Stages are not present, and consequently disconformities occur between the Kaihikuan and Otamitan Stages and between the Otamitan and Otapirian Stages respectively. Similar non-appearance of characteristic fossils has been recorded from other areas of Mesozoic rocks as, for example, in the Kaihiku Ranges, where the Otapirian Stage is apparently missing (Ongley, 1939), or at the coastal section near Glenomaru, where the Noric beds characterized by *Monotis richmondiana* Zitt. are not found, though they occur in proper sequence 10 miles inland (Mackie, 1935).

Lateral and vertical changes in lithology are abundant. In the main, the sediments were directly derived from crystalline rocks and suffered little attrition during their transportation to the sea. Sedimentation was typically geosynclinal, accompanied by intermittent depression of the sea-floor as the sediments accumulated. The coarse-grained nature of many of the Jurassic rocks indicates that considerable relief prevailed on the land-mass from which much of the detritus was derived, and that uplift of this land-mass probably occurred from time to time.

Microscopic examination of some of the rocks showed that they exhibit well the features of lithic and crystal tuffs, many of the



Geological Map and Sections of Eastern Hokonui Hills

PLATE 96

Block diagram of Eastern Hokonui Hills.

Facing page 474]

sections* (e.g. 10498, 10500, 10502, 10508, 10510, 10511, 10518) showing large euhedral crystals of feldspar and small angular fragments of keratophyric and andesitic rock. The occurrence of thin bands of vitric tuff (10506, 10509) has already been mentioned. These rocks show the characteristic vitroclastic structure described by Pirsson (1915). Although no igneous rocks occur in place, volcanic activity evidently prevailed on the land-mass from which the Mesozoic sediments were derived. Some of the pyroclastic material erupted may have been showered directly into the sea; much of it was probably deposited on the land, followed by its transport to the sea together with detritus derived by normal weathering and erosion.

TERTIARY SEDIMENTS

A narrow, poorly exposed strip of Lower Tertiary sediments flanks the south and south-west margin of the hills. Near Mandeville, Tertiary rocks outcrop along a terrace following Otamita Stream, while a small outlier of lignite and mudstone occurs near the junction of Boundary and Otamita Streams. The best exposures of Tertiary rocks will be briefly described as follows:

Near Grant's Bush: A small outcrop of dark mudstone with poor lignite occurs approximately 1¾ miles south-east of East Peak (Grid reference, S.170, 792453). A short distance to the north-east there is an abandoned pit, formerly worked for lignite. The only rock now exposed at this second locality is a soft yellow sand similar to that occurring as lenses in the Pleistocene high-terrace gravels.

A little over a mile to the south-west occur two large residual blocks of hard quartz-sandstone similar to the silicified Tertiary sandstones of Landslip Hill, near Pukerau.

Lower Waimumu and Whisky Streams: Lower Tertiary mudstone with associated quartz gravel and lignite outcrop over a downland area of a little over a square mile near the junction of Waimumu and Whisky Streams. The mudstone is a soft, light-coloured rock with numerous tiny flakes of chlorite. The lignite occurs as irregular bands and lenses up to 25 feet in thickness. The conglomerate is a compact rock with pebbles mainly of quartz. It is difficult to determine the thickness of the coal-measure rocks exposed here. The dip is variable and at no locality is the base of the Tertiary sequence seen. An incomplete section observed in a small gully leading into the lower part of Waimumu Stream shows the following downward sequence: grey mudstone 15 feet, quartz conglomerate 10 feet, shaly lignite 5 feet.

Macpherson (1937) has given an account of similar rocks outcropping at the Waimumu alluvial goldfield, several miles south-east of the present area. Associated with the coal-measure rocks are many outcrops of hard, sintered, brick-red or orange mudstone which has been baked during spontaneous combustion in the underlying lignite.

Two hundred yards north-west of the junction of the north and south branches of Waimumu Stream (Grid reference, S.169 736456), a road cutting shows a good outcrop of light blue-grey, glauconitic sand-

* Numbers refer to catalogued specimens, Geology Department, Otago University.

stone underlying fine-grained, blue, sandy mudstone, and containing numerous very friable fossils. The writer is indebted to Dr. J. Marwick, who has informed him of the Duntroonian (Lower Oligocene) age of this sandstone. Dr. Marwick has also kindly forwarded the following list of fossils collected from the same locality several years ago by officers of the Geological Survey:

Nuculana probellula Marw.
Cucullaea sp.
Lentipecten sp. juv.
Solecurtus chattonensis Fin.
Notocallista (Fossacallista) ? tecta Marw.
Dosinia sp. cf. *D. imperiosa* Marw.
Hedecardium sp. cf. *H. waitakiense* (Suter)
Panope worthingtoni Hutt.
Struthiolaria sp.
Friginatica sp.
Austrofusus precursor Fin.
Baryspira sp.
Austrotoma sp.
Dentalium sp.
Cadulus sp.

Lower Otamita Stream, near Mandeville: McKay (1892) noted the presence of coal-measure beds along the lower reaches of Otamita Stream in a report dealing with the coal and associated rocks of the Waimea Plain, several miles to the north-west. The rocks are exposed along the lower levels of a high terrace following the south bank of Otamita Stream. The best exposure, at the bridge ¾ mile south-west of Mandeville, shows a variable thickness (15–25 feet) of light blue-grey, sometimes rusty, sandy mudstone. Its broadly undulating surface is covered by high terrace gravels. Immediately downstream from this exposure are a few outcrops of light-coloured sandstone with irregular rusty concretions. The same mudstone is exposed at many points downstream for about half a mile, but no lignite was seen.

The Tertiary beds at this locality form an outcrop only along the edge of the terrace which is too narrow to appear on the geological map (Plate 95) accompanying this paper.

Otamita Stream: A few small outcrops of greasy, blue mudstone and lignite occur near the junction of Boundary and Otamita Streams. The mudstone is similar to that occurring at Waimumu Stream; the associated lignite shows in one outcrop a thickness of ten feet. A small mass of orange-coloured, baked mudstone occurs ¼ mile west of the junction of Boundary and Otamita Streams.

High Terrace Gravels (probably Pleistocene): These gravels, the Kamahi Terrace and Waimumu Terrace gravels of Willett (1948, p. 232), are found as several small remnants of a high terrace near Mandeville, and as a broad strip on the south of the hills. The rock consists of rounded pebbles of quartz and weathered greywacke in varying proportions and scattered pebbles of jasper. There are numerous small lenses of sand, often current-bedded. Near Mandeville the maximum thickness is 10 feet. To the south the thickness is variable, probably exceeding 35 feet in places. In the largest exposure seen, along the terrace bordering the lower part of Waimumu Stream, the thickness is between 25 and 30 feet.

At several localities, e.g. lower Waimumu Stream, these gravels are overlain by a variable thickness (up to 12 feet) of coarse unsorted gravel, composed mainly of angular pebbles of greywacke with some small rounded pebbles of igneous rocks evidently derived from Mesozoic conglomerates.

Recent Alluvium: Recent gravel and silt of the Waimea and Mataura rivers flank the hills on their northern and north-eastern sides. A few thin strips occur along Otamita and Waimumu streams.

NOTES ON CONGLOMERATE PEBBLES

Short petrographic descriptions are given of representative pebbles collected from the principal conglomerate bands in the district.

1. *Middle Triassic Conglomerate.* East Peak: Headwaters of Stony Creek.

Keratophyres (10417, 10418). Both rocks are porphyritic with a very fine-grained, light yellow or yellow-brown ground-mass. The phenocrysts are subidiomorphic grains of albite obscured by dusty kaolin and shreds of sericite. In 10417 the feldspars also contain small grains of epidote. Anorthoclase occurs rarely as large phenocrysts (10417). The ferromagnesian minerals include corroded crystals of augite (10417), or shreds and larger aggregates of celadonite (10418). There are numerous scattered granules of iron ore.

Quartz-porphyrites (10414, 10436). These rocks are strongly porphyritic with scattered phenocrysts of plagioclase, quartz and altered biotite set in a pale-coloured microcrystalline ground-mass. The plagioclase is dusty oligoclase (10436) or albite An_{10} (10404) showing albite twinning. It is accompanied by rare crystals of anorthoclase with faint, blotchy, cross-hatched twinning. 10414 could perhaps be classified alternatively as a quartz-keratophyre. The phenocrysts of quartz are usually strongly corroded. The ferromagnesian minerals are rare crystals of altered biotite (10414), or green patches of chlorite and celadonite (10436).

Porphyrites (10420, 10423, 10430). Plagioclase (An_{27}–An_{55}) occurs in numerous, subidiomorphic, often zoned phenocrysts, always dusted with fine-grained decomposition products. In 10430 the feldspar crystals show marked regular arrangement of dusty, opaque inclusions parallel to the edges. Nearly all the crystals show albite twinning, with much less common pericline twinning. The ferromagnesian minerals include uncommon crystals of augite (10420) and weakly pleochroic hornblende (10430) 10420 also shows a small basal section of brown hornblende. Small, irregular, green or green-brown patches of chlorite and celadonite are common. The ground-mass is light-coloured and fine-grained, either cryptocrystalline (10420, 10423) or microcrystalline (10430). In 10420 flow structure is well developed. The same section shows a few small phenocrysts of quartz.

2. *Kaihikuan Conglomerate.* Otamita Stream.

Granite (10438). The rock contains large (up to 3 mm.) crystals of dusty perthitic orthoclase and quartz. Oligoclase (An_{15}–An_{18}) with well-marked albite twinning makes up about 10 per cent. of the rock. There are a few small flakes of partly chloritized biotite.

Microgranite (10439). The rock is fine-grained and non-porphyritic although a few crystals are noticeably larger than the average. Dusty kaolinitized orthoclase and quartz each make up about 35 per cent. of the rock. In places these minerals show a coarse graphic intergrowth. Acid oligoclase, often in large subidiomorphic grains, forms 25 per cent. of the slide. Biotite occurs in small, strongly pleochroic flakes. It is accompanied by larger corroded crystals of pale hornblende.

Quartz-porphyrite (10441). The rock is strongly porphyritic with phenocrysts of dusty oligoclase (An_{23}) and scattered irregular grains of quartz. These are set in a pale yellow, fine-grained ground-mass with well-marked flow-structure, adjacent bands showing different degrees of crystallinity. The ferromagnesian mineral is poorly birefringent chlorite in corroded aggregates usually containing opaque granules of iron ore.

3. *Rhaetic Conglomerate.* Boundary Creek.

Oligoclase-granite (10452, 10463). Oligoclase (An_{22}–An_{30}) in subidiomorphic crystals averaging 1 mm. makes up about 50 per cent. of the rock. Orthoclase occurs in small amount only. Both feldspars are covered by dusty decomposition products. Quartz in interstitial grains forms 20–25 per cent. of the slide. The remainder of the rock is made up of roughly equal amounts of strongly pleochroic biotite and hornblende, the latter mineral occurring in small subidiomorphic crystals showing the following pleochroism:

Z = dark green
Y = light blue-green
X = pale yellow-green

Accessory minerals include a few crystals of light green, secondary epidote and grains of iron ore.

Porphyrite (10454). This rock is considerably altered, the phenocrysts of feldspar being covered by shreds and spots of sericite and kaolin. Oligoclase (An_{14}–An_{20}) occurs in large subidiomorphic phenocrysts ranging up to 4 mm. long. Pale green hornblende forms a few large corroded phenocrysts with weak pleochroism. The phenocrysts are set in a very altered ground-mass made up of feldspar, quartz, shreds of pale green celadonite and abundant granules of iron ore and sphene.

Meta-porphyrite (10456). The structure is porphyritic although this is obscured by the very altered condition of both phenocrysts and ground-mass Colourless augite occurs in large, corroded, subidiomorphic phenocrysts. A few small altered grains of plagioclase with albite twinning occur. The ground-mass is usually very fine-grained with much green, fibrous, celadonitic material, granular epidote and iron ore. At one place there are numerous irregular cavities filled with almost isotropic pale green chlorite.

Andesites (10458, 10459, 10460). The andesites are all strongly porphyritic with well-marked pilotaxitic structure. The predominant phenocrysts are idiomorphic labradorite, much of it as basic as An_{60}. The feldspar is remarkably fresh, although it contains numerous dusty inclusions. Albite twinning, occasionally combined with pericline twinning, is very common. 10458 and 10459 contain rare stumpy crystals of augite. The ground-mass in these rocks is very fine-grained. In 10458 it is obscured by opaque, dark reddish-brown, limonitic material. Iron ore in tiny granules, granular epidote and sphene are abundant.

In 10458 chalcedony occurs in fibrous aggregates filling small cavities in the ground-mass. Calcite is a common secondary mineral in each rock, and in 10460 it also fills large (3–4 mm.) spherical vesicles.

Silicified mudstone (10461).

4. *Lower Jurassic Conglomerate.* Near road from Waimumu to Otamita Stream.

Granophyres (10465, 10466). Both rocks are porphyritic with phenocrysts of albite covered by dusty kaolin and shreds of sericite. Orthoclase was not definitely recognized, but probably occurs on a fine scale in the ground-mass of the rock. Quartz occurs in relatively few allotriomorphic phenocrysts. Graphic intergrowth between the feldspar and quartz is shown on a coarse scale in 10465, but is perfectly developed in 10466, where the feldspar contains numerous, tiny, regular inclusions of quartz. The ferromagnesian constituent is partly chloritized biotite accompanied in 10466 by numerous granules of highly refringent epidote.

Spherulitic granophyre (10467). Again the rock is porphyritic with few large phenocrysts of anorthoclase (optically negative) showing blotchy gridiron twinning, and one or two corroded phenocrysts of quartz. These are set in a fine-grained ground-mass containing scattered, imperfect spherulites of feldspar and quartz. The only dark constituent besides numerous granules of iron ore is an indeterminate brown alteration product occurring as scattered fragments.

Andesite (10471). This slide is similar to those described from the Rhaetic conglomerate, the main difference being its somewhat finer grain-size.

Silicified mudstone (10470).

5. *Jurassic Conglomerate.* Kelvin Peak and Ship Cone.

Granophyres (10475, 10480, 10489, 10493). Acid to medium oligoclase makes up between 30 and 40 per cent. of these rocks. Orthoclase in kaolinitized crystals showing Carlsbad twinning is always in smaller amount than the plagioclase. Quartz occurs in clear shapeless grains always easily distinguished from the dusty feldspar crystals. Graphic intergrowth of quartz and feldspar (usually orthoclase) is prominent. In 10489 the little intergrown fragments of quartz are rounded, irregular, or even vermiform in shape. The commonest dark mineral is biotite in small pleochroic flakes. In 10475 and 10480 a few ragged crystals of pale green hornblende occur. Accessory minerals include granular iron ore, small crystals of epidote, and sphene.

Fine-grained granite (10476, 10484). The structure of these rocks is subidiomorphic granular with grain-size averaging about 1 mm. In both slides the approximate composition is dusty orthoclase 40 per cent., quartz 30 per cent. and oligoclase (An_{23}) 25 per cent. All three minerals show marked undulose extinction, while granulation has produced small amounts of fine-grained, crushed material at the edges of some of the larger crystals. Strongly pleochroic, partly chloritized biotite occurs in small subidiomorphic flakes.

Crush-rocks (10479, 10487). Quartz is the chief mineral present in each slide, occurring as large irregular grains surrounded by a granulated mass of smaller interlocking crystals. Under crossed nicols strain shadows are very prominent. In 10479, albite (?) in very irregular altered crystals occurs, but in 10487 the quartz is accompanied by a nearly opaque, granular alteration product in large aggregates or small stringers and shreds. The larger crystals in both slides are cut by thin veins of very fine-grained quartz. 10487 contains several crystals of pale clinozoisitic epidote.

Quartz-biotite-hornfels (10483). Grain-size is small, the greater part of the rock being made up of a granoblastic mass of quartz and possibly some feldspar. There are no large porphyroblasts, but accompanying the light minerals are numerous tiny flakes of sericite and somewhat larger crystals of pale brown biotite. Grains of the latter mineral are here and there collected into narrow irregular bands. Tiny black granules of iron ore or graphite are abundant. Cutting through the rock are a number of thin veins of quartz in comparatively large angular crystals.

Note on the Conglomerate Pebbles. Many of the rocks, e.g. keratophyres, oligoclase-granites, and some of the granophyres and porphyrites, show marked richness in soda, a feature that has also been noted in the Mesozoic conglomerate pebbles of the Glenomaru district (Mackie, 1935). Strain effects such as undulose extinction of quartz and feldspar, and bending of mica flakes are prevalent. The only metamorphic rocks noted are rare pebbles of crush-rock and hornfels.

Pebbles of granitic rocks appear to be absent from conglomerates occurring below the base of the Kaihikuan Stage. Mr. D. S. Coombs (1950) has also recorded this in the Mesozoic rocks of the northern Taringatura Hills. Another feature of interest is the appearance in abundance of granophyre pebbles in the Jurassic conglomerates.

The present writer has nothing to add to the remarks of Mackie (1935, p. 298) regarding the possible source of the Mesozoic sediments.

Structure of the Mesozoic Rocks

Nearly everywhere the Mesozoic rocks dip steeply to the south-west or south-south-west. McKay (1878, p. 75) described the structure of the eastern part of the Hokonui Hills and mentioned the slight eastward pitch of the syncline between Ship Cone and Hedgehope Hill. He summed up well the broad features of the structure when he stated (1881, p. 42) that "the beds forming the Hokonui Hills have been described, and shown to consist in the eastern part of the district of a great assemblage of strata arranged as a syncline, which on the northern side, from the lowest to the highest beds, dip everywhere at very high angles, while on the southern side of the syncline, the dip is everywhere at a very moderate angle."

In the Triassic rocks the angle of dip varies usually from 65° to 75°. In the section along Otamita Stream, for example, the angle of dip nearly always lies between 70° and 75°. Occasionally steeper dips than these are observed, and in one or two localities the strata have been overturned. For example, a large outcrop of Kaihikuan mudstone beside Otamita Stream shows vertical dip, and the strata are overturned at one point so that the beds dip at very high angles to the north-east.

The tuffaceous siltstone and mudstone of the lower part of the Middle Triassic sequence show locally moderate dips as low at 30°. These occur on the steep front of the hills, not far from the bounding fault, and are attributed to local drag of the beds during uplift in late Tertiary times.

As the Jurassic rocks are followed across the strike south-westwards from Boundary Creek the angle of dip still remains high, being 60° near the summit of Ship Cone. Beyond this point, however, dips of 50°–55° are encountered and at the south-west corner of the area the sandstone and conglomerate are dipping to the south-west at 30°. Thus the axis of the Hokonui syncline lies just south of the present area. In his section GH, Cox (1878) and after him Park (1887) show the axis of this syncline too far to the north, but Cox did not examine the beds along the section beyond the outcrop of the Putataka Series on the north face of Ship Cone (1878, p. 36). McKay, however (1878, p. 75) records that the axis of the syncline coincides approximately with the valley between Ship Cone and Dunsdale. The accompanying diagrammatic section (Fig. 1) shows the general arrangement of the strata between the flank of Ship Cone and Hedgehope Hill. The line of section is somewhat oblique to the direction of dip so that the angles of dip shown are a few degrees below the true values.

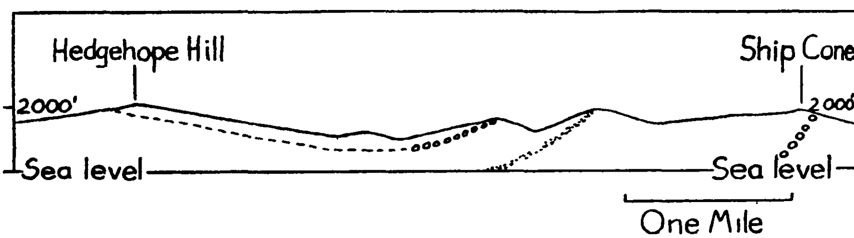


FIG. 1—Section between Hedgehope Hill and the flank of Ship Cone.

GEOMORPHOGENY

After strong folding of the Mesozoic sediments in late Jurassic or early Cretaceous times, a period of erosion followed during which the uplifted land-mass was reduced to a surface of low relief. On this surface Lower Tertiary coal-measure rocks were laid down. In Duntroonian time the sea flooded much of the present Southland area (Finlay and Marwick, 1948, p. 36), with the deposition of glauconitic sandstone in the present area. That a cover of Lower Tertiary rocks probably extended over the region of the present Hokonui Hills is indicated by the presence of such rocks fringing the hills at Forest Hill, Hedgehope, Waimumu, Waimea Plain and Balfour, and by the occurrence of a small outlier of mudstone and lignite in the Otamita Valley.

In 1935 Dr. W. N. Benson presented evidence that over much of of the southern part of the South Island crust movements occurred after the cessation of sedimentation in mid-Tertiary times, followed by erosion and perhaps peneplanation before the late Tertiary Kaikoura orogeny. He thought that during the period of erosion most of the Tertiary cover on the Hokonui Hills was removed, streams consequent on this cover were superposed on to the Mesozoic undermass, and development of subsequent valleys in the latter had reached an appreciable stage when their courses were inherited by the streams of the present cycle developed after the down-faulting of the Waimea area. He suggested that if the present drainage pattern had evolved after stripping of the Cretaceous peneplain in post-Tertiary time, then abundant residuals of resistant Tertiary rocks might be found on gentle valley floors in the hills.

The present writer believes that after broad asymmetric uplift of the Hokonui Hills region, much of the Lower Tertiary cover was stripped from the underlying Mesozoic rocks during the later part of the Tertiary period. Nevertheless the presence of relatively weak coal-measure rocks in the Otamita valley indicates that some of the cover still remained when uplift took place during the Kaikoura orogeny.

The streams consequent on the Tertiary cover were superposed on to the Mesozoic undermass, but it is probable that only shallow valleys were excavated in the latter. Small subsequent gullies were developed along belts of less resistant mudstone and greywacke. Block faulting took place at the end of the Tertiary period, as in many other parts of Southland and Otago, the hills being elevated to their present position. Any remaining areas of Tertiary rock were stripped off during the Pleistocene period, except the small outlier in the Otamita valley and the fringing strip, both of which in all probability had been depressed below the base level of the late Tertiary streams (Benson, 1935). Any valleys formed during late Tertiary times have been inherited by the streams of the present cycle so that development to the present stage of dissection has been carried out during the Pleistocene period. The absence of "valley-in-valley" forms from most of the area suggests that the streams of the late Tertiary cycle had only eroded shallow valleys in the Mesozoic rocks.

High terrace gravels were deposited round the flanks of the hills, probably in the late Pliocene or early Pleistocene. The abundance of quartz pebbles in this rock suggests that it was derived from the schist terrane lying at the headwaters of the Mataura and Waikaia rivers. During the later part of the Pleistocene period coarse unsorted gravel was laid down in places over the quartz-greywacke gravels. The predominance of angular greywacke pebbles and the presence of pebbles of igneous rocks indicates that this gravel may have been deposited by small streams draining the closely adjacent Hokonui Hills.

Fault Scarps. The most striking topographic feature of the area is the steep north-west-trending scarp which bounds the Hokonui Hills on the east and north-east, broken only by the valleys of a few transverse streams such as Otamita Stream and Stony Creek. It is crossed by the Mataura valley near Gore, and its continuation may be traced along the front of the hills between Gore and Waipahi, to the Kaihiku Ranges, and eventually to the coast near Kaka Point (Ongley, 1939, p. 24). The parallel scarp bounding the hills on the south was originally lower than the main Hokonui Hills scarp and is now maturely dissected. Near Waimumu Stream strong updrag of the coal-measure rocks has been produced in the neighbourhood of the fault-line, giving dips up to 60° to the south and south-east (see also Healy, 1938).

A low south-west-trending scarp cuts across the south-eastern end of the Hokonui Hills. The fault-angle depression between the Hokonui Hills and their continuation immediately east of the Mataura River at Gore forms the depressed strip through which this river passes from the Waimea to the Southland Plain.

A little east and south-east of Otamita Stream a south-west-trending fault separates the eastern Hokonui block from the tilted continuation of the hills to the north-west. Along the scarp, now maturely dissected, is a pronounced steepening of the strike-ridges towards the Otamita valley. The preservation of the small outlier of shale and lignite in Otamita valley has been assured by its location on the downthrow side of this fault.

Other Features. Probably all traces of the Cretaceous peneplain on which the Tertiary rocks were deposited have been destroyed. Some of the long strike-ridges of the Hokonui Hills, however, are possibly not far below the original level of this surface Some gently sloping areas of Triassic rocks, flanking parts of the Otamita Stream (e.g. near the junction of Otamita and Boundary streams) may represent portions of this surface stripped of their former cover and dipping below the small outliers of Tertiary rock that remain. The development of subsequent streams is well-marked over much of the area. Many of the N.W.–S.E. ridges are aligned on resistant bands of sandstone or grit, and the intervening valleys (e.g. the tributaries of Stony Creek) have been excavated along less resistant mudstones. The hills show the fine adjustment to structure and, often, maximum relief characteristic of regional maturity (von Engeln, 1942). Slight rejuvenation of some of the streams and the development of "valley-in-valley" forms on a small scale is shown in several localities, e.g. in the upper part of Waterfall Creek.

[The block diagram (Plate 96) accompanying this paper has been drawn in an attempt to show the broad features of the topography of the district.]

ECONOMIC GEOLOGY

Lignite has been mined for many years near the junction of Waimumu and Whisky streams, where there are a number of disused pits. The only pit at present in production is that of Mr. D. McGregor, of Gore. Between 80 and 90 tons are produced weekly for domestic use.

Some small exposures of high terrace gravels beside the Gore-Mandeville highway have been worked for road metal.

LIST OF REFERENCES

BENSON, W N., 1935. Some Land Forms in Southern New Zealand *Aust. Geog.*, vol. 2, pp. 3–23.

COOMBS, D. S., 1950. The Geology of the Northern Taringatura Hills, Southland. *Trans. Roy. Soc N.Z.*, vol. 78, pp. 426–448.

COX, S. H., 1878. Report on the Geology of the Hokanui Ranges, Southland. *Rep. Geol. Exp. 1877–78*, pp. 25–48.

ENGELN, O. D. VON, 1942 *Geomorphology*. New York. The Macmillan Company.

FINLAY, H. J., and MARWICK, J., 1948 In *The Outline of the Geology of New Zealand*. H. H Tombs, Wellington.

HEALY, J., 1938 Notes on the Hokonui District. *Ann. Rep. Geol. Surv. N.Z.*, 1937–38, p. 19

LOBECK, A. K., 1924. *Block Diagrams*. London, Chapman & Hall.

MACPHERSON, E. O., 1937 The Geology of Waimumu Alluvial Goldfield and Notes on Quartz Conglomerates in Southland. *N.Z. Jour. Sci. Tech.*, vol. 18, pp. 772–778.

MCKAY, A., 1878. Notes on the Sections and Collections of Fossils in the Hokanui Ranges, Southland. *Rep. Geol. Exp. 1877–78*, pp. 73–90.

——— 1881. Mataura Plant Beds, Southland County. *Rep. Geol. Exp. 1879–90*, pp. 39–48.

——— 1892. On the Waimea Coal. *Rep. Geol. Exp. 1890–91*, pp. 31–35.

MACKIE, J. B., 1935. The Geology of the Glenomaru Survey District, Otago, New Zealand. *Trans. Roy. Soc. N.Z.*, vol. 64, pp. 275–302.

MARSHALL, P., 1908. Some New Zealand Fossil Cephalopods. *Trans. N.Z. Inst.*, vol. 41, pp. 143–145.

MARWICK, J., 1935. Some New Genera of the Myalinidae and Pteriidae of New Zealand. *Trans. Roy. Soc. N.Z.*, vol. 65, pp. 295–303.

——— 1946. The Geology of the Te Kuiti Subdivision. *N.Z. Geol. Surv. Bull.*, no. 41.

ONGLEY, M., 1939. The Geology of the Kaitangata-Green Island Subdivision. *N.Z. Geol. Surv. Bull.*, no. 38.

PARK, J., 1887. On the Jurassic Rocks of the Hokonui Hills, Mataura, and Waikawa. *Rep. Geol. Exp. 1886–87*, pp. 141–149.

PIRSSON, L. V., 1915. The Microscopical Characters of Volcanic Tuffs. *Am. Journ. Sci.*, vol. 40, pp. 191–211.

SPATH, L. F., 1923. On Ammonites from New Zealand. (Appendix to Trechmann, 1923). *Quart. Jour. Geol. Soc.*, vol. 79, pp. 286–308.

TRECHMANN, C. T., 1917. The Trias of New Zealand. *Quart. Jour. Geol. Soc.*, vol. 73, 165–246.

——— 1923. Jurassic Rocks of New Zealand. *Quart. Jour. Geol. Soc.*, vol. 79, pp. 246–286.

WILCKENS, O., 1927. Contributions to the Palaeontology of the New Zealand Trias. *N.Z. Geol. Surv. Pal. Bull.*, no. 12.

WILLETT, R. W., 1948. Preliminary Report on the Lignite Deposits of the Mataura Valley, Eastern Southland Coalfield. *N.Z. Jour. Sci. Tech.*, vol. 29, pp. 228–246.