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THE GEOLOGY OF NEW ZEALAND.

Waimangu Geyser, Rotorua District.

THE GEOLOGY OF NEW ZEALAND

AN INTRODUCTION TO THE HISTORICAL,
STRUCTURAL, AND ECONOMIC GEOLOGY.

BY

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OF LONDON; SOMETIME PRESIDENT OF THE NEW ZEALAND
INSTITUTE OF MINING ENGINEERS.

*WITH 145 ILLUSTRATIONS, 27 PLATES, AND
COLOURED GEOLOGICAL MAP.*

CHRISTCHURCH, WELLINGTON AND DUNEDIN, N.Z.;
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PREFACE.

The general view of the Geology of New Zealand presented in these pages was originally written for the Department of Mines, being primarily intended for the use of teachers, and mining students. It is hoped that it will also be found of use to those who are concerned with the progress and development of the mining industry, as well as those interested in the genesis of the existing surface features and geological structure of the country.

Geology is generally recognised as the most fascinating of the natural sciences. That it is not an exact science is perhaps where its chief charm, in a great measure, lies. Be that as it may, it is certain that the generous soil from which we draw our sustenance, the rocky constituents from which we mine our wealth of gold and supplies of the no less valuable baser metals, the sheets of coal, the entombed life of bygone ages—both exquisitely beautiful and wonderfully grotesque—present to every inquiring mind a perpetual source of enjoyable and profitable study.

In the preparation of these pages I have made use of data gleaned from many sources; and in this regard I wish more particularly to acknowledge my indebtedness to the work of the first Director of the Geological Survey, Sir James Hector, F.R.S., F.G.S., of Sir Julius von Haast, F.R.S., F.G.S., and of my old friends and colleagues, Captain F. W. Hutton, F.R.S., F.G.S., Alexander McKay, F.G.S., late Government Geologist, and Professor S. H. Cox, F.G.S., now of the Royal School of Mines, London.

The stratigraphical succession of the sedimentary formations has happily reached the point of agreement. The problems that now remain are principally concerned with the relationships that exist between certain formations, and with distant correlations. In 1889 Captain Hutton abandoned his classification of 1886; and the surveys of the past decade have shown that the classification of the old Geological Survey required revision.

In the revised classification here inscribed, native Maori names have been preferred to English names, and the old nomenclature has been adhered to wherever that could be done without causing confusion of idea or ambiguity. At the same time, it should be noted that the formations in the present classification are not always co-extensive with those bearing the same name in the old classifications,—thus the Waipara Series of Hutton excluded the Weka Pass Stone, which was by him included in the Oamaru Series. The Waipara Series as here defined includes the Weka Pass Stone, with the associated Grey Marls.

The Maori place names are soft and euphonious. And it is as well to bear in mind that all the vowels are accented and their quantity full and round, being almost the same as in the old Latin tongue. Thus the definite article *te* is not pronounced like tea, the well-known beverage, but as tā, in which a has the value of a in fāte. Similarly the word *ti* is not pronounced like the English word tie, but as tea or tee. Further the *ng* so common in Maori place names has the nasal sound of ng in ring, thus Wanganui is not Wan-ga-nui, but Wanga-nui. The Maori *a* has the value of a in father.

The total value of the metals and minerals raised in the Dominion to the end of 1909 amounted to about £100,000,000. Of this value gold contributed £75,000,000; coal £15,000,000; kauri gum, silver, copper, antimony, scheelite, manganese, chromium about £10,000,000. The country's greatest mineral wealth, so far as at present known, lies chiefly in its gold, coal and iron. The development of the known mineral resources is capable of enormous expansion; and the wide unexplored regions of the South Island, and of South-west Otago in particular, offer promising fields for further discoveries.

The Dominion's supplies of coal are scattered in detached blocks throughout the length and breadth of both islands, and although inconsiderable when compared with the Old World's supplies, it is obvious that when placed against the small annual output, and the conservation of the coal that is certain to accompany the increasing use of the water-power, which, next to the salubrious climate and fertile soil, is the country's greatest asset, the coal-supplies will probably outlast those of Britain and America. The water-power is perennial, and the soil always responsive, but the earth yields only one crop of minerals; and already the rapid depletion of the world's supplies of coal and iron, copper, lead, tin, and other useful metals, is causing much concern in the great manufacturing countries of Europe and America. The matter of greatest concern is the diminishing supplies of iron ore, the exhaustion of which is now within measurable distance. The Iron Age will be succeeded by the Aluminium Age, but aluminium cannot take the place of iron. The exhaustion of the world's iron will mean a readjustment of the relationship at present existing between industrialism and agriculture, for it seems inevitable that with the approaching exhaustion of the metals agriculture must become more and more the staple occupation of the people as it was with primitive man. In two centuries or less, the battleships will be beaten into plough-shares; and a plough-share will be treasured by each family as a priceless heirloom. It is almost certain that in half a century the output of the metals will be regulated by law; and in order to stop the prodigal waste with which coal and the useful metals are now mined, the winning and extraction will be conducted under the supervision of qualified mining engineers appointed by the State. The conservation of its mineral resources will soon be the chief care of every civilized country.

With regard to distribution of the world's iron ores it is not a little singular that all the great deposits are situated in the countries bordering the Atlantic Trough. All the countries fringing the Pacific Ocean, including China, Japan, India, Australasia and the east coast of America, are poorly supplied with iron ore. The cause of this differential distribution is not easy to explain. It is at any rate of some satisfaction to know that the only considerable deposits of iron ore on the shores of the Pacific are possessed by New Zealand.

In the preparation of the Bibliography forming Chapter XVI., I received invaluable assistance from Mr. Hamilton's lists of papers relating to the *Dinornithidæ* and geology of New Zealand (Trans. N.Z. Inst., vols. xxvi., xxvii., xxxv., and xxxvi.; and from the Bibliography of Professor Dr. Otto Wilckens, of Bonn University, whose "*Die geologische paläontologische und petrographische Literatur über Neuseeland bis Zun Jahr*, 1907," Stuttgart, 1910, is the most complete and comprehensive work relating to the geological literature of New Zealand ever published. Many obscure references were also obtained from Dr. Hocken's monumental "Bibliography of New Zealand Literature," published in 1909.

The plates and figures have been drawn from many sources, of which due acknowledgment is made in the text. For the use of Plates I.-IV. and VI.-XVI., and many of the figures from Hector's "Outline of New Zealand Geology, 1885," now out of print for over twenty years, I have to acknowledge my indebtedness to the Hon. Roderick M'Kenzie, Minister for Mines. Through the courtesy of Dr. J. M. Bell I have been able to use figures 13, 14, 49, 50, 67A, 86, 99-103, that have appeared in the Bulletins of the Geological Survey. Several photographs have been contributed by my friends, three blocks have been lent by "The Otago Witness," and one by "The Weekly Press," and four by the New Zealand Education Department, for the use of which I have to record my thanks. For supplementary notes on the Kermadec Islands, by Mr. R. Speight, M.A., F.G.S., and notes on "The Foreign Relationships of the Oamaruian," contributed by Mr. F. Chapman, of the Nation Museum, Melbourne, I also wish to make grateful acknowledgment. Plates I.-IV., VI., and VIII.-XVI. are a reproduction of the beautiful illustrations of New Zealand Secondary and Tertiary fossils issued in the *Paläontologie von Neuseeland* of the Novara Expedition, published in 1864. Where not otherwise specified the maps, sketches, and diagrams are my own work.

The first four chapters of this work were published by the New Zealand Government in the *Mines Record* of February, March and April, 1909. When the publication of that periodical ceased, the Government intimated that the publication of the remaining chapters would be continued in the new State Journal preparatory to the issue of the matter in book form. However, to avoid further delay, an arrangement was made with the Government by which I have been enabled to publish the book in its present form.

JAMES PARK.

Otago University,
Dunedin, June, 1910.

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The Geology of New Zealand.

INTRODUCTION.

Historical.

Up to the early seventies New Zealand was divided into provincial districts, each of which possessed the necessary machinery for the management of its own domestic affairs. These were the palmy days of goldmining, and each province vied with the other in providing for a geological examination of the land within its borders, this work being primarily undertaken with the view of developing the mineral resources of the young settlements. From this healthy rivalry sprang the geological survey of Otago and Southland, under James Hector (afterwards Sir James Hector); of Canterbury and Westland, under Julius Haast (afterwards Sir Julius von Haast); and of Wellington, under J. C. Crawford.

It should be noted that some time before these appointments were made a geological reconnaissance of the Provinces of Auckland and Nelson had already been undertaken by the distinguished Dr. Ferdinand von Hochstetter, with whom Julius Haast was associated as chief field-assistant and topographer. That was in 1859. In the years 1860 and 1861 Dr. W. Lauder Lindsay made a prolonged study of the geology of Otago and Southland. He grasped all the salient features of the geological structure, and his generalisations, which were based on careful field observation, still remain a monument of clear geological deduction. Thus while the genius of Hochstetter[a] laid the foundation of the geological story of the

a. F. von Hochstetter: "Bericht ueber Geologie unter suchungen in der Prov. Auckland," Sitz Akad. der Wissenschaft zu Wien. xxxvii., 123. Lecture on "The Geology of the Province of Nelson," *Nelson Gazette,* Oct. 22, 1859. "Geologie von Neu Seeland Beitrage zur Geologie der Provinzen Auckland und Nelson," *Novara* Exp. Geolog. Theil, i. band 1, Meus Jahrb. Mineralog. 874, 1865.

North Island, the shrewd observations of Lindsay[b] formed the basis of the geology of the South Island.

Fragmentary contributions to the geology of New Zealand were made by Dana[c] in 1840, by Dieffenbach[d] in 1843, by Darwin[e] in 1844, and by Forbes[f] in 1855.

The decade succeeding 1861 was one of intense geological activity in New Zealand. The rivalry of the provinces communicated itself to the State geologists. Expedition followed expedition in rapid succession, the results achieved being embodied in numerous official reports and in papers contributed to the learned societies in the Colony and Europe. In geographical discovery, and in the domain of botany and zoology, there was a rich harvest. It could not be otherwise in a country on which Science was laying her hand for the first time. But in reading over the geological records of this period it is notable how little of real moment was added to the generalisations of Hochstetter and Lindsay, whose names are now well-nigh forgotten.

The geological survey of each province was carried on as an independent unit, with the result that there was no co-ordination in the work of the adjoining provinces, nor harmony in the classification and nomenclature of the stratified formations, which did not always conform to the artificial boundaries defined by political exigency. The same rocks commonly received a different name in each province. Hence, in process of time place-names multiplied to such an extent that relationships became obscured, while correlation was often rendered impossible through the diverse methods of grouping the rocks adopted by the State geologists.

In 1865 my old chief, Sir James Hector, was appointed Director of the Geological Survey of New Zealand, but the

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b. W. Lauder Lindsay: "On the Geology of Otago and Southland," lecture, Dunedin, January, 1862. "On the Tertiary Coals of New Zealand," The Geologist, vol. vi., p. 143.

c. James D. Dana, Geology, chapter viii., U.S. Expl., x., 437.

d. Ernst Dieffenbach: "On the Geology of New Zealand" (abstract), Rep. Brit. Assoc. 50, 1845.

e. Charles Darwin, "Remarks on the Elevation of the Land; and, as a Note, a Catalogue of Rocks met with at Bay of Islands," Geol. Obs. on Volcanic Islands, 142, 1844.

f. Charles Forbes, "On the Geology of New Zealand," Quart. Jour. Geo. Soc., xi., 521, 1855.

provincial surveys of Otago and Canterbury continued to exist until 1879 under the direction of Captain Hutton and Sir Julius von Haast respectively.

Associated with Sir James Hector in the first Geological Survey of New Zealand were Sir Julius von Haast, F.R.S., Professor F. W. Hutton, F.R.S., E. H. Davis, Professor S. Herbert Cox, F.G.S., A. McKay, F.G.S., Professor James Park, F.G.S., as field geologists; William Skey, F.C.S., as analyst; and John Buchanan, F.L.S., as botanist and draughtsman.

The second geological survey, under Dr. J. M. Bell, who succeeded Sir James Hector, was commenced in 1904; and since that date there have been published eight memoirs, namely Bulletins Nos. 1, 3, 4, 6 and 8, by Dr. Bell and his field assistants, Percy Gates Morgan, Colin Fraser, E. J. H. Webb, E. de C. Clarke, and J. H. Adams; and Bulletins Nos. 2, 5 and 7 by myself, working during the University vacation under a special arrangement with the department.

Since the publications of the synoptical views of the geology of New Zealand by Captain Hutton[g] in 1885, and Sir James Hector[h] in 1886, numerous memoirs of various detached districts have been contributed to the "Quarterly Journal," the "Transactions of the New Zealand Institute," and the records of the Geological Survey. Many facts have been recorded that tend to modify the views of Hutton and Hector, more particularly with regard to the succession of the stratified formations and the Pleistocene glaciation of New Zealand. I have, therefore, thought that as during the past twenty-five years I have geologically examined the greater part of the Dominion, and in the past nine years devoted the long summer vacation to the study of the problems that formed centres of controversy, it might be useful to prepare a connected outline of the general geology of the country for the information of students and others.

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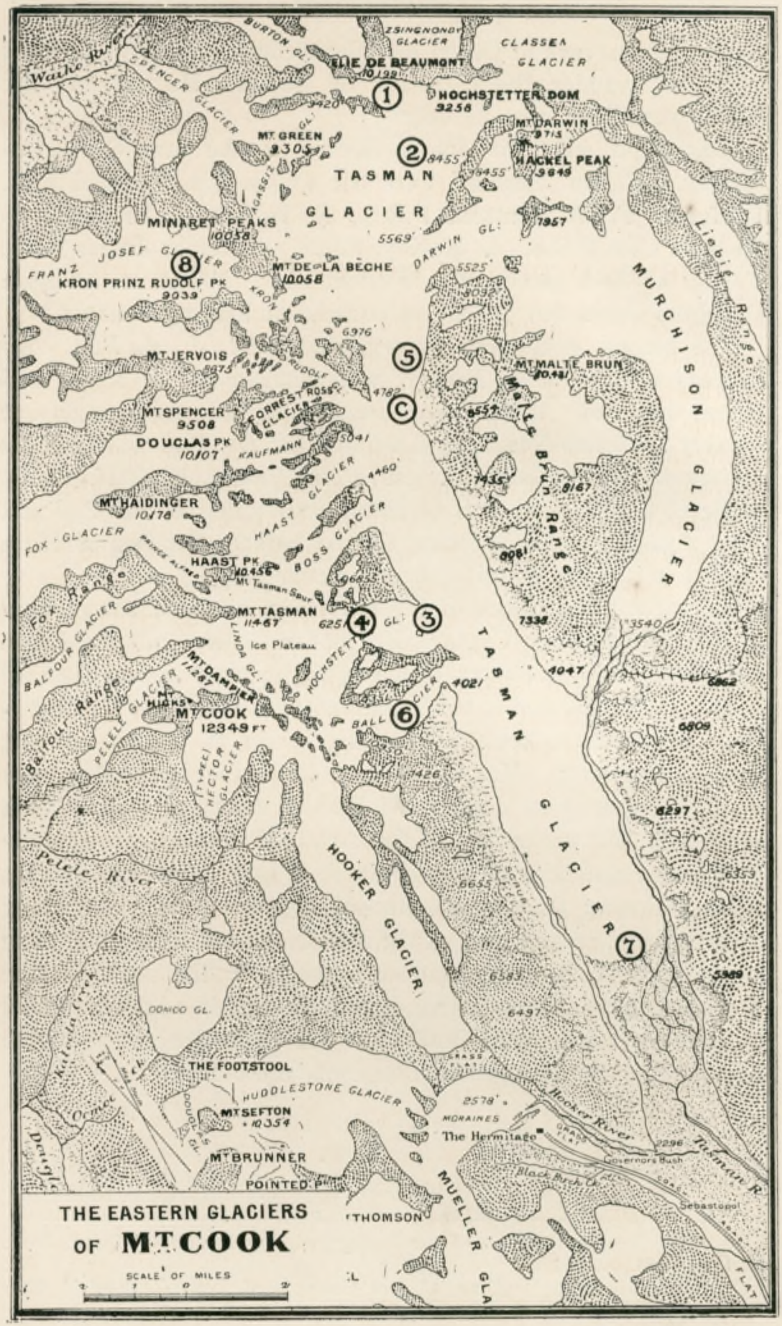
g. F. W. Hutton, "Sketch of the Geology of New Zealand," Quart. Jour. Geo. Soc. xli., p. 191.

h. James Hector, "Outline of the Geology of New Zealand," Gov. Printer, Wellington, 1886. (Out of print since 1890.)



Lent by the Education Department.

CHAPTER I.

GENERAL DESCRIPTION OF PHYSIOGRAPHY.

New Zealand consists of two large islands lying within the parallels of 32° and 47° south latitude, Stewart Island at the southern end of the South Island, and a number of small windswept rocky islets that lie a considerable distance off the mainland to the north, east, and south. Of these last the best known are the Kermadecs, Chatham, Bounty, Antipodes, Auckland, Campbell, and Macquarie Islands.

The two main islands, known as the North Island and South Island respectively, lie across the mean meridian, 172° 30′ of east longitude, in a N.N.E.-S.S.W. direction, the general trend being almost parallel with the east coast of Australia, which lies from 1,200 to 1,300 miles to the westward.

The North Island has a maximum length of 300 miles, and mean breadth of 120 miles. It sends off a long, narrow, deeply-indented prolongation to the north-west for a distance of 300 miles.

The orographical axis of the Island runs along the east coast, extending from Cook Strait to East Cape in an almost unbroken chain for a distance of 320 miles, and is the only continuous chain in the North Island.

In the South Island the alpine chain between Canterbury and Westland supports many summit and valley glaciers of great size, of which we have the following:—

On Canterbury Side:—

Tasman, 18 miles long; rate of flow, 18in. a day.
Murchison, 11 miles long; rate of flow, 7in. a day.
Hooker, 7.25 miles long.
Mueller, 8 miles long.

On Westland Side:—

Fox, 9.75 miles long.
Franz Josef, 8.5 miles long; rate of flow, 16ft. a day.

On the moist West Coast, where the precipitation is heavy, the Fox and Franz Josef glaciers approach within 670 and 690 feet of sea-level respectively in 43° and 44° south latitude.

On the eastern slopes of the Alps, where the precipitation is less and the gradient flatter, the terminal face of none of the glaciers descends below 2550 feet.

The largest glacier in New Zealand is the Tasman, which, with a length of 18 miles and an average breadth of one and a quarter miles, covers an area of 22.5 square miles.

Fig. 1. Tasman Glacier with Mount de la Bêche in middle distance.

South of Mount Cook summit glaciers of great size occupy Mount Aspiring, 9975 feet, and Mount Earnslaw, 9165 feet. In the North Island, the only permanent ice-field is that occupying the crater of Mount Ruapehu.

The alpine chain, which gradually diminishes in height going northward, ends abruptly at Cook Strait, which, as suspected by Hochstetter, lies along the course of a transverse dislocation, on the North Island side of which the dissevered chain became submerged by a profound subsidence.

The probable existence of a submerged chain with a core of crystalline schists received singular confirmation from a discovery made by the author in 1892 near Otorohanga, on the western fringe of the volcanic zone of Central Auckland. In the bed of a small stream were found many large rounded and sub-angular boulders of biotite-granite, granitic gneiss, and quartzite. The crystalline rocks were traced to a conglomerate at the base of a group of beds belonging to the Oamaru Series of Lower Miocene age. There seemed now a good hope of discovering an outcrop of the crystalline rocks *in situ*, but further investigation showed that the material in the Miocene conglomerate had been derived from a great conglomerate of crystalline rocks in the Juro-Triassic formation, on the denuded surface of which the Miocene beds rested.

McKay has also reported the occurrence of granite in a Jurassic conglomerate at Kawhia; and more recently Bell and Clarke[i] record the presence of granite in the basal conglomerate of the Cretaceous Kaeo Beds, in the Whangaroa district of North Auckland.

The nearest known outcrop of granite and crystalline schist is at Golden Bay, in Nelson, over 220 miles away—a distance which seems to add confirmation to the view that a core of these rocks underlies the sheet of Juro-Triassic strata forming the basement of western and northern Auckland.

Hutton[j] considered it probable that the geanticlinal of the South Island runs through the centre of the North Island—a view that was afterwards indorsed by Professor Suess[k]. Hochstetter[l] had already suggested that the Taupo volcanic zone of the North Island lay along a downthrow area, the eastern boundary of which ran along the foot of the Ruahine Range.

The Tararuas lie along the axial prolongation of the Kaikoura Mountains, on the south side of Cook Strait; and this circumstance, when taken in connection with a common geological structure, lends strong support to the view that the Kaikouras are the dissevered ends of the North Island divide, which end abruptly at Cook Strait.

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i. Bell and Clarke, Bulletin No. 8 (New Series), N.Z. Geol. Survey, Gov. Printer, Wellington, 1909, p. 48.

j. F. W. Hutton, "Sketch of the Geology of New Zealand," Quart. Jour. Geol. Soc., London, May, 1885.

k. Edward Suess, "The Face of the Earth," English translation, vol. ii., 1906, p. 147.

l. F. von Hochstetter, "Geologie von Neu Seeland," p. 197.

The central portion of the North Island is occupied by an elevated volcanic plateau, from which rise the intermittent volcanoes Ruapehu, Ngauruhoe, and Tongariro. Besides these, with the notable exception of the beautiful isolated cone of Mount Egmont, that stands at the south-west angle of Taranaki, there is no other mountain of note in this Island.

The main divide, in the provincial districts of Wellington, Hawke's Bay, and Auckland, is flanked by extensive alluvial plains reclaimed from the sea.

The South Island is about 500 miles long, and except at the north-east and south-west corners, where it is deeply indented, its outline is comparatively uniform and unbroken, the mean width of the northern half being 95 miles, and of the southern half 100 miles.

The dominant feature of this Island is the great alpine divide, which extends from Tasman Bay, in Nelson, to the fiord-land of Otago in an almost direct south-west course. It varies from 6,000ft. to 12,000ft. high, and forms a narrow, almost insurmountable barrier for a distance of 400 miles. For scores of miles together its crest is no wider than the ridge of a tent. It traverses the middle of the Province of Nelson, divides Canterbury from Westland, and ends at Mount Aspiring, in North Otago, where it breaks up into a number of high parallel ranges that trend southward and south-westward like the spread-out fingers of the hand. For nearly 200 miles of its course—that is, between Canterbury and Westland—it lies within 30 miles of the western sea.

Between the alpine divide of the South Island and the sea on the east side there are a number of more or less parallel mountain chains. These subsidiary ranges, like the Southern Alps itself, are composed of great crustal folds of Mesozoic and younger Palæozoic rocks, the domes of which have been deeply truncated.

The seaward and inland Kaikouras, in Marlborough, also lie parallel with the great divide, and are, as recognised by Hochstetter, the southern prolongation of the main divide of the North Island. They attain a height varying from 6,000ft. to 9,400ft., and are chiefly remarkable for their steep slopes and razor-back summits. The distance of the crest of the seaward range from that of the inland range varies from five to ten miles, the profile presenting the appearance of an inverted V. The Clarence Valley, which separates the ranges, is a deep V-shaped rift that has been shown by McKay to follow the line of a powerful fault, along the course of which Cretaceous and Tertiary beds are deeply involved.

To the south of the Kaikouras lies the Canterbury Plain, which forms a wide alluvial fringe following the coast-line for a distance of 75 miles.

Eastern Otago is occupied by the Barewood plateau, which is an uplifted base-level of erosion lying at a height of 2,000ft. above the sea. To the west and north of this ancient tableland, Central and Northern Otago are occupied by two groups of table-topped ranges that vary from 20 to 40 miles long, and maintain a height generally between 5,000ft. and 5,500ft. above the sea. The main group comprises five parallel ranges running north-east and south-west, the other three ranges running north-west and south-east—that is, at right angles to the first.

The ranges of the main group are separated from each other by deep flat-bottomed basins, athwart the ends of which lie the ranges of the smaller group. The basins vary from 500ft. to 1,000ft. above the sea, and are traversed along the foot of the ranges by powerful faults.

The author has elsewhere shown[m] that in these table-topped ranges we have a group of *block mountains* more remarkable than the *horsts* of the great basin between the Sierra Nevada and Wasatch Mountains, or those of the Vosges and Black Forest.

The basins enclosed by the *block mountains* were at one time the sites of lakes, but are now filled with lacustrine and fluviatile deposits, the former of which are deeply involved in the great fractures that run along the foot of the ranges. The fluviatile deposits are of glacial and post-glacial date, and rest on the upturned edges of the lacustrine series.

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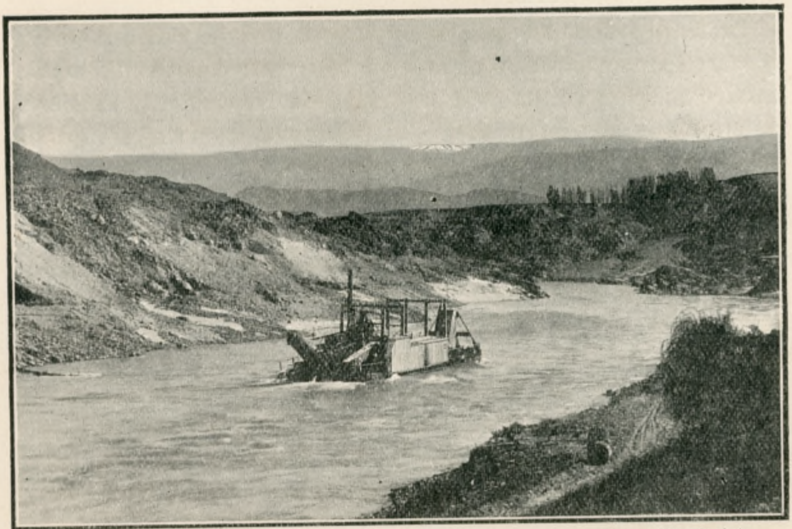
m. James Park, "The Geology of Alexandra District, Central Otago," Bulletin No. 2, N.Z. Geological Survey, 1907, p. 6.

The *block mountains* rise abruptly from the basins. They possess no descending spurs and no foothills, but commonly present a straight even slope that suggests the glacis of some gigantic earthwork. The plateau-form of the summits is independent of the character and disposition of the rocks. Thus, while the Garvie, Old Man, Dunstan, and Pisa ranges are composed of older Palæozoic mica-schist arranged in monoclinals, the Hawkdun Range, which runs athwart the Dunstans, is formed of Permo-triassic mudstone and greywacke disposed



Muir and Moody photo.

Fig. 2. Showing table-topped Carrick Range in the distance.

in a shallow synclinal, presenting a summit-line that for a distance of twenty-five miles is as even as the ridge of a house.

When we come to consider the origin of these table-topped ranges, the evidence seems to prove conclusively that they are the remains of an uplifted peneplain or base-level of erosion of great antiquity.

When first discussing the genesis of this remarkable group of *block mountains*, it seemed to present the fewer mechanical difficulties to conceive that the lake-basins were *graben* or strips of subsidence bounded by great faults, than to suppose that the sites of the basins remained stationary while the fringing block mountains were uplifted to their present height[n]. Since then McKay[o] has brought to the author's notice the occurrence of Miocene marine fossils in a bed near the base of the lacustrine series at Kyeburn, in the north-east corner of the Maniototo Basin, which dispels all difficulty in arriving at a satisfactory solution of this problem. It is obvious that the marine bed and the associated lacustrine beds must have been deposited at sea-level; and in this we have the proof that the *block mountains* are merely uplifted portions of a maritime *base-level* of erosion.

The basins formed by the uprising blocks soon became separated from the sea, and in them were deposited at first fine sediments, scarcely water-worn, and then coarser material as the gradually increasing height of the fringing mountains gave greater scope for denudation and fluviatile erosion.

New Zealand, as we have seen, is dominated by a N.E.-S.W. mountain system, which comprises the great alpine chain running from end to end of the South Island, the subordinate parallel chains in Canterbury, and the Kaikoura Ranges in Marlborough, the continuation of which north of Cook Strait forms the main divide of the North Island.

As recognised by Professor Gregory, the remains of a transverse mountain-system that ran N.W.-S.E. can still be traced in Auckland and Otago. The highland plateau and group of table-topped ranges in Eastern and Central Otago are believed to be the truncated stump of an ancient range, and running parallel with this we have the Auckland prolongation, which is a submerged mountain-block detached by the Cook Strait and Taupo dislocations.

The lakes of New Zealand fall into two groups—namely, those that owe their origin to volcanic agencies, and those that are valley-lakes. To the first group belongs the string of lakes situated in the central volcanic region of the North Island; to the latter, the cold lakes that flank the main alpine divide of the South Island.

The volcanic lakes are shallow, and fringed with hot springs, geysers, and fumaroles. The valley-lakes are for the most

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n. J. Park, "The Geology of Alexandra Subdivision," Bulletin No. 2, Geol. Survey, 1906, p. 7.

o. A. McKay, Repts. Geol. Expls., 1883-84, p. 64.

part deep, and occur in regions that were at one time overrun by great glaciers. They lie in rock-basins, and their depth is commonly increased by barriers of fluvio-glacial accumulations at their lower ends.

The deep fiords of South-west Otago, and the beautiful wooded sounds of Marlborough, fronting Cook Strait, are drowned valleys, partly of fluviatile and partly of glacial origin.

The two great river systems of the North Island are the Wanganui and Waikato, which rise together in the great volcanic plateau of Southern Auckland—the first flowing southward, the other northward.

The rivers on the east side of the main divide of the South Island do not always reach the sea by the shortest route, but radiate from the neighbourhood of Mount Cook to the north-east, east, and south-east. The Canterbury rivers are distinguished by broad, bare shingle-beds; those of Otago by the deep narrow channels they have cut in the mica-schist plateau; the rivers of Westland are short torrential streams.

Age of Main Physiographical Features.

The Moonlight Overthrust.—The marginal character of the Oamaru Series furnishes proof that the main land-forms of New Zealand had already been determined when that formation was deposited in the Miocene. This general statement is true of all parts of New Zealand except the mountainous region of Otago lying between Mount Aspiring and Lake Wakatipu, and the Ben Nevis range in Nelson. At Bob's Cove, on the north shore of that lake, there is a small patch of the Oamaru formation, the upper members of which have been tilted at a high angle and warped along their strike, so as to present the appearance of the letter S, while the lower conglomerates have been caught up in an overthrust fold of the mica-schist.

The involved band of fossiliferous Tertiaries varies from 14ft. to 150ft. thick, and can be traced over valley and mountain for a distance of twenty-five miles in a nearly north and south course.

The depth of the involvement is extraordinary. In the many deep transverse gorges that traverse the Moonlight and Shotover areas the Tertiary wedge can be traced from 1,400ft.

above the sea to 5,000ft., ascending and descending from mountain to gorge like a well-defined mineral lode, and showing a visible involvement of 3,600ft. But the mountain ranges bear evidence of intense glacial erosion, and the bottom of the wedge is not seen in even the deepest gorge; therefore the actual entanglement may very well be 4,000ft. or more[p].

The main significance of this deeply involved wedge of Tertiaries lies in the evidence it affords of the age of the mountains of Western Otago, for it is obvious that where the Richardson Mountains now stand there existed a sea-floor at the beginning of the Tertiary epoch. The constituent rocks and fossils of the marine band are such as would be deposited along the shore of a rocky strand. The enclosed schistose material and the littoral shells do not tell us whether the open sea lay to the east or west of the Richardson Mountains, or whether the beds were deposited in a long narrow fiord that afterwards became the axis of the overthrust fold in which they became involved.

Along the south side of the Waimea Plain, Nelson, the whole of the Miocene Tertiaries are turned over, being involved in an overturned fold of the Triassic rocks composing the Richmond Hills (see Figs. 16 and 18). Fuller reference to the involvement of the Tertiary strata at Wakatipu and Nelson will be found on p. 105.

Synopsis of Physiographic Features.

New Zealand consists of two main islands, separated by Cook Strait, and a number of small islands, all of which, with the exception of Stewart Island, lie at some distance from the mainland.

The South Island is excessively mountainous, being traversed by the Southern Alps, which lies close to the west coast throughout the greater portion of its length. The provincial district of Otago is occupied by a remarkable group of table-topped *block mountains* that are chiefly composed of older Palæozoic mica-schist, slaty schist, and argillite. Canterbury and the northern end of the Island are occupied by a jumble of subsidiary ranges, mainly composed of great folds of

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p. J. Park, "The Geology of Queenstown Subdivision," Bulletin No. 7 (New Series), N.Z. Geol. Survey, 1908.

older Mesozoic rocks. The most prominent of these subsidiary ranges are the two Kaikoura chains that run nearly parallel with the main divide, ending abruptly at Cook Strait.

The surface of the North Island is broken but not mountainous. It is diversified with wide stretches of coastal plains and broad valleys leading inland to a high central volcanic plateau, which is flanked on its eastern side by the main divide of the Island. This divide runs parallel with the east coast, and it is the geographical and geological continuation of the Kaikoura chains in the South Island.

The deep involvement of Miocene strata in Otago and Nelson proves that mountain-making on a gigantic scale took place as late as the mid-Tertiary.

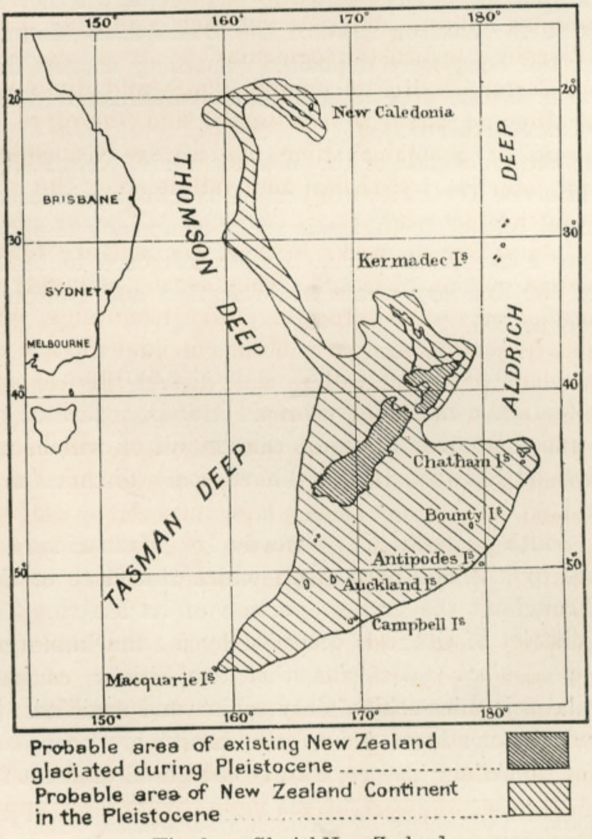

Fig. 2A. Glacial New Zealand.

CHAPTER II.

GENERAL GEOLOGICAL STRUCTURE.

Although so isolated and so small in area, New Zealand possesses a geological record even more complete and varied than the neighbouring Continent of Australia. And, as might be inferred, the structure is simple, and free from the complexities that distinguish the continental areas of the Northern Hemisphere, where the resistance of the greater mass to the travel of tangicial impulse more readily lent itself to the complex folding and shearing that commonly accompanied the overriding of crustal segments.

New Zealand, with its narrow limits and diminutive mass, could offer no effective resistance, and therefore since the beginning of geological time has always responded to the vagrant impulse by rising and falling like the unresisting waves of the open sea.

The oldest known rocks in New Zealand are found in the south-west portion of Otago. They consist of highly contorted gneiss and mica-schist, forming lofty mountains, whose bold outlines frequently present a blunt cuboidal form, a result due to the many profound valleys that dissect this region and the softening effect of glacial erosion.

On the west coast of Otago the valleys are submerged in the sea, forming a maze of deep, narrow fiords that for scores of miles wind in and out among high, unscalable ranges, fringed with a dense growth of forest vegetation, presenting a combination of maritime and mountain scenery of unequalled grandeur.

Wrapping round the gneissic rocks, but apparently intimately associated with them, is a succession of hornblende-schist, and mica-schist, alternating with subordinate bands of chlorite-schist, quartz-schist, and claystone.

From Fiordland the crystalline schists extend northward to Nelson forming the core of the main divide, now appearing on the western slope, and then disappearing under the great succession of Permo-Triassic claystone and sandstone that composes the greater part of this chain. In south-west Otago they are arranged in a simple anticlinal, whose axis runs north and south till the head of Doubtful Inlet is reached, beyond which it trends nearly north-east.

The geological structure of the alpine chain is remarkably uniform throughout, and of great simplicity, mainly consisting of a series of overturned folds.

North of Mount Aspiring the dip of the schists, as well as that of the overmantling formation of unaltered claystone and sandstone, is eastward, whereby we have the singular spectacle of a great alpine chain, consisting solely of the eastern wing of an anticlinal the western portion of which has been destroyed by denudation or submerged below the Pacific Ocean. It is at once obvious that the cause of the extreme narrowness of the crest of the main divide, to which reference has already been made, is due to the continuous high dip of the strata.

The schists are mostly confined to the western slopes of the main chain, but in a few places in Canterbury they form the crest of the divide itself, and even reach a few miles on to the eastern slope.

Eastern and Central Otago are occupied by a broad band of mica-schist and other altered sedimentaries arranged in a great anticlinal, the axis of which, from near Dunedin on the east coast to the Cromwell Basin, a distance of ninety miles, follows a north-west course, and thereafter a northerly course. These altered rocks consist of two well-marked divisions—the lower being highly altered and finely plicated mica-schist, in places intercalated with subordinate bands of chlorite-schist and quartz-schist; the upper, semi-metamorphic mica-schist, followed by phyllite and greywacke. The lower are the Maniototian and the upper the Kakanuian schists of Otago.

From the sea to the Maniototo Plain the anticlinal forms a wide flat truncated dome, exposing only the upper semi-altered Kakanuian; but in Central Otago it gathers itself into a narrow fold with steep sides, along the denuded axis of which there is presented to view a great thickness of the underlying Maniototian.

On both sides the Otago anticlinal is flanked by a great series of altered greywacke, claystone and greenstone-tuff intruded by massive sheets of serpentine and peridotite, and by dykes of granite, diorite, and norite. These rocks form the Te Anau formation, which in Southland and South Canterbury is in its turn flanked by claystones and sandstones of Juro-Triassic age.

In Canterbury and Nelson the great subsidiary ranges that descend from, or run parallel with, the axial divide, including the Kaikouras in Marlborough, are mainly composed of Permo-Jurassic mudstones and greywacke that spread eastward, arranged in a succession of deeply dissected folds.

These rocks extend across Cook Strait, and compose the main chain of the North Island. A core of the same formation underlies the pile of andesitic gold-bearing rocks of the Hauraki Peninsula, and forms the basement of the Auckland prolongation that stretches far to the northward.

Marginal marine deposits were laid down on the younger Cainozoic shores of New Zealand in the Cretaceous period. In the Older Eocene, during a period of elevation, these were largely destroyed, but remnants still exist in the coastal regions of Otago, Marlborough, Westland, Wellington, and North Auckland.

The Eocene Uplift.—Since the Eocene, New Zealand has been rising and sinking with singular regularity. The South Island, at the close of the Eocene, consisted of a long mountain-chain, with many descending ridges and outlying rocky islets. The watershed was so narrow that no large streams existed, while the subsidence that now began lessened the height of the dry land and correspondingly decreased the velocity and erosive power of the meteoric waters. Torrential streams were absent, and the denudation of the land relatively slow. Marine deposits were laid down on the floor of the open sea and in all the bays and deep indentations of the land. Everywhere the same conditions of quiet deposition existed. The molluscous fauna was rich and varied, many of the forms being of remarkable size, clearly proving the mildness of the climatic conditions and the abundance of food.

In the South Island marine deposition continued with only a small break from the close of the Eocene to the Older

Pliocene; and in the North Island, continuously from the Eocene to the close of the Pliocene.

The Pliocene Uplift.—The South Island began to rise towards the close of the Older Pliocene, and the North Island after the close of the Newer Pliocene. The uplift continued without interruption in the South Island until the Tertiary beds were raised to a height of over 3,500ft. above the sea, and in the North Island to 4,000ft. The beds rise from sea-level in a gently ascending sheet that clings to the higher flanks of the main divide in each Island.

This mantling sheet of Middle and younger Tertiaries rises an equal height on both the east and west flanks of the Ruahine and Kaimanawa Ranges, thus affording evidence of a uniform uplift along the main orographic axis of the North Island.

In the South Island the main divide lies closest to the west coast. On the east side the Tertiaries rise as a gently ascending plane, as they do in the North Island; but on the west side, where the slopes were steeper and the horizontal distance from the sea to the mountain-chains consequently shorter, the Tertiaries have been uplifted by a series of powerful faults that run parallel with the axis of the main chain. We have thus evidence that the uplift of the alpine axial divide of the South Island was differential, the movement which was relatively more rapid on the west side adjusting itself to the slower uplift on the east side by a series of parallel dislocations.

The Pleistocene Glaciation.—The uplift of the South Island, as we have seen, began at the close of the Older Pliocene, ushering in a period of refrigeration which became so intense that in the early Pleistocene nearly the whole Island was covered with an ice-sheet that in many places reached the sea on both coasts. This was the phase of maximum glaciation.

The widespread stony boulder-clay, the thousands of erratics, the perched blocks, the striated boulders, the polished and striated rock-surfaces, the deep rock-basins and tarns, the terraced and mammillated mountain-slopes, the outcrop bending of the rocks, the flowing contours, and dome-shaped mountains throughout the South Island, and the great andesitic glacial drift in the Rangitikei Valley in the North Island, all unite to prove the existence of a period of glaciation of no less intensity than that of Northern Europe.

There is satisfactory evidence that the thickness of the invading ice-sheet at the time of maximum refrigeration exceeded 7,000ft. in the Wakatipu lake-basin. The western slopes of the Richardson Mountains have been shorn by ice into broad, gently undulating rock-shelves that rise tier above tier to a height of 6,500ft. above the sea. Solitary erratics of granite and norite from Fiordland have been transported across the Humboldt and Richardson Ranges and dropped in the upper basins of the Arrow and Shotover, which are girt by a continuous mountain barrier rising from 6,500ft. to 7,500ft. above the sea.

The existence of beautifully polished and striated *roches moutonnées* of greywacke on the higher shoulders of Mount Rosa on the Mount Cook Range, at a height of nearly 6,000ft. above the sea, and more than 3,000ft. above the present surface of the Hooker glacier, affords convincing proof that the thickness of the ice-sheet in the alpine region of Canterbury during the epoch of maximum glaciation was not less but probably greater than in the Wakatipu region.

At the close of the Pleistocene there began a general subsidence, which was accompanied by a softening of the climatic conditions. The ice-sheet retreated southward, but left behind gigantic glaciers that maintained their position in the lower valley-basins for a considerable time, as shown by the vast moraines which they piled up at their terminal ends. This was the secondary or valley phase of glaciation.

The melting ice and snow made this a time of unparalleled fluviatile activity. The rivers draining the glaciers of Westland transported their load to the sea, forming the celebrated gold-bearing gravels of the West Coast; the Buller River, before its diversion to the western watershed, flowed into Golden Bay, near Nelson, and piled up the Moutere gravels that ascend from sea-level to the Hope Saddle; while the rivers draining the eastern slopes of the alpine chain formed the Canterbury and Southland plains, and filled up the old lake-basins of alpine Canterbury and Central Otago.

From their stronghold, at the entrance of the inland mountain-basins, the glaciers made two short sallies towards the lowlands, and then beat a precipitate retreat to the more sheltered recesses of the higher mountains, where the shrunken remains of the larger glaciers still survive, clinging to the flanks of the main divide. The smaller glaciers and those that took their rise in the valleys of the subsidiary ranges have long since disappeared.

The Late Pleistocene subsidence was followed by a general uplift of the northern half of the South Island, and of the southern portion of the North Island, during which the newly formed gravels were denuded and terraced as we now see them. This is the last land-movement of which we have any geological record.

Former Greater Extent of Land.

The investigations of the "Challenger" expedition have shown that New Zealand and its outlying islands are situated on a submarine platform, or shelf, that extends southward towards the Antarctic and north-westward towards the northern coast of Australia. On the south-west the ledge of the shelf coincides with the present coast-line. To the eastward the extent of the plateau is unknown.

The upper surface of the plateau lies from 300 to 600 fathoms below the level of the sea, while the depth of the surrounding ocean varies from 2,000 to 2,600 fathoms. An uplift of 1,000 fathoms would make an almost continuous bridge between New Zealand and New Guinea, and link the former with most of its outlying islands.

Sir Joseph Hooker,[q] as early as 1853, discussed at some length the probable former extension and land connections of New Zealand. In an essay "On the Physiognomy and Affinities of the New Zealand Flora," he stated that about two-thirds of the flowering plants are endemic. Of the remaining third, 193 species, or nearly one-fourth of the whole, are Australian; 89 species, or nearly one-eighth, are South

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q. Joseph Dalton Hooker, "The Botany of the Antarctic Voyage of the H.M. Discovery Ships 'Erebus' and 'Terror,' in the Years 1839-1843," 11, Flora Novæ-zealandiæ, Part I.

American; 60 species, or nearly one-twelfth, are European; and fifty species, or nearly one-sixteenth of the whole, are Antarctic forms.

Hooker argued that the affinities of the flora made it necessary to assume that there was at one time a land connection with Chile; at the same or another time with Australia; at a third, with the Antarctic; and at a fourth, with the Pacific. He did not contend for a continuous connection between any two of these regions, thinking that an intermediate land, as a common centre of dispersion, may have existed between New Zealand and Chile when neither of these was above water.

The absence of certain extensive groups of distinctively Australian plants in New Zealand seems opposed to the hypothesis of a direct land connection. This absence is conspicuous in the case of the *Eucalypti* and the great genus *Acacia*.

Similar difficulties oppose a former direct connection with South America. For, whereas the New Zealand mountain flora is Antarctic, and contains none that are peculiarly Arctic, the South American, besides Antarctic forms, contains many that are peculiarly northern and Arctic.

An investigation of the fauna throws no more light on the problem, and adds some perplexities. The land fauna of New Zealand is notoriously scanty, and does not include a single representative of the peculiarly Australian marsupials. The tuatara (*Sphenodon punctatum*), one of the few reptiles in the Dominion, belongs to an archaic type, and is without a living representative elsewhere. The struthious birds of New Zealand, Australia, and South America are closely related, and probably have a common ancestry; and almost all the land-birds show Malayan affinities.

Captain Hutton,[r] in a discussion "On the Geological History of New Zealand," contended for a Permian land connection with Australia and Tasmania; a middle Jurassic connection with a South Pacific continent, of which New Caledonia and New Guinea formed a part; an Eocene connection with a Malayan continent that was not connected with New Guinea or northern Australia; and a Pliocene connection

r. F. W. Hutton, Trans. N.Z. Inst., Vol. xxxii., 1899, p. 159.

with the Antarctic land which was not connected with Patagonia or South Africa. These views are confronted with the difficulty that the Miocene forest floras of Tasmania and New Zealand, consisting chiefly of oak, elm, alder, laurel, etc., were closely related, and must have had a common origin.

There seems good reason for the belief that during the Eocene uplift New Zealand, Tasmania, and Australia were joined to the Antarctic continent by continuous land connections; that during the Miocene submergence the land connections were broken; that during the Newer Pliocene uplift New Zealand was once more joined to the Antarctic continent which was now dissevered from Tasmania and Australia, but connected by land bridges or stepping-stones with South America and the Malayan continent. The subsidence that closed the Glacial period once more isolated New Zealand, and towards its close led to the disseverment of the North and South Islands.

During the Eocene uplift there came an invasion of plants and animals from the north, the descendants of which form the greater part of the existing fauna and flora. In the Pliocene invasion came the Antarctic and South American forms.

CHAPTER III.

DESCRIPTIVE GEOLOGY.

Grouping of the Rocks.

The investigation of the geological succession of the sedimentary rocks of New Zealand is attended with no little difficulty. The dense vegetation with which in many places the strata are covered at the line of junction, the lack of continuity in the sections, due to the great denudation which the land has suffered, and the absence of clear sections in those situations where the relationship of the rocks is involved in obscurity, present numerous, and in many instances insuperable, difficulties to accurate observation.

The differences that exist between the views of Captain Hutton and those of the author relate chiefly to the grouping of the Secondary strata and to the stratigraphical succession of the Tertiaries; and between those of Hector and McKay and the author to the existence of the so-called Cretaceo-Tertiary formation. The author's work for many years has been chiefly directed to the investigation of the problems involved in these differences. On the broader matter of the stratigraphical succession there is now practical agreement, except on one or two minor points.

In attempting to group the sedimentary rocks of a country so remote as New Zealand from the regions where the geological record was first established, we are compelled to consider, firstly, what evidence there is of parallelism in the fossil life of the two hemispheres up to the time that extreme differentiation became apparent in the Eocene; and, secondly, what evidence there is of synchronism in these parallel groups of life. Obviously there may exist homotaxial parallelism without synchronal agreement.

The evidence on the first point proves overwhelmingly that the progressive succession of life from the primitive up to the more highly developed forms followed the same order in New Zealand as in Europe, the distinctive genera appearing and disappearing in the well-established order, as will be shown in the sequel. The constant association of certain genera is as conspicuous in the Dominion as in the Northern Hemisphere, being apparently controlled by some subtle principle of *paragenesis,* the secret of which Nature seems to guard with jealous care.

The evidence bearing on the synchronism of the parallel groups of life is necessarily scanty. In any case, the investigation is one that must encounter peculiar difficulties when dealing with an isolated oceanic area like New Zealand. There is, however, some reason for the belief that there existed a synchronous parallelism of life in both hemispheres—that is, in corresponding biological provinces and bathymetrical horizons—up till the advent of the Cainozoic. At any rate, the almost continuous succession of fossiliferous formations found in Europe and New Zealand does not leave much room for chronological divergence. In applying European time-names against our New Zealand place names of formations we are pursuing a course that does not seem to be inconsistent with the facts relating to the distribution of life throughout geological time.

The stratified rocks of New Zealand seem to arrange themselves into seven systems, the constituent formations of which exhibit a considerable relationship to each other. In the Palæozoic we have two great systems; in the Mesozoic two, and in the Cainozoic three, as under:—

Palæozoic	1. Manapouri system	...	26,000 feet.
	2. Te Anau system	...	12,000 ,,
Mesozoic	3. Hokonui system	...	27,500 ,,
	4. Amuri system	...	3,000 ,,
Cainozoic	5. Karamea system	...	5,500 ,,
	6. Wanganui system	...	1,500 ,,
	7. Glacial period	...	2,000 ,,

The main subdivisions of these systems are shown in the following table of sedimentary formations:—

TABLE OF SEDIMENTARY FORMATIONS OF NEW ZEALAND.

Systems.	Series.	Probable Age.
Recent ...	River alluvium, drifting sand ... Beach sands and gravel ...	Recent.
Pleistocene	Raised beaches ... ... Older gravel drifts ... ... Newer moraines ... ... Older moraines ... ... Boulder-clays and eskar drifts	Pleistocene
Wanganui system	(*a.*) Petane Series	Newer Pliocene.
	(*b.*) Waitotara Series ... (*c.*) Awatere Series	Older Pliocene.
Karamea system	(*a.*) Oamaru Series	Miocene.
	(*b.*) Waimangaroa Series ...	Eocene.
Amuri system	Waipara Series	Cretaceous.
Hokonui system	(*a.*) Mataura Series ... ... (*b.*) Putataka Series	Jurassic.
	(*c.*) Otapiri series ... ... (*d.*) Wairoa Series	Triassic.
	(*e.*) Kaihiku Series ... ... (*f.*) Aorangi Series	Permian.
Te Anau system	(*a.*) Maitai Series ... ... (*b.*) Te Anau Series	Carboniferous.
Manapouri System	(*a.*) Wangapeka Series ...	Silurian.
	(*b.*) Kakanui Series	Ordovician.
	(*c.*) Maniototo Series ...	Cambrian.

Synopsis of Geological Structure.

Geologically considered, New Zealand is the remnant of a submerged continent of great antiquity. It contains representatives of almost every rock-formation found in the Northern Hemisphere; but with our present meagre knowledge of the fossil fauna and flora, it is impossible to draw a close parallel with the strata of these far-off lands.

The core of the main alpine divide of the South Island is a complex of metamorphic and semi-metamorphic rocks that spread out like a fan going southward until they embrace the greater part of Otago.

These are the oldest rocks in New Zealand, and they may be conveniently divided into three groups or divisions, comprising the greater portion of what has been termed the Manapouri system as under:—

Manapouri System.
1. Kakanuian—Slaty schist, phyllite, and limestone.
2. Upper Maniototian—Mica-schist, with bands of chlorite-schist, and quartz-schist.
3. Lower Maniototian—Gneiss, granulite, crystalline schists, and limestone.

The Kakanuian contains Ordovician graptolites, and is followed by argillites, quartzites, and limestones with Silurian fossils.

Lying in wide folds of the metamorphic rocks in Otago and Nelson there is a pile of greywacke, argillite, greenstone-tuff, and conglomerate comprising the Te Anau system of probably Carboniferous age. Wherever it occurs it is significant that this great and distinctive formation is associated with vast masses of magnesian igneous rocks, chiefly serpentine and peridotite.

The axial divide and the subsidiary ranges of the South Island, as well as the main mountain-chains of the North Island, are composed of a pile of fluvio-marine claystone, sandstone, and conglomerate comprising the Hokonui system that, like the Gondwana and great Karroo, ranges in age from the Permian to the Jurassic.

On the east coast of the South Island, and on both coasts of the North Island there are isolated stretches of Cretaceous rocks; and around the shores of both Islands there exist extensive marginal deposits of lower and middle Tertiary date, beginning with terrestrial beds, and ending with marine limestones. The terrestrial beds of this formation are the chief coal-measures of New Zealand, containing valuable seams of bituminous and brown coal.

In the central region around Cook Strait there occur considerable marine deposits—marginal in distribution—ranging in age from Miocene to Newer Pliocene.

During the Pleistocene, or Glacial period, the greater portion of the South Island was covered with an almost continuous ice-sheet that reached to the sea on both coasts, in places exceeding a thickness of 7,000ft. There was also extensive glaciation in the south end of the North Island.

In the sand-dunes, swamps, and cave deposits that have accumulated since the recession of the ice-sheet are found the remains of several genera of flightless birds, including the *Harpagornis, Cnemiornis, Aptornis,* and the gigantic *Dinornis.*

The rocks of the Manapouri system have been intruded by masses of granite, syenite, norite, and diorite; and by later dykes of serpentine, peridotite, dolerite, basalt, diabase, hornblende-lamprophyre, etc.

The Te Anau system, which includes the Maitai Series, is especially distinguished by the presence of gigantic sills or sheets of serpentine, peridotite, saxonite, and related ultra-basic rocks, as well as by intercalated beds of red and green tuff that are never very thick but are rendered conspicuous by reason of their colour and hard resistant character.

The Hokonui System, extending in age from the Permian to the Jurassic, contains no trace of contemporaneous volcanic activity. The dykes that ramify the system in Southland, Marlborough, East Coast of Wellington, and Hauraki Goldfields were probably intruded in early Tertiary times.

The volcanic activity which began in the Upper Cretaceous epoch has continued with little cessation up to the present day.

CHAPTER IV.

MANAPOURI SYSTEM.

(*a.*) Wangapeka Series.
(*b.*) Kakanui Series.
(*c.*) Maniototo Series.

Classification.—Hector[s], in 1886, divided the crystalline schists of Fiordland into two divisions, the lower consisting of contorted gneiss of unknown age, the upper comprising a series of mica-schist, hornblende-schist, clay-slate, and granular limestone of probably Devonian age. The foliated mica-schists of Central Otago he thought were chiefly altered Silurian rocks, or even those of formations as young as Lower Carboniferous.[t]

Hutton,[u] in 1885, grouped all the crystalline schists of Fiordland in his Manapouri System of pre-Cambrian age, the foliated schists of Central Otago being referred to his Wanaka Series of Ordovician date. In 1889 he abandoned his Manapouri System, believing that the rocks he had formerly ascribed to it belonged to his Wanaka System, which he now referred to the pre-Cambrian period.[v]

It should be noted that as early as 1879 Haast[w] had expressed the belief that Hutton's Wanaka formation was simply the upper portion of the Manapouri formation, and that both ought to be united—a course that, as we have just seen, was followed by Hutton ten years after.

In 1906, and in the two following years, the author referred the highly metamorphic foliated schists of Central Otago to the Maniototo Series[x], and the conformably overlying mica-schist, altered greywacke, clay-stones with graphite and

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s. J. Hector, "Outline of New Zealand Geology," 1886, p. 85.
t. J. Hector, *loc. cit.*, p. 83.
u. F. W. Hutton, "Sketch of the Geology of New Zealand," Quart. Jour. Geol. Soc., May, 1885, p. 191.
v. F. W. Hutton, Trans. N.Z. Inst., Vol. xxxii., 1899, p. 183.
w. J. von Haast, "Geology of Canterbury and Westland," 1879, p. 255.
x. J. Park, Bulletins Nos. 2, 5, and 7, N.Z. Geol. Survey, 1906, 1907, 1909.

probably graptolites, to the Kakanui Series. Later investigation in every way confirms the soundness of the judgment of Haast and Hutton in correlating the crystalline schists of Fiordland with the schists of Central Otago.

The foliated mica-schists of Central Otago and the crystalline schists of Fiordland are now included in the Maniototo formation, the name Maniototo being peculiarly related to the terrain of Central Otago, where these schists cover a greater continuous area than that of any other rock-formation in New Zealand.

The crystalline schists of Collingwood, in Nelson, can be traced southward along the flank of Mount Arthur to the Wangapeka, and thence continuously through Mount Owen, Lyell Mountains, Victoria Mountains, and along the base of the alpine divide into Northern Otago, where they expand to a width of forty miles, forming a band that bends eastward, reaching the sea near Dunedin. They have always been associated with the schists of Fiordland—an association which has been strengthened by the discovery of graptolites in closely related rocks both at Collingwood and at Preservation Inlet, in South-west Otago.

The classification that has been adopted for the Lower Palæozoic rocks of the South Island is as follows:—

Silurian—Wangapeka Series Ordovician—Kakanui Series Cambrian—Maniototo Series	} Manapouri System.

Maniototo Series.

Distribution.—This great formation is chiefly developed in Otago, Westland, and Nelson. In Otago it occupies an area of some twelve thousand square miles, of which seven thousand square miles are comprised in the broad band that stretches from the east coast to central and northern Otago, the remainder lying in the south-west angle of the province, in Fiordland, where it forms the mountainous region that lies between the Pacific Ocean and the western shores of Lake Te Anau.

In eastern Otago the band of schist is fifty miles wide, and trends first to the west and then to the north-west until it reaches the main divide, where the gradually steepening sides of the anticlinal have allowed it to gather itself into a narrow fold. This anticlinal forms the core of the alpine divide, appearing as a narrow band in the foothills of Westland. In the head-waters of the Grey it leaves the main divide, and pursues a nearly due-north course as far as Collingwood in Nelson, ending suddenly on the shores of Golden Bay, in Cook Strait.

The Maniototian also occupies a large portion of Stewart Island, but is unknown in the North Island.

Rocks.—The rocks in Fiordland consist chiefly of various gneisses, hornblende-schist, mica-schist, quartz-schist, and quartzite, with subordinate bands of chlorite-schist and granular limestone. With these are associated vein-granite, norite, diorite, and massive sheets, or dykes, of serpentine, dunite, and other ultra-basic igneous rocks.

The gneisses are described by Marshall[y] as containing little quartz, but much feldspar, some pyroxene, hornblende or biotite, and often garnet; while the hornblende-schists, in addition to hornblende (a pale-green variety) and quartz, contain oligoclase, brown mica, garnet, rutile, and sphene.

In the mineralized fahlbands interbedded with the schists at Dusky Sound, the author[z] found orthoclase, calcite, epidote, and tremolite associated with pyrrhotite and chalcopyrite, Many fine crystals of idocrase are also present in the schists.

The mica-schist of Central Otago consists almost exclusively of quartz and grey sericitic mica arranged in irregular laminæ. Rutile and plagioclase are nearly always present, and sometimes epidote resulting from the alteration of chlorite. In places where the laminæ are plicated and the quartz predominates the rock presents a gneissoid appearance; but where the mica predominates, or where the mica and quartz occur in paper-like laminæ, the rock is weak and friable, and possesses the grey silky lustre of a typical phyllite.

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y. P. Marshall, Trans. N.Z. Inst., Vol. xxxix., 1906, p. 498.
z. J. Park, Repts. of Geol. Expls. 188, 1887-88, p. 9.

The chlorite-schist occurs mostly in irregular bands that are often lens-shaped in transverse section[a]. An exaggerated lens which crosses the upper end of the Arrow Gorge widens out from 20 yards to 400 yards in a distance of a mile along the strike, and then thins out as rapidly.

The chlorite-schist consists chiefly of green chlorite, often epidotised, and quartz, with associated rutile, calcite, and magnetite. Its field occurrence and petrological character indicate that it is an altered basic lava or tuff of contemporary date, or an altered laccolitic intrusion.

The quartz-schists of the Maniototian frequently contain feathery, sheaf-like aggregates of pale-green amphibole, sometimes in such abundance as to form an amphibole-quartz-schist. In other places they are spotted with red garnets, and a red mica that is not related to lepidolite.

The mica-schist of eastern and central Otago, for many thousands of square miles, is singularly free from disturbance by igneous intrusions. In the mountains lying between the source of the Shotover and Mount Aspiring, and from there along the western side of the alpine divide to North Westland, the mica-schist and associated rocks are intruded by a few scattered dykes of hornblende-lamprophyre, some related to the camptonite and some to the monchiquite type of this group. Near Victoria Bridge, in the valley of the Springburn, a branch of the Kawarau River, there is a narrow dyke of serpentine[b]. At Waipiata the mica-schist is broken through and overspread by a great mass of dolerite, while in the maritime strip between the Waitaki and Clutha Rivers it is overlain by piles of basic and semi-basic lavas and tuffs of late Tertiary date.

In Westland the Maniototo Series is represented[c] by gneiss, mica-schist, chlorite-schist, phyllite, quartz-schist, and quartzite; in Nelson, by gneiss, mica-schist, and micaceous sandstones; and in Stewart Island, by gneiss and mica-schist, with which are associated masses of granite.

Origin of Schists.—The mica, hornblende, and various granitoid gneisses as well as the foliated granulite, amphibole

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a. J. Park, "Bulletin No. 7 (New Series)," N.Z. Geol. Survey, 1909, p. 55.
b. J. Park, "Bulletin No. 5 (New Series)," N.Z. Geol. Survey, 1908, p. 24.
c. J. M Bell and Colin Fraser, "Bulletin No. 1 (New Series)," N.Z. Geol. Survey, 1906, p. 43.

and chlorite-schists of the Maniototian are probably altered eruptives or tuffs of contemporaneous date, and as such would appear to be the oldest rocks of igneous origin known in New Zealand. Many of the mica-schists and quartz-schists are obviously altered sedimentaries.

Thickness.—Hutton[d], assuming a continuous westerly dip from the western shores of Lake Te Anau to the entrance of Thompson Sound, estimated the thickness of the crystalline schists at 160,000ft.; but Hector[e] showed that on this line the rocks are arranged in anticlinal and synclinal folds, thus reducing Hutton's estimate to less than 40,000ft.

Early in 1888 the author examined the section of these rocks extending from near the head of Dusky Sound to the Acheron Passage. In a distance of nine miles the average dip for six miles is 45°, and for the remaining three miles about 25°,

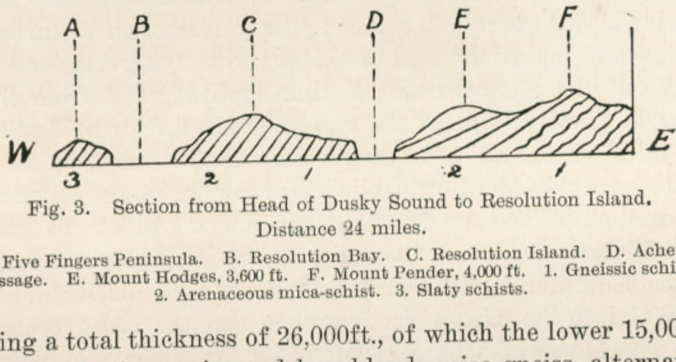

Fig. 3. Section from Head of Dusky Sound to Resolution Island. Distance 24 miles.

A. Five Fingers Peninsula. B. Resolution Bay. C. Resolution Island. D. Acheron Passage. E. Mount Hodges, 3,600 ft. F. Mount Pender, 4,000 ft. 1. Gneissic schists. 2. Arenaceous mica-schist. 3. Slaty schists.

giving a total thickness of 26,000ft., of which the lower 15,000ft. consists of mica-gneiss and hornblende mica-gneiss, alternating with bands of mica-schist and granular limestone; and the upper 11,000ft. of coarse arenaceous mica-schist, alternating with bands of mica-schist, quartz-schist, hornblende-schist, chlorite-schist, and granular limestone.

In this line of section the rocks are quite undisturbed by faults or igneous intrusions. On the west side of the Acheron Passage, across Resolution Island to the open sea, the dip of the schists and associated rocks is still westward, but it would not be safe to assume that this westerly dip exposes a further

d. F. W. Hutton, "Geology of Otago," 1875, p. 28.
e. J. Hector, "Reports of Geological Explorations," 1873-74, section facing p. vi.

thickness of strata, as the disposition of the rocks points to a repetition due to a fault running parallel with the Passage.

The thickness of the mica-schist in Central Otago was estimated by Hutton[f] at 100,000ft., but the author's recent investigations in that region tend to show that in the section from the Arrow to Shotover, relied on by Hutton, the continuously westerly dip is the result of overthrust folding[g], the actual thickness probably not exceeding 14,000ft. or 15,000ft.

Hector estimated the thickness of this formation in Nelson at from 15,000ft. to 18,000ft.

Age.—These rocks were ascribed by Hutton to the Laurentian[h] in 1875, to the Archæan[i] in 1885, and to the pre-Cambrian[j] in 1889. In 1876[k] Haast classified them as Azoic; while ten years later Hector[l] believed them to be metamorphic rocks of not very ancient date—probably Devonian. But nothing very certain was known about their age until the discovery of graptolites near Collingwood in 1882, and at Preservation Inlet in 1896 in certain slaty rocks belonging to the Aorere or Kakanui Series that immediately overlies them. The association of the Maniototian with the graptolite-bearing formation is so close that there is no reason to suppose that its age is older than Cambrian.

Economic Minerals.—Economically this has proved the most important metalliferous-bearing formation in New Zealand. Throughout central and western Otago, Westland, and Nelson, it is traversed by many small, somewhat irregular veins of gold-bearing quartz, the truncation of which by denudation has furnished the great bulk of the alluvial gold obtained in the South Island, amounting altogether to over £52,000,000, of which Otago has contributed some £23,000,000.

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f. F. W. Hutton, Quart. Jour. Geol. Soc. May, 1885, p. 199.

g. J. Park, "Geology of Queenstown Subdivision, Bulletin No. 7," p. 57.

h. F. W. Hutton, "Geology of Otago," 1875, p. 28.

i. F. W. Hutton, Quart. Jour. Geol. Soc., 1885, p. 194.

j. F. W. Hutton, Trans. N.Z. Inst., 1899, Vol. xxxii., p. 183.

k. J. von Haast, "Geology of Canterbury and Westland," 1876, p. 251.

l. J. Hector, "Outline of New Zealand Geology," 1886, p. 85.

Lodes of scheelite, antimony, cinnabar, and copper also occur in the Maniototian, but so far only the first has been profitably worked.

At Dusky Sound the schist contains highly mineralised zones, or fahlbands, containing pyrrhotite, chalcopyrite, pyrite, and a heavy black ferro-manganese ore.

At Stewart Island there is tin-stone; and at Collingwood tetrahedrite; while in connection with the peridotite eruptives at Milford Sound there are considerable deposits of bowenite, the valued *tengawai* of the Maori.

Kakanui (Aorere) Series.

Distribution.—This formation is developed along the flanks of the Maniototian anticlinal which tranverses eastern and central Otago. On the north-east side of the anticlinal it occupies a large tract in north Otago extending from Oamaru to the Upper Waitaki, in its course passing through the Kakanui, Kurow, and Hawkdun Ranges. On the south-west side it runs from Dunedin along the north boundary of Southland, forming a wide band that includes the Umbrella, Garvie, and Eyre Mountains. Further west it crosses the middle arm of Lake Wakatipu, and forms the main mass of the Richardson Mountains. It follows the crystalline schists along the alpine divide, and appears in the Sounds district of Marlborough and in the ranges between the Wairau River and Waimea Plain, where it covers a considerable area. It occurs at Collingwood, but on account of the close folding of the rocks in that area it is not easily distinguished from the underlying Maniototian and the overlying Wangapeka (Baton) Series.

It is probable that the arenaceous mica-schist and slaty rocks of Fiordland, so well seen in the Dusky Sound section, should be referred to the Kakanui formation.

Rocks.—In Otago and Southland the rocks of this formation are, for the most part, semi-metamorphic, consisting chiefly of arenaceous mica-schist, with occasional bands of clay-slate, schistose greywacke, argillaceous mica-schist, phyllite, quartzite, granular limestone, and graphitic slaty shales.

In Collingwood the prevailing rocks are slates, fissile greywacke, quartzite, and graphitic shales.

The Kakanui formation in Otago is quite conformable to, and passes insensibly into, the underlying Maniototian, the chief difference between the two formations being that the lower is more altered than the upper. They were first recognised as two formations by Hector[m] in 1866, and afterwards by Hutton[n] in 1875, and Haast[o] in 1876.

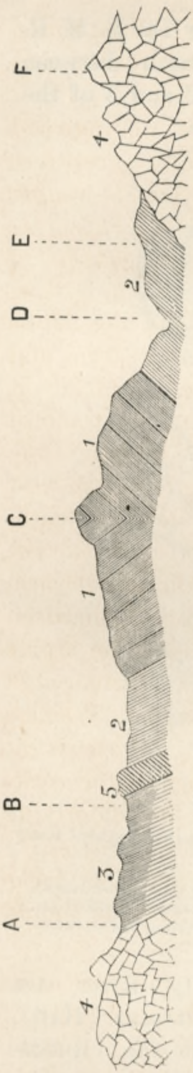

Fig. 4. Section from Gouland Downs to Mt. Olympus.

A. Head of Turimaiwiwi. B. Gouland Downs. C. Whakamarama Range. D. Aorere River. E. Quartz Ranges. F. Mount Olympus. 1. Indurated greywackes, alternating with slaty bands. 2. Alternating bands of quartoze sandstone and blue and black slates. 3. Grey quartzose sandstones. 4. Granite. 5. Band of syenitic gneiss.

The line of demarcation between the two series is quite arbitrary, but there is no difficulty in recognising them in the field.

Thickness.—In 1875 Hutton[p] estimated the thickness of this formation on the north-east wing of the Otago anticlinal, as seen in the Lindis section, at ten miles, or 52,800ft.; but the frequent changes of dip there do not afford much scope for trustworthy estimation. The thickness, as estimated by the author in the Kawarau-Remarkable section, is 12,500ft.; in the Mid-Wakatipu section, 14,000ft.; and in the Dusky Sound section, 13,000ft.

In the section between the source of the Turimawiwi and Mount Olympus, in Collingwood, there is exposed a thickness of not less than 14,000ft., the rocks being arranged in the form of a syncline, flanked on each side by granite, as shown in Fig. 4.

Age.—The graphitic slaty shales at Slaty River, Collingwood, have

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m. J. Hector, "New Zealand Exhibition Jurors' Reports," 1866, p. 203.
n. Hutton, "The Geology of Otago," 1875, p. 26.
o. Haast, "The Geology of Canterbury and Westland," 1876, p. 251.

yielded a large assemblage of graptolites, some of which Hutton[p] regarded as identical with forms found in the Ordovician of Victoria and New South Wales.

Hutton's identifications have been confirmed by Dr. E. M. R. Shakespear[q], who also states that the comparison between the New Zealand graptolites and those of beds 2 and 3 of the Deep Kill section in New York is especially close.

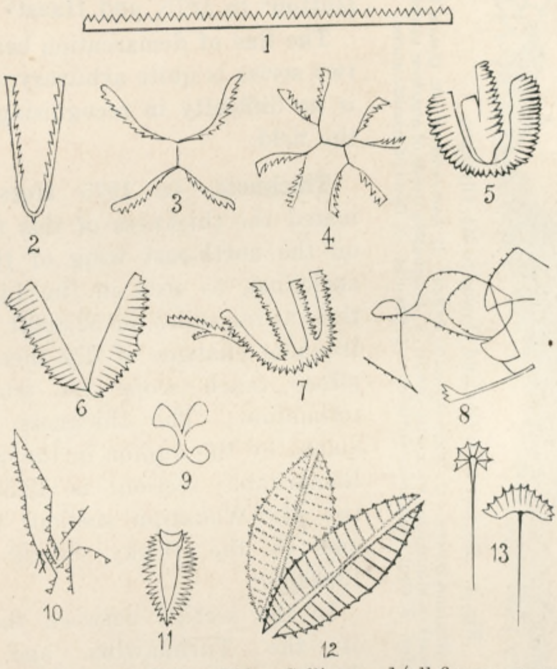

Fig. 5. Graptolites from Golden Ridge, Collingwood (all figures are natural size.) After Hector.

1. *Didymograptus extensus.* 2. *Loganograptus.* 3. *Tetragraptus quadribrachiatus.* 4. *Loganograptus octobrachiatus.* 5-7. *Didymograptus*, different stages. 8. *Rastrites.* 9. Genus doubtful. 10. *Rastrites* ? 11. *Phyllograptus* ? 12. *Phyllograptus typus.* 13. *Didymograptus caduceus.*

Among the more common forms at Slaty River are *Dichograptus octobrachiatus* (Hall), *Dichog. extensus* (Hall), *D. gibberculus* (Nicholson), *Goniograptus perflexilis* (Ruedemann), *Loganograptus Logani* (Hall), *Phyllograptus Anna* (Hall), *Didymograptus nanus* (Lapworth), *Tetrograptus Bigsbyi*

p. F. W. Hutton, Quart. Jour. Geol. Soc., xli., 1885, p. 199.
q. Ethel M. R. Shakespear, D.Sc., ''On Some New Zealand Graptolites,'' Geol. Mag., April, 1908, p. 148.

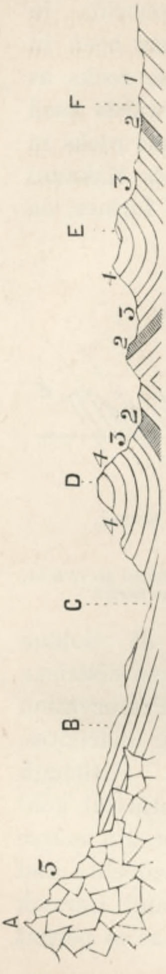

Fig. 6. Section from Mount Olympus to Gouland Downs.

A. Mount Olympus. B. Quartz Ranges. C. Aorere River. D. Brown Patch. E. Murray's Peak. F. Gouland Downs. 1. Grey quartzites. 2. Hornblende-gneiss. 3. Black graphitic slates, followed by blue and grey fissile slates. 4. Quartzites. 5. Granite.

(Hall), and *Tetrag.* cf. *pendens* (Elles), many of which are figured by Bell, Webb, and Clarke[r].

Indistinct remains of graptolites have been found in this formation at Gouland Downs[s], Collingwood, Wangapeka, and Preservation Inlet[t].

It is not unlikely that a search of the graphitic slates at Dusky Sound, Hawksburn, near Cromwell, and Chain Hills, near Dunedin, will result in further discoveries of this zoophyte.

The arrangement of the graptolite-bearing Kakanuian between Golden Ridge and the Gouland Downs is shown in Fig. 6.

The relationship of the Kakanui formation to the underlying Maniototian and overlying Te Anau Series is well seen in the section from Wakatipu to Fiordland (Fig. 7).

Nomenclature.—This is the Kakanui Series of Hector[u], the Tuamarina formation of Hutton[v], and the Waihao formation of Haast[w]. It is identical with the Walter and Cecil Peak Series of Hector[x]; in part, the Takaka System of Hutton[y] and Aorere Series of Hector[z], Cox[a], Park[b], Bell, and Fraser[c], and the "Kurow schist" of McKay[d].

r. Bulletin No. 3, Government Printer, Wellington, 1907, p. 37.
s. J. Park, Reports of Geol. Expl., 1888-89, p. 236.
t. A. McKay, Parliamentary Paper C.-11, 1896, p. 31.
u. Quart. Jour. Geol. Soc., 1865, p. 128.
v. Reports of Geol. Expl., 1872-73, p. 31.
w. "Geology of Canterbury and Westland," 1876, p. 251.
x. Reports of Geol. Expl., 1883-84, p. xv.
y. Quart. Jour. Geol. Soc., xli., p. 194; and Trans. N.Z. Inst., Vol. xxxii., p. 183.
z. Reports of Geol. Expl., 1883-84, p. xv.
a. Reports of Geol. Expl., 1882-83, p. 63.
b. Reports of Geol. Expl., 1888-89, p. 229.
c. "Bulletin No. 5 (New Series)," N.Z. Geol. Survey, p. 30.
d. Reports of Geol. Expl., 1881, p. 128.

Hutton[e], in 1875, suppressed the name Tuamarina in favour of Hector's place-name Kakanui, which has been in continuous use ever since 1865 to distinguish these rocks as they occur in Otago and Southland. Hector afterwards used the name Aorere for a local development of the same rocks in Collingwood. The selection lies between the names Kakanui and Aorere. The preference must be given to the former, on account of prior use and euphony.

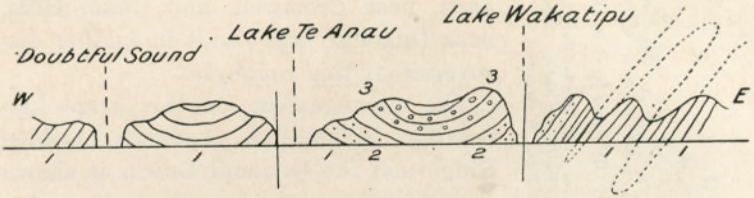

Fig. 7. Section from Richardson Mountains to Doubtful Sound. Distance seventy miles.

1. Maniototian Schists. 2. Kakanuian semi-metamorphic schists and altered greywacke. 3. Slates, slaty shales, greywacke, and greenstone tuffs of Te Anau Series.

Economic Minerals.—The gold-bearing veins at Golden Ridge, Quartz Ranges, Baton, Wangapeka, and Owen districts, in Nelson, Pelorus Sound, Carrick Range, and Preservation Inlet, are contained in graphitic shales, sandstones, quartzites, and schistose rocks belonging to this formation. Although the veins have not often proved profitable, the alluvial gold derived from their denudation has in some places been a source of rich returns for many years. Besides gold, scheelite and antimony have been found at Pelorus Sound and Carrick Range, in Central Otago, but not in such quantity as to permit a continuous output to be obtained.

Wangapeka Series.

In the Baton and Wangapeka Valleys, in the Mount Arthur district of Nelson, the Lower Palæozoic rocks can be divided into three series, all of which appear to be conformable to each other. The lowest, or Maniototo Series, consists of granular limestone, hornblende-gneiss, and hornblende-schist; the middle,

e. F. W. Hutton, "Geology of Otago," 1875, p. 34.

or Kakanui Series, of altered claystones, altered greywacke, quartz-schist, and graphitic slaty shales containing graptolites; and the upper, or Wangapeka Series, of calcareous slaty shales and sandstone, argillaceous limestones, and quartzites, the former containing an abundant marine fauna of Silurian age.

The relationship of these series is well seen in the Baton section, which is represented in Fig. 8.

In the Baton section the Ordovician (Kakanuian) and Silurian (Wangapekian) form part of a closely related succession of ancient sediments.

The absence of Silurian fossils in the Mount Olympus-Golden Ridge section makes the two series indistinguishable.

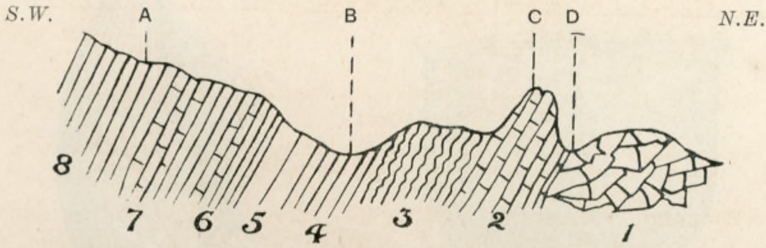

Fig. 8. Baton-Mount Arthur Section. Distance two miles.

A. Slopes of Mount Arthur. B. Upper Baton. C. Camelback. D. Baton River. 1. Granite, Maniototo Series. 2. Granular limestone, Maniototo Series. 3. Hornblende-gneiss, Maniototo Series. 4. Graphitic slates and quartz-schist, Kakanui Series. 5. Blue slates, fissile sandstone, and quartzite, Kakanui Series. 6. Calcareous slaty shales with fossils, Wangapeka Series. 7. Argillaceous limestone with fossils, Wangapeka Series. 8. Quartzites, schistose greywackes, Wangapeka Series.

It is, however, almost certain that the rocks ascribed to the upper part of the Kakanui Series in that area belong to the Wangapeka Series.

Rocks of Silurian age are represented in the Reefton district by fossiliferous slaty shales, limestones, and cherty quartzites and quartz-schists; but no rocks of this date are known to the south of this.

Age.—In a collection of fossils from the Baton River McKay[f] identified the following forms: *Calymene Blumenbachii, Homalonotus Knightii, Orthoceras* sp., *Murchisonia terebralis, Avicula lamnoniensis, Pterinea spinosa, Spirifera radiata, Rhynchonella*

f. A. McKay, Reports of Geol. Expl., 1877-78, p. 126.

Wilsoni, Stricklandia lyrata, Atrypa seticularis, Orthis sp., *Strophomena corrugatella, Chonetes striatella,* many corals and corallines.

Besides these the author collected at the same place[g], in 1883, *Orthis,* 4 sp., *Strophomena,* 3 sp., *Rhynchonella,* 4 sp., and *Spirifera,* 2 sp. In addition to many forms found at the Baton, the Lanky Gully beds at Reefton contain *Spirifera vespertilio* and *Homalonotus expansus*[h].

Hector always classified the Reefton beds as Devonian, and the Baton beds as Upper Silurian; while Hutton, with whom the author agrees, referred both to the Silurian. The number

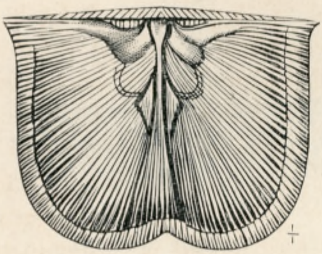

Fig. 9. *Strophomena*, sp. ?, from Baton River.

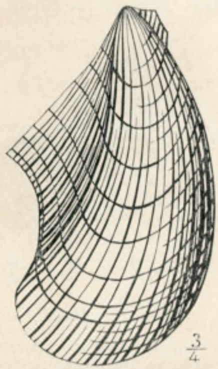

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Fig. 10. *Avicula*, sp. ?, Reefton Beds.

of fossils common to the two places and the correspondence of the succession of rocks do not seem to warrant their separation.

Thickness.—In their estimates of the thickness of the Kakanui (Aorere) Series, Hutton and others include the rocks now referred to the Wangapeka Series, which is the equivalent of the Baton Series of Hector[i]. The separation of the Kakanui and Wangapeka Series is made on palæontological grounds, and is quite arbitrary.

Nomenclature.—This formation is well developed in the valleys of the Wangapeka and Baton Rivers, which are only

g. J. Park, "On the Older Fossiliferous Rocks in Nelson," Rep. Geol. Expl. 1885, p. 178.
h. J. Hector, Trans. N.Z. Inst., Vol. ix., p. 602.
i. J. Hector, "Outline of New Zealand Geology," 1886, p. 40.

a few miles apart, both rising on the south-east slopes of Mount Arthur Range. It is generally conceded by New Zealand geologists that the chief formations should be distinguished by Maori names, and for that reason the Saxon name Baton has been suppressed in favour of the Maori place-name Wangapeka.

Igneous Rocks of Manapouri System.

Acidic Intrusives.—The mica-schist of Stewart Island belonging to the upper division of the Maniototian is intruded by a grey granite; and at Rugged Point there is an acidic mass described by Marshall[j] as being on the border-line between a graphic granite and a granophye. The slaty shales of the Wangapeka formation are intruded at Preservation Inlet by a coarse-grained pink granite[k]. Granulites are of frequent occurrence in Fiordland. They have been described by Marshall[l] at Dusky and Breaksea Sounds. The banded granulite at the entrance of Milford Sound is probably the eurite of Hutton[m] and Hector[n].

Fig. 11. A Eurite vein, Milford Sound. (After Hector.)

In North Westland[o], the gneissoid and associated schists are cut by dykes and irregular veins of pegmatite and aplite. The prevailing rocks are granite and granitite, which may be either porphyritic or granitoid in texture.

The acidic plutonic rocks of this system extend northward along the main divide into Nelson. They are mainly granite varying in colour from pink to grey; the latter predominating, and often intruded by veins of pegmatite.

In places they contain tourmaline[p]; and at Separation Point where the porphyritic texture is strongly marked, they carry a

j. P. Marshall, Trans. N.Z. Inst., vol. xxxix., 1906, p. 499.

k. A. McKay, Papers and Reports Relating to Mineral and Mines, 1896, C. 11, p. 35.

l. P. Marshall, Proc. Aust. Ass. Ad. Sc., vol. xxii., 1907.

m. F. W. Hutton, Quart. Jour. Geol. Soc., xli., 1885, p. 215.

n. J. Hector, "Outline of New Zealand Geology," 1886, p. 85.

o. J. M. Bell and Colin Fraser, "Bulletin No. 1 (New Series)," N.Z. Geol. Survey, 1906, pp. 61-64.

p. S. Herbert Cox, Repts. of Geol. Expls., 1874-76, p. 71.

great deal of sphene[q]. At Clark's Creek[r], in Collingwood, the granite has invaded the slates of the Kakanuian as thin parallel sheets running along the bedding planes as shown in Fig. 12.

At Waikaromumu, in the Takaka Valley, the intruding granite has broken off and enclosed large flaggy masses of granular limestone[s].

Besides true granites and granitites, the crystalline schists and argillites of Collingwood are invaded by syenites, often possessing a marked porphyritic structure, and by porphyries[t].

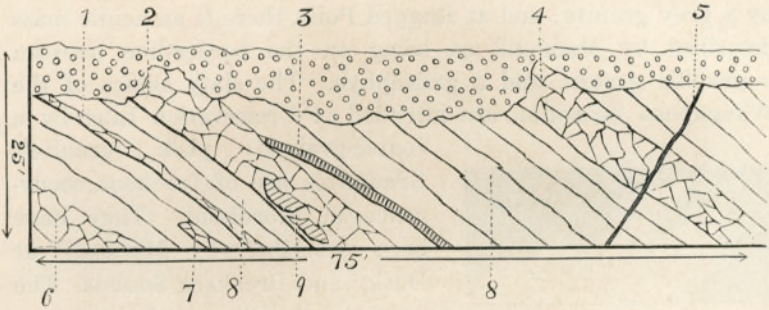

Fig. 12. Slates invaded by granite dykes.

Date of Acid Intrusions.—The first appearance of granites as detrital material is in the conglomerites of about Permian age, near the base of the Hokonui System. This places the date of the intrusion of the various granites as lying between the Cambrian and Permian.

Basic Intrusions.—At Bluff Hill and Round Hill, Orepuki, in Southland, the argillites of the Wangapeka formation are intruded by masses of norite[u]; and in the Darran Mountains, lying east of Milford Sound, there is a mass of mica-norite[v].

Ice-borne boulders of norite and hornblende-diorite[w] are abundant in the stony boulder-clay around Queenstown; and

q. P. Marshall, Proc. Aust. Ass. Adv. Sc., vol. xiii., 1907.
r. J. Park, Repts. Geol. Explts., 1888-89, p. 209.
s. J. Park, *loc. cit.*, p. 223.
t. J. M. Bell, E. I. H. Webb, and E. de Courcy Clarke, "Bulletin No. 3 (New Series)," N.Z. Geol. Survey, 1907, p. 72.
u. F. W. Hutton, Jour. Roy. Soc., N.S.W., Aug., 1889, p. 128.
v. P. Marshall, Trans. N.Z. Inst., vol. xxxix., p. 499.
w. J. Park, "Bulletin No. 7 (New Series)," N.Z. Geol. Survey, 1908, Chap. vii.

judging from the associated rocks and direction of flow of the ice they appear to have come from the head of the Eglinton on the Te Anau watershed.

At Anita Bay, Milford Sound, there is a boss of peridotite mainly dunite, with which is associated a fresh hartzbergite[x], in portions of which magnesite completely replaces the enstatite, imparting to the rock a marble-like appearance. Much of the dunite is altered to serpentine, and to *tengawai,* a variety of greenstone well known to the ancient Maori.

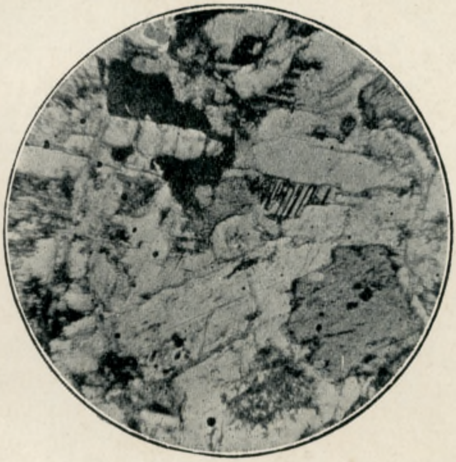

Fig. 13. Norite.

At the head of the Springburn[y], a branch of the Kawarau, draining the south-east slopes of Mount Allen, the mica-schist is intruded by a dyke of peridotite that is completely altered to serpentine. The alteration of the rocks in the contact-zone is very marked, the schist being hardened by silicification and impregnated with secondary actinolite and biotite.

Another development of magnesian igneous rock of much interest and economic importance has been described by Bell and Fraser in North Westland[z]. In the area lying between

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x. P. Marshall, Trans. N.Z. Inst., vol. xxxvii., 1904, p. 483.

y. J. Park, "Bulletin No. 5 (New Series)," N.Z. Geol. Survey, 1908, p. 29.

z. J. M. Bell and Colin Fraser, "Geol. of Hokitika Subdivision," "Bulletin No. 1 (New Series)," N.Z. Geol. Survey, 1906, p. 67.

the Arahura and Teramakau rivers there is a band of schist containing several sheet-like masses of foliated serpentine and peridotite rock passing in places into nephrite—the well-known *pounamu* (greenstone) of the Maori. The serpentine and related rocks occur as intercalated sheets following the bedding planes of the altered sedimentaries in which they occur; but whether they are intrusive sills, or only altered contemporary

Fig. 14. Hornblende-lamprophyre, Shotover River.

ultra-basic magnesian lavas has not yet been determined. The enclosing rocks are mica-schist, amphibole-schist, and phyllites that should probably be referred to the middle of the Manapouri System.

Ultra-basic magnesian rocks occur as sills in the crystalline schists of Collingwood, within the watershed of the Parapara River and Campbell Creek. They consist of talc-rock and serpentine, the alteration products of peridotite. The serpentine is supposed to belong to the variety known as antigorite[a]; In places the serpentines contain so much calcite that they become ophicalcites.

Of the other basic and semi-basic intrusions there are narrow dykes of hornblende-lamprophyre and tinguaite cutting the schists along the alpine divide, from the source of the Shotover[b] to North Westland[c].

In Otago there are among the lamprophyres varieties that are related to the camptonite and monchiquite types. In the Shotover area there are dykes of olivine-basalt and hornblende porphyrite; and in North Westland, besides various lamprophyres there are present hornblende-porphyrite; phroxene-porphyrite, diabase, and augite-diorite[d].

Date of Basic Intrusions.—Of the four developments of magnesian igneous rocks which have been described as occurring at Springburn, Milford Sound, North Westland, and Collingwood, none is known to pass into the overlying formation; and what is perhaps more singular is the absence of dunite or serpentine in the detritus of the Upper Palæozoic, and Mesozoic

Fig. 15. Section near Pilot Station, Bluff Peninsula.

1. Norite. 2. Black siliceous slates of Kakanuian.

formations. No trace of these rocks is met with in detrital form until the lower Tertiary is reached. At present there is no data available to fix the date of intrusion even approximately; but it should be noted that no trace of the basalts, lamprophyres and related rocks occurs even in the conglomerates at the base of the Oamaru formation, a circumstance that would

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a. J. M. Bell, E. I. H. Webb, and E. de C. Clarke, "Bulletin No. 3 (New Series)," N.Z. Geol. Survey, 1907, p. 66.

b. J. Park, "Bulletins Nos. 5 and 7," N.Z. Geol. Survey, 1907-08.

c. J. M. Bell and Colin Fraser, "Bulletin No. 3," 1906, p. 82; and J. H. Smith, Trans. N.Z. Inst., vol. xl., p. 122.

d. J. M. Bell and Colin Fraser, *loc. cit.* p. 82.

indicate that the intrusions have taken place since the mid-Tertiary.

The diorites and granites of Otago and Nelson are well represented among the material in the Permian and Jurassic conglomerates of the Hokonui System, thus fixing the date of their eruption as some time pre-Permian.

At Bluff Hill the norite has intruded argillites that belong to Kakanuian, or middle, series of the Manapouri System. The granites generally penetrate the lower series. In all probability the intrusion of the diorites and norites succeeded that of the granite.

CHAPTER V.

TE ANAU SYSTEM.

(*a.*) Maitai Series.
(*b.*) Te Anau Series.

This system occurs on both sides of the Otago anticlinal, forming the main mass of the Takitimu and Longwood ranges, in Southland, besides occupying a large tract of the mountainous country lying between Lake Wakatipu and Lake Te Anau. In Otago it is present in both the Kakanui and Kurow mountains.

In the Provincial District of Nelson it overlies the Wangapeka Series on the north-east side of Mount Arthur, and flanks the dunite and serpentine band which follows the divide between the Waimea and Wairau river-systems.

Te Anau Series.

Rocks.—The prevailing rocks of this formation are alternating slaty shales and greywacke, the latter varying from fine to coarse in texture, and from pale-green to mottled red and green in colour. The slaty shales are grey, blue, or green, and interbedded with narrow bands of red or purple jasperoid shale. With the greywacke are commonly associated beds of conglomerate and greenstone-tuff.

Disposition of Strata.—In Otago the rocks of this series lie in two synclinal folds, one on each side of the great anticlinal of the Maniototian, the succession of formations on each side being Maniototian, Kakanuian, Te Anauian. The Wangapeka Series is not present, or, if present, is represented by rocks that in the absence of fossils are not distinguishable from those of the Kakanuian.

In Collingwood the Te Anau and associated Maitai rocks are arranged in a simple synclinal fold, flanked on each side by the Kakanuian.

Thickness.—Perhaps the clearest and most continuous section of the Te Anau and related Maitai Series is that lying between Slate River Peak and Boulder Lake, in Collingwood, where in a distance of two miles there is exposed a total thickness of some 12,000ft. of strata.

Contemporaneous Igneous Rocks.—The most distinctive feature of this formation, and the one that is always a certain proof of its identity wherever it is found, is the presence of thick masses of a greenstone-tuff, both fine-grained and coarse-grained, that occurs intercalated with the greywacke. This tuff is the well-known "aphanite breccia" of the Geological Survey; and is unknown in any other Palæozoic formation in New Zealand. It is largely developed in the valleys of the Greenstone and Routeburn, on the west side of Lake Wakatipu; in Long Ridge, Southland; and in various parts of Nelson and Marlborough.

The intercalated igneous material in this series is mainly, or wholly, of a fragmentary character, being the production of subaqueous eruptions.

Age.—The Te Anau Series contains no internal evidence of its age, but at Mount Arthur it overlies unconformably the Wangapeka Series, containing Silurian fossils; and in the Nelson area is followed by the fossiliferous limestone of the Carboniferous Maitai Series.

In the Humboldt Mountains, west of Lake Wakatipu, the Te Anau rocks lie apparently unconformably on the Kakanuian; and further north, behind Mount Cosmos, abut against the silvery-grey mica-schist of the Maniototian, the line of demarcation being a powerful fault, which runs nearly due north and south. It is along this line of dislocation that the serpentine and olivine rocks generally occur[e].

In the Collingwood district the rocks of the Te Anau and Kakanui Series form what appears to be an unbroken stratigraphical succession of strata[f], the basement bed of the Te Anau Series being a coarse conglomerate lying directly on the graptolite-bearing shales of the Ordovician Kakanuian.

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e. J. Park, Reports of Geol. Expls., 1886-87, p. 137.

f. J. Park, Reports of Geol. Expls., 1886-87, p. 257; and Bell, Webb, and Clarke, "Bulletin No. 3 (New Series)," N.Z. Geol. Survey, 1907, p. 46.

On the south side of the Dun Mountain range on the west side of Lake Wakatipu, the rocks of the Kakanuian pass insensibly into the overlying Te Anauian. The separation of the two formations is mainly based on lithological grounds.

At first Hector referred the Te Anau Series to the Lower Mesozoic[g], and afterwards to the Devonian[h]. On the other hand Hutton placed it first in the Carboniferous[i], and then suppressed[j] it altogether by attaching it to the Maitai formation. The evidence as to the separate existence of the Te Anau and Maitai formations is far from satisfactory. At present the author agrees with Hutton that they are identical, or in part the upper and lower members of the same formation.

The name Te Anau is now used to designate the great succession of related strata of which the Maitai Series is the upper portion.

Maitai Series.

Distribution.—This formation is typically developed in the Nelson area, where it lies on the north-west side of the olivine mineral belt forming the higher foothills fronting the Waimea Plain. As distinguished from the Te Anau Series, it has not been identified in any other part of New Zealand, except as the upper part of that formation.

Rocks.—The rocks consist of alternating slaty shales and greywacke intercalated with beds of greenstone-tuff. The slaty shales are chiefly grey, blue, green, and red in colour; and the greywacke pale-green and grey, or mottled red and grey.

Near the base of the series there is a band of bluish-grey limestone that is over 1,000ft. thick in the Maitai Valley, but rapidly thins out going south-westward, finally disappearing a few miles south of the Wairoa River.

Disposition of Strata.—The strata are arranged in the form of a syncline, the limestone on the Waimea side being the lowest, or nearly the lowest, rock exposed in Nelson. On the Waimea side the syncline is bounded by a fault against which the

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g. J. Hector, Quart. Jour. Geol. Soc., 1864, p. 128.
h. J. Hector, "Outline of New Zealand Geology," 1886, p. 40.
i. F. W. Hutton, Quart. Jour. Geol. Soc., Vol. xli., 1885, p. 194.
j. F. W. Hutton, Trans. N.Z. Inst., Vol. xxxii., 1899, p. 183.

fossiliferous Lower Mesozoic rocks of the next formation abut abruptly; while on the opposite, or Dun Mountain, side the limestone is in contact with the serpentine of the "mineral belt," or separated from it, in places, by a band of coarse friction-breccia. The arrangement of the beds, and their relationship to the serpentine and Lower Mesozoic rocks, is shown in Fig. 16.

Thickness.—The thickness of the Maitai Series is estimated by Hector at from 7,000ft. to 10,000ft.; but the obscurity of the sections makes it difficult to form a trustworthy estimate. Perhaps the clearest section is that seen along the course of the Roding River, where in a distance of a mile and a half there is exposed a thickness of 7,000ft. of strata; but how much of this thickness should be referred to the Maitai and how much to the Te Anau Series is unknown.

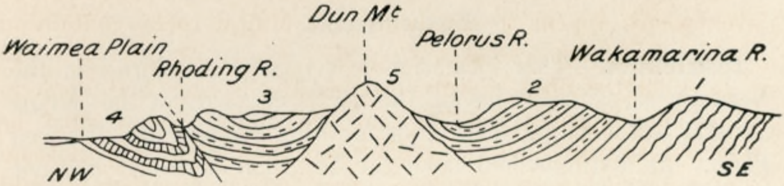

Fig. 16. Section from Waimea Plain to Whakamarina. Distance 26 miles.

1. Kakanui Series, consisting of semi-metamorphic mica-schist, phyllite, altered claystone and greywacke. 2. Te Anau Series: Grey, blue, green, and red slaty shales, and greywacke, with beds of greenstone-tuff (aphanite breccia). 3. Maitai Series: Grey, blue, green, and red slaty shales, and greywacke, with beds of greenstone-tuff (aphanite breccia), and a bed of limestone in north end of district. 4. Lower Mesozoic (Wairoa and Otapiri Series). 5. Serpentine and dunite.

Age.—Hochstetter[k], who examined these rocks in 1857, referred them to the Lower Trias, placing them conformably below the Wairoa Series of Hector. In 1870 Hector[l] and Davis[m] agreed with Hochstetter in referring them to the Trias.

In 1873 Hutton[n] placed the Maitai Series in the Jurassic, and the Wairoa Series in the Trias, thus reversing the relative positions formerly assigned to these formations. In the same year Hector[o] suggested that the Wairoa Series was older than,

k. F. von Hochstetter, "New Zealand," 1867, p. 57.
l. J. Hector, "Catalogue of the Colonial Museum," 1870.
m. E. H. Davis, "Reports of Geological Exploration," 1869-71, p. 103.
n. F. W. Hutton, Reports of Geol. Expls., 1873-74, p. 34.
o. J. Hector, *loc. cit.*, Progress Report.

and unconformable to, the Maitai rocks, which he afterwards assigned to the Upper Palæozoic, placing it below the Te Anau Series[p].

In 1877 Hector placed the Maitais in the Carboniferous[q]. In that year McKay discovered some fossils in the Maitai limestone in the Wairoa Gorge, among which Hector identified *Spirifera bisulcata*, *Spirifera glabra*, *Productus branchythærus*, *Cyathophyllum*, and *Cyathocrinus*.

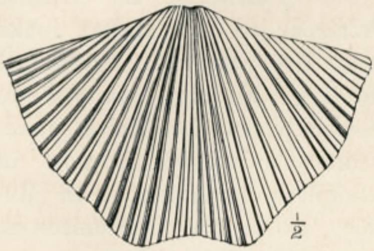

Fig. 17. *Spirifera bisulcata*.

At the same time McKay[r] reported the occurrence of a form of *Inoceramus* in the limestone and overlying slates, and mentioned that the beds of the Wairoa Series everywhere appear to dip below the Maitai rocks containing the supposed *Inoceramus*.

In 1903 the author contended, as Hochstetter had done in 1857, and Hutton in 1873, that the Maitai Series must be referred to the Jurassic period[s], arguing that a formation containing such a distinctly Secondary fossil as *Inoceramus* could not be referred to the Carboniferous. The stratigraphical evidence also supported this view, the Triassic Wairoas as reported by McKay everywhere appearing to dip under the Maitais.

In 1907 W. F. Worley, of Nelson, having expressed some doubt as to the organic origin of the so-called *Inoceramus* remains in the Maitai rocks, the author in that year re-examined the Maitai, Dun Mountain, and Wairoa sections. A careful search was made for fossils at the place where *Inoceramus* was said to occur, but without success. On the other hand, it was found that the slaty shales at these places contained short, narrow gash-like contraction rents, from which a fibrous mineral had been partially or completely removed by leaching on the surfaces exposed to weathering.

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p. J. Hector, Reports of Geol. Expls., 1876-77, p. v.
q. J. Hector, Reports of Geol. Expls., 1877-78, p. xii.
r. A. McKay, Reports of Geol. Expls., 1878-79, p. 117.
s. J. Park, Trans. N.Z. Inst., Vol. xxxvi., 1903, p. 431.

An examination of the section lying between the Hope Hills and Port Hills disclosed the complete inversion of the maritime fringe of Middle Tertiary strata lying against the Triassic foothills. This, while opposed to his own views, strongly favoured the contention of McKay that the seeming inferior position of the Triassic Wairoas to the Maitai rocks was the result of overthrust folding. Having examined the fossils from the Maitai limestone the author is now in complete agreement with McKay as to the Carboniferous age of the Maitai Series.

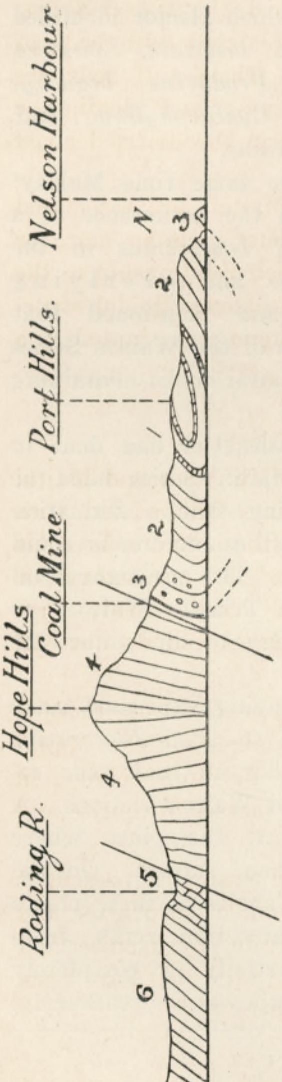

Fig. 18. Section from entrance of Nelson Harbour to upper part of Roding Valley. Distance eight miles.

1. Soft sandstones ... ... } Oamaru Series (Miocene).
2. Marly clays... ... ...
3. Conglomerates with brown coal ... ...
4. Claystones and sandstones ... ... Triassic.
5. Limestone ... ... } Maitai Series.
6. Slaty shales, greywacke, and greenstone-tuffs ...

Relationship to Te Anau Series.—The author has already expressed his agreement with Hutton in the belief that the Maitai and Te Anau formations are identical. It is always difficult to distinguish them as two separate formations in the field; and in several of his reports McKay has grouped them together, or referred to them as the upper and lower members of one continuous succession of strata. It will be found that where they have been mapped as two series by the Geological Survey it is as the upper and lower members of one formation. Both names are now well established in the nomenclature of New Zealand geology. The strata they represent are not less than

7,000ft. thick, and, if assumed to designate the upper and lower portions of the Carboniferous, no valid objection can be taken to their continued use.

Contemporaneous Igneous Rocks.—Like the Te Anau Series, with which it is wholly or in part identical, the Maitai Series, in its typical locality in Nelson, is intercalated with beds of green or green-and-red greenstone-tuff. These tuff beds are commonly thin, but from their toughness and distinctive appearance they are always conspicuous in the drifts derived from the denudation of this formation.

In Brook Street Valley, Nelson, the Maitais are associated with many masses of amygdaloidal diabase running more or less parallel with the bedding-planes. Their relationship to the enclosing rocks is not very clear, but the amygdaloidal structure would tend to show that the rock-magna was erupted as a contemporaneous lava-flow.

IGNEOUS ROCKS OF TE ANAU SYSTEM.

Contemporaneous Igneous Rocks.—The Te Anau and Maitai formations wherever they occur are always intercalated with conspicuous beds of green and red tuffs (the aphanite breccias of Hector and McKay), and with flows of greenstone, or melaphyre, of very fine texture. These have already been described as integral members of each series and do not call for further mention here.

Acidic Intrusions.—At Mackay's Bluff, near Nelson, there is a plutonic mass of hornblende-granite[t] intruding the Maitai mudstones and greywacke; and in the Eglinton county, in Otago, the Te Anau series is intruded by masses of diorite and norite.

Basic Intrusions.—Wherever the Maitai System is present it is associated with an enormous development of serpentine and dunite, with which are found hartzbergite, pyroxenite and other rocks of the ultra basic type, some of which have been described by Marshall[u], Finlayson, and others.

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t. J. H. Hutton, Jour. Roy. Soc. N.S.W., Aug., 1889, p. 124.

u. P. Marshall, Trans. N.Z. Inst., vol. xxxvii., 1904, p. 481; Trans. N.Z. Inst., vol. xxxviii., 1905, p. 560; Trans. N.Z. Inst., vol. xxxix, 1906, p. 496; Trans. Aust. Assoc. Ad. Sc., vol. xiii., 1907.

In Otago several sheet-like masses of serpentine and peridotite rock occur along the boundary of the Te Anau Series and Maniototian, on the west side of Lake Wakatipu; notably in the Caples and Routeburn, at the source of Hidden Falls and Olivine streams, behind Mount Cosmos, and at Red Hill[v]. The magnesian mass at the last named place is of unusual size, covering an area of 100 square miles. It culminates in Red Hill, which is a bare dun-coloured mountain over 6000 feet high, with a circumference of 20 miles, composed chiefly of dunite, saxonite[w], and other peridotite rocks fringed with serpentine.

In Nelson there is the so-called "Mineral Belt," which is a sheet-like development of serpentine and dunite that extends from D'Urville Island in Cook Strait south-westward for a distance of 60 miles. It varies from 100 yards to 2000 yards wide, and for the most part lies along the boundary of the Te Anau and overlying Maitai Series. The culminating point of this great band of magnesian rocks is Dun Mountain, which is a protruding mass of dunite fringed with serpentine. Another development of serpentine in this formation occurs near Mount Peel in Collingwood, but it is of small extent.

In the Hidden Falls area, the Te Anau formation is intruded with massive dykes of diorite[x] and gabbro, the relationship of which to the adjacent ultra-basic magnesian rocks has not yet been determined.

Date of Basic Intrusion.—The Jurassic and Triassic conglomerates in Nelson[y] and Southland contain a varied assemblage of granite, granophyre, diorite and porphyrite, but nowhere in them is there a trace of dunite or serpentine, not even in Nelson, where the Triassic rocks form the foot-hills flanking the main range along the slopes of which the dunite and serpentine are chiefly exposed[z]. The great conglomerate at the base of the Oamaru Series at Nelson and Waimea contains a variety of acid platonic rocks; but no ultra-basic magnesian rocks are known in it, although they are now the

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v. J. Park, Repts. Geol. Expls., 1886-87, p. 121.
w. G. H. F. Ulrich, Quart. Jour. Geol. Soc., xlvi., p. 619.
x. P. Marshall, Trans. N.Z. Inst., vol. xxxviii., 1905, p. 564.
y. P. Marshall, Trans. N.Z. Inst., vol. xxxvi., 1903, p. 467.
z. J. Park, *loc. cit.*, p. 435.

dominant igneous intrusives in the district. But their absence cannot be taken as conclusive proof that the magnesian outburst took place after the Eocene; for it is obvious that the Maitai formation may have been covered by the Permo-Jurassic rocks during the Eocene period; or the Eocene strand on which the conglomerates were deposited may have lain to the northward in the direction of the Riwaka and Golden Bay, thus leaving the dunite area submerged in deep water. But even when allowance is made for these possibilities the evidence points to a late date of eruption.

CHAPTER VI.

HOKONUI SYSTEM.

(*a.*) Mataura Series ⎫ Jurassic.
(*b.*) Putataka Series ⎭
(*c.*) Otapiri Series—Upper Trias.
(*d.*) Wairoa Series—Lower Trias.
(*e.*) Kaihiku Series—Permo-Trias.
(*f.*) Aorangi Series—Permian.

Distribution.—The Hokonui System comprises a great assemblage of strata ranging in time from the Permian to the Jurassic in one unbroken succession. It is the chief mountain-builder in New Zealand, and in its extent, character of sediments, and tectonic importance bears a marked resemblance to the Gondwana system of India, and the Karroo of South Africa. Its nearest equivalent is the great Permo-Jurassic system of New Guinea, which is in part represented in New South Wales.

In the South Island it is nowhere so fully developed as in the Hokonui Hills, and in the low undulating tract that occupies the south-west portion of Southland. It forms the greater part of the Southern Alps, and composes the secondary ranges in Canterbury, the Kaikouras in Marlborough, and the Waimea foothills in Nelson. In the North Island it forms the Tararua, Rimutaka, Ruahine, and Kaimanawa ranges, which extend in one unbroken chain from Cook Strait to East Cape. Outlying patches, that are probably the truncated remains of the submerged Hauraki transverse mountain system are found in the Upper Wanganui, Waipa, Kawhia, Coromandel, Middle Waikato; and near Te Aroha, Thames, and other places around the shores of the Hauraki Gulf; and in the North Auckland district.

Rocks.—These consist of alternations of mudstones, sandstones, and gritstones, with which are imbedded beds of conglomerate, composed for the most part of granite and other crystalline igneous rocks. Limestones are absent, and calcareous members are only feebly represented. The sediments contain many fossiliferous beds, which, however, comprise only an inconsiderable portion of the total thickness. The frequent alternations of mudstones, sandstones, and thin beds of conglomerate, with here and there a horizon containing the remains of marine molluscous life, or shales with the impressions of a terrestrial flora, indicate conditions of deposition that must have been estuarine or fluvio-marine. The total absence of limestones, and the uniform character of the sediments, afford proof that practically the same conditions of deposition existed from the beginning to the end. Muds and sands followed each other with monotonous regularity, their alternations in thin layers probably marking the succession of seasonal changes. They were deposited on a gradually sinking surface, the persistence of the submergence from the Permian to the close of the Jurassic, undisturbed by volcanic outbursts or violent oscillations of the land, being almost without a parallel in the geological history of the globe.

Thickness.—In the section along the coast-line from Nugget Point to False Island, in Southland, which runs almost exactly at right angles to the strike, and in which the strata are exposed in a continuous series, like a row of books standing on a shelf, the thickness of the Triassic and Jurassic strata[a] has been estimated at 18,000ft. In the Hokonui Hills, where the sections are also clear, Cox[b] and Hutton[c] have estimated the thickness at from 20,000ft. to 25,000ft.

Perhaps the clearest continuous section of the Hokonui System is that exposed on the coast-line to the south of Nugget Point, shown in Fig. 19.

From Rocky Gully to Mount Goethe, near the head of the Rangitata, there is exposed a continuous succession of sandstones, greywacke, shales, and mudstones, that appear to be conformable to the Mount Potts *Spiriferina* beds, which have been referred to the Permo-Trias. For a distance of some nine

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a. J. Park, "The Lower Mesozoic Rocks of New Zealand," Trans. N.Z. Inst., Vol. xxxvi., 1903, p. 378.

b. S. Herbert Cox, Reports of Geol. Expls., 1877-78, p. 25.

c. F. W. Hutton, Quart. Jour. Geol. Soc., Vol. xli., p. 203.

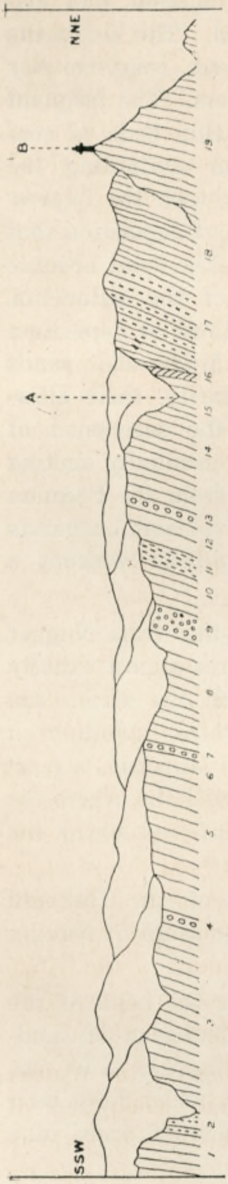


Fig. 19. Section from South Head, Shaw Bay, to Nugget Point. Distance one mile.

1. Claystones and sandstones. 2. *Athyris* sandstone (pebbly). 3. Coarse sandstones. 4. *Mytilus* and oyster-bed (29 ft.). 5. Banded claystones and sandstones. 6. *Trigonia* beds. 7. Granite conglomerate (10 in.). 8. Sandstones, with beds of claystone. 9. Breccia conglomerate. 10. Claystones and sandstones. 11. Greywacke. 12. Indurated claystones. 13. Breccia conglomerate. 14. Claystones and sandstones. 15. *Halobia* claystones. 16. Dyke of porphyrite. 17. Greywacke and sandstone. 18. Black (*Spiriferina*) claystones. 19. Claystones, plant beds. A. Track to Roaring Bay. B. Nugget Point Lighthouse.

miles the dip is north-west at angles varying from 65° to 85°, giving a thickness of 40,000ft. of strata[d]; but the evidence presented in the Mount Cook district where the arrangement of the strata is exposed with exceptional clearness, would lead to the belief that this great thickness is more apparent than real, being the result of overthrust folding, in which the crests of the anticlines have been truncated by denudation, thus presenting what looks like a continuous succession of strata for a distance of many miles.

The Mount Torlesse formation of Haast[e], which form a portion of the Hokonui System, has a thickness, according to that author, of 25,000ft.

The evidence is conclusive that the Hokonui System comprises the greatest continuous succession of sediments present in New Zealand. In this great pile fossiliferous beds are not common; and in thousands of feet of strata there is no trace of organic life except some obscure plant-remains.

Origin of Sediments.—The Hokonui System stretches from Waipapa in Southland, to East Cape, in Auckland—a distance

d. J. Park, Trans. N.Z. Inst., Vol. xxxvi., 1903, p. 390.
e. J. von Haast, Geology of Canterbury and Westland, 1879, p. 279.

of 1,500 miles—lying along the main axis of elevation, arranged in more or less parallel folds. It forms the main divide of the North Island and the submerged foundation of the remainder of that territory. In the South Island it composes the main mass of the alpine divide, besides all the secondary ranges of Canterbury and Marlborough, in the former resting as a folded sheet on the core of gneiss, mica-schist, and other lower Palæozoic strata.

The character of the sediments and of the enclosed organic remains show that this system was laid down on the littoral of a great continental area stretching from Southland to East Cape, from East Cape to North Cape, and thence onward towards North Queensland and New Guinea. The line thus traced marks the position of the old shore-line of the continent that provided the material to form the thousands of feet of strata which we find spread over tens of thousands of square miles.

The Hokonui System, even in New Zealand, extends many hundreds of miles beyond the limits of the Palæozoic areas in Nelson and Otago; and when we consider the fluvio-marine character of the sediments, and their great linear extent, we are warranted in the belief that the land-surface of erosion from which they were derived was of continental dimensions.

In the North Island the Permo-Jurassic system extends from Cook Strait to North Cape—a distance of 650 miles. It is, as we have seen, a pile of fluviatile and estuarine sediments deposited on a sinking seafloor; but the continent from which the sediments were derived has long since disappeared beneath the waters of the Pacific Ocean. The Palæozoic areas in Nelson, Westland, and Otago are merely remnants of the fringe of the submerged Indo-African continent, which appears to have existed up till near the end of the Secondary period.

Evidences of Permian Glaciation.—At the base of the Wairoa Series there is a great conglomerate, chiefly composed of granite and other crystalline rocks. The constituent boulders which are rounded, subangular, and angular, range in size up to 5ft. in diameter. This conglomerate varies from 50ft. to 400ft. thick, and is always present wherever the Hokonui

System is represented. It seems to closely resemble the great conglomerate at the base of the Gondwana System in India, and although no polished or striated blocks have been found in it, its origin is believed by New Zealand geologists to be in some way connected with a period of glaciation somewhere about the close of the Permian or early Trias.

Disposition of Strata.—The strata are commonly arranged in a succession of folds that in the South Island flank the Otago anticlinal, and going northward run parallel with the axis of the main divide. In the main chain of the North Island they

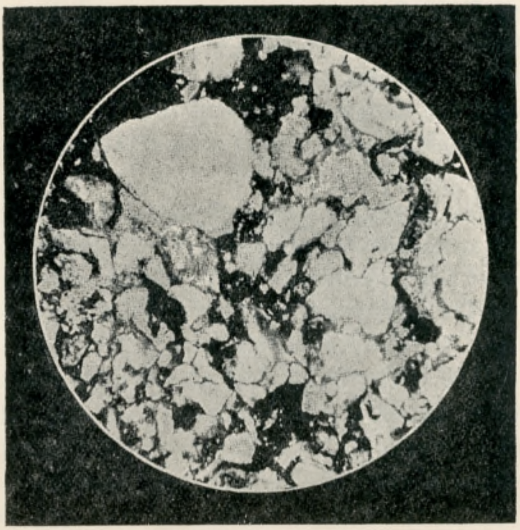


Fig. 20. Greywacke.

are arranged in a sharp synclinal, flanked by minor anticlinal folds.

Classification.—The subdivision of this system in the Hokonui Hills was carried out by Cox[f] and Mackay[g], and in the Nugget Point area by the author[h]; but its correlation with the Trias of Nelson and Auckland presents a more difficult problem than might be supposed. Not only do the rocks occur

f. S. Herbert Cox, Reports of Geol. Expls., 1877-78, p. 28.
g. A. McKay, Reports of Geol. Expls., 1877-78, p. 49.
h. J. Park, Trans. N.Z. Inst., Vol. xxxvi., 1903, p. 393.

in many disconnected areas, but even in the same area the strata have been so wasted by denudation or disturbed that it is often impossible to correlate group with group except within a limited distance. To these difficulties is added the comparative scarcity of fossils. It is evident that a classification is of little value which follows too closely the subdivisions as they occur in Europe—subdivisions perchance grouped on the presence of a few genera whose association in a particular horizon may have been the result of peculiar local conditions prevailing at the time of deposition.

Contemporaneous Igneous Rocks.—There are no contemporaneous volcanic rocks associated with any member of the Hokonui System, or even with the overlying Waipara formation of Upper Cretaceous age in any part of New Zealand. So far as known, this country, during the whole of the Secondary period, appears to have been singularly free from volcanic outbursts—as free, perhaps, as the British area during the same period.

The persistence of the genera *Athyris* and *Spiriferina* right up to the base of the Jurassic must always impress the New Zealand Trias with Palæozoic affinities, and tend to correlate it with the Alpine Trias rather than the Trias of the Great Germanic basin.

Hokonui System	Jurassic ...	1. Mataura Series. Plant beds. 2. Putataka Series. *Inoceramus* beds.
	Triassic ...	3. Otapiri Series. (*a.*) *Clavigera* beds. (*b.*) *Mytilus* beds. 4. Wairoa Series. (*a.*) *Trigonia* beds. (*b.*) *Halobia* beds.
	Permo-Triassic ...	5. Kaihiku Series. (*a.*) *Spiriferina* beds. (*b.*) Plant beds. 6. Aorangi Series.

Aorangi Series.

This series comprises the great succession of apparently unfossiliferous strata conformably underlying the fossiliferous Kaihikus, so well-developed in Southland. In other words it includes all the beds of the Hokonui System lying below the Kaihiku horizon.

Fig. 20A. Mount Cook. From Seeley.

By courtesy of "The Weekly Press."

In Southland the Aorangi Series rests on the semi-metamorphic Kakanuian; in Canterbury and Westland on the schists of the Maniototian.

In the Hokonui Hills, the thickness of this group of strata was estimated by Cox at 4,000 ft.; but in the Canterbury Alps, where it attains its greatest development, it is impossible to form even an approximate estimate on account of the repetition caused by overthrust folding.

The rocks are mainly greywacke and slaty shales, occurring in alternating beds that vary from an inch to many feet, or many yards, in thickness. The greywacke generally occurs in thicker bands than the slaty material, and in most places largely predominates, particularly in the lower division of the series as exposed along the alpine divide.

Proceeding eastward from the divide we gradually ascend into the higher beds of the Hokonuis, meeting first the Kaihikus and then the upper members of the system, and in these we find a greater proportion of the slaty material.

The greywacke is commonly excessively hard, and always much shattered. In many places it contains coarse gritty bands that occasionally pass into a fine pebbly conglomerate. A peculiar feature of the finer-grained greywacke is its inclusion in some

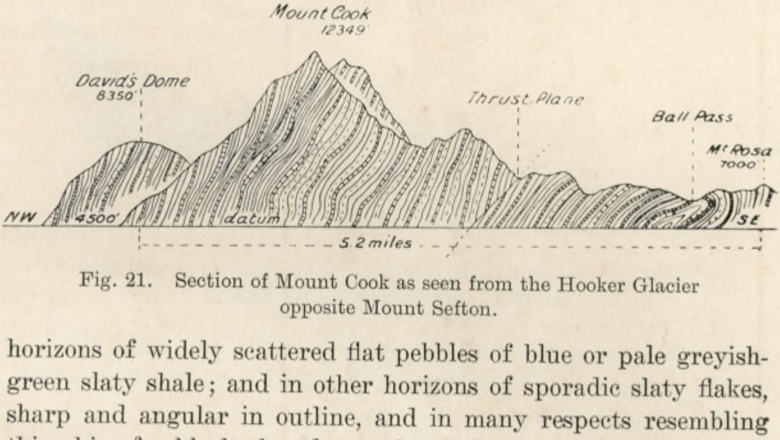


Fig. 21. Section of Mount Cook as seen from the Hooker Glacier opposite Mount Sefton.

horizons of widely scattered flat pebbles of blue or pale greyish-green slaty shale; and in other horizons of sporadic slaty flakes, sharp and angular in outline, and in many respects resembling thin chips freshly broken from a hard siliceous non-fissile Lydian stone.

The slaty shales are mostly blue in colour, but greyish-coloured bands are not uncommon. In the Malte Brun Range forming the eastern wall of the Tasman Valley there is a prominent band of dark red jasperoid slaty shale varying from ten to a hundred feet thick. This red band forms a conspicuous horizon that can be seen in many parts of the range, following all the complicated folds into which the strata have been bent.

In the Malte Brun Range and in the main divide, where involved in the overturned folds, the slaty shales are frequently altered into a fine silky argillite. And it is noticeable in the same folds that many of the thinner beds of shale when lying between two heavy bands of greywacke are highly micaceous. It is obvious that the alteration of the shale, and the development of the micaceous constituent are the result of dynamical metamorphism.

When examined in thin section, the greywacke is found to consist mainly of a mosaic of quartz grains, mostly rounded, but occasionally semi-angular. A little feldspar is nearly always present, and also sericitic mica as an alteration product. When slightly altered, as it sometimes is in the more deeply involved folds, the greywacke nearly always shows the presence of chloritic matter apparently resulting from the alteration of ferro-magnesian minerals originally contained in the fresh unaltered

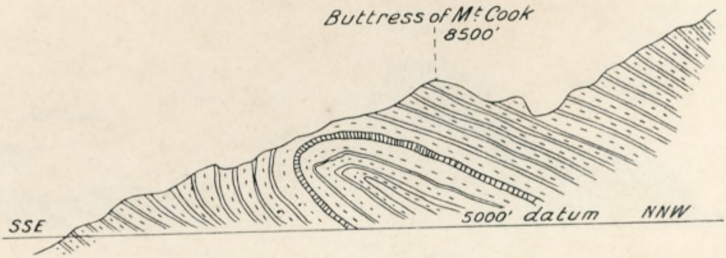


Fig. 22. Section of Eastern Buttress of Mount Cook as seen from the Rudolph Moraine, Tasman Valley.

rock. In some sections a little epidote, rutile and magnetite can also be recognised. The feldspar, it should be noted, is generally kaolinized and cloudy.

The prevailing greywacke is a light greenish-grey rock, very hard and commonly fine-grained. As seen in the Mount Cook region, where it is typically developed, it presents to the eye, as seen piled up in broken masses on the surface of the Tasman Glacier, the appearance of a grey siliceous sandstone. In many places it is traversed with irregular parallel or interlacing quartz veins ranging from thread-like seams to veins several inches thick.

In a few places the greywacke, where it occurs in thin beds, alternates with correspondingly thin layers of bedded-quartz. The irregular quartz veins are obviously stress cracks that have become filled by infiltration; but the bedded-quartz layers are continuous for considerable distances, are more or less of uniform thickness, and cannot have been formed in the same way as the veins. We must either suppose that they are the result of contemporaneous deposition, or of subsequent segregation. If the latter we must then assume that they represent a metasomatic replacement of thin shaly bands that at one time occupied their place. The circumstance that a certain amount of shaly matter is generally present in the quartz layers would give colour to this view.

Mention has already been made of the fact that the Hokonui System is the chief mountain-builder in New Zealand. It may now be further stated that of all the formations that constitute the Hokonuian the Aorangi is the most important in as much as it forms the alpine divide and enters into the structure of all

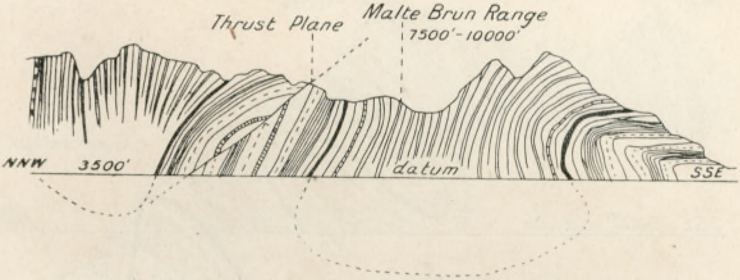


Fig. 23. Section of Malte Brun Range as seen from Tasman Glacier.

the great ranges that spring from the divide. This obviously results from the inferior position of this formation which, as we have seen, rests unconformably on the band of crystalline rocks that forms the core of the Southern Alps.

The Aorangian extends from North Otago to the Spencer Mountains in Nelson, in an unbroken band, a distance of 250 miles. The constituent strata are arranged in a series of great folds, the axes of which run about N.E.-S.W., that is, more or less parallel with the trend of the main chain. The folds have been subjected to so much thrust from the westward that they are overthrust or recumbent.

Nowhere can the arrangement of the strata be seen to better advantage than in the Mount Cook and Malte Brun ranges, where the precipitous slopes of the mountains, mostly devoid of vegetation and bare of overburden, enable the unaided eye to trace the various bends and folds from the floor of the valleys to the summit of the ridges, in many places through a vertical height of 6,000ft. or more. In the month of March, when all but the permanent snow has been removed by the summer warmth, the sectional view of the folding is as clear as a text book diagram.

The arrangement of the folds shown in Figures 21, 22, 23, and 24 was not constructed from observed dips and strikes as is customarily the practice in representations of tectonic folding, but was sketched in the field from actual observations made at points of vantage in the adjacent valleys.

It will be observed that not only have the strata been bent into overturned folds that pitch westward, but they have been broken

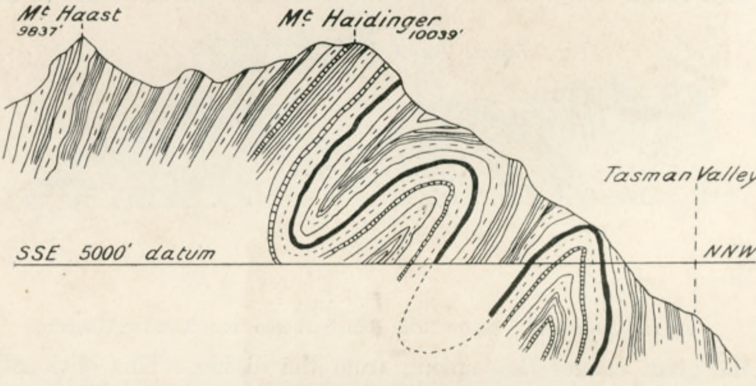


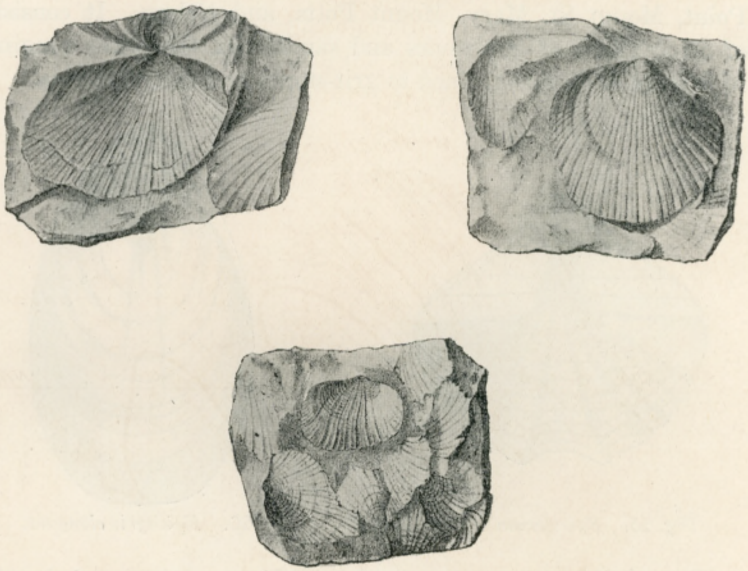
Fig. 24. Section through Mount Haast and Mount Haidinger as seen from Tasman Glacier.

by shear-planes resulting from tangicial stress exerted from the west. The best-defined thrust-plane is that which crosses Mount Cook Range near the Ball Pass and thence trends north-east until it traverses the Malte Brun Range.

In Mount Darwin the strata are bent into many complicated folds that seen from a distance resemble gigantic knots in a piece of gnarled timber.

The relationship of the Aorangi Series and of the whole Hokonui System to the Maitai Series is not very clear. It is, however, certain that the Hokonuian embraces many rocks in different parts of the Dominion that recent discoveries have shown to be erroneously correlated with the Maitais.

PLATE I.



Halobia lommeli, Wissm. (After Zittel.) Lower Trias. Nat. size.

If the conformably overlying Mount Potts and Mount St. Mary beds are Permo-triassic as their fauna would indicate, and the underlying Maitais, Carboniferous, we are left no option but to place the Aorangi Series in the Permian.

Kaihiku Series.

(*a.*) *Spiriferina* beds.
(*b.*) Plant beds.

This is typically developed in the Hokonui Hills, at Nugget Point, Mount St. Mary, Mount Potts, and Nelson. It consists of alternations of mudstones and sandstones, the latter ranging in texture from fine-grained to grit-stones and slaty breccias.

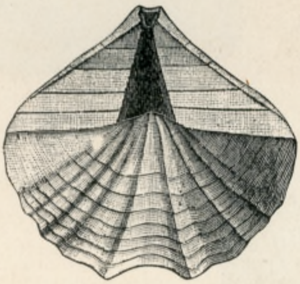


Fig. 25. *Spiriferina cristata* (?).

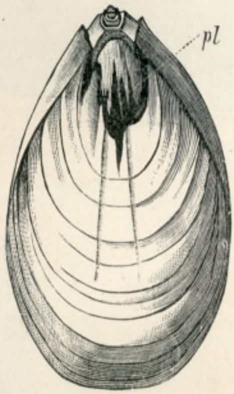


Fig. 26. *Epithyris elongata.*

The plant-beds occupy the base of the series, and in the Hokonui Hills are not less than 3,000ft. thick. Among the plant-remains from these beds at Tank Gully, Mount Potts, Ettingshausen[i] identified *Tæniopteris pseudovittata, Asplenium Hochstetteri, Palissya podocarpoides,* and *Baiera Australis,* all more or less related to Triassic forms. The *Glossopteris* of Hector, from that place, was determined by Ettingshausen to be a *Tæniopteris.*

The *Spiriferina* beds embrace the lowest marine sediments of the Hokonui System. They occur, according to Cox[j], 4,000ft.

i. Ettingshausen, Trans. N.Z. Inst., Vol. xxiii., p. 237.
j. S. Herbert Cox, Reports of Geol. Expls., 1877-78, p. 30.

above the lowest beds exposed in the Hokonui area. They are referred by that author to the Permo-Carboniferous[k].

Among the fossils found in this series at Nugget Point are *Spiriferina*, three sp., the subgenus *Psoidea* of Hector[l] which somewhat resembles *Spiriferina cristata*, Schloth., *Epithyris*, *Rhynchonella*, and *Pleurotomaria*.

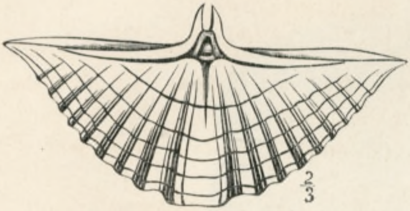


Fig. 27. *Spirifera undulata.*

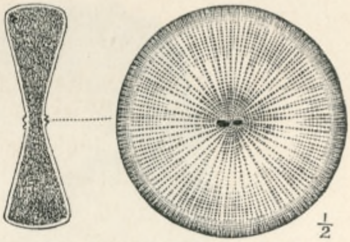


Fig. 28. *Verbebra of Ichthyosaurus* (?).

In the Mount St. Mary horizon[m] there occur *Spirifera*, *Spiriferina*, *Athyris*, *Epithyris*, *Rhynchonella*, *Trigonia*, *Pleurotomaria*, a nautiloid shell, and the remains of *Ichthyosaurus*.

Both Cox[n] and McKay[o] have reported spirifers in the Kaihiku Series in the Hokonui Hills.

The Mount Potts *Spiriferina* beds have yielded[p] several species of *Spiriferina*, *Athyris*, *Rhynchonella*, *Orthoceras*, *Megalodon* (?), *Nuculana*, and the remains of a saurian related to *Ichthyosaurus*[q] or *Eosaurus*[r].

In the Kaihiku Series we have what appears to be a curious commingling of Permo-Carboniferous and Upper Triassic forms.

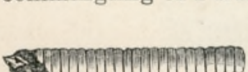


Fig. 29. Encrinite stem from Eighty-eight Valley, Nelson.

The Kaihiku beds at Eight-eight Valley, Nelson, have yielded *Spiriferina*, *Athyris*, *Epithyris*, *Patella*, *Pleurophorus*, encrinite stems, and saurian remains.

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k. S. Herbert Cox, *loc. cit.*, p. 46.
l. J. Hector, Trans. N.Z. Inst., Vol. xi., p. 537.
m. J. Park, Trans. N.Z. Inst., Vol. xxxvi., 1903, p. 450.
n. S. Herbert Cox, Reports of Geol. Expls., 1877-78, p. 44.
o. A. McKay, *loc. cit.*, p. 71.
p. J. Park, Trans. N.Z. Inst., Vol. xxxvi., 1903, p. 389.
q. J. Hector, Trans. N.Z. Inst., Vol. vi., p. 334.
r. J. Hector, Reports of Geol. Expls., 1878-79, p. 11.

Monotis salinaria, var. *Richmondiana*, Zittel. Size, ¾ nat. (After Zittel.)
From Wairoa Series. Triassic.

Wairoa Series.

(*a.*) *Trigonia* beds.
(*b.*) *Halobia* beds.

This series is typically developed at Nugget Point, Hokonui Hills, and Waimea district, Nelson. The rocks consist for the most part of sandstones that are often gritty and pebbly, mudstones, and beds of granite-conglomerate.

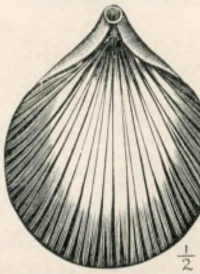

Fig. 30. *Retzia*, sp. ?

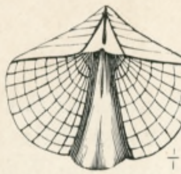

Fig. 31. *Psioidea* (Hector) (*Spiriferina ?*)

The distinctive fossil of the lower fossiliferous horizon is *Halobia lommeli*, Wissm., with which there is generally associated *Retzia, Epithyris,* and *Psoidea,* the latter appearing for the last time.

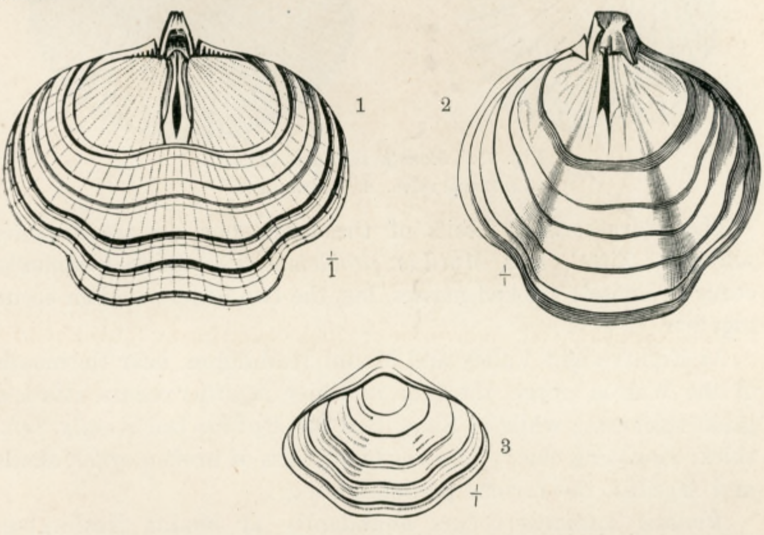

Fig. 32. *Spirigera Wreyii* (Suess).
1 and 2, internal casts ; 3, the test.

The *Trigonia* beds, forming the upper and most important portion of the Wairoa Series, is well exposed at Well's Creek, Eighty-eight Valley, and Mount Heslington, in Nelson; in the Shaw Bay section, at Nugget Point; and in many parts of the Hokonui Hills. The characteristic fossils are *Trigonia, Estheria minuta, Edmondia, Ammonites, Orthoceras,* a nautiloid shell, *Terebratula,* and *Spirigera Wreyi,* Suess, the latter, according to Zittel, most nearly related to the Devonian *Spirigera undata,* Defr.

Otapiri Series.

(*a.*) *Clavigera* beds.
(*b.*) *Mytilus* and *Monotis* beds.

Both horizons of this series are widely developed at the Nugget Point, Hokonui Hills, and in the foothills fronting the Waimea Plain between the Wairoa Gorge and Eighty-eight Valley, near Nelson. The rocks are chiefly sandstones and mudstones containing thin beds of conglomerate.

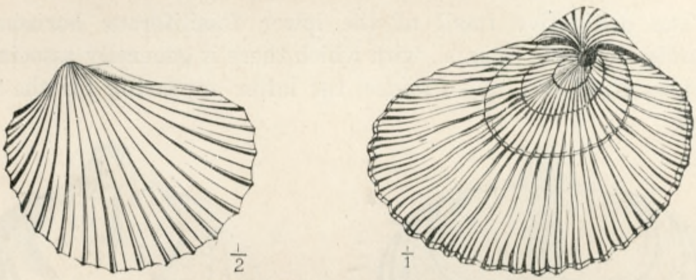

Fig. 33. *Monotis salinaria* (Zittel).
1. Dorsal valve. 2. Ventral valve.

The characteristic fossils of the lower horizon are *Monotis salinaria,* Zittel, and *Mytilus problematicus,* which commonly occur in densely packed masses, but the two genera seldom occur together.

At Eighty-eight Valley and Mount Heslington, near the mouth of the Wairoa Gorge, the beds in which *Mytilus* occurs attain a great thickness; while at Shaw Bed the *Mytilus* bed is only 29ft. thick, consisting chiefly of a confused mass of broken oyster-shells and *Mytilus,* the former predominating.

Monotis salinaria occurs abundantly at Mount Heslington, French Pass, Okuku (Canterbury), and many parts of the

Hokonui Hills. It is absent in Shaw Bay. In the Hokonui sections *Monotis* seems to take the place of the *Mytilus*, so abundant in Nelson.

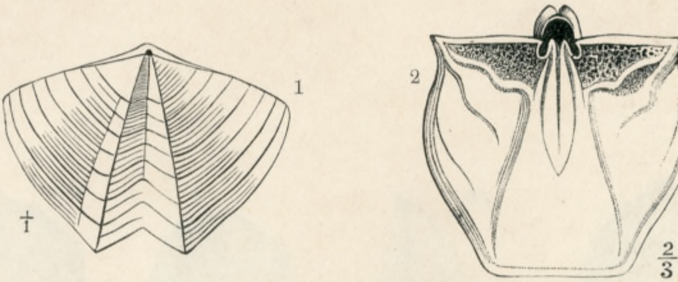

Fig. 34. *Clavigera* (Hector).
1. Testiferous specimen. 2. Internal cast.

The *Clavigera* beds mark the upward limit of *Spiriferina*, and form the natural close of the Trias, although there is no stratigraphical break in the succession of the strata. At Shaw Bay they contain only two distinct fossils—namely, the *Clavigera* of Hector[s]—a subgenus related to *Athyris*—and *Rastelligera*[t], Hector, a subgenus of *Spiriferina*, which is easily identified by its long, straight hinge-line with comb-like dentition occupying its whole length.

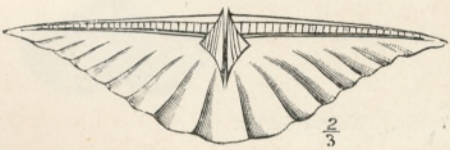

Fig. 35. *Rastelligera* (Hector).

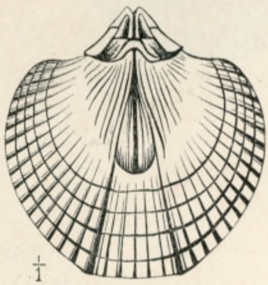

Fig. 36. *Spiriferina*, sp. ?

At Well's Creek, Nelson, the *Clavigera* horizon contains several species of *Spiriferina*, including *Rastelligera*, which is confined to these beds and is therefore characteristic, *Clavigera*, fragments of saurian bones, corals, and encrinite stems.

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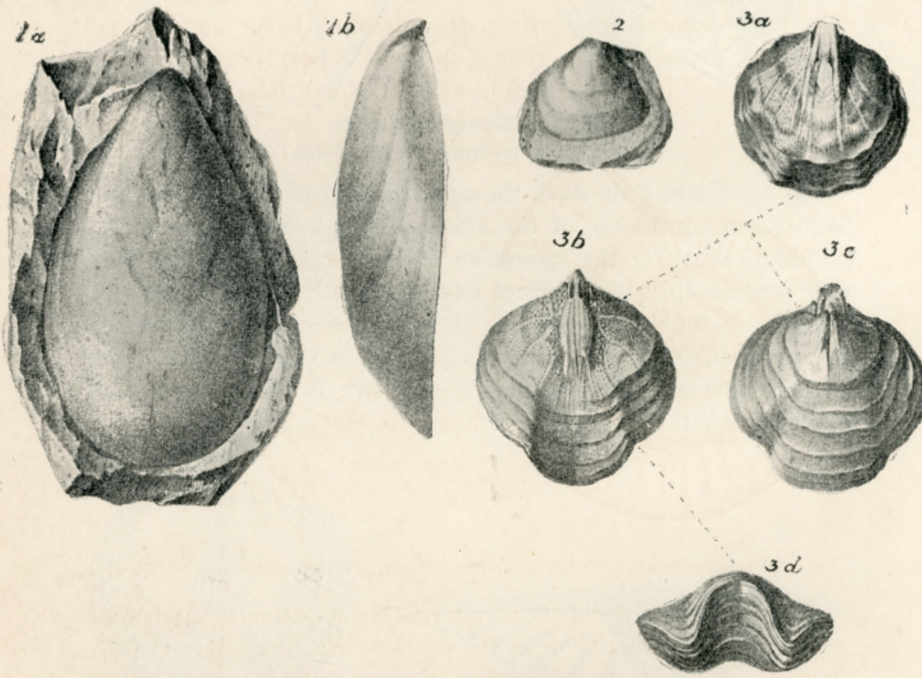
s. J. Hector, Trans. N.Z. Inst., Vol. xi., 1878, p. 537.
t. J. Hector, *loc. cit.*, p. 537.



Triassic Fossils. Wairoa Series.

Fig. 1, *a*, *b*. *Mytilus problematicus*, Zittel.
Fig. 3, *a*, *d*. *Spirgera wreyi* Suess.

Size, $\frac{3}{4}$ nat. (After Zittel).

Putataka Series.

Syn.: Part of *Mataura Series,* Lindsay, Hector and Hutton.
Putataka Formation, Hutton.
Putataka, Flag Hill, and *Bastion Series,* Cox and McKay.
Catlin's River Series, Hector.

This great series of beds occupies a large area in Southland, Canterbury, Wellington, and Auckland.

It enters largely into the structure of the Hokonui Hills, and the low ranges lying between the Mataura River and the east coast, of the subsidiary ranges in Canterbury; of the Tararua, Ruahine, and Kaimanawa ranges in the North Island.

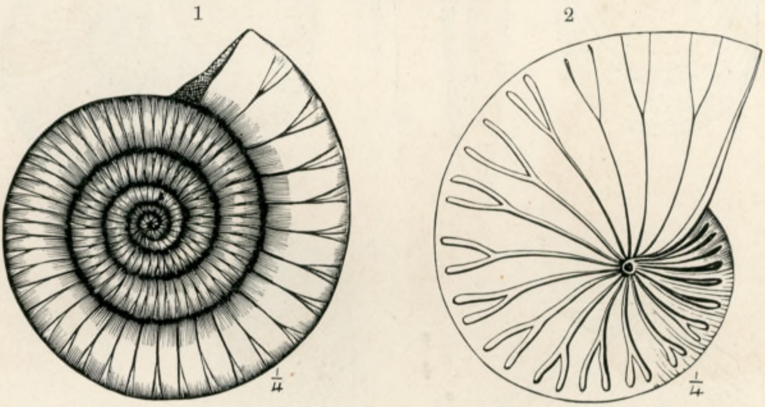


Fig. 37. 1. *Ammonites sisyphinus*, Catlin's River. 2. *Ammonites*, sp. (?), Kawhia.

The rocks consist chiefly of alternating mudstones, sandstones, and greywacke, that show in the section from Shaw Bay to False Island (including the overlying Mataura plant beds)—a total thickness of some 13,000ft[u].

The marine horizons associated with the Jurassic beds are few in number, and seldom rich in fossils. Characteristic forms are rare, and the majority of the species have not yet been determined.

In their survey of the Hokonui Hills, in 1878, Cox and McKay subdivided the Jurassic into four groups or series of beds, among which Hector interpolated his Catlin's River Series, which was placed sometimes above and sometimes below the Bastion Series.

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u. J. Park, Trans. N.Z. Inst., Vol. xxxvi., 1903, p. 401.

In a revision of the Jurassic of Southland in 1886[v], the author showed that the Mataura and Flag Hill Series of Cox and McKay apparently referred to the same group of beds.

What is probably the highest marine horizon of the Putataka Series occurs near the Mataura Falls. It contains *Belemnites*,

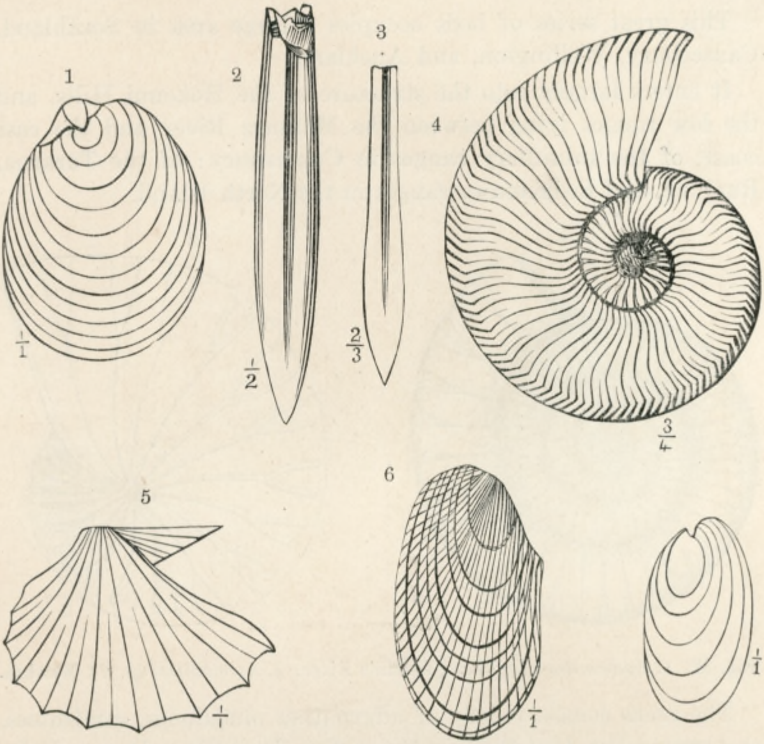


Fig. 38. Putataka fossils. (After Hector.)

1. *Aucella*, sp. ? 2. *Belemnites Aucklandicus*. 3. *Belemnites*, sp. ? 4. *Ammonites Aucklandicus*. 5. *Avicula*, sp. ? 6. *Pholodomya*, sp. ? 7. *Aucella plicata*.

Ostrea, *Pecten*, and *Pholadomya*[w]. Overlying the shell bed there are shales containing *Pecopteris grandis*, *Asplenium Hochstetteri*, two species of *Tæniopteris*, probably *T. pseudo-simplex* and *T. lomariopsis*, Ettings.

The Putatakian contains two marine horizons from the lower of which have been collected *Ammonites*, *Pinna*, *Arca*, *Panopæa*,

v. J. Park, Reports of Geol. Expls., 1886-87, p. 146.
w. J. Park, *loc. cit.*, p. 146.

and *Trigonia*; from the middle horizon, *Inoceramus Haasti*, Hoch., *I. labiatus*, Schloth., and *Pecten;* and from the upper, *Ammonites Aucklandicus, Belemnites Aucklandicus, Pholodomya, Astarte, Aucella plicata, Avicula,* and *Panopæa.*

A fairly complete series of the lower Jurassic rocks occurs on the south side of Kawhia Harbour[x].

In 1864 Hochstetter and Zittel referred the rocks at Port Waikato to the Jurassic, and later investigation has fully confirmed this view.

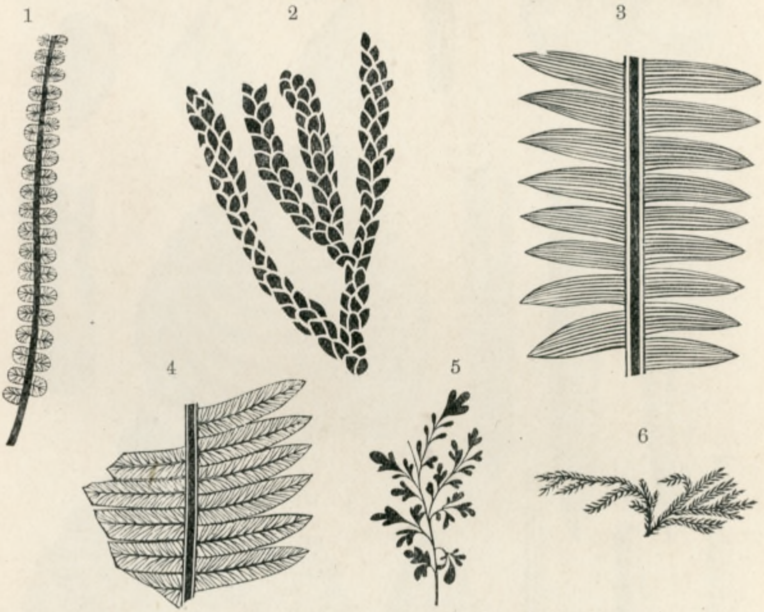
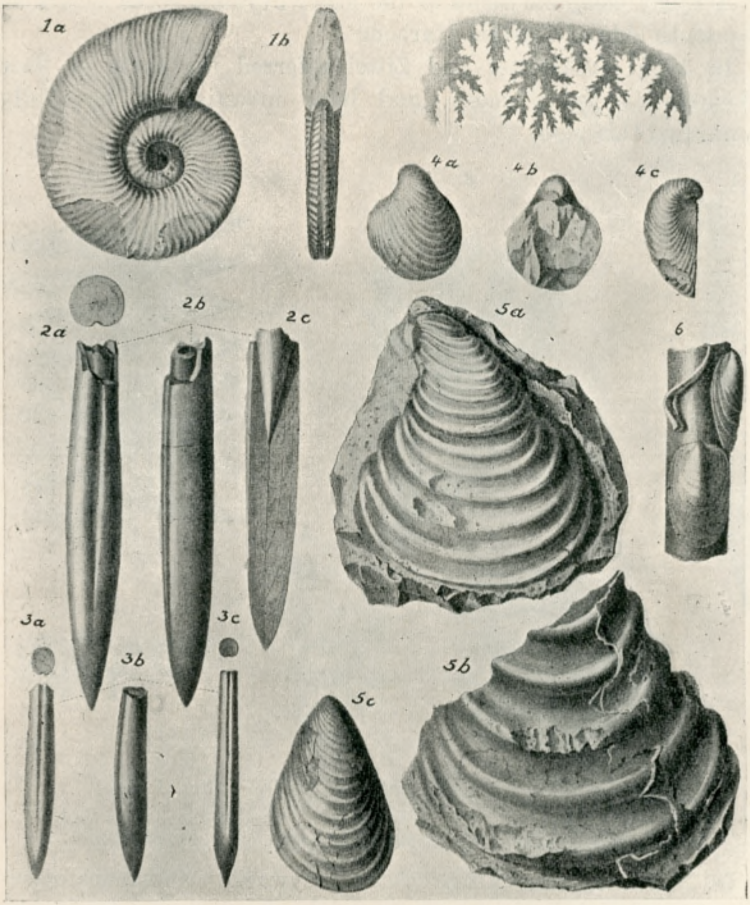


Fig. 39. Plants from Mataura Falls Beds. (After Hector.)

1. *Lomarites pectenata.* 2. *Taxites manawao.* 3. *Pterophyllum matauriensis.* 4. *Pecopteris grandis.* 5. *Sphenopteris asplenoides.* 6. *Taxites kahikatea.*

In 1907 the Jurassic age of the greywacke, sandstones, mudstones, and conglomerates forming the basement rocks of the Hauraki Peninsula[y] was conclusively proved by the discovery of *Inoceramus Haasti* and *Belemnites* at Manaia, near Coromandel.

x. A. McKay, Reports of Geol. Expls., 1883-84, p. 140.
y. C. Fraser and J. H. Adams, Bulletin No. 4, "The Geology of Coromandel Subdivision"; Report by Professor A. P. W. Thomas on fossils from Manaia Hill, 1907, p. 49.



Jurassic Fossils.

Fig. 1, *a*, *b*. *Ammonites Novo Zelandicus*, Hauer.
,, 2, *a*, *c*. *Belemnites Aucklandicus*, Hauer.
,, 3, *a*, *c*. *Belemnites Aucklandicus*, var. *minor*, Hauer.
,, 4, *a*, *c*. *Aucella plicata*, Zittel.
,, 5, *a*, *c*. *Inoceramus Haasti*, Hoch.
,, 6. *Placunopsis striatula*, Zittel.

⅝ natural size. (After Zittel.)

MATAURA SERIES.

This series is well developed at Kawhia, Clent Hills, Upper Rangitata, Hokonui Hills, Mataura, and Waikawa, and is believed to be the closing member of the great Permo-Jurassic System. It consists mainly of estuarine sediments containing plant-remains and thin seams of bituminous coal. Marine fossils are rare or absent.

The rocks are mostly mudstones, shales, and sandstones, with which are associated beds of conglomerate. The characteristic plants of this formation are *Macrotæniopteris lata*, Hector, *Pecopteris grandis*, and *Asplenium Hochstetteri*, all of which are common at Mataura Falls and Waikawa.

Fig. 40. *Macrotæniopteris lata* (Hector).

Perhaps the most distinctive plant in the Mataura Falls beds is a large *Tæniopteris*, the *Macrotæniopteris lata* of Hector, and apparently the *Tæniopteris lomariopsis* of von Ettingshausen.

The Clent Hill beds in Canterbury contain a flora that has led to their correlation with the Mataura beds. The more common plants found in those beds are shown in Fig. 41.

At Waikawa South Head there are exposed on the shore-platform the remains of a Jurassic forest that was entombed in the sediments of the Mataura Series. The stumps of giant fern-trees still stand erect in the position in which they grew, surrounded with many prostrate trunks, some of which are over 50ft. in length. The stumps and trunks are silicified, the latter occurring mostly in short disconnected lengths with the even ends of sawn logs. It would appear that the trees were silicified while standing, becoming afterwards broken into lengths when they fell prone in the mud.

In the lower secondary mudstones and slaty shales of Mount Torlesse, Ashley Gorge, Mount Cook, Kowhai River, and Wilberforce River, all in the Province of Canterbury, and in different parts of west Nelson and Wellington, there occurs what is known as the Mount Torlesse annelid, which is a flattened siliceous tubular body, commonly varying from 2in. to 3in. long, and from 1/8in. to 1/4in. wide.

Dr. Bather[z], who named this fossil *Torlessia McKayi*, mentions that a closely related annelid is found in Alaska, in the Yakutat slates, which are believed to be of Jurassic age.

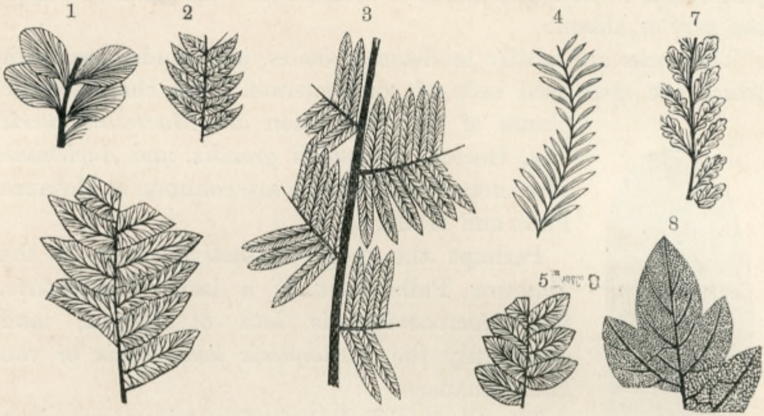


Fig. 41. Plants from Clent Hill beds. (After Hector.)

1. *Asplenites rhomboides.* 2. *Pecopteris acuta.* 3. *Pecopteris linearis.* 4. *Taxites maitai.* 5. *Pecopteris ovata.* 6. *Pecopteris obtusata.* 7. *Asplenites palæopteris.* 8. *Camptopteris incisa.*

Dentalium Huttoni, Bather, a curved, tapering, silicified tubular body, has been found at the Kowhai River, Wilberforce River, and Taipo Range, and is believed to belong to the same horizon as *Torlessia McKayi.* The latter has been referred by Hector and McKay to the Maitai formation, but up to the present

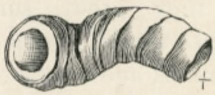


Fig. 42. *Torlessia McKayi* (Bather).

has not been found in the rocks of that formation in the typical section at Nelson. The rocks in which it occurs elsewhere, have been, it would appear, erroneously correlated with the Maitais. On the other hand, *Torlessia McKayi* has been found in the Tararua Range in mudstones with which

z. F. A. Bather, "The Mount Torlesse Annelid," Geol. Mag., Dec., 1905, p. 532.

Monotis is associated; and Cox[a] mentions the occurrence of annelid beds in the Triassic rocks of the Hokonui range.

Age of Reefton Gold-bearing Rocks.—The gold-bearing rocks in the Reefton district consist of alternating clay-stones, shales, and sandstones that have been referred to the Maitai Series by McKay[b]. They rest unconformably on fossiliferous Silurian slates and limestones, and are themselves overlain by older Tertiaries. They contain no very conclusive evidence as to their age, but what there is does not favour a Carboniferous date. Cox mentions the occurrence of a *Dentalium*[c] in the mudstones of the Taipo Range, which Bather[d] thinks is probably the *Dentalium Huttoni* of the Kowhai River and Wilberforce. At a later date both Hector[e] and McKay[f] mention the occurrence of the Mount Torlesse annelid *Torlessia McKayi* in the slaty shales at the Inangahua Junction, and also north of Greymouth.

The *Dentalium* and *Torlessia McKayi* have never been found in the Maitai Series, but in Canterbury they occur in rocks associated with those containing *Monotis* and the Clent Hill Jurassic plant-remains.

Lithologically the Reefton rocks bear a closer resemblance to the Permo-Triassic rocks of Nelson, Wellington, and Coromandel than to those of the Maitai formation and the nearly related Te Anau. Further reference will be made to the age of these rocks when dealing with the geology of the Reefton Goldfields in Chapter XIV.

Economic Minerals.—The gold-bearing veins at Reefton consist of strings of lens-shaped masses that follow the bedding-planes of the rock-formation. The lenses are sometimes linked up with a string of quartz, and sometimes with a track of compressed clay, following the line of fracture along which the lenses occur.

The seams of bituminous coal at Mataura, Catlin's, and Waikawa are too thin to work with profit, as they seldom exceed a thickness of 6in. or 8in.

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a. S. Herbert Cox, Reports of Geol. Expls., 1877-78, pp. 28 and 31.
b. A. McKay, Reports of Geol. Expls., 1882, p. 91.
c. S. Herbert Cox, Reports of Geol. Expls., 1874-76, p. 78.
d. F. A. Bather, Geol. Mag., Dec., 1905, p. 532.
e. J. Hector, Reports of Geol. Expls., 1890-91, p. xxxii.
f. A. McKay, Reports of Geol. Expls., 1882, p. 131.

Igneous Rocks in Hokonui System.

Contemporaneous Igneous Rocks.—It has been already mentioned that this great system is singularly free from evidences of contemporaneous volcanic activity, an immunity that extends far beyond the limits of the New Zealand area. To this general statement there is, however, a notable exception to be found in the Hauraki Peninsula. At Coromandel, the Juro-Triassic mudstones and greywacke are interbedded with acidic tuffs and siliceous mudstones[g], which on the east side of Tokatea Range are associated with flows of ancient rhyolite[h]. The mudstones are no doubt of pyroclastic origin, being mainly composed of rhyolitic muds somewhat similar to those ejected around Rotomahana during the Tarawera volcanic eruption in June, 1886. A siliceous mudstone resembling that at Tokatea Range is associated with the basement slaty shales at Rocky Point, Thames[i].

The fine gritty conglomerates in the Jurassic portion of the basement rocks at Manaia and elsewhere near Coromandel consist chiefly of igneous rocks among which are represented andesites of various kinds, dacites, and silicified rhyolites[j], the source of which has not yet been satisfactorily determined.

Intrusive Rocks.—At Nugget Point the lower Triassic beds are intruded by a narrow dyke of porphyrite[k]; and near Moeraki[l] and Reefton there are dykes of dolerite[m].

In the Clent Hills and Mount Somers districts between the Rakaia and Waimakariri the Triassic strata are broken through and overlain by a complex of volcanic rocks ranging from semi-basic to acidic. The most distinctive rock is a biotite-rhyolite[n]

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g. Sollas and McKay, "Rocks of Cape Colville Peninsula," vol. 1, 1905, p. 151.

h. Colin Fraser and J. H. Adams, "Bulletin No. 4 (New Series)," 1907, p. 45.

i. J. Park, "Geology and Mineral Resources of Thames Goldfield," Auckland, 1894, p. 2.

j. Sollas and McKay, "Rocks of the Cape Colville Peninsula," vol. 1, 1905, p. 52.

k. J. Park, Trans. N.Z. Inst., vol. xxxvi., 1903, p. 381; and R. Speight, *loc. cit.*, p. 477.

l. F. W. Hutton, Jour. Roy. Soc. N.S.W., Aug., 1889, p. 147.

m. W. A. McLeod, Trans. N.Z. Inst., vol. xxxi, p. 487.

n. F. W. Hutton, Jour. Roy. Soc., N.S.W., Aug., 1889, p. 116.

with almandine; while glassy varieties and pitchstones are common.

Among the semi-basic rocks (the melaphyres of Haast[o]) are mica-andesite, angite-andesite, and hornblende-andesite and andesitic tuffs. The order of emission of the magmas was semi-basic followed by the acidic. The Jurassic rocks were elevated, tilted and denuded before the andesitic outbursts began. The piles of andesite in their turn were subjected to considerable erosion before the emission of the rhyolites[p].

The rhyolites are overlain by the conglomerates lying at the base of the Oamaru Series. The conglomerates[q] contain many fragments of rhyolite. The date of eruption thus lies between the close of the Jurassic and the beginning of the Eocene.

Near Moehau, in the Coromandel district, the Juro-triassic mudstones and greywacke are intruded by dykes of mica-diorite[r] and porphyrite[s], erupted probably about the middle Tertiary; and in the North of Auckland district by a diorite at Mangonui, and by an olivine-norite at Ahipara[t].

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o. J. von Haast, ''Geology of Canterbury and Westland,'' 1879, p. 281.

p. J. von Haast, loc. cit., p. 283, and Repts. Geol. Explorations, 1873-74, p. 7.

q. J. von Haast, Repts. Geol. Explts. 1870-72, p. 141; Repts. Geol. Explts. 1873-74, p. 13; S. H. Cox, Repts. Geol. Explts., 1876-77, p. 2.

r. J. Park, Trans. N.Z. Inst., vol. xxiii., 1900, p. 339.

s. Sollas and McKay, ''Rocks of Cape Colville Peninsula,'' vol. 1, p. 73.

t. P. Marshall, Proc. Aust. Assoc. Adv. Sc., vol. xiii., 1908.

CHAPTER VII.

AMURI SYSTEM.

WAIPARA SERIES.

(*a.*) Weka Pass Stone & Grey Marls.
(*b.*) Amuri limestone.
(*c.*) Waipara greensands.
(*d.*) Saurian Beds.
(*e.*) Puke-iwi-tahi conglomerates and sandstones with coal.

Syn: *The Waipara Series of Hutton plus the Weka Pass Stone.*

Distribution.—This formation was originally deposited as a marginal fringe around the slowly sinking Cretaceous shore-line. It is of great economic importance, as it contains, at its base, the valuable brown coals of Kaitangata in Otago, and the fine pitch coals of Whangarei and North Auckland. There is little doubt that it at one time formed a continuous sheet along the east coast of both islands, although now we find it only here and there in small disconnected blocks. And if we may judge from the distribution of the Cainozoic formations, it would seem to have suffered more during the Eocene than Pliocene uplift.

Although occupying a considerable area on both sides of the North Auckland Peninsula, it is singularly enough absent from the western side of the axial divide of both islands, being unknown in Auckland, south of the Waitemata, Taranaki, West Wellington, West Nelson, Westland, or Fiordland.

On the east side of both islands the Oamaruian, the next marine formation in upward succession, rests sometimes on the Amurian and sometimes on the older Mesozoic or Palæozoic formations, a circumstance which clearly proves that the Amuri system suffered considerably from denudation before the deposition of the Tertiary formation began. But on the west side, the Oamaruian, or its related underlying Waimangaroaian coal-bearing series of

Upper Eocene age, always rests directly on the older Mesozoic and Palæozoic formations, which is, of course, conclusive proof of the absence of the Amurian in that region.

The total absence of the Cretaceous Amurian from the west side of the main axial chains in the North and South Islands presents a problem as puzzling as it is interesting.

In attacking the problem we are confronted with two probable solutions. In the first place we may suppose that the Amurian was deposited along the western Cretaceous strand, as it was on the eastern, but was completely destroyed by denudation before the deposition of the Waimangaroaian coal series began in the late Eocene. That a formation extending along a sea-strand 500 miles long could be so completely destroyed, or obliterated, as to leave no trace or vestige whatever seems so improbable that it may be set aside.

Or, in the second place, we may suppose that the Amurian was never deposited along the western margin of the axial chains. This hypothesis at once opens up the question, what evidence is there that a Cretaceous strand ever existed on the western side of the present divide? It is obvious that an open Cretaceous sea existed somewhere to the westward, but have we any evidence that the strand of this sea during the progress of the Cretaceous period had any relation to the existing mountain axis of the islands? Let us consider this question in relation to the South Island. The Southern Alps and the mountain chains that lie between it and the east coast consist of a series of dissected folds, or corrugations, of Permo-jurassic strata. The western wing of the great fold that forms the main chain no longer exists. There are no corresponding folded ranges of Mesozoic strata on the west side; but instead, the alpine fold is broken off abruptly, and to the westward there is exposed the basal core of altered Palæozoic rocks. In the Hokitika and Okarito areas, the Alps are so close to the west coast that the dissevered ends of the Mesozoic strata forming the alpine fold seem almost to overhang the narrow coastal strip of land.

New Zealand geologists have always been willing to believe, as first suggested by von Hochstetter, that a great extension of land existed to the seaward of Westland in pre-Tertiary times. If this view is sound, then the Amurian could not, for obvious reasons be deposited along the flanks of the present alpine range, which would sufficiently account for its complete absence.

In Otago, the Amurian Waipara Series occupies the coastal strip extending from the Clutha to Saddle Hill, embracing the important Kaitangata and Tokomairiri coalfields; and also the maritime area between Shag Point and Moeraki.

In Canterbury, there is an isolated patch in the Trelissic Basin, at a height of 2,600ft. above the sea; and another, but larger, remnant at Waipara, where all the members of the series are well-developed.

In South Marlborough, the Amurian occurs at Amuri Bluff, and occupies the narrow coastal foothills extending from the Kaikoura Peninsula to Cape Campbell.

In Wellington there are isolated blocks extending along the east coast as far as Hawke's Bay.

In the North Auckland Peninsula, this formation covers a considerable area in the Wade, Mahurangi, Whangarei, Kaipara, and Whangaroa districts.

All the members of the Waipara Series are represented at Amuri Bluff, Kaikoura Peninsula, and North Auckland. At Waipara the Grey Marls are absent. Elsewhere only the basal conglomerates, shales, and sandstones are present.

Rocks.—The sediments of this formation represent a complete cycle of deposition beginning with the fluvio-marine drifts that now form the basal conglomerates of the Shag Point beds and ending with a marine limestone. The conglomerates rest on the different members of the Hokonui system in the North Island and in Marlborough; and on the Maniototian and Kakanuian in Nelson and Otago.

Thickness.—Hutton's[u] estimate of the thickness of this series at Shag Point, in Otago, was from 6,000ft. to 7,000ft. McKay's[v] estimate from 1,850ft. to 2,150ft., of which 1,200ft. to 1,500ft. were ascribed to the Puke-iwi-tahi conglomerates. The author's estimate[w], made in 1903, agrees very nearly with that of McKay, being 2,200ft. for the whole series of which

u. F. W. Hutton, "Geology of Otago," 1875, p. 45.
v. A. McKay, Geol. Reports. and Expls., 1886-87, pp. 4-6.
w. J. Park, Trans. N.Z. Inst., vol. xxxvi., 1903, p. 414.

the conglomerates comprise 1,500ft. At Amuri Bluff the thickness is 1,900ft[x].

Age.—Each of the sub-divisions of this series contains one or more fossiliferous horizons from which a number of younger Secondary fossils have been obtained. Thus from the Puke-iwi-tahi beds above the coal have been collected *Ammonites, Belemnites, Baculites, Hamites, Lucina, Trigonia sulcata, Inoceramus*, and *Conchothyra parasitica*; from the Greensands, *Ancyloceras, Belemnites, Rostellaria* and saurian remains, from the Amuri Limestone, *Ammonites*; and from the Weka Pass Stone, the teeth of Lamna and broken echinoderm plates and spines.

Fig. 43. *Baculites*, sp. ?

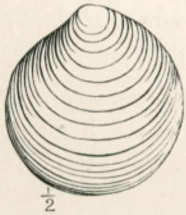

Fig. 44. *Lucina Americana* (?)

At Coverham, in Marlborough, there have been found *Ammonites haumeriensis, Inoceramus Sp. ?, Belemnites Sp. ?*; in the east coast of Wellington, *Inoceramus*; and at Waipawa Gorge in Hawke's Bay, *Ammorites McKayi.*

Among the saurian remains are represented the genera *Plesiosaurus* and *Mauisaurus* (Hector). The latter belongs to the large genus *Cimoliosaurus*, and has not yet been proved specifically different from the European *C. constrictus*[y] of Cretaceous age; the former is a genus that is now exclusively confined to the Upper Trias and Lias.

In 1861, Owen[z] was of the opinion that the beds at Waipara, which contained *Plesiosaurus australis*, were Jurassic.

x. A. McKay, Repts. Geol. Expl., 1874-76, p. 172.
y. H. A. Nicholson, "A Manual of Palæontology," 1889, p. 1077.
z. R. Owen, British Association Report, 1861, p. 122.

Hutton placed the Waipara series in the Upper Cretaceous. The author has elsewhere shown that the Tertiary fossils[a] ascribed by Haast to the Weka Pass Stone, the closing member of the series, were derived from tumbled blocks of the Miocene calcareous sandstones (Mount Donald beds) that crown the range overlooking the outcrop of the Weka Pass Stone.

At present there is good warrant for the belief that the Waipara formation ranges throughout the whole of the Cretaceous reaching down to the Lias. On the other hand Haast[b] stated that he found the impressions of dicotyledinous plants in the coal beds underlying the Saurian beds at Waipara. If the identification of the plants can be relied on, and the relationship of the plant-beds to the Saurian beds has been accurately determined, we have a condition of things resembling that of the Laramic (lignitic) series of the Western States, which is referred by American geologists to the Upper Cretaceous.

Relationship to Underlying Formations.—In Otago and Nelson the Waipara series lies unconformably on deeply dissected surfaces of Palæozoic schists; and in North Canterbury, Clarence Valley, and East Wellington on the upturned and denuded edges of mudstones and greywacke of Jurassic and Triassic age. The Cretaceous beds, although deeply involved in the great faults that follow the foothills of the Inland Kaikouras take no part in the tectonic arrangement of the rocks of the Hokonui System, but rest against them as marginal deposits that follow the strand of the pre-Cretaceous sea, invading even the narrow tortuous fiords that stretched far back among the mountains of that date, as for example into the Trelissic Basin and along the ancient rift-like Clarence valley.

Relationship to Overlying Formations.—The Oamaru Series overlies the Waipara series unconformably at Weka Pass, Shag Point, Kaipara and Wade. At Waipara and Weka Pass the stratigraphical unconformity is not very well marked, the sandy clay beds at the base of the Oamaru Series having assumed the inclination of the underlying Weka Pass Stone, the upper surface of which so far as can be seen still presents fairly uniform planes.

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a. J. Park, Trans. N.Z. Inst., vol. xxxvii., 1904, p. 546.
b. J. von Haast, ''Geology of Canterbury and Westland,'' 1879, p. 291.

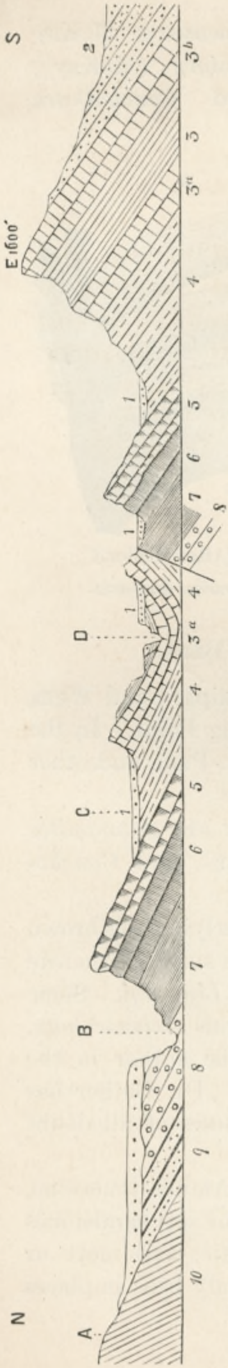


Fig. 45. Section—Doctor's Range to Mount Brown.

A. Doctor's Range. B. Waipara River. C. Ram Paddock. D. Bobby's Creek (near mouth). E. Mount Brown. 1. Recent alluvial deposits. 2. Pareora sands and clays. 3. Mount Brown Beds. 3*a* and 3*b*. Limestone bands. 4. Marly clays. 5. Weka Pass stone. 6. Amuri limestone. 7. Greensands. 8. Saurian sands. 9. Quartz-sands and coal. 10. Old slates and sandstones.

The unconformity is no better marked than that between the London Clay and the Chalk in the south-east angle of England.

On the other hand the palæontological unconformity is clearly defined; thus while the Waipara Series contains the remains of saurians, *Ammonites*, *Belemnites*, and *Inoceramus*, and no living species of mollusca of any kind, the Oamaru Series contains a marine fauna possessing a distinctively Tertiary facies, of the mollusca alone, no less than some 20 to 30 per cent. being represented by living species.

In the section between the Doctor's Range and Mount Brown in the Waipara district, both the Oamaru and Waipara series are well represented as shown in Fig. 45.

Puke-iwi-tahi Beds.

These are typically developed at Shag Point and Kaitangata, in Otago. At Shag Point they consist of quartz conglomerates, grits and shales, some 1,500ft. thick, the former resting on the semi-metamorphic mica-schist of the Kakanuian. The coal seams at this place are enclosed in loose sands and quartz conglomerates. The coal is a brown coal similar in quality to the Kaitangata coal.

The coal shales at Shag Point contain many imperfectly preserved plant remains, among which Hector identified *Auricaurites Buchanani*, *Auricaurites carinaria*, and *Taxites maitai*.

From the sandstones overlying the coal measures McKay collected *Trigonia McKayi* (Park), *Ostrea nigra* (McKay), *Inoceramus multiconcentrica* (Hector), and *Conchothyra parasitica* (McCoy).

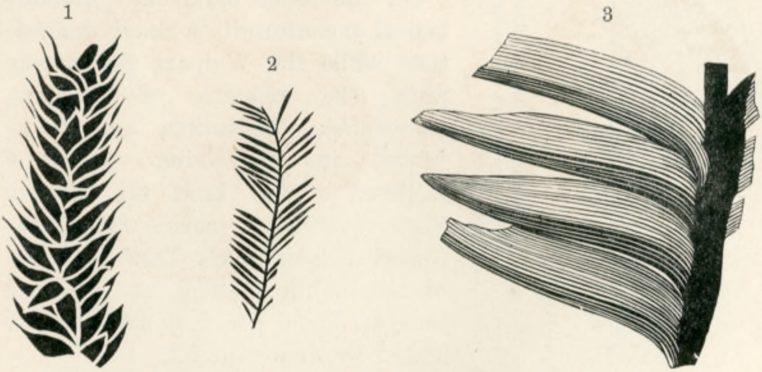


Fig. 46. Plants from Shag Point Coal Measures. (After Hector.)
1. *Auricaurites Buchanani.* 2. *Taxites maitai.* 3. *Auricaurites carinaria.*

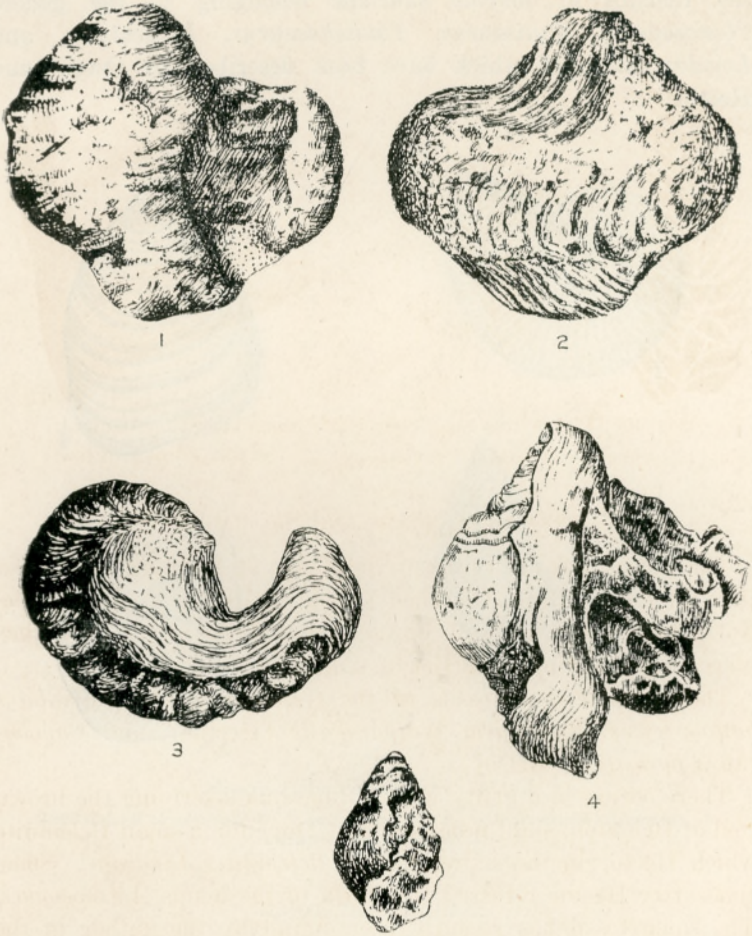
WAIPARA GREENSANDS AND SAURIAN BEDS.

The greensands are typically developed at Waipara and Weka Pass, at Amuri Bluff, Clarence Valley, and Shag Point. In the North Island they are well represented at Batley, Pahi, and other places in the Kaipara district of Auckland.

The characteristic fossils of the Greensands are *Ammonites haumeriensis*, *Rostellaria Waiparaensis* (Hector), and *Conchothyra parasitica* (McCoy).

There occurs in a gritty impure limestone overlying the brown coal at Brighton, eight miles south of Dunedin, a small Belemnite which Hector in the sixties named *Belemnites Lindsayi.* Some time after Hector referred this form to the genus *Actinocomax.* The same fossil has recently been found by the author in the saurian beds at Shag Point, overlying the coal. Dr. Bather has examined specimens from both places, and disposes of all doubt by pronouncing them to be true *Belemnites.*

The Greensands immediately underlie the Amuri limestone, and commonly consist of dark glauconitic sands or soft sandstones that, passing downward, become less glauconitic, and more or less sandy, argillaceous, or shaly. The sandy shaly beds in places



Conchothyra parasitica, McCoy. Waipara Series. Upper Cretaceous.
Natural size. (After Hutton).

contain concretionary boulders that are sometimes covered with a crust of cone-in-cone limestone. In these boulders at Moeraki, Waipara, Kaikoura, Batley, and other places have been found the remains of marine saurians belonging to the genera *Plesiosaurus, Mauisaurus, Taniwhasaurus, Polycotyles,* and *Leiodon,* some of which have been described by Owen[c] and Hector[d].

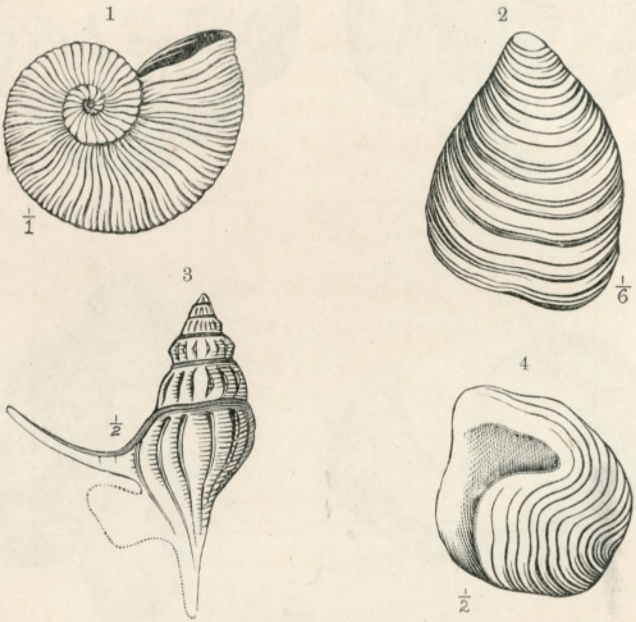


Fig. 47. Upper Secondary Fossils.

1. *Ammonites haumeriensis.* 2. *Inoceramus,* sp. ? 3. *Rostellaria Waiparænsis.* 4. *Conchothyra parasitica.*

AMURI LIMESTONE.

This is one of the most persistent and characteristic members of the Waipara Series, being especially well developed along the east coast of Canterbury, Marlborough, Wellington, Hawke's Bay and Auckland. It is a greyish-white siliceous limestone, often occurring in thin beds that are much broken up. Near Amuri

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c. R. Owen, Brit. Assoc. Rept., 1861, p. 122, and Geo. Mag., 1870.
d. J. Hector, Trans. N.Z. Inst., vol. vi., p. 333.

Bluff, at Kaikoura Peninsula, Clarence Valley, and Kaipara, it contains thick beds, layers or nodules of yellow and grey chert that frequently pass into flint.

This limestone has a very characteristic appearance, and is easily distinguished from any other rock in New Zealand. At many places it is argillaceous and possesses all the constituents of a natural cement; and in the neighbourhood of Mahurangi, north of Auckland, is largely used in the manufacture of hydraulic cement.

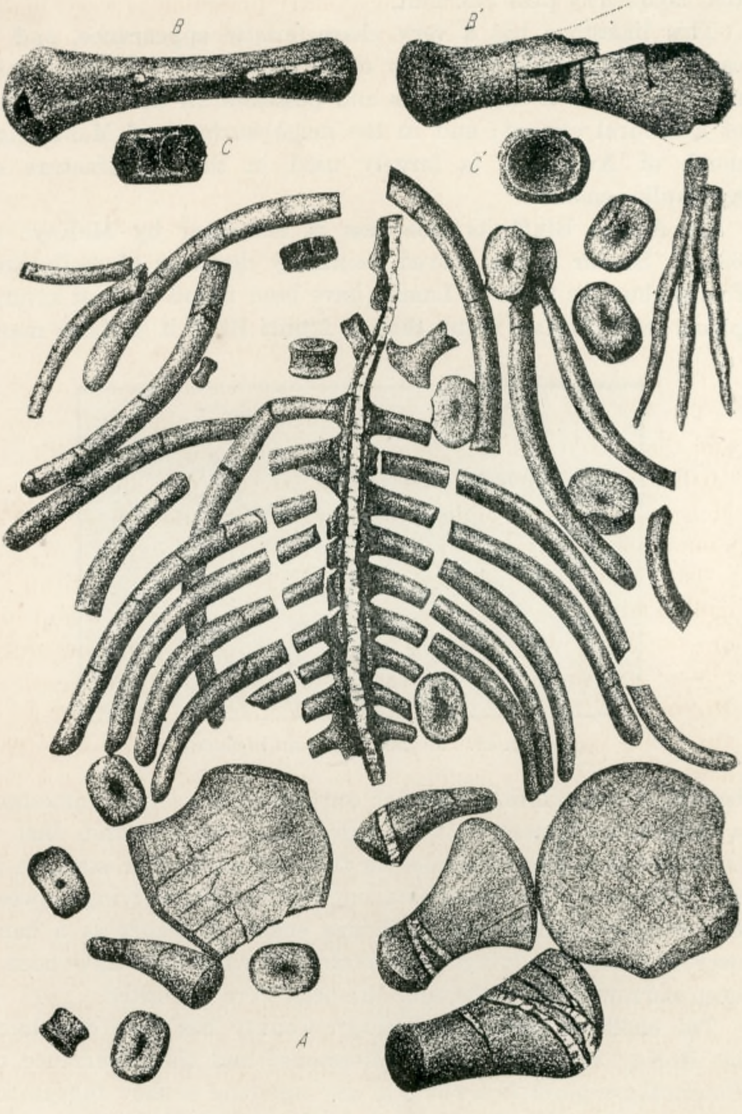
At Amuri Bluff its thickness is estimated by McKay[e] at 630ft. So far it has proved peculiarly destitute of molluscous fossils; but the teeth of Lamna have been found in it at several places; and McKay[f] states that at Amuri Bluff it contains many

Fig. 48. Moeraki Septarian Boulders.

beautiful foraminifera. Hector considered the Amuri Limestone a deep-water deposit, but in many places it is certain that it could not have been deposited far from the land. For example, in the Clarence Valley, which is a long rift-like gutter lying between the Seaward and Inland Kaikoura chains it occurs as a band over 40 miles long lying in the bottom of what must have been a deep narrow fiord at the time the beds were deposited.

The chalk at Oxford in Selwyn County has been correlated by McKay with the Amuri Limestone; and the occurrence of *Conchothyra parasitica* would at any rate tend to show that in the Oxford district we have an extension of the Upper Secondary

e. A. McKay, Repts. Geol. Expls., 1874-76, p. 178.
f. A. McKay, Repts. Geol. Expls., 1886-87, p. 90.



A. *Plesiosaurus australis.* B, C. *Polycotylus tenuis.* (After Hector.)

rocks of the Malvern Hills. The position of the chalk would lead to the belief that it was deposited in a deep clear inlet of the sea.

The material composing the Amuri limestone is very fine in texture. It appears to consist mainly of consolidated calcareous slime that was probably precipitated in comparatively still water by the action of marine algae.

Weka Pass Stone.

This is generally a hard grey limestone, sometimes sandy and flaky, and in places crowded with fucoid-like markings. At the Weka Pass, in North Canterbury, where it is typically developed it varies considerably in composition, the upper portion being often more calcareous than the lower, which, near its junction with the Amuri limestone, is merely a calcareous sandstone.

The Weka Pass Stone, in the Amuri Bluff, Kaikoura Peninsula, and Clarence districts is represented by or intercalated with grey earthy chalky marls. These are the *Grey Marls* of Hector and McKay, and always follow the Amuri Limestone and Weka Pass stone conformably[g].

The Weka Pass Stone seems to be entirely destitute of molluscan fossils. The only organic remains hitherto found in it are the fucoid-like stems referred to above, and a few broken plates and spines of an echinoderm doubtfully referred to *Micraster*. In the chalky marls at Amuri Bluff McKay[h] found an *Amussium*, which he said resembled *A. Zitteli*. This, however, is not surprising, as the genus *Amussium* has a considerable range. In 1885, a pecten[i] that could not be distinguished from *A. Zitteli* was collected from the Jurassic mudstones on the Huntly-Kawhia road, associated with *Belemnites* and *Inoceramus*.

The Island Limestone near Whangarei is frequently flaky and fucoidal, and in physical appearance closely resembles the Weka Pass Stone, with which it has been correlated. Broken echinoderm spines and plates are the only recognisable fossils that have been obtained from it. On the shores of the Whangarei Inlet this limestone is found resting conformably on the hydraulic (Amuri) limestone.

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g. A. McKay, Repts. Geol. Expls., 1874-76, p. 36.
h. A. McKay, Repts. Geol. Expls. 1874-76, p. 40.
i. J. Park, Repts. Geol. Expls., 1885, p. 144.

Local developments of the Island Limestone occur at Whangarei, Hikurangi, Kamo, Waiomio, Kawakawa, Maungatoroto, Pahi, Skelton's Hill, in every case associated with the hydraulic limestone.

Economic Minerals.—The Amuri limestone in may places contains all the constituents of a natural hydraulic cement; and at Mahurangi, north of Auckland, it is extensively quarried for that purpose.

The coals found in the basal conglomerates and sandstones at Whangarei, Shag Point, and Kaitangata are of great value and considerable extent. They are fully described in the chapter on the Coalfields of New Zealand.

Eocene Glaciation.—The confused pile of breccias and breccia-conglomerate at the base of the Waimangaroa Series, 1000ft. or more thick, would appear to be of glacial origin. According to this view the Eocene uplift was distinguished by a period of glaciation similar to, but probably less intense, than that of the Pleistocene.

Igneous Rocks of Amuri System.

So far as at present known this formation contains no evidence of contemporaneous volcanic outbursts; and it is only in the North Island that it appears to be intruded by later eruptives.

At Wade, some eighteen miles north of Auckland, the hydraulic limestone is associated with an intrusive mass of serpentine. The same rock is intruded at Tokatoka by a hornblende-andesite[j], and at Komiti Point by an augite-andesite[k].

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j. F. W. Hutton, Jour. Roy. Soc. N.S.W., Aug., 1889, p. 134.
k. F. W. Hutton, *loc. cit.*, p. 141.

CHAPTER VIII.

KARAMEA SYSTEM.

(*a.*) Oamaru Series
(Brown Coal Measures.)
(*b.*) Waimangaroa Series
(Bituminous Coal Measures).

Synopsis.—This is a great succession of marine and fluvio-marine beds ranging from Upper Eocene to Middle, or, perhaps, Upper Miocene. It possesses an economic importance second to no other formation in New Zealand, its claim to this pre-eminence resting on a two-fold basis. In the first place it embraces the two principal coal-bearing formations of the Dominion, namely, the Waimangaroa Series containing the fine bituminous coals of Western Nelson; and the Oamaru Series, containing the valuable brown coals of Auckland, Wellington, Canterbury, Nelson, Otago, and Southland. In the second place it occupies the undulating downs of Eastern Otago and Canterbury, so justly famed for their wonderful fertility.

In Western Nelson, the two coal-bearing formations exist in stratigraphical conformity, as shown by Hector, Cox, and McKay, in the Grey and Buller coalfields, and by the author in the West Wanganui area. Wherever the two formations are present there is an unbroken succession from the basal conglomerates to the marine limestone which closes the Oamaru Series. At the same time the presence of the upper grits, conglomerates and coal afford proof of a cessation of the general subsidence which accompanied the deposition and preservation of the lower coal-measures. There was a return to terrestrial conditions for a time, but we have no evidence of a sufficient uplift to permit the denudation of the newly-formed lower measures.

The lower measures contain half a score, or more, of seams of superior bituminous coal occurring in two horizons; the upper measures frequently two or three seams of which, it rarely happens, that more than one is workable.

The lower, or bituminous, measures exist only in the western portion of Nelson. Elsewhere, in their absence, the Oamaru Series rests unconformably on various Palæozoic and Mesozoic formations, the contained seams of brown coal invariably occurring within a few yards of the basement rock.

The members of the Karamea System, with two notable exceptions, are not involved in the great tectonic folds of the Mesozoics and older rocks that comprise the great mountain chains of the North and South Islands; but they are in many places deeply entangled along the course of powerful crustal fractures, as for example in the Clarence and Waitaki rift-valleys, and along the course of the maritime Awarua fault, which runs parallel with the coast-line north of Milford Sound. This great fracture intersects the extreme end of the projecting headlands, between Martin's Bay and Barn Bay, tilting the lower Tertiary strata on end against the Palæozoic rocks[l].

The marginal distribution of the rocks of the Karamea System; the manner in which they ramify into and around the narrow fiord-like valleys in Nelson, and Otago; and the mantling sheet they form in Western Nelson, gradually ascending from sea-level up to 4,000 feet on the higher slopes of the main divide, seem to afford indubitable evidence that the main tectonic features of the country were already determined before the advent of the Cainozoic epoch. But the notable examples of infolding of the Tertiaries referred to above deserve more than passing mention, since, quite apart from the problems of crustal dynamics they present to the stratigraphist, they afford conclusive proof of progressive folding and mountain-building in some portions of New Zealand as late as the Middle Tertiary.

At Bob's Cove, Lake Wakatipu[m], the whole formation of Tertiary strata, comprising a thickness of 1,495 feet, is deeply involved in an overturned fold of the Maniototian mica-schist, the upturned edge or outcrop of the rocks being also sharply warped or twisted into the form of the letter Z.

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l. J. Park, Reports Geo. Expls., 1886-87, p. 131.
m. J. Park, "Bulletin No. 7 (New Series)," N.Z. Geo. Survey, p. 65.

On the lower, or footwall, side of the great overturned fold there is another and sharper fold in which there is entangled a narrow wedge of Tertiary breccia-conglomerate varying from 14 to 150 feet thick. This remarkable fold has been named the Moonlight Overthrust. With its contained wedge of Tertiary strata, it can be traced from Lake Wakatipu northward into the upper waters of the Shotover, a distance of twenty-five miles. It runs across mountain and valley, rising in places to a height of over 5,000ft. above the sea, in others descending to a little over 1,000ft., but is not now continuous, having been removed by denudation in some of the deeper gorges.

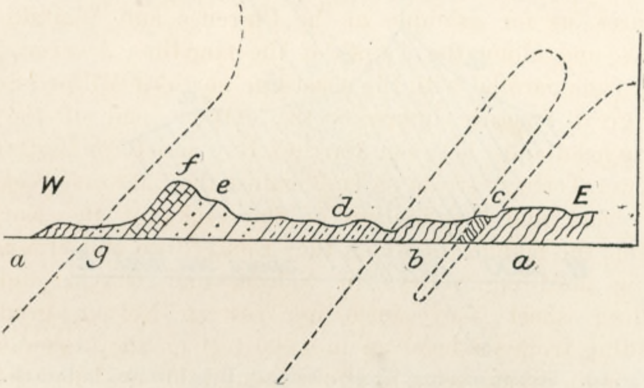

Fig. 49. Section from Bob's Cove towards Twelve-mile Creek showing involved Tertiaries.

a. Mica-schist, crushed and brecciated. *b*. Mica-schist, soft and crumbling. *c*. Infolded Tertiary marine breccia-conglomerate, 65 ft. thick. *d*. Marly clays. *e*. Marly sandstones. *f*. Limestone. *g*. Sandstone and conglomerate.

It is a geological feature of extraordinary interest, and, so far as known at present, there is nothing comparable to it except the narrow wedge-like strips of nummulitic limestone (Eocene) involved in the Malm (White Jura) on the west side of the Jungfrau, in the Bernese Oberland, in Switzerland. It was first noted by McKay in the year 1880, but its significance appears to have escaped the notice of Captain Hutton when discussing the mountain-building of the New Zealand Alps at a later date.

The main significance of this narrow band of involved Tertiaries, the constituent rocks and fossils of which are such as would be deposited on the shores of a rocky strand, lies in the evidence it affords as to the age of the mountains of Western Otago. Here we have a portion of a marine littoral involved in a great crust-fold, and elevated to a height exceeding 5,000ft. above the sea, affording the clearest proof that a sea-floor existed in the early Miocene where the Richardson Mountains now stand. The horizontal distance through which the Tertiary strata have been pushed by the folding movement cannot be less than two miles, and may even exceed five.

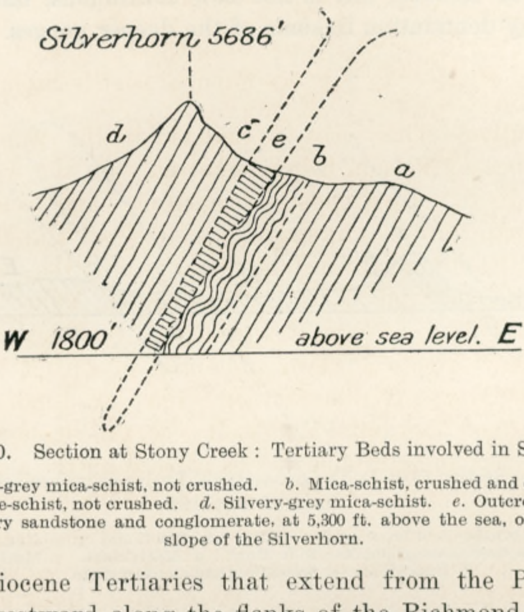

Fig. 50. Section at Stony Creek: Tertiary Beds involved in Schists.

a. Silvery-grey mica-schist, not crushed. *b*. Mica-schist, crushed and contorted. *c*. Chlorite-schist, not crushed. *d*. Silvery-grey mica-schist. *e*. Outcrop of band of Tertiary sandstone and conglomerate, at 5,300 ft. above the sea, on the east slope of the Silverhorn.

The Miocene Tertiaries that extend from the Port Hills, Nelson, westward along the flanks of the Richmond Hills, are completely overturned, being involved in an overfold of the neighbouring Triassic and Carboniferous strata forming the north side of the Dun Mountain range. (See Fig. 18.)

Contemporaneous Freshwater Deposits.—The floor of the ancient lake basins of Central Otago are occupied by a succession of freshwater deposits to which an older Pliocene or Miocene age has been at different times ascribed. There are seven distinct basins in which these sediments occur, namely, the Maniototo, Ida Valley, Manuherikia, Cromwell, Kawarau, Cardrona, and Roxburgh.

The first three were formerly united, forming a great inland lake to which at one time the sea had access. At the north-east corner, near the base of the series, the lacustrine beds are intercalated with thin layers of marine sediments, containing a molluscous fauna that is believed by McKay to be Miocene. According to this view the Manuherikia lacustrine series is the freshwater equivalent of the Oamaru Series.

Waimangaroa Series.

(*a.*) Brunner coal horizon.
(*b.*) Paparoa coal horizon.

Distribution.—This series is confined to the West Coast of the province of Nelson, being found only on the west side of the main divide. It extends as a maritime band from the Grey Valley northward to Pakawau in Collingwood, a distance of 160 miles. Going northwards it wraps around the flanks of the Paparoa Range; and in the Waimangaroa Valley, north of Westport, it occurs in the Coalbrookdale basin at a height of 1,800ft. above the sea. Two miles east of this it lies on the summit of Mount William at a height of 3,400ft. In the Ngakawau and Mokihihui Valleys it occurs at sea-level near the coast-line, but going inland it rises rapidly on the slopes of the dividing chain until it attains a height of 3,700ft. above the sea.

Rocks.—The rocks of this series consist of the great Inangahua conglomerates that in places pass into coarse breccias near the base of the formation. The thickness of these beds varies from 200ft. to 1,000ft., according to the local conditions that prevailed at the time of their deposition. The conglomerates are followed by a succession of shales, grits, and micaceous sandstones, comprising the Paparoa Beds, that contain many seams of fine bituminous coal. In the shales and sandstones are found fossil leaves of dicotyledinous trees, including those of the oak, elm, beech, myrtle, laurel, pines, etc.

Thickness of Beds.—The total thickness of the Karamea system of Lower Tertiary strata is given by Hector at 5,100ft., of which 2,300ft. are ascribed to the lower coal-measures, and 2,800ft. to the upper measures (Oamaru Series).

The lower measures are purely fluviatile gravels and sand that were piled up on an ancient strand until the strip of uneven sea-floor running parallel with the coast-line was filled in and reclaimed from the sea. On this newly reclaimed land the coal-vegetation established itself and grew luxuriantly until covered over by the encroachment of sands and mud. The succession of seams that occurs in these measures proves that general subsidence was accompanied by intervals of rest during which vegetation was able to re-establish and maintain itself for a time.

The upper or brown coal measures are estuarine, while the succeeding and closing members of the series are marine.

The lower coal-measures are confined to the maritime strip of land which, as we have seen, was reclaimed along the sea-board; but the upper measures and succeeding beds in rising inland on to the flanks of the mountains gradually overlap the lower measures. As a result of this overlapping the lower measures disappear going eastward, the Oamaru Series being found lying directly on the Palæozoic basement rocks, as may be seen in the Inangahua, Buller, Maruia and Owen valleys, and on the main divide at the sources of the Mokihinui, Karamea, and Wangapeka.

On the Mount Arthur Tableland, the Oamaru Series is found at an altitude of 3,700ft. above the sea, there consisting of a bed of tabular shelly limestone and an underlying thin bed of conglomerate. In some places, however, the limestone is found riding hard on the basement rock, the recession of the comparatively steep shore-line having permitted it to overlap the lower members.

Thus in a distance of 28 miles the Karamea System, consisting of a pile of sediments 5,100ft. thick along the western boundary, is found to thin out to less than 100ft. thick, affording a conspicuous example of the overlap that takes place on a sinking and receding shore-line.

The progressive overlap of sediments must always be a concomitant of the subsidence of a shelving shore-line; but subsidence with its consequent overlap does not necessarily imply a sensible decrease in the thickness of the sediments laid down. Such decrease can only take place when the magnitude of the subsidence is so great as to seriously diminish the area of denudation. There is good reason for the belief that the thinning of the sediments of the Karamea System going northward can be directly attributed to this cause.

When the lower coal-measures were laid down as a fringe along the late Eocene shore-line, the main divide was a broad mountain chain standing from 5,000ft. to 7,500ft. above the sea and drained by many torrential streams that carried the products of erosion and denudation down to the sea, where they were spread out on the floor until a maritime plain was prepared for the growth of the coal-vegetation.

The depth of the sediments laid down on a sinking floor must always be an approximate measure of the extent of the submergence when due allowance is made for the depth of the water in which the sediments were laid down. In the present case, judging from the form and contours of the existing watershed, it is certain that when the subsidence amounted to 2,000ft., the area of denudation was diminished by probably one-half, and that when it amounted to 3,500ft., there was not more than one-quarter of the original surface exposed to denudation, the main divide being then reduced to a narrow steep chain flanked by a few ridges and small rocky islets.

Coal-bearing Horizons.—There are three coal-bearing horizons in the Karamea System on the West Coast as follows:—

Upper Coal Measures:—

(*a.*) Brown and pitch coals—Reefton horizon.

Lower Coal Measures:—

(*b.*) Brunner bituminous coal horizon.

(*c.*) Paparoa anthracite coal horizon.

The Reefton coal-measures occur at the base of the Oamaruian, and are therefore the time equivalent of the brown coals of the Waikato, Raglan, Waipa, and Mokau areas, in the North Island; and of the brown coals at West Wanganui, Motupipi, Nelson, Tadmor, Wangapeka, and Green Island, near Dunedin.

In the Grey district there is no coal at the base of the Oamaruian, the coal being represented by streaks and nests of coaly matter. Proceeding northward, continuous seams of good coal are developed along the ancient Tertiary strand where the Oamaruian overlapped the lower coal-measures, and now rests on the Mesozoic or Palæozoic basement. The seams are variable in thickness.

North of the Buller, the Brunner coal-measures overlap the Paparoa measures; and the enormous pile of basal conglomerate that underlies the Buller coals thins out to a few score feet at Mokihinui.

At Puponga, near Cape Farewell, both the upper and lower conglomerates are present. Seams of coal overlie the lower conglomerate, but none have been found overlying the upper. Brown coals appear in their proper place in grits and sandstones below the Paturau coastal limestone. Bed No. 1 of Fig. 51 contains *Pseudamussium Huttoni*, *Meoma Crawfordi*, etc.

Fig. 51. Section across Puponga Point.

1. Calcareous greensands. 2. Grey sandstones and grits with pebbly bands. 3. Coarse ferruginous pebbly sandstones; 150 ft. 4. Coarse conglomerates and pebbly sandstones; 350 ft. 5. Ferruginous sandstones and shales, containing thin coal-seams; 300 ft. 6. Coarse conglomerates.

Succession of Strata.

The succession of Tertiary strata at the Pakawau, Buller, and Grey coal-fields has the same general character, comprising the following groups of beds, as distinguished by Hector in 1869:—

(*a*.) Tabular (Cobden) limestone passing down into calcareous greensands, containing *Pseudamussium Huttoni*, *Cirsotrema lyrata*, *Meoma Crawfordi*, and the remains of the gigantic penguin *Palæeudyptes antarcticus*. Thickness, 700ft.

(*b*.) Tough blue clays with tabular calcareous layers, containing *Pseudamussium Huttoni*, *Plagiostoma lævigata*, and *Meoma Crawfordi*. About 800ft. thick.

(*c.*) Sandy and marly clays with *Amussium Zitteli* and foraminifera. About 400ft. thick.

(*d.*) Sandstones and pebbly grits that going northward pass into conglomerates with brown coal. Thickness about 400ft.

(*e.*) Tough blue clay passing down into argillaceous and micaceous sandstones, with seams of coal from 4ft. to 10ft. thick. Limonitic concretions in the micaceous sandstone contain *Cardium Brunneri.* Thickness about 1,000ft. Brunner coal-beds.

(*f.*) Conglomerates, attaining a thickness of 800ft.; sometimes absent or pass into sandstones.

(*g.*) Micaceous sandstones, grits and shales, with many seams of bituminous coal varying from 4ft. to 20ft. thick, and containing an abundance of fossil leaves of dicotyledonous trees, zamias and palms. Paparoa coal beds.

(*h.*) Conglomerate with sometimes an angular breccia at the base, from 200ft. to 1,000ft. thick.

The succession and lithological characters of the constituent members of the Oamaru Series are almost the same on both coasts.

West Coast.	East Coast.
(*a.*) Cobden limestone.	(*a.*) Ototara Stone.
(*b.*) Tough blue clays.	(*b.*) Marawhenua beds—clays and sands.
(*c.*) Sandy and marly clays with hard tabular layers and concretions.	(*c.*) Waihao beds—sandy clays with hard tabular layers and concretions.
(*d.*) Sandstones and grits with brown coal.	(*d.*) Kaikorai grits and sands with brown coal.
(*e.*) Brunner sandstones, etc., with bituminous coal.	Absent.
(*f.*) Paparoa sandstones and conglomerates with antracitic coal.	Absent.

Relationship to Oamaru Series.—Hector[n] and McKay[o] have always maintained that the coal formations of the West Coast of the South Island consisted of a continuous succession of strata belonging to one system; and the author's observations[p] at the Grey, Buller, Mokihinui, West Wanganui, Upper Karamea, and Pakawau enable him to concur fully in this view.

The tabular limestone and associated glauconitic sands (Beds *a*), which close the sequence were correlated by Hector with the Kakanui limestone near Oamaru, in which the bones of the giant penguin *P. antarcticus* described by Huxley were first discovered associated with *Pseudamussium Huttoni*, *Meoma Crawfordi*, that are also characteristic of the Cobden limestone. This correlation, made so early as 1869, was afterwards confirmed by McKay, Cox, and the author; and has never been challenged by anyone acquainted with the Tertiary formations on both coasts.

The Waipara Series, with its characteristic members, the Weka Pass Stone, the Amuri limestone, and associated Saurian beds, are not present on the West Coast; and no Mesozoic fossils have ever been found in any part of the coal-bearing series in that region, the supposed large species of *Inoceramus* mentioned by Hector as occurring in the upper calcareous beds, associated with *Pseudamussium Huttoni*, *Cirsotrema lyrata*, and *Meoma Crawfordi*, having been found to be *Plagiostoma lævigata*, which is well-known in the Oamaru Series in both islands.

After a careful analysis of the evidence, the author is compelled to agree with Hutton[q] that the bituminous coals of the West Coast cannot be correlated with the Shag Point coals of the Waipara Series. There is no trace of any relationship between them. On the other hand the bituminous coal series underlies the Oamaru Series conformably, and must be regarded as belonging to the same stratigraphical system. It is merely an extension of the basement beds of the Tertiary series that is not represented on the east side of the axial divide

n. J. Hector, Trans. N.Z., vol. xxii., 1869, p. 345; Repts. Geol. Expls., 1871-72, p. 130; Repts. Geol. Expls., 1890-91, p. xxxviii.

o. A. McKay, Repts. Geol. Expls., 1874-76, p. 113, and *loc. cit.*, pp. 40-41.

p. J. Park, Repts. Geol. Expls., 1888-89, p. 238.

q. F. W. Hutton, Trans. N.Z. Inst., vol. xxii., p. 387.

proving that deposition began somewhat earlier on the west than on the east side of the South Island, a result that could only be due to subsidence beginning earlier in that region.

Nomenclature.—The upper and lower coal formations are fully represented in the Karamea district, where they were first described by Hector, and for that reason it seems only a deserved compliment to that geologist that the name "Karamea" should be used to designate the whole system. To the lower coal-series has been affixed the name "Waimangaroa," after the river of that name within the watershed of which is situated an important portion of the Buller Coalfield, and wherein the bituminous coal-measures are typically developed. Even if the lower coal-measures be considered as merely an earlier development of the basement beds of the Oamaru Series, it is still necessary to distinguish them by some place-name, and none other seems so appropriate as "Waimangaroa" from the dual standpoint of the miner and geologist.

Age of Lower Coal Measures.—The deposition of the overlying Oamaru Series probably began towards the close of the Eocene and continued throughout the greater part of the Miocene. The bituminous coal-measures are conformable to but older than the basement beds of the Oamaru Series as developed on the East Coast, and must therefore be referred to the Upper Eocene.

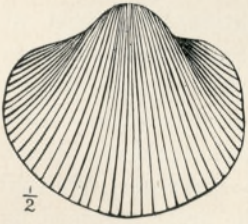

Fig. 52.
Cardium Brunneri.
(Hector.)

The sediments are fluviatile and fluvio-marine. They contain no evidence whatever of a Cretaceous age. On the contrary, the character of the dicotyledinous leaves in the coal shales indicate the existence of a purely Tertiary flora that singularly enough was more nearly related to the lower Tertiary flora of Tasmania and the present flora of Europe than to the existing flora of New Zealand.

The sandstones overlying the coal contain the well-known form *Cardium Brunneri*, which, however, has no age significance.

Oamaru Series.

Syn.: *Oamaru Series of Hutton less the Weka Pass Stone.*

(*a.*) Ototara Stone.
(*b.*) Pareora Beds.
(*c.*) Marawhenua Greensands.
(*d.*) Waihao Beds.
(*e.*) Kaikorai Coal Measures.

The Oamaru Series, like the Waipara, represents a complete cycle of deposition beginning with fluviatile drifts and ending with a calcareous marine sandstone or limestone, the whole succession of sediments having been deposited on the slowly sinking marine shelf, that contoured around the ancient Cretaceous strand of New Zealand.

During the late Pliocene uplift of the South Island this marginal fringe of newly formed lower Tertiary deposits was everywhere deeply dissected, and in some areas completely destroyed. On the East Coast of the South Island the destruction was less than on the West Coast, while the converse is true of the North Island, in each case denudation being greatest on the side possessing steep slopes drained by short torrential streams.

Isolated patches of the Oamaru formation still exist at Preservation Inlet, Waiau, and Winton in Southland; while an almost continuous band of varying width follows the present coast-line from South Otago to the Orari River, in South Canterbury, being especially well-developed between Milton and Dunedin, at Waikouaiti, Oamaru, Kakanui, Waitaki Valley, Waihao, Pareora, and Kakahu. The areas occupied by these rocks in North Canterbury, Marlborough, Nelson, and Westland are generally of small extent, the largest and most important being those in the West Wanganui district of Collingwood County, and in the Buller and Grey coalfields.

The Oamaruian covers a considerable area on the west coast of the North Island, extending in a continuous band from the Upper Wanganui into the Mokau, and thence northward to Kawhia, Raglan, and Lower Waikato. Many isolated remnants occur on the shores of the Hauraki Gulf, notably at Cabbage

Bay, Miranda, Papakura, and Auckland. From the Waitemata the series spreads northward to Cape Rodney on the East Coast, and to the Kaipara on the West Coast, where the basement beds are well-developed, notably at Komiti Point and Pahi on the Otamatea Arm.

Basement Rocks.—In the Waipara district, in several parts of Marlborough, and in the country between Onekakara, near Hampden, and the Upper Kakanui, the Oamaru series rests on the Waipara formation; elsewhere it lies directly on the older Mesozoic or Palæozoic basement rocks. Thus in the Province of Otago it rests principally upon mica-schist and altered sedimentaries; in Canterbury, upon Lower Mesozoic clay-stones and sandstones; and in Nelson and Westland passes down into the bituminous coal-measures which rest on granite, mica-schist, quartzites, slates, and other altered rocks.

Influence of Basement Rocks.—In the places where the Oamaru Series rests upon Lower Mesozoic or Palæozoic rocks its lowest member consists of grits and conglomerates, derived from the erosion of the adjacent country. Coal, too, generally occurs with these rocks—at any rate near the old shore-line; but in the localities where the series rests upon the members of the Waipara formation the grits, conglomerates, and coal are absent. The absence of the grits and conglomerates is doubtless due to the lack of the requisite hard rock in the Waipara series to supply resistant material, but the absence of the coal is the result of causes which are not very obvious.

Effects of Differential Elevation.—For the most part, the Oamaru Series forms the maritime hills and downs of Otago and Canterbury, Nelson, and Westland. It gradually ascends as it proceeds inland, in many places rising to an elevation of between 2,000ft. and 3,000ft. in the inland basins and valleys and on the flanks of the foothill ranges. And this feature is not confined to the East Coast alone—it is equally true of the western portion of the Province of Nelson, and of Westland, as the examples given hereafter will show.

In North Otago the Ototara Stone and its associated strata ascend the Waitaki Valley a distance of over fifty miles from the sea, ending in the mountain-girt Wharekuri basin, which is only a few square miles in extent. Here the Tertiary beds reach a height of over 2,300ft. above sea-level.

In the Trelissic basin the Oamaru Series rises to a height of 3,200ft. This basin is somewhat less than four miles square, and surrounded on all sides by steep mountains.

In the Waipara district the same beds form ridges reaching over 1,800ft. high at their highest parts.

The old Tertiaries at the lower end of the Takaka Valley in Nelson occur at sea-level, but they rise with the gradient of the valley, and gradually ascend till in a distance of thirty miles they reach Mount Arthur Tableland, 3,700ft. above the sea, where they are almost horizontal. From the tableland going southward the same beds cling to the western flanks of the main range at elevations varying from 2,000ft. to 3,000ft., descending westward towards the sea at Mokihinui and Westport and intermediate places. This mantling fringe of Middle Tertiary marine rocks ascending from sea-level on both coasts affords a measure of the elevation of the land since the beginning of the Pliocene, and, moreover, clearly proves the differential rate of the upward movement.

The greatest elevation has in all cases taken place along the main axis of the Island, which is situated closer to the west coast than the east. The differential land-movement being most acute on the west coast introduced unequal stresses in that area which resulted in extensive faulting of the coal-measures between the sea and the axial divide. A notable example of this faulting occurs in the Aorere Valley near Collingwood. On the south side of the river the Tertiaries lie at sea-level, but on the north side they crown the range at an elevation of 1,000ft., and dip westward.

Contemporaneous Volcanic Eruptions.—While the sediments of the Tertiary fringe were accumulating on the littoral of the Miocene seas, volcanic eruptions commenced in the area lying between Moeraki and Oamaru. They were submarine, and took place at points lying some miles to the seaward of the old shore-line, most notably in the areas now known as Ngapara, Waiareka, Oamaru, and Kakanui. These eruptions were not very violent; and it was only at Kakanui, and perhaps at Oamaru, that the ejected materials were piled up so as to form islands. So far as can be ascertained from the distribution of the matter, the volcanic activity began after the close of the Waihao horizon, and ended before the deposition of the Ototara Stone began. The main outbursts were apparently confined to the Mount Brown period.

The most violent outbursts took place between Oamaru and Kakanui River, where the middle and upper horizons of the Oamaru Series are intercalated with thick beds of basic ash, or tuff, and some flows of basalt.

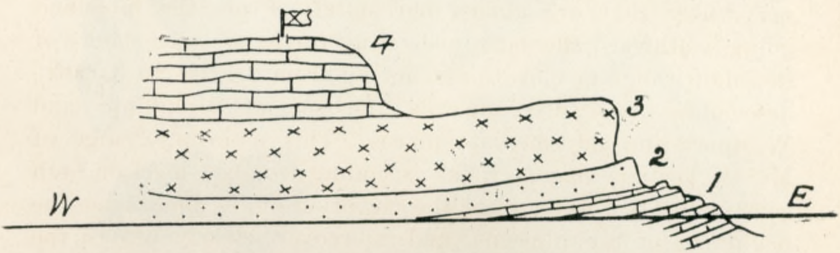

Fig. 53. Showing tuffs and basalt intercalated with Kakanui limestone.

1. Calcareous sandstone, fossiliferous. 2. Tufaceous greensands, fossiliferous.
3. Tuffs and basalt flow. 4. Calcareous sandstone passing into shelly limestone.

There is reason to believe that the volcanic eruptions in the Hauraki Gulf area which produced the tuffs imbedded with the Waitematas at Parnell, Auckland, were contemporaneous with those near Oamaru.

Life of Oamaru Series.—At the time of the deposition of the sediments of this formation there lived in the New Zealand seas a zeuglodon whale (*Kekenodon onemata,* Hector), a giant penguin (*Palæeudyptes antarcticus,* Huxley), a huge shark (*Carcharodon megalodon,* Agassiz), a ray (*Myliobatis plicatilis,* Davis), as well as a large nautilus (*Aturia australis,* McCoy). In the deeper waters there flourished a great variety of corals, bryzoans, and *Foraminifera,* and with these many brachiopods, pectens, and echinoderms. In the shallow water and estuaries there lived a great assemblage of molluscs, many of which were remarkable for their large size.

Tertiary Fossils. Lower Oamaruian.

Fig. 1, *a*, *b*. *Purpura textiliosa*, Lam.
,, 2. *Turbo superbus* Zittel.
,, 3, *a*, *b*. *Crassatellites ampla*, Zittel.
,, 4. *Toredo Heaphyi*, Zittel.
,, 5, *a*, *d*. *Rhynchonella nigricans*, Sow.
,, 6, *a*, *d*. *Terebratella dorsata*. Gmel.

$\frac{5}{8}$ natural size. (After Zittel.)

Among the shells, which grew to a great size in these genial Tertiary seas, were the following:—

Ostrea Wullerstorfi, Zittel.
Pecten athleta, Zittel.
Pecten Beethami, Hutton.
Pecten Hutchinsoni, Hutton.
Pseudamussium Huttoni, Park.
Plagiostoma lævigata, Hutton.
Cucullæa ponderosa, Hutton.
Cucullæa alta, Sowerby.
Crassatellites ampla, Zittel.
Scalpellum Aucklandicum, Hector.
Dosinia magna, Hutton.
Cardium patulum, Hutton.
Dentalium giganteum, Sowerby.
Pleurotoma Hamiltoni, Hutton.
Pleurotomaria tertiaria, McCoy.
Cirsotrema lyrata, Zittel.
Turritella Cavershamensis, Harris.
Natica Darwini, Hutton.

It should be mentioned that the beds of the Oamaru Series are nearly everywhere horizontal, or inclined at low angles. Hence in those areas where the formation has been dissected by valleys the harder calcareous members form conspicuous lines of escarpment that follow the configuration of the landscape like the contour lines on a map.

Age of Oamaru Series.—In Europe, where the Tertiary record is complete, it is comparatively easy to divide the scale of time into small units each characterised by some peculiar feature of its fauna or flora; but in New Zealand, where the Eocene cannot be distinguished with certainty, and where the Middle Tertiaries contain a purely local fauna, of which from 20 to 30 per cent. is still living, it is not possible to refer the beds with any degree of accuracy to the finer divisions recognised in the Northern Hemisphere.

In 1906 Hutton[r] stated that several genera of marine mollusca that appear in the Eocene of Australia did not reach New Zealand until the Miocene and Pliocene periods.

The large proportion of living species which it contains[s] compels us to refer the Oamaru Series to the Miocene.

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r. F. W. Hutton, "Index Faunæ Novæ-Zealandiæ," p. 7.
s. J. Park, "On the Marine Tertiaries of Otago and Canterbury," Trans. N.Z. Inst., vol. xxxvii., 1904, pp. 489-551.

Relationship of Oamaru Series to Lower Tertiary Beds in the North Island.—The marine Tertiaries in the Waitemata district of Auckland will be first considered.

The pectens which distinguish the Mount Brown horizon of the Oamaru Series are also characteristic of the middle division of the Waitemata beds near Auckland, which yielded a number of the types originally described by Zittel.

Among the forms common to the middle division of the Oamaru formation and the Waitemata beds are *Pecten Fischeri*, *P. vellicatus*, *P. polymorphoides*, *P. Williamsoni*, *Pseudamussium Huttoni*, and *Amussium Zitteli*. A large number of the corals, bryzoans, and *Foraminifera* found in the Orakei Bay beds are also present in the lower limestone at Kakanui and Teschemaker's, commonly associated with the pectens enumerated above. On the other hand, the brachiopods, which are so plentiful at Kakanui, Hutchinson Quarry, Waitaki Valley, Mount Brown, and some parts of Mount Donald, are practically absent from the Waitematas, but are plentiful at Cape Rodney and Komiti Point. This, however, can hardly be regarded as surprising in places so widely separated. Even in the Oamaru and Waipara districts the brachiopods are by no means evenly distributed in the same bed, but commonly occur in colonies, often comprising a vast number of individuals.

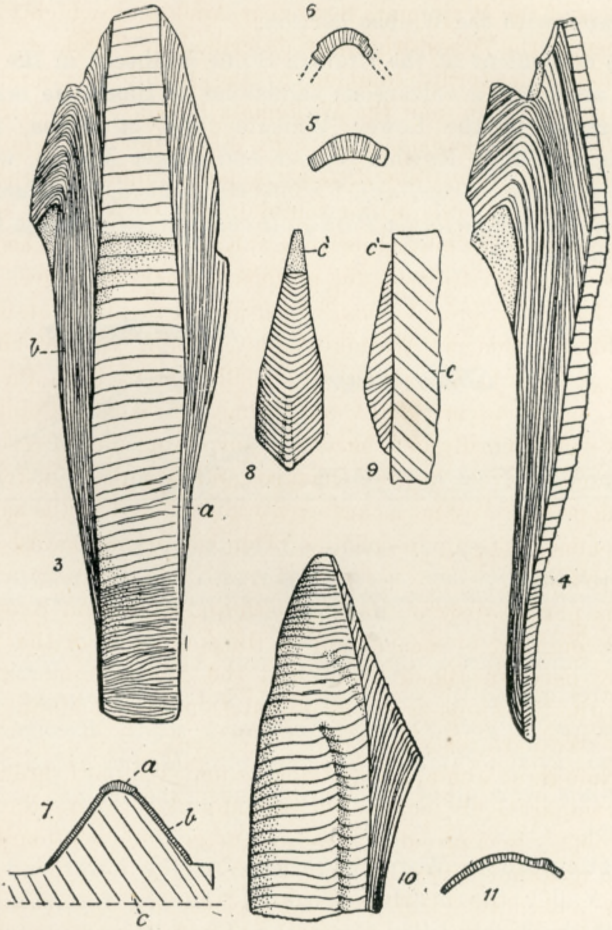
This partial distribution in horizontal extension is well seen in the long line of escarpment on the south side of the Waitaki Valley between Black Point and the Marawhenua, and also along the limestone crests of Mount Donald and Mount Brown, in the Waipara district.

Although so abundant at Oamaru and Waipara, brachiopods are comparatively scarce in the Mount Brown (Caversham Sandstone) horizon at places in Otago and Southland south of the Kakanui River.

The palæontological evidence seems, at any rate, to be sufficiently strong to connect the middle horizon of the Oamaru Series, comprising the Kakanui, Hutchinson Quarry, Mount Brown, and Mount Donald beds, with the Orakei Bay beds of the Waitematas of Auckland.

The basement beds or lower division of the Waitematas, as exposed at Cape Rodney, Kawau Island, Motutapu Island, and

PLATE VII.



A giant Cirripede *(Pollicipes ? Aucklandicus)* from Oamaruian Base of Waitemata Beds, Auckland (after Benham).

Figs. 3-7, the carina ; Figs. 8-9, the rostrum ; Figs. 10-11, the latus (?).

All figures ⅔ nat. size.

Papakura, contain a molluscous fauna which includes many of the characteristic fossils of the Waihao horizon of the Oamaru Series, as for example, such characteristic forms as *Ostrea Wullerstorfi*, *Pecten Burnetti*, *P. Beethami*, *Crassatellites ampla*, *Pseudamussium Huttoni*, *Rhynchonella nigricans*, and should be correlated with the Waihao horizon.

The equivalent of the Ototara Stone is absent in the Waitemata area, but a calcareous sandstone or limestone makes its appearance in the Lower Waikato, and at Aotea, Raglan, Pirongia, Waipa, Kawhia, Upper and Lower Mokau, where it contains *Meoma Crawfordi*, *Cirsotrema Browni*, *Pseudamussium Huttoni*, and *Magellania Parki*, all characteristic of the Ototara Stone horizon.

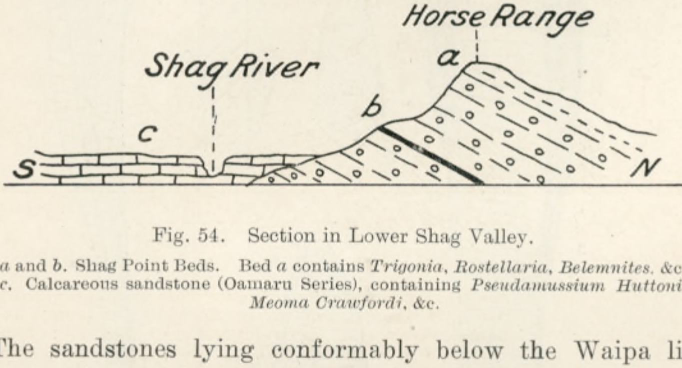


Fig. 54. Section in Lower Shag Valley.

a and *b*. Shag Point Beds. Bed *a* contains *Trigonia*, *Rostellaria*, *Belemnites*, &c. *c*. Calcareous sandstone (Oamaru Series), containing *Pseudamussium Huttoni*, *Meoma Crawfordi*, &c.

The sandstones lying conformably below the Waipa limestone, resting on the coal-measures, contain *Cirsotrema Browni*, *Calyptræa calyptræformis*, *Cassidaria senex*, *Pseudamussium Huttoni*, *Pecten Fischeri*, *Cucullæa alta*, *Lucina divaricata*, and *Dentalium lævis*, all of which are found in the Waihao beds above the coal.

Relationship to Waipara Series.—At the lower end of the Shag Valley the nearly horizontal Oamaru formation abuts against the highly tilted Cretaceous Shag Point beds in such a way as to indicate a well-marked stratigraphical unconformity.

This unconformity was recognised by Hector in 1862, and figured by him in the coloured manuscript section across Otago now hanging in the Otago School of Mines, at the University, Dunedin.

At Weka Pass the unconformity cannot be distinguished as the flat-shelving Weka Pass Stone which closes the Waipara Series is followed by sandy clay beds which exhibit no bedding planes but are followed conformably by the Mount Brown calcareous beds, which possess practically the same angle of dip as the Weka Pass Stone[t], the stratigraphical relationship of the two formations being as already mentioned the same as that existing between the London Clay and Chalk in the south-east of England. The overlapping which prevents the exposure of the lowest beds of the Oamaru Series tends to show that the parallelism of the stratification is not so perfect as it appears to the eye. (See Fig. 55.) It is also found that faults which dislocate the Waipara beds do not affect the overlying formation. Moreover the Grey Marls, the youngest member of the Waipara formation, are absent.

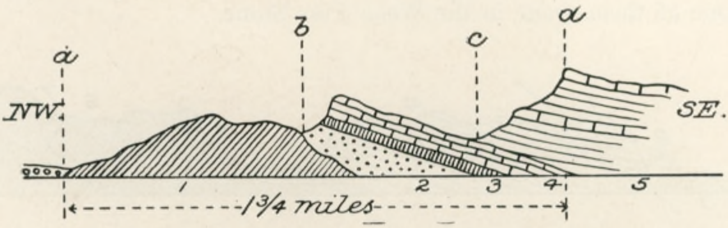


Fig. 55. Section from Waikari Flat to Mount Donald Range.

a. Waikari Flat. *b*. South-east boundary-line of Section 8198. *c*. Valley opposite viaduct. *d*. Mount Donald Range. 1. Palæozoic or Secondary claystones and sandstones. 2. Glauconitic greensands. 3. Amuri limestone. 4. Weka Pass Stone. 5. Tertiary beds.

A few miles north of the Waitemata the horizontal Waitemata beds rest unconformably on the hydraulic limestone which is correlated with the Amuri limestone—the middle member of the Waipara Series. And at Komiti Point, opposite Batley, the basement beds of the Oamaru Series also lie on a highly denuded surface of the hydraulic limestone, as shown in Fig. 56.

The Cretaceo-tertiary of Hector.—The Cretaceo-tertiary system of the old Geological Survey comprised both the Waipara and Oamaru formations, the confusion having arisen through the erroneous correlation of the Ototara Stone—the

t. J. Park, Trans. N.Z. Inst., vol. xxxvii., 1904, Figs 16 and 17, pp. 543, 544.

closing member of the Oamaru Series—with the Weka Pass Stone—the closing member of the Amuri Series.

The supposed discovery by Haast of the characteristic fauna of the Ototara Stone in the Weka Pass Stone was for long a stumbling block, barring the way to the unravelling of the tangled skein that in time became woven around the Cretaceo-tertiary problem.

Haast[u], in his report on the geology of Waipara district in 1869, gave a list of fossils purporting to have come from the Weka Pass Stone, and then further on stated that the greater part of the fossils came from the Curiosity Shop beds in South Canterbury. The species he enumerated are the fossils characteristic of the Mount Brown beds. Nearly all of them are present at Mount Donald, and can be collected from the loose fallen masses lying in Weka Pass, near the railway-line. None of them occur in the Weka Pass Stone.

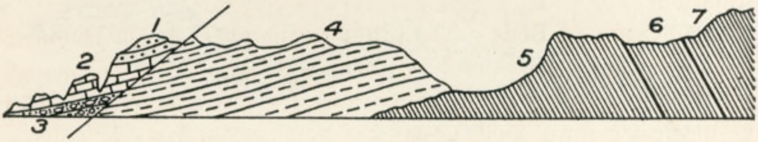


Fig. 56. Section at Komiti Point showing unconformity between Oamaru Series and Cretaceous hydraulic limestone.

1-4. Komiti Miocene beds. 5-7. Shaly clays and marlstones passing into hydraulic limestone.

Many of the large masses of Mount Donald Stone are strewn on the surface both above and below the outcrop of the Weka Pass Stone in the pass in the vicinity of the railway. The fossils credited to the Weka Pass Stone were, it would seem, obtained from these masses.

The Weka Pass Stone seems to be entirely destitute of molluscan fossils. The author spent many hours searching acres of its bare weathered surfaces, and only succeeded in finding a few broken echinoderm spines and a thin calcareous tube. The ganger at the railway quarry near the 45-mile post stated that he had never seen a trace of fossils in the stone, of which tens of thousands of tons had been broken.

u. Julius von Haast, Reports of Geol. Expls., 1870-71, p. 13.

The problem was made all the more difficult from the fact that the succession of beds constituting the Oamaru Series showed a general resemblance to that of the Waipara Series. But beyond this general resemblance there was no further relationship. For the Waipara Series contains a scanty fauna that is purely Cretaceous; while the rich and varied fauna of the Oamaru Series is distinctively Tertiary.

In the Waipara district the Tertiary and Cretaceous formations are both well developed, the one resting on the other.

Captain Hutton contended that there was an unconformity between the Weka Pass Stone and the Amuri limestone, the former being attached by him to his Oamaru Series. Hutton was doubtless influenced in thus separating the Weka Pass Stone from the Amuri limestone by the supposed occurrence of Ototara fossils in the Weka Pass Stone itself. McKay[v], has sufficiently shown that the Weka Pass Stone and Amuri limestone are quite conformable and members of the same formation.

Classification of Beds.—The different members of the Oamaru Series exhibit a wonderful uniformity of character from one end of New Zealand to the other, and are easily separated into five natural groups, each possessing some peculiarity of constitution or distinctive fossils which render its identification and correlation in distant places comparatively easy. The typical succession of deposits is as shown below:—

(*a.*) Limestone or calcareous sandstone.
(*b.*) Clays and sandy beds.
(*c.*) Glauconitic sands and calcareous sandstone.
(*d.*) Marly clays and sandstones.
(*e.*) Quartz sands and conglomerates with brown coal.

For these groups the following names have been adopted:—

(*a.*) Ototara Stone.
(*b.*) Pareora Beds.
(*c.*) Marawhenua Greensands.
(*d.*) Waihao Beds.
(*e.*) Kaikorai Quartz sands and grits with seams of brown coal.

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v. A. McKay, Reports of Geol. Expls., 1886-87, p. 78.

In the district lying between Oamaru and Kakanui, and in the Waipara and Weka Pass districts of North Canterbury, there are two calcareous members representing the Ototara Stone and Marawhenua Greensand horizons respectively. In the Oamaru district, the lower of these two calcareous horizons is the well-known Oamaru building stone. The beds lying between the Ototara stone and the Oamaru Stone are certain fossiliferous sandy clays and sandstones to which the local names Awamoa or Pareora were applied by McKay in 1874.

The most complete development of the lower Tertiaries is in the Oamaru district, where we have the following succession:—

(*a.*) Ototara Stone.
(*b.*) Awamoa Beds (Pareoras).
(*c.*) Hutchinson Quarry Greensands.
(*d.*) Oamaru Stone.
(*e.*) Waiareka tuffs and sandstones.
(*f.*) Ngapara quartz grits, shale and brown coal.

In the Waipara and Weka Pass districts the succession is as follows:—

(*a.*) Upper Mount Brown Stone—(Ototara Stone).
(*b.*) Sandstone and sandy beds—(Pareora Beds).
(*c.*) Lower Mount Brown Stone—(Marawhenua Greensand).
(*d.*) Sandstones and clays—(Waihao Beds).
(*e.*) Not exposed—(Kaikorai Beds).

The Oamaru building stone is intercalated with the Hutchinson Quarry beds, and, being a purely local deposit covering a few square miles to the south of Oamaru, it is not found elsewhere in the colony.

The Pareora beds are typically developed between Awamoa Creek and Kakanui River, where they consist of blue clays and sandy beds. At Mount Harris, Waihao district, at Wharekuri, and most places south of the Shag Valley, as Waikouaiti, Puketeraki, and Milburn, they are represented by loose sandy beds or by calcareous sands often passing into calcareous sandstones that are known to belong to the Pareora horizon by the presence of the Pareora fauna. Elsewhere in New Zealand the Pareoras are absent or cannot be distinguished from the Mount Brown (Marawhenua) beds, to which they are closely related, and from which it is not always easy to separate them.

In all parts of New Zealand except at Oamaru and Waipara where there are, as we have seen, two well-marked calcareous horizons, the members of the Oamaru series consist of four clearly defined horizons, which are as follows:—

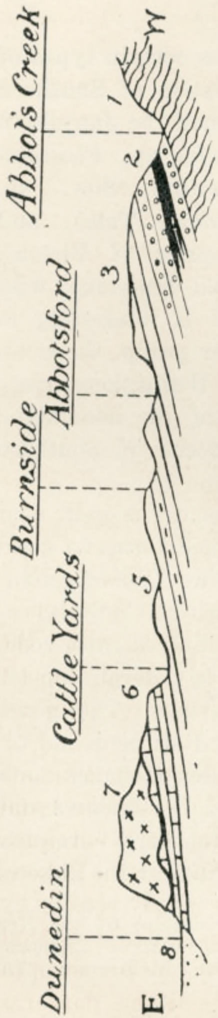

Fig. 57. Section across Green Island Coalfield. Distance three miles.
1. Kakanui schists. 2. Quartz sands and clays with brown coal. 3. Abbotsford sandstone. 4. Burnside marl. 5. Glauconitic sandstone. 6. Caversham sandstone. 7. Dolerite flow. 8. Harbour muds and gravels.

(*a.*) Ototara Stone—
Limestone or Calcareous sandstone.

(*b.*) Marawhenua Greensands—
Glauconitic sandstone and sandy beds, in places passing into limestone.

(*c.*) Waihao Beds—
Marly clays and sandstones.

(*d.*) Kaikorai Beds—
Quartz sands, grits, and conglomerates, with fireclays and brown coal.

Thus at Green Island coal-field, near Dunedin, the succession of beds is as follows:—

(*a.*) Caversham Sandstone—(Ototara Stone).

(*b.*) Glauconitic sandstone—(Marawhenua Greensands).

(*c.*) Burnside marly clays—(Waihao Beds).

(*d.*) Abbotsford sandstone—(Waihao Beds).

(*e.*) Fernhill quartz-sands and gritstone with brown coal.

At Winton, Milburn, Waihao, Kakahu, Mokau, and Waikato the sequence is almost the same as at Green Island.

Thickness of Beds.—The thickness of the Oamaru Series as exposed between Dunedin and Fairfield, exceeds 1,500ft., and in the Oamaru district, varies from 1,000ft. to 1,500ft. At Bob's Cave, Lake Wakatipu, it is about 1,500ft. On the West Coast of the South Island the Oamaru Series in places attains a thickness of 2,900ft.

Relationship of Oamaruian to Australian, S. American, and European Miocene[w].

The Oamaru series of New Zealand contains certain types of fossils which are known in the Tertiary System of Southern Australia, particularly from that portion termed the Janjukian series. Examples of such fossils are, *Squalodon* sp., *Pleurotomaria tertiaria* (McCoy), *Limopsis insolita*, Sow. sp. *Terebratulina suessi*, Hutton sp. (=*T. scoulari*, Tate), and *Graphularia* sp. Further, the Janjukian series of Victoria includes an extensive development of polyzoal limestone, with occasional beds rich in foraminifera; and it is interesting to compare the evidence of a section of the latter group, the nummulinoid forms, with those of the Northern Hemisphere, since they have lately afforded convincing proof of the homotaxial relationship of the Janjukian with the Miocene of Southern Europe, India, Borneo and the New Hebrides[x].

The principal beds in Victoria showing this evidence occur near Geelong, where a limestone contains these discoid forms in great abundance. They belong chiefly to the genus *Lepidocyclina*; although other genera occur in association, such as *Cycloclypeus* and *Amphistegina*. The *Lepidocyclinæ* are of a distinct zonal value, and have so far proved a useful factor in determining the age of Tertiary strata where this form occurs. The genus *Amphistegina* is found both in the New Zealand Miocene and the corresponding beds in Victoria. It has long been mistaken for a true nummulite, a form which is absent from the Australasian fauna, and characteristic of Eocene strata elsewhere. *Amphistegina*, as a generic type, replaced the nummulite at the close of

w. This interesting summary of the foreign relationships of the New Zealand Oamaruian was specially written for this work by Mr. F. Chapman, the well-known palæontologist of the National Museum, Melbourne.—[*The Author.*]

x. Proc. R. Soc. Vict., vol. xxii., pt. II., 1910.

the Eocene, and is found in abundance in all parts of the world where the Miocene seas extended. In Pliocene times the climate appears to have been generally colder, and the genus was consequently restricted in its occurrence; but it reappears with renewed vigour in all moderately shallow seas in inter-tropical areas at the present day.

The South American Tertiary fauna, as developed in the Santa Cruz beds of Patagonia, includes many types either common to, or closely allied with, those of the New Zealand Oamaru series[y]. And the same may be said of the Southern Australian Tertiary fauna. Dr. Ortmann, in describing and comparing the Patagonian fossils, arrives at the conclusion that the two series of Tertiary strata in Patagonia, viz., the Magellanian beds and the Patagonian beds, are of Upper Eocene or Oligocene, and Lower Miocene ages respectively[z]. On the other hand, Dr. Ameghino, in discussing the groups of the fishes, echinoids, and corals, concludes the Patagonian beds to be of Eocene age[a].

The Australasian Miocene, although not having a molluscan fauna in common with European deposits of similar age, have analogous groups of genera and closely related species; which fact points to the homotaxial relationship existing between the two sets of beds. Many of the foraminifera of restricted types are, as before stated, specifically the same in both hemispheres.

Kaikorai Beds (Brown Coal Measures).

These generally consist of quartz sands and pebbly drifts that may be loose, or cemented into hard gritty sandstones or conglomerates. In many places the loose quartzose drifts contain layers cemented with peroxide of iron into flaggy rusty-coloured conglomerates that vary from a few inches to several feet thick. The material is generally quartzose, but is found to vary to some extent with the character of the bed-rock on which the formation lies and from which the constituent detritus was derived. Thus throughout Southland, Otago, South Canterbury and Nelson the brown coal-measures are

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y. Rep. Princeton Univ. Exped., 1896-99, vol. iv., pt. II., 1902.
z. *Op. supra cit.*, p. 297, *et seq.*
a. Anales del Museo Nacional de Buenos Aires, ser. III., vol. viii., 1906.

mostly quartz sands and grits that are in places cemented with peroxide of iron into flaggy beds of conglomerate; while in Wanganui, Mokau, Waikato, and North Auckland districts, they are commonly sandstone conglomerates, sandstones, clay, and shales.

In the Oamaru district the coal-measures are about 140ft. thick, and at Green Island, in the Kaikorai Basin, near Dunedin, 250ft. In Auckland they vary from 100ft. to 200ft.

The Kaikorai beds are the brown coal-measures of New Zealand to which the bulk of the coal of the Dominion belongs. They often contain two or more seams of coal, but it is seldom

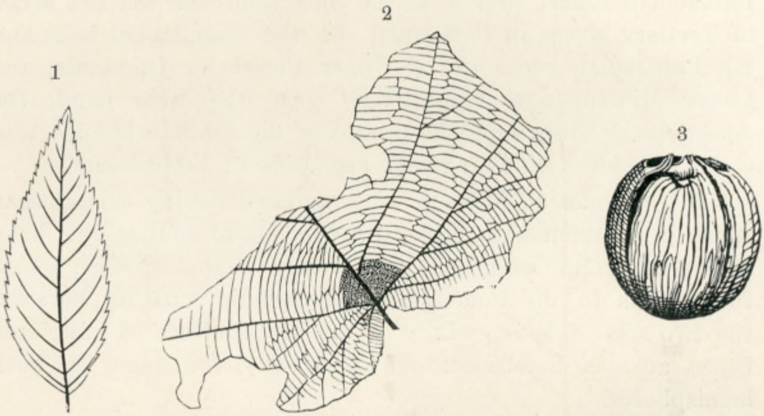


Fig. 58. Plants from Brown Coal Measures. (After Hector.)

1. Phyllites, sp. ?, Pakawau. 2. *Aralia*, Pakawau. 3. Palm-nut, Livingstone Tunnel, Oamaru.

that more than one seam, generally lying not far from the bed-rock, is found to be workable.

The coal varies from 8ft. to 20ft. thick, but at Huntly, in the Waikato, it has been found to widen out to 50ft., and even 60ft.

At many places the coal vegetation grew and accumulated on an undulating surface of the bed-rock; and in these cases the resulting seam of coal is thickest in the hollows and thinnest on the ridges.

In the shales associated with the coal there have been found many plant remains, including leaves of the oak, ash, elm, beech, myrtle, *Aralia*, *Dammara*, *Podocarpus*, *Dacrydium* and numerous ferns, all showing a genetic relationship to the existing flora. In the coal seams there are sometimes found trunks and limbs of trees, and nests of a resinous gum resembling Kauri gum.

In many places the coal contains well-rounded pebbles of quartz, which commonly occur singly and not in layers.

The workable seams are found in disconnected basins; and from the evidence presented to us it would appear that the

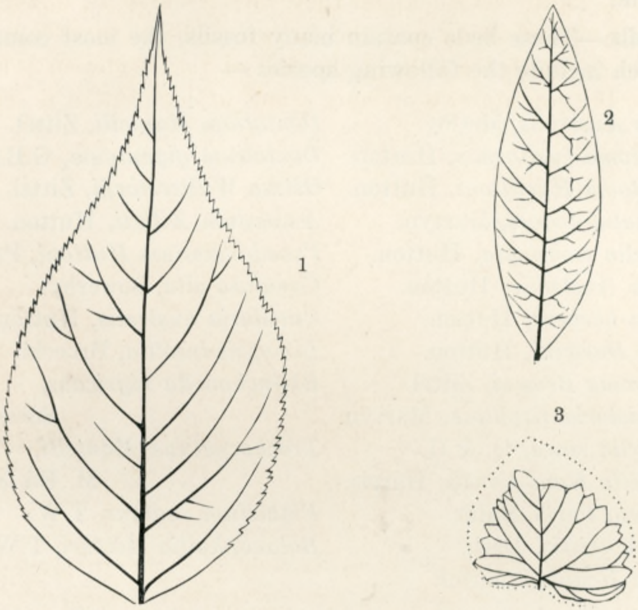


Fig. 59. Plants from Brown Coal Measures. (After Hector.)
1 *Grewiopsis pakawauica*, Pakawau. 2. Cupanites, Wangapeka. 3. Phyllites ? Pakawau.

coal-vegetation established itself and grew luxuriantly in low-lying swampy estuaries and bays, or on mud-flats newly reclaimed from the sea by fluviatile drifts of sand and gravel. In some cases the vegetable matter derived from this source seems to have been augmented by peaty matter that slid on to the flats from moving bogs growing on the neighbouring slopes.

WAIHAO BEDS.

These generally consist of marine clays, sandy beds and sandstones varying in different places from 100 to 600 feet thick. They are typically developed at Waihao Forks in Canterbury;

Abbotsford, near Dunedin; Bob's Cove, Lake Wakatipu; Port Hills, Nelson; Mokau, Kawhia, Raglan, Waipa, and in the North Auckland district.

The muds and sands of which they are composed were deposited on a slowly sinking sea-floor. The character of the deposits and the contained fauna indicate the absence of incoming gravel-laden streams, and of swiftly moving sea-currents.

Fossils.—These beds contain many fossils, the most common of which include the following species:—

Aturia Australis, McCoy.
Pleurotoma fusiformis, Hutton.
Pleurotoma Hamiltoni, Hutton.
Siphonalia nodosa, Martyn.
Scaphella corrugata, Hutton.
Ancilla Australis, Hutton.
Ancilla herbera, Hutton.
Natica Darwini, Hutton.
Cirsotrema Browni, Zittel.
Struthiolaria papulosa, Martyn.
Turritella rosea, Q. & G.
Turritella Kanieriensis, Harris.
Lapparia Parki, Suter.
Terebra tristis, Desh.
Teredo Heaphyi, Zittel.
Dentalium Mantelli, Zittel.
Dentalium giganteum, G.B.S.
Ostrea Wullerstorfii, Zittel.
Amussium Zitteli, Hutton.
Pseudamussium Huttoni, Park.
Cucullæa alta, Sowerby.
Cucularia australis, Hutton.
Limopsis insolita, Brocchi.
Rhynchonella nigricans, Sowerby.
Trochocyathus Mantelli, M. Ed. & H.
Flabellum radians, T.W.
Balanophyllia Hectori, T.W.

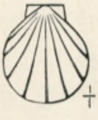


Fig. 60. *Amussium Zitteli*, Hutton.

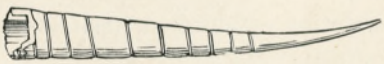
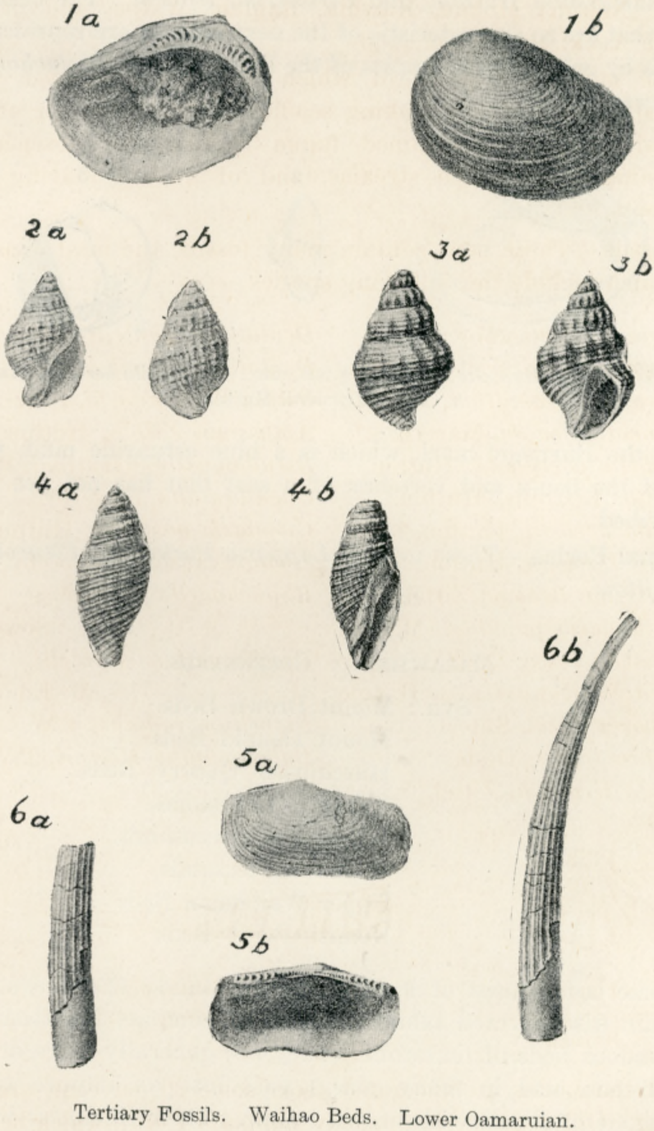


Fig. 61. *Dentalium giganteum*, ½ nat. size.

Of the mollusca enumerated above some 20 per cent. are still living. Only one species, namely *Lapparia Parki*, which belongs to a genus that is not known in any formation younger than the Eocene, in Europe and North America, is confined to the Waihao beds; 20 species rise into the Marawhenua Greensands; 18 into



Tertiary Fossils. Waihao Beds. Lower Oamaruian.

Fig. 1, *a*, *b*. *Limopsis insolita*, Sow.
,, 2, *a*, *b*. *Siphonalia Robinsoni*, Zittel.
,, 3. *a*, *b*. *Siphonalia*, Sp.
,, 4, *a*, *b*. *Scaphella gracilicostata*, Zittel.
,, 5, *a*, *b*. *Solenella Australis*, Quoy et Gaim.
,, 6, *a*, *b*. *Dentallium Mantelli*, Zittel.

Natural size. (After Zittel.)

the Pareoras; and only two reach the Ototara Stone, namely *Pseudamussium Huttoni*, and *Cirsotrema Browni*. The brachiopods that are so characteristic of the next horizon are represented in this by only a few examples of the living species, *Rhynchonella nigricans*.

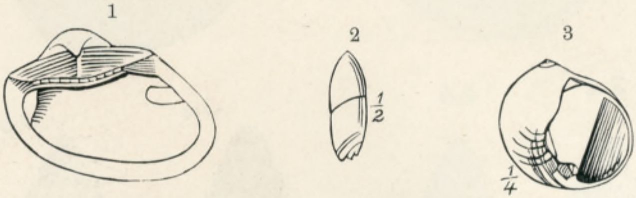


Fig. 62. 1. *Cucullæa alta*, Sowerby, $\frac{1}{3}$ nat. size. 2. *Ancilla herbera*, Hutton. 3. *Natica Darwini*, Hutton.

In the Burnside marl, which is a blue estuarine mud, were found the bones and vertebræ of a seal that has not yet been described.

Zonal Forms.—These include *Lapparia Parki*, and *Pleurotoma Hamiltoni*.

Marawhenua Greensands.

Syn.: Mount Brown Beds.
Mount Donald Beds.
Hutchinson Quarry Beds.
Kakanui Limestones.
Wharekuri Greensands.
Waihao Greensands.
Upper Waitemata Beds.
Komiti Point Beds.

These beds consist of loose glauconitic sands, that frequently contain disconnected tabular masses of compact limestone, or continuous beds of limestone. They are generally more or less calcareous, and in many places pass into an impure sandy limestone of a yellowish brown colour. Their thickness varies from 50ft. to 150ft. They are typically developed around Oamaru, being well exposed at Hutchinson's old quarry, and in the sea-cliffs south of Oamaru, where they are intercalated with tuffs and flows of basalt. As loose sandy beds they are exposed to great advantage along the south side of Waitaki Valley where they lie immediately under the Ototara Stone which forms the long line of steep escarpment extending from Oamaru to Otakaike.

Fig. 63. *Plagiostoma lævigata*, Hutton, 1/5 nat. size. A large smooth shell with faint concentric markings.

Fig. 64. *Celeporina papulosa*, Kakanui limestones and Parnell tuff at Cheltenham Beach and Parnell, Auckland.

The Kakanui limestones at the mouth of the river of that name belong to this horizon of the Oamaru Series as also do the Mount Brown and Mount Donald beds at Waipara and Weka Pass; the Orakei Bay beds, Auckland; and the Orbitolite beds at Komiti Point, Kaipara.

Fossils.—These beds are everywhere rich in fossils, a large proportion of which are found in the underlying Waihao beds. The most distinctive forms are as follows:—

Kekendon onemata, Hector.
Palæeudyptes antarcticus, Huxley.
Myliobatis plicatilis, Davis.
Carcharodon megalodon, Agassiz.
Harpactocarcinus tumidus, H. Woodward.
Aturia Australis, McCoy.
Cassideria senex, Hutton.
Cirsotrema lyrata, Zittel.
Cirsotrema Browni, Zittel.
Amussium Zitteli, Hutton.
Pseudamussium Huttoni, Park.
Plagiostoma lævigata, Hutton.
Mactropsis Traili, Hutton.
Cucullæa alta, Sowerby.
Crassatellites ampla, Hutton.
Cardium patulum, Hutton.
Tapes curta, Hutton.
Magellania Parki, Hutton.
Magellania novara, Jhering.
Terebratella Oamarutica, Boehm.

Turritella Cavershamensis, Harris.
Turritella rosea, Q. & G.
Dentalium giganteum, Sowerby.
Dentalium Mantelli, Zittel.
Natica Darwini, Hutton.
Dosinia magna, Hutton.
Lima palæata, Hutton.
Limopsis insolita, Sowerby.
Pecten athleta, Zittel.
Pecten Hutchinsoni, Hector.
Pecten Beethami, Hutton.
Pecten Hochstetteri, Zittel.
Terebratella gaulteri, Boehm.
Terebratula Tayloriana, Colenso.
Bouchardia elongata, Hutton.
Bouchardia tapirina, Hutton.
Trochocyathus Mantelli, T.W.
Sphenotrochus Huttonianus, T.W.
Meoma Crawfordi, Hutton.
Isis dactyla, T.W.
Flabellum radians, T.W.
Balanophyllia Hectori, T.W.
Graphularia, *Sp.?*

Fig. 65. *Kekenodon onemata*, Hector.

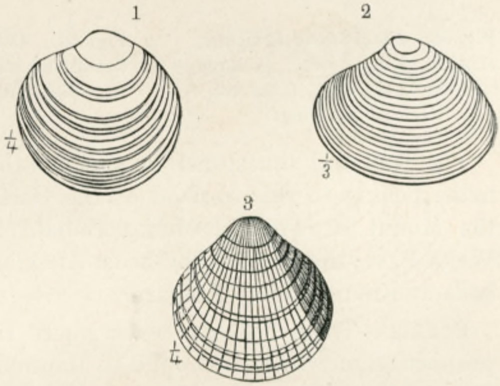


Fig. 65A. 1. *Dosinia magna*. 2. *Tapes curta*. 3. *Cardium patulum*.

The *Zeuglodont* (*Kekenodon onemata*) has been found at Waitaki Valley, Waihao, Ngapara, Waikouaiti, and Milburn. The gigantic penguin (*Palæeudyptes antarcticus*) occurs at Kakanui near Oamaru, at Curiosity Shop, in Canterbury, and at Brighton, in Nelson. The crab (*Harpactocarcinus tumidus*) has been found near Brighton, in Nelson, and at Wharekuri in the Waitaki Valley. The large nautilus (*Aturia Australis*) which first appears in the Waihao horizon, becomes fairly common in the lower part of the Marawhenua Greensands, but disappears before the Ototara Stone is reached. The whale, penguin, and crab mentioned above are characteristic of this horizon, as also are *Pecten Hochstetteri, P. Fischeri, P. polymorphoides, Plagiostoma lævigata,* the fine coral *Trochocyathus Mantelli,* and the distinctive *Isis dactyla.*

The beautiful pecten, *Pseudamussium Huttoni* first appears in the Waihao beds, reaches its greatest development in the Marawhenua horizon, and is seen sparingly in the Ototara Stone, in which it disappears. It ranges throughout all the marine horizons of the Oamaru Series, but is never found outside that formation which makes it a shell of great value to the field geologist. Its form is so distinctive that it can be identified even when broken or fragmentary. Near Duntroon, in the Waitaki Valley, it occurs in thousands, associated with *Plagiostoma lævigata* and numerous brachiopods.

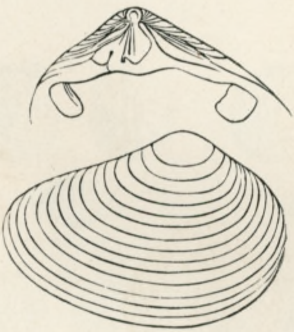


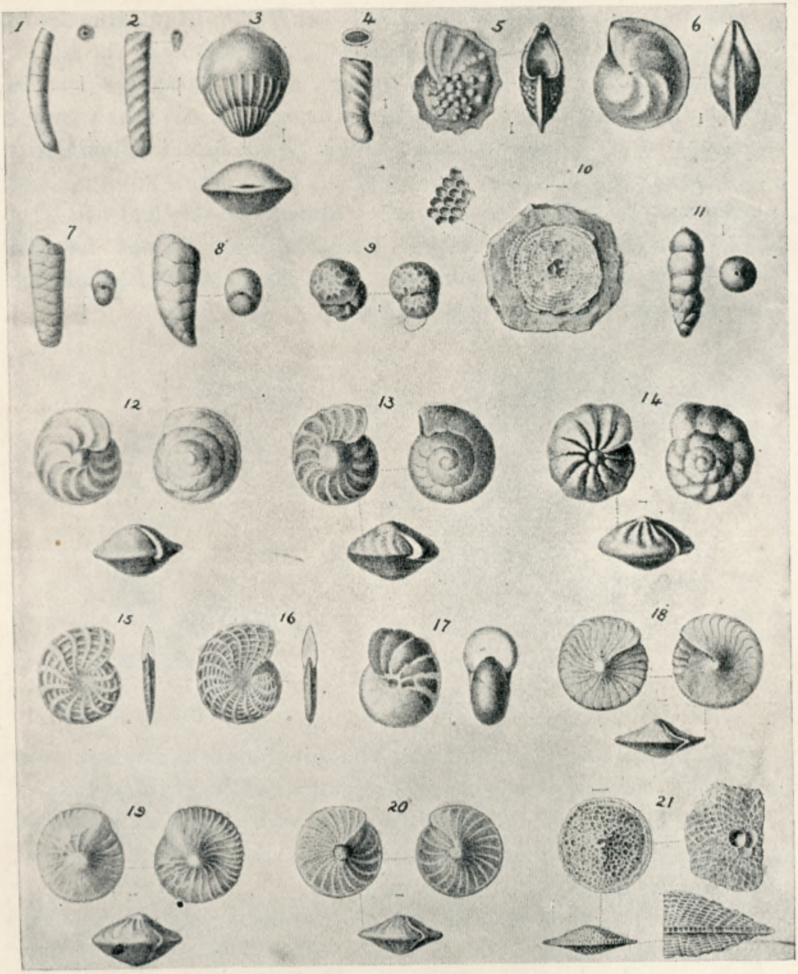
Fig. 66. *Crassitellites ampla.*

Fig. 67. *Turritella Cavershamensis,* Harris, ¾ nat. size.

It is significant that the fossil penguin found at Brighton, on the west coast of Nelson, is associated with *Pseudamussium Huttoni, Cirsotrema lyrata, Meoma Crawfordi,* and *Plagiostoma lævigata,* all of which occur with the same penguin in the Kakanui limestone near Oamaru.

The Brighton Stone (Nelson) is the closing member of the upper coal-measures of the West Coast. That it is the time equivalent of the Kakanui limestone of the Oamaru Series is now placed beyond all doubt.

Zonal Forms.—The fossils that are not known outside the Marawhenua horizon are *Turritella Cavershamensis, Pecten Hutchinsoni, Pecten Hochstetteri, Plagiostoma lævigata, Terebratula Tayloriana, Terebratella Oamarutica, Magellania Parki, Magellania novara, and Isis dactyla.*



Foraminifera. Waitemata Beds, Auckland. Middle Oamaruian. (After Karrer.)

Fig. 1, *Dentalina aequalis*. Karr.
2, *Vaginulina recta*, Karr.
,, 3, *Lingulina costata*, d'Orb.
,, 4, *Marginulina neglecta*, Karr.
,, 5, *Cristellaria mammilligeri*, Karr.
,, 6, *Robulina regina*, Karr.
,, 7, *Textilaria Hayi*, Karr.
,, 8, *Textilaria convexa*, Karr.
,, 9, *Texlilaria minima*, Karr.
,, 10, *Orbitulites incertus*, Karr.
,, 11, *Clavulina elegans*, Karr.

Fig. 12, *Rotalia Novo-Zelandica*, Karr.
,, 13, *Rotalia perforata*, Karr.
,, 14, *Rosalina Makayi*, Karr.
,, 15, *Polystomella Fichtelliana*, d'Orb.
,, 16, *Polystomella tenuissima*, Karr.
,, 17, *Nonionina simplex*, Karr.
,, 18, *Amphistegina Campbelli*, Karr.
,, 19, *Amphistegina Aucklandica*, Karr.
,, 20, *Amphistegina ornatissima*, Karr.
,, 21, *Orbitoides Orakeiensis*, Karr.

The Waitemata beds, so well exposed on the shores of Auckland Harbour, contain a molluscous and foraminiferal fauna that clearly shows their close relationship to the Middle Oamaruian. They consist of a great succession of alternating thin beds of soft sandstone and tough partially hardened blue clays. In some places the beds are quite horizontal, in others they have been dislocated, tilted, and bent into sharp and undulating folds by the thrust exerted by the comparatively recent volcanic outbursts that culminated in the formation of Rangitoto Island, standing at the entrance of the harbour, and of Mount Eden and the numerous small scoriæ cones scattered about the Auckland Isthmus.

The peculiar dynamical effect of faulting, combined with lateral thrust caused by local volcanic action, is well seen in the

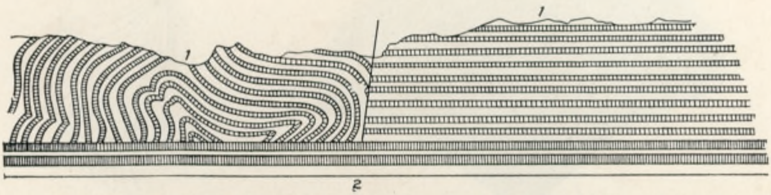


Fig. 67A. Section of sea-cliff near Wade showing sharp-folding of strata by volcanic thrust.

1. Thin-bedded sandstones and clays. 2. Thick-bedded sandstones and clays.

steep sea-cliffs near Wade, where the strata, on the north side of a fault which does not descend into the lower beds, lie quite horizontal, while the same beds on the south side of the fault have been pushed up into sharp folds as represented in Fig. 67a.

The sandstone beds of the Waitematas are both fine and comparatively coarse, and where an excess of carbonate of lime is present they pass into tabular lenses, or irregular layers, of harder material that sometimes contains an abundance of foraminifera and diminutive molluscs. Among the foraminifera from the Orakei Bay horizon are represented the genera *Nodosaria, Cristellaria, Amphistegina, Rotalina, Vaginulina, Dentilina,* and *Frondicularia,* many species of which were described and figured by Stache.

The molluscs are mostly pectens, among them being *P. polymorphoides, P. Fischeri, P. Williamsoni,* and the well-known *Amussium Zitteli,* all of which are present in the beds at the base of the Ototara Stone at Kakanui, Totara, and elsewhere in the Oamaru district.

The clay beds contain in many places an abundance of comminuted plant-remains that would seem to have become imbedded in the fine sediments in the way that the scum of broken twigs, so frequently seen spread over estuarine flats, becomes covered over with mud by the rising tide.

The Waitematas are intercalated with a conspicuous bed of fossiliferous andesitic tuff that is well exposed among the folded strata on the south side of the harbour near Judge's Bay, and at the north end of Cheltenham Beach.

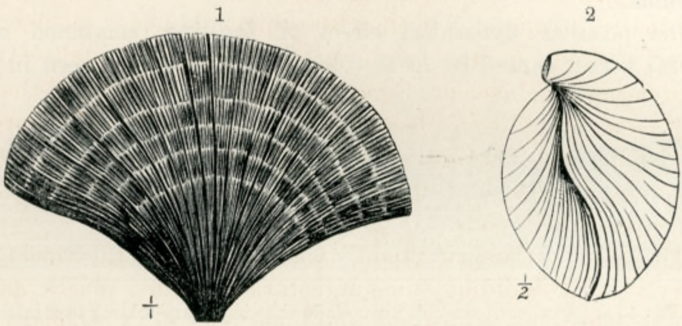


Fig. 68. 1. *Flabellum radians.* 2. *Terebratula Tayloriana.*

Among the fossils in this tuff-bed are *Terebratella Oamarutica, Magellania Parki, M. lenticularis, Pecten polymorphoides, P. vellicatus,* a great variety of net and branching corals, and many beautiful cup-shaped bryzoans, all of which are found in the tuff-beds underlying the Ototara Stone in the district lying between the Kakanui River and Oamaru.

In a rubbly shell-bed at the base of the Waitematas, exposed on the beach at the west side of Motutapu Island, adjoining Rangitoto Island, there is a large assemblage of the molluscous forms characteristic of the Cape Rodney, Papakura, and Waihao horizons. The Motutapu beds are chiefly notable for the occurrence in them of the giant cirripede, *Scalpellum Aucklandicum.*

In a paper on "The Volcanic Grits and Ash-beds in the Waitemata Series," Mulgan has given a good description of the arrangement and fossils of the strata exposed on the shores of Auckland Harbour. The Waitematas are historically interesting, as it was from them that the band of distinguished Austrian palæontologists, including Zittel, Karrer, and Stache, obtained a large number of the fossil mollusca and foraminifera described in the publications of the "Novara" expedition.

Oamaru Stone.—This is merely a local expansion of the Hutchinson Quarry beds of Oamaru. The typical building stone as now being quarried at Deborah, Totara, and Teschemaker's on the main South railway-line to Dunedin, is a soft pale-grey limestone of even texture composed chiefly of comminuted corals and foramifera[b]. It is very pure and greyish white at Deborah and Totara; but going southward and westward it gradually assumes a yellowish tinge, becomes coarser in texture, and spotted with grains of glauconite. As it approaches the ancient Eocene strand it loses its distinctive character, merging in places into a yellowish-brown calcareous sandstone, in others into a sandy limestone, that contains the remains of *Meoma Crawfordi, Pseudamussium Huttoni*, and numerous brachiopods.

The name "Oamaru Stone" was applied by the Geological Survey to the building stone at Totara and other places, and to all the calcareous sandstones and limestones in the Oamaru and Waitaki and South Canterbury districts without regard to their stratigraphical position. McKay[c] was the first geologist to recognise two calcareous horizons in the Oamaru and Waitaki areas.

The relationship of the Oamaru Stone to the Hutchinson Quarry beds is very clearly seen in the section of the sea-cliffs near the Oamaru Rifle-butts shown in Fig. 71.

PAREORA BEDS.

In the Oamaru district at Awamoa Creek, the Marawhenua Greensands (Mount Brown or Hutchison Quarry beds of Geological Survey) are followed conformably, as always contended by McKay, by certain bluish green sandy beds, sandstones and clays closely resembling the sediments of the Waihao horizon. In these beds there is a remarkable reappearance of

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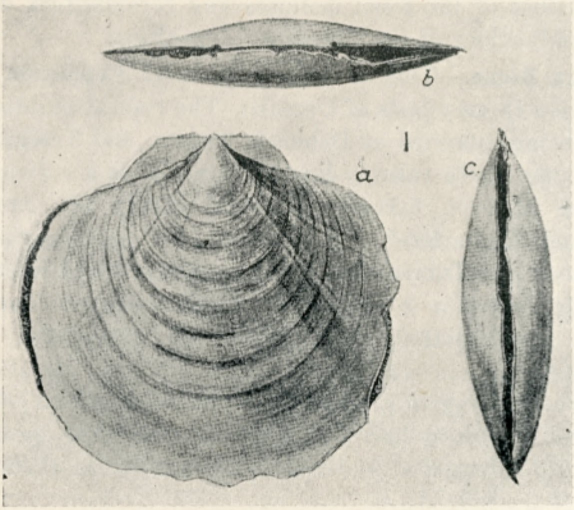
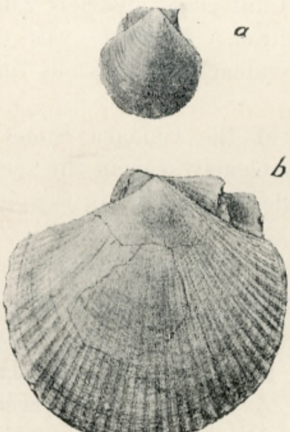
b. J. Park, "The Marine Tertiaries of Otago and Canterbury," Trans. N.Z. Inst., vol. xxxvii., 1904, p. 496.

c. A. McKay, Reports of Geol. Expl., 1881, p. 66.

PLATE X.



Pseudamussium Huttoni, Park. (After Boult.)



Pecten Hochstetteri, Zittel. (After Zittel.)

a, Smooth valve. *b*, Ribbed valve. Size $\frac{3}{4}$ nat. Marawhenua Beds. Middle Oamaruian.

many fossils that are first seen in the Waihao beds. The Pareoras are typically developed near Awamoa Creek, a few miles south of Cape Wanbrow, not far from the rifle-butts, where they pass insensibly into the Hutchinson Quarry beds. They are also seen in the Lower Pareora Gorge, where they underlie the Ototara Stone.

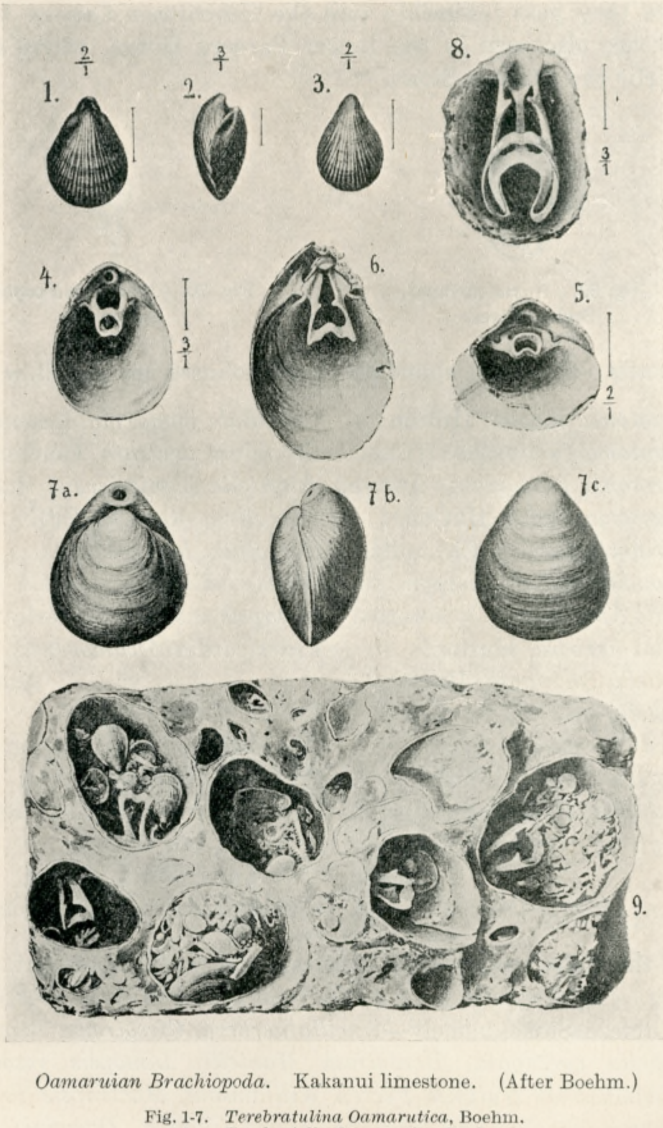
Fig. 69. *Nassa carinata*, Broken River.

Fig. 70. *Pleurotoma pagoda*, Awamoa.

Fossils.—The most abundant fossil mollusca are as follow:—

Pleurotoma pagoda, Hutton.
Pleurotoma fusiformis, Hutton.
Pleurotoma Buchanani, Hutton.
Pleurotoma Traili, Hutton.
Lotorium spengleri, Chemnitz.
Siphonalia nodosa, Martyn.
Ancilla Australis, G. B. Sowerby.
Ancilla herbera, Hutton.
Scaphella corrugata, Hutton.
Scaphella gracilis, Swainson.
Natica Darwini, Hutton.
Cirsotrema Browni, Zittel.
Struthiolaria papulosa, Martyn.
Calyptræa calyptræformis, Lamarck.
Nassa carinata, Hutton.
Crepidula monoxyla, Lesson.
Crepidula aculeata, Gmelin.
Turritella Kanieriensis, Harris.
Dentalium Mantelli, Zittel.
Dentalium lævis, Hutton.
Chione vellicata, Hutton.
Limopsis insolita, Sowerby.
Venericardia Awamoaensis, Harris.
Dosinia Greyi, Zittel.
Glycimeris globosa, Hutton.
Pecten Williamsoni, Zittel.
Pseudamussium Huttoni, Park.
Lima palæata, Hutton.
Mactropsis Traili, Hutton.
Crassatellites Traili, Hutton.

Of the above twenty-eight species, eight, or 28.5 per cent., are living. Eight species have never been found in beds overlying the Ototara Stone, namely—*Ancilla herbera, Cirsotrema Browni, Scaphella corrugata, Dentalium Mantelli, Limopsis insolita, Pseudamussium Huttoni, Pecten Williamsoni, Mactropsis Traili.* To these should probably be added *Natica Darwini* and *Pleurotoma fusiformis.*



Oamaruian Brachiopoda. Kakanui limestone. (After Boehm.)

Fig. 1-7. *Terebratulina Oamarutica*, Boehm.
,, 8. *Terebratella Oamarutica*, Boehm.
,, 9. Examples of 1 and 8 in the matrix.

The relationship of the Pareora beds to the Hutchinson Quarry beds is well seen in the sea-cliffs south of Oamaru.

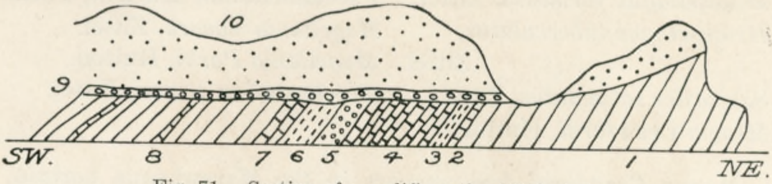


Fig. 71. Section of sea-cliff north of Rifle-butts.

1. Tuffs. 2. Bed of coralline limestone, 6 ft. 3. Greenish-blue sandstone, 9 ft. 4. Coralline limestone (Oamaru building-stone), 80 ft. 5. Yellowish-green fossiliferous-tuff bed, 12 ft. 6. Hutchinson Quarry beds, consisting of hard rubbly limestone, 7 ft., overlain by greensands, 11 ft. thick. 7. Impure shelly limestone, 3 ft. thick, crowded with *Turritella Cavershamensis*. 8. Fine bluish-green sandstones weathering brown, exposed on beach for a distance of 50 yds. 9. Raised beach, 5 ft. or 6 ft. above high water of spring tides, consisting of beach-shingle mixed with littoral shells all belonging to living species The most common forms are *Mactra discors*, *Chione oblonga*, *Dosinia Australis*, *Atactodea subtriangulata*, *Mytilus edulis*, *Trochus tiaratus*, &c. 10. Glacial clay. Beds 1-6. Hutchinson Quarry beds. Beds 7 and 8. Awamoa (Pareora) beds.

Ototara Stone.

This is found throughout New Zealand wherever the Oamaru Series is represented. It is sometimes a compact grey limestone, and frequently a yellowish brown calcareous sandstone locally known as freestone. In nearly every district it is designated by some local name. Some of the more common of these local names are as follows:—

Ototara Stone.—

Syn.: Raglan Limestone.	Totara Limestone
Aotea ,,	Maheno ,,
Waipa ,,	Kakanui ,,
Mokau ,,	Waikouaiti Stone.
Tata Island ,,	Caversham Sandstone.
Mount Somers Stone.	Milburn Limestone.
Kakahu Limestone.	Winton ,,
Waihao ,,	Forest Hill ,,
Waitaki Stone.	Waiau ,,
Otakaike ,,	Cobden ,,
Ngapara Stone.	Paturau ,,

The Caversham Sandstone shows a thickness exceeding 400ft. Elsewhere the thickness of the Ototara Stone, which is everywhere the closing member of the Oamaruian, varies from 50ft. to 200ft.

Fossils.—The characteristic fossils of this horizon are:—

Cidaris striata, Hutton.
Hemipatagus formosus, Zittel.
Hemipatagus tuberculatus, Zittel.
Schizaster rotundatus, Zittel.
Meoma Crawfordi, Hutton.
Cirsotrema Browni, Zittel.
Pseudamussium Huttoni, Park.
Magellania novara, Zittel.
Magellania Parki, Hutton.
Terebratulina Suessi, Zittel.

Meoma Crawfordi first appears in the Marawhenua horizon, disappears in the Pareora, and reappears in the Ototara limestone, in which it reaches its upward limit.

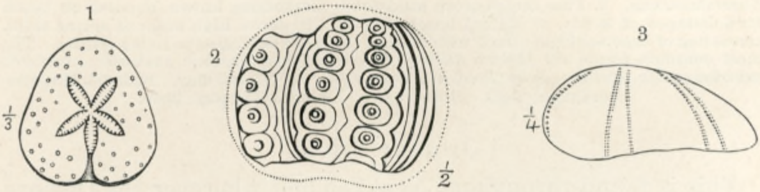


Fig. 72. 1. *Hemiaster posita*. 2. *Cidaris*, Sp. Nov., Waihao limestone. 3. *Macropneustes*, Cobden limestone.

Nomenclature.—The name "Ototara" was first applied to the Waitaki and Oamaru stones by Mantell as far back as 1850, and must therefore take precedence of the various names, Aotea, Raglan, Oamaru, Waitaki, etc., used by Hochstetter, Hector, McKay, and Park.

MANUHERIKIA LACUSTRINE SERIES.

This series is found in Central Otago occupying the floor of the Maniototo, Ida Valley, Manuherikia[d], and Cromwell Basins, and also at Gibbston, Kawarau, and Cardrona Valley. It is typically developed in the Manuherikia[e] Basin, where it consists of quartz sands and shales with lignite, sandy clays, and soft sandstone, followed by beds of sandstone gravel. The total thickness of the different strata is not much less than 1000ft.

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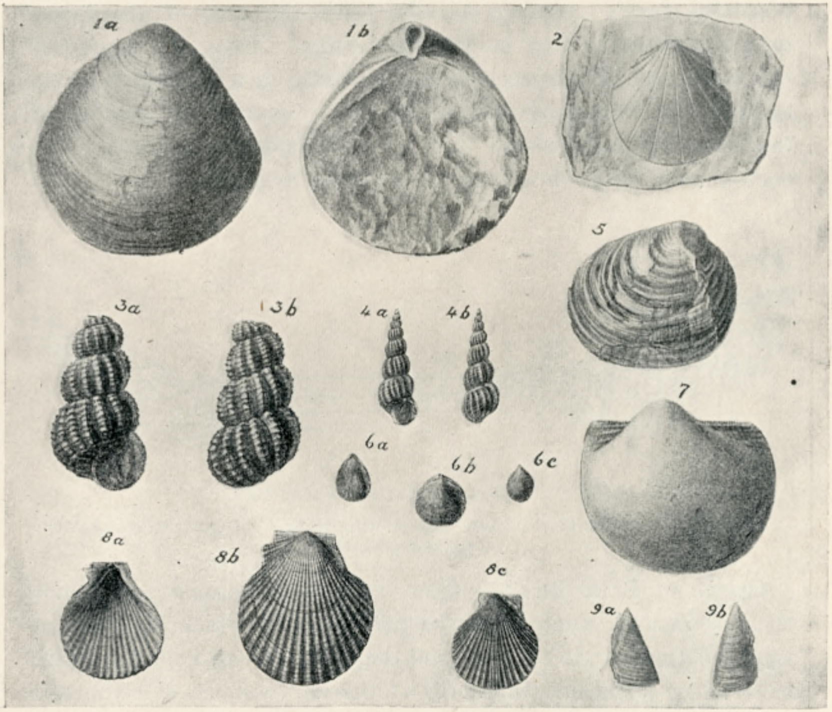
d. J. Park, "The Geology of Alexandra Subdivision," "Bulletin No. 2 (New Series)," N.Z. Geo. Survey, 1906, p. 9.

e. J. Park, "The Geology of Cromwell Subdivision," Bulletin No. 5, 1908, p. 31.



Tertiary fossils. Upper Oamaruian.

Fig. 1, *a*, *b*. *Magellania gravida*, Suess.
,, 2. *Amussium Zitteli*, Hutton.
,, 3, *a*, *b*. *Cirsotrema lyrata*, Zittel.
,, 4, *a*, *b*. *Cirsotrema Browni*, Zittel.
,, 5, *Panopæa* Sp.

Fig. 6, *a-c* *Terebratella Suessi*.
,, 7. *Cucullæa singularis*, Zittel.
,, 8, *a*, *b*. *Pecten Williamsoni*, Zittel.
,, 9, *a*, *b*. *Scalpellum* Sp.

$\frac{5}{8}$ Natural size. (After Zittel).

At the time of deposition the Maniototo, Manuherikia, and Ida Valley basins were connected with each other forming a large inland lake. In the Kyeburn[f] area of the Maniototo Basin the lower lacustrine strata are intercalated with sandy clays containing marine shells, proving that for a time at least the sea had access to that part of the basin, the channel of communication probably lying along the Shag Valley.

One and sometimes both sides of each basin is traversed by powerful faults running parallel with the axis of the table-topped mountains that enclose the basins. Along the course of the faults the lacustrine beds are standing in a vertical position against the Palæozoic mica-schist, but towards the middle of the basins the beds assume their normal horizontal position. The beds in each basin thus form an inverted monoclinal.

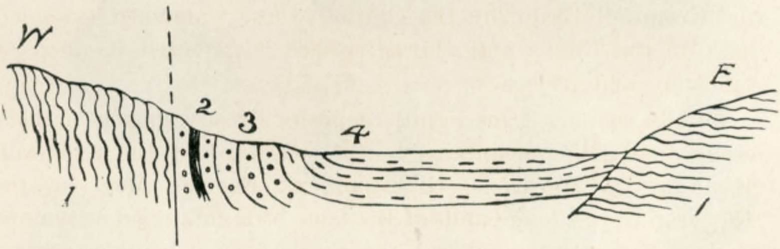


Fig. 73. Section across Ida Valley Basin.

1. Mica-schist. 2. Quartz sands, gold-bearing, with lignite. 3. Quartz sands and grits. 4. Clays and sands.

Origin of Lake Basins.—The ancient lake-basins in which these sediments were deposited are areas in which the rate of uplift of the fringing ranges and deposition about kept pace with each other. The fine character of the lower 400ft. of sediments proves that the lakes were at first shallow basins that were fed by no large streams. In the upper beds the material becomes progressively coarser until we reach the closing member of the series, which consists of coarse sandstone gravels transported from a distance by large rivers.

When the uplift began the adjoining mountains were not drained by streams occupying defined water-courses, hence the material washed into the newly-formed lakes was generally fine

f. A. McKay, Repts. Geol. Expls., 1883-84, p. 64.

in texture. As the uplift continued, the slopes of the mountains grew longer, and in course of time the meteoric waters were gathered into streams, running in defined channels and capable of transporting coarser material.

It would appear that with increasing uplift of the block-mountains erosion became more active, the evidence of this being found in the pile of fluviatile drift with which the lacustrine series closes.

The basal sediments in each basin are composed of clays and sands derived from the denudation of the adjacent mica-schist mountains; while the upper fluviatile drift forming the well-known *Maori-bottom* of the miner, some 300ft. or 400ft. thick, is mainly composed of sandstone and greywacke transported from a distance. It is obvious that the united Maniototo-Manuherikia basin became in time dominated by the Manuherikia River, and the Cromwell Basin, by the Clutha, whose watershed extended back to the Lindis and Hawea, where it gathered its load of sandstone and greywacke.

Besides the lacustrine lignitic deposits already spoken of there occur among the mountains to the westward of the Cromwell Basin at the Cardrona, Gibbston, and Roaring Meg in the Kawarau Gorge, long bands of the same beds entangled as narrow wedges in overthrust folds of the mica-schist, at heights varying from 1,000ft. to 3,000ft. above the sea. These wedges of lacustrine strata cannot be older than middle Tertiary, and afford conclusive proof of the comparatively late date of the tectonic folding of the mica-schist of the Maniototian in Central and Western Otago. And since the mountains cannot be older than the folds that form them we are able to determine their age with a considerable degree of certainty.

Age of Lacustrine Series.—The only fossils known to occur in the lacustrine beds are the leaves of dicotyledinous trees; a fresh-water mussel which is abundant in the shaly clays overlying the lignite at Clyde and Cromwell; and fish remains at Cambrians. None of these have been critically examined, and hence afford little help in solving age of the series. But with respect to the fossiliferous marine beds interbedded with the lower members of the series at Kyeburn, in the north-east corner of the

Maniototo Basin, we are on surer ground. McKay[g] describes the fossils as occurring at the base of a bed of marine sandy clays about 100ft. thick, overlain conformably by white clays and thick seams of lignite. The fossils, he states, are mostly such species as are common in the Pareora or Awamoa beds of North Otago and South Canterbury, referred by him to the Lower Miocene. As the Awatere beds are not known south of North Canterbury there seems to be little doubt of the accuracy of McKay's correlation.

The author has elsewhere shown that the Pareora (Awamoa) beds cannot be older than Miocene, and whether they are referred to the lower or upper portion of the epoch is not a matter of much moment. What is of real importance is the presence of a recognisable marine horizon which enables us, with some confidence, to refer the lacustrine series to its marine contemporary. The Manuherikia lacustrine beds must therefore be considered the time-equivalent of the upper portion of the Oamaru Series.

The occurrence of marine fossils near the base of the Manuherikia series shows that deposition began at sea-level, proving that the old lake-basins were formed not by the subsidence of portions of an elevated plateau but by the elevation of portions of an ancient maritime base-level, the uplifted portions enclosing the basins and forming the existing group of remarkable *block-mountains* that occupies Central Otago.

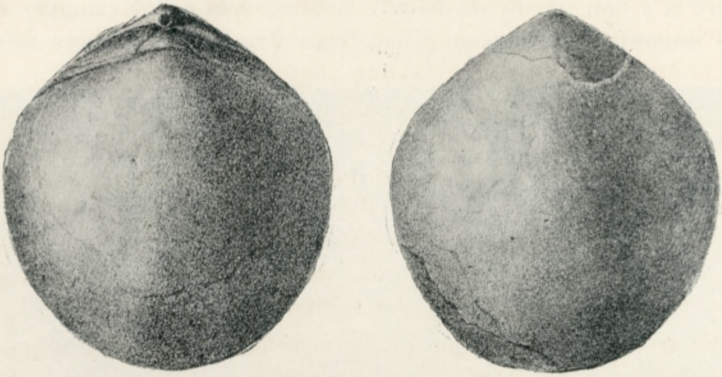
Igneous Rocks of Karamea System.

Contemporaneous Igneous Rocks.—During the deposition of the middle members of the Oamaru Series the New Zealand coastline was the scene of considerable volcanic activity. The chief centres of eruption in the South Island were at Oamaru and Mount Somers; and in the North Island, at Auckland and Kaipara.

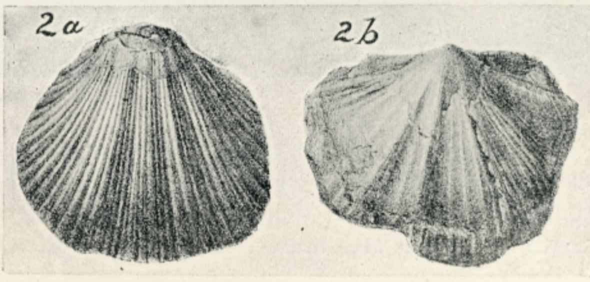
Around Oamaru the Hutchinson Quarry beds are intercalated with fossiliferous tuffs, with which are associated an abundance of the basic glass tachylite, flows of basalt and dolerite. In

g. A. McKay, Repts. Geol. Expls., 1883-84, p. 64; and "The Older Auriferous Drifts of Central Otago," Wellington. Second Edition, 1897, p. 100.

PLATE XIII.



Magellania lenticularis. Desh.



Pecten Burnetti. Zittel.
Marawhenua Series. Middle Oamaruian.
Size $\frac{3}{4}$ natural. (After Zittel.)

the tuffs exposed in the sea-cliffs at the mouth of the Kakanui River, there occurs a remarkable assemblage of minerals, including among others black augite, hornblende, garnet, diopside, diallage, biotite, olivine, smaragdite; and of rocks, basalts, greywacke, mica-schist, granulite, gneiss, besides representatives of such ultra-basic plutonic rocks as lhersolites, wehrlite, and garnetiferous peridotites[h]. North of Cape Wanbrow there is a flow of olivine-dolerite that exhibits a fine example of the somewhat uncommon pillow-form structure sometimes seen

Fig. 74. Showing pillow-form lava near Cape Wanbrow, Oamaru.

in basalts[i]. The interstices are filled with fossiliferous limestone. The presence of a sill of basalt in the limestone between Kakanui township and Maheno would tend to show that volcanic activity continued in this area until near the close of the Oamaru Series[j].

At Mount Somers there is a bed of tuff underlying the Mount Somers stone; and in the greensands under the tuff Cox mentions the occurrence of included fragments of vesicular lava, probably

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h. J. A. Thomson, Trans. N.Z. Inst., vol. xxxviii., p. 492.
i. J. Park, Trans. N.Z. Inst., vol. xxxvii., p. 514.
j. J. Park, *loc. cit.*, p. 509.

andesite derived from the underlying Cretaceous igneous complex.

In the vicinity of Auckland, the Waitemata beds of the Marawhenua, or Hutchinson Quarry horizon of the Oamaru Series, are intercalated[k] with a bed of fossiliferous igneous tuff locally known as the "Parnell Grit." At Cheltenham Beach this ash-bed contains small fragments of augite-andesite. At Whangaparaoa Peninsula[l], some miles further north, the fragments of andesite are larger and more abundant than nearer Auckland. Towards the end of the Peninsula occur many large angular blocks, one of which, embedded in soft sandstone and shale, measures at least 18 feet across[m]. The vent from which these rocks were hurled has not been located, but cannot lie far from the peninsula.

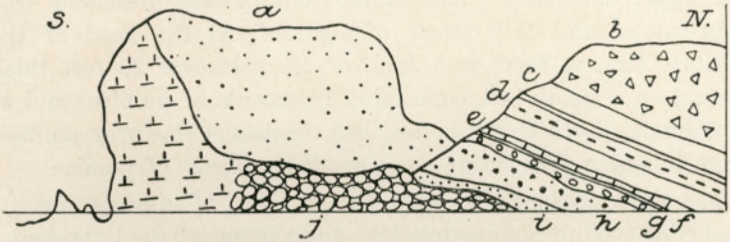

Fig. 75. Section of Sea-cliff north of Cape Wanbrow.

a. Yellow Pleistocene silts. *b*. Agglomerates and tuffs. *c*. Bedded tuffs. *d*. Greensands and tuffs, fossiliferous. *e*. Coralline limestone, 3 ft. to 3.5 ft. thick. *f*. Thin-bedded blue clays. *g*. Rubbly calcareous ash-bed, with thin layers of limestone from 2 in. to 6 in. thick near the upper part. *h*. Yellowish-green ash-bed, 18 ft. to 20 ft. thick, fossiliferous. *i*. Sands, silts, and ash, current-bedded; no fossils. *j*. Pillow-form lava and agglomerates.

Post-Oamaruian.

(Probably late Miocene and Pliocene.)

There are three Tertiary volcanic areas in New Zealand, namely, Otago Peninsula, Banks Peninsula, and Hauraki Peninsula, each forming a petrological province distinguished by at least two distinct periods of eruption.

Otago Peninsula.—This is composed of a pile of basic and semi-basic lavas[n], tuffs and agglomerates that rest mainly on a

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k. J. Park, Repts. Geol. Explts., 1885, p. 160.
l. E. K. Mulgan, Trans. N.Z. Inst., vol. xxxiv., p. 414.
m. E. K. Mulgan, *loc. cit.*, p. 428.
n. G. H. J. Ulrich, Aust. Assoc. Adv. Sci., vol. iii., p. 127; P. Marshall, Quart. Jour. Geol. Soc., vol. lxii., 1906, p. 381.

deeply eroded surface of the different members of the Oamaruian, but in places reach on to the fringe of the neighbouring Maniototian mica-schist. Among the lavas there are many varieties of semi-basic rocks, those of an alkaline type being well represented. Dyke rocks are not uncommon.

The first period of activity was chiefly distinguished by the emission of phonolite, dolerite, trachydolerite, andesite, basalt, and basanite; and the second period by the eruption of basalt and perhaps also andesite and phonolite.

During the cession of volcanic activity, the lavas of the first period were subjected to considerable erosion, and in the hollows then formed a series of fresh-water sediments were deposited consisting of shales, sands, and conglomerates, the latter being the upper member[o]. The shales contain well-preserved leaf impressions, and thin seams of lignite. At the head of the Waitati Stream, there is a seam of oil-shale over 20 feet thick resting on a sandy bed, containing fragments of pumice; and at Waikouaiti North Head the leaf-bed consists of fine grey pumice-sand, in which there occur many small fragments of pumice.

The dyke rocks represented in the Otago Peninsula include nepheline-syenite[p], augite-dolerite[q], and tinguaite[r], the latter being common. They are only found intruding the lavas of the first period of eruption.

The succession of the lavas is not very easy to determine, being complicated by the proximity of the sea where possibly the products of the first outbursts were laid down and covered over by later ejecta; and by the erosion of the lavas of the first period into valleys that were afterwards filled up with the lavas of the second period, the juxtaposition rendering it impossible to determine whether we are dealing with the flows of the first or second period of activity. At different places we find basalt, basanite, dolerite, trachy-dolerite, and phonolite resting directly on the basement rocks, and Marshall has shown that in the section at Otago North Head flows of basalt, trachyte, phonolite, and basanite alternate with each. There appears to have been no

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o. J. Park, Trans. N.Z. Inst., vol. xxxvi., 1903, p. 418.
p. C. N. Boult, Trans. N.Z. Inst., vol. xxxviii., 1905, p. 425.
q. P. Marshall, Quart. Jour. Geol. Soc., vol. lxii., 1906, p. 394.
r. P. Marshall, *loc. cit.*, p. 394.

definite order of succession of the lavas, which may be taken as indicative of the absence of the extreme magmatic differentiation seen in the North Island.

Date of Eruption.—The date of volcanic activity in this region can be determined within comparatively narrow limits. The lavas of the first period of eruption lie on a highly denuded surface of the various members of the Oamaru Series of middle or lower Miocene age; while the basalts of the second period are overlain unconformably by the fluviatile and glacial drifts of the Pleistocene Glacial Period. Being thus wedged in between the Miocene and Pleistocene, the emission of the igneous complex forming Otago Peninsula must be referred to the Pliocene, the earlier eruptions probably extending over the older Pliocene, the interval of rest and later eruptions bridging over the newer Pliocene.

Banks Peninsula.—This consists of a pile of rhyolites and agglomerates, followed by flows of andesite and basalt[s].

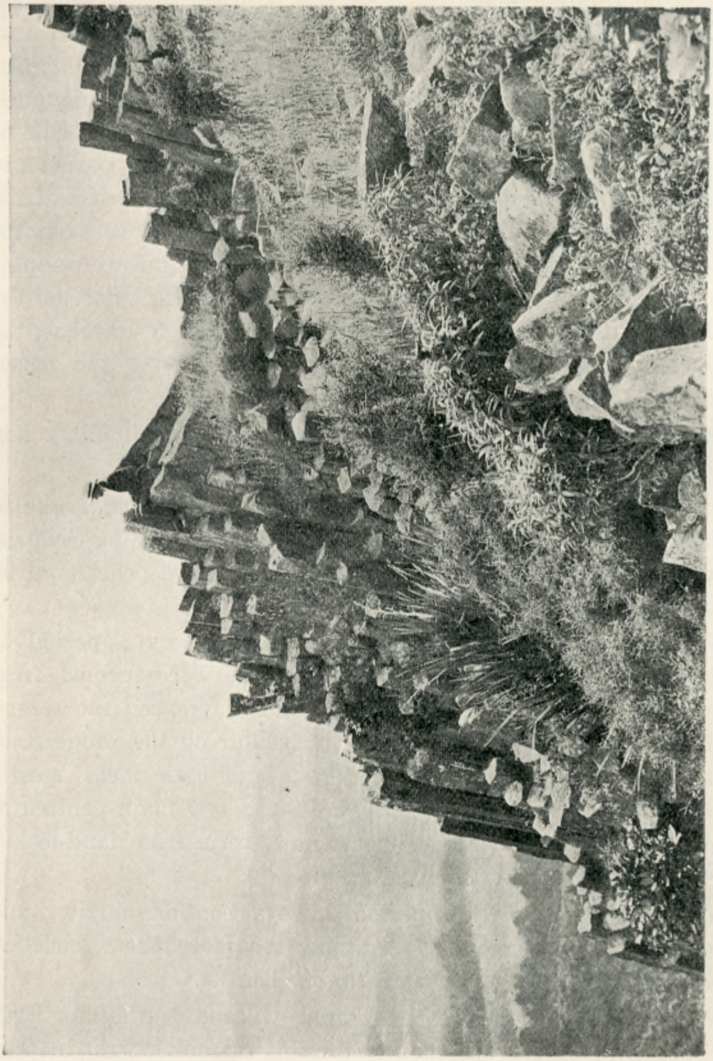
The basement rocks are mudstones, cherts, and greywacke of unknown age. On a deeply-eroded surface of these at Gebbies' Pass rest flows of rhyolite and beds of coarse tuff penetrated by dykes of rhyolite and pitchstone[t].

The emission of the rhyolites was followed by a period of quiescence during which beds of sandstone were formed from the denudation of the acidic rocks[u]. Then followed the second and greatest period of volcanic activity, during the progress of which were ejected floods of semi-basic and basic lavas, mostly andesites of a basic type, and basalts, the two main centres of eruption being the caldera that now form the land-locked harbours of Lyttelton and Akaroa.

The andesites of this period always contain augite, and generally a small amount of olivine, the more basic varieties, according to Speight[v], passing into true basalts.

The lavas emitted by the Akaroa volcano contain a large proportion of basalts and mainly for this reason Speight inclines

s. J. von Haast, "Geology of Canterbury and Westland," 1879, p. 324, *et seq.*
t. R. Speight, Trans. N.Z. Inst., vol. xl., 1907, p. 176.
u. F. W. Hutton, Quart. Jour. Geol. Soc., xli., 1885, p. 216.
v. R. Speight, Trans. N.Z. Inst., vol. xl., 1908, p. 177.



From "Otago Witness."

Fig. 75A. Columnar basalt, Mount Cargill, Dunedin.

to the belief that they are of slightly later date than those coming from the Lyttelton volcano.

Volcanic activity in this area closed with the effusion of andesite and basalt flows at Mount Herbert and Mount Sinclair.

The rocks of the second period of activity are intruded by a dyke of trachyte[w] containing tridymite near Lyttelton, and by a soda-amphibole-trachyte[x] at Cass's Peak. The only plutonic rock is a syenite[y] which occurs at the extremity of the peninsula.

So far as we can judge from what is seen at the present time, it would appear that the acidic eruptions took place on the shore of a rocky island lying twenty or thirty miles off the mainland. There is not direct evidence available as to the date of eruption. The rhyolites, however, bear a close lithological resemblance to the garnetiferous rhyolites of Mount Somers and Malvern Hills, and for that reason have been referred by Hutton[z] and Speight[a] to the Cretaceous period; which may be accepted until something more definite is discovered.

Of the date of the andesitic outbursts we are equally in the dark, there being nothing to show us whether they were contemporaneous with those of the Middle and Upper Oamaruian around Oamaru and Mount Somers; or with those of Otago Peninsula and Coromandel which began some time after the close of the Oamaru period, probably in the late Miocene or older Pliocene. The crater-rings of the Akaroa and Lyttelton volcanoes are too clearly defined to be of great antiquity; and should not be placed earlier than the Pliocene.

Hauraki Peninsula.

This covers an area of 1000 square miles, and is occupied by a rugged chain of hills varying from 1,200ft. to 3,000ft. in height. The basement rocks are indurated mudstones and greywacke of Juro-triassic age, being mainly developed in the Coromandel end. Overlying these there are isolated patches of marine strata belonging to the Oamaru Series.

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w. P. Marshall, Trans. N.Z. Inst., vol. xxvi., p. 368.
x. R. Speight, Trans. N.Z. Inst., vol. xl., p. 176.
y. F. W. Hutton, Jour. Roy. Soc., N.S.W., Aug., 1889, p. 125.
z. F. W. Hutton, *loc. cit.*, p. 216.
a. R. Speight, Trans. N.Z. Inst., vol. xl., 1908, p. 176.

On the highly denuded surface of both the Juro-triassic and older Tertiary rocks there is piled up throughout the length and breadth of the peninsula a great accumulation of andesitic lavas, tuffs, and agglomerates, which are in their turn overlain by lavas and tuff of a rhyolitic character.

The earlier andesitic outbursts were followed by a cessation of volcanic activity for a considerable time, during which were formed beds of sandstone and shale containing thin seams of impure coal. The close of the second andesitic period was followed by another cessation of activity of long enough duration to allow forest-vegetation to establish itself on the andesitic floor before the great rhyolitic outbursts began.

In the expiring phases of both the andesitic and rhyolitic outbursts there was widespread hydrothermal activity which resulted in the formation of the valuable gold and silver-bearing veins that are scattered throughout the peninsula.

First Period.—The eruptions of the first andesitic period were distinguished by the emission of floods of lava and the ejection of fine and coarse ash, the latter now forming beds of breccia.

The lavas are mainly andesites and dacites, the former predominating largely. Among the andesites are augite-andesite[b], hypersthene-andesite[c], hypersthene-augite-andesite[d], pyroxene-andesite[e], and hornblende-andesite[f]; and between these occur many intermediate varieties. The dominant type is a hypersthene-augite-andesite, a rock with which many of the most productive gold veins are associated.

The dacites, except where they contain primary quartz, are difficult to distinguish from the andesites; but the absence of quartz does not always remove the difficulty. Sollas[g], when

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b. F. W. Hutton, Jour. Roy. Soc., N.S.W., Aug., 1889, p. 137; and G. H. F. Ulrich, and in "Geology and Veins of Hauraki Goldfields," by J. Park, Trans. N.Z. Inst. M.E., vol. 1, p. 27; and Colin Fraser and J. H. Adams, "Bulletin No. 4 (New Series)," 1907, p. 71.

c. G. H. F. Ulrich, *loc. cit.*, p. 27; and Sollas and McKay, "Rocks of Cape Colville Peninsula," vol. 1, p. 118; and Fraser and Adams, *loc. cit.*, p. 170.

d. G. H. Ulrich, *loc. cit.*, p. 28; J. Park, Trans. N.Z. Inst., vol. xxxiii., 1900, p. 342; Sollas and McKay, *loc. cit.*, p. 199, *et seq.*

e. Sollas and McKay, *loc. cit.*, p. 144; Fraser and Adams, *loc. cit.*, p. 72.

f. F. W. Hutton, Jour. Roy Soc. N.S.W., Aug., 1889, p. 131; J. Park, Trans. N.Z. Inst., vol. xxxiv., 1901, p. 435; Fraser and Adams, "Bulletin No. 4 (New Series)," N.Z. Geol. Survey, 1907, p. 72.

g. Sollas and McKay, "Rocks of Cape Colville Peninsula," vol. 1, 1905, p. 118.

discussing this matter, says that chemical analysis can be the only court of ultimate appeal. In any case he states that the andesites are divided from the dacites by a very narrow line, both containing quartz.

Fraser and Adams mention that a narrow belt of rhyolite overlies directly the Mesozoic and Tertiary rocks near Cabbage Bay[h], which is interesting as establishing the usual orderly succession of acidic, semi-basic, and basic lavas in the Hauraki Gulf petrological province.

Second Period.—The rocks of the second period are mainly fragmentary, consisting for the most part of andesitic and dacitic tuffs, breccias, agglomerates, often rudely stratified with intercalated lavas. In these occur intruding dykes of various andesites and porphyrite.

Propylitisation of Andesites.—At and around the centres of emission the andesites and dacites of the first period have been altered to a depth of 1,000ft. or more below sea-level to a comparatively soft grey or yellowish-grey rock. This is the rock in which the majority of the payable gold-bearing veins occur, and hence it has received the name **kindly country**, by which it is known to the miners at the various mining centres. The transition from the solid andesite to the altered propylite is generally gradual; but in some cases the line of demarcation is sharply-defined.

The alteration reaches far below the known limit of circulating meteoric waters, and must be ascribed to deep-seated agencies, among which the most active would be ascending thermal waters, steam and acid vapours, these being the products that mostly abound around centres of waning volcanic activity.

The andesites are not everywhere altered, but only at the old centres of eruption and at the secondary vents grouped around these. For example, there is evidence that prolonged solfataric action took place at the old Kapanga volcano, Coromandel; Waiokaraka volcano, Thames; Waitawheta volcano, Karangahake; Martha volcano, Waihi; and Te Aroha volcano, Te Aroha.

The name propylite cannot be taken to indicate a distinctive type of rock as originally contended by Richthofen in 1868, and

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h. Fraser and Adams, "Bulletin No. 4 (New Series)" N.Z. Geol. Survey, 1907, p. 64.

by Zirkel in 1876, but only as a convenient term serving to distinguish a well-marked and interesting pathological **facies**, or habitus, of the andesitic lavas.

Correlation of Andesites.—The andesites and dacites of the first and second periods extend far beyond the limits of the Hauraki Peninsula, being found extensively developed at Great Barrier Island and outlying rocky islets, at Whangarei Heads, Kaipara, and Whangaroa Heads.

The vast pile of andesite tuffs, breccias, agglomerates, and lavas, and ramifying dykes forming the Waitakerei Range running northward from the Manukau Harbour, appears to belong to the second andesitic period.

The andesites in the vicinity of Blind Bay, Great Barrier Island, have been extensively propylitised. They are overlain by a sheet of rhyolite which is so highly silicified as to pass almost insensibly into huge deposits of sinter-like chalcedonic quartz containing gold and silver. A flow of rhyolite occurs on the mainland near Whangarei.

Age of Andesitic Eruptions.—The presence of the intercalated ash bed in the Oamaruian Waitemata beds in the neighbourhood of Auckland show that the first eruptions were andesitic, and took place somewhere about the middle Miocene. The absence of volcanic material among the sediments of the Oamaruian Torehine marine beds near Coromandel also show that the Waitemata outburst was local and merely premonitory of the later paroxysms that built up the Hauraki Chain on the floor of the shallow Hauraki sea.

The Hauraki andesites and andesitic ejecta rest on highly dissected surfaces of the Torehine beds; and when we take into account the age of the Oamaru Series[i], the higher members of which cannot be placed as older than middle Miocene, the date of the Hauraki andesitic outbursts of the first period must be referred to the upper Miocene, and of the second period probably to the older Pliocene.

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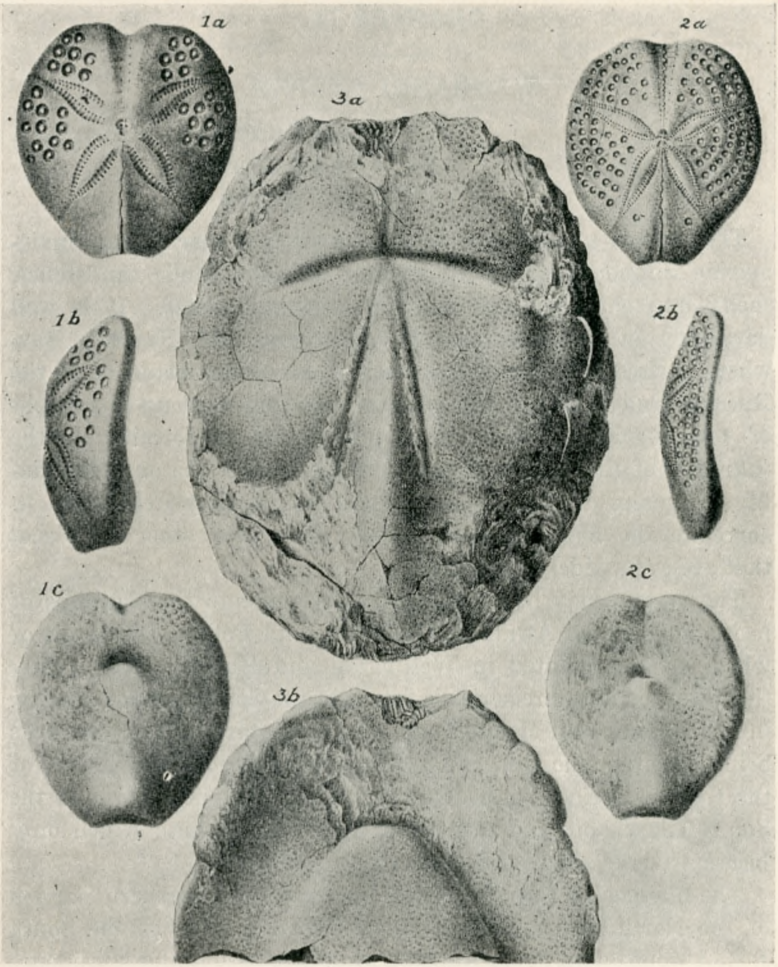
i. J. Park, Trans. N.Z. Inst., vol. xxxvii., 1904, p. 491.



Echinoderms from Otototara Stone. Upper Oamaruian.

Fig. 1, *a-c* *Hemipatagus tuberculatus*, Zittel.
,, 2, *a-c* *Hemipatagus formosus*. Zittel.
,, 3, *a, b*. *Meoma Crawfordi*, Hutton.

⅚ natural size. (After Zittel.)

CHAPTER IX.

WANGANUI SYSTEM.

(*a.*) Petane Series.
(*b.*) Waitotara Series.
(*c.*) Awatere Series.

This system consists of a great succession of marine and fluvio-marine sediments, chiefly alternations of clays, sands, sandstones, shelly and coralline limestones and conglomerates. It is well developed in the provinces of Wellington and Hawke's Bay, where it rises from sea-level on both sides of the island on to the Ruahine Range, on which it lies as a mantling sheet up to a height of over 4,000ft. There is a remarkable uniformity in the character of the sediments and the contained fauna on both sides of the main divide which renders it comparatively easy to correlate the main groups of beds with each other in places that are even widely separated.

The system may be conveniently divided into three groups of beds, namely, the Awatere, Waitotara, and Petane, series, all of which are represented in Wellington and Hawke's Bay. Only the lower, or Awatere series is found in the South Island, namely, in Canterbury and Marlborough, the Waitotara and Petane beds being absent. The Pliocene uplift which preceded the advent of the Glacial Period stopped the continuance of deposition in the South Island, but did not affect the North Island, which only began to rise about the close of the Pliocene.

The absence of the Wanganui system in the northern portion of the North Island, and in the southern portion of the South Island would seem to prove that while deposition and subsidence were going on in the Cook Strait region, a differential uplift was taking place on both sides. It would appear that the deposition of this great formation began while the Ruahine Range stood some 1,600ft. lower than at present, that is judging by the height at which we find the basement beds of the system. Subsidence and deposition continued in the middle area until the Ruahine

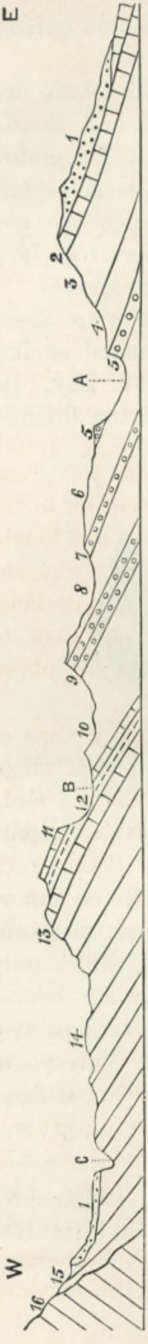


Fig. 76. Section from sea to Ruahine Range. Distance 16 miles.

1. Pleistocene gravels and pumice sands. 2-10. Petane Series. 11-13. Waitotara Series. 14-15. Awatere Series. 16. Lower Mesozoic mudstones and sandstones.

Range was 4,300ft. lower than now, or until a pile of sediments exceeding 2,000ft. thick had been deposited. At this time all but the summit of the main divide was submerged, both slopes being laved by wide shallow seas on the floor of which lay the newly formed beds of mud, sand, and gravel, mingled with banks of shells, and the ruins of coral reefs.

The land continued to sink until the close of the Pliocene period, being immediately succeeded by the Pleistocene uplift, which did not cease until the group of beds forming what is now the Waitotara Series was elevated to a height of over 4,000ft. above the sea. The land rose more rapidly along the axial divide than elsewhere, with the result that the different groups of beds are found to overlap as they pass inland, rising from the sea by a succession of long sloping planes. The general disposition of the beds, as shown by McKay in Hawke's Bay, may be taken as typical of their arrangement.

There are no contemporaneous lavas or ash beds in the Wanganui System, but pumice sands and water-logged fragments of pumice appear in the middle of the Petane Series and continue up to the closing beds, thus proving that volcanic activity began in the Central Plateau about the beginning of the Newer Pliocene.

The fossils of this system are very different from those of the Oamaru Series. The lower beds are distinguished by many fine *Struthiolaria,* which now appear for the first time, while we miss *Amussium Zitteli*, *Pseudamussium Huttoni*, and the other pectens that are so abundant in the Marawhenua horizon of the Oamaruian.

On the other hand *Murex, Trophon, Pisania* and *Cassis* first appear in this system, as also do *Oliva, Sigaretus*, and *Risella*, three genera that are not now represented in our seas. The middle or Waitotara series is distinguished by a number of large pectens and a gigantic oyster (*Ostrea ingens*), all of which are now extinct. All the Brachiopoda are living. Altogether from 70 to 90 per cent. of the mollusca are represented by living species.

In the Waipara district, the Greta beds of the Awatere Series are found resting unconformably on a highly denuded surface of the Oamaruian. In Wellington and Hawke's Bay, the Awatere beds abut against the Secondary rocks of the Ruahine

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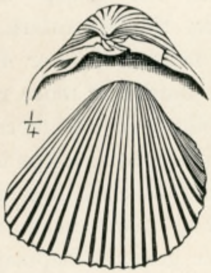

Fig. 77. *Cardium spatiosum*, Hutton.

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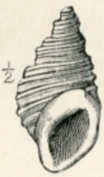


Fig. 78. *Struthiolaria sulcata*, Awatere ; Castle Point.

Range, or rest unconformably on rocks belonging to the Waipara or Oamaru Series.

In the lower portion of this system at the Mata River, inland of Tokomaru Bay, in the East Cape District, there are thick beds of conglomerate composed to a large extent of crystalline rocks, none of which occur *in situ* in any part of the North Island. Many of the constituent rocks are sub-angular in form and over two feet in diameter. They are described by McKay[j] as resembling the crystalline hornblende rocks of South-west Otago.

Awatere Series.

This series includes the Waverley, Patea, Taipo, Whareama, and Castlepoint beds in Wellington; the Mohaka and Hauroto

j. A. McKay, Repts. Geol. Expls., 1886-87, p. 212.

beds of Hawke's Bay; the Waikaremoana beds of South-east Auckland, the Awatere beds of Marlborough, and the Greta and Motanau beds of North Canterbury.

It is not a little singular that no marine beds of Pliocene age are known in the South Island, south of Middle Canterbury; or in the North Island, north of East Cape district.

The rocks of the Awatere Series consist of blue clays, sandy clays, shelly sandstones, and conglomerates. The thickness of the Motanau beds, according to Hutton[k], is 370ft. At other places the thickness is unknown.

On the Ruahine Range[l] they rise to a height of over 4,000ft. above the sea.

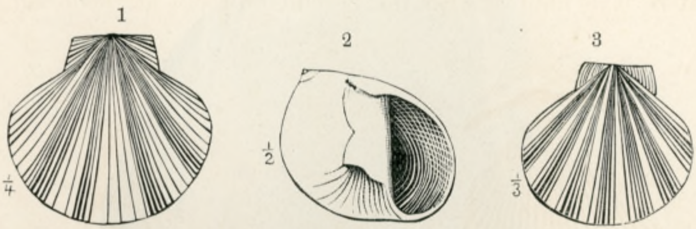


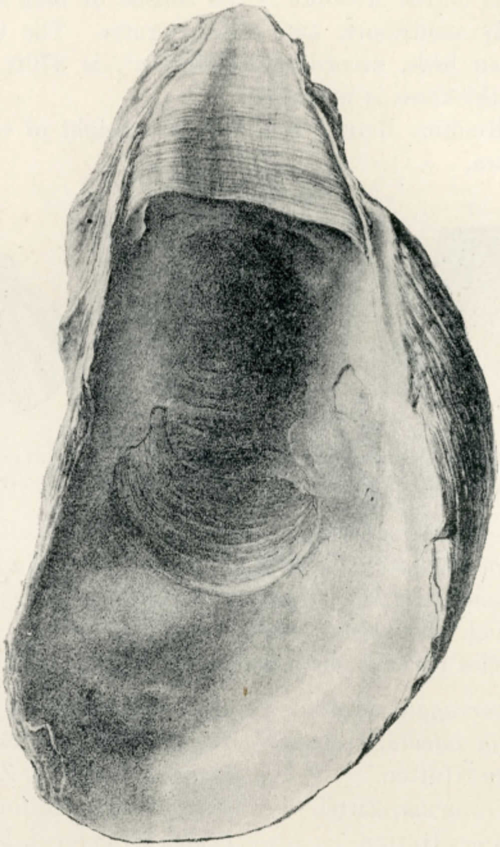
Fig. 79. 1. *Pecten Crawfordi*, Wellington Taipos. 2. *Natica ovata*, Motanau, Awatere, Napier. 3. *Pecten secta*, Motanau, Napier.

Fossils.—These include many species of *Siphonalia, Struthiolaria, Scaphella, Turritella, Natica, Ancilla, Dentalium, Cardium, Ostrea, Pinna, Mytilus, Glycimeris, Corbula, Panopæa, Tapes,* etc., of which about 70 per cent. are still living. Among the extinct species perhaps the most distinctive are the following:—

Scaphella corrugata, Hutton.
Struthiolaria sulcata, Hutton.
Natica ovata, Hutton.
Dentalium conicum, Zittel.
Dosinia magna, Hutton.
Cardium spatiosum, Hutton.
Cardium striatulum, Sowerby.
Tapes McKayi, Park.
Pecten Triphooki, Zittel.
Pecten secta, Hutton.
Pecten Crawfordi, Hutton.
Pecten delicatula, Hutton.

Zonal Fossils.—So far as known *Struthiolaria sulcata, Cardium spatiosum*, and *Scaphella corrugata* have never been found outside this horizon. *Natica ovata* rises into the Petane

k. F. W. Hutton, Trans. N.Z. Inst., vol. xx., 1887, p. 257.
l. J. Park, Repts. of Geol. Expls., 1888-89, p. 66.



Ostrea ingens. Sowerby.
Size, ½ natural. (After Zittel.)
From Te Aute and Waitotara Beds. Awatere Series – Lower Pliocene.

Series at Petane and Shakespeare Cliff, Wanganui. *Dosinia magna,* which makes its first appearance in the Pareoras, does not rise higher than the Awatere horizon. On the other hand, the large *Dentalium, D. conicum,* which is abundant in the Awateres, appears sparingly in the Petanes.

WAITOTARA SERIES.

This series is well developed in the provincial districts of Wellington and Hawke's Bay. In the former it extends from the Wanganui Bight northward to the inland Patea and upper Rangitikei, where it rises up to 4,000ft. on the higher flanks of

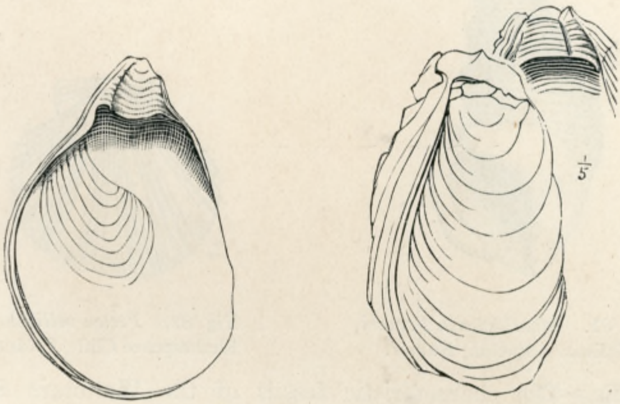


Fig. 80. *Ostrea ingens,* Waitotara, Te Aute, Napier, Castle Point, Broken River.

the Ruahine and Kaimanawa ranges; in the latter it reaches from the sea to the Ruahine Range, on to which it climbs to a height of about 4,000ft.

The sediments generally consist of yellowish brown coralline crag, associated with sandy clays, sandstone, and shelly limestone. The thickness of the whole series is not less than 800ft. Included in this formation are the Waitotara coralline beds, Te Aute limestone, and the Te Whaka limestone crag, with its associated sandy and clayey beds.

The sandy beds contain a large assemblage of marine shells, among which the following genera are represented:—*Pecten, Pectunculus, Pinna, Panopæa, Dosinia, Mytilus, Glycimeris,* *Venus, Turritella, Struthiolaria, Dentalium,* and others. The coralline crag is mainly composed of *Ostrea ingens,* large pectens and numerous broken corals, the most distinctive of the latter being *Fascicularia intermedia,* Ten-Woods, which is almost identical with *F. aurantium,* Milne-Edwards. This extinct genus is considered characteristic of the Older Pliocene of England and Continental Europe. Below the crag beds there is a bed of brown calcareous sands containing *Pecten radiatus, Magellania lenticularis, Ostrea ingens,* and corals.

Fig. 81. *Struthiolaria Fraseri,* McLean's Station, Napier.

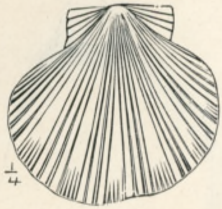


Fig. 82. *Pecten vellicatus,* Shakespeare Cliff; Petane.

Fossils.—The characteristic fossils of the Waitotara Series are as follows:—

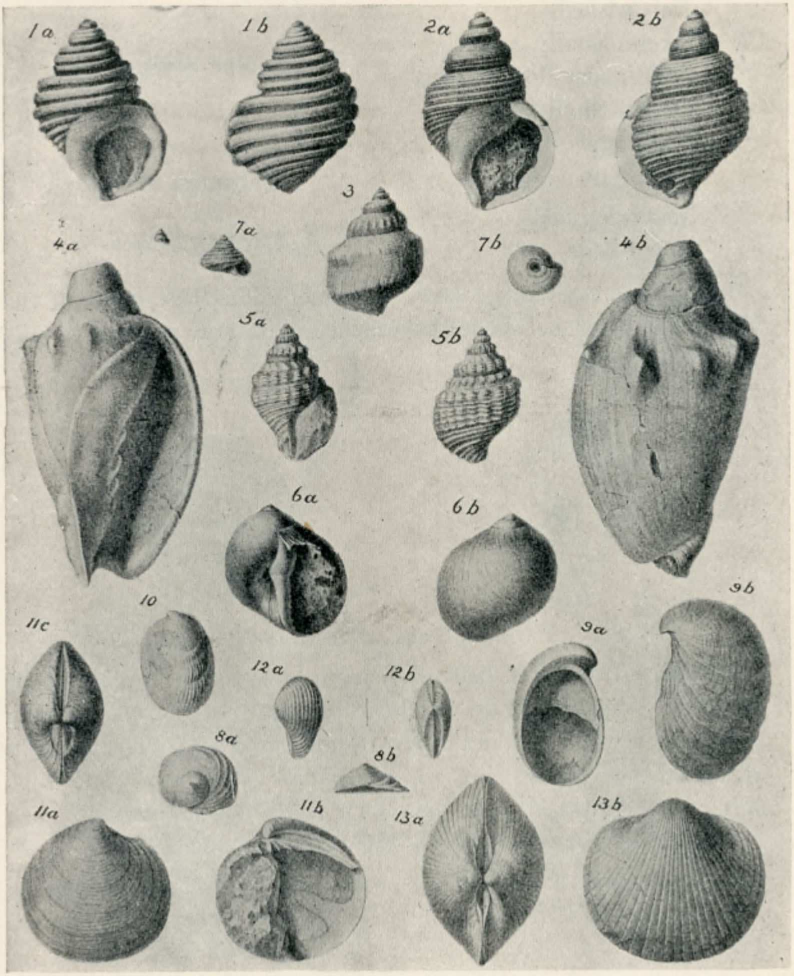
Ostrea ingens, Zittel.
Pecten accrementa, Hutton.
Pecten Triphooki, Zittel.
Pecten radiatus, Hutton.
Fascicularia intermedia, T.W.

The first three of these are also found in the Awatere beds, but are not known in any beds higher than the Waitotara.

Petane Series.

This series consists of sandy shell beds, blue sea muds commonly crowded with fossils, conglomerates, and shelly limestones, generally sandy or pebbly and flaggy in structure.

It is well developed between Wanganui and Waitotara, and in the maritime hills north of Napier. The thickness exceeds 1,200ft.



Tertiary Fossils.—Lower Pliocene.

Fig. 1, *a, b.* *Struthiolaria canaliculata*, Zittel.
,, 2, *a, b.* *Struthiolaria cingulata*, Zittel.
,, 3, *Struthiolaria*, Sp.
,, 4, *a, b.* *Scaphella pacifica*, Sol.
,, 5, *a, b.* *Purpura conoidea*, Zittel.
,, 6, *a, b.* *Natica solida*, Sow.
,, 7, *a, b.* *Trochus dilitata*, Sow.
Fig. 8, *a, b.* *Trochita stoliczkai*, Zittel.
,, 9, *a, b.* *Crepidula incurva*, Zittel.
,, 10, *Crepidula*, Sp.
,, 11, *a-c* *Dosinia Greyi*, Zittel.
,, 12, *a, b.* *Leda*, Sp.
,, 13, *a, b.* *Glycimeris laticostata*, Quoy et Gaim.

$\frac{5}{8}$ Natural size. (After Zittel.)

Proceeding northward along the coast from Wanganui, we get the following succession of beds in descending order:—

Putiki (Shakespeare Cliff) beds	Petane Series.
Kai-iwi beds	
Okehu Shelly sands... ...	
Nukumaru Rotella beds ...	
Okehu Shell beds	
Nukumaru limestone ...	
Waitotara crags	Waitotara series.
Waverley beds	Awatere Series.
Patea beds	

The same succession of beds is exposed along the course of the Wanganui river between Shakespeare Cliff and a point a mile above Parakino.

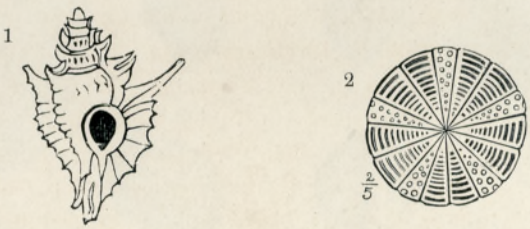


Fig. 83. 1. *Murea Zealandiæ.* 2. *Arachnoides Zealandiæ.*

Fossils.—The Putiki beds at Wanganui contain a large number of shells, 95 per cent. of which are recent. In the Okehu shell beds were found the bones of a bird and small seal. The seal was identified by Hector[m] as *Arctocephalus cinereus.* The bird bones were supposed to be those of a small moa (*Dinornis*).

Among the characteristic fossils[n] of the Petane Series are:—

Trophon expansus, Hutton.
Pisania Drewii, Hutton.
Pleurotoma Wanganuiensis, Hutton.
Pleurotoma tuberculata, Kirk.
Galerus inflatus, Hutton.
Trochus conicus, Hutton.
Zizyphinus Hodgei, Hutton.
Dentalium nanum, Hutton.
Cytherea assimilis, Hutton.
Ostrea corrugata, Hutton.
Trochocyathus guinarius, T.W.
Flabellum rugulosum, T.W.
Arachnoides zealandiæ, Gray.

m. J. Park, Repts. Geol. Expls., 1886-87, p. 63.
n. F. W. Hutton, Quart. Jour. Geo. Soc., xli., p. 212.

IGNEOUS ROCKS OF WANGANUI SYSTEM AND POST-TERTIARY DATE.

The Rhyolites.—These consist of lavas, tuffs, and fine pumiceous agglomerates. They rest, in the Hauraki area, on highly denuded surfaces of the andesites of the first and second periods of activity, being chiefly developed on the north-east side of the main dividing range, in the region lying between Mercury Bay and Tauranga. Many of the rhyolite flows are finely banded, and nearly all possess a spherulitic structure. The majority are comparatively soft pumiceous rocks, but there are many varieties including some that are dark green and intensely hard. Primary quartz is not relatively rare, and a plagioclase feldspar is nearly always present.

The rhyolites are in many places highly silicified[o], and have associated with them large mushroom-shaped sinter deposits.

Age and Correlation of Rhyolites.—The rhyolites lie unconformably on the andesites and dacites of both the first and second periods. They can be traced continuously from Mercury Bay south-east to Tauranga, and thence southward to Rotorua and Rotomahana in the Central Volcanic Region, where they cover an area of thousands of square miles, embracing within its limits the Taupo and Upper Wanganui watersheds.

In the Upper Wanganui[p], Mokau, Waipa, and Waikato, horizontal flows of rhyolite are found capping many flat-topped hills and ridges which on examination are found to be the remains of a deeply dissected rhyolite plateau that at one time covered a large portion of the King Country.

Water-borne pumice sands with fragments of pumice first appear in the Okehu shell beds of Wanganui, and in the Petane beds of Hawke's Bay, that are referred to the newer Pliocene. Pumice sands are present in all the members of the newer Pliocene, while the thick drifts of wind-borne pumice on the summit of the Kaimanawa Range[q] overlooking the Taupo crater cannot be older than Pleistocene.

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o. Park and Rutley, Quart. Jour. Geol. Soc., lv., 1899, p. 449; and Rutley, *loc. cit.*, vol. lvi., 1900, p. 493.

p. J. Park, Repts. Geol. Explorations, 1888-89, p. 175.

q. J. Park, Repts. Geol. Expls., 1886-87, p. 58.

The vents or centres of eruption from which the rhyolite lavas issued have not yet been identified.

Andesites.—On the surface of the rhyolite-plateau there has been reared the huge andesitic volcanoes Ruapehu, 9,175ft.; Egmont, 8,260ft.; and Ngauruhoe, 7,615ft.

The lavas of Ruapehu and Ngauruhoe are mainly hypersthene-augite-andesite[r], but augite-andesites[s] and hornblende-andesites[t] have also been described from there.

The lavas of Mount Egmont are hornblende-augite-andesite with a hyalopilitic base[u].

Basalts.—The basalt-plateau lying between Drury and the Waitemata, first described by Hochstetter, consists of flows of basalt that Marshall[v] has found to be related to the basanite type, nepheline in small quantity being nearly always present.

At the cones in the Auckland Isthmus the lavas are interbedded with irregular layers of basic scoriæ.

There are some other basic rocks in the Auckland provincial district that are probably somewhat older than the basanites of Auckland. Mount Pirongia, near Kawhia, is composed of thick flows of dolerite[w], and north of Kerikeri, and between Kaitai and Ahipara there are fine-grained basalts[x].

RECENT VOLCANIC ACTIVITY.

The Tarawera Eruption.

The ejected material was entirely fragmentary, being grey rhyolitic and black andesitic matter, which occurred in all sizes from a fine dust to angular and nodular fragments several inches in diameter. Besides the ash-like material there were ejected many large blocks of andesite, both solid and vesicular, some at Mount Tarawera weighing over eighty tons.

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r. P. Marshall, Trans. N.Z. Inst., vol. xl., 1907, p. 95.

s. F. W. Hutton, Jour. Roy. Soc., N.S.W., Aug., 1889, p. 136; and A. P. W. Thomas, Trans. N.Z. Inst., vol. xxi., p. 338.

t. F. W. Hutton, Jour. Roy. Soc., N.S.W., Aug., 1889, p. 133.

u. F. W. Hutton, Trans. N.Z. Inst., vol. xxxi., 1898, p. 484; and P. Marshall, Trans. N.Z. Inst., vol. xl., 1907, p. 95.

v. P. Marshall, Trans. N.Z. Inst., vol. xl., 1907, p. 96.

w. P. Marshall, *loc. cit.*, p. 96.

x. P. Marshall, *loc. cit.*, p. 97.

The chief centres of eruption immediately after the opening of the fissure were Wahanga, Ruawahia, Tarawera, Rotomahana, Black Crater, and Echo Crater. The rent was nearly nine miles long, with a mean width of ten chains. The greatest width was a mile and a quarter. The depth varied from 900ft. at the north end to 300ft. at the south.

The fissure extended for four miles along the summit of Mount Tarawera, following the axis of the mountain, and for five miles across the Rotomahana rhyolite plateau, the rent on the low ground running in the same line as the mountain fissure, the general bearing of which was about 58° (true).

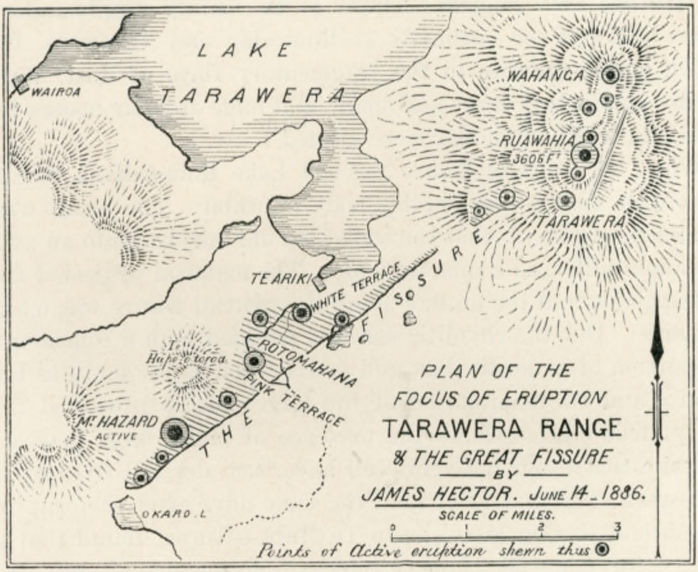

Fig. 83A.

It would appear to be clearly established from the evidence of European and native eye witnesses that the formation of the fissure was not caused by a single paroxysmal outburst, but was the result of a comparatively slow rending, which began at Wahanga, an elevation on the north end of Tarawera, and gradually travelled southward, passing successively through Ruawahia, and Tarawera, thence traversing the plain until it reached Lake Rotomahana, which lay in its path, whence it passed onward to Lake Okaro. The time occupied in opening the fissure was three or four hours.

Mount Tarawera was an old volcano composed of rhyolite flows and tuffs. The country around Lake Rotomahana for many miles in all directions was a dissected rhyolitic plateau on the denuded surface of which lay alternating layers of fine and coarse rhyolitic and pumiceous ash or tuff—the ejecta of former eruptions—that conformed to the undulations of the surface on which it was spread. Until the eruption of 1886, no basic or semi-basic igneous lava or tuff was known to exist nearer than Mount Edgecombe, sixteen miles from Tarawera, and outside the zone of activity.

The eruption began with the fissuring of Wahanga and the welling up of a semi-basic lava, which subsequent examination by Hutton and Thomas showed to be mainly augite-andesite. Then followed the outbursts at Ruawahia and Tarawera, from which augite-andesite in the fragmentary form of dust, scoriæ, lapilli, bombs both large and small, and huge angular masses both solid and highly vesicular were ejected.

When the rending fissure reached Lake Rotomahana, it came in contact with a considerable body of water. The result was a shattering explosion that converted the old lake-bed into an active volcano a mile and a quarter wide. The material projected from Rotomahana and the craters along the plateau fissure was mainly rhyolitic. But the rhyolitic ash was mingled with a considerable proportion of andesitic dust and scoriæ, even as far south as Lake Okaro, and an examination of the larger blocks projected from the plateau-craters shows the presence of many large masses of andesite that could not very well have been derived from Mount Tarawera. As a matter of fact, for some days after the eruption, the author, during his visits to Te Hape-o-Toroa, found that the only solid material being ejected at Rotomahana and Black Crater consisted of boulders of black andesite.

That andesite lava welled up in the fissure in the Rotomahana area, as well as in the overhanging rent in Tarawera seems to be a conclusion in every way in harmony with the facts. It would, however, appear that the lava did not rise so high as at Tarawera, a circumstance that may have been due to the cooling effect of the lake waters. On the other hand, the water becoming suddenly converted into steam by contact with the molten matter below would inevitably exert an enormous explosive force which, following the line of least resistance in an upward direction, would shatter the overlying rhyolites and sinters into the dust and fragments which we now find covering the Rotomahana end of the field of volcanic activity.

Radiating northward from Tarawera, and thence spreading out to the north-east and north-west like an open fan, the covering of dust, ash and scoriæ is wholly andesitic. The scoriæ is coarsest between the radii passing through Lake Rotoiti and Tarawera River, being especially coarse in the belt between Mount Tarawera and the sea in the line of prolongation of the fissure. Beyond this limit it passes into a coarse sand which, north-west of Te Puke and north-east of Opotiki graduates into a fine dust.

The volcanic ejecta was spread over an area of nearly 6,000 square miles in a sheet varying from 0ft. to 50ft. thick, the greatest thickness being found in the immediate vicinity of the fissure-rent. It did not extend far beyond the scene of activity on the eastern side of the fissure, owing to the strong southerly gale which was blowing at the time of the eruption. On the other hand, this wind, while limiting the effect of the eruption on the east side, helped to carry the ash westward a distance of ten or twelve miles toward Rotorua, and northward to the sea between Tauranga and Opotiki, a distance of seventy-five miles. At the same time a thin coating of excessively fine wind-borne dust was deposited as far north as Tairua, and as far east as East Cape; and also on vessels in the Bay of Plenty, a hundred miles from Rotomahana, but it was only within a radius of twelve miles that the material was thick enough to have a destructive effect.

At the south end of the fissure, the ejecta extended about a mile to the westward, but north of this it spread over a gradually widening area until opposite Tarawera it reached as far as Tikitapu, twelve miles from the great rent in Mount Tarawera. Wherever the dust or mud was over two feet thick the vegetation was entirely destroyed; and even where only twelve inches thick the trees were stripped of their foliage and branches, and so badly injured that the majority of them eventually died.

The native village at the Pink Terrace, on the shore of Rotomahana, being situated on the edge of the fissure-rent, was blown out of existence, and the inhabitants, eleven in number, were instantly killed. The native villages at Te Ariki, Moura, and Te

Wairoa were overwhelmed with dust and mud, all the inhabitants of the first two being killed, namely fifty-two natives at Te Ariki and thirty-nine at Moura. The fourteen killed at Te Wairoa included several Europeans.

As a result of the eruption the hills and valleys adjacent to Rotomahana were covered with a smooth sheet of grey ash, the thickness of which could not then be ascertained. This once smooth mantle has become, in recent years, scored by the rain into narrow V-shaped ridges and corresponding gutters that furrow the slopes from top to bottom. Outside the furrowed area, which lies close to the seat of volcanic activity, the ash is now covered with a dense jungle of vegetation consisting mainly of bracken, tutu, veronica, tree-ferns, and many forest trees, among which the blue gum and prickly acacia of Australia are conspicuous. It was some three or four years after the eruption before vegetation began to establish itself, but since the year 1890 the growth has been rapid, many of the gums at the buried village of Te Wairoa having grown to a height of over thirty feet.

The dissection of the ash-sheet has revealed many points of interest that could not be formerly observed. It is now seen that the greatest proportion of black andesitic ash occurs at the Tarawera end of the fissure and the least at the south end.

It is also found that the explosions which took place during the earlier stages of the paroxysm broke up into large blocks and piled into ridges the older rhyolitic lavas that formed the sides of the fissure-rent. Among these masses of rhyolite there occur innumerable angular blocks of siliceous sinter and many semi-rounded boulders of augite-andesite ejected from the vents during the progress of the eruption.

The ash-sheet as seen from the floor of the fissure, which is now quite accessible between Echo and Rotomahana craters, is found to consist of alternating thin layers of fine, grey dust, of grey dust mingled with black andesitic ash, and of andesitic ash or fine andesite rubble, the whole being partially consolidated. The material everywhere presents a well-stratified appearance; and if the conditions under which it was deposited were not so well-known it might be easily mistaken for a subaqueous tuff. The alternation of fine and coarse ash is due to the varying fineness of the material ejected by the different explosive outbursts, which appear to have followed each other in rapid succession; and in some degree to the wind with its powerful intermittent gusts which effected a sorting or winnowing action by removing the finer dust to a greater or less distance from the craters.

It is noticeable that the inclination of the ash-beds is always towards, and not away from, the centres of eruption. In all cases the layers of ash lie parallel to the original surface of the ground on which they rest; and they maintain a uniform thickness for considerable distances.

The premonitory signs of the coming disaster consisted of subterranean rumblings and earth-tremors lasting several hours; but whether these were of such a nature as to cause anxiety or alarm to those living near Rotomahana and Tarawera is unknown, since all the native villages within a radius of four miles were destroyed, not a soul escaping. It is, however, certain from the evidence of the survivors at Te Wairoa, situated on the west side of Lake Tarawera, that the titanic outburst which split Mount Tarawera in twain from end to end and opened the yawning fissure that stretched southward for miles over the low plateau near Rotomahana, took place with appalling suddenness. For a space of four hours the craters situated on the line of the newly-formed rent poured out piles of ash that overwhelmed the whole country, which, as far as the eye could reach, was converted into a weird grey-draped smoking desert.

After this, the violence abated; and at the time of the author's visits to Mount Te Hape-o-Toroa, situated on the edge of the fissure overlooking Lake Rotomahana and commanding a perfect view of the whole field of volcanic activity, the vents on Mount Tarawera, at Rotomahana, Black Crater, and Echo Crater were centres of great activity, from which clouds of andesite boulders were projected high into the air, some being shot over the crater-rim, where they were piled up in confused masses, others, and apparently the majority, falling back into the throats of the vents, where they were churned up by the escaping steam until again tossed out. The steam issued from the vents with a terrific continuous roar; and the descending blocks of rock struck the ascending masses with shattering violence, the united effect being stupefying and overpowering. At short intervals that rarely exceeded twelve minutes, there took place heavy underground bumps—such as might be caused by subterranean explosions. These were instantly followed by short, sharp earthquakes of such violence that it was, after a time, deemed advisable to withdraw to the vicinity of Black Crater, as there seemed to be an imminent danger of the hill being precipitated into Rotomahana Crater.

The effect produced on those witnessing this grand display of plutonic force at short range was diverse. At first some became hysterical, but in time all relapsed into a subdued mood of indifference followed by a stupefying languor. It is not improbable that the stupor was caused by the presence of carbon monoxide in the gaseous emanations of the craters.

The chief centre of activity at this stage was the Rotomahana vent, from which there issued a vast pillar of steam that reached to a height of over 15,000ft. After a few months of violent hydrothermal activity, solfataric action gradually waned, and in time practically ceased, thus permitting the crater to become filled up with water, forming a new Rotomahana, which is many times the size of the old lake. Things remained in this state for a number of years, until about 1897, when geysers again began to play.

In 1900 there came into existence Waimangu Geyser, situated in the floor of the fissure-rent at the north end of Echo Crater. This world-famed geyser played intermittently up till 1908, at times projecting an enormous column of water and mud to a height of over 1,200ft.

Although Waimangu has now ceased to play, solfataric and fumarolic action is still very conspicuous in the floor and on the walls of the old rent at Echo Crater, and on the western shores of Rotomahana, the waters of which are warm and heavily mineralized, possessing a yellowish-green colour.

Large masses of yellow iron pyrites ($Fe\ S_2$) are abundant in the sinters and pumiceous rhyolites at Rotorua. Their origin has always been somewhat obscure, but is no longer so, as iron sulphide can be clearly seen in the process of formation at Echo Crater. The floor of this crater, as seen by the author in March, 1910, was covered with a thin siliceous crust through which boiling water and steam escaped in all directions. Through the interaction of the hot ascending mineralized waters and the sulphuretted hydrogen with which the steam is charged, iron sulphide was being deposited, at first as a black and then a bright yellow film on all the loose stones lying in the bubbling seething portion of the crater known as the "Frying Pan."

Since the date of the emission of the flow of rhyolite which forms the ring of hills surrounding Rotorua and Rotomahana craters, as well as the plateau that extends northwards to Katikati, Tauranga, Te Puke, Maketu, and Whakatane; westward from Thames Valley to Middle Waikato; and southward to Taupo; forming also the plateau that stretches into the headwaters of the Waipa, Mokau, and Upper Wanganui, there have been two eruptions in the Rotomahana-Rotorua area, the chief product of which was showers of pumice and rhyolitic ash. These outbursts were in many respects similar to the memorable eruption of June, 1886. They took place after the dissection of the rhyolite plateau, as proved by the circumstance that the ash-beds follow the contours of the spurs and ridges that have been carved in the plateau.

The old buried land surfaces, with their black loam and charred timber, can be clearly seen in many places. Just how long these eruptions preceded that of 1886 is unknown. It is, however, obvious that the intervals of rest between them were of sufficient duration to permit the ash-covered land to become clothed with dense vegetation before the next eruption took place.

The ejecta of these old eruptions consist of fine and coarse rhyolitic ash and pumiceous tuffs that is spread over the ground in thick and thin layers. The andesitic ash so conspicuous in the Tarawera ejectamenta is entirely absent in the material emitted by these prehistoric outbursts.

In every volcanic region there is generally an orderly succession in the composition of the ejected material, in which three distinct phases of activity can be traced. When the products of the earlier eruptions are acidic, those of the second stage are semi-basic, and of the third basic, but notable exceptions to this general law have been recorded. That is rhyolite or other acidic rock is followed by andesite, and andesite by basalts. The Rotorua area would appear to have reached the second or semi-basic phase.

The origin, or cause, of the Tarawera eruption in 1886, like that of most volcanic eruptions, although a source of much investigation, is still a matter of mere conjecture. The welling up of a molten magna, with the resultant fissuring and sudden admission of the waters of Lake Rotomahana to the uprising glowing mass, and the collapse of the dome that supported the floor of the lake, accompanied by the instant contact of the waters with a highly heated igneous mass lying immediately under the line of fracture, is the hypothesis that has received the most attention and support.

Rotomahana and Tarawera lie on the line of the great Whakatane Fault, a dislocation which extends from the Bay of Plenty to Ruapehu, and on which are situated the only active and intermittent volcanoes in New Zealand. Along this great tectonic fracture are situated White Island volcano, Tongariro, Ngauruhoe, and Ruapehu, all of which are either active or intermittent; also Mounts Edgecombe, Kakaramea, and Tauhara, all dormant or recently extinct. It is along this fault that we find the great display of hydrothermal activity that has made Rotorua, Wairakei, and Taupo celebrated as tourist resorts. Elsewhere there is no solfataric action in the Dominion except the expiring effort at Ohaeawai in the Bay of Islands district. Moreover it is along this volcanic zone that is situated the North Island chain of wonderful crater-lakes, among which we have, beginning at the north, Rotoma, Rotoehu, Rotoiti, Rotorua, Okataina, Tarawera, Rotomahana, Okara, Rotokawa, and Taupo. These crater-basins were, it would seem, the scene of rhyolitic eruptions in the late Pliocene. At any rate, the presence of pumiceous tuffs and pumice sands interbedded with the marine Newer Pliocene strata of the Wanganui, Hawke's Bay, East Cape, Opotiki, and Whakatane districts, prove that widespread acidic eruptions took place along this fracture-zone some time about that epoch. The earlier rhyolites form the floor on which the andesitic mountains, Ruapehu, Ngauruhoe, Tongariro, Tauhara, and Edgecombe were afterwards piled.

Volcanic eruptions, at first acidic and afterwards semi-basic, have been in progress along the Whakatane fault-zone from the Pliocene up to the present day. The eruption of 1886 was, therefore, not an unusual or altogether unexpected occurrence, although it may be not easy to assign the immediate cause. It is now becoming generally recognised by geologists that many earthquakes, perhaps the majority, if not all of them, are caused by the jolts resulting from the settlement of crustal segments along great lines of tectonic fracture. Volcanic activity is not infrequent along these zones. In such cases, it may be, that the fracture is of sufficient magnitude as to afford at different points in its course communication with the molten magma below.

There seems no reason to doubt the conclusion of Thomas that the immediate cause of the eruption was the uprising of a molten mass charged with water and gases. No lava overflowed the fissure because the steam and gases caused its disruption and dispersal as dust, scoriæ, and large blocks.[y]

White Island.

This island lies in the Bay of Plenty, about thirty miles north of Whakatane. It is the summit of an active volcano projecting above the sea. Its area is somewhat less than a square mile. The centre is occupied by a crater-lake which is surrounded by a crater-wall that varies from 400ft. to 900ft. high. The crater-wall is broken down almost to sea-level on the south side of the island for a distance of ten chains, thereby making the crater quite accessible from what is known as Crater Bay.

The island is composed of flows of hypersthene-andesite and andesitic tuffs, the latter predominating.

The crater-wall on the inside is vertical, or so steep as to be unscalable. On the outside it is very steep. The crest of the wall is only a few feet wide, and in most places much decomposed and shattered with hydrothermal action.

The surface of the crater-lake is normally about sixteen feet above high water mark, but its level is subject to considerable fluctuations. At times it is so low that it is possible to walk around the edge of the lake to the "Blowhole" at the north-west end, where there is a display of solfataric and fumarolic action unrivalled at Rotorua or Lake Taupo. Around the fumaroles,

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y. The author accompanied Sir J. Hector to the scene of the eruption, which took place on 10th June, 1886, arriving at Rotorua on the 12th. On the 13th and 14th the author made a close examination of the scene of activity from the top of Te Hape-o-Toroa. The author subsequently visited the scene of the eruption in June, 1900, in June, 1909, and in March, 1910. On all of these dates visits were also made to White Island.

which are particularly active, there are conical mounds of pure sulphur, varying from 4ft. to 6ft. high. The floor and sides of the crater are covered to an unknown depth with alternating layers of siliceous mud, ash-beds, flower of sulphur, and gypsum.

The water of the lake possesses a vivid yellowish-green colour. Its mean temperature is about 110°. It is highly mineralized, and contains an unusual amount of free hydrochloric acid. The amount of this acid has been found to vary from 5.5 to nearly 8 per cent., according to the height of the lake.

Taupo Volcanoes.

Tongariro, Ngauruhoe, and Ruapehu form a chain of more or less active volcanoes lying to the south of Lake Taupo. Tongariro, a deeply truncated cone, and Ngauruhoe, a beautiful symmetrical one, are composed of sheets of andesite and piles of scoriæ. Ruapehu, on the other hand, is mainly composed of andesite flows, both solid and vesicular, the vesicular lavas in the crater-walls being strongly charged with sulphur.

Solfataric action on Tongariro is now very feeble; and no eruption is known to have taken place there since the European occupation of the country.

The last eruption of Ngauruhoe took place in 1869, when a flow of andesite, accompanied with showers of scoriæ, was emitted. A remarkable feature of this eruption was the loud underground detonations which continued for over three months, being clearly audible at a distance of 120 miles. Since then the mountain has been in a more or less violent condition of solfataric activity. Large volumes of steam that frequently rise high above the summit are being continually emitted at several large steam-holes. On many occasions the steam is accompanied with clouds of fine black ash.

Until a year before the Tarawera eruption no volcanic activity of any sort had ever been observed at Ruapehu, either by natives or Europeans. The mountain was looked upon as an extinct volcano. Even in January of 1886, when the mountain was ascended by the author, that was six months before the Tarawera eruption took place, what is now the crater-lake was occupied by a sheet of ice. Since the Tarawera eruption there has been a revival of solfataric action, mostly of a feeble kind. The crater is occupied by a lake of mineralized water, which is warm, and at times gives off a considerable volume of steam. Judge Chapman has informed the author that in January of 1910 the fresh snow was thickly covered with black ash and boulders. Similar showers of fragmentary matter have been reported from time to time since June, 1886.

SUCCESSION OF TERTIARY VOLCANIC ROCKS IN THE NORTH ISLAND.

The succession of the Tertiary volcanic rocks in the North Island, classified in accordance with their probable date of eruption, is as follows:—

(1.) Middle Miocene:—
- (*a*.) Andesitic tuffs of Waitemata beds.

(2.) Upper Miocene:—
- (*a*.) Andesites and dacites of Hauraki Peninsula.

(3.) Older Pliocene:—
- (*a*.) Manukau, and Coromandel andesitic tuffs, breccias, and agglomerates, with lavas.

(4.) Newer Pliocene:—
- (*a*.) Rhyolites of Hauraki area and King Country.
- (*b*.) Andesites of Ruapehu and Egmont.
- (*c*.) Earlier Andesites of Ngauruhoe.

(5.) Pleistocene:—
- (*a*.) Basanites of Auckland Isthmus.

(6.) Recent:—
- (*a*.) Later andesites of Ngauruhoe and Tongariro.
- (*b*.) Andesites of Tarawera Eruption, 1886.

Other Solfataras and Hot Springs.

At the south end of Lake Taupo, at and around Tokaanu there are many hot and boiling springs, and towards Waihi the slopes of the hills are honeycombed with hot springs and steam holes.

At the north end of Taupo there is the river of warm water called Waipahihi, rising in the extinct crater of Tauhara. Below the outlet of the lake, on the banks of the Waikato, there are hot pools, steam holes or fumaroles, and pots of boiling mud.

Twenty-five miles above the outlet at Orakei-Karako, there is a fine group of boiling springs and fumaroles, mostly intermittent. Here the banks of the river are covered with beautiful siliceous incrustations. The Hot-springs extend from Orakei-Karako across the Waikato to the foot of the Pairoa Range, where the warm-water river Waikite takes its rise.

The scene of greatest thermal activity in the Central Volcanic Region, prior to the eruption of 1886, was at Lake Rotomahana, on the shores of which were situated the far-famed Pink and White Terraces.

In the Rotorua area there are many boiling springs and geysers, the largest group of which is situated at Whakarewarewa. At Tikitere there are numerous cauldrons of boiling mud, and fumaroles, around which large quantities of sulphur have been deposited.

Valuable hot springs occur at the foot of Mount Te Aroha.

Hot springs are known at only a few places in the South Island, the best known and most frequented being those at the Hanmer Spa, in Amuri County.

Action of Ascending Alkaline Waters.—The waters which rise to the surface in the region about Lake Rotorua are alkaline, neutral, or acid. Shafts and bore-holes put down in the pumice and rhyolite, which constitute the great bulk of the rocks in this area, have shown that the alkaline waters come from a deep-seated source, while the acid waters have quite a superficial origin. This has led to the erroneous conclusion that all the waters have not a common origin.

Lake Rotorua is an old crater-lake, the southern shores of which are crusted over with deposits of sinter formed by existing hot springs. Below the sinter there is a thick deposit of pumice, and below the pumice flows of rhyolite, generally pumiceous or pisolitic.

In the pumice there are many deposits of finely disseminated marcasite, which were apparently formed by solfataric action at

Fig. 84. Mount Egmont with Patua Range on right.

Lent by Education Department.

some earlier date, in the way that the deposits of pyrites and cinnabar are now being formed at Ohaeawai Hot Springs, north of Auckland. The hot ascending alkaline chlorinated waters become partially or wholly oxidised into sulphates by contact with the decomposing iron sulphide with formation of free sulphuric and hydrochloric acids, and liberation of sulphuretted hydrogen and sulphurous acid. In this way the ascending alkaline waters that happen to come in contact with masses of pyrites become oxidised in the superficial layers of the pumice, and rise to the surface as neutral or acid springs according to the degree of oxidation they have undergone.

Thus, within a small area we have the singular phenomenon of waters that reach the surface in all conditions, ranging from highly alkaline to the extremely acid, according to the degree of oxidation of the contained salts.

The composition[z] of the salts in the alkaline waters of Rachel Spring in grains per gallon is as follows:—

Sodium chloride	69.43
Potassium chloride	3.41
Lithium chloride	traces
Sodium sulphate	11.80
Silica	5.87
Sodium silicate	18.21
Calcium silicate	4.24
Magnesium silicate	1.09
Oxides of iron and alumina	2.41
Total	116.46

The water also contains sulphuretted hydrogen and carbon dioxide which were not estimated.

In the majority of cases, the alkaline springs deposit layers of silica on the walls of the vent and at the surface, the latter often forming large mushroom-shaped masses.

z. "The Mineral Waters and Health Resorts of New Zealand," Dr. Wohlmann, Part I. 1904, p. 39.

The composition of the waters of the Priest hot springs, which may be taken as typical of the acid waters, is as follows:—

	Grains per Gallon.
Sulphate of soda	19.24
„ „ potash	traces
„ „ lime	7.41
„ „ magnesia	3.03
„ „ alumina	21.67
„ „ iron	1.24
Sulphuric acid (free)	22.12
Hydrochloric acid (free)	3.65
Silica	18.41
Total	96.77

The temperature of the alkaline waters, as their deep-seated origin would suggest, is very high, varying from 180° to 212° Fahr.; while that of the acid water is low, commonly ranging from 98° to 110° Fahr.

The sinters are found of all degrees of hardness. They are soft, spongy, and vesicular, or hard and compact. The sinter encrusting the walls of the fissures and pipes from which the water escapes at the surface is generally hard and chalcedonic, and arranged in layers which often present a fine, ribbon-structure. Hand specimens of the harder sinters cannot be distinguished from much of the ore found at the outcrop of the Martha lode at Waihi. In places the sinters contain finely disseminated marcasite, and a trace of gold and silver.

Around Rotorua we can see ore-deposits of the solfataric class still in process of formation on a scale of considerable magnitude. The sheets of siliceous sinter deposited by the alkaline waters frequently assume beautiful mammillated forms.

Of the genesis of the ascending alkaline waters nothing is known at present. It is not improbably magmatic.

CHAPTER X.

PLEISTOCENE OR GLACIAL PERIOD.

There is abundant evidence that New Zealand was subjected to intense glaciation in the late Tertiary. Moreover there is no little warrant for the belief that this country participated in the general glaciation that affected all the southern circumpolar lands in temperate latitudes—a glaciation that took place in the Pleistocene, and contemporaneously with the Great Ice Age of the Northern Hemisphere.

During this epoch South America was glaciated up to latitude 37°, and New Zealand to latitude 39°. Great glaciers descended to the sea in Tasmania; and Kerguelen Island, the Crozets, and all the islands lying south of 50° south latitude were overwhelmed by ice.

Hutton, in his glacial map of New Zealand, showed a continuous ice-sheet covering the whole of the southern and western half of the South Island. Evidence can now be adduced to show that the ice not only reached the sea on the West Coast, but also the existing strand of the East Coast.

The great Taieri Moraine has now been traced from the Clutha Valley to near Saddle Hill, a distance of over thirty miles. Moraines are known at the lower end of the Kaikorai Valley, at Puketeraki, at Shag and Waitaki Valleys, on the east coast of Otago; at Shades Creek, Kekerangu River, and Chalk Hills, near Cape Campbell in Marlborough, all at or about sea-level; in the North Island in the Rangitikei Valley, and on the Waimarino Plain, on the west side of Ruapehu.

Throughout Otago the land has been worn down into undulating flowing contours that are frequently hummocky or mammillated. Erratics, perched blocks, rock-platforms and steps, moraines, eskars, and stony boulder clay are well represented in Western Otago and Southern Canterbury.

It is noticeable that the great pile of hard volcanic rocks constituting the Otago Peninsula has been worn down into fine rounded crests and domes. The basalt-topped hills south of Dunedin, and those situated between the Waikouaiti and Shag rivers do not present the usual steep encircling escarpments so characteristic of basaltic plateaux, but only prominent rounded domes.

It is found that truncated crests and spurs are conspicuous among the ranges as far north as Marlborough.

The height at which the mountains of the main divide are ice-shorn and terraced with glacial steps affords a fairly trustworthy means of estimating the thickness of the ice during the period of maximum refrigeration. In the Wakatipu, Wanaka, and Hawea basins the ice could not have been less than 7,000ft. thick; and in the Mackenzie basin of the Canterbury alpine region, probably not less than 6,500ft. It is obvious that such a mass of ice would form a continuous plateau-like sheet through which only the higher narrow crests of the alpine divide, of the Spencer and St. Arnaud ranges, of the Kaikouras, and secondary ranges in Canterbury and Nelson would project, forming deeply serrated ridges, or rocky *inselbergen*, resembling the dorsal fin of a fish.

The glaciation of Boulder Lake, in Collingwood, the ice-shorn Gouland Downs, the beautiful *roches moutonnées* on the crest of Mount Burnett, and the great fluvio-glacial drift which covers the floor and southern slopes of the Aorere Valley, speak of a period of antarctic severity, during which the Aorere glacier reached the shores of Golden Bay.

Glaciation extended into the North Island. In the Rangitikei watershed there is a glacial moraine of great extent, composed of andesitic blocks torn from the higher slopes of Ruapehu and transported across the Rangitikei divide into the lower Hautapu Valley. This conspicuous morainic sheet is spread over the denuded surface of marine clays of Pliocene age.

A great crescent-shaped moraine formed by the confluent glaciers descending from the west side of Ruapehu, Ngauruhoe, and Tongariro, occupies the western fringe of the Waimarino Plain, forming an encircling chain of hummocky ridges that extend from the Maunga-nui-a-tea to the Upper Wanganui. It occupies an area from two to three miles wide and over twenty miles long, everywhere resting on a highly-denuded surface of the lower members of the Oamaruian brown coal-measures.

It is almost certain that further research will extend the glaciated area of the North Island to the region lying north of the Kaimanawas.

Two Phases of Glaciation.—There is evidence of two distinct but related phases of Pleistocene glaciation in New Zealand, namely, an ice-sheet phase, and a valley-glaciation phase, the former marking the epoch of maximum refrigeration, the latter the period of progressive decadence of refrigeration reaching down to the present time.

The second phase is marked by two or more inter-glacial phases, during each of which there was an arrestment of the decadence accompanied by a short-lived increase of cold. In these intervals the retreating glaciers entrenched themselves behind piled up terminal moraines, across which they made a few feeble sorties before the final recession began.

The evidences of glaciation on a gigantic scale are found, as already mentioned, in the North Island up to latitude 39° S., and all over the South Island from Cook Strait to the Bluff, even in places where there now exist no permanent or seasonal snow-fields, and where the rainfall, as in the dry belt of Central Otago, does not much exceed 12in. in the year.

The existing glaciers in the Canterbury Alps, although counted among the largest outside the polar regions, are but the shrunken stumps of glaciers that at one time descended to the present coast-line, or even beyond.

The maximum refrigeration took place during the early Pleistocene. The phase of valley-glaciation began in the later Pleistocene.

The late Pleistocene epoch, chiefly owing to the return of milder climatic conditions with the consequent melting of the vast ice-fields, was a period of unparalleled fluviatile activity. It was then that were formed the great fan-like plains in Southland, Canterbury, Marlborough, Nelson, and Wellington. These plains represent a complete climatological cycle of deposition, beginning and ending with purely fluviatile debris as follows:—

Glaciers advancing	1. Fluviatile drifts deposited on basement or floor by the rivers draining the first formed snow-fields and ice on the ranges. 2. Fluvio-glacial drifts formed by the glaciers descending the valleys.

	3. Morainic drifts deposited by the glaciers.
Glaciers retreating	4. Fluvio-glacial drifts formed as valley-trains in front of retreating ice-face.
	5. Fluviatile drifts formed by rivers draining the glacial basins.

It is obvious that the maximum phase of glaciation could only be reached after a long epoch of gradually advancing glaciation. That is the maximum phase must have been preceded by an advancing phase inversely co-relative with the last or waning phase.

The increasing refrigeration in temperate latitudes to whatever cause it might be due, would first lead to the formation of permanent snowfields and summit glaciers among the higher ranges; or if snow-fields already existed to a corresponding increase in their size. As the ice-fields grew larger they would begin to creep down the valleys, becoming longer and deeper with the increasing refrigeration, until in time they filled up the valleys and basins in which they lay. Here would end the advancing phase of valley-glaciation.

With increasing refrigeration fluviatile activity would gradually diminish and finally cease on account of the precipitation becoming locked up in the form of ice.

When the advancing glaciers overflowed the valley-walls they would unite thus forming a more or less continuous ice-sheet. Until the period of maximum refrigeration was reached, the ice-sheet would continue to increase in thickness and extent. In continental areas it would form a nearly flat-topped plateau through which only the summits of the higher peaks appeared; but where the ice projected itself across the sea, it would form a continuous sheet like the great ice-barrier of Ross Sea, in the Antarctic.

After the period of maximum refrigeration the ice-sheet would begin to diminish in area. Its thickness would also decrease until the dividing ridges and valley-walls once more became bare, this stage marking the beginning of the last, or retreating phase of valley glaciation. In regions where the refrigeration was not so intense, there would be only the advancing and retreating phases; or in other words, the glaciers would at no time override the valley-walls.

Through the imprisonment of the precipitation in the form of ice, the pre-glacial fluviatile erosion would reach the vanishing point some time before the ice-plateau phase made its appearance. It would attain its maximum activity at an early stage; and the magnitude of the drifts formed by it would be dependent on the amount of the precipitation, the extent of the catchment area, the character of the rocks, the gradient, and other local conditions.

The erosive action of the advancing ice would be greater than at any later stage, for the land would be frost-shattered, and stream-dissected, presenting land-forms in all their native ruggedness. The advancing ice, when, through its growing mass, it had acquired sufficient power to erode effectively, would not have the angularities of a broken land-surface to work upon. In the waning stages the ice would merely erode surfaces already rounded, all the phenomena of glaciation being presented in the inverse order.

Classification of Pleistocene Deposits, Etc.

These are all of terrestrial origin, and nearly all of them, either directly or indirectly, have a glacial origin.

(*a.*) Raised beaches.

(*b.*) Fluviatile plains, old fans, and resorted moraines.

(*c.*) Valley moraines and eskars.

(*d.*) Fluvio-glacial drifts and high-level terrace gravels.

(*e.*) *Roches moutonnées,* mammillated hills, grooved and terraced mountain slopes, striated rock-surfaces, and erratics.

(*f.*) Boulder clays.

(*g.*) Older moraines and stratified fluvio-glacial drifts.

Older Moraines and Stratified Drifts.

The best known of these are the Taieri and Clutha (Blue Spur) morainic drifts in Otago, and the stratified andesitic drift underlying the great andesitic morainic deposit in the lower Hautapu Valley in Western Wellington.

Taieri Moraine.—This is the largest and most important pile of glacial drift in New Zealand. It forms the range of hills bounding the east side of the Taieri Plain, being plastered against the ridge of Palæozoic mica-schist that separates that plain from the sea, rising from sea-level up to a height of 1,000ft. It extends from Allanton, some fifteen miles from Dunedin, to a point at the south end of Mount Misery, in the Clutha Valley, a distance of twenty-seven miles. From Mount Misery it can be traced along the north side of the ancient Clutha glacial-valley by a series of isolated patches to the celebrated Blue Spur near Lawrence, where it has been worked for gold since the early seventies.

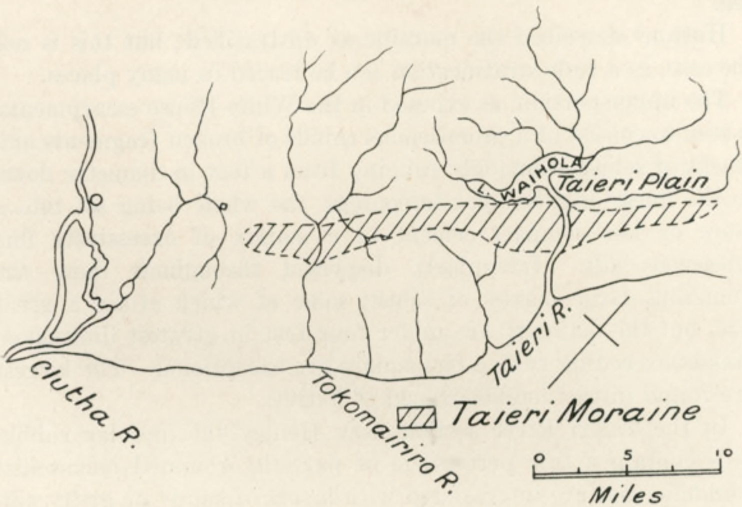

Fig. 85. Map showing Taieri Moraine.

In the hills on the east side of the Taieri Plain, this great glacial deposit varies from half a mile to three miles wide. It dips towards the plain at angles that vary from 4° to 20°, but the inclination is somewhat steeper in a few places. The flatter inclination is found in the higher portion of the deposit, and the steeper in the lower portion.

If we take the mean inclination at 12° we get a total thickness of 2,500ft., of which the upper 500ft. are characterised by the presence of many large angular flaggy masses of semi-metamorphic mica-schist.

The Dunedin-Invercargill railway skirts the chain of hills formed by the moraine for over twenty miles. And it may be noted in passing over this route that the front of the morainic hills is broken by numerous large slips that frequently present steep escarpments on the footwall side. In these escarpments the character of the upper portion of the drift is exposed to great advantage.

A complete and very clear sectional view is presented in the road cuttings following the north bank of the Taieri near Henley, where that river has cut its course through the coastal hills to the sea.

Hutton[a] described the moraine as unstratified; but this is not the case, as a rude stratification can be traced in many places.

The upper portion, as exposed in the White House escarpments, is seen to consist of a promiscuous rubble of broken fragments and blocks of schist, commonly ranging from a foot in diameter down to the finest angular rock-screenings, the whole being set into a more or less compact cement in a matrix of excessively fine micaceous silt. Irregularly dispersed throughout there are numerous large masses of schist, some of which attain a great size, but the majority are under four feet in greatest dimension. Masses exceeding twelve feet square are exceptional. The largest are found in the neighbourhood of Titree.

In the Taieri River section near Henley the angular rubbly beds contain a fair percentage of partially rounded mica-schist boulders; and are intercalated with layers of sandy or gritty silt, which impart a distinctly stratified appearance to the deposit.

Continuing down the river towards the base of the drift the sandy beds and silt layers become more numerous and the rubble layers correspondingly thinner. The latter also contain more and more water-worn material, which is now mainly composed of semi-metamorphic greywacke, occurring for the most part in pebbles of fairly uniform size, generally about two or three inches in diameter. The confused rubble layers of broken rock continue down to the base of the deposit.

The prevailing colour of the upper portion of the drift is red or pink, and of the lower portion yellowish brown, but many of the streaks or seams of silt are dark red.

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a. F. W. Hutton, "The Geology of Otago," 1876.

Fig. 86. Upper portion of Taieri Moraine on hill behind Henley.

Generally speaking the material is compacted into what the local alluvial miners term *cement*. Near the Taieri Bridge at Henley it is so hard as to form steep well-weathered cliffs.

North of Milton practically the whole of the material in this great glacial deposit is mica-schist or altered greywacke, both of which exist on the west side of the Taieri Basin. But on the slopes and summit of the hills overlooking the Tokomairiro Plain there are many blocks of basalt apparently transported across the basin from the Clarendon district. The schistoze material is commonly much decomposed.

The Taieri moraine was obviously formed by the great ice-sheet that descended the Clutha Valley, and overspread the Barewood Plateau, passing over and around Mount Maungatua into the upper end of the Taieri Basin. The main flow of the ice was southward towards the lower end of the basin, but the

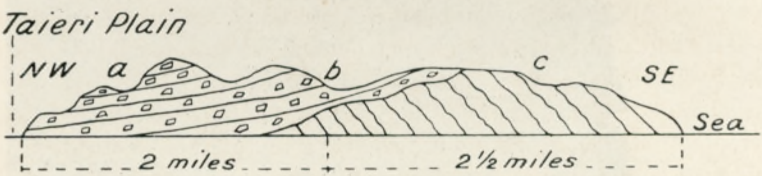

Fig. 87. Section from Taieri Plain to the sea.

a. Upper portion of moraine rudely stratified. *b*. Lower portion well stratified. *c*. Palæozoic semi-metamorphic greywacke and mica-schist.

altitude to which the morainic matter rises on its eastern limit proves that the ice also flowed across the site of the existing coastal range to the sea.

The rock-rubble forming the upper portion, with its matrix of fine silt, and the contained masses of mica-schist, some of which weigh hundreds of tons, and the alternations of rock-rubble, silt, and gravels forming the lower portion, leave no doubt as to the glacial origin of the Taieri moraine. The mechanics of its formation is, however, not so easy to understand. The great thickness and uniform dip towards the Taieri Plain also add conflicting elements to the problem.

The northerly dip may be due to the downthrow caused by a fault running parallel with the Taieri Basin, or to an uplift of the coastal range. Of the fault there is no evidence whatever, either at the margin of the basin or at its ends. On the other hand the presence of the Taieri Gorge, which has been cut through the coastal range is certain evidence of uplift. For it is obvious that if the Taieri River entered the sea near its present outlet, the gradual uplift would enable the river to excavate its present gorge. And the cutting of the gorge, which is admittedly post-glacial, cannot be satisfactorily explained in any other way. Considering then the character of the material, we are compelled to the conclusion that the deposit is mainly sub-glacial, and was formed in a long depression running parallel with the trend of the ice-face. The presence of the fine micaceous silt in the matrix of the rock-rubble layers in the upper portion proves clearly enough that the material was not subjected to the sorting action of running water.

It seems not improbable that the current-bedded silts, sands, gravel, and rubble beds in the lower portion of the deposit, were of fluvio-glacial origin laid down in front of the advancing ice-sheet; and that the coarser upper portion was sub-glacial, or may be rock-rubble interstratified in the ice.

The lower slopes of the hills running parallel with the railway from Wingatui to Allanton, and the undulating foothills are mainly composed of fine glacial silt or loess in places arranged in thin horizontal layers. Mr. J. Hardcastle, who has made a special study of the loess of Canterbury, considers the Taieri silts identical with the loess of Timaru, the glacial origin of which is generally acknowledged.

Clutha Moraine.—This is represented by nine isolated patches extending in a line from near Crichton, at the south end of the Tokomairiro Plain to the Blue Spur near Lawrence. It everywhere consists of a partially consolidated sand and gravel drift and rock-rubble.

The best known deposits are those at Munro's Gully and Gabriel's Gully, forming what is commonly spoken of as the Blue Spur claim, Weatherstone's, Forsyth, Waitahuna, Scandinavian, Glenore, Adam's Flat, and Crichton's. Besides these, small areas of schistoze brecciated material occur at various places on the surface of the Kaitangata coalfield[b].

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b. A. McKay, "The Older Auriferous Drifts of Central Otago," Gov. Printer, Wellington (2nd edition), 1897, p. 10.

Speaking of the breccia-conglomerate at Adam's Flat, near Mount Stuart, Cox[c] says:—"From Adam's Flat the best idea can be obtained of the flow of the glacier which deposited these beds, for from here a distinct depression in the country can be seen in the direction of Waitahuna and Weatherstone's. Moreover, the character of the beds is so identical along this line as to leave no doubt in my mind that the rocks constituting the cements have travelled in this direction—namely, from north-west to south-east; and also that the means of transport has been glacier-ice."

The glacial drifts at Mount Stuart, Waitahuna, and the other places mentioned above are exactly similar in character, consisting mainly of water-worn material set in a matrix of silt, sand, and shattered rock-rubble. The crushed rock is mica-schist of local origin. The well-rounded material is largely quartz boulders and pebbles derived from the interfoliated quartz of the mica-schist, together with greywacke and a few large rounded jasperoid blocks. The greywacke and jasperoid rock are foreign to the district, and are not found *in situ* nearer than the Tapanui Mountains, which are situated from twenty to forty miles from these deposits.

The drifts are everywhere gold-bearing, and have been profitably worked for many years. They occur high up on the northern slope of the ancient Clutha glacial valley, at elevations ranging from 400ft. to 800ft. above the sea. The area of the patches ranges from a few acres to several hundred acres.

Blue Spur Glacial Drift.—This deposit may be described as a typical example of the older moraines. It occurs at the head of Gabriel's Gully, about two miles from Lawrence. The material consists of a more or less stratified mass of breccia-conglomerate and cemented gravel-drift, occupying a cup-shaped hollow in a ridge dividing two nearly parallel gullies. The original area was about sixty acres, the greater portion of which has now been removed by sluicing. The country rock is mica-schist.

The deposit is bounded on the north by a remarkable fault, the smooth slickensided surface of which has been laid bare by the removal of the drift for a height of 400 feet.

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c. S. H. Cox, Reports of Geol. Explorations, 1878-79, p. 42.

The surface of the fault is covered with a layer of almost black mudstone from three to six inches thick, consisting of schist that has been crushed into mud by the superincumbent pressure during the progress of the faulting, and has become hardened into a rock now resembling an indurated clay-stone. The average dip of the fault-plane is 22° 30′ towards the south-west.

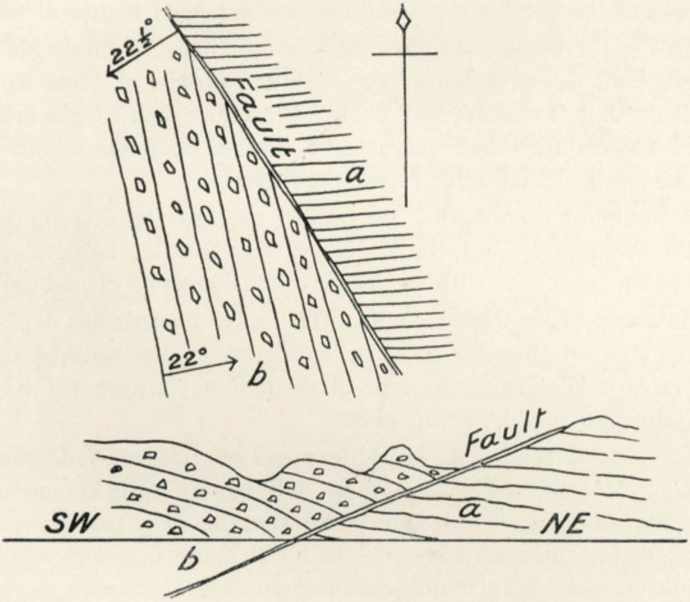


Fig. 88. Map and section of Blue Spur Deposit.

a. Mica-schist. *b*. Gold-bearing cemented glacial drift.

Rickard[d], who examined the Blue Spur in 1892, describes the pebbles of the conglomerate bands as imbedded in the soft, crushed mica-schist. The same writer also states that when he examined the mine workings there were longitudinal furrows in the schist parallel to the strike of the country and to the longer axis of the deposit.

The deposit has a gentle dip towards the south-east at angles varying from 20° to 22°. The material is coarsest towards

d. T. A. Rickard, Trans. Am. Inst. Min. Eng., 1892.

Monro's Gully, that is towards the west. Its thickness exceeded 600ft. before it was disturbed by mining operations. The upper portion in the oxidized zone is rusty brown, and the lower portion blue.

Besides the coarse gravels and rubbly cements, the deposit contains a few sandy beds and several thin layers of excessively fine micaceous silt, forming what are locally known as slippery seams. In the sandy beds there have been found thin irregular streaks of lignite that appeared like water-logged trunks of trees.

This great breccia-conglomerate is obviously of fluvio-glacial origin, and the presence of the included trunks of trees would indicate that it was formed during the first epoch of glaciation, when the country that was not yet covered with the advancing ice was still clothed with forest vegetation.

It is almost certain that the glacier gravels forming the base of the Southland, Canterbury, Nelson, and Westland Plains must be contemporaneous with the Taieri and Blue Spur glacial drifts.

Hautapu Older Glacial Drift.—There are two glacial deposits in the Hautapu, namely an older, consisting of fluvio-glacial drift interstratified with sands and clays, and a younger till which rests unconformably on the older.

The older glacial drift is well exposed on Mataroa Hill, south-east of Mataroa railway station, and in the railway cuttings between Turanga-a-rere and Mataroa, being specially well developed at mile-peg 252½ on the Main Trunk Railway. It lies unconformably on a highly denuded surface of marine clays of Pliocene age, and is overlain unconformably by the glacial boulder-clay that is so wide-spread in the lower Hautapu Valley.

On Mataroa Hill, where it occurs at a height of about 2,000ft. above the sea, there is a thickness of 40ft. exposed in the face of the quarry. The material consists of well-worn andesitic gravels, sands, and silts containing many large masses of the soft underlying late Tertiary clays and sandstones.

At mile-peg 252½ this ancient glacial drift consists mainly of silts, well-bedded gritty sands, and rubbly grits. At the base of the deposit there is exposed a short lens of coarse andesitic gravel, and throughout the finer beds there are scattered a few large semi-angular blocks of andesite. All the material is andesitic, and some of it occurs in small pieces of uniform size forming beds that present an appearance curiously like partially consolidated tuffs. The sandy beds are sufficiently consolidated to be termed soft sandstones.

In this railway cutting the ancient drift and the basement blue clays, or *papa*, are traversed by several parallel faults. The faults, however, do not affect the younger glacial boulder drift which rests unconformably against the faulted ends of the older glacial beds.

The whole of the andesitic material in the ancient drift is foreign to the Rangitikei watershed. It is obviously of fluvio-glacial origin, having been transported across the Wangaehu divide by glacier-ice and spread out on the floor of the ancient Hautapu glacial valley by the river draining the glacier.

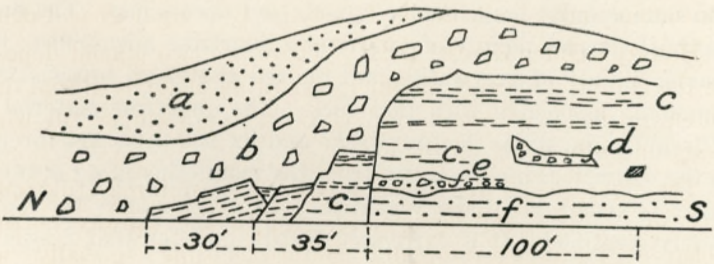


Fig. 89. Section of Railway Cutting at Mile-peg 252½, Hautapu Valley, North Island Main Trunk.

a. Sandy clay. *b*. Younger andesitic boulder drift. *c*. Soft sandstones and gritty beds. *d*. Intercalated grit bed. *e*. Coarse andesitic gravels. *f*. Pliocene marine clays.

The meaning to be attached to the occurrence of the different beds of gravel, sand, and clays is not very clear. Referring to the stratified intercalations in the glacial deposits of the Northern Hemisphere, Sir Archibald Geikie says:—"The boulder-clays are now well-known to be split up with inconstant and local stratifications of sand, gravel, and clay, often well stratified."

These intercalations are believed by some geologists to indicate seasonal variations in the limits and thickness of the ice; by others, among them Professor James Geikie, they are held to furnish proof of successive inter-glacial intervals of mild temperature.

YOUNGER GLACIAL DEPOSITS.

(*a.*) Valley moraines and loess.
(*b.*) Fluvio-glacial drifts.
(*c.*) Boulder-clays.

Boulder Clays.—These are well developed in the Wakatipu area; in the lower end of the Kaikorai Valley, near Dunedin; in the lower Hautapu in the Rangitikei watershed, and on the west side of Ruapehu in the North Island.

Wakatipu Boulder-Clay.—The floor of the Arrow Flat and the gently undulating slopes of all the ice-shorn ridges lying in the bottom of the Arrow Basin, between the Shotover and Arrow rivers and between the foot of the Crown Range and Kawarau, are covered with a sheet of greyish-coloured stony glacial till, consisting of a confused deposit of excessively fine glacier sand and silt mingled with a sprinkling of rounded gravel and angular and semi-angular fragments of quartz and mica-schist. The finer material consists mainly of quartz and quartzose mica-schist; the coarser mainly of greywacke, and the red and green breccia-tuffs commonly associated with that rock. The quartzose material is of local origin, while the greywacke and its associates are foreign to the district, being ice-borne from the mountains lying between Lake Te Anau and Lake Wakatipu. In a few places the till is rudely stratified. It is extremely fertile, and for that reason is highly cultivated.

The till also covers the surface of the Crown Terrace, and is found on the slopes and summit of Queenstown Hill, up to a height of 3,000ft. above the sea, or 2,000ft. above the surface of Lake Wakatipu. A thin sprinkling of greywacke gravel, and occasionally red clay, is also found on the slopes of Perseverance Peak, on the track to Ben Lomond, up to a height of 3,000ft. above the lake. On the slopes facing Queenstown there occur in the till some large angular masses of Tertiary limestone transported from Bob's Cove at 1,050ft. above the sea, and perched at over 3,000ft.

In general terms it may be said that this till is found everywhere, over hill and dale, in the wake of the Kawarau branch of the great Wakatipu glacier.

It should be noted that among the foreign material in the till there is always a small percentage of granite, norite, diorite, and other crystalline igneous rocks. In a few places these rocks occur more plentifully than in others, and in this respect the lower slopes of Queenstown Hill, facing Frankton Arm, and the vicinity of Lake Johnson are specially favoured localities.

The crystalline rocks occur in small pebbles and in well-rounded boulders up to 2ft. in diameter.

A few erratic boulders of greywacke and greenstone breccia of large size lie imbedded in the till on the Arrow Flat and Crown Terrace.

The till varies considerably in composition in different places. In one place fine-bedded silts predominate; in another, clays, silts, sands, grits, and angular fragments of quartz and schist of all shapes and sizes are intermingled in a confused mass or perhaps rudely stratified, while in other places the material is mainly fluvio-glacial drift, in which well-rounded foreign rocks are conspicuous. Along the margin of the Arrow Basin the till consists mostly of small angular pieces of schist, always quite fresh and undecomposed, and closely resembling the small screenings of broken rock often used in the making of concrete-work. But one class of material is found to pass into another sort with a suddenness that sometimes causes much perplexity and astonishment.

The origin of the till does not appear to be due to the operation of one cause, but rather to two or more causes or agencies operating at the same time. In one place we have silts and rock-flour that were manifestly laid down in still water, in another the boulder-clay of a ground-moraine, in another gravels and drifts, and in another gravels and drifts that are purely fluvio-glacial.

The water-worn drifts were obviously formed by sub-glacial streams that drained the ice-sheet at different points, uniting, and branching, and uniting again. The boulder-clays appear to have been infra-glacial material spread out in the wake of the retreating ice-sheet; while the finely bedded silts, with paper-like laminæ, consist of rock-meal and rock-flour that settled slowly in tarns or lagoons. Gold-bearing slimes that are allowed to settle slowly in the settling-tanks used in connection with the cyanide treatment of gold and silver ores always exhibit a finely laminated structure; and in tarns with a gentle overflow the silts would doubtless settle in the same manner. At certain points the different sorts of glacial material meet and intermingle.

The boulder till spread over Queenstown Hill and adjacent ridges, up to 3,000ft. and more above the surface of Lake Wakatipu, is mainly fluvio-glacial drift, which must have been inter-glacial material, entangled in or near the under-surface of the ice, and carried upward as the advancing sheet surmounted the ridges it encountered in its path. The masses of fossiliferous marine sandstone plucked from the Lower Tertiary rocks at Bob's Cove, and carried to a height of 3,000ft. on the slopes of Bowen Peak, prove conclusively that the Wakatipu glacier flowed upward and over the obstacles it could not remove.

The proportion of foreign material in the till varies in different places. In the fluvio-glacial drifts on Queenstown Hill probably 60 per cent. of the pebbles and boulders are greywacke and greenstone breccia derived from the east side of the mountains drained

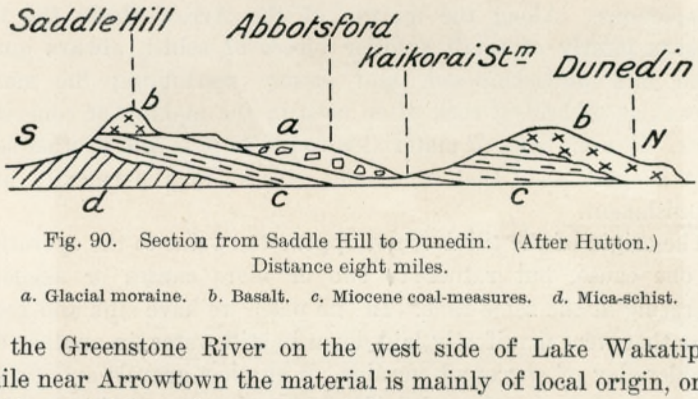


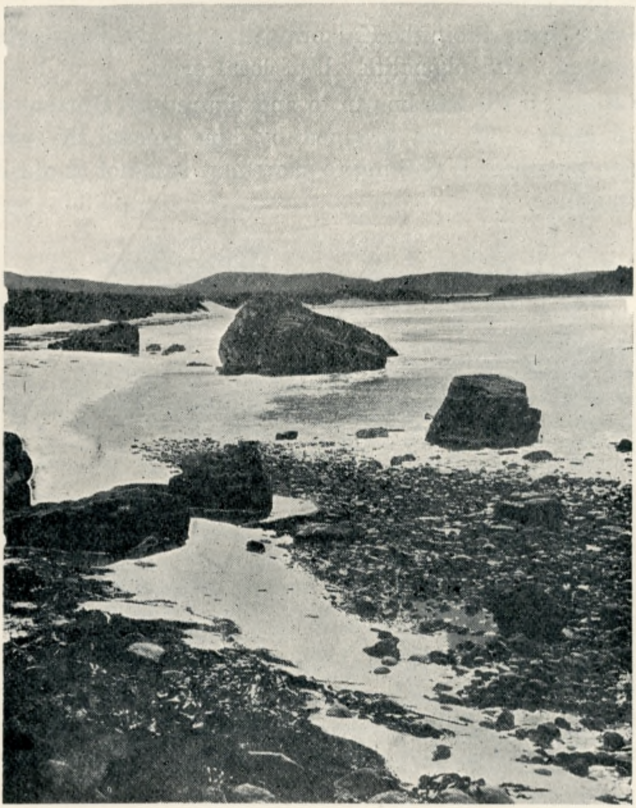
Fig. 90. Section from Saddle Hill to Dunedin. (After Hutton.) Distance eight miles.

a. Glacial moraine. *b*. Basalt. *c*. Miocene coal-measures. *d*. Mica-schist.

by the Greenstone River on the west side of Lake Wakatipu; while near Arrowtown the material is mainly of local origin, only a thin sprinkling of greywacke being present.

Along the western slope of Queenstown Hill, facing Frankton Arm, as far north as Lake Johnson, there is a zone in which, besides greywacke, boulders of granite, norite, and diorite are comparatively common—more common than in any other part of the district. These crystalline rocks are not known *in situ* nearer than the divide between the head of the Eglinton River and the upper end of Lake Te Anau, which means that they have been carried some forty miles from a distant watershed lying on the west side of Lake Wakatipu, and are therefore more travelled than the greywackes which have been transported from the watershed of the Greenstone River.

The great abundance of crystalline rocks between Frankton Arm and Lake Johnson would indicate that this area lay in the track of that portion of the ice-stream which flowed from the country at the head of the Eglinton River.



Lent by "Otago Witness" Co.

Fig. 91. Puketeraki Moraine, near Waikouaiti.

Kaikorai Boulder-Clay.—This glacial deposit occurs on the north and west sides of the lower Kaikorai, extending from Burnside Freezing Works, two miles from Dunedin, to Fernhill coal mine, where it rises on to the summit of the ridge dividing the Kaikorai Basin from the Taieri Plain. It consists of tumbled masses of angular and semi-angular blocks of igneous rock set in a matrix of stiff clay and broken rock. Behind Abbotsford it is a confused pile of rock-rubble, often with no material filling the interstices.

At the Fernhill exposure the morainic material occurs rudely sorted into layers of clay, sandy material, and broken rock. The peaty matter, which in places occurs at the base of the deposit, has yielded moa bones.

The stony material in the Kaikorai till is mainly dolerite, basalt, trachydolerite, and phonolite, all of local origin.

The Kaikorai till was known to and figured by Hutton[e] as far back as 1876. It was grouped by him among the younger moraines, but there is nothing to show that it is not as old as the Taieri moraine.

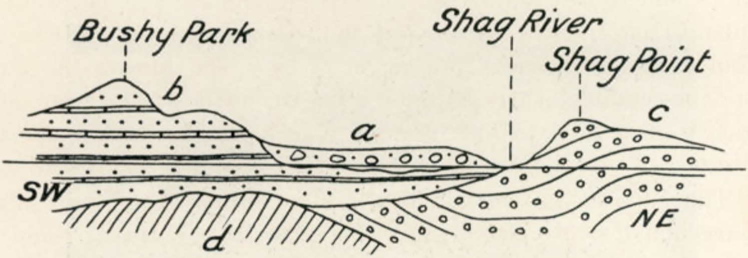


Fig. 92. Section Bushy Park to Shag Point. (After Hutton.) Distance two miles.

a. Glacial till. *b.* Miocene strata, Oamaruian. *c.* Upper Cretaceous, Waiparaian. *d.* Mica-schist, Maniototian.

The Puketeraki Moraine.—This extends from Seacliff to the Waikouaiti Valley. Near Seacliff it forms hummocky ridges separated by undrained hollows. It consists mainly of tumbled masses of basalt, dolerite, and phonolite, set in a matrix of rubbly clay.

The character of the moraine is well seen in the railway cutting at Puketeraki railway station. On the beach there are many tumbled blocks of columnar basalt, of which, one mass exceeds 2,000 tons in weight. Many angular and rounded masses of igneous rock lie scattered over the surface of Puketeraki Peninsula, and along the shore, and over the floor of Waikouaiti Inlet and bay. (See Fig. 91.)

e. F. W. Hutton, "The Geology of Otago," 1876, plate vii.

Shag Valley Till.—This was recognised and figured by Hutton in his "Geology of Otago," in 1876 (plate vii.). It consists mainly of clays and silts with included boulders of basalt, spread over the floor of the Shag Valley on the denuded surface of the Miocene strata.

MARLBOROUGH MORAINES.

Glacial drifts and moraines of great magnitude occur in the provincial district of Marlborough, being particularly well-developed on the Chalk Range, a few miles from Cape Campbell, and at the mouth of the Kekerangu River.

Cape Campbell Moraine.—This deposit occurs about three miles and a half south-west of Cape Campbell and two miles inland from the sea. It occupies the western slopes of the Chalk Range, rising in places to a height of over 800ft. above the sea, and descending nearly to sea-level. Its width varies from an eighth of a mile to half a mile, and it can be traced for a distance of nearly three miles in a north-east-south-west direction.

The material consists principally of consolidated and partially consolidated sandy layers, gravels, boulder drift, and rock rubble, mingled, in its lower portion, with a large percentage of angular blocks of great size. The exposed thickness of the deposit is not less than 200ft. The underlying bed-rock is the grey marly clays of the Amuri Series, the different members of which are well-developed in this district.

Among the constituent material, the sands and gravels are chiefly greywacke and slaty shale, with which are associated boulders of basic dyke rocks derived from the inland Mesozoic ranges. Among the angular blocks are represented large masses of Saurian Sandstone, Amuri Limestone, and even large masses of soft sandstone and impure shelly limestone containing in great profusion the characteristic fossils of the Awatere Series.

This great moraine was first described by McKay[ee] in 1874, when he recognised its resemblance to "an old morainic accumulation." In his subsequent reports of 1885 and 1888 it constituted what he termed a "Post-Miocene Conglomerate."

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ee. A. McKay, Repts. Geol. Expls., 1874-76, p. 190; also 1885, p. 113; and 1888-89, p. 168.

The occurrence in it of blocks containing the Awatere fauna enables us to fix its age within comparatively narrow limits. The molluscous fauna of the Awatere Series includes over 70 per cent. of living species, and it seems not improbable that the tendency of fresh discoveries will be to increase rather than decrease that proportion. And, although the percentage method is perhaps not

Photo by A. McKay.

Fig. 93. Kekerangu South Head, showing blocks of Amuri limestone in old moraine.

a very satisfactory, or even safe, basis to use for determining the geological age of a formation, it can hardly be urged that the Awatere beds so well represented in the Chalk Range Moraine are older than early Pliocene.

The general character of the deposit would lead to the belief that it belongs to the more ancient of the glacial accumulations of the Pleistocene glacial epoch. It was formed by glacier-ice descending from the Kaikoura Mountains.

Comparing the Cape Campbell moraine with the Taieri moraine we find that both are more or less stratified, and that both contain a considerable proportion of water-worn material. On the other hand the angular blocks in the Taieri Moraine are not so large or varied as those in the Cape Campbell Moraine. Besides this they occur mainly in the upper portion of the deposit, whereas at the Chalk Range the angular masses mostly occur in the lower portion.

Fig. 94. Summit Glacier-Ruapehu. *From "Otago Witness."*

Kekerangu Moraine.—This glacial deposit occurs at the mouth of the Kekerangu River, which enters the sea about twenty-three miles south of Cape Campbell. It forms the headland and reefs on the south side of the river, and thence extends along the coast-line for a distance of half a mile. It is even more largely developed from two to four miles up the valley from the sea, where it is faulted down against the Amuri formation.

The constituent material, like that of the Cape Campbell moraine, consists of sandy beds alternating with water-worn drift, mingled with angular rubble. In the lower portion of the deposit there occur in the rubble-beds many angular blocks of Amuri Limestone, some of enormous size, together with masses of grey marly clay and fossiliferous sandstones and clays belonging to the Awatere Series. The greater proportion of the smaller water-worn material is composed of greywacke, basic and semi-basic dyke rocks, derived from the distant Kaikoura Range.

The Awatere formation, from which so large a proportion of the angular blocks was derived, is not present in the Kekerangu district, or even within the watershed of that river, the nearest point at which it is known being in the Flaxbourne Valley, eight miles south of Cape Campbell.

The presence of the Awatere blocks is capable of two explanations. If we assume that the confluent Awatere and Clarence glaciers flowed southward on reaching the sea the difficulty at once disappears, as the material would be picked up

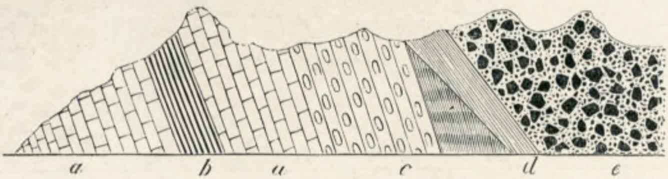

Fig. 95. Section along Shades Creek from sea-coast Westward. (After Hector).
a. Amuri limestone. *b*. Lower marls. *c*. Concretionary and grey marls.
d. Fine silt with plant remains. *e*. Great morainic breccia-conglomerate.

on the way in the lower Awatere or Flaxbourne Valley. If this hypothesis is passed over we may assume that the Awatere formation at one time covered the coastal hills, and that the advancing ice broke up and removed it, the only portion to escape destruction being the masses picked up and carried onward by the ice to the terminal end. The members of the Awatere series are clays, soft sandstones, and shelly limestones, that would be easily removed by a moving mass of ice.

A strip of glacial moraine also occurs a short distance from the mouth of Shades Creek, which enters the sea four miles south of Kekerangu River.

A similar Post-Miocene breccia-conglomerate has been described by McKay as occurring in the Clarence Valley, where it is particularly well developed in the gorge of the Mead River, which is excavated in it, as shown in Fig. 95a. As at Kekerangu and Shades Creek on the sea coast, the Mead River deposit consists of huge angular masses of fossiliferous rock mixed with smooth water-worn boulders and pebbles. Hector reports that at this place it also contains large patches of sandy silt containing plant-remains.

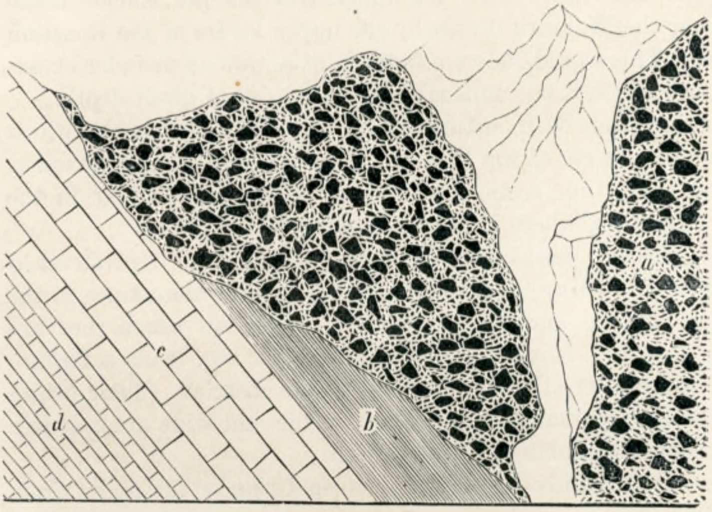

Fig. 95A. Section of Mead Gorge, Clarence Valley, Marlborough. (After Hector).

a. Post-Miocene breccia-conglomerate. *b*. Grey-marls. *c*. Weka Pass stone. *d*. Amuri Limestone.

Hautapu Till.—This is the most important glacial deposit in the North Island. It follows for over twenty miles the course of the ancient Hautapu glacial valley, on the floor and sides of which it is spread to a depth ranging from 0ft. to 60ft.

The Pliocene marine clays on which the till rests are deeply eroded, and in many places excavated into fantastic pinnacles, knobs, and overhanging cornices that are deeply buried in the glacial material. In a few places the till rests unconformably on the faulted and eroded surface of the older glacial drift already described in the preceding pages, and shown in Fig. 89.

Over 95 per cent. of the stony material in the deposit is composed of andesite blocks derived from Mount Ruapehu, 9175ft. high. This gigantic volcano is situated at the sources of the

Wanganui, Wangaehu, and Waikato rivers; and is separated from the Rangitikei Valley, in which the Hautapu lies, by the Karioi Basin and the Waiouru plateau. The Karioi Basin is drained by the Wangaehu River; and the Waiouru plateau forms the divide between the Wangaehu and Hautapu watershed.

It is therefore obvious that the andesitic material from Ruapehu must have been transported across the Karioi Basin and over the Waiouru divide by the upper layers of the Ruapehu glacier. This would indicate a differential flow of the glacier ice, a feature which is not unusual in bodies of ice of great depth.

The numerous deep cuttings on the Main Trunk Railway, which follows the course of the Hautapu glacial valley for thirty miles, disclose many fine sections of the till, more particularly in the lower Hautapu, where it has its greatest development.

The andesitic blocks are all erratic, or foreign to the watershed in which they occur; and their presence in such abundance in the railway cuttings and on the adjacent ridges, on which they are perched up to a height of 2,000ft. above the sea, lends a feature of peculiar interest to the geology of the district. Their origin and the agency that scattered them so far and wide are a source of continual speculation to the settlers.

The till is mainly developed between Utiku, a few miles from the Rangitikei junction, and Turanga-a-rere, a distance of twenty-one miles. Following up the Hautapu from the latter place to Waiouru, that is proceeding towards Ruapehu, the source of the material, it at first becomes thinner, and further on appears only as isolated patches. On the Waiouru divide it is but sparingly represented. Thus singularly enough the blocks of andesite are largest and most numerous towards the southern limits of the deposit in the neighbourhood of Taihape and Utiku.

This peculiar mode of distribution is the converse of that met with in stream and river deposits, and would indicate that the material was at first inter-glacial, and did not become infra-glacial until it had been transported some distance past the summit of the Waiouru divide.

A fine section of the andesitic till is exposed near the 250 mile-peg, to the south of Turanga-a-rere railway station. At this place the railway cutting passes through the glacial drift for a distance of fifteen chains, exposing in one place a face forty feet high.

The andesite boulders here are mainly angular, semi-angular, or partially rounded. They range from a few inches up to over ten feet in diameter; and in this cutting there are also seen large angular masses of soft Tertiary sandstone mixed with the andesite blocks. The spaces between the boulders are filled mostly with incoherent silts, gritty clays, sandy material, and small pieces of andesite mixed with a small amount of rounded water-worn pebbles and small boulders.

Many of the harder andesite blocks present smooth polished surfaces on one side. These surfaces are sometimes undulating or rounded, and sometimes perfectly flat. The polished surface of one boulder presented very distinct striæ.

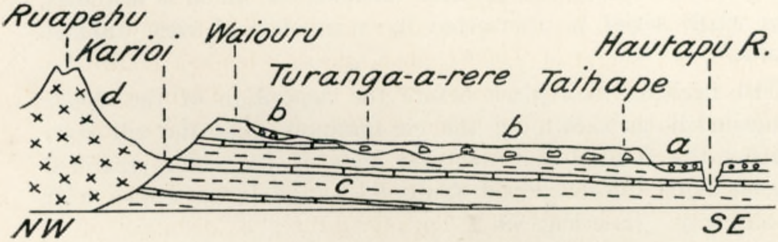

Fig. 96. Section from Ruapehu to Utiku. Distance forty miles.

a. Terrace gravels, mainly resorted from the andesitic till. *b*. Andesitic till. *c*. Pliocene marine strata. *d*. Andesites of Ruapehu.

At the south end of the big bend, about three miles south of Turanga-a-rere, at a point immediately opposite the Hautapu Falls, the andesite till crowns the hills to a height of 300ft. above the floor of the valley.

Overlooking the falls there is a nest of large andesite blocks, one of which measures 8ft. x 6ft. x 6ft., and another 9ft. x 7ft. x 6ft., the weight of the last being about 27 tons. They are large, irregular masses, frequently with one side well polished.

It should be noted that the masses of andesite that lie on or project above the surface frequently show a tendency to assume a more or less rounded shape, through the process of spheroidal weathering, which so commonly affects rocks of a basic or semi-basic type.

About half a mile further south there is another exposure of the glacial deposit, in a railway cutting about eight chains long. Here, as at the 250 mile-post, the andesite blocks are mingled with many large angular masses of Tertiary sandy clay torn from the adjacent bed-rock. These masses of sedimentary material are quite angular, and so soft that they could not have withstood, even for a few yards, the pounding action of running water. Hence we are compelled to conclude that they now lie in the places where they were dropped by the ice.

At the 252½ mile post there is a deep cutting, in which the till is seen to overlie unconformably a series of stratified silts, sandy clays, and loose gritty andesite tuff-like material, the exposed thickness of which is about 50ft. This stratified series comprises the older glacial drift already described. It is obviously of fluvio-glacial origin. At its base it contains a tapering lens of andesitic river-drift, the greatest thickness of which is five feet. The whole series is intersected by a number of very distinct faults.

The faulting took place before the deposition of the upper andesite-till, as shown by the circumstance that the till rests against the faulted and denuded ends of the older stratified glacial drift. Moreover, the faults do not affect the upper drift in any way. (See Fig. 89.)

The occurrence of a glacial deposit resting unconformably on marine beds that are admitted to be Pliocene is of great importance, as it clearly proves the existence of Pleistocene glaciation in the North Island.

The genesis of the Hautapu till presents no difficulty, for there is no agency but glacier-ice known to science competent to bear huge masses from their parent rock, transport them over a divide into another watershed, and scatter them in a sheet over an area several hundred square miles in extent, from a point over twenty miles from their source to a point at their extreme limit over forty miles from the parent rock.

And, as previously mentioned, the greatest development and largest masses of rocks are at the southern limit, and the least development and smallest blocks nearest the source which is the converse of the conditions that pertain with river deposits.

Near Turanga-a-rere, and at many places between Mataroa and Utiku, there occur horizontal terrace gravels following the present course of the river. Below Taihape they attain a considerable thickness. They are mainly composed of andesitic material derived from the rewash of the andesitic till spread over the slopes of the old glacial valley, in the floor of which the existing Hautapu cañon-like channel has been excavated. These gravels are comparatively recent; and can be traced down the valley to the Rangitikei junction, where they gradually merge into the high-level drifts of that river.

Fig. 97. Andesitic Glacial Till, 250 mile-post, looking south.

In all its physical characters the Hautapu till resembles the boulder-clay of England and the till of Scotland. Perhaps the main point of difference is that the Hautapu till contains less water-worn gravel than that of Scotland. The water-worn material in it constitutes only a fraction of that in the ancient moraines of Otago. The Taieri moraine contains about 40 per cent. of gravel, and the Kingston, Queenstown, Kawarau, and Clyde moraines over 60 per cent.

The till of Scotland has been described by Sir Archibald Geikie[f] as "a mere unstratified conglomeration of boulders and gravel in a matrix of stiff clay. This is undoubtedly its prevailing character. But it also contains lenticular stratified beds." In another place he says[g], "A boulder-clay is not merely a clay with a greater or less number of boulders scattered through it; it is rather an earth, a mixture of gritty clay, sand, gravel, and boulders heaped together indiscriminately in constantly varying proportions."

It is almost certain that further research will discover many glacial deposits in other parts of the North Island besides those occupying the Hautapu Valley. The great andesitic drift that covers the plateau lying north of Mount Egmont, and over which the railway line runs to New Plymouth is evidently of fluvio-glacial origin. It extends in some places over twelve miles north of the railway line, being found spread over the head-waters of the Waitara and Patea rivers.

Already Mr. A. Hamilton[h] has reported the occurrence of an andesitic till on the Main Trunk railway near Raurimu, situated on the west side of Ngauruhoe. And Mr. H. Hill[i] has written that the hummocky ridges he had formerly described as eskar-like, lying on the Ruataniwha uplands towards the Ruahine and Whakarara Ranges in Hawke's Bay, had now been shown by the clearing and burning of the forest to be of glacial origin.

Waimarino Moraine.—The western limits of the Waimarino Plain, as the author found, is fringed with an encircling chain of morainic hills that rise above the level of the plain to a height varying from 50ft. to 250ft. The moraine extends from the west side of Ruapehu to the Upper Wanganui, a distance of over twenty miles; and it occupies a width varying from two to four miles.

The Main Trunk Railway runs along the plain following the eastern side of the morainic hills as far as Waimarino railway station, beyond which it descends to the Wanganui River, in its course down the "Spiral," winding backward and forward

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f. A. Geikie, "Glacial Drifts of Scotland," p. 36.
g. A. Geikie, *loc. cit.*, p. 35.
h. A. Hamilton, letter to author, 5th Feb., 1910.
i. H. Hill, letter to author 28th January, 1910.

through the morainic hills as far as Raurimu, a distance of seven miles.

The structure of the moraine is beautifully exposed in the numerous deep cuttings through which the railway runs. The material consists of a rock-rubble of angular and semi-angular blocks of andesite of all sizes up to twelve feet or more in diameter set in a matrix of reddish-brown clay. Its thickness varies from 0ft. to 250ft. In many places it is overlain by a considerable thickness of reddish-brown clays in which there is embedded an occasional isolated block of large size. In a few places the clays are rudely bedded.

Near Raurimu, which is situated on its western fringe, the moraine is overlain by a pumiceous drift that in places attains a

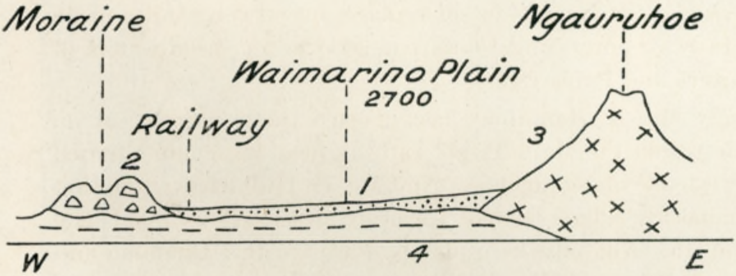

Fig. 98. Section from Waimarino Moraine to Ngauruhoe

1. Pumice sands and clays. 2. Andesitic moraine. 3. Andesite lavas and scoriae. 4. Dark shaly clays of Tertiary coal measures, Lower Oamaruian.

thickness of 60ft. For some miles north of Raurimu little is seen of the glacial boulder-clay until the railway passes into the old glacial valley of the Wanganui, where it is again well developed. In this area a good deal of the moraine has been re-sorted into well waterworn andesitic gravels.

At the Waimarino Plain the moraine occurs at a height of 2,700ft. above the sea. At Raurimu it descends to 2,000ft. It everywhere rests on a highly denuded surface of the dark shaly clays of the middle Oamaruian.

The rocky material in the moraine is andesitic lavas transported from the western slopes of Ruapehu, Ngauruhoe, and Tongariro by the confluent glaciers that radiated from the west side of these mountains in the Pleistocene.

Fig. 98A. Ruapehu Volcano from West Side.

Lent by Education Department.

Waimarino Plain is situated in 39° south latitude, which is the furthest north that glacial *débris* has been so far discovered in New Zealand.

Striated Stones.—Striated stones are abundant in the stony till that is so well developed in the Wakatipu district. The finest

Fig. 99. Striated *roches moutonnées*, Bob's Cove, Lake Wakatipu.

examples are those found at Bob's Cove, at the foot of the beautiful *roches moutonnées* uncovered in a narrow gulch by the recent sluicing operations. Many beautifully-striated boulders occur in the Tasman lateral moraine, between the Ball Hut and the terminal face, and in the Tekapo moraine, but elsewhere in New Zealand they are not common.

Fig. 100. Striated greywacke boulder from Bob's Cove.

Perched Blocks.—A very fine example of a perched block, and the first described in New Zealand, is found resting on the crest of a low but somewhat steep ice-worn ridge on the Kawarau side of Hogan's Road, that leads from the upper end of Lake Hayes to the Arrow Bridge on the Cromwell Road. It is situated about half a mile from the junction of Hogan's Road and Arrow South Road, running behind the Hospital, and can be seen from many points within a radius of a mile[j]. (See Fig. 101.)

This great erratic of greywacke measures some 24ft. by 12ft. by 10ft., and weighs about 230 tons. It rests directly on the ice-worn surface of the mica-schist. Its lower surface is grooved, polished, and covered with fine striæ, that run in the same direction from one end of the boulder to the other. The striæ are remarkably well preserved. The polished and striated surface covers an area of over 400 square feet. (See Fig. 102.)

About 15 chains west of the perched erratic just described there is another erratic of greywacke lying in a hollow. Its dimensions are 20ft. by 14ft. by 10ft., and its weight about 240 tons.

Another large erratic of greywacke lies stranded on the floor of the old sluicing-claim on the Arrowtown end of the Crown Terrace, near the base of Mount Beetham. It weighs about 80 tons, and is situated some 700ft. higher than Hogan's Road erratics.

Many of the large blocks of andesite in the Hautapu till are perched on ridges of Pliocene clays at a height of 2000ft. above the sea. A reference has already been made to the block on the crest of Mataroa Hill, near Mataroa.

Queenstown Eskar.—The foothills of Queenstown Hill, lying between Arthur's Point Road and the Frankton Arm of Lake Wakatipu, are composed of fluvio-glacial drifts arranged in the form of hummocky ridges and eskars that lie immediately above and behind the terrace, at the 150ft. level, on which the Convent is built. Starting a little beyond the stone bridge in the street leading up from the wharf, the ground rises somewhat abruptly on to the topmost of the ancient lake-strands which forms the narrow terrace spoken of above.

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j. J. Park, *loc. cit.*, p. 30.

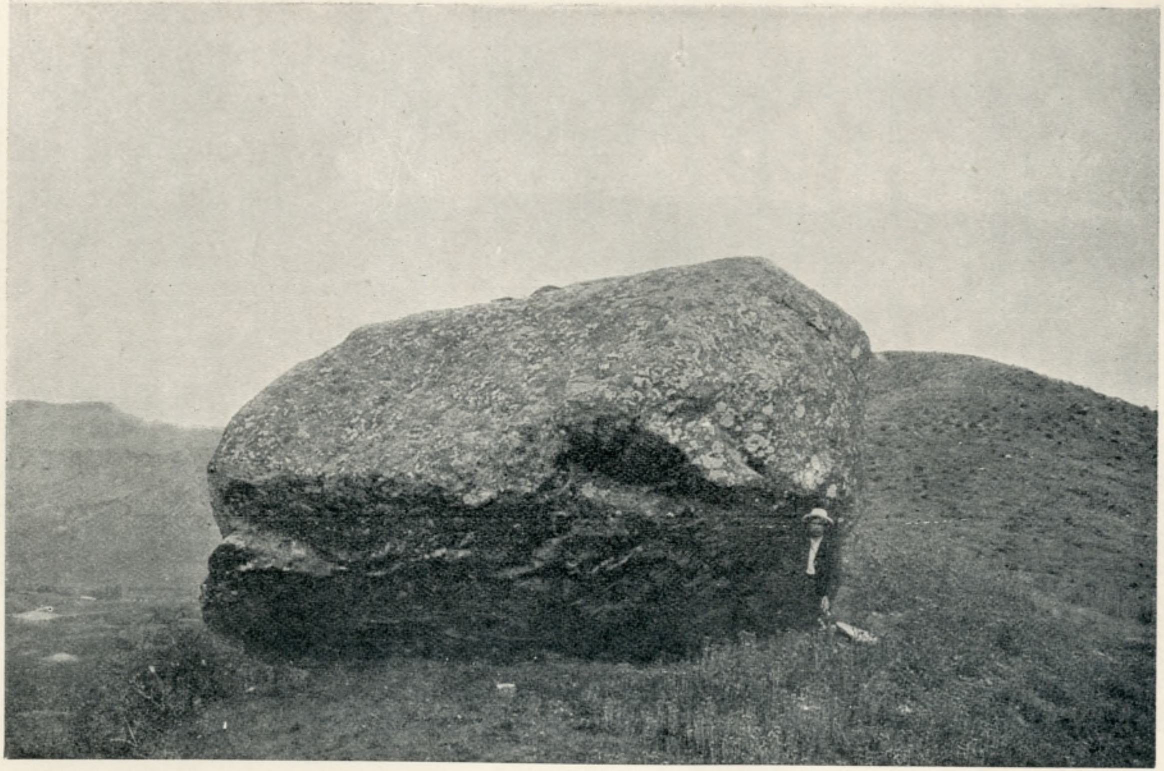

Fig. 101. Perched erratic near Arrowtown.

Behind the terrace, and nearly in a line with the street, there are two short hummocks, while a third and larger kame or eskar runs along the back of the terrace for some distance towards Frankton Arm. This eskar varies from 60ft. to 100ft. high, and is mainly composed of rudely bedded sands and gravels, commonly a yellowish rusty-brown colour. It is cut through in a few places by small lateral streams, and is there seen to be overlain by a coarse boulder-clay or drift, mainly composed of sand, clay, and greywacke boulders. It is probably this covering of coarse drift that has preserved this deposit from destruction.

This eskar lies nearly at right angles to the path of the glacier-flow, and the comparatively uniform size and bedded character of the material render it difficult to understand the conditions in which it was deposited. Its shape and material would, however, lend colour to the belief that it was laid down in an ice-tunnel drained by a stream running parallel with the flank of Queenstown Hill.

Whatever the true explanation of its formation, it is interesting to note that in outline and structure the Queenstown eskar is not dissimilar to those found in Scotland. Its resemblance to the kames around Highlaw, a mile or two south of Cruden Bay, near Slain's Castle, on the coast of Aberdeenshire, is very noticeable.

Slope and Crag.

The peculiar configuration of the isolated ridges and hills lying between Lake Wakatipu and Arrow River affords unrivalled evidence of the intense abrasion to which obstacles in the path of the great ice-sheet were subjected during the glacial period. These ridges commonly present a long, smooth, gradually ascending slope on the side that faced the ice-flow, while the opposite side, protected from abrasion, is steep and rough. The long, smooth, glaciated slope is what is known as the *stoss-seite,* and the steep craggy side as the *lee-seite*. In nearly all cases the long slope has fine flowing contours, and is commonly covered with a thin mantle of boulder-clay.

Queenstown Hill; Fortification or Ferry Hill, situated between Lake Johnson and the Shotover; Cave Hill, also called Slope Hill, lying between the Shotover and Lake Hayes; and Morven Hill, immediately east of Lake Hayes, all exhibit this feature in a very marked degree, Slope Hill and Ferry Hill, as seen from Arrowtown Road, being perhaps the best examples.

The glaciated hill lying on the south side of Frankton Arm, named the "Crag-and-Tail," is a typical example of the slope-and-crag phenomenon of ice-erosion. Its beautiful ascending

Fig. 102. Striated under-surface of perched erratic.

ice-smoothed slope and steep crag can be well seen from the Frankton Road at any point half-way between Queenstown and Frankton Flat.

At the foot of the long slope, or *stoss-seite*, there is commonly a hollow or basin. Thus, at the foot of the Crag-and-Tail we have Lake Wakatipu; at the foot of Queenstown Hill, the arm of that name; at the foot of Ferry Hill, Lake Johnson; at the foot of Slope Hill, the Shotover Valley; and at the foot of Morven Hill, Lake Hayes.

The islands in Lake Wakatipu during the period of glaciation penetrated the bottom of the Wakatipu glacier like the *platten* of the modern Swiss glaciers, and were on this account subjected to intense erosion. They also exhibit the slope-and-crag feature, which is always characteristic of extreme glaciation. The islands in Lake Wanaka, as well as Mount Iron at the south end of that lake, also present the same configuration.

Roches Moutonnées.—A fine rounded ice-polished and striated rock-hummock occurs at Bob's Cove, Lake Wakatipu[k].

The *roches moutonnées* at the Arrow Flat occur in narrow, more or less continuous, ridges that trend from Arrowtown to the Kawarau—that is, they follow in a general way the strike of the mica-schist, which is about north west-south east. They are commonly rounded in outline and whale-backed in longitudinal elevation. In some places they are so worn down as to be almost obliterated, in other places they attain a height of 30ft. or 40ft. In the area lying between Lake Hayes and Arrowtown the space between the successive rock hummocks and ice-planed ridges is filled with fluvio-glacial drift, which is sometimes so deep as to all but cover the underlying hummocks, forming in places chains of low hills that on the east coast of Scotland are known as *drums* or *drumlines.*

East of Hogan's Road, near the junction of that road and the Arrowtown-Cromwell Road, the hummocks are often separated by undrained hollows that become tarns in the winter and spring.

The general trend of these ice-worn ridges lies at right angles to the flow of the glacier-ice, as determined by the direction of the striæ on the rock-surfaces found at Arrowtown and elsewhere.

There are some beautiful *roches moutonnées* on the shoulders of Mount Rosa, near Mount Cook, where, at a height of 5,500ft. above the sea, or 3,000ft. above the present surface of the Hooker Glacier, large mammillated areas of greywacke present finely-polished and striated surfaces. There are also some well-preserved *roches moutonnées* in the Upper Rangitata Valley, near Mount Potts; and at Lake Guyon, in the Upper Clarence; and at Boulder Lake and Mount Burnett, in Collingwood.

k. J. Park, "Bulletin No. 7 (New Series)," N.Z. Geol. Survey, 1910, p. 34.

Fig. 103. Showing glacial steps cut in mica-schist on slopes of Ben More, Lake Luna, Wakatipu district.

Erratics.—The bulk of the stony material composing the stony boulder-clay spread over the uplands and lowlands of the Wakatipu district has been transported by ice from the mountains on the west side of Lake Wakatipu. The rocks principally represented are greywacke, which predominates, granite, diorite, and norite.

The andesite blocks transported from Ruapehu across the Wangaehu watershed and spread over the lower Hautapu Valley are the only erratics known in the North Island.

Lake Luna Ice-benches.—Finely preserved examples of these benches are exposed on the west side of Ben More, rising from the shore of Lake Luna to the summit of the range, where they stand out in fine relief in their carpet of yellow tussock. (See Fig. 103.)

Thirty or more benches or shelves can be distinguished when standing on the west side of Lake Luna, the uppermost being as sharply defined as the lowest. They are horizontal or gently undulating, and many have an undrained hollow behind them. They vary from a few yards to fifty yards wide, and from 30ft. to 70ft. high, although some are lower and others higher than these limits. The lower terraces are the highest and widest. The rock in which they are excavated is a moderately hard quartzose mica-schist.

It is noticeable that all the rock-benches contour round the inequalities of the slope on which they are impressed. The mechanics of their excavation is difficult to understand; but it is almost certain that all were carved out at the same time, for it is impossible to conceive that each shelf can represent a separate epoch of advance and recession of the ice-sheet during the period of glaciation.

These beautifully preserved rock-shelves present as fine an example of ice-erosion, or, more properly, ice-shearing, as there is recorded in the literature of geology. They are probably unique, and are certain to be of much interest to glacialists in all parts of the globe.

Mammillated Slopes of Coronet Range.—The crescent-shaped tussock-covered slopes of this range fronting the Arrow Basin, almost from the level of Millar's Flat to the saddle on the road leading over the range to Skipper's Point, are terraced with long lines of ice-formed benches, many of which have undrained hollows behind them. On approaching the saddle, the continuous benches and low horizontal ridges are replaced by rounded knobs that impart a beautifully mammillated appearance to the higher slopes of the range. The country rock is a weak, rather friable mica-schist, and in almost all the hummocks and benches examined it was found to be broken and shattered, and where not shattered, always much bent and crumpled by the weight of the ice-sheet.

Glaciated Remarkables.—The benches on the slopes of the Remarkable Mountains near Kingston, although not so distinct and continuous as those at Lake Luna, are nevertheless notable examples of ice-erosion. They extend from the level of the lake to the summit of the range, which in the glaciated portion reaches a height somewhat exceeding 6,500ft. above the sea.

Ice-benching on Concave Slopes.—It is noticeable that the benches and ice-terraces are in all cases most strongly impressed on the concave side of the faces against which the ice-flow was directed in its downward course towards the lowlands. The inner or convex side is commonly worn into smooth, even, billowy slopes. It is not certain whether this can be applied as a broad generalisation in all glaciated lands, but it is a point that should not be lost sight of in future investigations.

Ice-cut Platforms.—The best example of an ice-cut rock-platform in Otago is what is known as the Crown Terrace, which extends along the foot of the Crown Range from Arrowtown past Mount Beetham to the Kawarau Gorge, a distance of some six miles in an unbroken stretch. It varies from half a mile to two miles wide, and is covered with a thin mantle of glacial till, of which the pebbles and boulders are mainly greywacke. In a few places on the Arrow face of the terrace there is a layer of schistose glacial drift, consisting chiefly of large fragments of micaceous quartz-schist, chlorite-schist, and quartz, with only a small percentage of water-worn greywacke gravel. In this drift, which has the appearance of a ground-moraine or a moraine that has been overrun by ice, there are a few very large masses of greywacke, one of which weighs about 80 tons.

The Crown Terrace is excavated in the solid rock, and lies from 600ft. to 700ft. above the Arrow Flat—that is to say, it lies at the same level as the floor of the old Arrow glacial valley, and is merely the eastern continuation of that old floor, having been excavated by the Arrow glacier, one branch of which entered the great Arrow Basin at Arrowtown, while the other passed round the back of Mount Beetham, and thence crept eastward along the foot of the Crown range, against which it was thrust by the united Shotover and Kawarau glaciers.

The floor of the Arrow glacial valley stood some 700ft. above the floor of the Arrow Basin, relatively to which it was a hanging-valley. The Arrow glacier, on meeting the great glacier occupying the Arrow Basin, was deflected sharply to the east, and, following the general direction of flow of the ice-sheet, ploughed its path along the base of the Crown Range, its work resembling that of a coal-cutting shearing-machine making a horizontal cut. The face of the Crown Terrace fronting the Arrow River shows traces of horizontal grooves and benches that were probably excavated by the ice-sheet that thrust the Arrow glacier against the Crown Range.

It has been mentioned elsewhere that the slopes of the Crown Range behind Mount Beetham still show the remains of an ascending succession of narrow rock-benches that are fairly well preserved in places. These were doubtless the work of the Arrow glacier.

Pig Island, in the upper reach of Lake Wakatipu, has been ice-planed down to a flat platform only a few feet above the surface of the water. If the lake were drained dry this island would present the appearance of a table-topped ridge.

Thickness of Ice-sheet during Maximum Refrigeration.

The ice that covered the alpine region of the South Island was probably nowhere thicker than in the ancient Wakatipu basin.

The marks of ice-abrasion, in the form of mammillated and terraced slopes, are seen on the Remarkables from the surface of Lake Wakatipu up to a height of over 6,500ft., and on the Eyre and Richardson mountains up to 6,000ft. The dome-shaped crests and terraced slopes of the Crown, Wakefield, Macandrew, and

Coronet ranges tell us that even the highest peaks were overridden by a continuous ice-sheet of continental dimensions. But how far the surface of this ice-plateau stood above the 6,500ft. contour is a matter of almost mere conjecture, in the present state of our knowledge with regard to the digging and abrasive power of glacier-ice.

In the Arrow Basin there stood a thickness of ice that we know exceeded 5,000ft., a mass capable of exerting a compressive stress exceeding the ultimate crushing-strength of the weak mica-schist in that area. In such a case we have no difficulty in understanding the genesis of the mammillated floor over which the ice slowly moved in its seaward course.

What we cannot satisfactorily determine is the thickness of ice that stood over the 6,500ft. contour of the Remarkables. An examination of our modern glaciers shows us that a considerable thickness of ice seems incapable of abrading or modifying to any extent the surface over which it slowly glides, even when carrying a load of rock-fragments locked in its under-surface. From this premise we are compelled to conclude that the thickness of ice above the summit of the southern half of the Remarkables must have been very considerable—sufficient, at any rate, to give the necessary compressive stress to furrow and sculpture the mountain-summits at 6,500ft., as we now see them.

The country rock is a semi-metamorphic mica-schist, often friable and crumbling on weathered surfaces; but when worn down to the fresh rock, as it would be by ice-abrasion during the glacial period, it is found to be tough and resistant, as strong perhaps as the sandstones used for building purposes in Great Britain—such as the Arbroath, Dean Forest, Polmaise, Blue Hailes, Darley Dale, and other well-known building-stones—possessing an ultimate crushing-strength varying between 400 tons and 600 tons per square foot.

These sandstones, it should be noted, are only of moderate strength compared with such rocks as the Potomac Red Sandstone of United States, with a crushing-strength of 1,223 tons, and the Molasse Sandstone of Kempten, 1,850 tons per square foot. The crushing-strength of Welsh clay-slate ranges from 700 to 1,000 tons per square foot, and the mica-schist of Scotland from 400 to 650 tons.

If we assume that the mica-schist of the Remarkables is not more resistant than, say, the soft band of Chilmark Stone, of Tisbury, in Wiltshire—a weak building-stone somewhat resembling our Waikawa Stone, with a crushing-strength of 100 tons per square foot—it is obvious that it would require a thickness of 3,500ft. of ice to exert a pressure above the ultimate breaking-strength of the schist. But we have no warrant in supposing that any such thickness of ice existed above the 6,500ft. contour. It seems impossible to avoid the conclusion that the sculpturing performed by moving ice must be mainly due to the abrading action of the rock-fragments locked in its lower surface, like the cutting-action of diamonds set in the soft-iron crown of a boring-rod. Without the requisite pressure on the revolving crown, the diamonds will not bite. Moreover, for effective work the pressure on the crown must be regulated to the hardness of the rock being bored.

Pure water is a perfect lubricant, and, even when running at a high velocity, exerts practically no erosive action on its channel. The cutting-power of running water is almost entirely dependent on the abrasion caused by the transported material.

In like manner our New Zealand experience of valley-glaciers shows that a considerable thickness of ice, containing no sub-glacial *débris*, may glide over its bed without modifying the surface on which it rests to any appreciable extent.

It seems improbable that moving ice will abrade its bed, unless the pressure of its own mass is sufficient to force the transported rock-fragments into the yielding surface below.

It is well known that even a revolving rod of soft iron will cut the hardest rock if sufficient pressure is exerted on it; and in the same way a moving sheet of ice should be capable of abrading its bed if the gravitational stress due to its mass exceeded the ultimate strength of the bed-rock. The rock-surface would fail and crumble, and the removal of the abraded material by sub-glacial streams would expose fresh surfaces, so that in time extensive rock-planing might take place through this cause, operating either alone or in conjunction with the disintegrating action of alternating freezing and thawing.

It will be seen from the foregoing that we are almost entirely without data that would enable us to estimate even approximately the thickness of ice that stood over the summit of the southern portion of the Remarkables, often spoken of as the Hector Range. It is doubtful whether the thickness exceeded 1,500ft., although it might very well have been much greater; but it is equally improbable that it was less than 750ft. during the period of maximum refrigeration, judging from the strongly marked evidences of ice-erosion found on all the mountains above the 5,000ft. contour.

Taking a thickness of 750ft. as surmounting the 6,500ft. contour, we get a maximum thickness of ice in the Wakatipu basin of 7,490ft., computed as follows:—

Hector Range, ice-eroded to	6,500ft above sea-level
Floor of Lake Wakatipu	240ft. below ,,
Thickness of ice-plateau above summit of Hector Range	750ft.
Total	7,490ft.

The thickness of ice in the Arrow basin, which lies at a height varying from 1,200ft. to 1,400ft., on this basis would be some 6,200ft. Even assuming that the surface of the ice-plateau did not rise above the crest of the Hector Range—although we know that it must have done so—we get a maximum thickness of 6,740ft. in the Wakatipu basin and 5,540ft. in the Arrow basin, the latter exceeding the computed maximum thickness of the continental ice-sheet covering Scotland in the glacial epoch of the Northern Hemisphere.

In attempting to estimate the probable thickness of the ice-sheet that covered the Mount Cook region in the period of maximum glaciation, we are confronted with difficulties even greater than those encountered at Wakatipu. Lake Pukaki occupies an old glacial basin that is being rapidly filled up with fluvio-glacial drift, but which at one time extended up the Tasman and Hooker Valleys for many miles. The present depth of the lake affords no kind of clue whatever to the depth of the basin when it was occupied by the ancient Tasman Glacier. But, judging from the form of the cross-section of the valley, it seems not unreasonable to assume that the depth was not less than

1,000ft. If we take 1,000ft. from 1,585ft. the height of the lake surface above the sea, we get 585ft. as the height of the bottom of the basin.

The evidence is almost conclusive that the confluent Tasman and Hooker Glaciers overflowed Mount Rosa and Mount Kinsey on the Mount Cook Range, and David's Dome on the main divide, all over 6,500ft. high. If we take it that the surface of the ice-plateau stood 1,200ft. above the 6,500ft. contour, we get 7,700ft. as the height of the surface of the ice-sheet above sea-level; and if from this we take 585ft., the estimated height of the floor of the basin, we get 7,115ft. as the maximum thickness of the ice.

The Excavating-power of Glaciers.

This is a subject on which there is still much difference of opinion. Sub-alpine lakes were claimed as the result of glacial excavation by Ramsay as far back as 1862[l], but this view was not indorsed by his contemporaries Lyell and Murchison. At the present day, Bonney, Heim, and other distinguished glacialists, while admitting that glaciers are capable of wearing down the asperities of a land surface, and of grooving, rounding, and planing all prominent obstacles that happen in their path, deny the power of ice to create new features. It can only, they contend, modify pre-existing land-forms, but cannot excavate rock-basins. On the other hand, such eminent geologists as Geikie and Penck are equally strong supporters of Ramsay's views.

After a prolonged examination of a region that has suffered profound glaciation, the author finds himself with a distinct leaning towards the views of Ramsay.

A hoe that is dragged along the ground does no useful work—it does not even abrade; but by exerting pressure on the handle it is made to scoop out the soil in its path. A glacier may be compared to a graving-tool, and except its own mass is sufficient to exert an irresistible pressure, it will glide over or merely smooth or polish the surfaces over which it passes.

A summit-glacier, by reason of its wide sectional area and relatively wide bearing surface, does not abrade the surfaces on which it rests. Its thickness can commonly be measured in

l. Quart. Jour. Geol. Soc., London, 1862, p. 185.

Lent by Education Dept.

Fig. 103A. Tasman Glacier, looking towards terminal face F, with enormous load of morainic debris.

hundreds and not in thousands of feet. It carries no rocky load on its back; and its method of wearing down and modifying its bed is by picking up the loose frost-shattered fragments of rock in its path, and carrying them forward to its terminal face, where they are piled up like a huge talus. But it does not abrade, and for this reason striated stones are rarely found in the transported *débris*. The pressure of its mass relatively to its rubbing-surface is too little to cause abrasion, much less gouging or scooping.

Similarly, a valley-glacier with a wide bearing-surface relatively to its depth is incapable of exerting a scooping action. It does not always abrade, and in many of our mountain-valleys occupied by shrunken glaciers at the upper end it would be difficult to trace the former extension of the ice but for the morainic *débris* scattered along the floor of the valleys. None of the existing glaciers in New Zealand are capable of excavating their bed, and it is doubtful if any in Europe or America are more competent to do so.

It is obvious that a glacier can only excavate when a certain relation exists between the pressure of its mass and its sectional area. A sharpened carpenter's chisel, with a sectional area of, let us say, one-thousandth of a square inch, will cut effectively with a pressure of 40lb. exerted on it, while the same chisel blunted so as to present a sectional area of ten-thousandths of a square inch with the same pressure will only scratch the surface of the wood. The chisel is only able to gouge a hole when the pressure exerted on the cutting-edge in a unit length of time so far exceeds the ultimate strength of the wood as to cause rupture of the resisting fibres. It is equally certain that ice can only excavate its bed when the pressure of its mass exceeds the ultimate crushing-strength of the bed-rock. A thickness of 4,000ft. of ice is capable of exerting a pressure of about 100 tons per square foot, and 6,000ft. a pressure of 150 tons per square foot.

The mica-schist in the Wakatipu basin has a crushing-strength that probably exceeds 100 tons per square foot when the rock is lying horizontally, but the load to cause the rock to fail will be much less when the strata are tilted so as to present an inclined edge to the pressure-load. It has been proved experimentally that a rock possessing a crushing-strength of 200 tons to the square foot will fail with a load of 100 tons when set at an angle of 30° to the line of force, and with a load of 75 tons at an angle of 60°.

From this it will be seen how incapable the pigmy valley-glaciers of to-day must be to excavate their bed. As gouging-instruments they are sufficiently rigid, but deficient in mass. With the superadded weight of the continental ice-sheet of the glacial period they would be at once converted into effective excavators.

A glacier is one of Nature's graving-tools. Even Ruskin, while doubting the power of ice to excavate rock-basins, admits "that a glacier may be considered as a vast instrument of friction—a white sandpaper applied slowly but irresistibly to all the roughness of the hill which it covers." Why, then, should we deny it the capacity to wear away the surface, and thus form basins, if sufficient pressure be exerted upon it for long enough? A continental ice-sheet, such as that which covered Otago and Southland and the greater part of the South Island, would certainly exert sufficient pressure to cause the glaciers or ice-coulters flowing through the narrow gorge-like valleys that prevail in the Wakatipu district to deepen their beds in favourable places, not so much by scooping as by the furrowing action due to the irresistible surface-abrasion exerted by the rocky fragments locked in its under surface. Moreover, any structural weakness that might have caused, or contributed to, the original selection of the site of the valley prior to the glacial epoch would also assist the glacier in its work of excavation.

It is not a little singular that Lake Wakatipu, as well as all the smaller lakes, lies in a narrow gorge-like valley of small sectional area relatively to the height of the enclosing mountains.

It does not necessarily follow that the Wakatipu glacier, when it was surmounted by and formed part of the great ice-plateau of Central and Western Otago, excavated the rock-basin in which the lake now lies. We know that the Wakatipu Valley existed prior to the glacial period, and there is good reason for the belief that its origin has a close relationship to the powerful faults that traverse each of the main arms of the lake. Not only did the valley exist, but it is possible, or perhaps even probable, that a lake occupied a part of the floor of the valley before the advent of the ice. The dominant lines of dislocation following the course of the valley, and the work already performed by the great river draining the valley, would render the task of the glacier in excavating its bed to the present depth of the lake less formidable than it might at first appear to be. Moreover, it must not be forgotten that the depth of the Wakatipu rock-basin is but a small fraction of the total depth of the ice that at one time stood over it.

Lakes Luna, Hayes, Moke, and Johnson are only exaggerated rock-tarns scooped out by ice in the floor of the valleys in which they lie. That some of them lie in the track of faults is not the cause of their formation, although the faults doubtless played a part in determining the situation and direction of the pre-glacial valleys in which these lakelets lie.

OLDER FLUVIO-GLACIAL DRIFTS.

In the old lake basins of Central Otago there exists a brown or reddish brown drift, mainly composed of partly decomposed greywacke. This drift is in places over 1,000ft. thick. It generally rests on a slightly denuded surface of the older lacustrine series[m], and where the latter has been involved in faults, it is also involved.

Throughout the goldfields of Otago, this brown drift is known as *Maori bottom*. It is nearly everywhere gold-bearing, but not often to a profitable extent. On its denuded surface, however, there rests unconformably a sheet of younger fluvio-glacial drift which has yielded the bulk of the gold produced in Otago. This younger drift, it should be noted in passing, has proved particularly rich where it contains a large admixture of re-sorted glacial material, as for example in the neighbourhood of Clyde and Cromwell.

The Maori drift at one time covered the floor of the old lake-basins, having been formed in the period immediately preceding the first advance of the glaciers. The advancing glaciers and the rivers that drained them denuded the older drift over considerable areas, and during the waning stages of glaciation, when fluviatile activity reached its maximum, the denuded remnants were covered with a sheet of younger drift, with which the

m. J. Park, "Bulletin No. 2 (New Series)," N.Z. Geol. Survey, 1906.

lake-basins were once more filled, forming a flood-plain similar to that of the present Mackenzie Plain.

Considerable areas of the Maori drift exist at Naseby, in the Maniototo Basin; at Waikeri-keri, in the Manuherikia Basin; and along the foot of the Pisa Range, and at Quartz Reef Point, in the Cromwell Basin.

Ancient drifts of the *Maori Bottom* epoch are, however, not confined to the Otago lake-basins. They were formed in front of the advancing ice along the foot hills behind the Canterbury Plains. And, as in Otago, they were denuded and covered over by the younger drifts that formed the Canterbury Plains. Remnants of them occur in many places in Canterbury, notably in the Timaru area and Ashley Downs.

The Port Hills gravels at Nelson, and the well-known Moutere gravels that form the undulating hills lying between the Waimea and Motueka rivers, appear to be the contemporaries of the older Otago drift.

The Port Hills Drift.—This is a blue fluvio-glacial gravel with sandy beds weathering a rusty brown colour in the oxidized zone. It is mainly composed of greywacke and granite boulders, the former derived from the country lying behind Wakapuaka, and the latter from the granite area at Mackay's Bluff.

At many places on the sea front, the drift is seen resting on a highly denuded surface of the Port Hills marine beds of the Oamaruian. Not infrequently it is tilted at considerable angles.

It is clear that the Port Hills drift is but a fringing remnant of a deposit that extended across the present Nelson Inlet to Wakapuaka and Happy Valley, where small isolated patches of it can still be traced. And we are left in little doubt as to the direction from which the material was transported, for the Maitai, the only considerable stream in the neighbourhood, does not drain a granite watershed.

As the granite could have come from no other source than Wakapuaka, some twelve miles away, we are compelled to conclude that the glacier or glacial river which transported the material must have flowed from the direction of the French Pass. The Maitai River, coming in from the south-east, would doubtless contribute its dole of greywacke, and at the same time exercise a sorting action on the granitic material carried forward from Wakapuaka.

During the last or waning phase of glaciation, the drift was subjected to denudation by the Maitai, a portion of the re-sorted material being heaped up by the water draining from the land on the one side when opposed by the strong sea-current, setting into the bay, acting on the other side. Between the two agencies the material was in time drawn out in the form of a natural mole. The genesis of the Nelson Boulder Bank is in all respects similar to that of the greater sand bank forming Cape Farewell Spit.

YOUNGER FLUVIO-GLACIAL DRIFTS.

At the close of the first glacial epoch the rivers draining the retreating glaciers filled the inland basins with well-worn gravels and sands forming a flood-plain that in the case of the Manuherikia and Cromwell basins stood 400ft. above the present floor. The high broad terraces at Clyde, Alexandra, and Lowburn are the remains of this old flood-plain, as also are the gravel terraces at the south end of Lakes Tekapo and Pukaki.

When the second glacial epoch took place, the glaciers once more advanced, but it is doubtful if in any instance they reached beyond their mountain confines. During the advance the glaciers ploughed into and scooped out the drifts they found filling their old basins. They then remained stationary for a time and piled up the terminal moraines that are now so conspicuous a feature in the mountain valleys of Otago and Canterbury.

At the outlets of Lakes Tekapo and Pukaki, at the mouth of the Kawarau Gorge, at Cromwell, and wherever sectional exposures are to be found, the valley moraines are seen to rest against and over the fluviatile drifts in an unconformable manner.

Valley Moraines.

Morainic *débris,* mostly in the form of terminal and lateral moraines, are found among the mountain chains from Southland to Nelson. The best known moraines are the Waiau, Kingston, Queenstown, Mount Nicholas, Kawarau, and Clyde, in Otago; the Waitaki, Pukaki, Tekapo, Rangitata, Rakaia, and Waimakariri, in Canterbury; the Rotoiti and Rotoroa, in Nelson. Besides these there are enormous piles of morainic material spread over the maritime foothills in Westland.

Waiau Moraine.—The low ground on the east side of Lakes Te Anau and Manapouri as far as the foot of the Takitimu Range is strewn with large and small blocks of gneiss and greywacke, derived from the west side of the lakes. The terminal moraine of the ancient Waiau glacier forms hummocky hills between Red Bank Creek and Black Mount.

Kingston Moraine.—This is situated at the south end of Lake Wakatipu, and was formed by the Wakatipu glacier. It extends from Kingston to Athol, a distance of nineteen miles; but is nowhere over half a mile wide. The old channel in the moraine through which the lake discharged before the present outlet at the Kawarau Falls was excavated can still be seen at a height of 150ft. above the surface of the lake.

The morainic material consists principally of large angular masses of greywacke and semi-metamorphic mica-schist set in a matrix of well-waterworn gravels composed mainly of greywacke and a small percentage of pebbles and boulders of granite, syenite, diorite, norite, porphyrite, basalt, and hornblende-lamprophyre.

Queenstown Moraine.—This moraine lies against the foot of Queenstown Hill, facing Lake Wakatipu, and, although of small extent, is well known from the circumstance that the greater part of Queenstown is built on it, while the beautiful Domain of that picturesque town is situated on the tongue of land it forms projecting into the lake between Frankton Arm and Queenstown Bay. It is a lateral moraine, composed chiefly of fluvio-glacial drifts of sand and gravel, with which are mingled numerous angular fragments of rock, ranging from small pieces up to masses weighing over 200 tons. The bulk of the boulders in the fluvio-glacial drift is greywacke, while the angular masses are mainly composed of the same rock. The prevailing greywacke is a fine-grained grey rock, but it is found in endless variety of colour and texture—namely, green, red, purple, and speckled; gritty and brecciated.

Among the well-worn material there are many pebbles of granite, syenite, diorite, norite, basalt in two varieties, hornblende-lamprophyres of the camptonite and monchiquite varieties, and many porphyrites.

The crystalline rocks have come from the mountains lying between Lake Te Anau and Lake Wakatipu, where they are associated with the Te Anau Series. The basalts, porphyrites, and lamprophyres occur as dykes in the schists of the Maniototian on the east side of Lake Wakatipu drainage area.

Mount Nicholas Moraine.—This is the largest moraine in the Wakatipu Basin. It extends from Beach Bay to the Von River, a distance of eight miles, and forms the foothills lying between Walter Peak and Lake Wakatipu. It is a lateral moraine, resting on an ice-eroded core of mica-schist and schistose greywacke. It consists mainly of tumbled fragments of mica-schist and greywacke, some of them of enormous size, mingled with fluvio-glacial drifts that are composed mainly of greywacke and quartzose material. Its thickness exceeds 300ft.

Greenstone Moraine.—This is a lateral moraine lying between Rere Lake and the mouth of the Greenstone River. It is mainly composed of greywacke, but on its upper surface there are scattered many angular masses of an excessively coarse crystalline conglomerate, composed for the most part of large and small well-rounded boulders of granite, syenite, diorite, and norite. This great conglomerate has not yet been found *in situ*, but doubtless belongs to the Te Anau Series, which is well developed in the neighbouring western ranges.

The Greenstone River, in cutting down its present gorge, has destroyed a large portion of this moraine.

Kawarau Moraine.—The remains of an old moraine occur at the end of the Kawarau Gorge, about three miles from Cromwell. It consists of angular masses of schist, some of them of enormous size, mingled with fluviatile *débris*. In some places it reaches a height of 300ft. above the present bed of the river.

A good deal of morainic matter is scattered on the terrace bounding the Kawarau at Gibbston, and masses of ice-carried material can be seen in almost all parts of the Cromwell basin; but, generally speaking, the amount of glacier-*débris* seems relatively small compared with the evidences of ice-erosion which are everywhere present on the mountain-slopes.

Victoria Moraine.—This occupies the floor of the basin between Victoria Bridge and Nevis Bluff. Like the Kawarau moraine, it has suffered considerably from the action of the river since its formation, having been scoured out on the river-edge into a precipice a hundred feet high and levelled on the top into what is now a fairly flat terrace.

Clyde Moraine.—This great moraine occurs at the mouth of the Dunstan Gorge, in the Manuherikia Basin. It occupies the triangular space between the foot of the Dunstan Range and the Waikerikeri stream. Altogether it covers an area of some ten square miles; and at Clyde attains a thickness of over 400ft. Its upper surface is flat and terrace-like.

It is mainly composed of tumbled masses of mica-schist, and quartz-schist set in a loose incoherent matrix of clay, sand, and water-worn gravel, which is mainly composed of pebbles of greywacke, quartz, and olivine-basalt.

The Victoria, Kawarau, and Clyde moraines mark the stopping places of the Kawarau and Clutha glaciers during the final recession to the mountains.

Waitaki Moraine.—This moraine occurs on the left bank of the Waitaki, about six miles below the junction of the Hakateramea, rising up to a height of about 600ft. above the floor of the valley. It was formed by the ancient Waitaki glacier, the total length of which was at least 112 miles.

During the maximum period of glaciation four principal and many minor glaciers flowed down the valleys of the Tekapo, Pukaki, Ohau, and Ahuriri, all uniting in the Mackenzie Plains to form the Waitaki trunk glacier, which attained a breadth of thirty miles. The *roches moutonnées* and glacial shelves on the mountains prove that the ice was many thousand feet thick. Its surface stood so high that besides the main outlet by way of the Waitaki Valley an outlet was found across the Lindis Pass, where the Clutha and Waitaki Glaciers united. Outlets were also formed at Burke's, Mackenzie, and Hakateramea Passes, affording evidence that North Otago and South Canterbury were covered with a continuous sheet of ice, radiating seaward, through which only the higher dividing ridges projected.

The Hakataramea ice-stream united with the Waitaki trunk glacier at the Kurow. The Burke's Pass branch was of considerable size, and threw a broad moraine across the valley of the Opihi. It also formed the beautiful glacial steps that, as seen from the main road to Mount Cook, are so conspicuous on the northern slopes of the ranges on Guthrie's Estate, between Fairlie and Burke's Pass. The mountains are terraced from the level of the road at the bottom of the valley at 1,200ft. above the sea up to nearly 4,000ft. Altogether over forty benches are seen to contour around the ranges for over half a mile without a break. The steps are not so high as those in the Wakatipu country, but they are better preserved.

Pukaki Moraine.—The morainic accumulations at the south end of Lake Pukaki rise to a height of 250ft. above the level of the lake. A series of old lacustrine benches contour around the lake. The benches rise one above the other to a height of 80ft., clearly indicating successive levels at which the lake waters have stood since the retreat of the glacier. Several outlets were used and abandoned before the existing outlet was cut down through the morainic barrier.

The Pukaki is the largest valley-moraine in the South Island, altogether covering an area of some forty square miles. With its lateral moraines it forms a ring of glacial *débris* completely encircling the lake on three sides.

The lateral moraine on the west side of the lake and valley extends without a break from Twin Creek to the south end of the lake, a distance of twenty miles, where it joins the terminal moraine, which stretches northward some eight miles, almost reaching Simon's Pass. The eastern lateral moraine thence follows the margin of the lake as far as Braemar Station, a further ten miles. The total length of the morainic ring around the lake is thus about thirty-eight miles, with a width varying from a quarter of a mile to over three miles. The material is mainly greywacke.

Tekapo Moraine.—This moraine forms a crescent-shaped barrier at the south end of the lake. Its length is about ten miles and greatest width two miles and a half. It is not so massive as Pukaki moraine, being chiefly composed of scattered blocks of greywacke resting against the scooped out drifts of the old flood-plain.

Between Tekapo and Pukaki there are two large moraines on the plains, namely the **Balmoral Moraine**, which is crossed by the main road leading to Pukaki and Mount Cook, after passing Parkburn, and the **Maryburn Moraine**, which extends along the north bank of the Maryburn for a distance of eight miles, and is skirted by the main road for three or four miles between Irishman's Creek and the Maryburn. Both moraines consist of single scattered blocks of greywacke or of piles of rock forming mounds rising above the surface from ten to fifty feet high. The Balmoral Moraine is probably an extension of the Tekapo Moraine. The Maryburn Moraine was obviously formed by a portion of the Tasman Glacier, which overflowed the Pukaki Basin, passing down the ice-shorn depression lying between Mount Cox and the Mary Range.

Rakaia, Rangitata, and Waimakariri Glaciers.—The presence of *roches moutonnées*, morainic terraces, truncated crests and spurs afford conclusive evidence that the valleys of these rivers were at one time occupied by large glaciers that deployed on to the site of the Canterbury Plains.

Glacial accumulations are common in the higher valleys, but the amount of morainic material on the Canterbury Plains, beyond the limits of the ranges, is comparatively small. This is perhaps not surprising when we remember the destructive effect that the powerful torrential post-glacial rivers would exert on the incoherent piles of glacial *débris*. The ancient terminal moraines that marked the eastern limits of the great ice-streams descending from the Canterbury Alps have been mostly destroyed, re-sorted, and spread out among the lower drifts of the Canterbury Plains.

Rangitata Moraines.—The glacier which flowed down the Rangitata Valley during its greatest extension reached several miles into the Canterbury Plains, crossing the range before the present gorge was cut, by a depression to the south. After the retreat began a lake was formed behind the range. In course of time this lake became filled with alluvial detritus, forming a flood plain, the remains of which can still be clearly traced on the slopes of the present valley.

The glacial shelves and terraces in the lower valley and the beautiful *roches moutonnées* in the middle valley bear eloquent testimony to the great thickness and erosive power of the ancient Rangitata glacier.

A portion of this glacier flowed through the depression now occupied by Lakes Tripp and Acland, and united with the Ashburton glacier.

The glacial drifts on the banks of the lower Potts River, a large tributary of the Rangitata, are very extensive and thick. They consist of alternations of rock-rubble, sand, and fine silts, the latter partially consolidated and frequently occurring in thin layers of paper-like thickness. In many respects these deposits resemble the constituent members of the Taieri moraine.

Rakaia Moraines.—The morainic accumulations at Woolshed Creek, seven miles below the Rakaia Gorge, probably mark the eastern limits of the ancient Rakaia glacier on the Canterbury Plains; or at any rate they indicate a resting place during the final recession.

Glacial benches, moraines, and *roches moutonnées* are present in many places in the middle and upper Rakaia.

The Rakaia glacier, besides its principal outlet by the main valley, sent a lateral branch down to the plains by the valley of the Selwyn. Important branches of this glacier also passed over the depression into the Cameron Valley, afterwards uniting with the Ashburton glacier.

Waimakariri Moraines.—The glacial terraces, moraines, glacial lakes, glacial terraces, and *roches moutonnées* prove that this valley, like those of the Rakaia and Rangitata, was occupied by an ancient glacier of great size. The St. Bernard Saddle moraine has been partly re-sorted by the ancient glacier-stream. It contains numerous striated stones[n].

Nelson Moraines.—The barriers at the outlet ends of Lakes Rotoiti and Rotoroa are huge piles of morainic *débris* that accumulated at the terminal faces of the ancient glaciers that at one time occupied these lake basins.

Lake Tennyson, at the source of the Clarence, is partially dammed by a terminal moraine of small size.

Lake Guyon, at the source of the Waiau, is a perfect rock-basin surrounded with very fine *roches moutonnées*.

Boulder Lake, in Collingwood, is also a true rock-basin—an exaggerated mountain tarn—with morainic material perched well

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n. M. C. Gudex, Trans. N.Z. Inst., vol. xli. 1908, p. 33.

up on the slopes on the east side, and fine *roches moutonnées* on the west side. The lake lies at an altitude of over 3,000ft. above the sea, and from there to the Aorere Valley, the sloping plain that descends to the sea is covered with a sheet of fluvio-glacial drift, composed mainly of quartzite, greywacke, and granite boulders.

Westland Moraines.—Morainic material is spread over the greater portion of the Westland coastal plain from the Paringa northward to the Teremakau River. It is especially well developed in the hummocky hills at the township of Kanieri, and around Lake Kanieri. Morainic material surrounds the base of the coastal foothills everywhere from Rimu southward.

The most northerly moraines were formed by the Teremakau and Arahura glaciers. They form what Haast[o] described as a large circumvallation around the lower end of Lake Brunner, reaching within twelve miles of the sea.

Further south there are the terminal moraines of the ancient Hokitika Glacier, separated from the sea by a narrow strip of recent marine littoral. Still further south there is the large terminal moraine of the Mikonui-Waitaha glacier, which forms Bold Head, a remarkable headland on the coast-line. This conspicuous object rises abruptly to a height of 250ft. According to Haast[p] it consists principally of till, with numberless blocks of all sizes and shapes embedded in it. Morgan[q] states that the material is mainly schist and greywacke, with a little granite.

Loess.—This is an excessively fine yellowish-coloured silt which is spread over a considerable area on the east coast of the South Island. It forms a more or less continuous sheet, in the places where it occurs, varying from 0ft. to 60ft. thick. Its greatest development is near the sea, but it is also found inland.

It is exposed to great advantage near Oamaru, where it crowns the sea-cliffs between that town and Awamoa Stream. (See Fig. 71). North of Cape Wanbrow it rests on a raised beach, some five or six feet above high-water at spring tides, consisting of beach-shingle mixed with a large number of littoral shells, all of which belong to living species. The common forms are *Mactra*

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o. J. von Haast, "Geology of Canterbury and Westland," 1879, p. 392.
p. J. von Haast, *loc. cit.*, p. 393.
q. P. G. Morgan, "Bulletin No. 6 (New Series)," 1908, p. 117.

discors, Chione oblonga, Dosinia australis, Atactodea subtriangulata, Mytilus edulis, and *Trochus tiaratus.*

The loess extends northward to the Waitaki, Waihao, and Timaru Downs. It is especially well exposed in the railway cuttings at Timaru Railway Station, where it has been made the object of particular study by Hardcastle[r].

Further north, the loess spreads over a large portion of Bank's Peninsula, and caps the downs rising from the Canterbury Plains at the foot of Mount Grey, reaching as far as the Ashley and Motanau Downs. It is well represented in the Malvern Hills.

A fine yellowish-coloured silt covers the undulating hills that rise out of the Taieri Plains between Wingatui and Allanton. This deposit is an excessively fine micaceous flour. It is generally unstratified, but at the Wingatui brick-yard it occurs in thin horizontal layers. The origin of the Canterbury silts, or loess, has been a subject of keen discussion among New Zealand geologists for the past forty years. The belief is now gaining ground that it is glacial.

Speaking of the loess of Europe, Sir Archibald Geikie[s] believes that it is a "flood loam of glacial times." He thinks that the vast accumulations of loess in southern and south-east Russia owe their origin chiefly to the flood-waters escaping from the margin of old land-ice. Chamberlin and Salisbury[t] state that "The best-known portions of the loess in America and Europe are associated with glacial formations."

Professor Heim, the distinguished Swiss glacialogist and geologist, who examined the New Zealand loess in 1904, has expressed his belief in its glacial origin in unmistakable terms. In 1905 he wrote[u]:—"When the great glaciers which were thrust forward to the outlets of the alpine valleys receded, and the ground moraines which were left behind were dried up by the north-west wind, then the fine dust was blown far over the surface right up to the sea."

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r. J. Hardcastle, Trans. N.Z. Inst., vol. xxii.
s. A. Geikie, "Earth Sculpture," 1902, p. 192.
t. Chamberlin and Salisbury, "Geology," vol. iii., p. 405.
u. Albert Heim, "Neujahrsblatt von der Naturforschenden Gesellschaft auf das Jahr, 1905, Neuseeland." Zurich, 1905.

OLDER POST-GLACIAL DRIFTS.

The maritime gravel plains of Southland, Canterbury, Nelson, Rangitikei, and Taranaki were formed during the close of the Glacial Period.

The Southland Plains extend from Mataura to Jacob's River, gradually rising from sea-level to a height of 625ft. at Lumsden. They are composed of gravel, sand, and clay; and contain near their base thick seams of lignite.

The Canterbury Plains extend from near Timaru to North Canterbury, and stretch from the sea westward to the foot-hills, a distance varying from 32 to 44 miles, with a mean gradient of about 40ft in the mile. They have been proved by bore-holes to consist of river shingle and sand, in places cemented into hard layers with peroxide of iron. Their depth has not been ascertained, but is known to exceed 700ft.

Speight[v] mentions that beds of peat have been met with at 400ft, 500ft, and 700ft. below the surface near Christchurch, or some 380ft., 480ft., and 588ft. below sea-level respectively, affording conclusive proof that subsidence was in progress during the recession of the ice at the close of the Pleistocene. The amount of the subsidence cannot be estimated even approximately as we do not know the total thickness of the drift nor the elevation above the sea at which the interbedded peat bogs grew.

The drifts forming the plains between the Ruahine Range and Wanganui, and those covering the land between Hawera and New Plymouth are mainly fluviatile, being composed of gravels, sand, and clay, the latter frequently containing seams of impure lignite.

The Wairarapa Plains, in Wellington, and the Ruataniwha Plains in Hawke's Bay, are also post-glacial, and should be included in this group.

The terraces excavated in the Rangitikei, Waimea, and Canterbury[w] Plains prove that the negative movement, or subsidence, during which the detritus accumulated and reclaimed wide strips from the adjoining seas, was followed by an uplift in comparatively recent times; but this uplift does not appear to

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v. R. Speight, "Terrace Development of Canterbury Rivers," Trans. N.Z. Inst., vol. xl., 1908, p. 29.
w. R. Speight, *loc. cit.*, p. 23-25.

have affected the extreme south or north of New Zealand. Thus in the Thames Valley, where we have clear proof of prolonged subsidence, there is no evidence of a positive movement since the Pleistocene.

Among the drifts that accumulated during the great diluvial period that immediately succeeded the retreat of the ice must be included the vast piles of fluviatile gravels that cover the floor of the old lake-basins in Central Otago, and the fluvio-glacial drifts that are filling up the cold lakes in Canterbury.

These drifts have reclaimed large tracts of land at the upper ends of Lakes Tekapo, Pukaki, and Ohau. The ancient Ahuriri Lake, near Omarama, is completely filled, being represented by a mere string of marshy lagoons. Many square miles of land have been reclaimed at the upper end of Lake Wakatipu, and the filling-in process is still in operation, not only there but in all the mountain lakes.

RAISED MARINE BEACHES.

At Bushy Park[x], south of Shag River, a raised beach occurs at about 100ft. above sea-level; and near Cape Wanbrow[y], Oamaru, there is a bed of gravel at the base of the glacial silt, containing a large assemblage of moraine shells. (See Fig. 71.) This bed lies some 5ft. or 6ft. above the high-water mark of spring tides.

At Amuri Bluff there are three terraces that extend southward to the Conway, in the highest of which, at a height of 500ft. above the sea, McKay[z] found recent marine shells. At Motanau, in North Canterbury, a raised beach[a] with marine shells lies at a height of 150ft. above the sea.

On the West Coast of the South Island, Hector[b] mentions the occurrence of comparatively recent beach-terraces extending to more than 220ft. above the sea.

At Taranaki Hector[c] has described Pleistocene deposits with marine shells at 150ft. above the sea.

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x. F. W. Hutton, "Geology of Otago and Southland," 1876, p. 78.
y. F. W. Hutton, *loc. cit.*, p. 70; and J. Park, Trans. N.Z. Inst., vol. xxxvii., 1904, p. 516.
z. A. McKay, Repts. Geol. Expls., 1874-76, p. 77; and 1888-89, p. 181.
a. F. W. Hutton, Quart. Jour. Geol. Soc., xli., p. 212.
b. J. Hector, Repts. Geol. Expls., 1866-67, p. 29.
c. J. Hector, Repts. Geol. Expls., 1866-67, p. 3.

Raised beaches occur around Wellington Harbour, about 8ft. above high-water mark, and McKay[d] describes some as more than 200ft. high near Cape Palliser in Cook Strait. On the north side of Mahia Peninsula[e], there is a raised beach from 5ft. to 7ft. above the present high-water mark; and at Te Kaha Point, McKay[f] mentions the occurrence of a sea-worn shingle 50ft. or 60ft. above the sea. South-west of this there are deposits of sand and clay forming cliffs 40ft. to 50ft. high, containing an abundance of marine shells and impressions of tree-leaves, all of recent species.

No raised beaches are known in the province of Auckland north of Gisborne. In the Bay of Plenty, near Opotiki, the remains of a submerged forest were met with 50ft. below sea-level. In the Thames Valley[g] the mine-workings passed into harbour muds and gravels containing water-logged pieces of timber at a depth of 600ft. below sea-level; and at Turua, near the Thames, the remains of an old forest were met with at a depth of 30ft., buried in harbour mud and sand. Here, as in the case of the Canterbury Plains, we have evidence of late Pleistocene subsidence. At the mouth of the Waitotara River[h], between Wanganui and Taranaki, a submerged forest occurs at the base of the Pleistocene drift in which there are intercalated beds of marine shells, all of which are recent.

Post-Glacial Fans.

Fluviate drifts arranged in the form of fans have been formed by the existing rivers and streams at the places where they deploy from their gorge-like valleys. Such fans are still being formed. On the other hand some of the fans formed during the period of intense fluviatile activity that succeeded the retreat of the glacier to their mountain basins have been partially destroyed and re-sorted.

The Southland, Canterbury, and Rangitikei Plains, to which reference has already been made in the preceding pages, are in

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d. A. McKay, Repts. Geol. Expls., 1878-79, p. 84.
e. A. McKay, Repts. Geol. Expls., 1886-87, p. 198.
f. A. McKay, *loc. cit.*, p. 199.
g. J. Park, "The Geology of Hauraki Goldfields," Trans. N.Z. Inst., Min. Eng., vol. i., 1897, p. 41.
h. J. Park, Repts. Geol. Expls., 1886-87, pp. 55, 59, and 60.

reality nothing more than great wide-spreading maritime fans with a gentle slope from the uplands to the sea.

The Rangitikei fan occupies the triangular space lying between the Ruahine Range and Wanganui, with its base resting against the sea and its apex reaching up the Rangitikei Valley. It is not the work of one river alone, but the result of the united effort of the Pohangina, Manawatu, Oroua, Rangitikei, Turakina, and Wangaehu rivers.

Photo A. G. Macdonald.

Fig. 104. Section of old fan of Bucklerburn, Lake Wakatipu.

A comparatively recent elevation of the land, amounting to some 200ft. or 250ft., has enabled these rivers to excavate their present deep channels in the old drifts.

The Canterbury Plains extend from the Ashley River south to Timaru. Like the Rangitikei Plains they were formed by the uniting of the wide-spreading fans of the numerous rivers that debouch from the highlands. Generally speaking they represent so much land reclaimed from the sea with material derived from the denudation of the uplands.

Comparatively late elevation of the land has allowed the rivers to excavate and terrace the old fans; and in places this action has been probably aided by the recession or cutting away of the toe of the fans by the northerly sea-currents that sweep along the coast, thus enabling the rivers to regrade and deepen their channels.

Many fine examples of fans are to be seen in the old inland mountain basins, formed by the lateral streams at the point where they joined the trunk valley.

The arrangement of the material forming these fans is not often sufficiently exposed for close observation, except where recent elevation, or the lowering of the base-level in the case of an inland basin has allowed the river to excavate a new channel.

The majority of the old fans in the Wakatipu Basin were formed at the time the surface of the lake stood 150ft. above its present level. The gradual lowering of the level of the lake has permitted the lateral streams to cut deep channels in the old fans.

The section exposed on the east bank of the Bucklerburn shows a very clear and instructive view of the bedded and inclined arrangement of fluviatile drift discharged into still water.

The mean angle of dip of the sands and gravels is about 30° for a distance of 3,200ft. This gives an apparent thickness of 1,600ft. of strata, whereas the actual thickness is probably less than 200ft.

It is obvious that in a dry-fan, that is a fan spread over a land surface, the material will not exhibit the same even bedding and partial sorting that is seen in a fan formed in water.

The bedded structure of the Bucklerburn fan conveys an instructive lesson to the geologist. It shows that extreme caution must be exercised in estimating the thickness of fluviatile, fluvio-lacustrine, or fluvio-marine sediments that have accumulated on a steeply shelving shore, in bays or lakes sheltered from swift tides or currents.

Old Lake Beaches.

Nearly all the lakes that occupy old glacial basins in the South Island present evidence to show that at one time the surface of the water was higher than it is to-day. The outlet was in the majority of cases blocked with morainic accumulations or with ice; or in some cases partly with ice and partly with morainic *débris*.

The successive levels at which the water stood is frequently marked by old lake beaches composed of water-worn shingle and sand.

Wakatipu Lake Beaches.—These are very conspicuous, and may be described as a good example of this class of deposit.

The tiers of old lake-beaches, seven or more of which can be distinctly traced in different places around the old shore-line, rise to a height of 150ft. above the present lake-level, and afford convincing proof that the surface of the lake at one time stood much higher than it now does. The old beaches are nearly always composed of small biscuit-shaped pieces of mica-schist of fairly uniform size. They are in all cases unconformable to the glacial drifts and morainic matter on which they rest, as, for example, at Queenstown, at the Five-mile Creek, and other places.

The old beaches contain little morainic or foreign ice-borne material, nor are they overlain by glacial drift, from which it may be inferred that it was after the recession of the valley glacier that the lake stood at the higher level.

It is a noticeable feature of the old beaches that the highest one is often bounded by an even line of steep scarp or cliff, such as may be seen on any shore-line of the present day. Even when the top beach is so fringed it is commonly composed of the usual yellowish-brown biscuit-shaped shingle, but not everywhere. In places between the Five-mile Creek and Queenstown, and from Frankton southward along the lake-face of the peninsula, the 150ft. beach is found to be excavated in the solid schist. Perhaps it would be more correct to say that the rocks have been eaten into rather than excavated by the action of the water, which appears to have remained at this level for a considerable time. It is just probable, although there is no proof of it, that the eating-away of this old strand was in part the work of floating masses of ice. Alternating frost and thaw, by shattering and crumbling the rock, would also afford the water effective help in the work of erosion.

When the waters stood at the 150ft. contour Lake Wakatipu covered a much larger area than it now does. The Domain at Queenstown, Frankton Flat, and a large part of the peninsula were submerged, while all the low-lying lands in the lower Shotover and Arrow were included within the limits of the glacial lake, as also was Lake Hayes and all the low ground in its vicinity. The lake extended from the Kawarau Falls along the foot of the Remarkables, thus isolating the Crag-and-Tail Hill, which then stood out of the water as a steep ice-worn island. In other places there was little change in the size or form of the lake on account of the steepness of the land, except at the upper end, where the waters extended far up the Dart and Rees valleys, and ramified along the floor of all the lateral streams.

Pleistocene Life.

The gravels at the base of the glacial-silt near Cape Wanbrow, Oamaru, contain a large assemblage of marine shells, all belonging to recent species; and in the silts on the north side of the same cape, there was found the broken pelvis and femur of the extinct moa (*Dinornis*). A few miles inland of Oamaru there was found in the same silts, the skull of a large sea-elephant[i] (*Morunga elephantina*).

At Timaru the silt contains a few marine shells[j] as well as moa bones. Haast mentions the occurrence of moa bones in morainic accumulations in Canterbury[k], and the author has found that moa-bones usually much decomposed are not uncommon in the fluvio-glacial drifts forming the high terraces between Alexandra and Clyde in Central Otago.

A few moa bones were unearthed in October, 1908, during the progress of the railway works at the south end of the Caversham tunnel, Dunedin, in a stiff peaty blue glacial clay lying at the base of the boulder-clay, which at this place is over 30ft. deep.

RE-PEOPLING AND RE-CLOTHING OF NEW ZEALAND AFTER THE GLACIAL EPOCH.

The great coastal glacial moraines between the Clutha Valley and Dunedin; at Shades Creek, Kekerangu River, and Cape Campbell, in Marlborough; at Lake Brunner, Lake Kanieri, and South Westland; as well as the morainic deposits in the Rangitikei Valley, and on the Waimarino Plain, leave little room for doubt that the South Island during the period of maximum

i. F. W. Hutton, "Geology of Otago," 1876, p. 70.
j. A. McKay, Repts. Geol. Expls., 1876-77, p. 49.
k. J. von Haast, Geology of Canterbury and Westland," 1879, p. 437.

refrigeration was covered with a continuous sheet of ice, through which only the narrow crests of the higher mountains projected.

How far the ice-sheet extended beyond the existing limits of the South Island is unknown; but there is good reason for the belief that in Southland, Fiordland, and South Westland it may have crept far beyond the present shore-line. The surface forms of these areas exhibit evidence of intense ice-erosion; and there is an entire absence of coastal moraines which would support the view that the glacial detritus resulting from the prolonged glacial sculpturing was transported beyond the present limits of the island and now lies submerged in the sea.

The cause of the glacial epoch in New Zealand has been ascribed by Hutton, Hector, Haast, and others to an elevation of the land, variously estimated at from 3,000ft. to 6,000ft. The spread of the ice-sheet from the centre of movement in the highlands would cause the destruction or migration of all the animal and plant life in the invaded region. But it must be borne in mind that such ice-invasion would not necessarily lead to the total obliteration of all animal and plant life, as has been assumed by some writers.

If the glaciation was caused by an uplift of the land, a view that seems to be endorsed alike by geologists and biologists, from Hooker to Hutton, then the significant fact should not be overlooked that the elevation which caused the glaciation would soon establish a land-bridge between the two islands, and at the same time greatly increase the dimensions of the united islands which in process of time would be linked up with the outlying islands. Pleistocene New Zealand would then have continental dimensions, reaching as far north as latitude 32° S. and as far south as 53° S.; but probably less than a third of its area was covered with ice.

Secular uplift and subsidence are known to be extremely slow, seldom amounting to more than a few inches in the course of a century. Hence an elevation of 4,000ft. or 6,000ft. would cover a period of many thousands of years. The climatic changes due to this slow uplift would be correspondingly slow, their effects being hardly perceptible even in a thousand years.

In the Northern Hemisphere the slow advance of the northern ice-sheet forced existing life to migrate slowly to the south, whence it returned on the recession of the ice. And this is obviously what took place in New Zealand. The two islands were united as the first effect of the uplift, and the area of the dry land was afterwards increased many fold. But only that portion of the land which now forms New Zealand was invaded by the ice-sheet, that and no more, except perhaps in the southern end, which thus enabled the existing fauna and flora to slowly migrate northward and eastward, the land area uncovered with ice being wide enough to permit them to keep within the range or zone of climatic conditions suited to their peculiar constitution and habit.

On the recession of the ice-sheet, due to the gradual subsidence of the land, the existing life returned to its present habitat. The re-peopling and re-clothing of New Zealand would seem to present even fewer difficulties than the re-peopling and re-clothing of Iceland after the retreat of the European ice-sheet.

The two islands are separated by a shallow trough, hence the disseverance of the two islands would take place in the converse order of the linking up. That is, while the uniting of the islands happened at the beginning of the uplift, at probably the end of the Pliocene, the disseverance took place towards the end of the Pleistocene.

In reviewing the question of the re-peopling and re-clothing of New Zealand after the Glacial Epoch, it must ever be remembered—(1) That Pleistocene New Zealand was many times greater than the existing New Zealand; and (2) that during the period of maximum glaciation only that portion which now forms the South Island was covered with an ice-sheet, thus leaving a wide field to the east and north for the migration and preservation of the fauna and flora.

Some writers have thought the time since the Glacial Period too short for the differentiation of some allied species of plants and birds at present inhabiting the North and South Islands. It seems impossible to attach much weight to this view for several reasons. Firstly there is no evidence to show that the differentiation referred to has taken place since the Glacial Period; and secondly, geologists find it difficult to say how long it is since the close of the Glacial Epoch. It is still a matter of controversy whether it is 50,000 or 250,000 years ago. Further, it is still unknown what time is required for the mutation of species.

CHAPTER XI.

RECENT.

The sections into which this period may be conveniently divided are as follows:—

(*a.*) Dinornian.
(*b.*) Moriorian.

DINORNIAN.

In this period are included only such deposits as are now in course of formation, or have been but recently formed by agencies that are still active. In the case of the Firth of Thames, which is not a drowned valley but a *graben*, or area submerged by faulting,

Fig. 105. *Dinornis* skull.

the filling reaches to a depth exceeding 600ft., and deposition is still going on. Although we have no measure of the rate at which the sediments have accumulated, it seems not improbable that deposition has been in progress there without a break from the Pleistocene up till now.

Sand-dunes form fringing hills in many places around the coasts of New Zealand, being specially well-developed near Waikawa in Southland; at Port Molyneau, and Dunedin, in Otago; at Cape Farewell, in Nelson; between Wanganui and Waitotara, and near New Plymouth; between Port Waikato and Manukau South Heads; and at many places on both coasts in the North Auckland district.

The sand-hills lying south of the Manukau Harbour are perhaps the greatest in New Zealand. They form ridges that rise to a height of 400ft. above the sea, and present fairly steep faces on the seaward side, the sands being frequently cemented by the

$\frac{1}{3}$

Fig. 106. *Cnemiornis* skull.

peroxide of iron resulting from the oxidation of the contained black iron-sand into a comparatively compact sandstone, in which horizontal bedding-planes are well developed. It is easily conceivable that in certain conditions, the æolian origin of these consolidated sands might be so obscured as to escape detection.

The sand-dunes, peat bogs, swamps, river alluvium, caves and rock-shelters scattered throughout New Zealand are chiefly of importance for the moa bones which they have yielded.

$\frac{1}{3}$

Fig. 107. *Aptornis* skull.

The remains of moas have been found in great quantity deeply embedded in ancient swamps and peat bogs in various parts of both islands, notably at Hamilton, in Southland; Glenmark, in North Canterbury; and Te Aute, in Hawke's Bay. The Hamilton deposit was estimated by Hutton[l] to contain the remains of at least 400 birds, all lying within a radius of 25ft. And Haast was of the opinion that more than 1,000 birds were embedded in the Glenmark swamp.

l. F. W. Hutton, Quart. Jour. Geol. Soc., xli, p. 213.

Altogether some eighteen species of *Dinornis* have been found; and of these, five are from the North Island only; nine from the South Island; while four are common to both islands. The sub-genera into which these have been divided by Hutton[m] and their distribution is as follows:—

Sub-genus.	North Island.	Both Islands.	South Island.
Movia (Reichenbach)	D. giganteus D. gracilis	D. ingens D. struthioides	D. maximus D. altus D. robustus
Syornis (Reichenbach)	D. didiformis	D. casuarinus D. dromoides	D. rheides D. Huttonii
Palapteryse (Owen) ...			D. elephantopus D. crassus D. gravis
Cela (Reichenbach)	D. geranoides D. curtus		D. parvus

Among other genera of flightless birds that have become extinct within comparatively recent times are the *Harpagornis, Cnemiornis,* and *Aptornis,* the bones of which are frequently found associated with those of the moa.

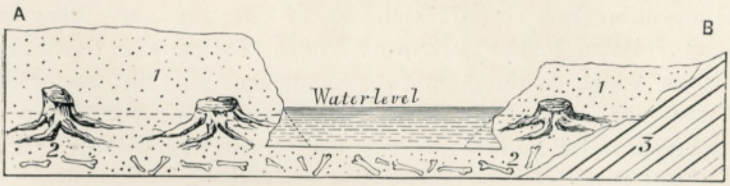

Fig. 108. Section of Patangata Swamp, Te Aute, Hawke's Bay.

1. Alluvial silts and clays overlying old forest. 2. Bone deposit. 3. Indurated marly clays.

m. F. W. Hutton, Quart. Jour. Geol. Soc., vol. xli., p. 214.

MORIORIAN.

This covers the period of early human occupation. It is the Neolithic section of the Stone Age of New Zealand, and is distinguished by the occurrence of human remains and stone implements in caves and rock-shelters.

The natives of New Zealand are a Polynesian people, who are said by tradition to have reached these shores by successive waves

Fig. 109. Te Pehi, a Maori chief, who visited England in 1826.

of migration from Hawaiki some 500 or 600 years ago. They are closely related to the natives of Samoa, Tonga, and Raratonga Islands, which would point to a common origin; but the cradle of the race, or perhaps more correctly speaking, the centre of dispersion in the mid-Pacific, is still shrouded in conjecture. The mythical Hawaiki has not yet been ascertained.

The Maori, when first he arrived in New Zealand, found the country already inhabited by the Moriori, who were probably the offspring of an earlier migration, speaking a dialect of his own language. The timid and peace-loving Moriori was soon enslaved, destroyed, or driven from the mainland by the hardier and more warlike Maori; and at the present time only a remnant survives on the Chatham Islands.

At the advent of Europeans the Maori and Moriori were a very primitive people, still living in what may be termed the *Stone*

Fig. 110. Maori carving.

Age. For, although the easily reduced limonitic ores of iron were abundant on the shores of Golden Bay, they had not acquired the necessary skill to smelt them.

Cradled in the Pacific, where the stepping stones were hundreds of miles apart, the Maori became a bold and enterprising navigator. He knew many of the stars by name, and by their aid he steered his frail canoe from Hawaiki to the shores of far-off

New Zealand. He was brave, chivalrous, skilled in the art of war, and well advanced in the primitive arts. The many beautiful designs used for the ornamentation of his houses and canoes showed craftsmanship of rare skill, combined with great artistic talent. His implements and weapons compared favourably with the best work of Neolithic man in Europe.

In the old middens have been found the bones of the extinct *Dinornis* and *Notornis,* and of the living kiwi, weka, and many

Fig. 111. The Great Spotted Kiwi, *Apteryx haasti.*

other birds, piles of shells, and the remains of the tuatara lizard (*Sphenodon punctatum*), which is now extinct on the mainland.

When Europeans arrived in New Zealand moa bones were abundantly scattered over the surface, or were plentiful in caves and swamps, from sea-level up to a height of 5,000ft., so that the mere finding of moa bones in Maori middens cannot be taken to afford conclusive proof that the Maori hunted the moa. Maori legend, commonly so rich and varied, is almost silent on the subject of the moa, which is surprising. It seems almost incredible that if the Maori hunted this gigantic and stately bird, of such high food value, it should not have become woven into many a wondrous myth and story. At any rate the solution of the problem is as far off as ever.

GREAT FAULTS.

New Zealand is traversed by a number of powerful faults that group themselves into three main systems. In the major system the faults run parallel with the axial lines of elevation, and can be traced from one island to the other. The general trend of these faults is N.E.—S.W.; and their geological position would tend to show that they are in reality stress fractures resulting from the shearing and overthrust folding of the Permo-jurassic rocks concerned in the building of the great mountain chains. They follow the crown of the arches, which have been split in two, thus permitting one limb to override the opposing limb, which has thereby become deeply engulfed with all its associated strata.

The second system of faults follows a N.W.-S.E. course, running at right angles to the major system.

The faults of the third system traverse the Kakanuian and Maniototian schists of Central and Western Otago. Their general trend is about north and south.

The faults of all the systems are geographically features of great importance. They invariably follow the trend of the main valleys and inland basins; and there is reason to believe that the origin of these valleys and basins can be traced to their presence.

McKay[n] was the first to appreciate the important part played by these great dislocations in determining the existing structural features. In his map of New Zealand's principal faults, published in 1890, that able geologist indicated the fractures in the Provincial District of Marlborough that were still what he termed "active." The subsequent violent seismic disturbances in that area in November and December, 1901, were accompanied by the opening of rents and by renewed faulting along the course of the old faults, thereby affording visible demonstration of the soundness of his contention. McKay made a close examination of the affected area immediately after the earthquakes, and the results

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n. A. McKay, Geol. Repts. and Explorations, 1890-91, p. 1.

of his observations are contained in a classic report[o] published in 1902.

Of all the faults in New Zealand none is so well known as the Moanataiari Fault in Auckland, the mining operations of the past thirty years, having disclosed many facts relating to it that could not have been gathered from a mere surface examination.

Description of Faults.

No. 1, Moanataiari Fault.—This is the greatest of two powerful faults that traverse the Thames goldfield. It trends across the course of the gold-bearing lodes, and is therefore a feature of considerable economic importance, and in this respect it plays an important *rôle* in the distribution of the gold.

Its surface line of outcrop crosses Hape Creek immediately below the gorge on that stream, and then strikes along the foot of Una Hill till it reaches Karaka Creek. Thence it proceeds up Collarbone Gully, a distance of nearly 10 chains, whence it crosses the spur into Waiotahi Creek. From there it runs across the dividing spur into the Moanataiari Valley, whence it follows a north-west course to the head of Kurunui Creek. From that point it follows a more westerly course and reaches the sea a few chains north of the mouth of Shellback Creek.

The course of this remarkable fault is marked on the surface by a distinct line of depression which can be easily traced by the unaided eye. On its north-east or upland side, the spurs and ridges which it crosses rise abruptly to a height of 300ft. or 400ft. above the general level of the corresponding spurs which descend towards the foreshore. This feature is well seen by a study of the section from the foreshore to Punga Flat.

It *hades* or underlies to the south-west—that is, towards the harbour—at a uniform angle of 45°, the Thames Valley being the depression or *graben* formed on the downthrow side. The angle of inclination has been verified in many places by reference to the working plans of the mines situated on its course.

Where the fault crosses hard rocks the striations and slickensides on the surface are often as fresh as if the faulting or sliding

o. A. McKay, "Report on Recent Seismic Disturbance within Cheviot County, in Northern Canterbury and Amuri District of Nelson."

had only taken place yesterday. The enormous friction and pressure due to the sliding on the walls have crushed and shattered the rocks for a considerable width on each side of the fracture, and caused the formation of bands of stiff impervious clays lying parallel to the original line of fissure. In the Moanataiari low level adit, where the fault is cut about 30ft. above sea level, the country is crushed and disturbed for a distance of 40ft. or 50ft., and when this point was first reached—when the tunnel was being constructed—the influx of water was so great that all mining operations had to be suspended for some considerable time.

It is also a memorable fact in the history of the goldfield that when the north-east crosscut from the 640ft. level of the Big Pump shaft reached this fault a mass of soft, irresistible plastic clay rolled down the drive with great velocity, causing the workmen to fly for safety. The fault thus acts as a great underground water-course or channel dividing the goldfield into two distinct parts, a seaward portion and an upland portion; and it is a noteworthy circumstance that this remarkable geological feature is constituted, by an Act of Parliament, the eastern boundary of the area under the control of the Thames Drainage Board.

On account of the absence of stratified deposits or any well-marked or distinctive geological horizon it is impossible to accurately determine the amount of the lateral and vertical displacements of the rocks and reefs caused by this great earth fracture or crack. When the reefs on the seaward side reach the fault they are suddenly cut off, and their displacement is so great that up to the present time not one of them has yet been recovered on the footwall or upland side. The only available data of any value is obtained by measuring the difference of altitudes of the spurs on each side of the fault. The difference of levels varies from 280ft. to 350ft., and allowing for the waste of denudation that has taken place since the origin of the fault it is probable that 400ft. will be found not far from the actual amount of vertical downthrow. Calculated from this basis, and using the known dip of the reefs and intersector in different parts of the field as constant factors, it is found that the apparent lateral displacement or heave for the steep reefs in Kurunui Hill would range from 150ft. to 185ft. to the left or north-east; in the area of flat-lying reefs between the Moanataiari and Waiotahi streams, from 350ft. to 420ft. to the north-east; and in the Queen of Beauty area, where the reefs are vertical or steeply inclined to the south-east, the displacement would be from no feet to 185ft., the heave in this case being to the right-hand or south-east.

The flatter the underlie of the reef the greater will be the heave, and conversely the nearer the reef approaches the vertical position the less the heave, and when truly vertical there will be no heave however great the amount of throw may be. Thus if we follow a reef, on the seaward side, up to the great fault in the Kurunui and Waiotahi areas, it will be necessary to cross-cut to the left if we wish to recover our lode on the upland side of the fault; and the length of the crosscut to be constructed will vary with the inclination of the reef.

Along its whole course the Moanataiari fault *hades* towards the harbour at an angle of 45°, and in the Kurunui Hill area the reefs die out as they descend into the hard country, hence it followed that when the sliding or faulting movement took place, in addition to the apparent heave and throw, the ends of the shallow reefs were pulled asunder or apart. In other words, the fault acted as a great sloping plane possessing an inclination of one in one. If the total depth of the reef were represented by the total throw there would be one foot of horizontal displacement parallel to the line of movement, that is, at right angles to the trend of the fault for every foot of vertical throw. The effect of the fault on shallow lodes would be that, on the upland side, the reefs would not reach the line of fault, except in cases where the depth reached by the lode was greater than the total throw caused by the fault. For this cause the Dixon's, Sons of Freedom, and Reuben Parr main lodes have not been traced on the surface to the fault, but end in strings and clay heads in the hard country as shown on the author's map of the goldfield.

In the case of lodes which live down to a greater depth than the total vertical throw of the fault, their severed ends will be found to abut against the faults on both sides, but the corresponding parts of the ends will not be found opposite to each other on account of the throw causing an apparent lateral heave.

Applying this law to Kurunui Hill, it will be found that if we drive on a lode up to the fault and wish to recover it beyond, on the footwall side, it will first be necessary to extend our drive in a straight line some distance beyond the surface-line of the fault, and then turn to the left and crosscut at right angles a distance varying from 150ft. to 185ft., according to the dip of the lode. In the case of a shallow lode it will be necessary to put up a rise from the end of our crosscut to recover the lost lode. In the Waiotahi area, where the lodes are deep-reaching, they would be recovered by simply crosscutting to the left.

The Age of the Moanataiari Fault.—The exact period at which this great fault originated is not easily determined, but its comparatively recent date is established by a number of its physical characters and peculiarities. Its course on the surface is still indicated by a marked line of depression, and on its upland side there is a very distinct modification of the physical features of the country, showing that the ever active and unceasing agencies of sub-ærial denudation have not had time to destroy and obliterate the evidences of its vertical displacement. Again, in places where the fault has been cut in the mines it has been found to contain masses of rotten wood, fernroots, and other partially-decayed vegetable matter entangled in the soft clays and "pug" lying on its hanging-wall. In places where it intersects rock masses the faces of the rock often present very fresh slickensides and striations.

When proceeding up the course of any of the streams which drain the goldfield, it is seen that at the point where the stream reaches the fault the valley suddenly contracts to a narrow gorge. This is caused by the fault intersecting the valleys at right angles to their general trend and admits of a very simple geological explanation. It is well known that when a fault crosses a syncline of stratified rocks the lines of outcrop of the strata or beds are thrown inwards or outwards according to the direction of the dip of the intersector. In the present case the sides of the valley represent a syncline, and as the fault *hades* towards the harbour the downthrow is in consequence in that direction. The immediate result of this is to bring, by faulting, a wide part of the valley opposite a narrow part, this narrow part forming the present gorge on the footwall of the fault.

The existence of this interesting feature is another proof that the denuding agencies have not been in operation long enough to excavate the valley to a uniform width since the date of the fault. The whole of the evidence when taken together seems to point to the very recent origin of this great fault, which may be put in the Newer Pliocene or older Pliostecene period.

No. 2, Whakatane Fault.—This fault traverses the centre of the North Island, extending from Whakatane through Lake Taupo and Ruapehu to Cook Strait. In the South Island it skirts the edge of the Waimea Plain.

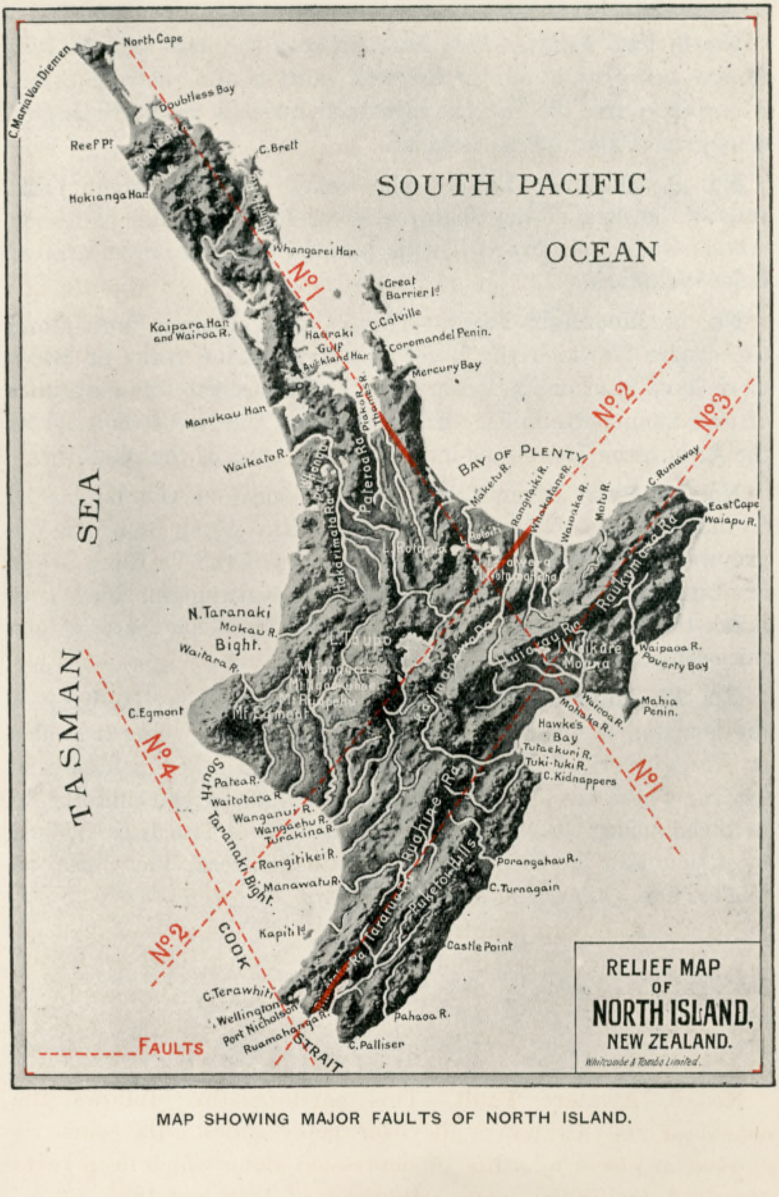
At Whakatane, as well seen in the cliffs behind the township, the lower Mesozoic rocks which it traverses are broken, sharply folded, faulted, sheared, and uptilted. At Nelson the Miocene brown coal-measures are tucked by it against the Triassic rocks of the Richmond and Hope Hills.

No. 3, Wairarapa or Clarence Fault.—This dislocation follows the eastern slope of the Rimutaka Range from the sea northward to Masterton. During the great earthquakes of the fifties earth-rents traceable for many miles opened along that portion of its course on the west side of Wairarapa Lake. In the South Island it follows the Clarence Valley, its course being traceable by movements of recent date, and by a line of depression along the surface of the ground for a distance of fifty miles.

No. 4, Cook Strait Fault.—The abrupt termination of the Mesozoic rocks at Cape Terawhiti, and the presence of the semi-metamorphic Kakanuian on the opposite side of Cook Strait would indicate that not only does a powerful dislocation separate the two islands, but that the North Island has been thrust eastward some distance relatively to the South Island.

No. 5, Kaikoura Fault.—This extends from the Kowhai River in a south-west direction to the Upper Lottery Creek, whence it trends more to the west, passing into the Hanmer Basin and Hope Valley. It was first identified and described by McKay in 1891.

No. 6, Awatere Fault.—This earth-fracture follows the course of the Awatere Valley for many miles. Its course is marked in places by a line of depression along which deep rents appeared during the great earthquakes of 1848 and 1855.



MAP SHOWING MAJOR FAULTS OF NORTH ISLAND.

No. 7, Blue Spur Fault.—This dislocation traverses the celebrated Blue Spur sluicing claim, and can be traced in a south-east direction through Weatherstone's towards Waitahuna.

No. 8, Pisa Fault.—This fault follows the east side of Pisa Range, being well seen on the west margin of Cromwell Basin. Along its course the Miocene lacustrine series is deeply entangled among the Palæozoic mica-schist.

No. 9, Shotover Fault.—The course of this great fault follows the floor of the Shotover River for a distance of fifteen miles. Going southward it runs parallel with the lower arm of Lake Wakatipu.

No. 10, Moonlight Fault.—This is an overthrust fault along the course of which the lower Tertiary marine rocks of Bob's Cove have been entangled among the mica-schist for a distance of over twenty-five miles. It is traceable from Bob's Cove across the Richardson Mountains into the head-waters of the Shotover.

No. 11, Pyke River Fault.—This dislocation can be traced from the source of the Olivine to Red Hill. Along its course the greywacke and associated magnesian rocks of the Te Anau Series are faulted against the mica-schist of the Kakanuian. For many miles the fault forms a sharply-defined boundary between the mica-schists and the Te Anau formation.

No. 12, Manuherikia Fault.—This fault skirts the base of the Dunstan Range for a distance of thirty miles, being traceable at Waikerikeri, Tinkers, St. Bathans, and other gold-mining centres where the lacustrine strata are tilted on end and deeply involved among the Maniototian schists. It was first distinguished by the author in 1888. Similar faults traverse the Cardrona Valley, Ida Valley, and Maniototo Plain.

MAP SHOWING MAJOR FAULTS OF SOUTH ISLAND.

CHAPTER XII.

OUTLYING ISLANDS OF NEW ZEALAND.

The principal outlying islands may be grouped as under:—

1. Kermadec Islands, lying north of Auckland.
2. Chatham Islands, east of Lyttelton.
3. Bounty and Antipodes Island, east of Southland.
4. Snares, Campbell, Auckland, and Macquarie Islands, lying south of Stewart Island.

These islands are situated on the New Zealand oceanic platform, and it is not without tectonic significance that none of them lie on the west side, which is entirely devoid of islands, reefs, or shoals. The Tasman Deep, which lies between the mainland and Australia approaches comparatively close to the West Coast of the South Island. All are zoologically and botanically related to the mainland, with which Hooker, Hutton, Chilton, and others believe they were at one time united. The elevation necessary to link them up with the mainland was probably somewhere about 5,000ft. Such an uplift would give New Zealand continental dimensions, and bring it within a few hundred miles of the Antarctic Continent.

It is obvious that while such uplift lasted the land, which now constitutes what we call New Zealand, would be merely the highlands of a great mountain chain, the present shore-line being situated a considerable distance from the strand of the surrounding Pleistocene seas.

The uplift would bring in its train profound climatic changes. Foremost among these would be the reduction of the mean temperature of the South Island some 20° Fahr., due to the elevation alone, and an added reduction resulting from the great accumulation of ice on the higher and now greatly extended alpine chain.

The whole of New Zealand as we now know it would be the summit of a great chain, with a climate of Greenland severity.

In these conditions it does not seem unreasonable to believe that the alpine chain in the southern portion would be covered with a sheet of permanent ice; and that in the northern portion valley-glaciers would radiate towards the sea from the higher ranges.

If glacial alpine New Zealand possessed a climate of such severity, and we must not forget that the evidences of intense glaciation compel us to this belief whatever we may assign as the cause of the refrigeration—we shall have no difficulty in conceiving that the degree of cold prevailing in the sub-Antarctic must have been polar. And if polar conditions prevailed, there seem to be no valid reasons contrary to the conception that the polar ice extended so far north as to meet the ice radiating from the highlands of what are now the sub-Antarctic islands, and from southern New Zealand.

Speight states that there is no evidence of recent elevation to be seen on the Auckland Islands except the remains of a maritime bench some 150ft. above sea-level. It is obvious that the elevation of the land which formed this bench bears no relationship whatever to the greater elevation which culminated in the late Pliocene, or early Pleistocene uplift. This uplift was followed by a subsidence which was relatively as great as the elevation, since it brought about a softening of climatic conditions that has all but caused the obliteration of the once gigantic glaciers that reached the present strand.

The marine shelf, or raised beach, on the Campbell Islands is merely a proof that the negative or downward movement was arrested and subsequently followed by emergence, which may or may not be still in progress.

That a similar recent secular uplift has taken place in the South Island is shown by the maritime bench, the remains of which can still be traced on nearly all the headlands from Southland to Cook Strait.

The evidences of a Pliocene uplift, that was followed by a subsidence, must be looked for not on the present land surface but on the submerged surfaces, where the evidences would be recorded in the form of detrital deposits such as those of the Canterbury Plains and deep leads of the West Coast.

Too much stress must not be placed on the absence of erratics and boulder clay on the sub-Antarctic islands. These islands, we must always keep in mind, are after all but the summits of submerged mountains projecting above sea-level. In the glacial epoch these islands would be high ranges covered with glacial ice radiating towards the sea on all sides. The ice-sheet, even if it were of diminutive size, would only need to travel a few miles from its gathering ground to extend far beyond the limits of the present strand, thus enabling it to deposit its rocky load in the lower end of valleys that are now submerged.

In the same manner the absence of erratics on the islands cannot be regarded as an evidence that the islands were not covered with an ice-sheet. The converse is the case. The ice-eroded peaks, the truncated crests and spurs, the beautiful domes, flowing contours, and flat-bottomed valleys, can be the work of no other agency than ice. They are admitted by Hector, Marshall, and Speight to be evidence of intense glaciation. But glacialogists, with much reason on their side, affirm that a body of moving ice only possesses the power to erode the surface over which it flows where it exists in considerable mass. If we assume that the ice was only 1,500ft. thick it is evident, from the low relief of the islands, that it would form a continuous sheet over nearly all the land.

The land-ice would radiate outward from the highlands, and even if we postulate that it only flowed as far as the present shore-line, it is easy to see that no erratics could be left on the existing land surface. But it is almost certain that in such southern latitudes the ice would reach the strand of even the elevated glacial land. And if this were so then no erratics could be left on the present land surface by the advancing polar ice; for it is well known that the pressure of land-ice, from its superior mass, is greater than that of an ice-sheet resting on the sea. It is for this cause that there are no Scandinavian erratics in the till of Scotland, the superior pressure of the ice descending from the Highlands having thrust the North Sea ice from the Scottish shores.

Sir E. Shackleton's[p] observations in the Antarctic afford a valuable confirmation of the superior thrust of land-ice. He states that he was easily able to discriminate between the Barrier ice

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p. "The Heart of the Antarctic," vol. i., p. 305.

and the glacier ice, which he found was in places thrust into the Barrier ice from the land.

The Barrier ice is not land-ice flowing northward, but is ice formed by the accumulation of layers of snow upon the surface more quickly than the ice was dissolved by the sea beneath. This view, which was first advanced by Professor J. W. Gregory[q], has been fully confirmed by Professor David.

Referring once more to the absence of boulder-clay on the Campbell and Auckland Islands, it is well known that glacial till is not formed near the source of glaciers or ice-sheets, but in the hollows and lowlands near their terminal ends.

There is no till on the mountains of Scotland or England; and it is quite certain that if Great Britain were submerged to the extent of 1,000ft. hardly a vestige of boulder-clay would be found in England, and little or none in Scotland. All that would remain of the two kingdoms above sea-level would be groups of islands presenting ice-shorn summits and flowing contours like the Auckland and Campbell Islands of the present day. Moreover, the existing glacial cirques would form broad bays and sheltered harbours.

For the best description of the geology of the sub-Antarctic islands of New Zealand we are indebted to Marshall and Speight, to whose work reference will be made in the sequel.

Chatham Islands.

These are a group of islands lying four hundred and fifty miles east of Lyttelton, between the parallels 43° 30′ and 44° 15′ south latitude. Chatham Island, the largest of the group, has a maximum length and breadth of some thirty miles, its extent being about 350 square miles.

The only other island of any size is Rangiauria, or Pitt Island, lying about fourteen miles south of the main island, from which it is separated by Pitt Strait.

The outline of Chatham Island is very irregular and broken. On the west side it is deeply indented with Petre Bay, and on the east by Hanson Bay; while the centre of the island is occupied by the great Te Whanga lagoon.

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q. J. W. Gregory, "Nature," vol. lxxiii., 1906, p. 300.

The surface relief is low, the highest land existing in the southern portion, where some of the hills rise to a height of about 950ft. The northern portion of the island is low and undulating.

The Chathams have been botanically examined by Dr. Dieffenbach, H. H. Travers, H. Halse, F. A. D. Cox, and Dr. L. Cockayne. Of the geology very little exact information is available.

The first outline of the geological structure was furnished in 1868 by Haast[qq], based on rock specimens collected by Travers in 1863. The following year, that was in 1869, Hector[r] supplemented Haast's notes with observation founded on large collections obtained by Charles Traill in 1868, and by S. Percy Smith in 1869.

The northern portion of Chatham Island, according to Hector[rr], is composed of mica-schist which in the southern portion is overlain by marine strata of Cretaceous and Miocene age. The upper marine series is associated with igneous rocks, which are chiefly dolerites and tuffs.

The mica-schist is stated to be similar to the schist of Otago; and its occurrence opens up an interesting question as to its tectonic relationship to the schists on the west side of the Canterbury alps. The Chatham Island ridge is the only schist massif to the east of New Zealand. It is doubtless the eastern wing of the great synclinal in the trough of which lie the folded Mesozoic rocks that compose the alpine divide and the parallel ranges of the Dominion lying to the eastward.

The succession of rocks on Pitt Island, as given by Haast[s], is as follows:—

(*a.*) Limestone, fossiliferous.

(*b.*) Fossiliferous calcareous tuffs, passing into grey tufaceous limestone containing fossils in great abundance, including pectens and brachiopods.

(*c.*) Palagonite tuffs.

(*d.*) Basalts and dolerites.

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qq. J. von Haast, Trans. N.Z. Inst., vol. i., p. 180.
r. J. Hector, Trans N.Z. Inst., vol. ii., p. 183.
rr. J. Hector, *loc. cit.*, p. 183.
s. J. von Haast, Trans. N.Z. Inst. vol. i., p. 181.

Bounty Islands.

This is a group of about twenty rocky islets lying about 500 miles east of Stewart Island, in latitude 47° 43′ S.

The prevailing rock is a biotite-granite, which Speight[t] describes as showing a closer resemblance to the granite at Cranley Harbour in the Auckland Islands than to the Snares granite. The same writer believes that the Bounty Islands are part of a great granite massif, of which the Auckland Islands and the Snares are submerged remnants.

Snares.

This island lies sixty-five miles south of Stewart Island, in latitude 45° S. It is a rocky islet presenting high cliffs with steep declivities on nearly all sides. On the west side the cliffs are over 300ft. high.

The island would appear to be entirely composed of muscovite-granite, much of which possesses a pink or red colour[u].

This boss of granite has probably some relationship to the granites at the south end of the mainland at Preservation Inlet, or to those on Stewart Island.

Antipodes Islands.

These islands lie about 490 miles east-south-east of Stewart Island, in latitude 49° 41′ S. They consist of a group of islands the largest of which is named Antipodes Island. Next in size comes Bollons Island. The remainder of the group consists of small rocky islets.

Antipodes Island is about two miles long and one mile broad. The highest point is Mount Galloway, over 1,200ft. high. The coast-line is everywhere bounded by bold precipitous cliffs.

The island is entirely volcanic, being composed of flows of basalt and enormous piles of breccia[v].

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t. R. Speight, "The Sub-Antarctic Islands of New Zealand," p. 739.

u. J. Hector, Trans. N.Z. Inst.. vol. xxviii., p. 736; P. Marshall, "The Sub-Antarctic Islands of New Zealand," 1910, p. 704.

v. J. Hector, Trans. N.Z. Inst., vol. xxviii., p. 737; and R. Speight, "The Sub-Antarctic Islands of New Zealand," p. 740.

AUCKLAND LSLANDS.

These islands are situated about 190 miles south of Stewart Island, in latitude 50° 40′ S. They consist of Auckland Island, twenty-five miles long and seventeen miles broad at its widest part; Adams Island, fifteen miles long with a mean breadth of two miles; and a group of smaller islands at the north end, the best known of which is Enderby Island.

The depth of the sea between the Auckland Islands and New Zealand is nowhere greater than 200 fathoms, which means that an elevation of 1,200ft. would connect the group with the mainland[w].

The surface of the main island presents gentle slopes and undulating contours. The highest part of the land rises to a height of some 2,000ft. The east and south-east side of the island is diversified with indentations and bays, the land in most places descending to the sea by long easy slopes. On the west side the shore is bounded by a long line of steep precipice and frowning cliff.

The centre of the southern half of Auckland Island is circular in form. The centre of this portion is occupied by Cranley Harbour, with its numerous ramifying arms and bays.

According to Speight[x], the rocks composing the southern half of these islands consist of a central core of granite, gabbro, and older trachyte, surrounded and enveloped by vast sheets of basalt. Dykes of trachyte, diabase, and porphyrite are numerous.

The igneous rocks are overlain in a few places by patches of coastal conglomerate containing boulders of granite, gneiss, contorted schist, and gabbro.

Speight describes the central granite as containing little muscovite but a good deal of biotite, and while bearing a resemblance to Bounty Island, it differs altogether from that on the Snares.

The moraines described by Hector and Speight were doubtless formed during the second or valley epoch of glaciation.

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w. R. Speight, ''The Sub-Antarctic Islands of New Zealand, vol. ii., 1910, p. 706.

x. R. Speight, *loc. cit.*, p. 718.

Campbell Island.

This island is situated about 330 miles south of Stewart Island, in latitude 52° 30′ S. It is somewhat circular in form, measuring altogether about thirty miles in circumference.

The surface is hilly; and in places plateau-like, while the coast-line is bounded by abrupt cliffs formed by marine erosion. The highest elevation is Mount Honey, 1,867ft.; and after it come Mounts Dumas and Eboulé, both 1,650ft.; and Mount Azimuth, 1,600ft.

The surface of the island is covered with a sheet of peat, which lies direct on the immediate bed-rock. This absence of soil or alluvium between the peat and the rock is ascribed by Marshall[y] to the effect of glaciation. And the semi-circular heads of the valleys, with their flat floors and straight or gently curved courses, which are further on described, would tend to show that this view is correct.

The basement rock is mica-schist[z], which does not appear to crop out above sea-level. Then follows a typical gabbro[a], the relationship of which to the schist is unknown. From similar occurrences on the mainland it may, however, be surmised that the gabbro is intrusive and younger than the schist.

The gabbro is overlain by a thick series of marine sediments consisting of conglomerates, grits, sandstones, and shales, capped by a limestone several hundred feet thick. These beds occur as a mantling fringe on the west side of the island. They are followed by a considerable thickness of fossiliferous tuffs, with which are associated flows of trachyte, phonolite, and basalt[b].

Dykes of trachyte and basalt are described by Marshall as intruding both the sedimentaries and the tuffs.

The position, so far as it relates to the age and grouping of the marine beds is still uncertain. Hector[c] assigned these beds to the Upper Cretaceous, being largely influenced in doing so by the reported occurrence in them of chalks with flints. Marshall refers them to the Miocene; but the occurrence of *Conchothyra parasitica*, reported by this writer, would support Hector's view as

y. P. Marshall, "The Sub-Antarctic Islands of New Zealand," p. 684.
z. Filhol, "Mission de l'île Campbell."
a. P. Marshall, "The Sub-Antarctic Islands of New Zealand," p. 704.
b. P. Marshall, *loc. cit.*, p. 706.
c. J. Hector, Trans. N.Z. Inst., vol. xxviii., p. 736.

that distinctive mollusc has never been found in Tertiary rocks in the mainland or elsewhere. *Conchothyra* is a genus peculiarly characteristic of the Amuri Series of New Zealand.

On the other hand *Magellania lenticularis, Pecten zealandiæ, P. delicatula,, P. Triphooki, P. polymorphoides, Lima colorata,* and *Venericardia australis,* identified by Marshall, would indicate a middle Tertiary age.

The evidence would seem to point to the existence of two marine formations, the older, probably including the limestone and lower beds, belonging to the Waipara Series; and the younger, embracing the fossiliferous tuffs, belonging to the Miocene Oamaruian. At any rate it is certain that all the fossils quoted by Marshall are common in the Hutchinson Quarry tuffs at Oamaru and Cape Wanbrow and Kakanui, with the exception of *Conchothyra parasitica,* which is characteristic of the reptilian beds of the Waipara Series.

Macquarie Island.

This lies about 570 miles south of Stewart Island and 300 miles west of Campbell Island, from which it is separated by a pelagic valley; but the soundings that have been taken in this oceanic area are too few to prove that it is not connected by a submerged ridge with the New Zealand sub-marine platform.

Macquarie Island, situated in latitude 55° S., is the most southerly of the outlying islands of New Zealand; and with the exception of some islands near Cape Horn, it is the nearest land to the present Antarctic Continent. It lies some distance south of Kerguelen Land or the Crozets.

The information with respect to its geological structure is very meagre, practically the only remarks bearing on that subject being a reference by Professor Scott[d] to the presence of greenstones.

The surface is ice-worn; and in referring to the plant life, Cheeseman[e] has expressed the opinion that the island was at one time covered with an ice-sheet which destroyed all the phaneorganic flora with the exception of two or three grasses. The

d. J. H. Scott, Trans. N.Z. Inst., vol. xv., p. 484.
e. T. F. Cheeseman, "The Sub-Antarctic Islands of New Zealand," p. 470.

present vegetation—a collection of waifs and strays—has arrived, he thinks, through trans-oceanic migration.

KERMADEC ISLANDS.

This is a wide-spread group of volcanic islands lying north of New Zealand, and situated between the parallels of 29° 10′ and 31° 30′ of south latitude. There are four islands, and some outlying rocky islets.

The principal and most distant island is Raoul, or Sunday Island, some 600 miles from Auckland. Then in order going southward come Macauley Island, 68 nautical miles from Sunday Island; Curtis Islands, 22 miles from Macauley; and L'Esperance, or Brind Island, 52 miles from Curtis Islands.

Sunday Island is somewhat triangular in shape, and about twenty miles in circumference, the area being 7,260 acres. The highest point is Moumoukai, 1,723ft. high.

Percy Smith[f], to whom we owe the best description of this group, describes the surface as rugged and broken; and, except in a few places, covered with forest. The most prominent feature is the large crater, which occupies a nearly central position.

There are two small lakes in the crater, the smaller of which was the centre of volcanic activity in 1872. Speaking of this place Smith says:—"Vast quantities of pumice, rock, sand and mud have been ejected, covering the old floor of the crater to a maximum depth of 12ft., the lighter fragments of which were cast on to the greater crater's rim, and in their fall brought down all the forest with them. A thinner deposit has been thrown on to the hills to the north-west. The vegetation is slowly gaining a hold on the crater-bottom, and clumps of pohutukawa, ngaio, tutu, and other shrubs are gradually hiding the desolate-looking ashes from sight. . . . The Green Lake is a perfect little crater, and on its banks in several places the steam still escapes, but not in any great amount. . . . Steam also escapes from crevices in the precipitous cliffs of Denham Bay, and warm water oozes out of the sand at low water on the north coast, thus showing that the volcanic forces have not entirely ceased action."

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f. S. Percy Smith, "The Kermadec Islands," Wellington, 1887, p. 20; *loc. cit.*, p. 21.

The vegetation is stated by the same writer to have a strong New Zealand facies, but there are several trees that are peculiar to Polynesia.

Macauley Island is an extinct volcano, a little over a square mile in extent, its area being 756 acres. The highest point is 781ft. above the sea-level, and from there the land descends by gentle slopes. The island is surrounded with cliffs varying from 200ft. high at the east side to 600ft. at the western end.

The larger of the Curtis Islands is about a mile and a half in circumference. It is everywhere surrounded with perpendicular cliffs that rise abruptly from the sea. The crater is still in the solfataric stage[g] of volcanic activity, and sends out a considerable amount of steam from numbers of fumaroles scattered over its bottom. The crater is about 150 yards in diameter, and is walled in by an encircling ring of steep cliffs varying from 400ft. to 450ft. high, except at the cove, where the rim is broken down to the level of the sea. The floor of the crater is occupied by mud and rocks, among which the hot water bubbles up in a number of places, and by pools of boiling mud, which seethe and twirl their contents about. Smith observed the interesting circumstance that a strong stream of hot water runs from the crater into the cove, the salt water of which is perceptibly warm for fifty yards from the shore. Steam escapes from crevices in the crater-cliffs in several places, and also from the outer cliffs away from the crater. Sulphur is said to be present, but not in great quantity.

The rocks collected by Smith were examined by Professor Thomas[h], who identified them as mainly basalt and augite-andesite, with glassy forms of basic rocks. Speight[i] has also described some andesites from Macauley Island.

In Smith's collection were pebbles and boulders of hornblende-granite and other granitoid rocks, which, taken in connection with the occurrence of granitic conglomerates in the East Cape district of New Zealand, at Otorohanga in the King Country, at Kawhia and Whangaroa district, north of Auckland, would point to the existence of a submerged ridge of ancient crystalline

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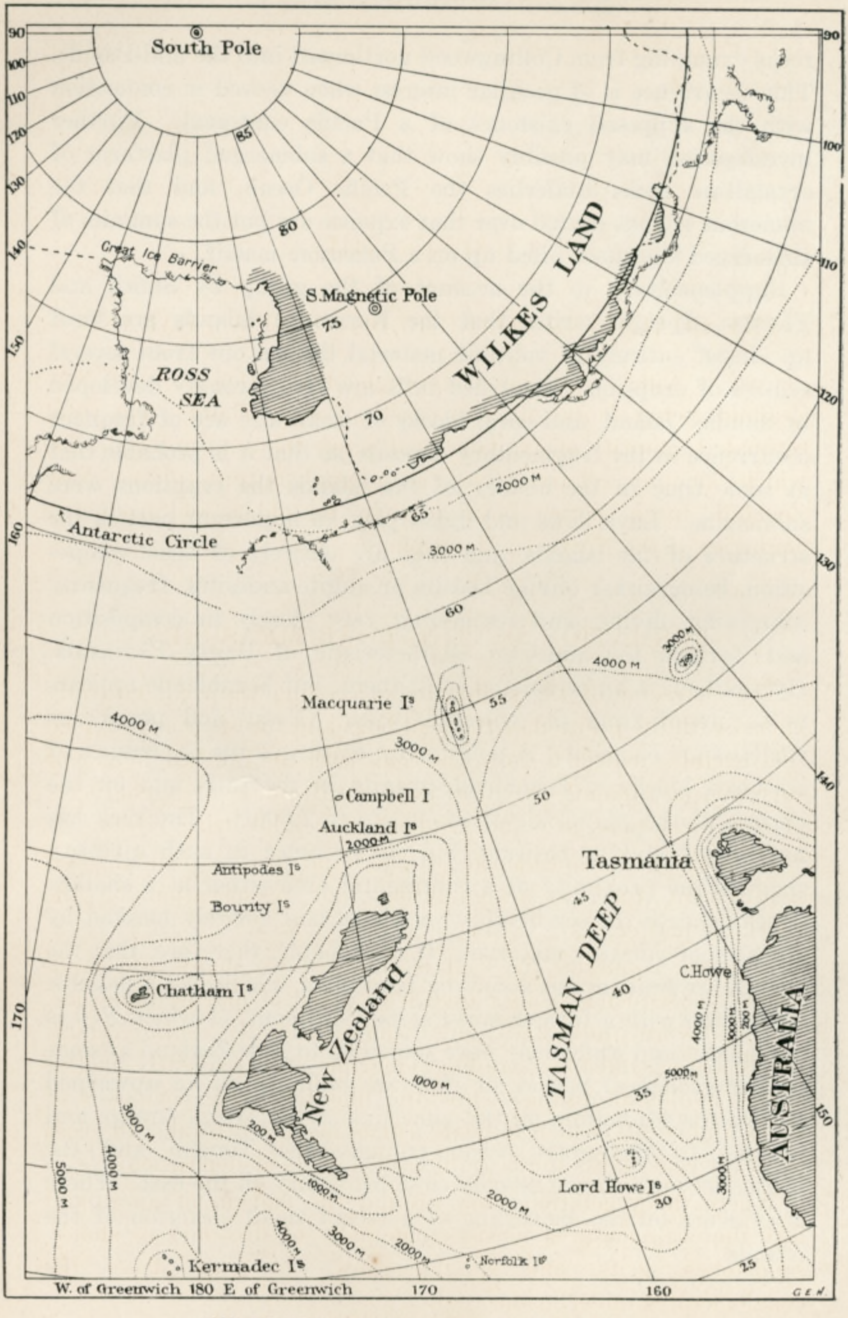
g. S. Percy Smith, *loc. cit.*, p. 28.
h. A. P. W. Thomas, Trans. N.Z. Inst., vol. xx., p. 311.
i. R. Speight, Trans. N.Z. Inst., vol. xxviii., p. 623.

rocks extending from Collingwood northward into the mid-Pacific. This occurrence is of peculiar interest when viewed in connection with the supposed existence of a Pacific continent. Further investigation may possibly show that a submerged platform of crystalline rocks underlies the Pacific Ocean, and that the numerous islands dotted over that expanse are but the summits of submerged volcanoes piled up on a Palæozoic massif.

Supplementary to the account of the group by Smith and Thomas, Speight writes that the Kermadec Islands are built up almost entirely of volcanic material thrown out from several centres of eruption. Stratified tuffs are very strongly developed in Sunday Island, and coral blocks of small size are of frequent occurrence in the fragmentary deposits, so that it is probable that at some time in the history of the islands the eruptions were submarine. Lava flows and dykes play an important part in the structure of the islands, and they are entirely of basic composition, being either olivine basalts or augite-andesites, frequently containing olivine, and resembling very closely in composition and texture the andesites characteristic of Banks Peninsula. Hypersthene is an occasional constituent, but hornblende appears to be absent from the volcanic rocks. Glassy and pumiceous varieties are common. A noteworthy feature is the occurrence of scattered blocks of hornblende-granite in the tuffs and on the surface of the island, at elevations up to 1,600ft. The rock has not been found in position, but its presence in such quantity suggests the proximity of a continental area either at a shallow depth beneath the sea or above sea-level and entirely masked by a veneer of volcanic material. It is probable, therefore, that the islands are built up on a sinking land mass, which had a possible connection with a former mid-Pacific Continent, of which Fiji is a remnant, and which may have joined on to New Zealand at some former geological period, or they are built up on an upwarped fold of the sea-bottom on the same line as the Tonga Group, and parallel to the great ocean troughs—the Tongan and the Kermadec—which are in such close proximity on the east. There is evidence on the shore line of a recent small elevation of the islands.



MAP OF NEW ZEALAND AND THE ANTARCTIC.

CHAPTER XIII.

THE COALS AND COALFIELDS OF NEW ZEALAND.

Coal is widely distributed throughout the Dominion of New Zealand, being found on both coasts of each island. The total estimated quantity of available coal is one thousand million tons, which amount relatively to the annual output places New Zealand in a better position than the older coal-producing countries of the Northern Hemisphere.

FORMATION OF THE COAL MEASURES.

The character of the sediments succeeding the coal naturally varied with the position of the peat-bogs and forests that provided the vegetable matter to form the coal, with the rainfall, height of surrounding uplands, extent of adjacent drainage area, character of rock-formations, size and gradient of neighbouring rivers.

In every case subsidence of the land was a fundamental requirement for the accumulation and preservation of the vegetable matter.

In many countries the coal is followed by shales and sandstones, the sequence being closed with a bed of marine limestone. The shales are indurated muds, which generally contain plant-remains; the sandstones are fluvio-marine, and frequently enclose a rich molluscan fauna; while the limestones are composed of shells and corals, which indicate a true marine littoral. In these cases the coal marks the beginning of a cycle of deposition.

Where the vegetation grew around the margin of an inland lake the coal-measures consist principally of fire-clays or shales, sandstones, grits, and conglomerates. In most places the conglomerates underlie the coal.

The coal-vegetation, as we find, grew mainly on estuarine flats, maritime and lacustrine plains. It was obviously in such situations that vegetable matter could most easily accumulate to such a depth as to form potential seams of coal. The adjacent uplands would be areas of denudation on the fringe of which the newly-formed coal measures would rest unconformably.

It is not improbable that similar vegetation flourished on the adjacent foothills that possessed gently undulating surfaces. But, judging from our knowledge of similar situations in present-day forests, it is unlikely that the growth there could ever become as rank and luxurious as on the flat, marshy lands nearer the sea.

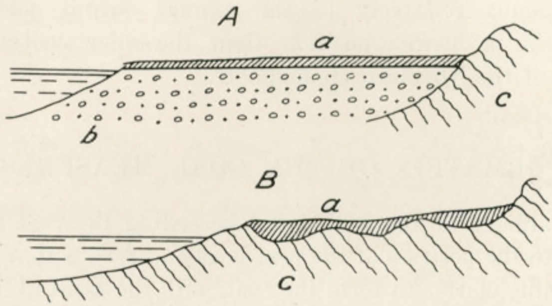


Fig. 112. Coal-vegetation accumulating—A, on detrital flat; B, on undulating shore line.

a. Coal-vegetation. *b*. Estuarine or littoral detritus. *c*. Basement rock.

On such undulating surfaces the decomposing vegetable matter would tend to slide into the hollows, where it would accumulate. It is conceivable that in some situations the depressions might thus in time become filled up so as to present a continuous surface of considerable extent.

From these premises we are able to postulate that the superficial area of a coalfield was mainly determined by the extent of the tundra-land on which the coal-vegetation grew. On the inland side the vegetable matter would thin out against the rising ground of the foothills; and on the seaward side end abruptly at the point where it met the strand of the sea.

Conceivably then the coal was formed (*a*) on low lying tundra-land or estuarine flats; (*b*) on undulating foothills; or (*c*) partly on level land and partly on the adjacent foothills.

A coal seam formed on estuarine plains would be more uniform in thickness than coal formed on undulating ground; and whereas the former would be underlain by a considerable thickness of detrital material, the latter would rest close to the basement rock of the undulating ground on which the vegetation grew.

Coal-seams which rest close to the basement rock are always the most subject to irregularities in thickness. This is a very noticeable feature of the Auckland coalfields of New Zealand, where the seams of brown coal conform to the contour of the basement rock. The result of this conformity is that the coal thins where the basement rock rises in ridges, and thickens in the hollows. In the depressions the seam is sometimes 60ft. thick, and on the ridges only a few feet.

The thickening and thinning of the seam does not necessarily imply that the coal is detrital, for it is manifest that the wet, peaty mass of vegetable matter, from which the coal was formed, like a moving bog, would slowly gravitate towards the depressions in the land surface on which the vegetation grew.

Coals formed on detrital plains were obviously composed of vegetable matter that grew on the site of the seam; while seams lying on, or near, the basement rock, although mainly composed of vegetable organisms that grew in place may be, to a small extent detrital.

It is not inconceivable that a moving peat bog, growing on the shore of a lake might in time fill up considerable hollows, or even creep into the lake where, becoming water-logged, it would accumulate on the floor. When protected from destruction by covering sediments such peaty matter would in time become converted into coal. Seams formed in this way would necessarily exhibit great variability in thickness.

Marginal Occurrence of Coal.

At the close of the Cretaceous period New Zealand presented the appearance of a main axial chain flanked by subsidiary ranges throwing out branching ridges that jutted into the sea.

The coastline was extensive and deeply indented; and, being narrow, offered only a small catchment area for drainage except in the Nelson block of mountains, now drained by the Grey and Buller rivers.

Wide swampy maritime plains for the growth and accumulation of coal vegetation did not exist. Vegetation could not accumulate on the steep hill-sides, and the only places where it could grow undisturbed were the river-flats bordering sheltered bays, and marshy estuaries reclaimed from the sea by large rivers.

In the coalfields of Auckland, Canterbury, Otago, and Southland the coal seams lie close to the basement rock, the thickness of detrital gravel, sand, and clays underlying the coal seldom exceeding 60ft. or 80ft. But on the West Coast of Nelson, where the Cretaceous slopes facing the sea were comparatively steep, the fluviatile material, composing the coastal plains reclaimed from the sea, and on which the coal vegetation established itself, is frequently over a thousand feet thick.

The Lower Tertiary and Cretaceous coal-measures are the most important, the former containing over 80 per cent. of the available coal in the Dominion, occurring in two horizons known as the Oamaru brown coal-measures and the Waimangaroa or bituminous coal-measures respectively.

The age and stratigraphical position of the Kawakawa, Hikurangi, and Ngunguru coals in the North Auckland district has for long been a matter of dispute. By some writers these coals are believed to belong to the Oamaru Series, by others to the Waipara Series. Those who hold the last view contend that they underlie the hydraulic limestone and saurian greensands as developed in the Kaipara and Whangarei districts, while those who oppose this view argue that they overlie the hydraulic limestone and associated beds unconformably, and hence belong to the Oamaruian coal formations at the base of which lie the Drury and Waikato brown coals.

The problem is not an easy one to solve on account of sectional obscurity. Both formations are present in a region that is deeply dissected by numerous ramifying inlets of the sea on both coasts; dislocated by faults and igneous intrusions; and obscured by volcanic ejecta and a heavy overburden of clay and other surface detritus.

Up till the year 1904 the writer referred the North Auckland coals to the Oamaru Series, believing them to be of the same age as the Waikato coals; but a re-examination of the field-sections in the Kaipara, Whangarei, and Waikato districts, and of the more recent evidence disclosed in the coal mines, has led to a modification of that view. The Kawakawa, Hikurangi, and Ngunguru coal-measures are now assigned to the Waipara formation.

Sir James Hector and his staff always maintained that the North Auckland and Waikato coals underlaid the hydraulic limestone, referring them to what was then termed the "Cretaceo-tertiary Series." It has been elsewhere[j] shown that the so-called Cretaceo-tertiary formation had no existence, but in reality consisted of two distinct formations, namely the Oamaru Series of Tertiary date, and the Waipara Series of Cretaceous age.

The author thinks that Hector, Cox, and McKay were right in placing the Kawakawa and Whangarei coal below the hydraulic limestone, but wrong in referring the Waikato brown coals to the same position.

The North Auckland coals underlie the Whangarei limestone; and the Waikato coals, the Waikato (Raglan) limestone. And the confusion, it is found, arose through the erroneous correlation of the Whangarei and Waikato limestones. The Waikato limestone is mainly a calcareous sandstone, or freestone, containing *Pseudamussium Huttoni*, *Cirsotrema lyrata*, and *Meoma Crawfordi*, while the Whangarei limestone is a compact crystalline, or semi-crystalline, limestone containing numerous *Cidaris* spines, echinoderm plates, and fish teeth, but none of the characteristic fossils of the Oamaruian Raglan Stone.

The confusion of the stratigraphical succession in Auckland was exactly on all fours with that caused by the erroneous correlation of the Oamaru Stone with the Weka Pass Stone in North Canterbury.

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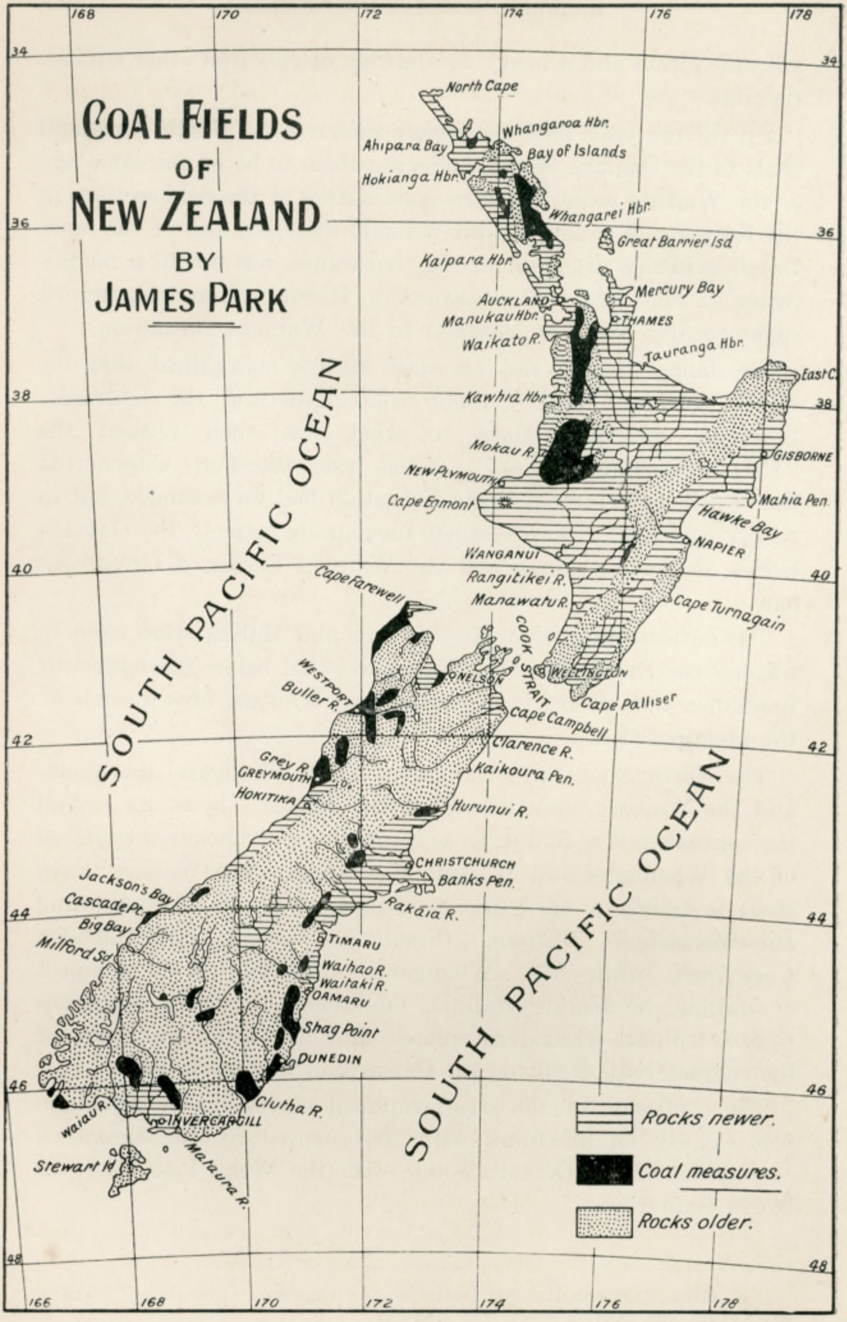
j. J. Park, "On the Marine Tertiaries of Otago and Canterbury," Trans. N.Z. Inst., vol xxxvii., 1904, pp. 489-551.



COAL FIELDS OF NEW ZEALAND BY JAMES PARK
SOUTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
North Cape
Whangaroa Hbr.
Ahipara Bay
Bay of Islands
Hokianga Hbr.
Whangarei Hbr.
Great Barrier Isd
Kaipara Hbr.
Mercury Bay
AUCKLAND
Manukau Hbr.
THAMES
Waikato R.
Tauranga Hbr.
East C.
Kawhia Hbr.
Mokau R.
GISBORNE
NEW PLYMOUTH
Cape Egmont
Mahia Pen.
Hawke Bay
NAPIER
WANGANUI
Rangitikei R.
Manawatu R.
Cape Turnagain
Cape Farewell
COOK STRAIT
NELSON
WELLINGTON
WESTPORT
Buller R.
Cape Palliser
Cape Campbell
Clarence R.
Grey R.
GREYMOUTH
Kaikoura Pen.
HOKITIKA
Hurunui R.
CHRISTCHURCH
Banks Pen.
Jackson's Bay
Cascade Pt.
Rakaia R.
Big Bay
Milford Sd.
TIMARU
Waihao R.
Waitaki R.
OAMARU
Shag Point
DUNEDIN
Clutha R.
Waiau R.
INVERCARGILL
Stewart Id.
Mataura R.
Rocks newer.
Coal measures.
Rocks older.

CLASSIFICATION OF THE COAL.

As the result of a large number of analyses made in the Colonial Laboratory, Sir James Hector in 1872, classified the coals of New Zealand as follows:—

I. *Hydrous* (coal containing from 6 to 20 per cent. of permanent water)—
- (*a.*) Lignite.
- (*b.*) Brown coal.
- (*c.*) Pitch-coal.

II. *Anhydrous* (coal containing less than 6 per cent. of water)—
- (*a.*) Glance-coal.
- (*b.*) Semi-bituminous coal.
- (*c.*) Bituminous coal.

The workable coals come under four principal divisions, namely:—

1. Lignite.
2. Brown coal.
3. Pitch coal.
4. Bituminous coal.

The geographical distribution of these varieties is singularly well defined, the lignites being mainly developed in Southland and in the old lake-basins of Central Otago; the brown coals, in Otago and Waikato Basin; the pitch coals, in Mokau and North Auckland; and the bituminous coals, in the West Coast of Nelson and Westland.

COMPOSITION OF COALS.

Brown Coal.—Coal of this class largely predominates, forming more than half of the available coal in the Dominion. Its greatest development is in the Drury, Huntly, Taupiri, Waipa, and Hikurangi districts of the Waikato Basin; in the Green Island, Saddle Hill, and Kaitangata coalfields of Otago; and Nightcap district of Southland.

The Mokau coal lies under a heavier cover of sandstone than the Waipa and Waikato coals. It is a superior brown coal, commonly classed as a pitch-coal.

The average composition of the brown coals of New Zealand is as follows:—

			Extremes.
Hydro-carbons	...	37.93	35.00 50.00
Fixed carbon...	...	41.92	37.00 51.00
Water ...	...	14.07	11.00 20.00
Ash ...	...	5.34	2.00 13.00

The average sulphur content is about 2.5 per cent. Some of the brown coals contain as little as 0.3 per cent. of sulphur, and others as high as 4 or 5 per cent.

Pitch-coal.—The pitch-coals are bright and friable, and do not coke, but form a friable *breeze* when burnt in a retort. In the North Island they include the Kawakawa, Whangarei, Hikurangi, Ngunguru, and other coals of North Auckland, and the Mokau coals. The Kawakawa coal is superior to most pitch-coals. It lies on the borderland of the semi-bituminous, and is sometimes classed as a glance-coal.

In the South Island, the coals of this class are often met with in a higher horizon than the bituminous coals. They are abundant in the Inangahua Valley and West Wanganui coalfields.

The average composition of the pitch-coals from the Wangarei coalfields and West Coast of the South Island is shown below:—

	Whangarei.	*Extremes.*	**West Coast, S.I.**	*Extremes.*
Hydro-carbons ...	41.13	38.00 46.00	38.29	30.00 39.00
Fixed Carbons ...	46.42	43.00 49.00	46.61	40.00 60.00
Water	7.45	6.00 9.00	7.61	4.80 9.20
Ash	5.00	3.00 8.00	7.47	0.50 12.00

The average sulphur content of these coals is generally high, some of the Kawakawa coals containing as much as 5.10 per cent.

Bituminous Coal.—This is found at Collingwood and Pakawau; and on the West Coast of Nelson, from the Mokihinui southward to Greymouth. The chief ports of shipment are Westport and Greymouth.

The average composition of the Westport and Greymouth coals is as follows:—

	Westport.	Greymouth.
Fixed carbon	31.88	38.73
Hydro-carbons	63.81	53.25
Water	3.08	1.48
Ash	1.23	6.54
	100.00	100.00
Sulphur	1.2%	0.03 to 1.85%

The Westport coal is extensively used for steam, household, gas, and smithy purposes. The Greymouth coal, besides being used for general purposes, is largely used in the manufacture of coke.

Semi-anthracitic Coals.—The coals now being developed in the Paparoa Range occur in a lower horizon than the Brunner coals, the analysis of which is quoted above. They contain a higher carbon content than any other coal in New Zealand, and approach in composition the valuable smokeless Welsh coals of Britain.

Analysis (Dr. J. S. Maclaurin).

Fixed carbon	79.52
Volatile hydrocarbons	15.69
Water	0.74
Ash	4.05
	100.00
Total sulphur	0.42
Calories, per gram	8.398
British thermal units	15.050
Evaporative power, per lb.	15.60lbs.

THE AMOUNT OF WORKABLE COAL.

In preparing the following estimate of workable coal, the lignites have not been included, nor coals of any kind where the thickness of the seam is less than two feet. Seams under two feet thick will no doubt be of great importance when the larger seams become exhausted. Until then they will have no market value.

BITUMINOUS COAL—TABLE NO. 1.

Name of Coalfield.	Author of Survey or Estimate.	Coal in Tons.
Grey	James Hector	37,500,000.
Paparoa	Computed	70,000,000.
Buller	S. Herbert Cox ...	140,000,000.
Mokihinui	James Hector	3,000,000.
Collingwood	S. Herbert Cox ...	1,500,000.
Pakawau	,, ...	2,500,000.
	Total ...	254,500,000.

PITCH COAL—TABLE NO. 2.

Name of Coalfield.	Author of Survey or Estimate.	Coal in Tons.
Kawakawa	James Hector	2,500,000.
Whangarei-Hikurangi ...	S. Herbert Cox ...	20,000,000.
Waipu	,, ...	5,000,000.
Mangawai	,, ...	6,000,000.
Te Kuiti	James Park	5,500,000.
Mokau-Awakino	,, ...	110,000,000.
Upper Wanganui	,, ...	50,000,000.
West Wanganui	,, ...	25,200,000.
Tadmor and Hope	,, ...	10,000,000.
Owen	,, ...	2,500,000.
Inangahua	A. McKay *jj*	50,000,000.
Maruia	S. Herbert Cox ...	20,000,000.
	Total ...	306,700,000.

jj Computed from Survey by McKay.

BROWN COAL—TABLE NO. 3.

Name of Coalfield.	Author of Survey or Estimate.	Coal in Tons.
Lower Waikato	F. W. Hutton ...	140,000,000.
Drury	S. Herbert Cox ...	8,000,000.
Waipa	James Park	10,000,000.
Kawhia	A. McKay	4,000,000.
Waitakururu	James Park	2,000,000.
West Wanganui	,, ...	12,600,000.
Malvern Hills	A. B. Lindop [k] ...	17,089,000.
Kakahu	James Park	3,500,000.
Oamaru, Waitaki	A. McKay	2,000,000.
Shag Point	Julius Von Haast ...	1,000,000.
Green Island and Saddle Hill	J. Denniston	74,700,000.
Kaitangata, Clutha ...	James Hector	140,000,000.
Wairaki (Night-Cap) ...	F. W. Hutton ...	100,000,000.
Orepuki	,, ...	5,000,000.
Forest Hill	James Park	1,000,000.
	Total ...	520,889,000.

[k] The altered brown coals are included in this estimate.

TOTAL AMOUNT OF COAL—TABLE NO. 4.

Bituminous coal	254,000,000
Pitch-coal	306,700,000
Brown coal	520,889,000
Total	1,082,089,000

After making the necessary deductions for losses due to faults, disturbances, and mining, the total quantity of available coal may be set down at a thousand million tons.

Until detailed geological surveys are made the above figures must only be looked upon as approximate, but in most cases they will be found to be over, rather than under, the actual amount available.

Much of the coal is water-free, and only such seams as are workable at the present time have been included in these returns.

In addition to coalfields mentioned in the above tables, small patches of coal-bearing measures occur at Takaka, Baton, Karamea, and Lyell Mountains in Nelson; at Waipara, in Canterbury; at Preservation Inlet, in Otago, and other places which will be described further on.

Annual Output of Coal.

The output of all classes of coal in the year 1878 amounted to only 162,218 tons. In the three succeeding years there was a wonderful development of the coal-mining industry, the production of 1878 doubling itself in 1881, amounting in that year to 337,262 tons.

The phenomenal annual rate of increase from 1878 to 1881 was not maintained, a decade passing before the output of 1881 was doubled. The production of 1891 amounted to 668,794 tons.

In another decade, that is in 1901, the output again doubled itself, in that year amounting to 1,239,686 tons.

The output of 1909, the last year for which statistics are available was 1,911,247 tons, showing an increase of 671,561 tons in eight years, which means that at the end of the third decade the output will again have doubled itself. That is in the year 1911, the output, barring some unforeseen happening, should amount to some 2,500,000 tons.

Duration of the Coal.

The latest, and highest recorded output—that of 1907, amounting to nearly 2,000,000 tons, bears but a small proportion to the estimated total quantity of coal in the Dominion, which in fact contains the former 500 times. But a little consideration will show that it would be absurd to speak as if we had enough coal to last 500 years since the present rate of consumption is not a fixed but a growing rate.

In New Zealand the coal mining industry is still in its infancy, and it is in consequence impossible at the present stage of its development to determine whether the annual rate of increase is geometrical or arithmetical.

It is obvious that the output is governed by two causes, namely, the natural increase of population and the growth of capital applied to the development and extension of manufactures and shipping.

Starting from the actual output in 1887, the author computed in 1888, that the output at intervals of ten years up to 1957 would be as follows[l]—assuming that the yearly increment continued uniform with the average yearly increase for the seven years from 1880 to 1887:—

		Tons.
1887	(actual output)	558,620
1897	(computed output)	910,000
1907	" "	1,471,500
1917	" "	2,397,000
1927	" "	3,905,000
1937	" "	6,503,000
1947	" "	10,593,000
1957	" "	17,250,000

Only twenty-two years have passed since 1888, which is too short a period to test the value of the premises used in these computations; but comparing the actual with the computed output for the two decennial periods that have passed since 1887, we get the following interesting figures:—

	Actual Output.	*Computed Output.*
	Tons.	Tons.
1897	840,713	910,000
1907	1,831,009	1,471,500

The decades of 1881-1891 and 1891-1901 each witnessed a two-fold increase; and although the decade 1901-1911 bids fair to show a like result, it seems probable that in the following years the computed output will more closely approximate the actual. If we assume this to be the case we arrive at the conclusion that in 1957—that is 48 years hence—the output will be eight or ten times its present amount. At that date something like a third of the coal existing in both islands will have been consumed, and this third will represent the most accessible, most easily-worked, and most valuable of our coal. The output in the year 1968 will have reached 20,000,000 tons, if the increase of the past three decades is maintained; but it is not improbable that

l. J. Park, "On the Extent and Duration of the Workable Coal in New Zealand," Trans. N.Z. Inst., vol. xxi., 1888, p. 325-331.

the maximum output will fall considerably short of that comparatively large amount.

If the maximum output were maintained for twenty years the date of exhaustion would fall within the present century, but we know that this will not be the case. When the high-water mark of production is reached the output will gradually diminish through a long succession of years until the inevitable exhaustion takes place.

Assuming that the rate of increase indicated by the past decade continues in the immediate future, the choicest and most available half of our coal will have been consumed in 1970, the total estimated output up to that date amounting to 400,000,000 tons. In that year the output would be 10,000,000 tons, and assuming that at this point the maximum output is reached and that a geometrical decrease backwards commences from that year, the date of exhaustion would be somewhere about the year 2050—that is 140 years from the present time.

Steam is the great motive power of the centuries; and though in a country so bountifully supplied with water-power as New Zealand, it is certain to be largely displaced by hydro-electric energy in the great manufacturing industries, it seems destined to hold its own as the propelling energy of the mercantile marine, in which the Dominion must ever be dependent for the interchange of commodities with the outside world.

The complement of a large mercantile marine is a strong navy, and a strong navy can only be maintained by the nation that possesses an abundant supply of bituminous coal. The bituminous coals of the West Coast amount to not much more than a fifth of the total quantity of coal known to exist in New Zealand. Next to our water-power, coal is the most valuable asset we possess, and for that reason it should be conserved in the public interest, so far as this can be done consistent with economic exigency.

As, therefore, the inevitable must come, whether in 90 years or 140 years, it is necessary that our coal-deposits should be worked with scientific skill and economy. Prodigal waste should be prohibited by law; and considerable areas of proved coal-bearing measures reserved for the future use of the navy that is certain to grow up for the protection of our shores and oversea trade.

Excluded from the estimate of a thousand million tons of coal are vast quantities of lignite, too low-grade for general use, and often too inaccessible to be profitably mined. Such coals, at some future period will prove of great value for the production of electric energy at the mine for transmission to industrial centres. When the good coals are exhausted, the day of the lignites and inferior brown coals will come.

COAL-FIELDS GROUPED ACCORDING TO AGE.

The more important developed or partially developed coal-areas tabulated according to their age are as follows:—

JURASSIC—*Mataura Series.*

Waikawa, Wyndham, Southland.

UPPER CRETACEOUS—*Waipara Series.*

Shag Point, Otago.
Kaitangata, Otago.
Malvern Hills, Canterbury.
Kawakawa, North Auckland.
Hikurangi, North Auckland.
Ngunguru, North Auckland.

LOWER TERTIARY—*Waimangaroa Series.*

Lower Measures—Upper Eocene.

Grey Valley, West Coast, S.I.
Paparoa Range, West Coast, S.I.
Westport, West Coast, S.I.
Mokihinui, West Coast, S.I.
Pakawau, Collingwood, S.I.

Upper Measures—Oamaru Series, Miocene—

Taupiri-Huntly, Waikato Basin.
Waipa-Hikurangi, Waikato Basin.
Mokau and Upper Wanganui.
West Wanganui, Nelson.
Inangahua Valley, Nelson.
Mount Somers, Canterbury.
Kakahu, Canterbury.

Waihao, Canterbury.
Ngapara, Otago.
Waikouaiti, Otago.
Green Island-Saddle Hill, Otago.
Forest Hill, Southland.
Nightcap, Southland.

DESCRIPTION OF COALFIELDS.

Jurassic Coal.

Mataura Series.

Bituminous coal belonging to the Mataura Series of Jurassic age occurs in many places between the Hokonui Hills and Catlin's River, but nowhere has a seam of profitable thickness been discovered. Such may, however, exist, although it must be recognised that with each succeeding year the probability of its existence is rapidly diminishing.

Thin seams of coal are known to occur in the valley of the Otapiri; in the district lying west of Makarewa; at Seaward Downs; at Toi-toi, near the mouth of the Mataura River; at Waikawa Harbour; and at Catlin's River.

There are generally two or more seams present at each place, but so far no seam has been found exceeding twelve inches of clean bright coal.

At Waikawa Harbour there are four seams ranging from four to eight inches thick. The coal-measures here, as elsewhere in the Mataura formation, consist of alternating conglomerates, sandstones, and shales, the latter containing numerous well-preserved examples of *Pecopteris grandis,* and *Macrotaeniopteris lata.*

Upper Cretaceous Coal.

Waipara Series.

The brown coals at Kaitangata, Shag Point, and Malvern Hills, as well as the pitch coals at Whangarei and Kawakawa belong to this period, occurring in coal-measures that lie at the base of Waipara Series. At all places the coal is conformably overlain by beds that contain Secondary fossils, among which are *Conchothyra parasitica* (McCoy), and saurian remains.

A seam of brown coal occurs near the base of the Waipara Series in the Waipara district, but it has proved too small and impure to be profitably worked.

Shag Point Coalfield.

The succession of coal-bearing strata at this place is as follows:—

1. Shales, clays, and sandstones with calcareous concretions, 150ft.
2. Brown sandstones with beds of quartzose gritstone, and conglomerate. The sandstones contain *Conchothyra parasitica*, etc., 250ft.
3. Sandstones, loose grits and gritstone, grey shales, and seams of brown coal, 300ft.
4. Quartzose conglomerate in lower portion containing numerous angular fragments of mica-schist, 1,500ft.

The conglomerates lie unconformably on the semi-metamorphic mica-schists of the Kakanuian, on which they are tilted at high angles. Their upper horizon forms the summit of Puke-iwi-tahi, on which stands the memorial cairn to the late Sir John Mackenzie.

Between this hill and the end of Shag Point Peninsula the beds form first a sharp syncline and then a flat anticline, the general arrangement of the beds being shown in the following figure:—

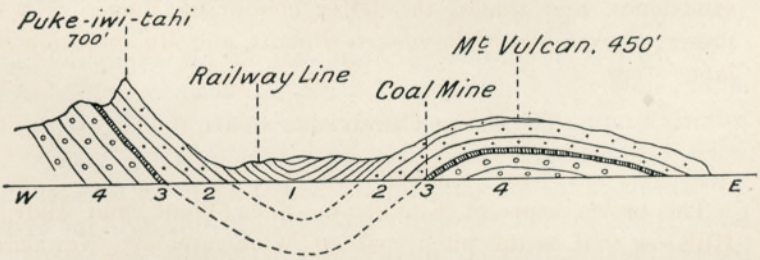


Fig. 113. Section across Shag Point Coalfield.

1. Shaly clays and sandstones with concretions. 2. Brown sandstones alternating with gritstones and conglomerates. 3. Sandstones, gritstones and loose grits with shales and coalseams. 4. Conglomerates, mainly quartzose, passing into breccia at base.

The total thickness of the series is about 2,200ft., of which the Horse Range conglomerates comprise about 1,500ft.

The Shag Point Coalfield contains seven seams of coal, most of which are thin. The seam worked in the old Shag Point Colliery at Vulcan Point varied from 7ft. to 10ft. thick, and was underlain by a 4ft. seam, from which it was separated by 4ft. of shale.

The Allandale Colliery, adjoining the old Shag Point area, is now the only mine carrying on active mining operations. It is working on three seams that vary from 4ft. to 6ft. thick.

This coal is one of the best of our brown coals, a result due to the compact sandstone roof which covers it. The average composition[m] is as follows:—

Fixed carbons	43.15
Hydro-carbons	33.70
Water	16.57
Ash	6.58
	100.00
Sulphur	2.10 to 4.20%

This coal, like that at Green Island, occasionally contains small rounded pebbles of quartz imbedded in it.

Malvern Hills Coalfield.

This coalfield consists of a number of isolated areas extending from the Rakaia River northward to the Upper Waimakariri Valley.

The coal is an ordinary brown coal in places altered into anthracite by the intrusion of sheets of dolerite in the coal-bearing strata. The main seam varies from 3ft. to 7.5ft. thick.

The coal-measures occur at heights varying from 1,000ft. to 3,100ft. above the sea; and for the most part lie in folds of the lower Mesozoic shales and greywacke, which constitute the great mass of the subsidiary mountain ranges in Canterbury. At Mount Misery they rest against ancient quartz-porphyries and rhyolites that are associated with the Mesozoic rocks.

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m. "Geology of Otago," 1875, p. 103.

The chief coal-bearing area lies along the flank of the foothills fronting the Canterbury Plains, stretching in a broad band from the upper part of the Hororata Valley to the Hawkins River, crossing the Selwyn Valley behind the Harper Hills.

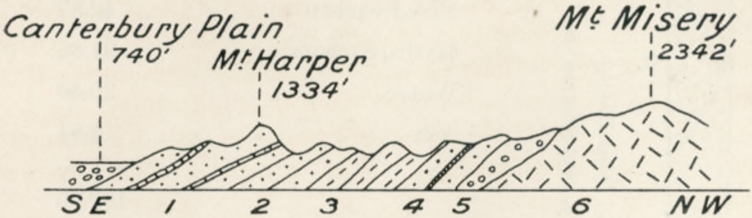

Fig. 114. Section from Mount Misery to the Canterbury Plains. (After Haast.)
1. Quartzose sands intercalated with sheets of dolerite. 2. Quartzose sands.
3. Sandstones, fossiliferous. 4. Sands and shales with seams of brown coal.
5. Porphyry conglomerate. 6. Ancient Rhyolite.

The coal-bearing series in the Malvern district belongs to the Waipara formation. The general succession of the rocks as seen along the eastern portion of the Malvern Hills, where they form a more or less continuous band sloping towards the Canterbury Plains, is as follows:—

1. Quartzose sands in places intercalated with sheets of dolerite.
2. Glauconitic greensands with layers of calcareous and micaceous sandstone containing fossils in great abundance.
3. Sandstones, calcareous and shelly, containing a large black oyster, *Conchothyra parasitica, Cucullæa, Aporrhais,* other molluscs, and saurian remains.
4. Grey quartzose sands, in places glauconitic.
5. Sands and shales, with seams of brown coal.
6. Conglomerate (rhyolitic) with layers of limonitic sandstone containing impressions of dicotyledinous leaves. Rests on basement rock.

The coal measures are a good deal disturbed by faulting of the strata; and in some places they have been intruded and tilted by sheets of basalt and dolerite. In these places the igneous heat has altered the coal to anthracite and semi-anthracite, but the amount of coal so altered is unimportant.

The average of thirteen analyses of the ordinary brown coals of this field give the following results:—

Fig. 115. Section along the west bank of Acheron River. Distance 2¾ miles. (After Haast.)
a. River shingle of Canterbury Plains. *b.* Sheets and dykes of dolerite. *c.* Coal measures. *d.* Sandstones and clays with concretions. *e.* Mesozoic slaty shales and Sandstones.

Fixed carbon	42.87
Hydro-carbons ..	31.89
Water	20.40
Ash	4.84
	100.00
Sulphur	2.10 to 3.60%

When the coal-measures are overlain by dolerite, the coal has become dehydrated, and has lost practically all the hydro-carbons, little being left except the fixed carbon and ash, as the accompanying comparative analysis[n] will show:—

	Average of four Samples of Ordinary Brown Coal.	Anthracite from Lake Coleridge.
Fixed carbon ..	43.28	84.12
Hydro-carbons	38.35	1.96
Water ..	15.68	1.80
Ash	2.69	12.12
	100.00	100.00

In extreme cases of alteration the roof coal has been changed into impure graphite, and the clay under the coal baked into porcellanite.

n. N.Z. Mining Handbook, p. 385.

The upper and lower portions of the same seam often vary considerably in quality. As an example of this Professor Cox quotes the following analyses of coal from the top and bottom of the Springfield[o] 4.5ft. seam:—

	Top of Seam.	Bottom of Seam.
Fixed carbon	63.2	47.9
Hydro-carbon	23.6	41.8
Water	3.2	6.3
Ash	10.0	4.0
	100.0	100.0

The principal colliery is the Homebush Mine, situated at Glentunnel, in the South Malvern district, where a good seam from 6ft. to 7ft. thick has been worked continuously since 1873. Other mines in the Malvern district are situated at Sheffield, White Cliffs, and Springfield, the coal at the latter being chiefly worked in connection with the underlying fireclays, which are sent by rail to Christchurch for manufacture.

North Auckland Coalfields.

Coal-bearing rocks of Cretaceous age extend over a large portion of the Bay of Islands and Hokianga Counties, and occupy considerable areas within Whangarei and Hobson Counties.

Workable coal has only been discovered at a few places, notably at Kawakawa, Kamo, Hikurangi, and Ngunguru. Seams of coal crop out at Hukerenui, Mangakahia Valley, and east of Kamo, but the seams are either too thin, or so situated as to be unprofitable to work at the present time. The position of the North Auckland coal-industry is far from satisfactory; and in view of the apparent exhaustion of the coal at Kawakawa and Kamo, prospecting in areas known to contain the coal-measures should be energetically prosecuted.

o. S. Herbert Cox, Trans N.Z. Inst., vol. xv., p. 368.

The succession of the coal-bearing formation, which belongs to the Waipara formation, is given below, reading downwards:—

1. Chalky clays with flint beds.
2. Hydraulic limestone.
3. Glauconitic greensands, sometimes with concretions covered with a skin of cone-in-cone limestone, and containing saurian remains. Sometimes passes into a thick flaky fucoidal calcareous sandstone or impure limestone.
4. Whangarei limestone, 200ft. to 245ft. thick.
5. Compact marly bluish-green sandstone, with marine fossils forming the roof of coal.
6. Gritty sandstones and conglomerates, with two seams of coal.

The succession of strata as seen in the section from Colbeck's to McMurdo's, at Pahi, Kaipara, is very complete and instructive. Here we have:—

1. Hydraulic limestone, thickness not seen.
2. Blue clays and marly greensands, with marine fossils, interbedded with three flaggy limestone bands in the upper part.
3. Hydraulic limestone, 80ft.
4. Flaggy limestone, 20ft.
5. Hydraulic limestone, 60ft.
6. Marly grenstones, with flints.
7. White siliceous limestone.
8. Hard calcareous greensands.
9. Marly greenstones.
10. Hard flaggy limestone.
11. Marly greensands with fossils.
12. Basement rock of shaly clays.

Kawakawa Coalfield.

This small coal-basin lies to the south-west of the upper arm of the Bay of Islands Harbour. In the eighties it possessed one of the most enterprising collieries in New Zealand, alone producing a seventh of the total coal production of the colony. All attempts to trace the coal into the adjoining lands having failed the output gradually declined, until, in 1900, the field became practically abandoned.

The section of the coal-measures exposed in sinking the pumping shaft at the old mine was as follows:—

	ft.	in.
Upper coal seam	4	3
Hard sandstone	7	0
Lower coal seam	5	9
Clay parting	0	4
Coal	2	9

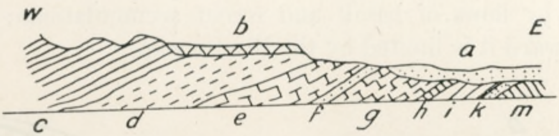

Fig. 116. Section across Kawakawa Coalfield. (After McKay.)

a. Superficial gravels and clays. *b*. Basanite. *c*. Marly clays. *d*. Upper greensands. *e*. Hydraulic limestone. *f*. Shale with flints. *g*. White limestone. *h*. Calcareous sandstone. *i*. Hard greensand with marine fossils. *k*. Fireclay with coal. *m*. Lower Mesozoic slaty shales.

A hard blue sandstone, containing marine shells, forms the roof of the upper seam. The sandstone parting under the upper seam widens out towards the dip, and at about a hundred feet from the shaft is fully 14ft. thick. At this point the upper seam has dwindled down to 1ft. 10in. The lower seam, which is here somewhat shaly, is 4ft. thick.

In the direction of the old workings, in No. 7, and eastward of the new dip, the coal is greatly disturbed, and sometimes the upper and sometimes the lower seam has thinned. The coal shows a tendency to improve towards the big swamp.

The coal varies considerably in physical character, being in places very hard, in others quite soft. The composition is fairly uniform throughout, the coal being a superior pitch, or glance coal. It is the best steam coal in the North Island, and when available was always in demand for ocean-going steamers.

Average Composition.

Fixed carbon	55.59
Hydro-carbons	38.10
Water	4.19
Ash	2.12
	100.00
Sulphur	2.8 to 4.5%

Hikurangi Coalfield.

This coalfield lies from thirteen to seventeen miles from Whangarei, and is separated from the Kamo coal-basin by a ridge of lower Mesozoic rocks.

To the north and north-west the coal-bearing formation is overlain by flows of basalt and recent accumulations; while to the westward it is limited by the Big Swamp.

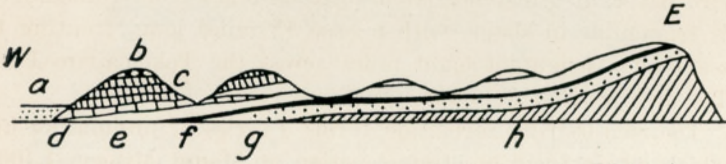

Fig. 117. Section across Hikurangi Coalfield. (After McKay.)

a. Recent alluvium. *b.* Sheet of basalt. *c.* Hydraulic limestone. *d.* Whangarei limestone. *e.* Greensands. *f.* Fireclays and coal. *g.* Sandstones and conglomerates. *h.* Lower Mesozoic shales and greywacke.

The different portions of the field lie from 300ft. to 700ft. above sea-level. The area over which the coal-measures have been traced is about fifteen square miles, but of this extent more than a third is either barren of coal, or is covered with swamp having an insufficient cover to permit the coal to be worked with safety.

The coal-measures so far as known contain only one seam, which varies from 2ft. to 11ft. thick. The coal is of good quality, and is largely used for steam-raising and domestic purposes, for which it is well adapted.

Average Composition.

Fixed carbon	42.70
Hydro-carbons	44.46
Water	5.93
Ash	6.91
	100.00

Ngunguru Coalfield.

This coalfield is situated to the east of Whangarei, lying within the watershed of the Ngunguru River. In the Ngunguru section the seam of coal was thin and much faulted.

In the Kiripaka section the seam has an average thickness of 16ft. of coal, which is hard, bright, and of excellent quality. Boring operations have lately disclosed the existence of a large area of coal-bearing measures to the dip-side of the Ngunguru section.

The port of shipment is Ngunguru Harbour, a shallow tidal estuary a few miles north of Whangarei Harbour.

Kaitangata and Tokomairiro Coalfield.

This coalfield is estimated by Sir James Hector to contain 140,000,000 tons of available coal. It lies along the sea-coast, extending from the Clutha River to a little beyond the Tokomairiro River, at a distance from 40 to 60 miles from Dunedin. It is triangular in shape, with a base 15 miles long, fronting the sea, and a height of eight miles across the Tokomairiro Plain. The area is about 60 square miles.

The coal-bearing formation forms a series of undulating hills which attain their greatest elevation at Mount Misery, 1,100ft. high. In consists of conglomerates, sandstones, and clay shales, with several seams of coal, of which four are workable, giving a total thickness of 38ft.

The seams are fairly uniform in thickness, but a good deal dislocated by faults.

The roof of the coal is often a tough shale. The floor is generally a conglomerate composed of fine material, but in a few places the seams rest on fireclay.

The succession of beds, as exposed on the coast, is as follows:—

1. Sandstone underlain by laminated clays, 60ft.
2. False-bedded sandstone underlain by quartzose gravels, 40ft.
3. Brown coal, 20ft.
4. Quartz-grit and shales alternating, 67ft.
5. Brown coal, 6ft.
6. Shales, grits, and conglomerates, alternating, 100ft.

7. Brown coal, 5ft.
8. Shales, fireclay, and grits, 74ft.
9. Brown coal, 18ft.
10. Shale and fireclay, 4ft.
11. Conglomerate, with stems of trees, 60ft.
12. Brown coal, 2ft.
13. Conglomerate.

A considerable area of workable coal exists between Milton and the sea, but the principal collieries are situated in the Kaitangata end of the coalfield. In the Taratu property the company is working on a good seam, varying from 14ft. to 20ft. thick. At the Kaitangata colliery two seams are being worked, 35ft. and 18ft. thick respectively, the latter occasionally split with clay partings into two seams of 12ft. and 6ft. The annual output of this mine is about 120,000 tons.

The Tokomairiro, Kaitangata, and Taratu coals are superior to the Green Island coals, the average composition showing a higher percentage of fixed carbon and less water.

Average Composition.

Fixed carbon	44.17
Hydro-carbons	38.24
Water	15.42
Ash	2.17
Total	100.00
Sulphur	2 to 3%

The annual output is about 170,000 tons, the bulk of which is used in Dunedin.

Lower Tertiary Bituminous Coals.

Waimangaroa Series.

These are mainly developed in the Grey Valley, on the Paparoa Range, and in the districts lying between Westport, Mokihinui, and Karamea. Small isolated areas occur near Collingwood, and at Pakawau, near Cape Farewell, but with these exceptions all the coal of this class is confined to the West Coast of the provincial district of Nelson.

The bituminous coal-measures consist of a considerable thickness of fairly compact sandstones, shales, and fireclays, lying conformably on a pile of conglomerates that are in places over 2,000ft. thick.

In the Paparoa Range, the Brunner coals are conformably underlain by a series of sandstones and shales, containing many valuable seams of semi-anthracitic coal. The lowest member of the Paparoa coal-measures is a heavy conglomerate.

The Grey coals have a heavier cover than the Westport coals, but do not always, in accordance with Hilt's law, contain less volatile matter than the latter. They are especially valuable for gas and coke manufacture. The Westport coals contain a comparatively high percentage of fixed carbon, and are held in high repute for steam purposes.

Grey Coalfield.

This is one of the most important and valuable coalfields in New Zealand. It extends from the Grey Valley northward to the Ten Mile Creek, and from the sea eastward to Blackball Creek. Altogether it comprises an area of some 75 square miles in a continuous compact block, in which a large proportion of the coal occurs water-free.

The Grey coal-measures are free from igneous intrusions, but are often disturbed and broken by faults, more especially along the floor of the Grey Valley and foothills of the Paparoa Range. The coal-bearing formation to which they belong rises at an angle of 12° in an easterly direction to a height of over 3,000ft. in Mount Davy; and to the westward dips below sea-level under a cover of 1.500ft. of sandstones and shaly clays, that are followed by marly clays, calcareous sandstones, and limestone. It wraps around the south end of the Paparoa Range, on which it forms a thick mantle resting unconformably on older Mesozoic slaty shales and sandstones.

The complete succession of the upper and lower coal-measures is already shown on page 104, and need not be recapitulated here.

The bituminous coal-measures at Brunner and Blackball contain two workable seams. Six or eight seams of semi-anthracite varying from three to twenty-one feet thick are reported to occur on the Paparoa Range.

No. 1 seam in the Paparoa Company's lease varies from 10ft. to 12ft. thick; No. 2 seam is 17ft. thick at the outcrop and 12ft. in the mine; and No. 3 maintains a thickness of 10ft. in the ground opened up.

This remarkable succession of seams is altogether without a parallel in any other coalfield in New Zealand, and sharply differentiates the bituminous from the brown coal-measures that seldom enclose more than one seam of workable coal which, as a rule, lies close to the basement rock.

The Grey coals range from ordinary bituminous to semi-anthracite, the fixed carbon commonly varying from 50 to 80 per cent.

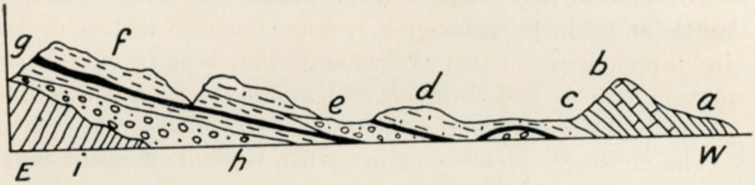

Fig. 118. Section from Greymouth to Brunnerton, showing succession and relationship of bituminous and brown coal-measures. (After Hector.)

a-e. Brown coal-series. *f*. Sandstone with concretions. *g*. Micaceous sandstones with seams of bituminous coal. *h*. Conglomerate. *i*. Lower Mesozoic slaty shales and sandstone.

The total output from the Grey Collieries up to the end of 1908 amounted altogether to some 5,000,000 tons, the port of export being Greymouth.

Hitherto the bulk of the coal has been produced by mines situated at Brunnerton, on the Grey River; Blackball Creek, and Point Elizabeth. At the present time extensive operations are being carried out with the view of tapping the fine seams on the higher part of the Paparoa range.

The average composition of the Brunner coals is as follows:—

Fixed carbon	56.62
Hydro-carbons	35.68
Water	1.59
Ash	6.11
	100.00
Sulphur	0.027%

Of these coals the highest and lowest grade showed the following composition:—

	Highest.	*Lowest.*
Fixed carbon	62.90	43.65
Hydro-carbons	33.53	42.94
Water	0.67	3.16
Ash	2.90	10.25
	100.00	100.00
Sulphur	0.33	0.09
Calorific value	15,251.1	12,164.9

Dr. Maclaurin reports that the majority of these coals are brittle and friable, although a few are tough, bright, and clean. In all points, except that of friability, they bear favourable comparison with the best Westport coal, and in the lowness of sulphur possess a distinct advantage.

The anthracitic coals show a carbon content of about 80 per cent., and less than 0.5 per cent. of sulphur.

Buller-Mokihinui Coalfield.

This great coalfield extends from the Buller Valley north-eastward to the Mokihinui; and from the sea eastwards to the Lyell Mountains, forming a coastal band twenty-five miles long and from two to six miles wide. It occupies for the most part a flat upland valley, or undulating plateau, the western portion of which overlooks the coast, having an elevation of from 1,500ft. to 2,500ft.; while in the other direction it slopes to the north-east, descending to sea-level at the Mokihinui Valley.

The coal-measures at one time formed a continuous sheet, but now occur in a number of isolated areas resulting partly from the dissection of the plateau on which they rest, and partly from the disjunction caused by powerful faults running parallel with the coast-line.

Viewed from the sea-coast, the coal-formation is seen to commence at Mount Rochfort, 3382ft., which presents a cliff of conglomerate 700ft. high, facing the south. From this point the measures dip northward until the gorge of the Waimangaroa

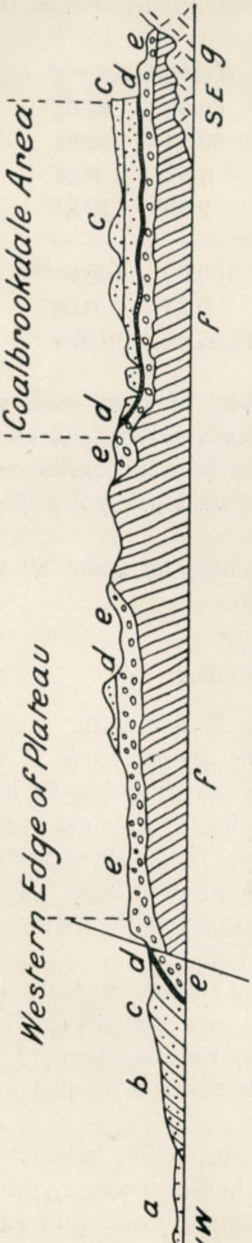

Fig. 119. Section from the sea westward across Coalbrookdale Plateau. (After Cox.) Distance 5¼ miles.

a. Shingle terraces. *b.* Black shaly clays. *c.* Brown and grey sandstones. *d.* Gritstone with seams of coal. *e.* Conglomerates. *f.* Slaty shales and sandstones, Triassic. *g.* Granite.

is reached, where they again rise until they surmount the summit of Mount Frederick, where they attain a height of 3,600ft. above the sea. From this elevation they once more descend, dipping towards the Ngakawau Valley, where the surface of the plateau is only 1,000ft. above the sea.

North of the Ngakawau watershed there is the Mokihinui coalfield, where the coal-measures dip northward, descending from 800ft. to sea-level. A considerable development of the Tertiary coal-formation exists on the flanks to the main divide at Little Wanganui, Karamea, and Heaphy rising in places to a height of 4,000ft. above the sea, but to what extent it is coal-bearing has not yet been determined.

The Buller coalfield is traversed by two or more great faults running nearly parallel with the coast-line, and dividing the coal-bearing region into three distinct sections, namely, the coastal section, extending from the back of the Westport Plains northward to the Ngakawau; the central section including the coalfields of Mount Rochfort Plateau, Mount Frederick, Ngakawau, and Mokihinui; and the inland section including the Mount Williams and Orikaka coal-areas.

The succession of strata forming the coal-formation in the Buller coalfields is as follows:—

1. Black shaly clays.
2. Brown and grey sandstones.
3. Grits and sandstones, with seams of bituminous coal.
4. Coarse grits and coarse conglomerates, the latter of great thickness in the Lower Buller Valley.

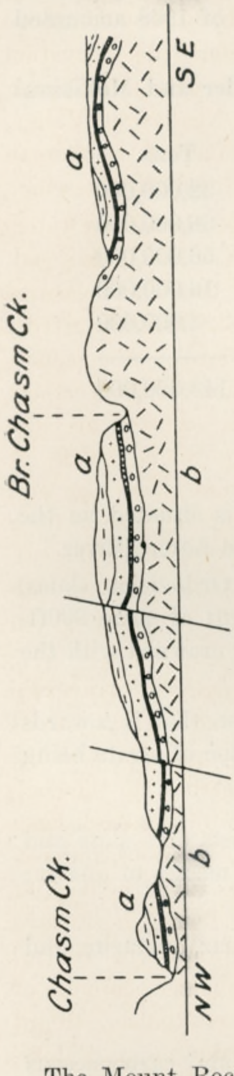

Fig. 120. Section across Mokihinui Coalfield. (After McKay.)
a. Coal-measures. *b.* Granite.

The basement rocks from the Buller Valley to the Ngakawau are slaty shales and sandstones of Triassic age[p], and north of Ngakawau, in the Mokihinui area, granite, quartzites, slate and schists.

The Mount Rochfort coalfield contains two seams of bituminous coal, an upper seam varying from 1ft. to 16ft. thick, and a lower varying from 3ft. to 30ft. thick. The seams lie from 20ft. to 40ft. apart, being separated by soft grits and soft grey sandstone.

In the Mokihinui coalfield there are also two seams of coal, the larger maintaining a thickness of from 16ft. to 20ft. over a considerable area.

At Mount Rochfort, in the southern end of the Buller coalfields, the lower conglomerates attain a thickness of over 700ft.; but going northward this thickness gradually diminishes, until at Mokihinui we find the lower seam lying within 60ft. or 80ft. of the basement-rock, which is a grey granite.

The Mount Rochfort Plateau is worked from Denniston, on the Waimangaroa Valley; the Ngakawau coalfield from Granity Creek and Ngakawau River; and the Mokihinui Coalfield from

p. S. Herbert Cox, Geol. Repts. and Expls., 1874-76, p. 17.

Seddonville. The port of shipment is Westport, situated at the mouth of the Buller River.

The bituminous measures are estimated to cover an area of 115,000 acres. The total output up to the end of 1908 amounted to somewhat over 8,000,000 tons.

The estimated quantity of coal in the Buller and Mokihinui coalfields is as follows:—

	Tons.
Waimangaroa Basin[q]	32,000,000
Ngakawau Basin, high level[q] ..	36,000,000
Ngakawau Basin, middle level[q] ..	56,000,000
Ngakawau Basin, low level[q] ..	16,000,000
Mokihinui Basin[r]	3,000,000
Total	143,000,000

Collingwood Coalfield.

This coalfield is only of small extent. It is situated on the slopes of Mount Burnett, near the mouth of the Aorere River.

The basement rocks consist of Silurian or Ordovician slates, quartzites, and mica-schist, reaching to a height of some 600ft. on the face of the Aorere escarpment, which is crowned with the lower Tertiary rocks containing coal.

The coal-measures dip towards the north-west, that is towards the West Coast, at an angle of 20°, the succession of strata being as follows:—

1. The lowest bed of the coal-measures consists of a slate and schist-breccia, containing rounded and angular masses of quartz; 35ft. thick.

2. This is succeeded by a conglomerate of quartz, quartzite, and greywacke; 20ft. thick.

3. Grey sandstone; 50ft. thick.

4. Brown and green argillaceous sandstone and carbonaceous shale, with layers of grit and coal seams; 250ft. thick.

---

q. Estimate by Professor S. Herbert Cox.
r. Estimate by Sir James Hector.

5. Brown micaceous sandstone, with dicotyledinous leaves, ferns, etc.

6. Hard brown carbonaceous sandstone, with fossil leaves.

The bituminous or lower coal-measures dip towards West Wanganui Inlet, where they are followed conformably by the upper coal-measures, containing seams of pitch and brown coal.

From Mount Burnett, the bituminous coal-measures extend northward towards Cape Farewell, between which and the Pakawau stream they form what is known as the Pakawau—Puponga coalfield.

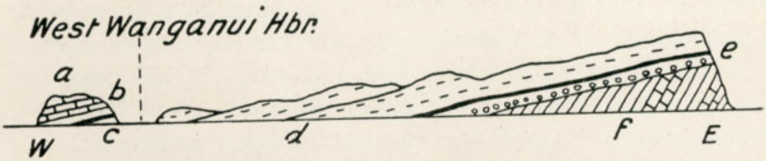

Fig. 121. Section from West Wanganui to Collingwood, showing relationship of bituminous and brown coal-measures.

a. Marly greensands. *b*. Shelly limestone. *c*. Sandstones with seams of brown coal. *d*. Coarse brown sandstones. *e*. Sandstones, shales, and conglomerates with seams of bituminous coal. *f*. Palaeozoic slates and schist.

At the old Ferntown coal-mine there are six thin coal seams as follows, in descending order:—

No. 1—1ft. thick.
2. 2ft. 5in., contains a stone-band of variable thickness.
3. 3ft., containing a stone-band varying from 6in. to 16in. thick.
4. 2ft., with 2in. stone-band.
5. 2ft. 6in. seam, with stone-band.
6. 4ft., containing so many shale bands as to be practically worthless.

Nos. 2 and 3 are the only seams that have proved profitable to work. For some years they yielded coal of fine quality, specially adapted for gas-making and for steam, coke and household purposes. The smallness of the seams, and the many faults met with have always been a serious handicap to the successful working of this field, which is now practically abandoned.

Average Composition of Coal.

Fixed carbon	57.31
Hydro-carbons	35.84
Water	1.95
Ash	4.90
	100.00
Sulphur	0.64%

Pakawau Coalfield.

This is a small coalfield lying immediately to the south of Cape Farewell. It is the most northerly of the bituminous areas, being a prolongation of the Collingwood lower Tertiary coal-measures.

Several seams of coal have been discovered in this area, but they are mostly small, and at present only one, about 7ft. thick, is being worked. The bulk of the coal lies below water-level.

Average Composition.

Fixed carbon	53.47
Hydro-carbons	36.26
Water	3.59
Ash	6.68
	100.00
Sulphur	1.04%

LOWER TERTIARY PITCH AND BROWN COALS.

Oamaru Series.

The pitch coals are chiefly developed in the Mokau basin, at West Wanganui and in the Inangahua Valley; the brown coals in the lower Waikato basin, at West Wanganui, Mount Somers, Kakahu, Waihao, Oamaru, Green Island, Saddle Hill, Forest Hill, and Nightcap.

Both the pitch and brown coals belong to the same coal-measures, the character of the coal being mainly dependent on the extent and nature of the cover. In the Mokau area the pitch coals in the lower basin pass into brown coals going eastward;

and a similar transition is seen at West Wanganui, where the pitch coal as seen and mined at the inlet of that name gradually passes into ordinary brown coal going southward towards Golden Ridge.

The succession of strata forming the formation known as the Oamaru series, to which these coals belong shows a remarkable uniformity from one end of New Zealand to the other. It is as follows, omitting the smaller subdivisions:—

(*a.*) Shelly limestone or calcareous sandstone, often resembling a freestone.
(*b.*) Greensands, often shaly or clayey.
(*c.*) Sandstones or marly clays.
(*d.*) Loose gritty sands and fireclays with coal seams.

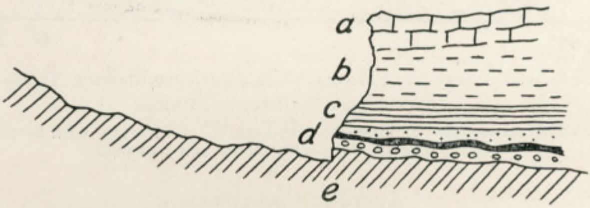

Fig. 122. Typical section of Oamaru formation with brown coal-measures at the base.

a. Limestone or calcareous sandstone. *b.* Greensands, commonly glauconitic. *c.* Marly clays or sandstone. *d.* Sands, grits, and conglomerate, with seams of coal. *e.* Basement rock.

Waikato Coalfield.

This is one of the largest and most important coalfields in New Zealand. It lies in the lower Waikato Basin, extending from the range of lower Mesozoic rocks, through which the Waikato has cut its gorge near Ngaruawahia, northward to Drury, a distance of 48 miles, and westward to the sea, a distance varying from 20 to 25 miles.

The outcrop of the coal-measures is along the eastern boundary, the dip of the strata being westward towards the sea.

A considerable extent of the coal-measures can be traced along the Waikato Valley; but by far the greater area is obscured by swamps, and recent alluvium, or lies below the higher beds of the same formation.

The succession of beds comprising the formation to which the coal-measures belong is as follows:—

1. Calcareous sandstone, in places passing into limestone.
2. Soft sandstones, alternating with clays.
3. Blue marly clays.
4. Fireclays with seam of brown coal.
5. Grits and conglomerates.

The Waikato brown coal contains a large percentage of water, and in consequence crumbles badly when exposed to the weather.

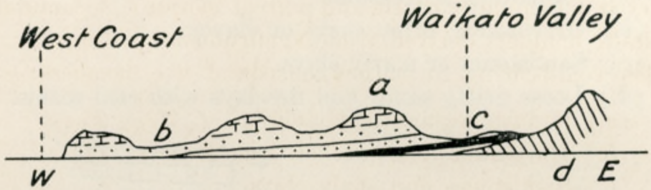

Fig. 123. Section of Waikato Coalfield from Waikato Valley to West Coast. Distance 18 miles.

a. Raglan limestone. *b*. Sandstones and clays. *c*. Fireclays with brown coal. *d*. Lower Mesozoic slaty shales and greywacke.

Average Composition.

Fixed carbon	47.08
Hydro-carbons	33.24
Water	17.60
Ash	2.08
	100.00
Sulphur	0.8 to 2%

The Taupiri Collieries in the neighbourhood of Huntly produced over 184,000 tons in 1909.

The Waikato coal-measures extend southward and westward to Raglan, Kawhia, Upper Waipa, Hikurangi, Awakino, and Upper Mokau, where they are undeveloped.

Mokau-Upper Wanganui Coalfield.

This is the largest coal-bearing field in New Zealand. It extends from the Upper Mokau and Awakino to the sea, a distance of 35 miles, and from the Upper Awakino southward to the Upper Wanganui, a distance of 40 miles. The dip of the coal-bearing formation is southward, that is towards Mount Egmont.

The coal-measures contain at least one seam of workable coal, varying from 4ft. to 16ft. thick. Coal outcrops have been discovered at many places in the Mokau watershed, at Mokauiti, Awakino, Tongapurutu, Tongarakau, Heao, Ohura, Retairuke, and at Te Maire, near Taumaranui.

The Tertiary coal-bearing formation also extends into the Upper Wanganui and Waimarino, forest country where it is covered with pumice drifts and a great morainic accumulation of andesite boulders derived from Ngauruhoe and Ruapehu.

The coal-bearing formation consists of five members:—

(*a.*) Sandstones and marly clays.
(*b.*) Hard limestone (Mokau Limestone).
(*c.*) Sandstones and shaly clays.
(*d.*) Blue sandy clays with seams of coal.
(*e.*) Grits and conglomerates.

The basement rocks are slaty shales and sandstones of Lower Mesozoic age.

Average Composition of Coal.

Fixed carbon	40.00
Hydro-carbons	38.20
Water	14.00
Ash	7.80
	100.00
Sulphur	1.8 to 3.0%

Green Island and Saddle Hill Coalfield.

This extensive coalfield occupies the valley of the Kaikorai stream, near Dunedin, whence it extends southward to Saddle Hill, and northward to the sources of the Silverstream.

The outcrop of the coal-measures follows the mica-schist ridge that runs from the Upper Silverstream to the Chain Hills, and thence southward to the mouth of the Otokaia.

From the lower Kaikorai to Flagstaff and Waitati the coal-measures are overlain by a pile of phonolite, basalt, dolerite, trachydolerite, and other volcanic rocks of late Tertiary date; and in the Kaikorai Basin the outcrop is obscured in many places by a thick mantle of glacial boulder-clay.

The dip of the strata is eastward at low angles; and it is almost certain that the coal-measures underlie Dunedin and Otago Peninsula.

In the Lower Kaikorai, near Abbot's Creek, the outcrop of the coal lies at sea-level. Going northward it gradually rises until, in the Upper Valley of the Silverstream, it is found at an elevation of 1,000ft., on the western slope of Flagstaff Hill. North of the Silverstream divide, the outcrop descends until it again reaches sea-level near Evansdale, a distance of 16 miles from Kaikorai.

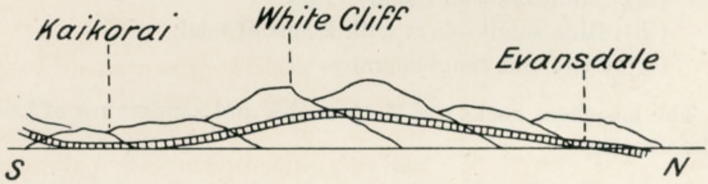

Fig. 124. Transverse section along outcrop of Tertiary brown-coal showing arching of strata due to volcanic uplift.

This remarkable differential uplift is traceable to the volcanic activity that formed Flagstaff, the arch of the dome being immediately opposite the centre of eruption.

The coal-bearing formation consists of the following members in descending order:—

1. Calcareous sandstone (Caversham Stone), 400ft.
2. Glauconitic greensands and soft sandstone, 300ft.
3. Blue marly clays, 100ft.
4. Soft dirty greenish-brown micaceous sandstone, 200ft.
5. Loose quartz sands with a thin bed of limonitic quartzose conglomerate, 6in. to 3ft. thick at the top, and seams of brown coal and fireclay near the base.

There are two workable seams of coal, an upper, varying from 2ft. to 8ft. thick, and a lower, varying from 6ft. to 20ft. thick.

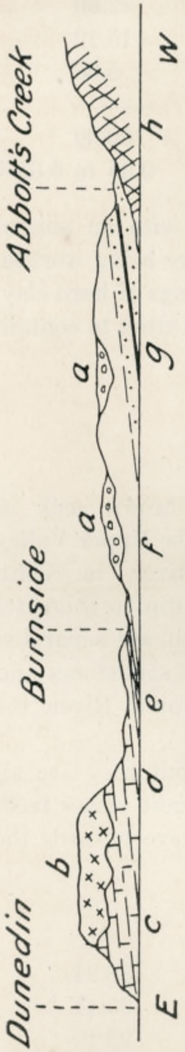

Fig. 125. Section from Green Island to Dunedin.

a. Glacial boulder-clay. *b.* Dolerite. *c.* Caversham sandstone, calcareous. *d.* Glauconitic greensands. *e.* Blue marly clays. *f.* Soft micaceous sandstone. *g.* Quartz sands and grits with seam of brown coal. *h.* Slaty mica-schist.

The coal, although of the same age as the Taupiri, is inferior in quality, which is doubtless the result of the loose incoherent character of the coal-measures.

Average Composition.

Fixed carbon	..	40.84
Hydro-carbons	..	36.57
Water ..	..	18.67
Ash ..	..	3.92
		100.00
Sulphur ..	..	2 to 2.4%

NIGHTCAP COALFIELD.

This coalfield is situated about 45 miles from Invercargill. It skirts the base of the Takitimu Mountains and Wairaki Downs for a distance of some eighteen miles. Near the Jacob River it has a width of about three miles, and gradually diminishes going westward, thus forming a long narrow triangle, the base of which lies at the southern spur of Mount Beaumont, known as Nightcap, and the apex of Taylor's Creek. The total area is about 27 square miles.

The coal is a superior brown coal, somewhat similar in appearance to the Waikato coals. It is overlain by brown clays and sandy grits, which are followed by 200ft. or 300ft. of marly clays and sandstones, the sequence being closed with a tabular limestone. The basement rocks consist of sandstones and slaty shales of Triassic age.

Average Composition.

Fixed carbon	47.16
Hydro-carbons	32.66
Water	15.12
Ash	5.06
	100.00
Sulphur	0.35 to 0.65%

The principal mine is the Nightcap Colliery with an annual output of some 50,000 tons. Three seams are here being worked, aggregating 36ft. of good coal separated by partings of hard clay.

This coalfield has been estimated by Captain Hutton to contain 100,000,000 tons of coal.

Kakahu Coalfield.

This is the principal undeveloped area of brown coal in the provincial district of Canterbury. It lies in the Upper Valley of the Kakahu, a tributary of the Opihi River, in South Canterbury. In Bush Creek the coal-measures dip to the east; and in the main stream and its branches, which are separated from Bush Creek by a ridge of Upper Palæozoic sandstones and slaty shales, the dip is westward towards the Opuha River, the main tributary of the Opihi.

Several seams of coal have been discovered, but they are all thin and somewhat inferior in quality. The largest varies from 4ft. to 7ft. thick, and may be expected to improve towards the dip.

Average Composition.

Fixed carbon	38.24
Hydro-carbons	35.41
Water	22.10
Ash	4.25
	100.00
Sulphur	2.24%

The coal-measures occur at the base of the Oamaru formation, which consists of four members.

1. Sandy limestone.
2. Marly clays.
3. Marly greensands.
4. Grits, shales, and brown coal.

None of the coal seams can be worked level-free.

Waihao Coalfield.

This is a small basin of inferior brown coal situated at the Waihao Forks, a few miles south of Waimate. The succession of strata is typical of that met with further south in the Waitaki Valley, and around Oamaru.

1. Calcareous sandstone.
2. Glauconitic greensand.
3. Marly clays and soft sandstones.
4. Sandy grits, fireclay and brown coal.

One seam has been discovered varying from 4ft. to 27ft. thick. The coal is of inferior quality, and from the outcrop dips below water-level.

Oamaru Coalfield.

This covers a considerable area extending from the Waitaki Valley to the Kakanui River, a distance of 12 miles, with a mean breadth of two miles.

Outcrops of brown coal occur at Ngapara, where the sequence of the coal-bearing formation is as under:—

1. Calcareous sandstone, passing into impure limestone.
2. Glauconitic greensands.
3. Soft marly sandstone.
4. Quartz-grits and sands with seam of brown coal.

The quartz-grits are in places cemented with iron peroxide into hard flaggy beds forming layers of gritty conglomerate.

The seam of coal varies from 4ft. to 20ft. thick. It is of inferior quality, and dips under water-level.

Waikouaiti-Palmerston.

The coal-bearing Oamaru formation occupies the floor of the lower Shag Valley, and thence extends southward to Waikouaiti, a distance of ten miles. No workable seam has been discovered in this area, but the presence of the coal-measures renders it a potential coal-bearing region, to which attention will doubtless be directed when the more accessible coals near Dunedin are exhausted.

The formation, at the base of which coal may be found, comprises four members, namely:—

1. Calcareous sandstone (Waikouaiti Stone).
2. Glauconitic greensands.
3. Marly clays and soft sandstones.
4. Conglomerates and breccias, micaceous sands and clays with brown coal.

A seam of coal 2ft. thick has been discovered on the east side of Mount Pleasant, at an altitude of 340ft. above the sea. Water-logged pieces of the coal taken from the outcrop showed the following composition:—

Fixed carbon	36.76
Hydro-carbons	28.07
Water	28.19
Ash	6.98
	100.00
Sulphur	2.37%

On account of the amount of surface cover it will be necessary to prospect this field by boring.

Forest Hill Coalfield.

This small coalfield is situated on the lower slopes of the Hokonui Hills, opposite the junction of the Makarewa and Otapiri rivers.

The coal-bearing series consists of four well-defined members, namely:—

1. Shelly limestone (Winton limestone).
2. Glauconitic sandstone.
3. Marly clays and soft sandstone.
4. Sandy grits, fireclay, and seam of brown coal.

The seam varies from 9ft. 6in. to 11ft. 6in. thick, as exposed along the outcrop. The coal is of fair quality and weathers well. The estimated quantity of coal is 1,000,000 tons.

Orepuki Coalfield.

This coalfield is of small extent. It is situated some 22 miles from Riverton, in the valley of the Waimea, which runs back to Longwood Range. It forms a triangular area about three miles in breadth and one mile in height.

The seam is very irregular, varying from four to fifteen feet thick, and is in places considerably shaken. It is covered with dark tough shales, and underlain by chocolate-coloured shales. The upper member of the coal-measures is a soft greenish-blue sandstone, dipping S.S.W. at an angle of 10°.

The coal contains very little ash, but is very hydrous.

Average Composition of Coal.

Fixed carbon	41.10
Hydro-carbons	37.20
Water	19.10
Ash	2.60
	100.00
Sulphur	1.3 to 1.8%

Preservation Inlet Coalfield.

This isolated coalfield is situated in the extreme south-west angle of Otago, lying along the sea-board of the first of the series of deep inlets that form the wonderful Fiordland of the south-west of Otago.

The members of the coal-bearing formation in descending order are as follows:—

1. Limestone, marly clays, and soft sandstone.
2. Shales, sandstones, and grits, with seams of brown coal.
3. Coarse breccia-conglomerate.

The coal-measures extend along the coastline of the mainland from a point near Goldburn to Otago's Retreat, a distance of eight miles. They occupy the greater portion of Coal Island, and north of this again appear on the mainland at Gulche's Head, which separates Preservation Inlet from Chalky Inlet. They also form the greater portion of Chalky Island.

A seam of good coal occurs at Coal Island, but it is too small to be profitable to work. The only workable coal so far discovered is situated on the mainland between Otago's Retreat and Puysegur Point. Here there are two seams, each about 3ft. thick.

Average Composition.

Fixed carbon	45.46
Hydro-carbons	33.49
Water	16.52
Ash	4.53
	100.00

Sulphur—From 2 to 3 per cent.

West Wanganui Coalfield.

This is a coalfield of considerable extent, extending, in an unbroken stretch, along the west coast from West Wanganui Inlet southward to Golden Ridge, and thence southward in detached areas as far as the Turimawiwi Valley, a total distance of 18 miles.

The beds enclosing the coal-measures belong to the Oamaru, or upper coal-bearing Tertiary series. They are as follows:—

Oamaru Series.

1. Many greensands, often calcareous.
2. Shelly limestone.
3. Coarse sandstones with seams of pitch and brown coal.
4. Quartz grits and conglomerate.

Underlying these beds conformably are the lower coal-measures, which rise on to the flat of the Whakamarama Range, the dividing range between the coalfield and the Aorere Valley.

Waimangaroa Series.

5. Sandstones and shales with thin seams of bituminous coal on the Aorere escarpment and at Pakawau.
6. Coarse conglomerate.

A seam of pitch coal, varying from 6ft. to 8ft. thick, in places divided by a clay-band, crops out near sea-level on the shore of the inlet. It was mined as far back as 1867.

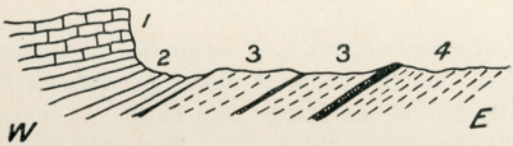

Fig. 126. Section across West Wanganui Coalfield.

1. Limestone. 2. Brown sandstone. 3. Gritty sandstone and shales with seams of brown coal.

Average Composition.

Fixed carbon	50.10
Hydro-carbons	37.10
Water	8.60
Ash	4.20
	100.00
Sulphur	1.86%

Southward of the Inlet the coal becomes more hydrous, and gradually passes into an ordinary brown coal.

Between the Paturau and Golden Ridge three seams have been discovered, but only one of them is workable.

Average Composition of Lower Seam.

Fixed carbon	51.17
Hydro-carbons	20.20
Water	12.41
Ash	16.22
	100.00
Sulphur	3.2%

The base of the coal-measures is not exposed near the Paturau, hence there is always the probability that prospecting by boring might prove the existence of a lower seam of better quality than that referred to above.

Takaka Coalfield.

This is of small extent. It comprises a number of small isolated areas, notably those at Motupipi, Baker's Hill, Page's Crossing, Waingoro, and Rangitaieta Head.

The coal is an impure brown coal. The main seam varies from 6ft. to 18ft. thick, and dips below water-level. This coal, on account of its impure character and small extent is not likely to be of any value except for local consumption.

Baton Coalfield.

This coalfield occupies a small portion of the valleys of the Baton and Clark rivers, draining the south-east slopes of Mount Arthur in Nelson. It is an outlier of the adjoining Wangapeka coalfield.

The succession of strata in the coal-bearing formation is as follows:—

1. Argillaceous limestone.
2. Marly greensands.
3. Coarse sandstones and black shales, with seams of brown coal.
4. Quartzose grits, and conglomerates.

Several seams of coal occur in the Baton and Clark valleys, but they are mostly thin and of poor quality. The situation is somewhat inaccessible, and being remote from centres of population, the coal is not likely to be sought after except for local consumption.

Wangapeka-Hope Coalfield.

This extends from the Wangapeka River to the Sherry, Tadmor, Hope, and Upper Motueka valleys. The coal-bearing rocks form the same succession as seen at the Baton. They cover a large area, but seldom crop out at the surface, being covered over by a heavy deposit of late Pleistocene gravels.

Seams of coal have been discovered at the Sherry and Hope valleys, but are so situated that little can be gathered, from a surface examination, as to their thickness or extent. The coal is a brown coal of somewhat inferior quality. It may possibly improve towards the dip.

Nelson Coalfield.

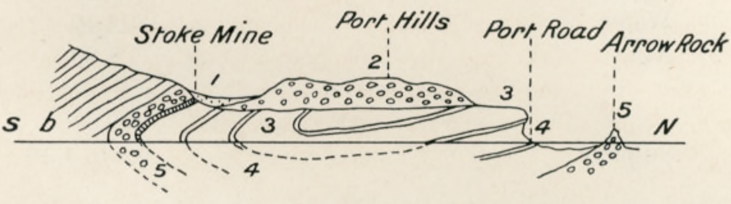

Fig. 127. Section from foothills to Port Nelson showing overturned coal-measures.

1. Recent alluvium. 2. Pleistocene gravels. 3. Marly clays and soft sandstones. 4. Gritty sandstones and clays with *Aturia australis*, &c. 5. Sandstones, shales, and conglomerate with seams of pitch coal.

A narrow strip of the upper coal-measures follows the southern margin of the Waimea Plain, extending along the foot of the Hope and Richmond Hills, from Brook Street Valley, Nelson, to the mouth of the Wairoa Gorge, near Brightwater.

The coal-bearing beds are involved in an overthrust fold of the Triassic rocks that form the Richmond Hills. This involvement and the heavy cover of recent and Pleistocene gravels forming the Waimea Plain have proved a serious hindrance to the adequate prospecting of these measures.

The succession of beds containing the coal belongs to the Oamaru formation, and consists of the following members in descending order:—

1. Marly clays and soft sandstones.
2. Gritty sandstones alternating with clays.
3. Grits, and conglomerates with seams of pitch coal.

Attempts have been made to work the coal at Brook Street Valley, at Stoke, and Wairoa Gorge, but so far without success. At the Enner Glynn mine, on the outskirts of Nelson, four seams were found, varying from 1ft. to 6ft. thick.

The coal along the line of involvement is steeply inclined, and generally crushed and broken.

It is of good quality, containing very little ash and a high proportion of fixed carbon.

Average Composition.

Fixed carbon	62.40
Hydro-carbons	21.40
Water	14.40
Ash	1.80
	100.00
Sulphur	..0.8 to 1.3%

The coal-measures extend northward under the Port hills to the entrance of Nelson Harbour, the basal conglomerate forming Arrow Rock at the end of the Boulder Bank. In this direction the coal-bearing strata should be less disturbed than along the foothills. The presence of a workable seam here could be proved at a comparatively small cost by boring near the roadway opposite Arrow Rock.

Owen Coalfield.

This coal-basin is an outlier of the lower measures of the greater Maruia coalfield, lying south of the Buller River. It occupies the floor of the Owen Valley, extending from the upper end to the Buller River, of which the Owen is a tributary.

The succession of beds belonging to the coal-bearing formation is :—

1. Coarse conglomerate.

Lower coal measures:

2. Blue clays.

3. Calcareous sandstones, containing scattered pebbles of granite, greywacke, and slate. They, in places, alternate with bands of clay and greensands. Between the Owen and Two-mile Creek the calcareous sandstone passes into a pebbly shelly limestone.

4. Sandstones, quartzose grits with shales, fireclay, and a seam of semi-bituminous or high grade pitch coal.

5. Coarse conglomerates.

These rest in a shallow oblong basin bounded by intrusive granite on the east side, and by Ordovician slates and limestone on the west.

The seam of coal is 6ft. thick, of good quality, the average composition being:—

Fixed carbon	40.79
Hydro-carbons	54.41
Water	1.40
Ash	3.40
	100.00
Sulphur	1.65%

Maruia-Matakitaki Coalfield.

This is one of the largest undeveloped coalfields in New Zealand, extending from the Owen River southward to the Matakitaki, a distance of thirty miles, the mean breadth being about two miles.

Both the upper and lower coal-measures of the West Coast are present in this basin, the succession of the coal-bearing formation being:—

Oamaru Series (upper coal-measures)	1. Limestone. 2. Marly clays. 3. Sandstones and shales interstratified with ten thin seams of brown coal.
Waimangaroa Series (lower coal-measures)	4. Upper conglomerate. 5. Sandstones, shales with seams of semi-bituminous coal. 6. Lower conglomerate.

Notwithstanding the presence of the upper conglomerate, the different members follow each other with perfect stratigraphical conformity, as we have already seen is the case at Pakawau and W. Wanganui, the upper members forming a complete cycle of deposition beginning with fluvio-marine gravels and ending with a marine limestone.

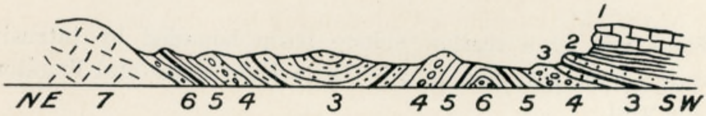

Fig. 128. Section across Maruia Coalfield from Hampden to Mount Murchison. Distance 10 miles. (After Cox.)

1. Limestone or calcareous sandstone with *Pseudamussium huttoni*. 2. Marly clays with *Amussium zitteli*. 3. Sandstones and shales with brown coal. 4. Upper conglomerate. 5. Sandstones and shales with semi-bituminous coal. 6. Lower conglomerate.

None of the known seams of brown coal in the upper measures are thick enough to be workable. A seam varying from 10in. to 2ft. was worked at Longford for a time, the output being used for local consumption.

The seams of bituminous coal are generally thin, varying from 2ft. to 6ft. thick. The two seams at Hampden are of good quality, as shown by the following analyses:—

	3ft. Seam.	4ft. Seam.
Fixed carbon	56.60	56.20
Hydro-carbons	38.79	38.82
Water	1.20	1.19
Ash	3.41	3.79
	100.00	100.00
Sulphur	1.20	1.16

A small seam 2ft. thick, at the mouth of Glenroy River, is even superior to the Hampden coals.

Fixed carbon	61.68
Hydro-carbons	32.37
Water	3.96
Ash	1.99
	100.00
Sulphur	1.62%

Inangahua Coalfield.

This is the south-west continuation of the coal-measures of the great Buller coalfield. The coal-bearing formation occupies the floor of the old Inangahua Valley, being bounded on the east by the Brunner and Victoria Ranges, and on the west by the Paparoa Range. It extends from the Buller River to Reefton, a distance of twenty miles, the mean width throughout being about ten miles.

The measures contain at least two seams of superior pitch coal admirably suited for steam-raising and domestic purposes.

The succession of strata comprising the coal-bearing formation is given below in tabulated form, reading downwards:—

1. Siliceous limestone (Cobden Limestone).
2. An impure coralline limestone, passing into calcareous sandstone.
3. Dark marly clays with concretions.
4. Impure limestone.
5. Brown sandstone, often micaceous.
6. Grits, coarse sandstones, and shales with seams of pitch-coal.
7. Quartzose grits, and conglomerates.
8. Coarse breccias.

The upper seam varies from 2ft. to 20ft. thick, and the lower from 4ft. to 18ft.

Average Composition of Murray Creek Coal.

Fixed carbon	54.52
Hydro-carbons	36.72
Water	7.68
Ash	1.08
	100.00
Sulphur	1.24%

The coal has been worked on a small scale at different places on the Buller Road, Little Boatman's Creek, Capleston, Waitahu, Burke's Creek, Murray Creek, and Lankey's Creek, and other places near Reefton. The total output is small, and limited by the local consumption.

Other Coal-bearing Areas.

The coal-bearing formation of North Auckland occupies a considerable area between Whangarei, the Northern Wairoa, and Hokianga. In many places the coal-measures are covered with a pile of lavas of late Tertiary date, and everywhere the surface is broken and heavily wooded. Outcrops of coal have been discovered in several of the tributaries of the Wairoa, the outcrop near Tangawahine being that of a workable seam of good quality.

Isolated patches of the coal-bearing series occur at Whangaroa, Mangonui, Parengarenga, and near North Cape. At Whangaroa the coal-bearing formation consists of green sandstones, grit, and sandy shales, containing small irregular seams of coal of fair quality. The thickest seam is only 2ft. thick, and cannot be traced far. The land is deeply indented by the sea, and over a large portion of it the coal-formation is buried under a sheet of volcanic lavas, tuffs, and agglomerates.

Many small isolated areas of the Tertiary coal-measures occur in different parts of Canterbury. Near the foot of Mount Grey there is a seam of brown coal four feet thick. South of the Rakaia small outliers of coal have been preserved in many localities, consisting generally of one seam only, but of considerable thickness. Thus on the right bank of Taylor's Creek the seam is 28ft. thick, and inclined at an angle of 70°. On the hillside close to Clent Hill station the seam is 28ft. 6in. thick.

Another small basin containing workable coal is situated in the neighbourhood of the junction of the Stour and Ashburton At Coal Creek the same measures contain a seam of good brown coal 14ft. thick. Coal also occurs in the bight formed by the junction of the Cox Range and Mount Somers. The Mount Somers coals are of great local value.

OLDER LIGNITES AND BROWN COAL.

Old Lake Basins of Central Otago.

The principal deposits of lignite in New Zealand are found in Central Otago, and in Southland.

In Central Otago lignite occurs around the margin of the Maniototo, Ida Valley, Manuherikia, and Cromwell basins, being found near the base of the great series of fluvio-lacustrine beds of Upper Miocene or Older Pliocene date that occupy the site of what were at one time great inland lakes.

The members commonly represented in the lignitic series are:—

(*a.*) Sandstone gravels partially consolidated.
(*b.*) Sands and soft sandstones.
(*c.*) Quartzose sand-drifts.
(*d.*) Sands, clays, and lignite.

Two or three seams of lignite separated from each other by loose quartz-sands or soft sandstones, occur in most places, but there is seldom more than one workable seam. The lower seam generally varies from 6ft. to 20ft. thick. In a few cases it attains vast dimensions. Thus at Alexandra the main seam is 28ft. thick; at Dairy Creek, Clyde, 44ft.; and at Coal Creek, Roxburgh, one seam, which is standing vertical, is over 100ft. thick.

At the Excelsior Mine, Bannockburn, the seam is 7ft. thick, and contains 5ft 6in. of workable coal.

Average Composition (Dr. Maclaurin.)

Fixed carbon	30.98
Hydro-carbons	39.86
Water	22.54
Ash	6.62
	100.00
Sulphur	0.51%

At Shepherd's Creek coal-mine, in the same district, the seam varies from 7ft. to 15ft. thick, divided into two portions by a thin clay parting. The lower coal only is worked.

Average Composition (Dr. Maclaurin.)

Fixed carbon	32.60
Hydro-carbons	39.90
Water	22.20
Ash	5.30
	100.00
Sulphur	0.32%

A small basin of brown coal occurs in the Plankburn, a branch of the Roaring Meg, at an altitude of 2,600ft. above the sea. A peculiarity of this seam is that it is deeply involved in the basement mica-schist.

Average Composition (Dr. Maclaurin.)

Fixed carbon	41.80
Hydro-carbons	37.31
Water	17.12
Ash	3.77
	100.00
Sulphur	1.82%

At Gibbston, Doolan's Creek, and Cardrona, the coal-measures are similarly involved; and singularly enough, where the involvement is greatest the lignite is of superior quality, in places being converted into a good brown coal.

The seam of lignite in Mathias's mine, near Alexandra, varies from 8ft. to 19ft. 6in., divided into two by a thin clay-parting.

Average Composition (*Dr. Maclaurin.*)

Fixed carbon	17.38
Hydro-carbons	49.38
Water	25.01
Ash	7.00
Sulphur	1.23
	100.00

The principal lignite mines in Central Otago are situated at Roxburgh, Alexandra, Clyde, Bannockburn, Gibbston, Cardrona, Cambrian's, St. Bathan's, Idaburn, Mount Highlay, and Nevis.

Central Otago is so completely destitute of forests and native vegitation suitable for fuel that the lignites of the ancient lake-basins have been an important factor in the settlement of the country and development of the gold-dredging industry. Without this natural fuel settlement would have been set back for a generation.

Pleistocene Lignite.

Southland.—The most extensive deposit of lignite of post-glacial age occurs in Southland. It mainly follows the valley of the Mataura River, extending from Gore to Mataura and Wyndham, and thence by way of Seaward Forest to Clifton, near South Invercargill, a distance of about fifty miles in length by one mile or more in breadth.

For the most part the lignite is horizontal or gently undulating, and occurs near the surface, the only cover being clays and gravel generally from 5ft. to 12ft. deep. The seam varies from 6ft. to 23ft. thick.

The chief lignite workings are situated at Pukerau, East Gore, Gore, Croydon, East Chatton, Waikaka Valley, Waikaia, Waimumu, and Wyndham.

The lignites produced in Southland are used for domestic consumption, and for steam-raising on gold-dredges.

REMARKS.

In connection with the preparation of this chapter the author has made a detailed examination of every coalfield in New Zealand. Many places have been visited twice, and a few three times where some problem had to be solved, or fuller information obtained. At the same time the author has drawn freely on the geological reports and memoirs by Sir James Hector, F.R.S., Professor S. Herbert Cox, F.G.S., Sir Julian von Haast, F.R.S., Captain F. W. Hutton, F.R.S., and Mr. A. McKay, F.G.S., from which much valuable information and fruitful suggestion were obtained. Where not otherwise specified, the coal analyses are the work of the late Mr. W. Skey, first analyst to the New Zealand Geological Survey.

CHAPTER XIV.

THE GOLDFIELDS OF NEW ZEALAND.

Gold-mining is one of the staple industries of the Dominion, the annual production of gold being valued at about two million pounds sterling. The principal goldfields are situated in Auckland, Nelson, Westland, and Otago. In Auckland the whole of the gold is obtained from lode-mining; in the other provinces the bulk of the production is obtained from alluvial sources.

EARLY GOLD DISCOVERIES.

The settlement of New Zealand began in the early forties, and was carried on with the energy and indomitable courage that have always characterised the colonising ventures of the roving Anglo-Saxon race. Ship-load after ship-load of hardy settlers from England and Scotland poured into the country, and in less than two decades practically all the land available for settlement in the South Island, and all but the King Country in the North Island, had passed into European hands. The remoteness of the colony from the motherland, the physical difficulties that hampered internal communication, and the hostility of the Maori—a brave and warlike race—might easily have daunted a less adventurous people.

The early settlers were a fine type of manhood—tactful but just in their dealings with the natives, resourceful, self-reliant, and courageous. Their attention was at first devoted to pastoral and agricultural pursuits, but the discovery of gold in California in 1847 and in New South Wales in 1851, led some of the more adventurous to search for gold.

The first indication of the existence of gold in New Zealand was communicated to Captain Cargill, Superintendent of the Province of Otago, on the 27th of October, 1851, by two squatters named C. J. Nairn and C. J. Pharazyn, who reported that they had found veins of gold-bearing quartz and alluvial gold in the neighbourhood of Goodwood, Otago. The veteran captain was not very sanguine, nor was he desirous that his community should be diverted from the even tenor of its way. The local newspaper cautioned people leaving their ordinary occupation, concluding a leader with the remark that "flour is more necessary than gold."

In October, 1852, a "Reward Committee" was formed in Auckland, which promised a reward of £500 to the discoverer of a valuable goldfield within the provincial district. In less than a week the reward was claimed by Mr. Charles Ring, a miner recently returned from California, who asserted that he had discovered gold in the vicinity of Coromandel Harbour, about forty miles from Auckland.

The specimens produced by Ring consisted of pieces of auriferous quartz and a little gold dust, found on the Kapanga stream, better known as Driving Creek, which flows into the harbour at the present township. A party of Commissioners was sent to Coromandel to investigate the discovery, and confirmed the existence of gold, but expressed some doubt as to the profitable character of the find.

This was the first discovery of gold in North New Zealand, and was the cause of much rejoicing. The most sanguine hopes were entertained, and arrangements were soon completed for the systematic search of the Hauraki Peninsula. As the land belonged to the natives, the Government agreed to acquire, for a certain payment, the right for Europeans to mine on the lands.

The first gold produced was sold by public auction in Auckland, but the heavy charges for licenses, and the increasing difficulties with the natives caused the budding industry to die out after some six months. The general opinion was that the gold did not exist in payable quantities, and the promised reward was not paid to the discoverer.

The gold produced up to that time amounted to the value of some £1,200, the whole of which was obtained by washing the sands and gravel along the course of the Kapanga. The largest nugget found was a piece of quartz weighing about a pound, containing a little over three ounces of gold.

For several years no more systematic mining was attempted, and only at long intervals did small prospecting parties of miners pay clandestine visits to different parts of the peninsula, the natives denying the right of Europeans to search for gold.

In the same year, that is in 1852, gold was found at Beaumont on the Clutha River, Otago; and in 1853 a small quantity of fine scaly gold was obtained not far from Mount Hyde. In December 1856 Charles Ligar, Surveyor-General of New Zealand, officially reported to His Honour the Superintendent of Otago the intimation of the existence of gold very generally distributed in the gravel and sands of the Mataura River, at Tuturau.

The first important discovery of gold in New Zealand was made in the Aorere Valley, Collingwood, in 1857; and in the next few years all the tributaries of the Aorere proceeding from the Haupiri Range were more or less successfully worked by various parties of diggers. In 1859 there followed the discovery of the Buller diggings.

Early in June of 1861 Mr. Gabriel Read, a Californian prospector, reported the discovery of rich gold wash in a tributary of the Tuapeka River, at a place that was afterwards named Gabriel's Gully. A rush soon set in, and in a short time the fabulous wealth of this diggings was disclosed. The following year was famous for the opening of several permanent goldfields, the most notable of these being the Dunstan diggings, discovered by Hartley and Reilly on the banks of the Clutha River, a short distance below the present site of Cromwell. The Nokomai, Nevis, Cardrona, Arrow, and Shotover diggings, discovered in the early sixties, have each been famous in their day, and are still far from exhausted.

The rich discoveries in Otago once more directed attention to Coromandel in Auckland, and in October of 1861, that is, nine years after Ring's discovery, that place again became the scene of busy mining operations. On the 28th June, 1862, it was proclaimed a goldfield. At that time there were about 300 miners on the field, but the breaking out of the native war in 1863 caused the field to be again deserted. After the cessation of hostilities miners returned to Coromandel, and since then mining has been carried on continuously up to the present time.

In 1864 rich gold-bearing deposits of fluvio-marine origin were found at Ross and Hokitika, and in the same year the discovery of vein-gold was announced at the Thames and Te Aroha. On the 27th July, 1867, an arrangement was made between the Government and the Thames natives, and three days later the lands were proclaimed a goldfield. On the 10th August the celebrated Shotover reef was discovered in the bed of the Kuranui stream, and the first miner's rights were issued on the 12th, that is, two days later. Before this date gold-bearing quartz veins had been discovered in Otago, Nelson, and Westland, but not of a profitable character. Reefs were prospected in Otago as early as 1862, but the earliest reef-workings were those on the Shetland Reef at Waipori in 1864.

The opening of Gabriel's Gully was followed by the discovery of gold at Waitahuna, Weatherstones and Blue Spur. The deposit at the last is of fluvio-glacial origin, and lies in a depression in the ridge at the head of Gabriel's and Munroe's Gullies. The finds of gold in Gabriel's Gully were unparalleled in richness, and attracted miners from all parts of the globe. Altogether some 2,000,000oz. of gold were dug out of this shallow gully in less than three years, the high water of production being reached in 1863, when considerably over 500,000oz. were obtained.

The Dunstan rush led to the discovery of diggings at Alexandra, Clyde, Tinker's, Black's, St. Bathan's, and other places around the margin of the Manuherikia ancient lake basin; at Ida Valley, and Maniototo Plain.

Up to the year 1865 the bulk of the gold exported from New Zealand was obtained in Otago, and practically all of this was alluvial. In 1865 Logan and party discovered a rich lode at Bendigo, near Cromwell, in Central Otago, at what is now known as the Bendigo goldfield. The discoverers worked there until 1876, and are stated to have obtained gold to the value of about £500,000, the dividends per man varying from £50,000 to £80,000 ("New Zealand Mining Handbook," 1906, p. 375.)

In 1868 the alluvial workings in Smith's Gully at Bannockburn led to the discovery of some small but rich gold-bearing lodes on the Cromwell flank of the Carrick Range. Lode-mining, however, was not started until 1870. The Bendigo and Carrick goldfields have been practically abandoned for some years.

The alluvial diggings of the West Coast, although not so rich as those of Otago, were spread over a wider area. As we have already seen, gold was first found in this region in 1864, the yield for that year amounting to 1,463oz. Next year the yield jumped to 289,897oz., a total which was almost doubled in 1866 with 552,572oz. From 1867 the production showed a decline; the yield in the next three years being in the neighbourhood of 500,000oz., 400,000oz., and 300,000oz. respectively. In spite of the discovery of the Reefton goldfields in 1870, the yield continued to decline with each succeeding year, until in 1883 it amounted to about 117,000oz. From that date till now the annual returns have fluctuated between 60,000oz. and 125,000oz. The improvement observable since 1900 is due to the increased productiveness of the Consolidated Goldfield mines.

The rapid exhaustion of the richest ground in the alluvial diggings directed greater attention to lode-mining, with the result that many important discoveries were soon made. Thus while the sixties may be claimed as the decade of alluvial gold, the seventies may fairly claim to be that of quartz-mining. The discoveries at Reefton, Boatman's, Lyell, Thames, Te Aroha, and Coromandel followed each other in rapid succession, and for some years the decline in the production of alluvial gold was more than stemmed.

The Auckland gold production, which in 1869 amounted to 132,451oz., fell in 1870 to 85,534oz., but rose the following year to 330,326oz., the return for that year being swelled by the yield of gold from the Caledonian bonanza, which is reported to have produced gold to the value of £600,000 in nine months.

From 1871 the Auckland returns showed a steady decline until the year 1895, since when there has been a continuous increase, the chief contributor in this yearly increment being the famous Waihi mine. Among other mines that have swelled the returns are the old Waitekauri and Komata mines at Waitekauri; N.Z. Crown and Talisman mines at Karangahake; and Grand Junction at Waihi; Waiotahi at Thames, and Hauraki at Coromandel. The Waihi mine was worked as early as 1882, but it was not until the introduction of the cyanide process of 1894 that complete success was achieved.

General Geology of the Goldfields.

The chief goldfields are situated in the Hauraki Peninsula, Auckland; at Reefton, on the west coast of the South Island; and in Otago.

In the Hauraki area the lodes occur in hypersthene-andesite and augite-andesite lavas of late Tertiary date, resting partly on older Tertiary marine strata, but mainly on claystones and sandstones of Juro-triassic age. The lodes occur as fissure-veins near the rim of the old centres of eruption. Thus the Waihi mines are situated on the rim of the Waihi Volcano; the Talisman and Crown mines on the rim of the Karangahake Volcano; the Thames mines near the Waiokaraka Volcano; and the Coromandel mines near the Kapanga Volcano.

The Reefton mines are contained in claystones and sandstones of probably older Secondary age. The lodes consist of strings of lens-shaped ore-bodies that lie along the bedding planes of the enclosing rock.

The Otago lodes are enclosed in older Palæozoic mica-schist. Many of them are fissure veins, while others are lenses following the planes of schistosity.

Geology of the Hauraki Goldfields.

The basement rocks of the Hauraki Peninsula, New Zealand, consist of fossiliferous mudstones and greywacke of Juro-triassic age. Overlying these, in the area north of Coromandel, there are isolated patches of calcareous and arenaceous marine strata belonging to the Oamaruian of lower Tertiary date.

On the highly-eroded surface of both the lower Secondary and Tertiary sedimentaries there is piled throughout the length and breadth of the peninsula a vast accumulation of andesitic lavas, tuffs and breccias, which are in their turn overlain by lavas and tuffs of a rhyolitic character.

The first outbursts of volcanic activity appear to have taken place about the close of the Miocene. They were characterised by the emission of great streams of lava, which poured over the dry land and the floor of the adjacent seas. Then followed a cessation of activity, during which vegetation established itself on the muds and ashes that had accumulated in the valleys and hollows around the base of the still smoking volcanoes. Peat bogs grew and forests flourished for a time, but on the renewal of volcanic activity they became buried beneath hundreds of feet of ashes and other fragmentary ejecta, afterwards forming beds of impure lignite. At the close of the lignitic period there was a renewal of the andesitic outbursts. Then followed another interval of rest, during which the newly-formed piles of lava, mud, and ash were eroded into ridges and valleys.

In the final paroxysm were poured out floods of rhyolitic lavas that filled up the valleys and flowed over the andesitic uplands. Thus we find that the volcanic activity which began in the Miocene with the effusion of andesitic lavas culminated, probably, in the newer Pliocene, with the emission of rhyolites, the highly acidic magmas following the semi-basic.

In the expiring phases of both the andesitic and rhyolitic outbursts there was widespread hydrothermal activity, which resulted in the formation of the metalliferous veins and mushroom-shaped sinter deposits that are scattered throughout the peninsula.

The first period of andesitic activity produced mainly lavas, alternating with showers of fine ash and mud that now form beds of tuff; the second period, mainly fragmentary material intercalated with minor flows of lava. To the miner the importance of this succession of material lies in the circumstance that many of the gold-bearing veins in the Hauraki Peninsula are in the andesitic flows of the first and perhaps greatest period of activity. The veins occurring in the coarser andesitic tuffs and breccias contain very little gold, while those in the rhyolites are seldom payable.

There are many veins in the basement sedimentaries, but so far they have proved relatively unimportant. They appear to have been formed contemporaneously with the veins in the older andesites.

The basement rocks are intruded by dykes of diorite, hornblende-andesite, and rhyolite; the andesites, by dykes of porphyrite. These dykes do not occur in the goldfield areas, and appear to have no connection with the genesis of the gold-bearing veins.

The andesites at the Waihi, Karangahake, Thames, and Coromandel centres of eruption are traversed by gold-bearing veins, and within the metalliferous zones are altered to a moderately soft grey rock composed mainly of chlorite, sericite, calcite, quartz, pyrites and other secondary products. This altered andesite is the rock in which the profitable veins are nearly always found.

Deep-seated Alteration of Andesites.—The soft bluish-grey pyritic kindly country of the miner is found in the deepest workings at the Thames, Coromandel, and Waihi, nearly 1,000ft. below sea-level, where the influences of surface weathering and decomposition could not possibly reach, thereby leading to the conclusion that hydrothermal action was the active agent concerned in the alteration of the andesite. In the lower levels of the Moanataiari, Waiotahi, Cambria, and Alburnia mines the transition from the hard undecomposed lavas to the soft, *kindly country* is often so gradual as to be imperceptible.

The hard bars traversing the soft country in the May Queen, Trenton, Moanataiari, and other Thames mines, in the basins of the Moanataiari and Waiotahi streams, contain distinct layers of fine tuff, and coarser ashes forming mottled breccias, but in most cases the matrix passes insensibly into solid andesite.

The hard belts of rock separating Dixon's, Sons of Freedom, Reuben Parr, and Golden Age reefs, consist of compact greenish-blue augite-andesite, which in places assumes a coarser texture, being black spotted on weathered surfaces, with large crystals of hypersthene.

The undecomposed cores, or bands of hard country on the seaward side of the Moanataiari fault, consist principally of indurated tuffs and ash-beds, or breccias of various degrees of texture intercalated with flows of hyperstene-augite-andesite.

In the process of alteration of the andesite three stages may be easily recognised.

First, the decomposition and hydration of the bi-silicates (the pyroxenes), resulting in the formation of chlorite and bastite, and the partial elimination of the liberated silica, iron, and lime.

Second, the destruction of the felspars with the formation of carbonates and kaolin, accompanied by the leaching and gradual removal of the secondary chlorite, and the alteration of the titaniferous iron into pyrites.

Third, the hydration and gradual removel of the iron oxides, together with the leaching out of the carbonates, leaving behind quartz, kaolin, and pyrites.

The soft gold-bearing country is almost entirely composed of secondary products.

The pyrites disseminated in the Thames rocks is found in all but the more solid lavas, and it certainly appeared at an early stage in the process of alteration.

In the mines at the Thames in the vicinity of the hard bars the country is saturated with CO_2 gas, which often interferes with the mining operations, especially during periods of low barometic pressure.

It is probable that after the volcanic forces which originated these rocks had spent themselves, solfatara action took place and continued in operation for a long time. In support of this we still have the thermal mineral springs at Te Aroha issuing from the same class of rocks.

The leaching action of thermal waters, doubtless accompanied by steam and acid vapours, would be more rapid and deep-reaching than the action of surface waters.

The former existence of solfatara action would satisfactorily explain the presence of the altered gold-bearing rocks at depths far below the reach of surface decomposition.

Propylite or Altered Andesite.—The soft gold-bearing rock, or *kindly country*, is now acknowledged to be an altered andesite, but for many years there was much controversy as to its true character and proper designation.

In 1868, Von Richthofen adopted the distinctive term "propylite" for the grey altered ore-bearing rocks of the Comstock lode, a name which was subsequently adopted by the officers of the United States Geological Survey.

In 1876, the result of Zirkel's microscopic examination of the North American rocks was published, and in this work he endeavoured to justify the retention of the term propylite as a distinct type of rock, although he went so far as to admit its association with the Tertiary lavas. In the following year

Rosenbusch refused to accept the name propylite as a distinctive group, but classed many rocks known as such with the andesites.

In 1879, Doelter showed that the Hungarian rocks, which possessed the features held by Von Richthofen and Zirkel to be characteristic of the propylites, could be seen to pass insensibly, by a gradual process of alteration, into ordinary andesites. Shortly after this Doelter's view was strongly upheld by Rosenbusch, and in the same year Wadsworth very forcibly insisted that the distinction between the propylites and andesites could not be maintained in the case of the North American rocks.

In his "Geology of the Comstock Lode and Washoe District, 1882," G. F. Becker states that the grey altered ore-bearing rock, which corresponds with the "kindly country" of the Hauraki goldfields, could not be regarded as a distinct group of rocks, but only as a distinct *facies* or habitus of the andesitic lavas. The microscopic examination of a large number of the rock specimens obtained in the deepest workings and during the construction of the Sutro tunnel enabled Becker to show that by the gradual alteration of their constituent minerals, the hornblende and augite-andesites gradually acquired those characteristics which had been held to be peculiar to the propylites.

In 1886, Rosenbusch accepted the term propylite, not, however, as indicating a distinctive group of rocks as originally contended by Richthofen and Zirkel, but only as a convenient name serving to distinguish a well-marked and interesting pathological variety of the andesitic type of rock. There seems to be no good reason why the term should not be used in the restricted sense suggested by Rosenbusch.

Types of Andesite.—The prevailing rocks are hypersthene-andesite, hypersthene-augite-andesite, enstatite-andesite, and quartz-andesite or dacite. North of Tapu, numerous dykes of hornblende-andesite are found intruding the mudstones and greywacke of the Juro-triassic basement rocks.

Pay-shoots.—The mining operations of the past 35 years have shown that in the different belts of propylite there are certain zones in which the lodes are more productive than in others. Even in the case of several parallel lodes, it has been found that all become enriched on entering the favourable zone, thus affording proof of the Cornish aphorism, *ore-to-ore.*

There are several such zones in the Moanataiari end of the Thames field, the best known being those at Kuranui Hill and Point Russell. The latter affords, perhaps, the most graphic illustration of the influence of favourable country. At that place the Moanataiari mine is traversed by four large parallel lodes—namely, the Dauntless, Reuben Parr, Golden Age, and Waiotahi, all pursuing a N.N.E.-S.S.W. course. On entering the productive zone, the ore changes from excessively low-grade to high-grade, this character being maintained till the zone is passed through, a distance of 600ft. This zone crosses the course of the lodes nearly at right-angles.

The payable gold occurs in the reefs in shoots, which are sometimes many hundreds of feet in length, and extend from level to level to a great depth, or are little more than narrow chimneys.

The reefs are generally richest where they are widest, the Martha, Crown, Caledonia, Golden Age, and Tokatea lodes affording noteworthy examples of this fact. At the historic Caledonia bonanza, the reef swelled out to a width of 30ft. The swelling is often due to a *horse* of mullock, or country, coming into the lode. A *horse* is always a favourable indication of a pay shoot, and is symbolized in the miner's saying that *a horse pays for itself*.

The pay-shoots are vertical, inclined, or flat, and in cases have been found to have a considerable linear extension with a depth of not more than a stope or two.

In the May Queen section of the May Queen Hauraki mine, the payable shoots of ore gradually widen out with each successive level, the longitudinal section of the stopes resembling a truncated cone.

The rich bonanzas for which the Thames and Coromandel goldfields are celebrated occur in the richer zones, and are places where the quartz contains coarse visible gold, forming what is locally called *picked*, or *specimen stone*, which is frequently found to yield as much as six ounces of gold to the pound of ore. They are found both in the small cross-reefs and in the large major lodes.

The Hauraki bonanza varied from 100ft. to 120ft. wide, and extended to the 300ft. level from a point about 60ft. from the surface. It plunged slightly to the north-east, and was cut off by a fault about 30ft. from Bunker's boundary.

In the Thames and Coromandel lodes, the rich places, or "shoots," most frequently occur in the main lode along the line of intersection of a cross-vein or "flinty."

The cross-veins vary from a mere thread to a few inches in thickness, and are often very rich. They are mostly found in the propylites. In the Cambria and Waiotahi mines, at the Thames, they are very numerous, and often black-coloured from the presence of ferrous sulphide.

Source of the Gold.—The information on this point is still very meagre and unsatisfactory. There seem to be two possible sources. The gold may have been carried upward from a deep-seated source by ascending thermal waters and steam, or it may have been leached out of the andesites by ascending magmatic waters. Careful research alone can solve this difficult problem.

But even if investigation should prove that the fresh andesites contain gold, it is obvious that such gold must have been originally magmatic, and therefore derived from a deep-seated source.

Form and Fineness of Gold.—The gold occurs principally as fine irregular grains, threads, and thin plates or scales, but one or all of these may be found in the same hand-specimen. The author has not infrequently met with crystallised gold, occurring mostly as cubes and octohedrons, arranged in short wiry strings, but regular well-shaped crystals are rare.

The gold is alloyed with silver to the extent of 30 or 40 per cent., the value ranging from 48s. to 56s. per ounce. The value varies in the different lodes, and even in the same lode the value will sometimes vary several shillings per ounce within the height of a stope.

The gold from the Kuranui Hill is usually of less value than that from other parts of the Thames, while that from the Sylvia reef system in Tararu Creek is much higher, ranging from 60s. to 72s. The gold obtained from Hunt's Shotover claim was valued at £2 9s. 8d. per ounce; from Barry's reef, £2 10s.; from Tookey's claim, £2 15s.; and from the Golden Crown at £2 15s. 10d. The present average fineness of Thames gold is about 680. The average value of the Coromandel gold is about £3 per ounce, and of the Hihi gold £3 3s.

Paragenesis.—The minerals associated with the gold are mostly very characteristic, and are generally spoken of by the miners as "favourable minerals." The most common and abundant is iron pyrites. After this, in the order of their common occurrence, come copper pyrites, zinc blende, stibnite, and ruby silver.

In the Tararu system of reefs, the gold is always associated with galena, manganese oxides, and calcite, besides blende, iron and copper pyrites. The former is seldom or indeed never seen in the Thames area, while calcite and manganese oxides are not at all common.

In the rich patches in the Una Hill, pearl spar is always found with the gold.

The distinctive and most favourable minerals in the different parts of the Thames goldfield are as follows:—In Una Hill and Karaka, pearl spar; in the central and northern divisions, ruby silver, copper pyrites and stibnite; and in Tararu Creek, galena, resinous-coloured blende, manganese oxides, and copper pyrites.

In the Occidental mine in Una Hill, resinous-coloured blende is a constant associate of the gold in the rich parts; and in the Moanataiari, Cambria, and Waiotahi mines the *specimen stone* is generally encrusted with ruby silver and radiating crystals of antimonite.

Arsenical pyrites and native arsenic are characteristic of the Coromandel goldfield, but are rarely seen at the Thames or Ohinemuri fields.

The common associate of the gold at Waihi is pyrites, with which there also occurs argentite. Selenium occurs in the bullion of the Waihi mine as obtained from the cyanide process of extraction, but the form in which this rare metal occurs has not yet been ascertained.

Gold-bearing Veins.—The veins in each mining centre occur in groups or systems in which the constituent veins are more or less parallel to each other and often linked up by subordinate cross-veins. They occur along lines of fracture through which the hot mineralising solutions and vapours ascended from below. their great width being due to the metasomatic replacement of the wall-rock along the course of the initial fracture. The deep-seated alteration of the andesite progressed outward from the walls of the fissure for varying distances on each side. In the case of veins lying near each other the rock was completely altered from vein to vein, forming what is known to the miners as *kindly country;* but where the veins were far apart there often remained between them an irregular core or lenticle of unaltered andesite, locally termed a hard bar or dyke.

These lenticular sheets of unaltered andesite commonly run parallel with the veins to unknown depths; but in a few cases they have been proved by mining operations to taper out both in length and depth, thus forming what might be termed *floating lenticles.*

The veins of the Hauraki goldfields group themselves into two great classes, namely, bonanza-veins and bullion-veins. The bonanza-veins occur in the lower andesites, commonly not far from the basement rock. To this class belong the veins of Thames, Tapu and Coromandel.

The dominant veins of these goldfields are large well-defined bodies of crystalline quartz that can sometimes be traced on the surface for many miles. Going downward they have been followed to a depth of nearly 1,000ft. below sea-level without change of course or decrease in size. Of typical examples at the Thames we have the celebrated Caledonia No. 1 reef, from 9in. to 30ft. wide; the Caledonia No. 2 reef, from 4ft. to 12ft.; the Waiotahi reef, from 8ft. to 40ft.; and the Mariners reef, from 2ft. to 20ft. wide, all distinguished for their continuity in depth and linear extent.

Gold is present in all parts of the bonanza-veins, but the profitable ore generally occurs in irregular shoots of limited extent. The distinguishing feature of these veins is the occurrence in them of isolated patches of rich ore commonly at and along the junction-line of a pyritic cross-vein. The rich ore is locally termed *specimen stone*, the best of which is a matted tangle of coarse gold and quartz, often of fabulous richness. A specimen patch may contain a few pounds or many tons of rich ore.

The minerals associated with the bonanza ore are commonly pyrites, zinc-blende, chalcopyrite, ruby silver, stibnite, and sometimes native arsenic.

The gigantic Martha lode at Waihi, with its great branching veins, and the Crown and Talisman lodes at Karangahake are typical examples of the celebrated bullion-veins of the Hauraki Peninsula. They occur in a higher horizon of the andesites than the bonanza-veins of the Thames and Coromandel goldfields, and always lie in, or contiguous to, the rhyolitic areas.

The most productive veins of this class are strong well-defined ore-bodies, composed mainly of chalcedonic, or sinter-like, quartz of hydrothermal origin, often showing a banded or ribbon-like structure in the upper levels. In the deep ground the ore is intersected by numerous small secondary veins of crystalline quartz formed at a later period.

The most distinctive features of the Waihi lodes are their hard flint-like vein-matter, and the wonderful continuity and uniformity of the pay-ore in linear extension and in depth. The values lie in free gold, generally occurring in very fine particles, and silver mostly in the form of argentite. The free gold is alloyed with about 30 per cent. of silver.

The Martha, Royal, Empire, Welcome, and other associated veins are situated on the rim of the ancient Waihi volcano. They are contained in altered andesites and dacites plunging steeply into the old vent; and as they stand at high angles, they are likely to descend to a greater depth than ever mining operations can follow them. And so long as they remain in the same class of country there is good reason to believe that the ore-values will be maintained with increasing depth. This should also be true of the Talisman lodes, which run across the throat of the ancient Waitawheta volcano.

The Thames lodes are situated near the rim of the old Waiokaraka volcano, which is surrounded by comparatively gently-inclined sheets of andesite and andesitic tuffs that dip southward. The lodes for the most part dip away from the old vent, and in descending pass successively through different kinds of rock, some of which are more productive than others. The different zones of rock, both lean and rich, dip southward, which is towards the vent of the ancient volcano.

The Thames goldfield is traversed by several powerful faults which have caused a serious dislocation and displacement of the productive zones and the contained lodes. Of the faults the best known is the Moanataiari fault, on the seaward side of which has been found the bulk of the rich bonanzas for which this goldfield has so long been celebrated. This important fault has been already fully described. (See p. 258).

Along the foreshore there is what is termed the Beach-slide, against which all the productive lodes have been found to terminate abruptly. Beyond this slide the mine workings down to the 640ft. level, that is 600ft. below sea-level, have passed, not into solid country, as might be expected, but into harbour muds, sands and gravels. Obviously the Thames harbour and valley must be an area of subsidence filled in with *débris* at a comparatively recent date.

In connection with the future of this field it is of paramount importance to determine the depth of this *débris*, and to ascertain whether the submergence of the floor of the harbour is the result of the downthrow caused by the Moanataiari fault alone, or by the united downthrow of the Moanataiari fault, and the Beach-slide. If the former, it would seem that the prospect of a second goldfield below the floor of the harbour is not very bright; but if the latter, the future should hold in store great possibilities for this historic mining centre.

Speaking broadly, the future of the Thames goldfield seems to be dependent on (*a*) the discovery of a new floor or zone of payable ore; and (*b*) on the continuity of the rich lodes below the harbour. There is good reason for the belief that the lodes lying in the area between the Waiotahi and Karaka Creeks, being nearest the old pipe, will descend in good country and carry gold to a great depth, or till cut out by the Moanataiari fault. Whether the lodes on the north side of the Waiotahi will pass through another productive zone is a question that can only be determined by cross-cutting, a work, moreover, that must in any case precede the exploration of the harbour floor.

Metallurgical Treatment of Ores.—The improvements introduced into the processes of gold recovery have been so great that the methods of the seventies and eighties have been completely revolutionised.

In the decade from 1870 to 1880 the processes of gold recovery consisted of:—

(*a*.) Crushing the ore in Californian stamp-mill with hand feeding.

(*b.*) Amalgamation in mortar boxes.

(*c.*) Amalgamation on copper or muntz-metal plates.

(*d.*) Blanket concentration.

(*e.*) Concentration in straight bundles.

(*f.*) Grinding and amalgamation of concentrates in Burdan and Chilian pans.

In the next decade the only marked improvements were the introduction of continuous grinding and amalgamation pans, mostly the Wheeler and Watson-Denny: and of combination amalgamating pans, these last being installed by the Waihi company for the treatment of their dry siliceous argentiferous gold-ore. Hand feeding of the mills was still universal.

The year 1890 saw the beginning of a new era. The roasting and chlorinating of the concentrates, which appeared in the previous decade, was now abandoned, the operations first at the New Zealand Crown Mines and afterwards at the Sylvia Mine having demonstrated the value of the cyanide process for the treatment of the crushed ore, of pyritic concentrates, and of quartzose tailings. But the cyanide process was not simple. It required considerable technological skill for its successful operation. In 1893 the Waihi Company discarded the pan-amalgamation of its ore in favour of cyaniding, the ore being first dry-crushed and then cyanided in wooden vats.

For the treatment of the free-milling gold ores of the Thames goldfield, improved batteries were erected, concentration being effected by vanners of various types, including the Free, Union, Triumph, and Luhrig. Mechanical feeding was now universal.

The dry siliceous ores of Waihi, Waitekauri, Karangahake, and Komata were for some years treated by dry-crushing and direct cyaniding, but by 1900 most of the mills had adopted wet-crushing, either with or without cyanide solution in the mortars, followed by concentration, the sands, slimes, and concentrates being treated by cyaniding, the sands by percolation, and the concentrates by agitation with compressed air in tall steel cylinders.* The successful treatment of the slimes had always

*The author patented a cyanide process for the agitation and treatment of sands and slimes with compressed air in 1894. (See "Handbook of Practical Cyanide Operations," by Dr. W. H. Gaze, Melbourne, 1898, p. 11.) Compressed air is now used extensively throughout the globe for the agitation and treatment of argentiferous gold-ores and concentrates.

presented a difficulty, but this was overcome by the introduction of filter-presses. Filter-pressing, although successful, was slow, and from its comparative cost prohibitive in the case of low-grade slimes. It was never held much in favour in New Zealand, and is now practically abandoned.

In 1900 the Waihi Company introduced the vacuum basket-filter, a modification of the Moore process, and its use has been attended with marked success. The slimes that were formerly the bugbear of the metallurgist are now a desideratum, and tube-mills for the production of slimes have been installed at all the large mills.

Geology of Goldfields of Otago.

In Otago the gold-bearing veins occur in mica-schist, both as fissure lodes and as lenses of quartz running more or less parellel with the foliation planes. It is not without significance that the fissure veins commonly occur in the highly altered Maniototian schists, and the bedded ore-bodies in the less altered upper schists of the Kakanuian.

Besides these two systems of lodes there occur in the Maniototian certain crush-zones along which silicification, accompanied by impregnation with gold, generally in very fine particles, has taken place to a profitable extent.

Thus in Otago we have presented to us gold-bearing ore as it occurs in the following forms:—

1. Fissure veins, as at Barewood and Bendigo.
2. Bedded veins, as at Macrae's.
3. Crush or shear zones, as at Shepherd's Creek, Bendigo.

Genesis of the Bendigo Fissure Lodes.

Origin of Fissures.—A close investigation of these lodes shows that they are what might be termed "lode-formations" rather than true lodes. They are mineralised zones of crushed rock lying between two parallel lines of fracture. Their main characteristics are so persistent and distinctive that they form a type of lode for which the writer has adopted the name *immature replacement lodes.*

In many places the lodes consist merely of a zone of crushed country lying between two sharply-defined fissures, on the walls of which there frequently lies a thin layer or clay or *flucan* formed by the movement of the wall-rock. In the majority of the lodes at Bendigo and Carrick ranges, where this type of lode is characteristically developed, the mineralization has started at both walls simultaneously and progressed towards the centre. Where the replacement is complete the quartz fills the lode from wall to wall. Where less complete replacement has taken place there is a thin vein of quartz on one or both walls, forming a sheet-like ore-body running parallel with the walls. In many places these wall-veins are joined by numerous ramifying veins of varying size.

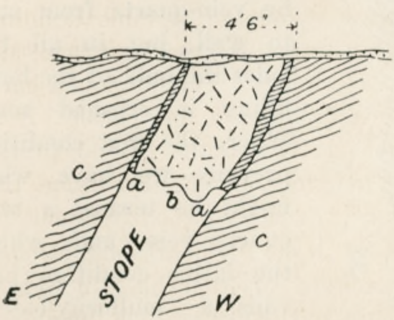

Fig. 129. Cross-section of New Caledonia Lode.

a. Quartz veins. *b*. Crushed rock. *c*. Mica-schist.

Judging from the unbroken character of the quartz-filling in many of the lodes, it is obvious that the crushing of the country took place before the filling began.

Horses of country that have been broken from the walls, and thus become included in the lode-matter are found occasionally in the large lodes at the Thames, but they are accidental happenings. They do not occupy the lode for its whole length, nor do they affect all the lodes. The Bendigo and Carrick lodes possess characteristics that are persistent in every lode throughout its length and depth. The chief characteristics of this immature replacement type of lode are as follow:—

1. They lie between two parallel fractures, on which more or less faulting has taken place.
2. They traverse the country rock independently of the planes of bedding or foliation.
3. The lode-matter lying between the walls consists mainly of crushed rock traversed by veins of quartz.
4. The crushed rock is more or less silicified and replaced by quartz. The extent of replacement is variable, even in the same lode.

As above stated the quartz was deposited first along the walls, giving sometimes, as in the case of the Caledonia lode on Carrick Range, two opposite, parallel, and contemporaneous veins separated by a zone of crushed rock. In other cases the quartz was deposited on one wall only.

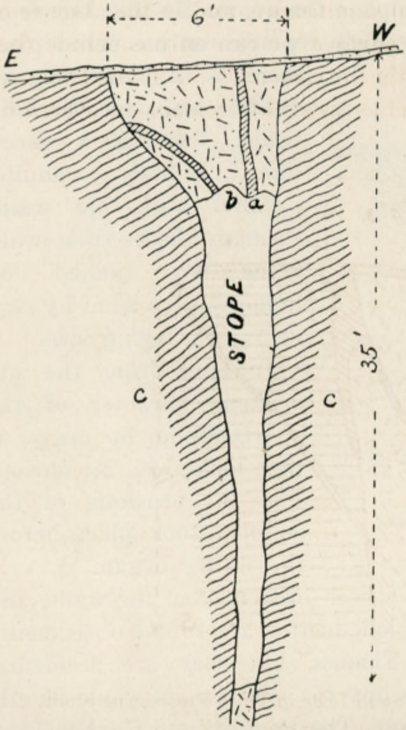

Fig. 130. Cross-section of Caledonia Lode at Stope passing under Nevis Road.
a. Quartz veins. *b.* Crushed rock. *c.* Mica-schist.

In some places the crushed rock is replaced by vein-quartz from wall to wall, but in all the lodes the bulk of the lode-filling is crushed rock. Where the first condition prevails we have what might be termed a true quartz vein, and, where the latter condition prevails, a "mullocky-lode." Between these two extremes we can trace every stage in the evolution of the massive quartz vein; and in this we have a valuable and instructive object-lesson in the genesis of ore-deposits that occur as veins.

Associated Minerals.—The following cases of paragenesis have been recorded by Finlayson[s]: (1) Gold, iron-pyrites; (2) gold, iron-pyrites, stibnite; (3) gold, iron-pyrites, stibnite, galena; (4) gold, iron-pyrites, galena, zincblende; (5) gold, iron-pyrites, bournonite, zincblende; (6) gold, iron-pyrites, scheelite; (7) gold, iron-pyrites, scheelite, stibnite; (8) gold, iron-pyrites, scheelite, stibnite, galena; (9) gold, iron-pyrites, cinnabar; (10) gold, iron-pyrites, copper-pyrites.

s. A. M. Finlayson, Trans. N.Z. Inst., vol. xli., p. 83.

Origin of Vein Matter.—At Bendigo the lodes traverse almost horizontal mica-schist, and at Carrick Range generally steeply inclined strata. At both places there is an absence of igneous rocks of any kind.

The fault-fractures in which the lodes lie do not appear to have any tectonic or structural significance, and in the absence of igneous rocks showing at the surface we can only conclude that the fissuring was caused by the intrusion of an abyssal magma that cooled so far from the surface as still to remain uncovered by denudation.

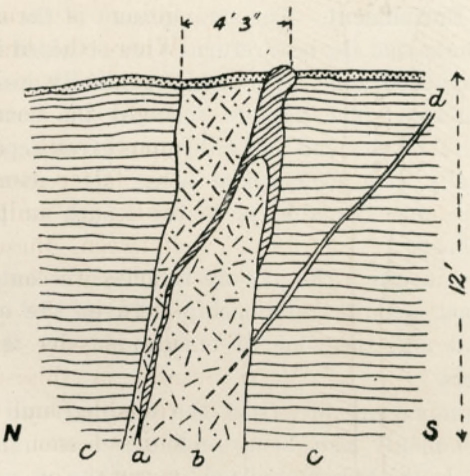

Fig. 131. Cross-section of Cromwell Lode in Third Prospecting Shaft, 3 chains from terrace.

a. Quartz vein. *b.* Crushed schist. *c.* Mica-schist. *d.* Foot-wall vein.

The presence of scheelite, the somewhat rare tungstate of lime, at Bendigo, of antimony, at Carrick Range, and of cinnabar at Waipori in similar lodes, would tend to support the contention that the metalliferous emanations and solutions ascended from below by cracks and fissures connected with an intrusive magma.

Age of Lodes.—The lodes of Otago are found in rocks of Cambrian and Silurian age, and the detrital rocks overlying them in the old lake basins are probably not older than Miocene. There is no evidence to show at what period between the Silurian and Tertiary the fracturing and vein-filling took place, but judging from the date of lode-formation in America in similar rocks, we have no reason to suppose that the Otago lodes are of extreme antiquity. That they were profoundly truncated before the Miocene is clearly proved by the presence of gold-bearing quartz in the auriferous drifts of the Manuherikia lacustrine series.

The Juro-triassic rocks that lie on the south-west flanks of the mica-schists in Southland contain no quartz-lodes. That this circumstance has any bearing upon the question of the age of the lodes of Central and Western Otago is open to doubt, but if it has not then the age of the lodes may be placed somewhere about the Cretaceous until more exact data are available.

Secondary Enrichment.—The arrangement of the old workings leaves little doubt that the best returns were obtained in the upper part of the oxidized zone, at a depth generally less than 50ft. below the outcrop. The pay-ore followed the contour of the ground, but did not descend vertically to a great depth. The ore was not equally rich everywhere along the outcrop, but no information is now available as to the length or pitch of the various pay-shoots.

The manner in which the pay-ore followed the outcrop clearly establishes some definite relationship between the surface-form of the ground and the zone of enrichment, by the action of meteoric waters.

The blue unoxidized ore from the deep ground at Carrick Range was commonly lean, being seldom rich enough to pay for working out. In the brown oxidized ground the ore was generally highly payable, and, as we have just seen, descended to a certain limited depth below the outcrop, whether on hilltop or steep slope. Hence we have reason to believe that the rich ore in the oxidized zone is the result of what is termed "secondary enrichment."

In accordance with this principle it is assumed that as the outcrop of the lode during countless ages became worn down by denudation the gold was liberated. A portion of this gold was carried into the neighbouring washdirt, while another portion was dissolved by mineral acids, liberated from the decomposition of the contained iron-sulphides, and carried downwards in solution through the upper oxidized zone, where it was redeposited in the crushed rock and clay, thereby enriching the existing lean ore, which thus became payable.

The precipitation of the gold in this process of concentration presents fewer difficulties since Skey, Kohler, and Weed have shown that clay and finely divided mineral matter possess the power of absorbing or extracting metals from their dilute aqueous solutions.

Secondary enrichment provides a satisfactory explanation of the circumstance that the rich pay-ore follows the contour of the ground along the outcrop of the lodes.

Alluvial Goldfields of Otago.

Alluvial gold in greater or less quantity is found in all the Recent and Pleistocene detrital deposits existing in Otago, and also in some of the Miocene lacustrine drifts. Of a total gold production to the end of 1909 of about 7,000,000ozs., valued at some £28,000,000, no less than 6,500,000ozs. have been won from alluvial sources.

There are seven distinct and easily recognisable classes of alluvial deposit that have been, or may in time become, a source of gold. They are stated hereunder in accordance with their age, beginning with the most recent at the top and reading downwards—that is, the deposits are arranged in the order of their succession in time, as shown by their superposition. They will be described in detail as they may be taken as typical of similar deposits in other parts of New Zealand.

Recent—

1. Crumbling schist and schistose wash.
2. Gravels and sands in the bed of Clutha and Kawarau Rivers.

Pleistocene—

3. Re-sorted fluvio-glacial drift, mainly derived from 4.
4. Fluvio-glacial deposits and moraines.
5. Fluviatile drifts forming terraces.

Older Pliocene or Miocene—

6. Sandstone gravels—"Maori bottom."
7. Quartz drifts—"Granite wash."

7. **Quartz Drifts**.—These occur at or near the base of the lacustrine series, and hence they follow the outcrop of that series around the margin of the Cromwell, Manuherikia, Ida Valley, and Maniototo basins. They form very few natural outcrops, being in most places buried underneath heavy detrital deposits of Pleistocene or later date. They crop out on the banks of the Kawarau and lower Bannockburn, but at Tinkers, St. Bathan's, and elsewhere their presence has only been disclosed by the sluicing-away of the overlying gravels in the course of alluvial mining.

The quartz drifts are mainly composed of angular pieces of quartz of all sizes up to an inch in diameter. They are commonly loose and incoherent, often sandy, and sometimes clayey.

At the mouth of Smith's Gully—that is, at the point where Smith's Creek enters the schist country at the foot of Carrick Range, and on the road leading from the Kawarau Bridge to Bannockburn—the quartzose drift is occasionally cemented by iron-peroxide into rusty-coloured layers of conglomerate. These layers are not continuous, and seldom over 6in. thick.

These drifts are important from the fact that they have proved a prolific source of gold at Tinkers and at St. Bathan's, in the Manuherikia basin· They always contain a little gold; but payable gold has only been found at the points where streams draining gold-bearing country have entered the old lake-basin.

The gold in the quartz drifts at Tinkers and at St. Bathan's is very fine; and tests of the wash made with the prospecting-dish are not always satisfactory, notwithstanding that mining on a large scale has been attended with profitable results for a number of years.

The problem that confronts the prospector is this: Were the gold-bearing veins on the Carrick Range subject to denudation at the time the quartz drifts were being deposited? The drifts, we know, are composed of quartz derived from the adjoining country, and the angular character of the quartz shows that it has not travelled far. Further, the writer has proved that fine gold at least occurs in the drifts at Cromwell and Bannockburn. The answer in the affirmative, based on the facts disclosed there and at St. Bathan's, seems to be a fair and reasonable conclusion.

6. **Sandstone Gravels.**—These consist of yellowish-brown sandstone gravels, well rounded, and fairly uniform in size. The material seldom exceeds 6in. in diameter, and is generally much decomposed.

These gravels form the well-known "Maori bottom" of the Maniototo and Manuherikia basins. They contain gold, but not in payable quantity. Their chief importance lies in the circumstnce that they form the false bottom on which the younger gold-bearing drifts rest on the high terraces between Lowburn and the head of Five-mile Creek, at Quartz Reef Point, at Naseby, and other places in Central Otago. In age they are related to the Moutere gravels of Nelson and West Coast.

At Naseby the "Maori bottom" is being worked for gold, but it has not proved very profitable.

5. **Fluviatile Drifts forming Terraces.**—These form the terrace known as Cromwell Flat. They are well seen along the banks of the Kawarau and Clutha, where they underlie the coarse, modified glacial drift. They are also extensively developed between Clyde and Alexandra, and at many places in the lower Clutha Valley.

The material composing this terrace is purely river-drift, and consists of varying proportions of sand and gravel. It is laid down in more or less distinct layers of varying degrees of texture. The coarser layers commonly contain the best gold.

A considerable area of this drift has been sluiced away above the Chinese camp at Cromwell, and at the present time it is being cut away by dredges at the river-edge between Cromwell and Deadman's Point, and between Clyde and Alexandra, and is yielding payable returns.

On the Bannockburn side of the Kawarau, opposite Cromwell, and between Cromwell and Deadman's Point, this drift rests on the schist bottom—that is, it lies on the schist around the margin of the old lake-basin. Towards the dip it passes off the schist or "reef" bottom on to the lignite series, which dips away to the westward.

The outcrop of the upper members of the lignitic series, as seen in the upper end of the deep tail-race half a mile above the Chinese camp, shelves rapidly under water-level into what appears to have been an old channel of the Kawarau, running parallel with the present face of the terrace at this place.

A quarter of a mile above the tail-race the Kawarau issues from a channel cut in the schist; and at the Bannockburn Bridge the river runs through a similar rock-cut channel.

These rock channels are of comparatively recent date, and are merely short cuts that the river has made for itself through flat spurs of schist that projected into the old basin.

Old Leads in Cromwell Basin.—There are three alluvial leads at Quartz Reef Point, known as No. 1 or River lead, No. 2 lead, and No. 3 lead. These leads run more or less parallel with the present course of the Clutha River, and are old gutters formed by the river at different levels as it cut its way down to its

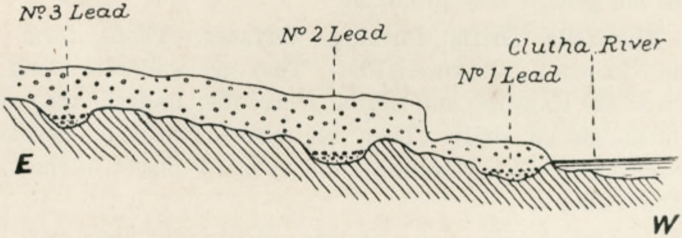

Fig. 132. Section showing position of gold leads at Quartz Reef Point. Scale, 5 chains to an inch.

present channel. They were very rich, and, although no longer being worked, are of great interest from the light they throw on the distribution of the gold along the old river channels.

4. **Fluvio-glacial Deposits and Moraines.**—Every glacier that descends a valley is drained by a river; hence, country that was once overrun by a glacier is found to contain two classes of transported material—namely, one transported by ice, the other by water.

The glacier carries on its back a load of broken rock and rocky *débris* that has fallen down from the high lands on each side of the valley. Here we find that the load is not spread evenly over the surfare of the ice, but occurs as long lines, one on each side of the glacier, as shown in Fig. 133.

As the ice advances the rocky load is carried forward, and in time reaches the end or terminal face of the glacier, where it is tipped and piled up in a confused mass on each side of the valley.

The river which drains the glacier brings down the usual gravels and sands found in river-beds.

At certain points below the terminal face of the glacier the morainic matter and river-gravels are mingled in the manner shown in Fig. 134.

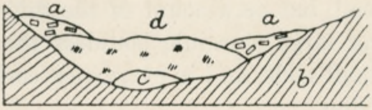

Fig. 133. Section of Glacier above Terminal Face.
a. Moraines. *b*. Basement rock. *c*. Glacier tunnel. *d*. Glacier-ice.

Where the country is gold-bearing, the glacier gravels and morainic matter contain gold. But the moraines are formed by ice, which cannot sort the gold from the rocky *débris*; hence the gold is scattered through the *débris* just as the glacier happened to drop it.

Even at the places where the morainic matter and the gravels mingle the gold is not concentrated into leads, but occurs in pockets at the points where the current has been arrested by large ice-borne rocks.

A glacier deposits morainic and fluvio-morainic matter both in advancing and retreating. But the matter deposited during the advance is broken up and overrun by the ice, while that dropped during the retreat remains in the wake of the glacier.

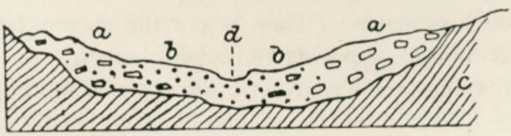

Fig. 134. Section of Glacier Valley below Terminal Face.
a. Glacier-moraines. *b*. Glacier river-gravels. *c*. Basement-rock. *d*. Glacial river.

Morainic matter left in a valley is often re-sorted by the glacier river, and in this re-sorting process any gold present in the drift becomes more or less concentrated into leads.

The fluvio-glacial deposits at the lower end of the Kawarau Gorge are typical examples of the class of glacier transport-work described above. The Kawarau moraine, three miles from Cromwell, is composed of rocky matter that fell from the Pisa Range side of the gorge on to the advancing ice. It is therefore a lateral moraine.

On the lower face it is mixed with gold-bearing river-wash; and several paddocks have been taken out in it a few chains back from the main road, but on account of the difficulty and danger of working among large morainic boulders the operations were conducted on a small scale, and in every case confined to the talus slope of the moraine.

3. **Re-sorted Fluvio-glacial Drift.**—The gravels formed by the glacier river are largely a rewash of the morainic matter tipped into the valley at the terminal face of the glacier.

When the glacier begins its last retreat, the river, having little supply of fresh matter to operate on, devotes its energy to cutting away and destroying the lateral moraines that were formed along the old line of retreat.

The existence of Clyde moraine, and the presence of the fluvio-morainic matter which we find spread over the lower end of Manuherikia basin, tell us that the Clutha-Kawarau glacier occupied the Dunstan Gorge for a considerable period. At one time this great glacier reached as far as Alexandra, where it blocked the outlet with *débris* to such a height as to permit the accumulation of the fluviatile and fluvio-glacial drifts that form the terraces between Springvale and Clyde.

The glacier retreated from Clyde and took up its next stand at Cromwell, where the outlet in time became blocked by the piled-up morainic matter. Then began the accumulation of the fluvio-glacial drifts composing the flood-plain, of which the high terraces that fringe the Cromwell basin are a remnant.

After the filling-in of the *débris*-blocked basins, the outlets began to be cleared out, and then commenced a period of destruction, during which the flood-plains were benched into the beautiful terraces we now see at Lowburn, and in the lower end of the Manuherikia Basin.

During this period of fluviatile destruction the Kawarau glacier entrenched itself in the Kawarau Gorge, where, sheltered by Pisa Range from the northern sun, it piled up a moraine along its exposed face.

The Clutha glacier beat a retreat at the same time, and from the small amount of morainic matter left behind we can conclude that its recession was relatively rapid and continuous. For, unlike the Kawarau glacier, which lay snugly sheltered in a deep gorge, it occupied a wide open valley exposed to the blaze of the morning and noonday sun. Hence it tarried nowhere, but receded rapidly to the upper end of the valley without leaving any morainic piles to mark its line of retreat.

After the reopening of the Cromwell outlet, which, as we have seen, was accompanied by the excavation and benching of the flood-plain not long formed, the Kawarau glacier once more advanced to Cromwell. Its narrow front ploughed out a channel in the fluviatile drifts forming Cromwell Flat.

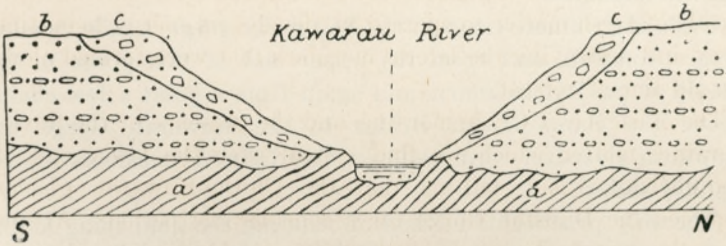

Fig. 135. Section across Kawarau River near Cromwell.

a. Mica-schist. *b*. Fluviatile drifts. *c*. Re-sorted fluvio-glacial drift.

The glacier soon after began its final retreat, scattering in its wake a confused mass of river-drift and morainic matter, which follows pretty closely the present course of the river.

This fluvio-glacial matter, since partially re-sorted by the river, was the source of the bulk of the alluvial gold found in the Cromwell district in the "seventies." It occurs on both sides of the Kawarau near Cromwell, and has long since been turned over.

It also forms the tongue of land on which the lower part of Cromwell is built, and thence passes up the west bank of the Clutha to Deadman's Point. The drift in this last stretch probably marks the trail of the Clutha glacier.

This re-sorted glacier drift rests on a denuded surface or false bottom of the purely fluviatile drifts that form Cromwell Flat.

Perhaps the only extensive area of this rich drift that now remains intact is that which lies under the township of Cromwell, in the narrow tongue of land lying at the junction of the Clutha and Kawarau Rivers. To work this ground effectively would mean the destruction of the lower end of the town; and as the results would hardly justify this course, it is obvious that much wealth must here lie buried for all time.

2. **River-bed Gravels and Sands.**—These occupy the beds of the trunk rivers and their affluents. They vary in depth from 2ft. or 3ft. to 20ft., according to the velocity of the current and the depth of the channel.

Throughout the Dunstan and Kawarau Gorges these gravels, commonly spoken of as river-wash, rest on the schist-bottom. From Cromwell to Deadman's Point they also rest on the schist, but beyond the latter they pass on to the lower members of the lignitic measures.

From the Chinese camp to the first rocky gorge, a mile or more from Cromwell, and from the upper end of this gorge to the mouth of the Bannockburn, and again from a point a few chains above the Bannockburn Bridge to the Kawarau Gorge the Kawarau river-bed wash rests on the different members of the lignitic series.

The only practicable method of winning the gold lying at the bottom of this river-wash is dredging. Dredges have already turned over the greater part of the bed of the Clutha and of the Kawarau from Cromwell to the Kawarau Gorge, and the experience gained during the course of the operations showed that the richest gold occurred where the river wash rested on the quartz drifts. These quartz drifts occur in two horizons—namely, at or near the base of the lignitic series, and at the top of the series as exposed at Bannockburn.

At Gabriel's Gully, near Lawrence, the gold-bearing wash was spread over the floor of the valley for a distance of some two miles. It varied from 0ft. to 12ft. deep, and was fabulously rich, yielding over 2,000,000ozs. of gold in a comparatively short time. The gully is narrow, and ends at the well-known Blue Spur fluvio-glacial deposit, which has been already described (see p. 192). The denudation and resorting of the Blue Spur cement produced the rich gold found in Gabriel's Gully.

Among other famous diggings are those in the Arrow and Shotover rivers. For countless ages before the advent of man they acted as natural sludge-channels, in which the gold, liberated from the lodes in the adjacent country by fluviatile dissection and glacial erosion throughout a geological epoch, became concentrated in pockets and leads, as it does in the tail-race of the modern miner.

The pioneer miners began operations by cleaning up the beds of the rivers and streams. The pay-wash was generally shallow, and often fabulously rich. The country swarmed with thousands of enterprising men, and before the close of the seventies practically all the shallow ground was exhausted. Small areas of deep ground, however, existed in the Arrow Gorge and in the Shotover at Arthur's Point, and these yielded rich returns for many years. Among the most successful of the dredging-claims taken up in the Shotover was the Sew Hoy Claim, on the Big Beach, near Arthur's Point, on which a dredge was erected by a Chinese merchant of that name in 1889.

There is a well-founded belief among the local miners that a large amount of gold still lies in the bed of the Shotover. The ground is deep, and the mechanical difficulty of recovering the gold is very great. With each successive year the cover of wash is becoming deeper and deeper, through the large amount of gravel sluiced into the river at and near Skipper's Point. To turn the river is impracticable, and for the present the gold must lie undisturbed.

1. **Crumbling Schist Wash.**—The most notable examples of this class of wash are to be found on the flanks of the Carrick Range above Bannockburn. The schist wash along the bottom of Adam's, Smith's, and Pipeclay Gullies and their numerous branches has been carefully turned over in the search for the precious metal. Even the crumbling schist that has accumulated in shallow hollows and dry gullies has often proved highly profitable.

This class of dirt nearly always contains a good deal of gold adhering to pieces of vein-quartz. Moreover, the bulk of the gold is honeycombed, and bears evidence of having been shed by gold-bearing quartz veins in the vicinity. Such is the case near Bannockburn. There we find that the creek-wash is gold-bearing only where a gold-bearing vein occurs within the drainage-area of the creek.

It is obvious that gold-bearing wash of this kind must be limited in extent, being necessarily confined to areas in which the outcrops of quartz veins have been subject to denudation. It should also be noted that the outcrop of the vein which shed the gold is not always exposed at the surface. In some cases schist wash carrying good gold has been traced almost up to the crest of the dividing ridge.

Most of the known deposits of this class of alluvium have been worked out, but there is reason to believe that new deposits may be discovered on the Dunstan Range, in the undulating tussock land lying between Castle Rock and Thompson's Creek; on the western upland flanks of Pisa Range, more especially in the area lying between Moonlight and Mitre Creeks, and on the slopes of Raggedy Ridge, between Ophir and the Manorburn.

The chief characteristics of this class are as follows:—

(*a.*) Ground generally shallow.

(*b.*) Confined to the bottom of small streams and hollow places lying below the outcrop of gold-bearing veins.

(*c.*) Gold commonly honeycombed.

(*d.*) Pieces of gold-bearing quartz are often found in the claims lying near the source of the gold.

Origin of Alluvial Gold in Otago.

It has been maintained by some writers that the quartz laminæ of the mica-schist is the source of the alluvial gold throughout Otago. This was the opinion of Ulrich[t], but the evidence he adduced is by no means convincing. The quartz veins described above often throw out thin spurs that run parallel with the bedding-planes of the mica-schist, and might easily be confounded with schist laminæ. Besides many of the gold-bearing lodes follow the planes of schistosity, and might be easily mistaken for exaggerated quartz-foliæ.

At the head of Chapman's Gully, near Alexandra, there is a quartz drift composed of greasy clays and small pieces of angular quartz derived from the decomposition of the adjacent micaceous quartz schists. The quartz fragments often contain visible gold, but an examination of the stone discloses the fact that it is not

t. Ulrich, "Geology of Otago," 1875, p. 157.

laminated but vein-quartz. The rock is traversed by thin veins of quartz and irregular seams of quartz running parallel with the bedding-planes, but the latter are seen to be slip bands that have been filled by segregation, probably at the time the ramifying veins were formed.

The gold in the bed of the Clutha and in the terrace on which Alexandra stands has an average fineness of 955, and is easily distinguished from the gold of the Manuherikia Valley. It has manifestly been carried down the river from some point above Clyde, probably even beyond Cromwell.

The alluvial gold from the Manuherikia Valley has an average fineness of 970, and would appear to be mainly derived from the numerous small gold-bearing veins that traverse the schists on the flanks of the Old Man Range, Raggedy Ridge, and Dunstan Mountains.

In the creek workings near its source the gold is rough, shotty, or hackly, sometimes crystallized, and often enclosed in a quartz matrix, forming what is known to miners as "specimen gold." Lower down the streams, where it occurs in water-worn wash, the gold is more rounded, and specimens are scarce; while in the larger streams and rivers it commonly occurs in flattened grains or pieces resembling a mixture of large and fine bran, the result of the pounding it has been subjected to among the gravels and boulders that travel along the river-bed. In the larger streams specimen gold is very rare, the pounding of the travelling gravels having in nearly all cases released the gold from its quartzose matrix.

Rickard[u], in his paper on "The Goldfields of Otago," discusses the origin of the alluvial gold in Otago at some length. He summarises his views in the following statement: "That the bulk of the gold of the extensive alluvium of Otago came from the degradation of the known lodes, I do not believe. The mere proportion of the known extent of the one to that of the other may be an insufficient basis for such a conviction, for in this country, as in other comparatively new regions, the mineral deposits are only in an infancy of development; yet this fact has some weight. The chief evidence comes, however, from the known relations of the lodes to the country rock, and from the character

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u. T. A. Rickard, Trans. Am. Inst. Min. Eng., vol. xxi., 1893, pp. 442-73.

of the alluvial gold itself. It is not necessary to recapitulate the observations made on the lodes—how they are for the most part ore-channels, the auriferous filling of which shades off into the surrounding country, as regards both gold-contents and structure. The gold of the alluvium has not that shotty character familiar to the digger of Australia or California. An exception must be made of the small placer deposits of some of the mountain-streams, the nuggety gold of which is easily traceable to its source in the neighbouring quartz veins. Such gold is, however, quite exceptional, and altogether of a character different from that of the great fluviatile and lacustrine deposits of the Clutha and Shotover, the wealth of which is contained in the very fine flaky gold, which is like bran and notable for its uniformity of size and wide distribution. It has a character making it easy of recognition among samples coming from other districts. It is also remarkable that quartz stones showing gold are of very rare occurrence at the Bluespur or in the gravel-deposits of the Clutha and Shotover. The gold came, I believe, as did the gravel through which it is distributed and the cement in which it is often imbedded, not from the few comparatively insignificant quartz lodes, but from the great mass of the quartzose schists. The quartz folia which form the characteristic feature of the schists of Otago are known in places to carry gold far outside the limits of any of the particular lode-channels which also traverse them. One could with perfect reason regard the whole belt of quartzose schists as one large bed-vein, in which the lodes now worked are merely small cross-veins—a large gold-vein, through which for ages the glaciers have ploughed an easy way, cutting furrows from which the quartz and schist have been swept by wind and rain into the swift waters of the Clutha and Shotover, to be laid down by them in the form of the great banks and terraces of gold-bearing alluvium which to-day are the chief depositories of the mineral wealth of Otago.''

The origin of the gold contained in the quartz grits so widely distributed throughout Otago has always been a prolific subject for discussion among miners and geologists, and the last word has not yet been said. Speaking of the quartz grits of Otago and their distribution, McKay[v] says, ''At one time these quartz grits

v. A. McKay, ''Gold Deposits of New Zealand,'' Wellington, 1903, p. 67.

seem to have been an almost continuous deposit over all the low grounds and middle heights throughout Otago and Southland, and to have occupied a considerable area of southern Canterbury as well. Subsequent to the close of the Cretaceous period movements of the land took place by which portions of the grit formation were elevated to positions 4,000ft. to 5,0000ft. above the sea, and at the same time other parts were deeply involved along lines of fault at unequal elevations, thus exposing in the one case the uplifted area to rapid denudation, and in the other case the upturned edges of the involved part to the same influence. In this manner great destruction of the quartz-grits took place, and it is a matter for marvel that so much of them has been preserved to the present time. Considering the comparative paucity of reef quartz over the whole of Otago and Southland, it is evident that reefs of quartz could not have supplied such a great formation of residual grits, even granting that an enormous denudation, far greater than what is usually supposed, did take place. The lower schist formation of central and northern Otago is strongly foliated with laminæ of quartz, which, though resembling, can in no sense be regarded as vein quartz, and this is evidently the source whence has been derived the great bulk of the quartz grits at the base of the coal-bearing formation; and as these quartz foliæ are known to carry gold—*e.g.*, at Skipper's Creek, on the Shotover, at Green's Reef, near Ophir, and at other places—such quartz folia must be regarded as the principal source of the alluvial gold of Otago. It has, however, to be stated here that, while much gold has been obtained from the quartz drifts, the larger pieces of quartz in the drifts, varying from 2in. to 5in. in diameter, do not contain gold, numberless trials having failed to show its presence. This has been regarded as showing that the country quartz does not contain gold, and could not have yielded the alluvial and cement gold of the quartz drifts. However, it has been shown that the denuded parts of existing reefs were as unlikely as a source of the twenty-three to twenty-four million pounds' worth of gold that has been obtained from the goldfields of Otago; and it is an undoubted fact that, whether in the solid parts of the quartz folia or no, gold is found in association therewith, and, as is often the case in connection with vein quartz, the casing and friable margins often contain gold, while the solid quartz of the middle part does not. So, also, this may be characteristic of the country quartz occurring as folia in the mica-schist. Other sources of gold may bè suggested, such as bodies of iron-sulphide or of oxide of iron (hæmatite); but aggregated bodies of these ores are comparatively rare, and the character of the gold in Otago is generally against the assumption. Other sulphide ores, such as copper or antimony, may be suggested, but these also are not likely on investigation to prove satisfactory.

"The gold of Otago must therefore be regarded as mainly having origin in the schists, and in near association with the quartz foliæ that characterize the middle and lower divisions of the schists, and is but little due to the quartz reefs occurring in the same rocks, as at but few places are the foliated schists rich enough to pay for working."

Finlayson[w], among the latest writers to examine the goldfields of Otago, supports the author's view that the quartz veins traversing the schists are a sufficient source of supply of the alluvial gold. At any rate the occurrence of gold in the schists is still unproven.

Geology of Reefton Goldfields.

This is the most important gold-mining centre in the South Island, and in point of gold production ranks next to the Waihi Goldfield in Auckland. It is situated in the lower Inangahua Valley.

The gold-bearing veins occur in a series of sharply folded mud-stones and sandstones lying in a trough between two parallel granite massifs, namely the coastal Paparoa Range on the west side and the Victoria Range on the east. The granite ranges run nearly north and south; and as would be expected, the axes of the flexures of the inclosed belt of sedimentaries have about the same general bearing.

On the east side of the goldfield there is exposed along the denuded score of an anticlinal, a thick series of older sedimentaries consisting of cherty quartzites, quartz-schists, slates and limestones. The calcareous members of this series have yielded a number of fossils that indicate a lower Devonian or Silurian

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w. A. M. Finlayson, Trans. N.Z. Inst., vol. xl., p. 77.

age. The character of the rocks and the contained fossils would indicate a close relationship to the Silurian rocks of Mount Arthur as exposed in the Baton Valley.

Through the absence of clear rock-exposures at the junction of the two formations the relationship between the Silurian rocks and the overlying Reefton gold-bearing series has not yet been satisfactorily determined. The Reefton rocks contain no internal evidence of their age, and even the unconformity that is believed by McKay to separate them from the underlying Silurian formation has not been well established. Cox and McKay have referred them to the Carboniferous Maitais; but there is nothing to show that they do not belong to the great Hokonui System of Permo-jurassic age, which in the province of Wellington is known to contain bedded veins similar in character to those at Reefton.

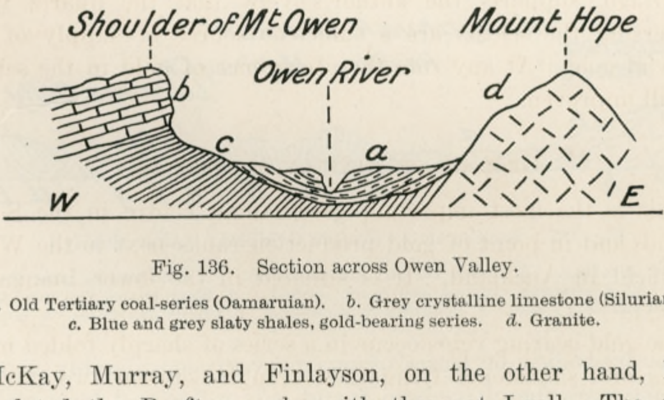

Fig. 136. Section across Owen Valley.

a. Old Tertiary coal-series (Oamaruian). *b.* Grey crystalline limestone (Silurian). *c.* Blue and grey slaty shales, gold-bearing series. *d.* Granite.

McKay, Murray, and Finlayson, on the other hand, have correlated the Reefton rocks with those at Lyell. The gold-bearing rocks at the Owen Valley across the range from Lyell underlie the Silurian limestone and rest against the granite. The Lyell rocks rest against the granite and appear to underlie the Silurian limestone and associated rocks. If this correlation could be established it would prove that the Reefton gold-bearing series is in reality a portion of the Silurian formation on which it is at present believed to rest unconformably.

In the Owen goldfield, as at Lyell and Reefton, the gold-ore occurs as bedded segregations[x].

x. J. Park, Repts. of Geological Explorations, 1887, p. 85.

At Reefton the gold-bearing rocks are overlain unconformably by the old Tertiary coal series of the West Coast, which contains valuable seams of coal.

Gold-bearing Veins.—The ore-bodies occur as bedded lenses or sheet-like segregations of quartz running parallel with the planes of stratification of the enclosing rock. They occur in a well-defined zone of soft crumbling slaty shale that presents all the evidences of a rock that has been subjected to intense stress.

The sharp folding of the gold-bearing series was probably caused by the intrusion of the granite massifs. The folding would appear to have been accompanied by the formation of minor corrugations in the more yielding rocks. By overthrust shearing the corrugations formed cavities which subsequently became filled with mineral matter.

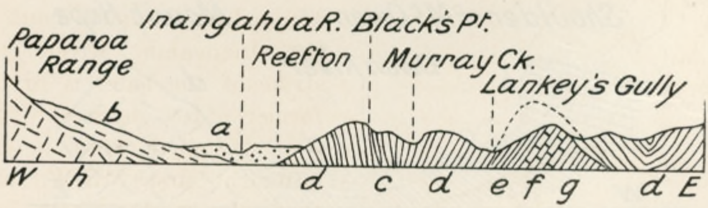

Fig. 137. Section across Reefton Goldfield. (After McKay.)

a. River alluvium. *b*. Lower Tertiary coal-measures. *c*. Gold-bearing zone of slaty shales and sandstones, crushed and much jointed. *d*. Slaty shales and sandstones. *e*. Slates and slaty shales. *f*. Fossiliferous limestone. *g*. Cherty quartzites *h*. Granite.

The ore-bodies, or lenses of quartz, vary considerably in size. In some cases they have been found only a few feet long, and in others over 500ft. Some of the lenses have produced thousands of tons of ore, others only a few tons.

The different lenses are linked up by a clay-track which is frequently filled with a seam of hardened, well-slickensided pug or clay. But in some cases the connecting track has been found very indistinct and difficult to follow.

The veins, on account of their bedded character, follow all the bends and folds of the enclosing rock. A conspicuous example of this is seen in the Progress Mines. The Progress lode from the surface to No. 4 level dips to the south-west at an angle of 60°.

From No. 4 to No. 5 level the dip is much flatter; from No. 5 to No. 6 it is flatter still; between No. 6 and No. 7 it steepens up to nearly 60°; from No. 8 to No. 10 it gradually flattens out again, and when No. 11 level is reached it is quite flat.

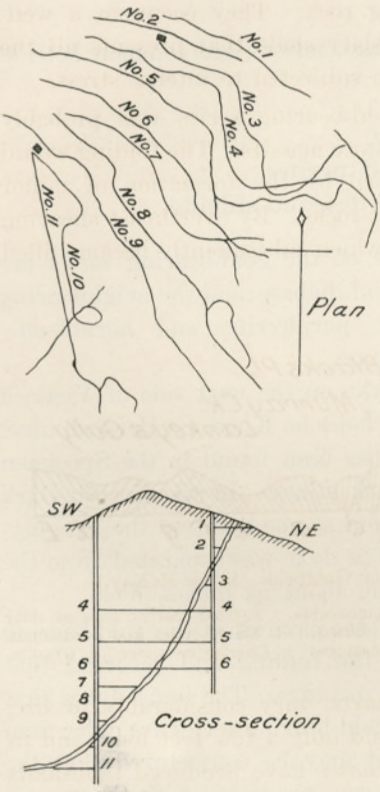

Fig. 138. Plan and cross-section of the Progress Lode, Progress Mine, Reefton. Scale of Plan, one inch = 8 chains.

In the Progress Mines, situated on the ridge between Orient Creek and Devil's Creek, the strike of the lode is N.W.-S.E., and the dip S.W. at angles, as shown above, varying from 0° to 60°. The pitch of the ore-lenses is towards the north-west.

At the Keep-It-Dark and Wealth-of-Nations mines, situated on the north bank of the Inangahua River, the strike of the lodes is in the former a few degrees to the west of north, and in the latter at first N.N.W., and then almost due north and south (true).

In the Golden Fleece group of mines, lying a little further north, the strike is about 20° east of true north, the dip of the lode being north-west at high angles as in the Wealth-of-Nations mine.

The Reefton gold-bearing zone runs north to Boatman's Creek, where the Welcome group of mines is situated, including the Seddon, Fiery Cross, Hopeful, and Welcome United leases. The Fiery Cross lode, which traverses all the claims, runs a few degrees to the east of true north, and dips towards the east at high angles.

Character of Ore.—In the small lenses the quartz is seamed with broken shaly rock, and commonly contains a considerable percentage of pyrites. In the larger lenses, besides the mullocky ore which generally lies on the walls, there is frequently a large development of vitreous crystallised quartz.

In the smaller lenses the ore is frequently high-grade, and in the larger medium to low-grade. The fineness of the gold is about 960.

Paragenesis.—The following associations are common both at Reefton and Boatman's:—

Gold and quartz.
Gold, quartz and pyrites.
Gold, quartz, pyrites, and stibnite.

Genesis of Lodes.—The rocks of the gold-bearing series are intruded with dykes of dolerite and diabase; and the neighbouring granite with dykes of diorite, porphyrite, and hornblende-lamprophyres of the camptonite type.

The dolerite[y] forms a large dyke on the west side of Victoria Range, running parallel with the lodes on Kirwan's Reward mine. Finlayson[z] reports that diabase has been found in the Specimen Hill, Inglewood, and Keep-it-Dark mines. In the Keep-it-Dark mine the dyke of diabase was found at one point on the hanging-wall of the vein at No. 5 level. The dyke was separated from the lode by a well-defined sheet of pug about six inches thick.

The fissuring and formation of the cavities in the gold-bearing zone were obviously caused by the folding and shearing that accompanied the intrusion of the granites. The basic dykes that intrude both the granite and the gold-bearing series are older than the lodes, and for that reason it may be conjectured that the intrusion of the dykes is in some way associated with the genesis of the solutions that filled the cavities already formed along the bedding planes of the fissured slaty shales.

Outlying Fields.—From Boatman's the gold-bearing zone runs northward to the historic goldfield at Lyell, which is now practically abandoned; and from Reefton runs southward about twenty miles to Blackwater and Snowy Creeks, in the Grey watershed, where a prosperous goldfield is being developed.

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y. W. A. McLeod, Trans. N.Z. Inst., vol. xxxi., p. 487.
z. A. M. Finlayson, Trans. N.Z. Inst., vol. xxxi., p. 94.

ALLUVIAL DEPOSITS OF WEST COAST.

The alluvial deposits of Westland show in many respects a close resemblance to the gold-bearing alluvia of Central Otago. This resemblance is not by any means superficial, but refers to the general character and succession of the various deposits in the two areas. The Otago alluvia were laid down in great inland fresh-water basins, the Westland detritus on a marine littoral; and therein lies the only conspicuous difference, which is one of condition rather than kind. The cycle of erosion and deposition followed the same order in both regions.

Cox, McKay, Bell and Fraser, and Morgan have recognised the following sub-divisions of the Westland Tertiary deposits:—

Miocene.—(*a.*) *Blue Bottom*—
Blue marine mud or clay; or in places soft sandstones and clays.

Late Pliocene.—(*b.*) *Old Man Bottom*—
Ancient decomposed river gravels—the Moutere gravels of Nelson.

Pleistocene.—(*c.*) *Fluvio-marine and Fluvio-glacial drifts*—
Humphrey's Gully gravels, etc.

Recent.—(*d.*) *Black sand placers and Recent River Drifts.*

The corresponding formations in Otago are shown in the following statement:—

	WEST COAST.	OTAGO.
Miocene	Blue Bottom (Marine)	False Bottom (Lacustrine)
Late Pliocene	Old Man Bottom	Maori Bottom
Pleistocene	Fluvio-Marine and Fluvio Glacial	Fluvio-Lacustrine and Fluvio-Glacial
Recent	River Drifts and Beach Places	River Drifts, &c.

Blue Bottom.—This commonly consists of blue marine clays or of sandstones and clays. It contains a large assemblage of marine molluscs, among which the following have been identified[a] :—*Dosinia grayi, Natica ovata, Turritella ornata, Dentalium*

a. Bell and Fraser, "Bulletin No. 1 (New Series)," 1906, p. 88.

solidum, Panopæa zealandica, Struthiolaria papulosa, S. cincta, Nassa robinsoni, Ancilla hebera, Cucullæa alta, C. ponderosa, Limopsis insolita.

There is a curious mingling of Awatere and Pareora (Oamaruian) forms, but the weight of the evidence would indicate a Miocene age.

It is obvious that the marginal Koiterangi marine beds of the Oamaruian were subjected to considerable erosion before the Old Man Gravels were deposited. In many places the formation was completely destroyed; in other places the basal beds only remained; elsewhere only the upper calcareous members of the series were removed. From this it follows that the *Blue Bottom* at one place may not be the exact horizontal equivalent of the *Blue Bottom* at another place. The same feature is also seen in Central Otago. For example, in the Cromwell Basin proceeding from Lowburn to Cromwell and thence southward to Bannockburn, the *False Bottom* is successively, sandstones with lignite, gritty quartzose clay and quartzose sands.

Morgan[b] has reported that the *Blue Bottom* contains ice-striated stones, as well as pebbles of schist, serpentine, and other rocks occurring in the present alpine area.

Old Man Gravels.—These are decomposed river gravels. They are believed by McKay and Morgan to have been largely derived from the denudation of the coal-measures conglomerates. Their origin is somewhat obscure. McKay has suggested that they were formed by a river that ran north-west from Ross.

The *Old Man Gravels* lie unconformably on the *Blue Bottom.* There is nothing to show their age, which, however, cannot be far from later Pliocene or early Pleistocene. It is almost certain that, like the *Maori Bottom* of Central Otago, they were deposited before the advent of the Glacial Epoch. They are gold-bearing, but not very rich. During the Glacial Period and later they were subjected to intense erosion, and in a resorted form their material and contained gold appear concentrated in later deposits.

Fluvio-marine and Fluvio-glacial Placers.—These are found in maritime areas where short torrential streams discharged their rocky load in the sea, or in an estuary.

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b. P. G. Morgan, ''Bulletin No. 6 (New Series),'' 1908, p. 35.

A good example of a fluvio-marine placer deposit is found at Ross. There the gravels attain a thickness of at least 400ft., of which about 300ft. lie below sea-level. In age they date back to the Pleistocene, when the West Coast glaciers descended to the sea; and although mainly fluviatile and fluvio-marine, they are intercalated with deposits that are no doubt fluvio-glacial, as first determined by Cox in 1875.

The pay-wash occurs on false-bottoms, no less than nine of which have been proved to exist in the Ross United Gold Mining Company's lease, six of them lying below sea-level.

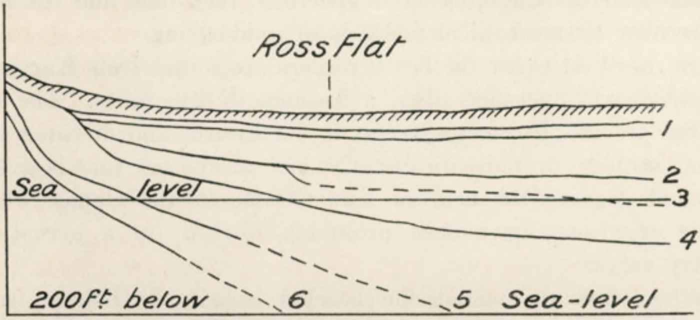

Fig. 139. Section showing false-bottoms on Ross Flat. (After Reed.)
1-6. False-bottoms on which pay-wash rests.

Marine Placers.—These consist for the most part of fine beach sand containing a varying proportion of black sand, which is mostly magnetite and ilmenite. In some places the sand contains numerous pebbles; in others it is overlain by, or enclosed in, layers of beach gravel.

The pay-wash in marine placers occurs as thin layers of black sand, of which there may be a succession at different levels, some lying above sea-level and some below, according to the upward or downward movement of the coastal land with reference to sea-level.

The concentration of the black sand and gold is due to the laving and sorting action of the tidal waves, which is always most effective where the waves strike the beach obliquely. The layer of black sand formed during one tide is broken up, re-sorted and again laid down by the next following tide. When this action is continued day by day and month by month for a succession of years, on a slowly sinking littoral, the layer of pay-wash becomes thicker and richer until in time it is buried under a fresh pile of beach sand and gravel, when under favourable conditions new layers will be formed.

Black sand leads formed on a rising area would soon be destroyed; and although rich marine black sand placers have been worked at Charleston, Brighton, and other places on the West Coast at fifty or more feet above the sea, there is good evidence for the belief that these owe their present elevated position to faulting.

The gold in beach-placers is generally very fine, and difficult to recover by mechanical methods of gold-saving.

On the West Coast the beach placers are found from Karamea southward to Jackson's Bay, a distance of 240 miles. The set of the prevailing ocean currents is northward, and at times the beach sand is covered with gravel, which at another time is swept onward, leaving the beaches bare. Some of the claims, when clear of gravel, have been profitably worked for a period of thirty years.

When first discovered the beaches south of Okarito were exceptionally rich, some of them at low tides presenting the appearance of a strip of cloth of gold[c].

Near the mouth of the Totara River, between Charleston and Westport, workings are being carried on below sea-level, or at least below high-water mark; while two miles inland at Charleston, Brighton, Cronanville, and Addison's Flat, sea-beach leads are being worked at a considerable elevation above the sea. In these localities much of the sand is cemented into a comparatively hard sandstone, which is crushed in stamper batteries, the gold being recovered on coconut matting.

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c. N.Z. Mining Handbook, 1906, p. 16.

CHAPTER XV.

OTHER MINERALS OF ECONOMIC VALUE.

Parapara Iron Ore.

The Parapara ironstone deposits in Nelson are the largest and most valuable in New Zealand or Australia. They are even of greater extent than any other known deposit on the Pacific seaboard. When we come to consider the distribution of the world's supply of iron it is not a little singular to find that all the great ironstone deposits of the globe, with the notable exception of those at Parapara in New Zealand, are situated in regions bordering the North Atlantic.

Situation of Ore.—The Parapara ironstone is contained in three contiguous rectangular blocks known as the Parapara, Tukurua, and Onakaka blocks respectively. It extends from near sea-level at Parapara Inlet southward for a distance of three miles, gradually rising in altitude until at its southmost limit it reaches a height of over 2,000ft. above the sea.

The ore crops out along the crest of a ridge that runs nearly parallel with the shores of Golden Bay, at a distance varying from a mile and a half to four miles from the deep water of the bay which is sheltered from most winds.

Geological Features.—The basement rocks of the district are grey quartzite, quartz-schist, mica-schist, and greyish-blue crystalline limestone of older Palæozoic age. They are unconformably overlain by a series of clays, sandstones, and shelly limestone of middle Tertiary date, which occupy the narrow fringe of terrace-land between the older rocks and the sea; and are overlain by heavy deposits of fluvio-glacial drifts that have been extensively worked for gold.

Character of Ore.—The ore is mainly limonite—the hydrous peroxide of iron, which contains when pure 59.8 per cent. of iron. The Geological Survey[d] also reports the presence of goethite, and perhaps turgite.

The bulk of the ore occurs in massive and concretionary form. Frequently the concretions are filled with ocherous limonite and clayey or sandy nodules; but on the weathered surfaces, where the softer material has been removed, the outcrops are very rugged, vesicular and cavernous.

The ore is generally silicious or argillaceous; and on the Tukurua and Onakaka blocks it is more or less micaceous throughout. On the Parapara Block a good deal of the ore contains water-worn pebbles of quartz and sandstone, in places imparting a conglomeratic appearance to the outcrop.

Genesis of Iron-ore.—The ironstone occurs along the junction of the quartz-schist and cherty limestone. It is partly a replacement ore after limestone, and partly a sedimentary ore; but the one runs into the other, and the line of demarcation between them is not always well marked.

The replacement ore is always of good quality, although in many places it contains nests of angular quartz fragments.

Quantity of Ironstone.—The outcrops form conspicuous crags and steep precipices varying from ten to fifty feet high. The actual depth to which the ore descends is at present unknown. And as much of the surface is covered with dense scrub or thick forest it is difficult to determine the surface extent of the outcrops. The continuity of the ore between two distant outcrops has been proved by the recent stripping operations that have been undertaken at Parapara, which is a circumstance of great importance.

The official estimates of the ironstone on the Parapara and Tukurau blocks vary from 23,000,000 to 60,000,000 tons. The only estimate of the ore on the Onakaka blocks is 63,000,000 tons.

Quality of Ironstone.—The quality of the ore as determined by the Geological Survey varies from low to high-grade, the average iron-content of thirty-four samples from the Parapara

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d. Bell, Webb and Clarke, "Bulletin No. 3 (New Series)," 1907.

Block being 51.79 per cent., of seven samples from the Tukurua Block, 50.48 per cent., and of forty samples from the Onakaka Block 47.15 per cent.

The average iron-content of twenty-seven samples selected by the author from the Parapara and Tukurua blocks in 1909, as determined by the Government Analyst, amounted to 49.86 per cent.; and of twenty-eight samples from the Onakaka Block 46.12 per cent.

Phosphorus and sulphur are not present in deleterious amount. The phosphorus content, according to analyses made by the Government Analyst is, for high-grade ore 0.17 per cent.; and for medium-grade ore, 0.08 per cent. The sulphur content, according to the same authority, is for high-grade ore 0.32 per cent., and for medium-grade ore 0.24 per cent.

Facilities for Working.—The ore-bodies lie on isolated ridges that do not offer facilities for steam-shovel working. On the other hand, they are well-situated for quarrying in benches at a very cheap rate, and passing by ground-shoots to the bottom of the gullies along which the branch tramways could be constructed.

At the craggy outcrops the ore is free of overburden, but there is overburden on all the lower slopes and in the depressions. Immediately west of Rinonui the surface clays and bouldery rubble varies from two to twelve feet thick. What the thickness is elsewhere has not yet been ascertained.

The bulk of the ironstone in the Parapara Block lies between 100ft. and 400ft. above the tidal mud-flat, at a distance ranging from a mile and a half to two miles from the sea.

The main ore-bodies in the Onakaka Block occur on the eastern face of the Onakaka Range, fronting the sea, at heights varying from 200ft. to 1,000ft. above water-level. The steepness of the slopes and the character of the outcrops will enable the ore to be cheaply won by open cuts and benching.

Flux:—A hard crystalline limestone of good quality occurs at Caldwell's Flat, near Parapara Inlet, about half a mile from the nearer of the Parapara ironstone deposits. Its composition, according to an analysis by Dr. Maclaurin, the Government Analyst is as follows:—

	Per cent.
Silica	1.38
Alumina	0.85
Ferric Oxide	0.40
Ferrous Oxide	0.22
Manganous Oxide	0.32
Carbonate of lime	96.50
Magnesia	0.10
Titanium Oxide	0.02
Alkalies	—
Loss on ignition	0.35
	100.14

Coal.—A bituminous coal of good quality and reported to form a hard coke occurs at Otamataura, a few miles from Parapara Inlet. The seams are thin, but if they are proved to be continuous over a large area, sufficient development would ensure a continuous output of coal for the production of coke for smelting.

Failing the Collingwood coal, there is an abundance of fine coking coal available in the Westport district, about 150 miles distant by sea, and at Greymouth, 215 miles by sea.

Silver.

Rich samples of silver ore, a variety of fahlerz, were found at Richmond Hill, Collingwood, and at the Rangitoto Mine, Westland, but the quantity of ore was not sufficient to be profitable.

The silver which figures in the annual exports of New Zealand is derived from the bullion ores of the Hauraki goldfields, the Waihi mine being the principal source of supply.

The bullion as it occurs in the lodes contains about 30 per cent. of silver. Besides this the dry argentiferous gold ores of Waihi and Karangahake contain a small percentage of argentite, from which a considerable amount of silver is extracted during the treatment of the ores by the cyanide process.

Scheelite.

This valuable ore is widely distributed throughout Otago, being found in greater or less quantity in almost all the quartz veins traversing the Maniototian and Kakanuian schists. It is found in payable quantity near Glenorchy, at the head of Lake Wakatipu, and at Donaldson's mines at Macraes, and Mount Highlay.

At Macraes the scheelite occurs in bedded-veins, and at all other places in fissure-veins[e]. The occurrence and geology of the scheelite veins in Otago have been well described by Finlayson.

The treatment and preparation of the ore for the market are extremely simple. The ore is crushed, preferably in a stamper mill, concentrated to a tungstic acid (WO_3) content of 65 per cent., dried, bagged, and shipped. The dressing of the ore is effected with Wilfley tables or Woodbury-Frue vanners.

Early in 1907, the value of ore containing 60 per cent of tungsten trioxide was 26/- per unit; and, in the middle of 1907 45/-. In December of the same year there was a sudden drop, the price fluctuating between 22/6 and 29/-. In 1908 the value ranged from 21/- to 25/- per unit, computed on the short ton of 2,000lbs.

Copper.

Ores of this metal occur at Dusky Sound, Dun Mountain, Aniseed Valley, Maharahara, and Whangaroa, but up to the present time it has not been found in sufficient quantity to place the industry on a profitable basis.

Other Metals.

Platinum is found in the gold-wash at Round Hill, Southland; osmium-iridium with the alluvial gold at Takaka; tin and wolfram in Stewart Island; molybdenite at Mount Radiant, in veins traversing granite; lead and zinc ores in the gold lodes at Te Aroha and Waiomo Creek, Auckland; manganese, in claystones at Kawau, Waiheke and Bay of Islands; but none so far have been found in large quantity.

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e. A. M. Finlayson, Trans. N.Z. Inst., vol. xl., p. 110.

There still exists in South-west Otago a large unexplored area occupied by crystalline schists, in which discoveries of ores or valuable minerals may yet be made. Particular search should be made for the rarer minerals, such as monazite and pitchblende, which are easily overlooked by the ordinary prospector.

Building Stones.

New Zealand possesses a great variety of durable building stones scattered throughout both islands. In Auckland there are basalts, andesites, porphyrites, and diorite. The latter is a hard coarsely crystalline rock capable of taking a fine polish. It is commonly spoken of as the Cabbage Bay granite. Besides these rocks there are the Whangarei limestone and Raglan Stone, the former an excellent building stone, the latter a good freestone.

Taranaki has the andesites of New Plymouth and Mount Egmont, and Wellington the andesites of Ruapehu. In Nelson there is the granite of Tata Island and the crystalline limestones of the Riwaka Range. West Nelson and Westland are well provided with granites and limestones of good quality, all well-adapted for building purposes.

Building stone is scare in Marlborough, but Canterbury is well supplied, having an abundance of Lyttelton bluestone (andesite), and Mount Somers stone, a freestone of exceptional quality.

In Otago there is an abundance of excellent building stone, ranging from the well-known Oamaru stone to the granite, gneiss and limestones of Fiordland, all close to deep water. In Southland there is the so-called Ruapuke granite, the norite at the Bluff, and the granites of Stewart Island.

Limestones.

Limestones occur in New Zealand in endless variety, and in almost every geological formation from the Cambrian to the Pleistocene. They may be conveniently divided into three groups as follows:—

1. Earthy limestones.
2. Shelly limestones.
3. Granular or crystalline limestones.

Earthy Limestones.

The best-known and most important of these are the hydraulic limestones, Amuri limestone, Oxford chalk, and Lake Hayes calcareous ooze. Limestones for building, for mortar and agricultural purposes are abundant in easily accessible places in both islands, while the deposits of crystalline and earthy limestones, marly clays and blue clays or old sea muds, suitable for the manufacture of Portland cement, are so extensive as to be practically inexhaustible.

Hydraulic Limestones.—These are chiefly developed in the North Auckland district, being particularly abundant on the east coast at Mahurangi, Whangarei, and Kawakawa; and on the west coast on the shores of the Otamatea Arm of the Kaipara at Batley, Komiti Point, Pahi, and Paparoa, associated with rocks that have yielded Cretaceous saurian remains.

Hydraulic lime of superior quality has been manufactured at Mahurangi for about thirty years. A sample of this cement analysed in the Government Laboratory by W. Skey showed the following composition:—

Silica and sand	25.44
Alumina and iron oxides	15.76
Lime	56.96
Magnesia	1.05
Alkalies and loss	0.70
Total	99.91

In the United States of America large quantities of natural cement are produced from argillaceous limestones interbedded with the Trenton and Niagara limestones of Silurian age. The purest and most accessible deposit is in Leigh Valley, in Pennsylvania, which offers so many advantages for the manufacture of Portland cement that the making of natural cement has now taken a secondary place.

The finest natural cement in the globe is that produced at Grenoble in France, where a bed of argillaceous limestone occurs interbedded in a compact limestone. The bed is fifteen feet thick, and is worked by square chambers with supporting pillars three feet thick.

The composition of the Grenoble rock is as follows:—

	Per cent.		Per cent.
Silica	13.40	to	13.37
Alumina	6.20	,,	12.37
Iron oxides	3.50	,,	12.37
Lime	60.50	,,	64.75
Magnesia	6.00	,,	traces
Water, loss, etc.	4.40	,,	5.50

After calcining, the resulting cement has the following composition:—

	Per cent.		Per cent.
Silica	27.30	to	26.30
Alumina	9.30	,,	12.70
Lime	50.80	,,	55.00
Magnesia	3.0	,,	0.00

The Grenoble cement is quick setting, taking from 8 to 16 minutes, and two hours after setting can bear a weight of 113lb. per square inch when mixed with three parts of sand, and after 28 days, 284lb. per square inch.

It will be observed that the composition of the Mahurangi natural cement already quoted closely approximates that of Grenoble, containing the higher lime constituent.

Amuri Limestone.—This is a grey siliceous limestone, of which enormous deposits occur in the Upper Cretaceous formations at Waipara, Amuri Bluff, Kaikoura Peninsula, and Clarence Valley. An average sample selected by the author over a thickness of 40ft. at the outcrop in the upper end of the Weka Pass, in North Canterbury, showed the following composition:—

Analysis by Dr. Maclaurin.

Calcium-carbonate	88.64
Magnesium-carbonate	0.45
Calcium-oxide	——
Alumina	0.66
Iron oxide (Fe_2O_3)	0.54
Silica	7.25
Organic matter and water	2.06
Undetermined	0.40
	100.00

This rock, when mixed with the blue clays, or old sea-muds, almost everywhere present in the Tertiary formations of New Zealand, would make an excellent Portland cement.

A grey earthy limestone that closely resembles the Amuri Limestone covers a large area in East Wairarapa, south of Castlepoint.

Oxford Chalk.—This occurs in the West Oxford district of Selwyn County, in Canterbury, forming an extensive deposit over 100ft. thick. Its age is probably Upper Cretaceous. Writing of this deposit, Hector stated that the samples obtained from it have more perfectly the mineral character and texture of English chalk than any previously discovered in New Zealand. The rock is pure white, fine-grained, and soft enough to be used for the manufacture of crayons.

Its composition, as determined by the late Government Analyst, is as follows:—

Calcic carbonate	82.26
Magnesic carbonate	1.84
Ferric oxide	traces
Silica	15.69
Water	0.21
	100.00

This chalk will in time be of great value for the manufacture of high-grade Portland cements.

Lake Hayes Calcareous Ooze.—This is a limestone or calcareous tuff of a somewhat unusual character. It is a fresh-water deposit that was formed in still water, the carbonate of lime having been precipitated from the waters of the lake by the action of mosses and fresh-water algæ.

The material is excessively fine in texture, and so soft as to be easily excavated with a spade without exerting much force. Its purity and pulverulent form render it of great economic value for agricultural purposes, both for dressing the land and in the manufacture of manures. Already several hundreds of tons of it have been bagged and forwarded to Southland.

The extent of the deposits at the places described above is not known, and can only be determined by boring or sinking shafts on the terrace. If the thickness as exposed in the present working-faces be maintained, it is estimated that each acre should contain some 12,000 to 15,000 tons of limestone of marketable quality, and 10,000 tons of impure limestone suitable for top-dressing agricultural and pastoral lands that are deficient in lime.

The results of the analyses of samples of the pure and impure limestone made by Dr. J. S. Maclaurin, D.Sc., F.C.S., Dominion Analyst, are given below in tabulated form:—

	1.	2.	3.	4.	5.
Silica	7.15	41.90	10.78	6.30	10.54
Alumina	3.24	18.50	5.12	2.61	4.28
Ferric oxide ..	2.00	7.68	2.40	1.76	2.12
Manganous oxide ..	0.07	0.25	0.05	0.05	0.12
Lime	47.70	12.52	44.25	48.44	45.30
Magnesia	0.20	2.57	0.40	0.25	0.30
Carbonic anhydride ..	36.90	8.32	34.43	37.85	34.80
Moisture and organic matter	1.77	3.72	1.03	1.57	1.61
Undetermined ..	0.97	4.54	1.54	1.17	0.93
	100.00	100.00	100.00	100.00	100.00
Equivalent to calcium carbonate ..	83.86	18.91	79.16	86.02	79.15

1. Top layer, south-east side of Reid and McDowell's quarry.
2. Grey band (middle layer).
3. Lower band, 6ft.
4. Impure limestone at base.
5. Average sample of whole face.

Shelly Limestones.

The majority of these are of Middle Tertiary date, being the horizontal and time equivalent of the Oamaru Stone. In the North Island there are the Te Kuiti, Waipa, and Mokau limestones, all strong compact rocks of great purity, and in the South Island, the Tata Island limestone, Mount Somers Stone, Oamaru Stone, Milburn, Winton, Forest Hill, and Waiau limestones.

Oamaru Stone.—This is a foraminiferal and coralline limestone possessing a grey or reddish-grey colour. It is a soft and homogeneous stone, which renders it eminently suited for building purposes, for which it is largely quarried. Its composition is shown by the following analysis made by Dr. Maclaurin:—

Calcium-carbonate	93.90
Magnesium-carbonate	1.00
Calcium-oxide	——
Alumina	0.51
Iron oxides (Fe_2O_3)	0.69
Silica	2.75
Organic matter and water	1.15
Undetermined	——
	100.00

Milburn Limestone.—This stone may be taken as typical of the purer of the hard tabular limestones of the Oamaru Series. It is a compact tabular limestone containing fossils in great abundance. Its composition as determined by A. R. Andrew is as follows:—

Calcium-carbonate	97.41
Calcium-phosphate	0.04
Silica	2.21
	99.66

The Milburn limestone is a rock of exceptional purity. It is extensively used in the manufacture of Portland cement of high grade, and also for agricultural purposes.

Large deposits of shelly limestone are interbedded with the Pliocene strata in Hawke's Bay and Wellington, the best known being those at Scinde Island, Napier, Te Aute, Taueru, Kaiwaiki, and Waitotara. The Napier limestone contains many bands of great purity.

Granular or Crystalline Limestones.

Included in this group we have the hard semi-crystalline Cretaceous limestones at Waiomio, Hikurangi, Whangarei, Skelton's, near Pahi, in the North Auckland district; at Weka

Pass, and Trelissic Basin in Canterbury. Also the Bob's Cove limestone at Lake Wakatipu.

Among the crystalline limestones there are the Maitai limestone, extensively developed along the north side of the Serpentine Belt, Nelson; the Riwaka, Graham, Baton, Wangapeka, Owen, Takaka, and Parapara Palæozoic limestones in North Nelson; the Dunback, Dusky Sound, George Sound, and Caswell Sound marbles. in Otago; all containing over 90 per cent. of calcium-carbonate.

The crystalline limestones are hard compact rocks that would make excellent building stones. They could also be used for the manufacture of cement, and calcium nitrate. At the present time the Dunback limestone is being extensively quarried for the making of lime for agricultural purposes. It contains about 98 per cent. of calcium carbonate.

CLAYS AND MARLS.

New Zealand is supplied with a large and varied assortment of clays that will become of great value for industrial purposes in the near future. The clays are well distributed throughout both islands, and are commonly found in places that are easily accessible. They fall into three natural groups as under:—

I. Residual clays.
II. Glacial clays.
III. Tertiary marine clays and marls.

Residual Clays.—These originate from the weathering or surface decomposition of rocks *in situ*. They are found in many parts of New Zealand, reaching their maximum development in the North Auckland district. In the South Island they are only found in protected situations, which is also the common experience in the glaciated areas of Northern Europe and North America.

The general character of the residual clays does not vary much whatever the nature of the parent rock. All are more or less ferruginous, and contain angular mineral particles, together with more or less decomposed blocks of the original rock. The colour ranges from yellow to reddish-brown or red.

The chief industrial value of these clays lies in their suitability for brick-making.

Composition.

	Lowest.	Highest.
Silica	40.00	75.00
Alumina	12.50	29.00
Iron oxides	5.75	17.00
Lime (carbonate)	0.25	3.50
Magnesia	0.35	2.00
Alkalies	0.10	4.00
Water	5.00	25.00

In most cases limestone or calcareous sandstone residuals are better suited for brickmaking than those from basic and semi-basic igneous rocks which are commonly deficient in sand. The residual clays of the argillites and greywacke of Wellington when free from stones form a good brick-making material, as also do the clays resulting from the weathering of the sandy clay beds of the Waitemata formation in Auckland.

Glacial Clays.—These are commonly tough and gritty, but often contain so many stones as to limit their value for brick-making.

The Kaikorai glacial clays, between Burnside and Abbot's Creek Bridge, form, as seen in the railway cuttings a sheet from 0ft. to 20ft. thick, large areas of which are comparatively free from boulders except at the base, where they rest on a gravelly boulder bed, which is intercalated in places with a stratum of black peaty clays. This is one of the most extensive and valuable brick-clay deposits in Otago.

In addition to the clays directly formed by ice there are those formed in lakes or in flood-plains by the streams issuing from the glacier. Such are the bands of tough clay intercalated in the lower portion of the Taieri Moraine, as seen along the banks of the Taieri River going towards the mouth of the river from Henley. These clays are composed of material derived from the ice, and since they were deposited in water they are stratified, and, according to local circumstances, may be lacustrine, estuarine, or fluviatile.

The stratified brick clays at Wingatui, near Dunedin, and the well-bedded clays that form the low hills lying in the old valley that runs from Wellington to Island Bay are probably glacial clays. The Wellington clays, as so well-exposed in the street-cuttings along the tramway line between Newtown and Island Bay, are found to alternate in their upper horizons with thin and thick beds of angular rock-rubble of greywacke, often resembling layers of coarse road metal. These rubble beds closely resemble the rubble beds interbedded with the Taieri and Pukaki moraines.

The glacial silt, or loess, so largely developed at Mosgiel, Oamaru, Timaru Downs, Banks Peninsula, and North Canterbury is, where not too gritty, good material for brick-making. It is mainly wind-formed, and hence may be termed an æolian clay.

Tertiary Marine Clays.—This class includes those clays that were deposited as a sea-mud on the floor of the ocean in quiet water. Except in estuaries and tidal harbours such as those of the Manukau, Kaipara, Kawhia, Thames, and east coast of North Auckland, these marine clays have been laid down at some distance from the shore, and are hence uniform in texture, and free from the coarser material often deposited in shallower water.

Beds of marine clay of this type are frequently of great extent and thickness; and the variations in character will generally be found in vertical rather than in horizontal extension, except where the deposits approach the shore-line of the ancient sea in which they were formed.

The North Island possesses an area exceeding 10,000 square miles, and the South Island 2,500 square miles, occupied by blue marine clays, belonging to the Miocene and Pliocene formations. In the North Island they occupy a wide coastal zone extending from East Wairarapa to Waikaremoana and East Cape, in many places reaching inland to the foot of the main divide. They compose the fertile lands lying between the Ruahine Mountains and Taranaki, whence they stretch northward to the Mokau and Upper Wanganui.

In the South Island these Tertiary sea-muds are well-developed at Collingwood, Parapara, Takaka, Baton, Port Hills, Awatere Valley, and Flaxbourne, North Canterbury, Pareora, Waihao, Awamoa, Waikouaiti North Head, Puketeraki, Burnside, near Dunedin, Waiau, and Bob's Cove, Lake Wakatipu.

In the North Island the lands occupied by these clays, generally known by the Maori name *papa* lands, are celebrated for their fertility, and it is mainly due to their presence that the provincial districts of Wellington and Hawke's Bay and South-east Auckland have become so distinguished for their fine flocks of sheep.

Apart from their pastoral value it would be difficult to exaggerate the part these marine clays and marls will eventually play in the industrial advancement of the Dominion. The many large deposits of limestone that exist in both islands, when taken in conjunction with the coals that are so widely distributed, and the water-power almost everywhere available, will render these clays of great value in the manufacture of cements, for which they are specially adapted.

Concrete is the coming building material of the future; and New Zealand, with its enormous deposits of limestone and clays in juxtaposition, its water-power and coals, its long sea-board and deep harbours is destined to become the centre of cement manufacture for the South Pacific.

MINERAL WATERS.

New Zealand possesses, as one of the after effects of a waning vulcanicity, a great variety of valuable mineral springs, both hot and cold, most of which are situated on the Rotorua-Taupo volcanic zone.

The mineral waters may be classified from the analyses made in the Dominion Laboratory into the following groups:—

Saline—Containing chiefly sodium chloride.

Alkaline—Containing carbonates and bicarbonates of soda and potash.

Alkaline siliceous—Waters charged with alkaline silicates. The silica is liberated in the form of sinter in contact with the atmosphere.

Hepatic or Sulphurous—Besides silica these waters are charged with sulphuretted hydrogen and sulphurous acid.

Acidic—These contain an excess of mineral acids, chiefly hydrochloric and sulphuric acids.

The following tabulated statement, prepared by Professor S. H. Cox from analyses mostly made by Skey, in the Government Laboratory at Wellington, gives a useful summary of the chemical character of the best known mineral waters in the Dominion:—

No.	Name and District.	Temp. Fahr.	Solid Grains per pint.	Chemical Character.
		Deg.		
1	Ohaeawai, Auckland	60-116	16.8	Acid, Aluminous.
2	Waiwera ,, ...	110	17.7	Alkaline, Saline.
3	Puriri ,, ...	60	67.1	Alkaline, Carbonates.
4	White Island Lake, Bay of Plenty	97-212	1850.8	Strongly Acidic.
5	White Island Springs, Bay of Plenty	210	207.7	Strongly Acidic.
6	Pink Terrace Geyser, Rotomahana	208	19.3	Sulphurous.
7	White Terrace Geyser, Rotomahana	210	18.0	Alkaline.
8	Turikore, Whakarewarewa ...	96-120	10.9	Sulphurous.
9	Te Koutu Spring, Rotorua ...	90-180	9.1	Akaline.
10	Koreteoteo ,, ...	214	13.0	Alkaline, Caustic.
11	Kuirua ,, ...	136-156	9.9	Alkaline.
12	Manupirua, Rotoiti ...	107	4.1	Sulphurous.
13	Cameron's Bath ,, ...	109-115	14.3	Acid.
14	Ariki-kapakapa ,, ...	160	6.6	Acid.
15	Perekari ,, ...	130-150	7.0	Acid.
16	Ti Kute ,, ...	100-212	6.1	Sulphurous.
17	Te Mimi ,, ...	90-112	3.8	Acid.
18	Te Kauwhanga ,, ...	80-100	8.0	Acid.
19	Painkiller Bath ,, ...	204	16.0	Acid.
20	Sulphur Bay Spring ,, ...	90-100	5.6	Acid.
21	Otumuhika (*a*) Taupo ...	100-150	1.5	Sulphurous.
22	,, (*b*) ,, ...	150	3.4	Sulphurous.
23	,, (*c*) ,, ...	78	1.2	Sulphurous.
24	Ruahine ,, ...	190	19.1	Sulphurous.
25	Orakeikorako ,, ...	90-106	10.6	Acid
26	McMurray's Bath. Taupo ...	126	4.2	Sulphurous.
27	Alum Cave Spring ,, ...	60	7.1	Sulphurous.
28	Crow's Nest Spring ,, ...	170	18.0	Saline.
29	Waipakahi ,, ...	98-120	2.8	Sulphurous.
30	Te Hukahuka ,, ...	116	1.8	Sulphurous.
31	Tarawera ,, ...	130	12.5	
32	Parkes' Spring ,, ...	Cold	25.1	
33	Wangape, Waikato	160-200	6.0	Alkaline.
34	Onetapu ,, ...	70	58.0	
35	Roparoa, Waiapu	Cold	...	Saline, Bituminous.
36	Manutahi ,, ...	Cold	...	Saline, Bituminous.
37	Pepoti ,, ...	Cold	...	Hydro-Carbon Gas.
38	Waipaoa, Poverty Bay ...	Cold	...	Bituminous.
39	Waipiro, Waiapu	144	...	Calcareous, Bituminous
40	Wallingford, Wellington ...	60	10.4	Acid.

No.	Name and District.	Temp. Fahr.	Solid Grains per pint.	Chemical Character.
41	Pahua ,, ...	Cold	184.2	Alkaline.
42	Barton's Spring ,, ...	Cold	...	
43	Akateo (*a*) ,, ...	Cold	62.4	Alkaline.
44	,, (*b*) ,, ...	Cold	4.8	Sulphurous.
45	Hanmer Plain Springs, Amuri	90-104	10.8	Akaline.
46	Sumner Lake Springs, Hurunui	93	2.3	Acid, Saline.
47	Amberley Spring, Canterbury	Cold	11.7	Chalybeate.
48	Wickliffe Bay Spring, Otago ...	...	34.6	Saline.
49	Gibson's Spring, Southland ...	Cold	2.3	Alkaline.

The hot mineral springs between Rotorua and Taupo can be counted by the score; and around the more important groups there have sprung up fashionable spas which are the favourite resort of thousands of tourists from all parts of the Dominion and Commonwealth. Besides the tourists, who throng these places for pleasure and sight-seeing, and jaded worn-out people who go to recuperate, many invalids are attracted by the marvellous curative properties of the waters. The spas at Te Aroha, Okoroire, Rotorua, Wairakei, and Taupo, in the North Island; and Hanmer in the South Island, are throughout the year healthful, invigorating, and enjoyable.

The hot springs at Te Aroha are celebrated for their medicinal and therapeutic properties. The following analyses by J. A. Pond show the composition of the contained mineral salts in three of the best known waters at that place:—

Analysis.	No. 1 Bath.	No. 2 Bath.	Drinking Spring.
Sulphate of lime	2.989	2.228	2.989
Sulphate of magnesia ..	.378	.336	.602
Sulphate of potash ..	10.293	9.800	10.794
Sulphate of soda	27.546	28.056	25.438
Chloride of sodium ..	73.514	72.072	77.748
Bi-carbonate of soda ..	728.737	698.513	682.123
Carbonate of ammonia ..	3.556	.112	.980
Carbonate of iron ..	.042	.063	.042
Carbonate of lithia		(heavy traces)	
Phosphate of soda	2.063	2.203	1.696
Phosphate of alumina ..	.143	.023	.476
Silica	8.568	8.778	8.778
Sulphuretted hydrogen ..	traces	traces	traces
Total solid matter ..	857.829	822.184	811.702

The results are expressed in grains per gallon. The temperature of the waters ranged from 105° to 119° Fahr.

In his remarks Pond says that these waters are all feebly alkaline and strongly charged with carbonic acid gas, which is constantly escaping from the springs in large quantities. The lithia, a valuable constituent of these waters, is present in an appreciable quantity. The analysis shows these waters to be very similar in composition. They closely resemble some of the European mineral springs so justly celebrated, more especially those of Vichy, Ems, and Fachingen. Their curative value will be greatest in rheumatic and arthritic diseases, calculus, affections of the kidneys, and dyspepsia.

Altogether there are eighteen springs, of which fifteen are hot, and with the exception of Nos. 16 and 17, all manifest an alkaline character, being heavily charged with carbonate of soda.

The hot springs at Rotorua are alkaline, neutral, and acid.

The distinguishing feature of the acid sulphur waters is the presence of free sulphuric and hydrochloric acids often in considerable quantity. In addition they contain sulphates of soda, alumina, lime, and magnesia, as well as other salts.

The best known of the acid springs are the *Priest* and the *Postmaster*. The composition of the *Priest* water as given by Dr. Wohlmann, is as under:—

	Grains per Gallon.
Sulphate of soda	19.24
Sulphate of potash	traces
Sulphate of lime	7.41
Sulphate of magnesia	3.03
Sulphate of alumina	21.67
Sulphate of iron	1.24
Sulphuric acid (free)	22.12
Hydrochloric acid (free)	3.65
Silica	18.41
Total	96.77

The water as it rises in the spring gives off sulphuretted hydrogen and carbonic acid gas.

The *Postmaster* spring differs only from the above in containing a larger proportion of free sulphuric and hydrochloric acids. Its temperature as it issues from the ground varies from 98° to 110°

Fahr. The composition of the contained mineral salts, according to Wohlmann, is as follows:—

	Grains per Gallon.
Sulphate of soda	32.87
Sulphate of potash	1.24
Sulphate of lime	4.93
Sulphate of magnesia	1.83
Sulphate of alumina	33.22
Iron-oxides	4.42
Sulphuric acid (free)	30.32
Hydrochloric acid (free)	6.14
Silica	17.61
Total	132.58

Also sulphuretted hydrogen.

The alkaline waters present a type common to many famous spas in Europe, and are suitable both for drinking and bathing purposes. They contain a small amount of common salt, but are more siliceous than the majority of European waters. Their temperature varies from 180° to 212° Fahr. They are perfectly clear, and possess a soft emollient feel.

The following table shows analyses of the *Rachel*, *Blue Bath*, and other alkaline waters at Rotorua in grains per gallon:—

——	Rachel Spring Rotorua.	Blue Bath, Rotorua.	Oil Bath, Whaka-rewarewa	Spout Bath, Whaka-rewarewa	Waikite, Ohine-mutu, 1903.	Corlett's Spring, Rotorua.
Sodium-chloride ...	69.43	60.44	66.34	53.61	38.75	66.44
Potassium-chloride ...	3.41	...	1.46	1.24	...	Traces.
Magnesium-chloride ...	...	1.04	...	...	...	0.31
Lithium-chloride ...	Traces.	...	Traces.	...	...	...
Calcium-chloride ...	...	...	...	...	...	6.72
Sodium-Sulphate ...	11.80	...	7.49	13.47	2.72	...
Potassium-sulphate ...	...	...	...	...	2.70	...
Calcium-sulphate ...	...	5.48	...	...	...	10.32
Sodium-bicarbonate ...	...	...	...	...	20.03	...
Calcium-bicarbonate...	...	...	...	...	0.82	...
Magnesium-bicarbonate	...	...	...	...	0.74	...
Calcium-carbonate ...	...	...	...	...	...	0.21
Aluminium-phosphate	...	...	...	Traces.	...	...
Alumina	...	...	...	...	0.16	Traces.
Silica	5.87	14.20	...	...	24.36	...
Sodium-silicate ...	18.21	8.38	2.08	16.32	...	29.27
Calcium-silicate ...	4.24	...	3.16	1.61	...	...
Magnesium-silicate ...	1.09	0.32	0.76	1.14	...	...
Silicates of Iron ...	...	1.42	0.85	0.39	...	...
Oxides of Iron and aluminium	2.41	...	...	...	...	...
TOTALS ...	116.46	91.28	82.14	87.78	90.28	113.27

Also sulphuretted hydrogen and carbonic acid in all.

The following analysis by Dr. Maclaurin of the mineral water in the crater-lake at White Island is interesting for comparison with the acid waters at Rotorua:—

	Grains per Gallon.	Per cent.
Potassium sulphate	101	0.14
Sodium sulphate	620	0.88
Aluminium sulphate	1,733	2.48
Ferrous and ferric sulphates ..	346	0.49
Calcium sulphate	351	0.50
Magnesium sulphate	182	0.26
Silica	9	0.01
Hydrochloric acid (free)	3,832	5.47
Total	7,174	10.23

Maclaurin reports that the water also contains heavy traces of boric acid, arsenic, and copper. The former, he thinks, may be of commercial value. An acid water of such strength is without a parallel in Europe.

LIST OF MINERALS FOUND IN NEW ZEALAND.

In the preparation of this list use has been made of Hector's list of 1865 (Jurors' Reports of New Zealand Exhibition, 1865); of Cox's lists of 1881 and 1882 (Trans. N.Z. Inst., Vols. XIV. and XV.); of Hector's list of 1890 (Rept. Aust. Assoc. Adv. Sci., Vol. II.); of the author's lists of 1891 (Trans. Aust. Assoc. Adv. Sci., Vol. III.) and 1892 (Trans. N.Z. Inst., Vol. XXVI.); and of Marshall's list of 1908 (Trans. N.Z. Inst., Vol. XLI.).

ALUMINIUM—

Corundum—Western slopes of Southern Alps (Haast); Collingwood (Hutton); also in boulders associated with green muscovite, Rimu (Marshall).

Sapphire—Southern Alps, and in gold-wash Collingwood (Skey).

Taranakite—Sugar Loaves, New Plymouth (Skey).

Wavellite—Associated with Taranakite (Skey).

Alunogene—In brown coal Tuapeka (Hector).

Alum—As efflorescence on clays in many places. Common in Central Volcanic Zone of Auckland in vicinity of hot springs.

Alunite—Rotorua, deposited by geysers (Ulrich).

Kyanite—Associated with quartz, Westland (Hector).

Mellite—Thames (Hutton); Bligh Sound (Hector).

ANTIMONY—

Cervantite—At Waikari, Bay of Islands, at outcrop of antimony lode (Park).

Senarmontite—At Waikari, Bay of Islands (Park); also Mount Radiant (Marshall).

Antimonite—Widely distributed throughout New Zealand, occurring in quartz lodes at Thames, Coromandel, Reefton, and in Otago. In massive form at Waikari, Bay of Islands, Endeavour Inlet, Carric Range, and many parts of Central Otago. Many fine acicular crystals of stibnite occur in cavities in the Thames lodes. Not often found in valuable quantity.

Kermesite—Waikari, Bay of Islands.

ARSENIC—

Native Arsenic—Kapanga Mine, Coromandel, in quartz lode associated with gold and pyrites. It occurs in reniform masses over an inch thick, lining drusy cavities in the quartz (Hector).

Orpiment—Coromandel (Maclaren).

Realgar—Coromandel (Maclaren).

Arsenolite—Coromandel (Maclaren).

Mispickel—Common in many of the quartz veins of Thames, Coromandel, Collingwood, and Reefton. Also found in schists of Otago.

BARIUM—

Barytes—Akiteo; Thames; Paonui Point, near Napier; Te Arai, Auckland; East Cape; Waihi; Puriri; Collingwood; Upper Baton.

Witherite—Thames (Skey).

BISMUTH—

Native bismuth—In gold ores, Owen Goldfield (Skey).

CALCIUM—

Calcite—All parts of New Zealand.

Travertine—Common as encrusting layers in caves and rock-shelters.

Arragonite—Quartz Hills, Collingwood, in limestone; at Thames, in andesite,; Bank's Peninsula and Otago Peninsula, in cavities in basic igneous rocks. In large crystals at Oamaru (Park).

Selenite—White Island, with sulphur in considerable quantity; in clays at Moeraki, Waitaki Valley, Waihao, Tengawai; Thames, and many other places.

Scheelite—See tungsten ores.

Melitite—As plates in basinite, Puketeraki, Otago (Marshall).

Apatite—In many igneous and metamorphic rocks throughout the Dominion.

CARBON—

Graphite—At Pakawau, in altered quartzose slate (Hochstetter); at Hawksburn, near Cromwell (Park); Rimutaka, and Otaki, Wellington (Crawford); Manaia, near Mount Egmont (Park); Jackson's Bay (Hector); Mount Potts (McKay); Dusky Sound (Docherty); Orari River (Tripp).

Bituminous Coal—Collingwood, Buller, Grey, and Paparoa coalfields.

Pitch Coal—Kawakawa, Whangarei, Reefton, and Inangahua coalfields.

Brown Coal—Waikato, Waipa, Mokau, Upper Wanganui, Takaka, Nelson, Tadmor, Sherry, Malvern Hills, Mount Somers, Waihao, Wharekuri, Shag Point, Green Island, Kaitangata, Tokomairiro, Nightcaps, and Winton.

CARBON—*continued.*

Lignite—Naseby, Kyeburn, Hyde, Alexandra, Clyde, Roxburgh, Cromwell, Mataura, Mohaka, Upper Rangitikei, etc.

Idrialite—Dunstan, Waipori, Ohaeawai (Skey).

Oil Shale—Orepuki, in Southland; Waitati, near Dunedin; Paparoa, Otamatea Arm, Kaipara.

Elaterite—Pieces on East Coast; Kawau Island. Native occurrence doubtful.

Petroleum—Sugar Loaves, near New Plymouth; Matatutu, Poverty Bay; Manutahi, Waiapu River. The oil at Taranaki is probably the result of the destructive distillation of the Mokau brown coals, which dip towards Cape Egmont. The Mokau coal-measures are overlain by a great thickness of Pliocene clays, and the clays by a pile of volcanic drift. At the Sugar Loaves it is probable that the coal lies at a depth not much short of 4,000ft. or 5,000ft.

Dopplerite—Waiapu (Hector).

Ozokerite—In brown coals of Dunstan (Hector).

Ambrite—In all brown coal in New Zealand.

Mellite—Thames goldfield (Hutton).

Methane (CH_4)—Wells of carburetted hydrogen gas exist on the east coast of Wellington at Maitakuna, Blairlogie, and Upper Taueru. Also near Gisborne, and at different places in Taranaki, where indications of petroleum have been found. A strong emission of this gas takes place at Hanmer Springs, where it is used for lighting the Government Spa.

CHROMIUM—

Chromite—Is a common constituent of the olivine and serpentines of the South Island. Was formerly mined at Dun Mount and Ben Nevis, Nelson; occurs abundantly in grains and nests in peridotite at Red Hill, N.W. Otago.

COBALT—

Erythrine—In schist and gneiss on West Coast (Hector).

Asbolite—Auckland district (Pond); and Rapaka, Bay of Islands (Skey).

COPPER—

Native Copper—Occurs as large slabs and strings in serpentine at Aniseed Valley, Nelson; and D'Urville Island. Also found at Dun Mount; Moke Creek, Lake Wakatipu, and as grains in a basic dyke at Manukau North Head (Cox). On mine timbers, Kawau (Baker).

Chalcantherite—In old drives Thames goldfield (Park).

Malachite—Occurs at the outcrop of all copper lodes, notably at Dun Mount, Aniseed Valley, D'Urville Island, Moke Creek, and Shotover.

Azurite—Occurs with malachite, but is not so abundant.

Dioptase—Occurs encrusting copper ores at Nelson; and also at Wonder Claim, Thames (Skey).

Chrysocolla—Is common as an incrustation on copper ores in Nelson district (Cox).

Cuprite—Dun Mount serpentine belt, and D'Urville Island; also at Bligh Sound (Hector); and in quartz lode at Wainui, Thames (Hutton).

Melaconite—Aniseed Valley, D'Urville Island in serpentine.

Copper Glance—Is constantly associated with cuprite at Dun Mount, Aniseed Valley, and D'Urville Island.

COPPER—*continued.*

Bornite—Kawau (Hector); Dunstan (Liversidge).

Chalcopyrite—Widely distributed throughout both islands, but has not yet been found in profitable quantity. Whangaroa, Kaipara, Kawau, Thames goldfield in many gold-bearing lodes, Coromandel, Great Barrier Island, Maharahara near Woodville, many places in Collingwood, Westland and Otago. Also occurs in mineralized zones of schist at Moke Creek, Shotover, and Dusky Sound; and at Lake Ohau and Moorehouse Range, Canterbury.

Covelline—D'Urville Island (Cox).

Tetrahedrite—Richmond Hill, Collingwood, in massive form (Skey); and at Koputaiaki Bay, Coromandel, in andesite associated with pyrites (Park).

GOLD—

Native Gold—This metal is widely distributed in veins and alluvia throughout both islands. It occurs at Hauraki Peninsula in middle Tertiary andesites, dacites, and rhyolite, and in Mesozoic shales and sandstones; at Terawhiti, near Wellington; at Collingwood and West Wanganui; Takaka; Baton, Mount Arthur, Wangapeka, Owen, Maruia, Lyell, Reefton, Boatman's, Blackwater, Browning's Pass, all in Nelson and Westland; at Pelorus Sound and Wakamarina, Wairau Valley, Top House; in many parts of Otago and Southland, mostly in mica-schist or in drifts.

Electrum—The gold of Te Aroha, Karangahake, Waihi, Waitekauri, Thames and Coromandel is alloyed in its natural state with native silver to an extent varying from 25 to 35 per cent. Commonly about one-third of the bullion is silver.

IRON—

Native Iron—Ocurs at Red Hill, in North-west Otago, in peridotite and serpentine alloyed with nickel in the mineral awaruite (Skey).

Meteoric Iron—In Wairarapa meteorite in Dominion Museum, Wellington. Weighs 9¼lb., contents 49 cubic inches, S.G. 3.254, contains 24 per cent. iron with silica, sulphur, nickel, etc. (Skey).

Magnetite—Occurs as nests and grains disseminated in mica-schist and chlorite state at Collingwood, and throughout Westland and Otago; is a common constituent of nearly all basic and semi-basic igneous rocks in both islands. Magnetite forms the bulk of the black sand occurring on the Westland and Southland sea-beaches, and in the gold-bearing alluvium of Otago, Westland, and Nelson.

Hæmatite—Occurs as small lenses and nests in a chloritic schist band in Moke Creek (McKay), and Shotover (Park); also in a chlorite state at Roaring Meg and Mount Pisa in Central Otago (Park). Reported from Collingwood and Whangaroa (Cox).

Specular iron—Occurs in grains, nests, and large masses in bands of quartzose chlorite schist in Central and Western Otago, frequently associated with hematite. Is abundant on west side of Pisa Range and in Shotover Valley in a mineralized chloritic band. This ore forms the pebbles and boulders in the gold wash of Otago known to the miners as *Black Maori.*

Limonite—Occurs in all parts of the Dominion as veins and sheets. The largest deposit occurs on coastal hills between Parapara and Onakaka, where it occurs partly or wholly as a replacement

IRON—*continued.*

of a cherty limestone. No other deposit of commercial value is known in New Zealand. Bog iron ore in granules and small masses is abundant in some swampy areas.

Goethite—In cavities in limonite at Parapara (Bell, Webb and Clarke).

Turgite—Associated with limonite at Parapara (Bell, Webb, and Clarke).

Chloropal—Otago (Liversidge).

Siderite—In contorted schist in Otago (Hector). The earthy form clay ironstone occurs associated with the Upper Cretaceous and Tertiary coals in many places, notably at Kakanui River, Mount Somers, Malvern Hills, Abbey Rocks, Westland, Grey River, Raglan, and Miranda; and in the Jurassic Mataura formation at Cairn Ranges, Canterbury (McKay).

Sphaerosiderite—In dyke rocks at Mount Somers and Bank's Peninsula (Haast).

Ilmenite—See Titanium ores.

Menaccanite—Brancepeth, Wairarapa (Skey).

Iserine—Ironsands West Coast, South Island.

Pyrites—Distributed throughout both islands in almost all kinds of rock. It is a common constituent of all the gold-bearing lodes at Thames, Coromandel, Reefton, and of Otago. Occurs in large granular masses and sheets in rhyolite and rhyolitic tuffs at Rotorua and Rotomahana.

Marcasite—Common in all the brown coals of New Zealand. Is also found in clays and shales of the coal-measures; and in many of the gold-bearing lodes at Thames and Coromandel.

Leucopyrite—Thames, Reefton, Collingwood (Cox).

Pyrrhotite—West of Mount Cook (Cox); Dusky Sound (Skey); Collingwood (Skey).

Glauconite—Occurs abundantly in the greensands of the Oamaru and Waipara formations. It passes upward, in the Oamaru Series, into the calcareous member closing the series.

Vivianite—North-East Valley, Dunedin; Timaru, Pohangina River, Port Chalmers, Taranaki, Thames.

Melanterite—Occurs abundantly in old drives at Thames goldfields in crystalline, massive, fibrous, and capillary form. It is also found as an efflorescence on clays containing pyrites or marcasite.

Delessite—Mount Somers and Malvern Hills (Haast).

Chlorophoeite—In cavities in igneous rocks at Mount Somers, Rangitata, and Malvern Hills (Haast).

Fayalite—In schist in Nelson (Skey).

Wolfram—See tungsten ores.

LEAD—

Native Lead—In creek wash Thames (Skey). In gold wash at Parapara (Park).

Cerussite—In large masses containing many tons in Tui Mine, Te Aroha (Park). In smaller quantity at Waiorongomai mines.

Wulfenite—Dun Mountain (Cox).

Cotunnite—Thames goldfield, Komata (Park).

Nagyagite—Sylvia mine, Thames (Park).

Anglesite—Champion mine, Te Aroha (Park).

Pyromorphite—Tui mine, Te Aroha; and Grace Darling mine, Waitekauri, where it was mistaken for gold (Park).

Dufrenoysite—Occurs associated with galena in diorite, Great Barrier Island (Hutton).

Bournonite—Rolling River, Wangapeka (Skey).

LEAD—*continued.*

Galena—Widely distributed in all parts of New Zealand. Occurs in quartz lodes at Waiorongomai, Te Aroha, and Waiomo, in the Hauraki goldfields, and at Perseverance mine, Collingwood, in a bedded-vein in slate; also at Richmond Hill and Rangitoto mine, Westland. Is found in grains in mica-schist and gneiss in Otago and Westland.

MAGNESIUM—

Magnesite—Rotorua, Chatham Islands; and Milford Sound (Marshall).

Rhodocroisite—Coromandel (Fraser).

Dolomite—Malvern Hills; Collingwood.

Pearlspar—Big Pump, Thames (Hector); Una Hill, Thames (Park).

Epsomite—As efflorescence on residual clays in volcanic regions but never abundant, Thames (Park).

MANGANESE—

Pyrolusite—This occurs with manganite at Waiheke and Kawau.

Hausmannite—As rolled pieces in Selwyn river-bed (Haast).

Braunite—Malvern Hills (Skey), Wellington and Bay of Islands (Skey).

Manganite—Occurs as veins and encrusting masses in many sandstone, slate, and schist formations in both islands. Large lenses have been worked at Waiheke, Kawau, and Bay of Islands. Is fairly abundant in many of the quartz veins at the Thames and Waihi.

Psilomelane—Bay of Islands, Kawau, Whangarei, Waiheke, Thames, Waihi, Waipu. At Kawau and Waiheke was mined for some time.

Wad—Is common in cracks in many lodes at Thames. Common wherever manganese ores abound.

Diallogite—Associated with calcite in the Sylvia lode, Tararu Creek, Thames (Skey); also at Makara Valley, near Wellington (Hector); and in Waitekauri lode in calcite (Park).

Rhodonite—Occurs in small lenses in mica-schists of Otago as at Kawarau, Dunstan, and Cromwell; also Waiheke (Skey).

Hauerite—Wakatipu District (Skey); Collingwood (Cox).

MERCURY—

Native Mercury—Occurs at Waipori (Hector); and at Ohaeawai Hot Springs, North Auckland (Hutton).

Cinnabar—At Ohaeawai, Puhipuhi, Thames, Waipori, and many places in Central Otago. At Thames it occurs impregnating an altered andesite. At Ohaeawai it occurs associated with large masses of pyrites, and is now being deposited at the hot springs which are connected with a basalt intrusion.

MOLYBDENUM—

Molybdenite—Dusky Sound (Cox); in quartz veins Sylvia Creek, Thames (F. B. Allen); at Mount Radiant, Upper Karamea, in quartz veins traversing granite.

NICKEL—

Awaruite—An alloy of nickel and iron (2 Ni + Fe) occurring as grains in peridotite and serpentine at Red Hill inland of Awarua Bay, in North-west Otago (Skey).

Genthite—In serpentine from Hoteo, Wade, Mahurangi (Pond and Skey); also in andesite Tapu Road, Thames (Park).

Pimelite—Malvern and Clent Hills in igneous rocks (Haast).

Pyrrhotite—Westland (Cox); Dusky Sound (Park); Aniseed Valley (Marshall). See iron ores.

OSMIUM and IRIDIUM—

Osmium-iridium—Occurs as small flat grains in gold-wash at Takaka (Hochstetter).

PLATINUM—

Native Platinum—Occurs in the gold drifts at Round Hill, Southland, where about an ounce is obtained for every 100 ounces of gold. Also Stewart Island, Takaka, and Collingwood.

Platiniridium—In gold-wash Takaka, Nelson (Hochstetter).

SELENIUM—

Traces of this rare metal were found in the sulphur at White Island by Liversidge. Ocurs in bullion of Waihi Gold and Silver Mining Co., Waihi.

SILICA—

Quartz—Distributed throughout, occurring as vein-matter and interfoliated in mica-schist and gneiss. Present in granites and all acidic and many semi-basic igneous rocks.

Amethyst—Rakaia Gorge; Tokatea Hill, Coromandel, in the big lode.

Prase—In quartz porphyries of Gawler Downs (Haast).

Jasper—In Mesozoic slaty shales in all parts of both islands; also in veins in tuffs at Manaia near Coromandel.

Agate-Jasper—Manaia, Coromandel, in andesitic tuffs.

Chalcedony—Clent Hills, Gawler Downs, Mount Somers, Tokatoka, Waihi, Karangahake, Rotorua, Rotomahana, Great Barrier. Agates occur in the tuffs at Coromandel; and onyx at Malvern Hills, Clent Hills, Mount Somers, etc. (Haast).

Carnelian—In volcanic rocks at Moeraki, Otepopo, and Dunedin Harbour; and from tuffs at Coromandel.

Plasma—Mount Somers and Gawler Downs (Haast).

Chroysophrase—Malvern Hills (Haast).

Bloodstone—Clent Hills, Snowy Peak, and Malvern Hills (Haast).

Tridymite—In andesite, Lyttelton Harbour (Ulrich); and in teprite, Auckland (Marshall).

Noble Opal—In rhyolite, Tairua, Auckland.

Wood Opal—Large masses occur in the volcanic tuffs and breccias at Manaia, near Coromandel, at Thames, Puriri, Komata, and many other places in the Hauraki Peninsula; at Great Barrier Island, Oamaru, and Otago Peninsula; also in the Mataura Series at Waikawa.

Flint—Abundant at Kaipara, forming bands in hydraulic limestone (Park); Clarence Valley in thick beds (McKay); at Campbell Island in chalk (Hector); Amuri Bluff (Haast).

Hyalite—Snowy Peak and Malvern Hills (Haast); Bell Hill, Dunedin (Liversidge).

Sinter (siliceous)—In volcanic zone from White Island to Taupo. Abundant around old craters, especially at Rotorua, Wairakei, Rotomahana, and White Island.

SILICATES and ALUMINATES—Hydrous and Anhydrous—

Wollastonite—Dun Mountain (Davis).

Chrysolite (Olivine)—Dun Mountain, Red Hill, in massive form; and as grains in basalts, dolerites, and other basic igneous rocks throughout the Dominion.

Augite—In tuffs Kakanui River (Thomson); and in many basic and semi-basic igneous rocks in both islands.

Aegirine—In alkaline igneous rocks, Dunedin (Ulrich).

SILICATES AND ALUMINATES—*continued.*

Riebeckite—Westland (Smith); in granite boulders Brunner and Campbell Island (Marshall).

Arfvedsonite—In trachyte, Banks Peninsula (Speight).

Asbestos—Milford Sound; Mount Allen, near Gibbston, Central Otago; Upper Takaka.

Hornblende—A common constituent of schists and acidic and semi-basic volcanic and plutonic rocks in both islands; the green variety in acidic and semi-basic rocks, and the brown or basic variety in camptonites and monchiquites of Westland and North-west Otago.

Amphibole—In gneiss and mica-schist.

Tremolite—In quartzite Lake Kanieri, and Dunstan Range. Also in gneissic schist at Dusky Sound (Park).

Actinolite—Paringa River (Cox); Dusky Sound, and Ophir in Central Otago (Park).

Anthophyllite—Dun Mountain (Davis).

Neprite—Milford Sound (Hector and Marshall); Arahura (Bell); Dun Mountain (Davis).

Diallage—In diorites on West Coast (Hector); in gabbro from Hokuri Creek, Martin's Bay, Lake McKerrow, and head of Kakapo Lake (Hector); in serpentine, Dun Mountain (Hector), in gabbro in Mount Torlesse and Upper Rakaia (Haast).

Diopside—In peridotite rock Hidden Falls Creek, Wakatipu District (Marshall). In basic tuff, mouth Kakanui River (Thomson).

Enstatite—Milford Sound (Marshall); Thames goldfield (Hutton); Lake Johnson (Park); North Cape (Marshall).

Hypersthene—In diorites from West Coast (Hector); Malvern Hills (Haast); Dun Mountain (Davis); Warp Point, Katuku River; also in andesites in Hauraki goldfields.

Bronzite—Dun Mountain (Davis).

Bastite—Dun Mountain (Hutton); North Cape (Marshall).

Sepiolite—Dun Mountain (Davis).

Hydrophite, var. Dermatin—Dun Mountain (Davis).

Talc—Jackson's Bay (Hector); Collingwood and Western Otago in schist.

Steatite—Milford Sound and Collingwood (Hector).

Serpentine (*common*)—Red Hill, Caples River, Lake Harris, Hidden Falls Creek, Mount Allen, Dun Mountain, and D'Urville Island, and Wade.

Serpentine (*noble*)—Milford Sound (Hector). This is the *tengawai* of the Maori.

Dunite—Dun Mountain, Nelson; Milford Sound, Red Hill.

Picrolite—Dun Mountain, Nelson (Cox).

Bowenite (= *tengawai*)—Milford Sound (Marshall).

Antigorite—Dun Mountain (Davis), Pounamu Belt, Teremakau (Bonney).

Hectorite—Dun Mountain (Cox).

Chrysotile—Dun Mountain (Cox); Head of Hidden Falls (Park).

Picrosmine—Dun Mountain (Cox).

Schiller Spar—With pyrites, West Coast South Island (Hector).

Chlorite—Abundant in mica-schists of Otago and Collingwood; and as alteration product in many basic and semi-basic igneous rocks.

Clinochore—In schists Central Otago (Marshall).

Heulandite—In felsite porphyry, Canterbury (Haast).

Apophyllite—In amygdaloids, Rangitata (Haast).

Stilbite—Tokatoka, North Auckland (Cox); Dunedin (Liversidge).

Prehnite—Moeraki and Otepopo (Hector); Snowy Peak Range (Daintree).

SILICATES AND ALUMINATES—*continued.*

Natrolite—Dunedin (Hector); Oamaru (Cox); Whakahara (Cox).

Smectite—In tuffs Great Barrier Island (Hutton).

Analcite—Igneous rocks Dunedin (Marshall).

Paragonite—Jacob's River, Westland (Marshall).

Chabasite—Dunedin (Hector); Banks Peninsula (Haast); Helenburn, Otago (Cox).

Gmelinite—Dunedin (Hector).

Laumonite—In veins and cavities in altered andesite, Martha lode, Waihi.

Kaolin—In nests and veins in many igneous and crystalline rocks.

Halloysite—Dunedin (Hector); Scinde Island, Napier (Skey); Bay of Islands (Skey); Drury and Hunua Range (Skey); Whangaroa (McKay).

Palagonite—Harper Hills and Two Brothers, Ashburton (Haast); Taipo Hill, Otago (Skey).

Schrötterite—Malvern Hills (Liversidge).

Pimelite—Malvern Hills, Clent Hills (Haast).

Iolite—In contact rocks Aorere, Collingwood (Marshall).

Epidote—Present in mica-schists of Otago (Park); Wairarapa (Cox); Dusky Sound (Park).

Aenigmatite (*Cossyrite*)—Abundant in phonolites and trachy-dolerites Dunedin (Marshall).

Zoisite—With epidote in schists Westland (Marshall).

Kyanite—Westland (Cox).

Chiastolite—Slate River, Collingwood (Cox).

Perthite—Stewart Island and Dunedin (Marshall).

Leucite—Castlepoint (Skey).

Scapolite—Dun Mountain (Davis).

Garnet—Common in schists and gneiss of Otago and Westland. Very abundant at Dusky Sound (Park).

Ouvarovite—Dusky Sound (Park).

Grossularite—In gabbro, Dun Mountain (Marshall).

Nepheline—In alkaline igneous rock, Dunedin (Ulrich); in basanite, Auckland (Marshall); in tinguaite, Brunner (Smith).

Sodalite—In alkaline igneous rocks, Dunedin (Marshall).

Muscovite—Plentiful in mica-schist, gneiss and granite in many parts of South Island.

Sericite—Common everywhere in metamorphic rocks and as alteration product in semi-basic igneous rocks in Otago Peninsula, etc.

Lepidolite—Thomson Sound (Hector).

Biotite—In many schists, granites and diorites in South Island; in quartz-mica-diorite Cabbage Bay (Park).

Rubellane—Banks Peninsula (Haast).

Lepidomelane—In schists and gneiss of West Coast (Hector).

Phagopite—In quartz-schist Dunstan Range (Park).

Margarite—Milford Sound (Hector).

Fuscite—A massive sea-green variety, probably glaucolite, Central Otago and Shotover, in mica-schist (Park).

Orthoclase—A common constituent of granite, syanite, and gneiss. The glassy form, sanidine, is a constituent of the rhyolites and trachytes in both islands.

Adularia—In quartz lodes Waihi and Thames.

Albite—In many igneous rocks.

Oligoclase—In many igneous rocks.

Anorthite—In igneous rocks.

Anorthoclase—In alkaline igneous rocks, Dunedin and Campbell Islands (Marshall).

SILICATES AND ALUMINATES—*continued.*

Andesine—In igneous rocks, Thames.

Bytownite—In igneous rocks, Thames.

Microline—In many granites at Golden Bay, Stewart Island, and West Coast Sounds.

Labradorite—In many basic and semi-basic rocks in both islands.

Saussurite—Mount Torlesse (Haast).

Gahnite—Pegasus, Stewart Island (McKay).

Spinel—Waipori (Hector); Manawatu, and Pahiatua (Skey).

Goodletite—Occurs as boulders in gold-drift at Rimu. It is a massive form of ruby (Ulrich).

Picotite—In South-west Otago (Marshall).

Zircon—Timbril's Gully (Hector); Southern Alps (Haast); Doubtful Inlet (Cox), Campbell Island (Marshall and Aston).

Topaz—Chatto Creek, Arrow River, and Waipori (Hector).

Topaz (*massive*)—Pegasus, Stewart Island (McKay).

Staurolite—In slate Golden Ridge, Collingwood (Marshall).

Titanite—In granite Separation Point, and in granulites West Coast (Marshall).

Emerald—Dusky Sound (Skey).

Beryl—In large hexagonal prisms at Stewart Island (McKay), Dusky Sound (Cox).

Chrysoberyl—Stewart Island (Skey).

Dioptase—Thames; and Nelson (Skey).

Tourmaline—In granite and gneiss on West Coast (Hector, and Haast); Dusky Sound (Cox); in granite Tata Island (Cox); Bedstead Gully, Collingwood, in fine large crystals in a chlorite schist.

Andalusite—As large crystals in schist, Parapara (Bell, Fraser and Clarke).

Sillimanite—With tourmaline Stewart Island and Dusky Sound (Marshall).

Mosandrite—In trachyte, Campbell Island (Marshall).

Perofskite—In diorite, Bell Hill, Dunedin, and in porphyry, Campbell Island (Marshall).

Monazite—In gold sands, Westport and Greymouth (Fry).

Hedyphane—Coromandel (Maclaren).

Smaragdite—Red Hill, Collingwood (Hector).

Schrötterite—Malvern Hills in igneous rocks (Liversidge).

Stilbite—Karori, Wellington, in thin veins in greywacke (Skey).

Idocrase (*Vesuvianite*)—Dusky Sound (Cox).

SELENIUM—

Selen-sulphur—White Island—Liversidge.

Native Selenium—This is found in the Waihi bullion, but cannot be detected in the ore; also in concentrates, Talisman mine, Karangahake (Aston).

SILVER—

Native Silver—Occurs as rolled fragments in the gravels of Kawarau and Lake Wakatipu and Waipori (Hector); also in gravels of Shotover, and in gold-bearing veins at Thames (Park).

Argentite—Common in the gold veins of Hauraki goldfields, more especially at Karangahake, Waitekauri, Te Aroha, Waihi, and Tairua. Also at Great Barrier Island and Puhipuhi, North Auckland. Argentite is a source of a good deal of the silver extracted by the cyanide process.

Pyrargyrite—Common at Thames and Coromandel in the rich or bonanza patches. It occurs mostly as a thin incrustation, and as isolated grains. Also at Puhipuhi (Park).

SILVER—*continued.*

Proustite—Occurs with pyrargyrite in bonanza patches. Is perhaps the more abundant (Park).

Petzite—Sylvia mine, Tararu Creek, Thames, where it occurred in a quartz lode traversing altered andesite (Park).

Kerargyrite—Common in gold-bearing veins at Thames, Marototo, Waitekauri, Waihi, and Te Aroha. A very rich deposit was found at the outcrop of the Marototo lode. Was more abundant at the outcrop of the bullion lodes than elsewhere. Also at Puhipuhi and Great Barrier Island (Park). Waikoromiko Valley, Coromandel (Fraser).

Hessite—Te Aroha (Skey).

SODIUM—

Glauber Salts—Brancepeth, Wellington.

Sulphur—Found deposited by fumaroles in many parts of Auckland Volcanic Region, from the Bay of Plenty to Ruapehu. Occurs in considerable quantity at White Island, Whale Island, Rotokawa, Rotoehu, and Tikitere. In these places the sulphur occurs in massive and crystalline form. At Tarawera there were formed small bombs of black amorphous sulphur some time after the eruption in 1886.

TITANIUM—

Brookite—In dolerite, Otepopo (Hector).

Ilmenite—Largely represented in black sands on sea-shore at New Plymouth, Hawera, Waitotara; present in many semi-basic igneous rocks in both islands, also in crystalline schists of Otago.

Rutile—Common in mica-schists and gneiss in Central and Western Otago. Dusky Sound (Park); Cromwell (Park); West Coast Sounds (Marshall).

Sphene—Occurs sparingly in mica-schist and crystalline rocks of Central and Western Otago.

Titanium-phosphate—Antipodes Island (Aston).

TIN—

Cassiterite—Lankey's Gully, Reefton; Tuapeka; and Pegasus, Stewart Island (McKay).

TUNGSTEN—

Scheelite—In quartz veins traversing mica-schist in many parts of Otago, notably at Macrae's, Bendigo, and Bucklerburn, Lake Wakatipu; also in Pelorus Sound in gold-bearing quartz-vein (Park).

Wolfram—Pegasus district, associated with tin in granite (McKay).

ZINC—

Native Zinc—A small slab of the metal was found in altered andesite at Hape Creek, Thames. Zinc is a metal that oxidizes so rapidly that some doubt must necessarily attach to this occurrence (Park).

Zincite—Bedstead Gully, Collingwood (Skey).

Calamine—Tararu Creek, Thames (Skey).

Zinc Blende—Tararu Creek, Thames; Tui mine, Te Aroha; Waiomo, and in most of the gold-bearing lodes at Thames, Waiorongomai, and Coromandel. Also occurs with galena at the old Perseverance mine, Collingwood (Hutton).

CHAPTER XVI.

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Abbreviations.

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Rep. G. S. = Reports of Geological Explorations [Geological Survey of New Zealand.—SIR JAMES HECTOR, Director].
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Fig. 140. The Tuatara.

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THE GEOLOGY OF NEW ZEALAND

JAMES PARK