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With the author's compliments

NEW ZEALAND

AND ADJACENT ISLANDS

BY

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HEIDELBERG 1912
CARL WINTER'S UNIVERSITÄTSBUCHHANDLUNG

Reprinted from the Handbuch der regionalen Geologie herausgegeben von Professor Dr. G. Steinmann-Bonn und Professor Dr. O. Wilckens-Jena. 5. Heft (Band VII, Abteilung 1.)

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I. Morphological Summary.

The three main islands of New Zealand lie between the parallels of latitude 34 and 47 degrees South. The extreme northern point of the North Island is in longitude 173 degrees east of Greenwich and the extreme southern point of the South Island is in longitude 169 degrees east. The width of the land is however by no means restricted to the space confined between these meridians; for the westerly portion lies in longitude 166°30′ east and the easterly point in longitude 178°30′ east. Thus the idea of north and south elongation which is derived from a consideration of the position of the extreme north and south points is erroneous. The trend of the South Island is almost exactly north-east and south-west and the same statement is true of the greater part of the North Island. It is the north-westerly projection for 200 miles of a narrow tongue of land nowhere more than 50 miles wide that brings the northern point so near the longitude of the southern one.

Included with New Zealand for descriptive purposes are the following island groups.

Chatham Islands	44°30′S	176°30′W
Bounty „	47°41·30″	179°3′E
Antipodes „	49°40′	178°50′30″
Auckland „	50°50′	166°1′
Campbell „	52°33′26″	169°8·47′
Macquarie „	54°40′	158°50′

Of these Macquarie Island is under the control of Tasmania but the others are subject to the New Zealand Government.

Structurally these islands show much resemblance to New Zealand. The stretches of ocean that separate them from the main islands are relatively shallow, and the flora and fauna are so similar as to prove that within later geological times there has been a land connection between them and New Zealand.

The coast line of the main islands is somewhat regular. In the South Island the prominent volcanic massif Banks Peninsula alone forms a conspicuous projection on the east coast. On the west the granite mass of Cape Foulwind is somewhat prominent. In the south-west the profound fiords strike 20 miles into the mountainous complex. In the north the long sandspit of Cape Farewell extends 12 miles into Cook Strait,

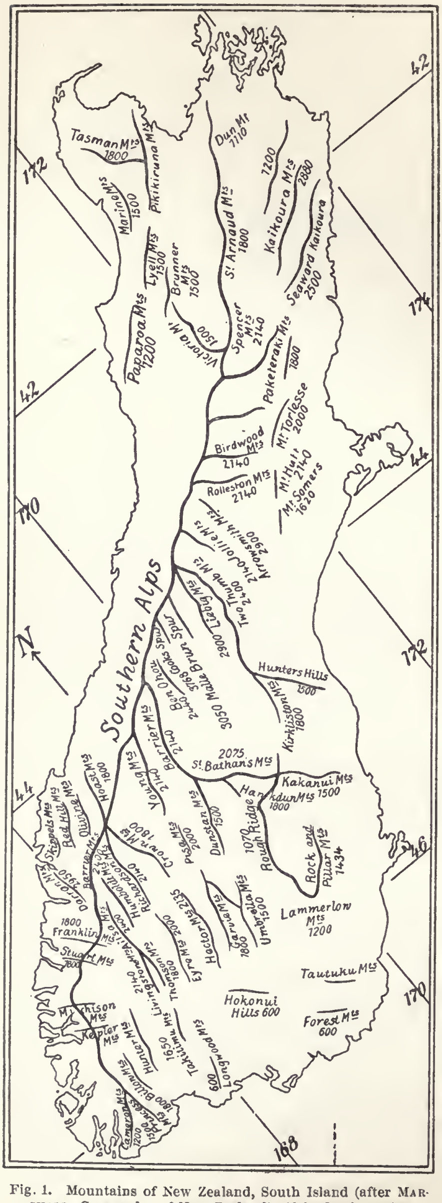

Fig. 1. Mountains of New Zealand, South Island (after MARSHALL, Geography of New Zealand). Altitudes in metres.

while Pelorus and Queen Charlotte Sounds with their many branches and smaller inlets form a network of waterways, and separate many islands from the mainland.

In the North Island the volcanic cone of Mt. Egmont interferes with the regularity of the west coast, which is for the most part fringed with rolling sand dunes. The south-east coast is somewhat interrupted by Mahia Peninsula, formed of gently inclined strata of Cainozoic rock, while the mass of the East Cape region, where the sea margin truncates the backbone of the island composed throughout of much disturbed Mesozoic shales and sandstones, separates the north-east from the south-east coast. The former is the least regular portion of the New Zealand coast. Cape Colville Peninsula formed for the most part of Cainozoic volcanics wrapping round a core of Mesozoic sediments is directed north and south, while Cape Brett and other northerly points are conspicuous projections further north. On the western side all the river entrances and harbour mouths are almost choked with drifting sand, but on the north-east the inlets are free and open. On the south-east side inlets of any dimensions are practically absent, while in the extreme south Wellington harbour is the only marked irregularity.

Topographical divisions.

The most striking physical feature of New Zealand is the mountain system. This has the general direction of north-east and south-west from Windsor Point to East Cape, but its continuity is interrupted by Cook Strait. Volcanic cones lie to the north-east of these mountains, and there are many smaller ridges in the north west tongue closely related in structure to the great mountain system, their mere enu-

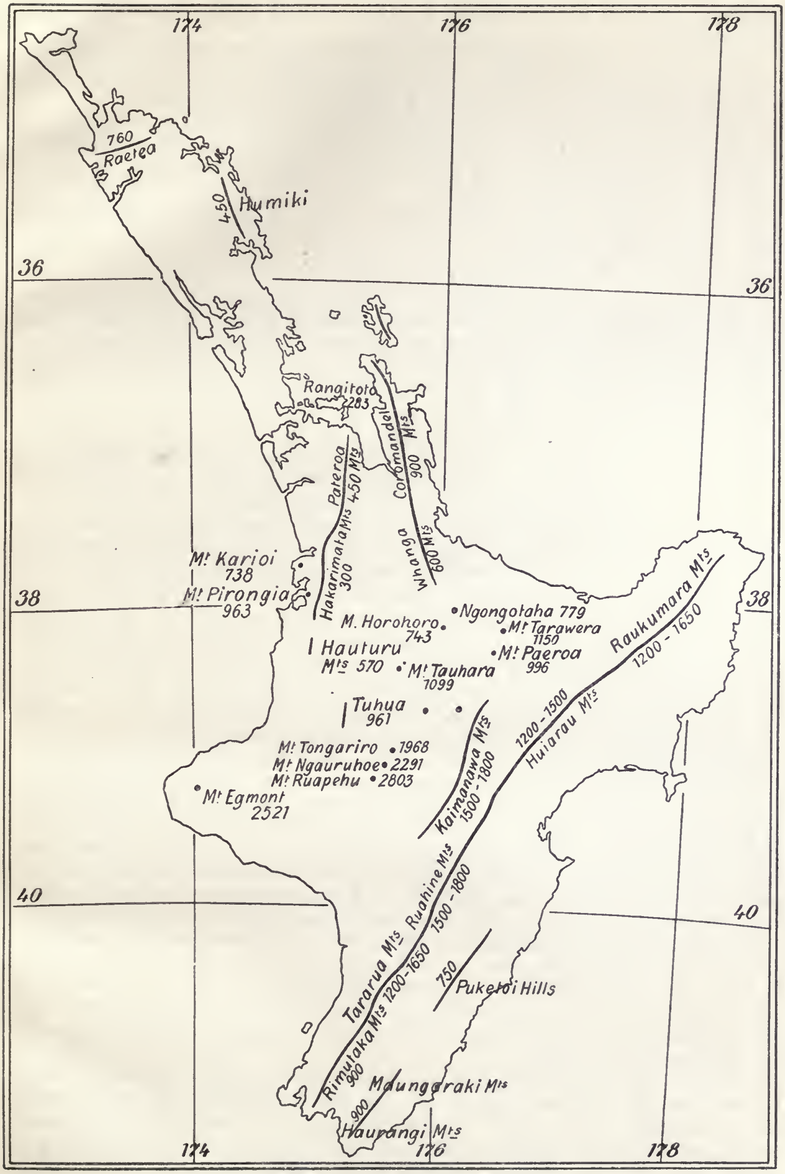

Fig. 2. Mountains of New Zealand, North Island (after MARSHALL, Geography of New Zealand). Altitudes in metres.

meration would show what a relatively large portion of the surface consists of mountainous country.

East and west of the main range in the North Island the surface is formed of Cainozoic rocks lying for the most part almost horizontally. The erosion of streams has worn them into steep, hilly country with a highly diversified appearance.

Between and around the volcanic cones that lie to the north-west of the mountain system of the North Island is a mass of fragmentary volcanic matter. Disposed in beds that are almost horizontal this material has a surface that is nearly level and constitutes an extensive volcanic plateau.

In many places extensive coastal plains of gravel lie between the hills and the shore. (See Fig. 15 and 16).

The Mountain System. (Fig. 1 and 2).

Suess has already called attention to the mountain syntaxis in Otago.[1] In this part of the South Island there are two distinct mountain chains. One, which is composed of gneiss and granulite forms the fiord region of the extreme west and extends to Steward Island. The second stretches from the coast line at Dunedin in a gentle curve to meet the first between Lake Wakatipu and Lake Wanaka a distance of fifty miles. This second chain is formed of schist rocks, but is flanked north and south by Mesozoic sediments which have also taken part in the folding to which the schist has been subjected. Within the schistose region the mountain chains are not parallel to the strike of the rocks, but are directed almost north and south.[2] These have been ascribed to the effects of denudation by most geologists but recently in a geological report they have been called block mountains.[3] The mountain chain formed by the union of these two axes extends thence with unbroken continuity to Cook Strait. All the eastern slopes are formed of shales and greywackes, which are here referred to the Mesozoic era though they have previously been referred by many geologists to the Carboniferous period. On the western slopes a schistose structure is gradually developed as one descends from the crest and at the foot hills the rock is sometimes gneissic. A discontinuous line of granite succeeds this on the west, and further on quite near the west coast this is often succeeded by shales, probably of the same Mesozoic age again. All the loftiest mountain summits of New Zealand are situated on this chain. For the most part they are situated in the middle of it and lie within the region of shales. Mt. Cook 12349 ft. (3766 m), Mt. Sefton 10359 ft. (3159 m), Mt. Haast 9835 ft. (2997 m), Mt. Tasman 11475 ft. (3502 m), are all close together and are associated with many other peaks all more than 3000 metres in altitude. From the mountain chain many spurs reach out eastward. One of them north of the Waitaki (Two Thumb range), and further north the Hunters Hills, extend for fifty miles from the main range before they dwindle down. Throughout almost the whole of this range the strike is remarkably uniform and parallel to the length of the range, the dip is almost everywhere very steep, but the exact nature and extent of the folds is not yet known. On the east the shales and greywackes of the main range have not been shown to be unconformable to the Mesozoic sediments of Mt. Potts, the Clent Hills, the rocks of the Ashley Gorge and in Nelson to the strata displayed in the Wairoa Gorge. This as will be afterwards stated more fully appears to justify the inclusion of the rocks of the mountain system with the Mesozoic rather than the Palaeozoic era, though the thickness of the strata in the aggregate must be very great.

Besides this main system there is a smaller mountain chain in the north-west. It consists of the Victoria Mts., Lyell Mts. and Tasman Mts. with an average trend nearly due north. The mountains are relatively low (1500 meters). They are formed of large intrusive granite masses on the western side with sediments of Ordovician and Silurian age, schists and marbles extending twenty miles to the east. These ancient rocks have been found as far south as Reefton where they lie unconformably below the shales and greywackes of the main mountain system which have always been classified as belonging to the Carboniferous system, though here placed in the Mesozoic era. Another mountainous region is that of the Kaikouras on the eastern side of the South Island. They are in the direct line of the main range of the North Island. Composed of shales and greywackes of supposed Maitai age they are stated by McKay to owe their elevation to immense movements of a somewhat recent nature along thrust planes. Gregory[4] states that there are two distinct mountain systems of distinctly different ages, but no New Zealand geologists have yet adopted this view except Park. The most conspicuous portions of the mountain system that he classes as older are to be found in Otago and in the Coromandel Peninsula. The North Island mountain chains are less extensive, less elevated and less intricate in arrangement and structure. From Cape Terawhiti near Wellington to the eastern side of the Bay of Plenty there is a continuous chain of much folded slates and greywackes, but only one or two peaks rise to the height of 2000 meters. This chain is known by different names in different portions of its length. The Rimutaka, Tararua, Ruahine, Kaimanawa and Raukumara Mts. are all comprised within this single chain. A range of hills of similar structure extends from Kawhia to the Hauraki Gulf and another from Whangarei to the Bay of Islands and there are several other more isolated outcrops of similar rocks, but in all these cases they fail to form mountains of any importance. At Kawhia, the Waikato Heads and in the Coromandel Peninsula these rocks contain Mesozoic fossils, but as far as known in the main range they are not fossiliferous. The strike of the rocks is very generally northeast throughout, but in the Coromandel Peninsula it is north, in the Whangaroa district it is variable and it is doubtful whether the strike has in this area any relation to the direction of the elongation of the land.

Volcanoes.

There are no large mountains of volcanic origin in the South Island, but there are large masses of volcanic rock that probably represent the denuded remnants of large volcanoes. Of these Banks and Otago Peninsulas are the most conspicuous, but the many volcanic necks between Dunedin and Oamaru though low are conspicuous features near the coast line. The highest mountain peaks in the North Island are volcanic. Ruapehu 9175 ft. (2796 m), Egmont 8250 ft. (2514 m), Ngauruhoe 7515 ft. (2290 m), Tongariro 6458 ft. (1968 m) are the most notable, but there is a score of mountains of less elevation. With the exception of Mt. Egmont which is in the extreme west the volcanoes mentioned are situated in the very centre of the island. Generally it may be said that the volcanic area is situated between the main mountain system and the westerly ridges of folded rocks. This is not always the case, for Mt. Egmont is west of this, as well as the much smaller volcanoes Kerioi and Pirongia. This is true also of the 65 puys in the neighbourhood of Auckland, and of the similar elevations between the Bay of Islands and Lake Omapere in the North Auckland Peninsula.

The eroded Cainozoic rocks.

The region where these are most prominent is that between Mt. Egmont and Mt. Ruapehu extending north to Kawhia and south to Feilding. There is also an extensive area on the eastern side from East Cape to Castle Point reaching from the coast to the main mountain system. Much of the north-west of the Auckland Province has this structure. There are also considerable areas in many coastal regions of the South Island especially between Amuri Bluff and Oamaru. At the latter place it extends for 15 miles inland. Generally these rocks lie nearly horizontally, and since they have not been elevated for any great length of time the rivers pass through them in steep gorges, though generally denudation has proceeded so far that nothing but razor back ridges separate adjacent river valleys. Where the harder beds of limestone crop out, escarpments have been formed in extreme sharpness. Generally the elevation of such country is not more than 1500 feet (457 m) above sea level though in the centre of the North Island and in the inland districts of Nelson (Maruia valley) the Cainozoic rocks are found at more than 3500 feet (1000 m) above sea level. Occasionally the strata are highly inclined and folded. This is the case in the Taipo Hills and the Puketoi Hills, but generally such disturbances are quite local and are confined to the immediate neighbourhood of the mountain masses of folded older rocks.

The volcanic plateau.

Within later geological times volcanic action has been extremely violent in some parts of the North Island, and a large amount of country is covered with the results of this action. The actual eruptions appear to have been largely of an explosive nature and pumice has been the chief product. Lava flows have been relatively unimportant. In consequence of this the greater part of the country between Ruapehu on the south, and from Ngaruawahia to Waihi and Whakatane on the North is covered with pumice except where occasionally volcanic cones rise above it. This pumice plateau rarely rises above 2000 feet (600 m); it is undulating and is intersected by deep river gorges such as those of the Waikato and Rangitaiki. In many places steam jets and hot springs still rise through the material of the volcanic plateau. Usually these thermal districts are situated in the bed of a stream or other relatively low lying locality.

The gravel plains.

The rapid denudation of the mountainous country has provided an enormous mass of detrital matter. This carried outwards by streams and distributed along the coast by wave action has built up extensive plains in some districts. During the deposition of this detritus the country has been rising and consequently the plains have a distinct slope seawards and where they are broadest—in Canterbury—the gravels at the foot of the hills are 1500 feet (457 m) above sea level, and in their landward portions they are remarkably terraced by the rivers that course through them. The most extensive areas of these plains are in Southland where they penetrate between the mountain ranges and reach from the lakes to the sea in Foveaux Strait, and in Canterbury where there is a stretch 100 miles (161 km) long and 30 miles (48 km) wide. The lower portion of the valleys of the Wairau, Waimea and Motueka have similar but smaller areas, while in Westland there is another narrow strip. In the North Island such plains are less extensive. The lower course of the Manawatu, of the Hawke Bay rivers and of the Ruamahunga are the best examples. All these plains constitute the most valuable agricultural districts of the country.

II. Stratigraphy and Lithology.

The following is the classification adopted in this works for the rock formations of New Zealand:

1. Manapouri System	Archaean.
2. Aorere „	Ordovician.
3. Baton River „	Siluro-Devonian.
4. Maitai „	Trias-Jura.
5. Oamaru „	Cainozoic.
6. Wanganui „	Pliocene.
7. Pleistocene „	
8. Recent.	

The rock series of New Zealand.

Rock	Thickness	System
Sand Loess Fluvioglacial		Recent.
Moraines Gravels		Pleistocene.
Basalts, Andesites Sands Marls	 200 ft. 500 „	Wanganui (Pliocene) 700 ft. (215 m).
Basalts Rhyolites in North Andesite Phonolite in South Conglomerate Sandstone Marls Coral limestone Limestone Greensands Graysands Coal Conglomerate	 200 ft. 2000 „ 2000 „ 200 „ 350 „ 500 „ 400 „ 100 „ 2000 „	Oamaru System (Early and middle Cainozoic. 7750 ft. (2365 m).
Peridotite, Granite — intrusive. Andesite Conglomerate Sandstone Mudstone Melaphyr Mudstone (argillite) Sandstone (Grauwacke) Conglomerate	 4000 ft. 2000 „ 5000 „ 5000 „ 2000 „ 15000 „ 20000 „ 200 „	Maitai System (Trias-Jura) 53200 ft. (16225 m).
Sandstone Mudstone Marllimestone	2000 ? ft. 2000 ? „ 500 „	Baton River System (Silurian) 4500? ft. (1375? m).
Argillite Sandstone Phyllite Amphibolite Micaschist Quartzite Marble	1500 ft. 500 „ ? ? ? 500 „ 1000 „	Aorere System (Ordovician) 8000? ft. (2440? m).
Granite Amphibolite Granulite Paragneiss Orthogneiss		Manapouri System (Archaean) 40000? ft. (12000? m).

This classification differs so much from the very divergent views of other geologists who have attempted to classify the New Zealand strata that it appears advisable to give a tabularised summary of the different divisions that they have described. This has proved to be rather a difficult matter, for in many cases the authors have not referred specifically to the localities mentioned by others. It is however believed that the following tabulation accurately represents the schemes employed by the authors named.

The reasons for departing from these classifications will be stated under each of the different systems.

HECTOR. Handbook of New Zealand Geology (1886).

1.	Gneiss, granite.	
2.	Foliated schists.	Lower Silurian to Carboniferous.
3.	Lower Silurian.	
4.	Upper Silurian.	
5.	Devonian.	5a. Reefton. 5b. Te Anau.
6.	Carboniferous.	
7.	Permian.	7a. Kaihiku. 7b. Oreti.
8.	Triassic.	8a. Otapiri. 8b. Wairoa.
9.	Liassic.	9a. Catlin's River. 9b. Bastion.
10.	Jurassic.	10a. Mataura. 10b. Putataka. 10b. Flag Hill.
11.	Lower Greensand.	11a. Buller. 11b. Porphyry Breccia. 11c. Amuri.
12.	Cretaceo-Tertiary.	12a. Waitemata. 12b. Ototara. 12c. Mawhera. 12d. Chalk. 12e. Waireka. 12f. Coal. 12g. Black Grit. 12h. Propylite Breccia. 12i. Great Conglomerate.
13.	Eocene.	13a. Mt. Brown. 13b. Oamaru. 13c. Waitaki
14.	Lower Miocene.	14a. Awatere. 14b. Pareora. 14c. Awamoa.
15.	Upper Miocene.	15a. Te Aute. 15b. Taueru.
16.	Pliocene.	16a. Napier. 16b. Kereru.

HUTTON. Quart. Journ. Geol. Soc. 1885.

Manapouri System.	(1). Archaean.
Takaka System.	(2). (3). Ordovician. (4). (5a). Silurian.
Maitai System.	(5b). (6). Carboniferous.
Hokonui System.	(7a). (7b). (8a). (8b). Triassic. (9a). (9b). (10a). (10b). (10c). Lower Jurassic.
Waipara System.	(11a). (11c). Including also some of the limestones placed by HECTOR in (12b). Some of (12f) at Shag Point and Pakawau. (12d). (12g). Cretaceous.
Oamaru System.	Most of (12b). (12c). (12e). Most of (12f). (12b). (12i). (13a). (13b). (13c). Oligocene.
Pareora System.	(12a). (14a). (14b). (14c). (15a). (15c). Miocene.
Wanganui System.	(16a). (16b).

In Transactions of the New Zealand Institute 1899 the name Wanaka System is used for the Otago schists which are classed as Pre-Cambrian.

The Manapouri System of 1885 is said to represent intrusive rocks of the Hokonui System.

Nr. 13a is moved from the Oamaru System to the Pareora System.

Nr. 5b is also transferred to the Hokonui System.

PARK. Geology of New Zealand (1910).

Manapouri System.	Maniototo series. (1). (2). Cambrian. Kakanui series. (3). Ordovician. Wangapeka series. (4). (5a). Silurian.
Te Anau System.	(5b). (6). Carboniferous.
Hokonui System.	Part of (6). (7a). Permian. (8a). (8b). Triassic. (9a). (9b). (10a). (10b). (10c). Jurassic.
Amuri System.	(11c). Part of (12b) in North Canterbury, and of (12f). (12g). Cretaceous.
Karamea System.	Waimangaroa series. (11a?). (12i?). Eocene. Oamaru series. (11b). (12a). Part of (12b). (12c). (12d). (12e). Part of (12f). (13a). (13b). (13c). (14b). (14c). Miocene.
Wanganui System.	(14a). (15a). (15b). Lower Pliocene. (16a). (16b). Upper Pliocene.

The following is the classification adopted in this description when compared in the same manner as above with HECTOR's divisions.

Manapouri System.	(1).
Aorere System.	(3).
Baton River System.	(4). (5a).
Maitai System.	(5b). (6). (7). (8). (9). (10).
Oamaru System.	(11). (12). (13). (14). (15).
Wanganui System.	(16).

Correlation with series described in Bulletins (N. S.) of the Geol. Surv.

These serial names refer to restricted localities only. No attempt has yet been made to correlate these locality series together.

Manapouri System.

Aorere System:

Bull. 3. Aorere series.

Baton River System:

Bull. 3. Haupiri series.

Maitai System:

Bull. 1. Arahura and Kanieri series.
Bull. 2. Maniototo series. (Metamorphic).
Bull. 4. Tokatea, Moehau and Manaia Hill series.
Bull. 5. and 7. Maniototo and Kakanui series. (Metamorphic).
Bull. 6. Arahura and Greenland series.
Bull. 8. Waipapa series.

Oamaru System:

Bull. 1. Koiterangi series.
Bull. 2. Manuherikia series. (?)
Bull. 3. Oamaru series.
Bull. 4. Torehine series. Volcanic rocks of 1st and 2nd periods.
Bull. 5. Pliocene series. (?)
Bull. 6. Koiterangi and Upper Miocene series.
Bull. 7. Oamaru series.
Bull. 8. Kaeo, Wairakau and Kerikeri series.
Bull. 9. Whatatutu series.

Intrusive into Maitai rocks: —

Bull. 1. and 6. Tuhua and Pounamu series.

I. Manapouri System. (Archaean).

The large mass of gneisses (granitic, dioritic, gabbro) and granulites extending south from Milford Sound and west from Lakes Te Anau, Manapouri and the Waiau valley, together with almost the whole of Stewart Island constitute the whole of the rocks classed in this system.

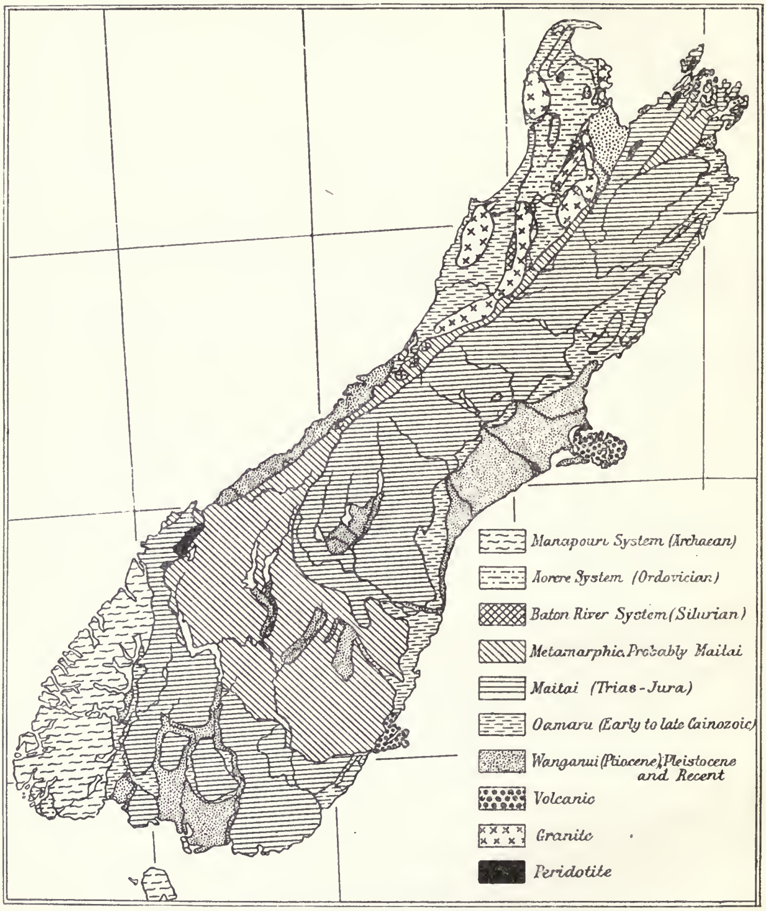

Fig. 3. Geological map of the South Island of New Zealand.

Hutton[5] at first classed these rocks as Archaean but afterwards preferred to regard them as the plutonic representatives of volcanic rocks of later age. These volcanic rocks constitute the Devonian (Te Anau) of Hector and the Triassic volcanic rocks of Hutton.[6]

The rough foliation of the rocks is the only guide as to the structure and thickness of the system. In general the plane of foliation is somewhat steeply inclined. It usually dips north-west but varies from west to north-north-west and the angle is seldom less than 45 degrees. This led Hutton to conclude that the total thickness is 180000 feet. Up to the present time no complete section across the system has been described; so exact statements are impossible.

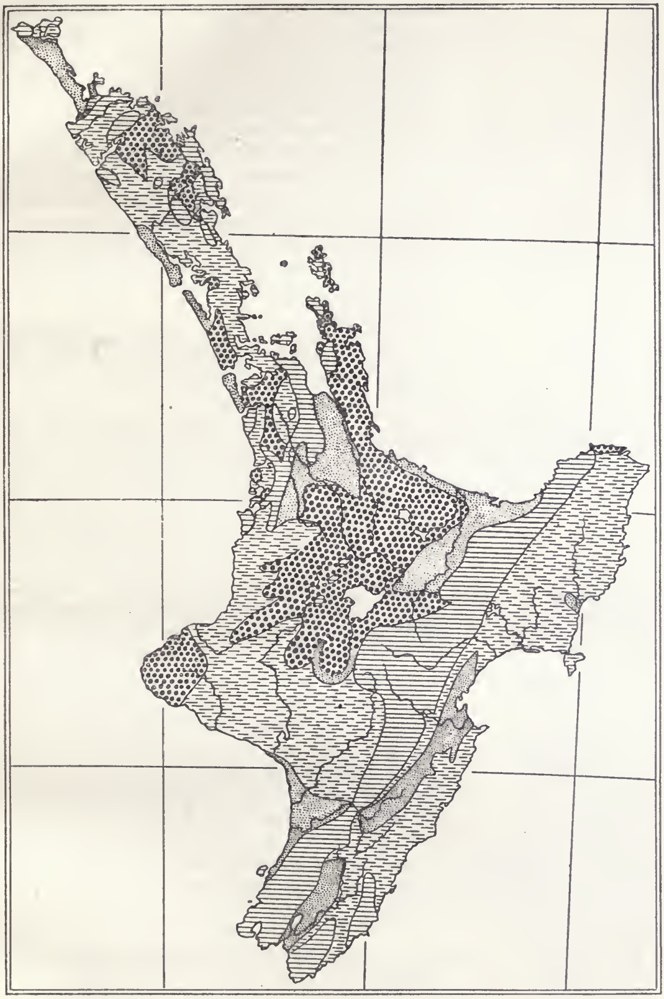

Fig. 4. Geological map of the North Island of New Zealand.

The commonest rock is a diorite gneiss[7] with extremely green hornblende. This type crops out over most of the distance between Milford Sound and Lake Te Anau. It often

Fig. 5. Section W to E 15 miles from Aorere Valley to Takaka Valley. (After Bull. N. Z. Geol. Surv. Nr. 3). 1. Argillites and quartzites (Ordovician). 2 Limestones etc. Oamaru System. 3 Schists. 4 Marble (3 and 4 Ordovician?). 5 Granite. 6 Diorite. 7 Argillites, breccias and conglomerate (more recent than Ordovician).

contains masses of amphibolite and is frequently garnetiferous. Relatively thin bands of hornblende schist occur in it as at Blanket Bay in Thompson's Sound and in Dea's Cove. In these rocks crystals of rutile are quite common. A pryoxene granulite is also quite a usual type especially in Breaksea Sound. Granite gneiss is less frequent but typical examples occur at Dea's Cove and at Pigeon Island at the entrance to Dusky Sound. In the latter locality the structure is sometimes coarse and the muscovite is in large scales, but on the heights between George Sound and Lake Te Anau muscovite has been found in plates more than twelve inches in diameter.

There is a belt of ultra-basic rock at Anita Bay close to the entrance of Milford Sound. It consists mostly of dunite but there is some Harzburgite and much of the dunite has been changed to talc schist. Marble occurs occasionally—the best known localities are Caswell Sound and Hall's arm in Doubtful Sound. In the former locality it contains a considerable amount of brown mica.

The hornblende schists which are found mainly on the western border were thought by Hector to be metamorphic rocks of Devonian age, but no good reason was advanced for this suggestion.

In the extreme south at Preservation Inlet the Manapouri system is in contact with shales that contain graptolite impressions, but the true relations between the two rock series is not evident for here there is a large mass of pink granite which is supposed to be intrusive and much younger than the Manapouri system though its contact with these rocks has not yet been described. At the north-east end of Te Anau the Manapouri rocks are in contact with green coloured sandstones which probably correspond to the Te Anau series of Devonian age in Hector's classification, but they are here classed as belonging to the great Mesozoic series.

The extremely mountainous nature of the country, its abrupt precipices, its situation in a region of very heavy rainfall (over 600 cm per annum) and its remoteness from the centres of population have hitherto prevented any accurate knowledge being obtained in regard to the surroundings of the Manapouri system and of its relations to neighbouring systems of rocks. At the present time there is no direct evidence that the system is separated from those near it by a fault such as that shown in Hutton's paper.[8]

In Stewart Island diorite is the most usual rock type in the northern portion and granite in the south.

2. Aorere System. (Ordovician).

It is only in the extreme north-west and south-west of the South Island that this system is known to occur with any certainty and even in these localities the limits of the formation are not known with any definiteness. In both places there are bluish shales with impressions of graptolites. In the north-west area near the West Wanganui Inlet, where the rocks are best known, they are associated with greywackes and quartzites, and followed in an easterly direction they give place to schists though the transition is not sudden, and the occurrences suggest that they merely represent shaly members of the system that have been subjected to dynamo-metamorphic action. The change from unaltered sediment to mica schist cannot be said to take place at any one horizon in any section but every possible gradation between shale and schist is found as one passes from west to east.[9] Associated with the schist as its lowest member is a thick formation of white and grey marble. This first appears at Parapara and extends thence at intervals almost as far east as Riwaka, and is largely developed on Mt. Arthur and in the upper Wangapeka valley. No undoubted fossil remains have yet been found in this lower formation if we except those referred to by Hutton for they are somewhat doubtful.[10]

This marble is the Mt. Arthur series of Hutton, who describes it as resting unconformably on the Manapouri system in the Pikikiruna Mts. near Riwaka.[11] Other observers however have failed to recognise any equivalent of the Manapouri rocks in the Nelson province. The plutonic rocks that occur there are intrusive into the members of the Aorere system.

A certain amount of alluvial gold is found in the gravels derived from the denudation of the more metamorphic rocks of this system and in the rocks themselves, notably at the Golden Ridge near the west coast, there are auriferous quartz veins that are worked with profit. Near the mouth of the Parapara river there are large masses of limonite. This rests on the marble of the Mt. Arthur series and is described by Bell as of secondary origin.[12]

The fossils that occur in the shales of the Golden Ridge near the West Wanganui Inlet are solely graptolites. Clarke[13] says that they show no zoning, for types characteristic of several different zones are to be found in a single specimen of rock. Dr. Shakespear[14] on the other hand finds that definite zones correspond with those of the Deep Kill slates of New York, in Wales, and in the Lake District of England. This opinion was based on specimens transmitted from New Zealand which were not previously sorted stratigraphically. The following species have been identified:

Bryograptus lapworthi Ruedem. *Dichograptus octobrachiatus* Hall. *Didymograptus extensus* Hall. *D. gibberulus* Nicholson. *D. nitidus* Hall. *D. nanus* Lapw. *Goniograptus perflexilis* Ruedem. *G. geometricus* Ruedem. *Loganograptus logani* Hall. *Phyllograptus anna* Hall. *P. ilicifolius* Hall. *P. typus* Hall. *Tetragraptus amii* Elles and Wood. *T. bigsbii* Hall. *T. quadribrachiatus* Hall.

Dr. Shakespear concludes that the fossiliferous beds of the Golden Ridge correspond to the middle Skiddaw slates of England.

As stated previously there are intrusive masses of igneous rocks in this series. On the western side the intrusive granite of the Gouland Downs is forty miles long and fifteen miles wide. It has produced a considerable contact effect on the fine grained sediments adjacent to it. Chiastolite and cordierite shales are the most usual type of contact rocks found in this aureole[14a]. The most detailed work on the north part of this area has recently been done by the Geological Survey[15] and the sections drawn there are the most accurate that have yet appeared. Another larger acid intrusion occurs on the western side of the Takaka valley. Besides these there are a few granite intrusions near Parapara and a few dioritic and ultra basic rocks further back from the coast.

The following appears to be the rock succession in this Aorere system

Marble 300 ft. (91 m) to 2000 ft. (610 m) }
Quartzite 500 ft. (152 m) } Mt. Arthur series of Hutton.

Greywackes, and shales or schists: Thickness great but not estimated.

The rocks are much folded and constitute a mountainous district that is covered almost throughout with dense vegetation and this has prevented the actual measurement of the thickness of the rocks. The sections issued by the geological survey exhibit a very complex structure of which it is almost impossible to give a summarised account.[16] There is however probably an anticline in the Pikikiruna Mountains. There are others between the Parapara and Takaka rivers and a succession of broad synclines with narrow acuter anticlines between them. The majority of these folds have their axial planes strongly inclined eastward but become slightly more vertical as the west coast is approached, but the country dealt with in the bulletin does not extend to the western declivities of the mountain range.

3. Baton River System. (Siluro-Devonian).

It is only in the valley of the Baton River and at Lankey's gully near Reefton that fossiliferous rocks of this system are known to occur.

Hutton included the rocks of this system in his Takaka system though he regarded them as distinctly an upper series of that system. In 1885 he correlated the series with the Silurian and in 1899 with the Siluro-Devonian. Hector correlated the Baton River rocks with the Upper Silurian and the Reefton rocks with the Devonian. McKay[17] shows the Baton River rocks highly unconformable to the Mt. Arthur limestones.

Hutton appears to think that the Mt. Arthur, Aorere and Baton River series are conformable. The reason for a difference of opinion is fairly obvious. The fossiliferous rocks of the Baton are 40 miles (64 km) away from the fossiliferous rocks of the Aorere and the intervening country is densely wooded and mountainous and has a most involved stratigraphy. On the other hand if the limestone that outcrops close to the Baton can be identified with the limestone at Parapara, a careful examination of the Baton area ought to establish the true relation between the Baton and Aorere series.

Both Hector and Hutton thought that the formation passed southwards into schists, and hence Hector stated that much of the schist area of the West Coast and of Otago belonged to this system. Hutton made similar statements but afterwards withdrew them and classed the Otago schists as Archaean because he thought that their structure was original as no agent of metamorphism appeared to have acted upon them on a sufficient scale to have produced such profound changes over such a wide area.[18] For reasons that will be afterwards explained the schists are here referred to the Trias-Jura or Hokonui system. The actual rock in which the fossils occur at the Baton River is a bluish argillaceous limestone. The organic indications are almost entirely casts and they are usually somewhat distorted. McKay[19] states that they are conformable with the bituminous schists which in this locality are supposed to correspond with the highest member of the subjacent Aorere system. The dip is 50 degrees south-west and the strike therefore is north-west and south-east. At Reefton the nature of the rock is quite similar and the fossils but little different.

This outcrop has been classed by Hector as of lower Devonian age though Hutton calls it Siluro-Devonian. There are no lower rocks exposed at Reefton but above it there is an unconformable junction with the Maitai system of Hector and Hutton. The rocks of the Reefton series are much folded, two synclines and an anticline being shown in the short section drawn by Hector.[20]

The Reefton outcrop appears to be very small but here again the rough country is at present little known and the thickness of the formation is unknown. The strike is north and south and the dip variable but high. The Baton River and Reefton localities are 70 miles (113 km) apart, and the intervening country is but little knwon in many parts. There is thus no stratigraphical reason for placing them in the same system but lithologically they are somewhat similar and palaeontologically there is a close relationship; though in the absence of descriptions and accurate identifications too much reliance must not be placed on this resemblance. *Homalonotus expansus* Hector appears to be the only new type described.

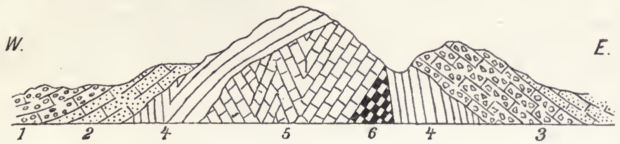

Fig. 6. Section along N. branch of Inangahua River (2 miles), showing relation of Baton River to Maitai System (After Mc Kay, Rep. of Geol. Expl. [N. Z. Geol. Surv.], 1882, p. 113).

1. Miocene conglomerate, 2. Coal rocks, 3. Breccia } Oamaru System
4. Maitai shales (Maitai System)
5. Limestones, 6. Cherts } Baton River System.

In the report on the Reefton series a general comparison is made between the fossils of the Baton and Reefton series.[21] The following lists are given but it is doubtful whether the specific identifications are satisfactory.

Baton River.[22]	Reefton.[23]
Calymene blumenbachii.	*Calymene blumenbachii.*
Homalonotus knightii.	*Homalonotus knightii.*
Orthoceras.	*Orthoceras.*
Murchisonia terebralis.	*Murchisonia terebralis.*
Avicula lammoniensis.	*Fenestella.*
Iterinaea spinosa.	*Corals.*
Spirifera radiata.	*Spirifer.*
Rhynchonella wilsoni.	*Rhynchonella wilsoni.*
Stricklandia lyrata.	
Atrypa reticularis.	*Athyris.*
Orthis.	*Orthis.*
Strophomena corrugatella.	*Strophomena.*
Chonetes striatella.	*Chonetes.*

Hector states that *Spirifer vespertilio* occurs at Reefton, Hutton quotes this list from the Baton River. Much more extensive lists of fossils are given by Park[24] and Hector.[25] The basis upon which the identification rests is not given.

The rocks in both localities are stated to be quartz sandstones, cherts and limestones.

4. Maitai System (Jura-Trias).

Fossils that are on all sides admitted to indicate a Triassic age for the rocks in which they occur are found in Nelson and in Otago. In the former district they are conformable with the shales, to which the name Maitai has been applied by Hector and Hochstetter. In the latter there is no unconformity between the Triassic and the Jurassic of Southland, on the one hand, and the great mass of schist on the other. The fossiliferous Triassic in Canterbury is conformable with the shales and greywackes as far as known. These facts compel the author to group all of these rock masses as Trias-Jura until unconformities have been established or until fossil evidence is found to justify the division of this large mass of rocks into two or more series.

In the North Island Trias-Jura fossils occur in several places but are not known within the limits of the great range extending from Cape Terawhiti to near the East Cape. The lithological nature of the rocks of this range is the sole justification for their inclusion in the Trias-Jura formation as just defined.

The Trias-Jura formation here includes all the folded rocks of the South Island east of the Hope Pass and Reefton. They occur throughout the Southern Alps to the Hollyford where the strike bends southwards and then south-eastwards, but an outcrop is found as far to the south-west as Riverton. From Fortrose to the Catlin's River the rocks are but slightly inclined. At Nugget Point they are highly inclined and folded and, when followed further north, they become metamorphic and maintain the same character as far as the Kakanui River, but north of Dunedin they do not actually occur on the sea coast. At Kakanui the Trias-Jura retreats some distance inland but reaches the coast again at Cheviot whence it extends through the Kaikouras to Picton.

In the North Island the rocks of the formation which compose the mountain ranges of the Rimutaka, Tararua, Ruahine, Kaimanawa and Huiarau Mts. are apparently destitute of fossils but on the other hand outcrops further west at Kawhia and Waikato Heads are markedly fossiliferous and at the Coromandel Peninsula fossils have been found, but elsewhere in the North they are quite unfossiliferous. Outcrops are found over a wide area though they are isolated from one another. The more important are from Ngaruawahia to Wairoa, Waiheke Island, Whangarei, Hokianga, Whangaroa and the North Cape.

As thus defined the Trias-Jura formation is the most important in the country because of its large area and because of the great part that it has taken in the formation of the mountain ranges.

It includes the Carboniferous and part of the Devonian (Te Anau) of Hector as well as his Triassic, Rhaetic, Liassic and Jurassic or the Maitai and Hokonui systems of Hutton; as well as the Otago schists and the narrow belt of similar rocks in Westland which Hector placed partly in the Silurian, Devonian, Carboniferous and Permian; while Hutton in his last work classed them as Archaean.

South Island.

Justification of this course is obviously necessary. In justifying it reference must first be made to Hochstetters description of the geology of the neighbourhood of Nelson. He states [26] "The Richmond sandstone belongs to the Triassic and so must the Maitai shales and the limestone of the wooded peak. Thus the Triassic sediments play a predominant part in the structure of the highlands of New Zealand as other researches must show." In the same place however he states that palaeozoic rocks lie on the eastern side of the intrusive mass of ultra-basic rocks of the Dun Mountain.

Subsequent examination of the district convinced Hector and McKay [27] that there are important structural breaks betwen the Triassic sandstones of Richmond and the Maitai shales. These breaks were supposed by them to separate the Triassic from the Permian, and the Permian from the Carboniferous, which was the age assigned to the Maitai shales and to the stratum of limestone at their base because of the presence of certain fossils in the limestone. These fossils were classed as *Productus brachythaerus, Spirifer bisulcatus, S. glaber, Cyathophyllum, Cyathocrinus.* [28] Hutton in his three main accounts of the geology of New Zealand shows that he is in grave doubt as to the stratigraphical position of the Maitai rocks; but in the absence of definite observations to the contrary he adopted Hector's classification; though in each instance he clearly hesitated to do so. More recent work by Park [29] caused him to classify the Maitai rocks as Jurassic because they rest conformably on the Triassic (Wairoa). Superior stratigraphical position instead of palaeontological characters was employed in arriving at this conclusion. The structure of the country was said by him to be a simple syncline.

Since this was in print, Park has issued his „Geology of New Zealand". In this work he shows that he has changed his opinion and he now refers the Maitai to the Carboniferous. The reasons for this are: — the supposed absence of *Inoceramus*, the inversion of the Cainozoic rocks lying further west, and a reexamination of the fossils from the Maitai limestone, though no statement is made as to the affinities of these. It must be repeated that remains of *Inoceramus* or of a similar fibrous shell are very abundant throughout the whole series in certain zones. The inversion of the Cainozoic rocks lying further west does not appear to affect the question.

In 1908 and 1909 the writer examined this district in great detail and was satisfied that the rocks from the Dun Mountain to the Waimea plain constitute a conformable series, but they are much and sharply folded. The commonest fossils are the definite Triassic forms described by ZITTEL[30]: *Monotis salinaria* var. *richmondiana* ZITT., *Halobia lommeli* WISSM., *Mytilus problematicus* ZITT., *Spirigera wreyi* ZITT. However in the lowest beds of the series a few specimens of *Trigonia* were obtained, and *Gryphaea* was found to occur occasionally with the *Mytilus*. This certainly justifies the use of the term Trias-Jura. The original specimens on which HECTOR's identifications were based are not now available and no subsequent collectors have obtained the types he mentions; no forms in fact that are different from Trias-Jura types in other parts of the country.

This small tract in Nelson must be considered the most important in New Zealand for it is admitted on all hands that the Maitai shales and greywackes are the same rocks which form such important mountain masses in many parts of the country. Here and there a little fossil evidence is obtainable and in all cases it is confirmatory of the classification adopted here. Thus fossils that indicate a Triassis age have been found at Kawhia, Cheviot, Ashley Gorge, Mt. Potts, Nugget Point, and the Hokonui Hills. In the last locality and at Kawhia there is a direct transition upward into strata that contain Jurassic fossils.

So far as known there is a continuous outcrop of these Maitai rocks from Nelson almost to Kakanui. The line of outcrop follows the structural curve of the country but it is very wide. It is directed south-west from Nelson as far as Mt. Cook where the easterly curve becomes pronounced and shortly afterwards the trend becomes south east.

It extends almost to the east coast as far south as the Amuri Bluff except for local patches and marginal Cainozoic sediments. It then recedes somewhat inland but again approaches the coast at Timaru; and at Kakanui it becomes metamorphic. Further south there is a belt that has escaped metamorphism on the borders of the Manapouri formation. This soon widens and in fact covers most of the country south of the line between the south of Wakatipu and the mouth of the Clutha, though in the neighbourhood of Foveaux Strait Cainozoic rocks and gravel plains cover a relatively large area.

The country between Lakes Wakatipu and Ohau, between Kakanui mouth and Molyneux Bay separate the two unaltered portions of the Maitai formation. This separating area is formed of schists; almost entirely muscovite quartz schist though here and there chlorite schist, actinolite schist, biotite schist and occasionally garnet schist are found. An area of similar rock extends east and south-east from Pelorus Sound on the southern side of Cook Strait.

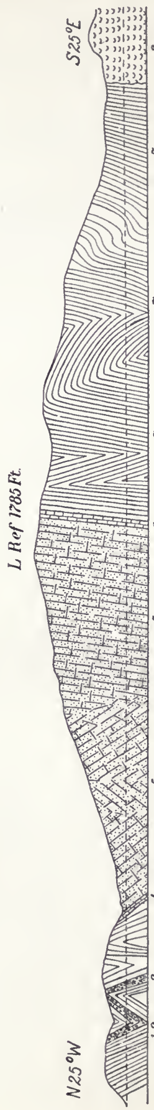

Fig. 7. Section showing arrangement of Maitai rocks in the typical district near Nelson: Section 3½ miles from ¼ mile S. W. of Wairoa Gorge to junction of argillites and serpentines on Lee River, Nelson. Scale 2 inches = 1 mile vertical and horizontal (— — actually observed). 1 Mytilus problematicus bed 2 Monotis salinaria bed. 3 Conglomerate. 4. Wairva limestone. 5 Greywackes. 6 Maitai limestone = Wairoa limestone. 7 Red and green argillites. 8 Serpentine.

These are the foliated schists of Hector[31] which he says consist mainly of lower Silurian rocks, and even of formations as young as the Lower Carboniferous rocks; thereby recognising that there is no stratigraphical break between his Maitai and the schist outcrop. Hutton at first[32] divided the schists into two series Wanaka and Kakanui but admits a complete conformity between them. Haast divides them into Westland and Waihao[33] but again admits a complete conformity and gradation in metamorphic characters. Both mention local instances of unconformity between the schists and higher series but state that in most outcrops there is conformity.[34 35]

Hutton in his last work says that the Maitai rocks rest directly on the schists in Otago Canterbury and Marlborough[36], but notwithstanding this he classifies the schists as of Archaean age.

Park who calls these rocks Maniototo series is evidently in doubt as to their true age. He first[37] calls them merely palaeozoic; next[38] probably not older than Carboniferous or Devonian; afterwards[39] almost certainly Cambrian or earlier. In no case does he show that an unconformity exists between them and the fossiliferous Triassic rocks that flank them on the south. The statement is even made in[38] that at St. Bathans the foliated schist passes up without a break in the succession into sandstones and mudstones that judging from their lithological character might be the Triassic or Jurassic rocks of Wellington.

In the Geology of New Zealand lately published the schists constitute the upper portion of Parks Maniototo series (Cambrian) of his Manapouri System.

It is therefore true that so far, as observations go, no unconformities of any importance have yet been discovered between the Trias-Jura and the schists of Otago, though the two formations extend side by side for 200 miles. The author's own observations strongly confirm this. In the Clutha valley there are typical Trias-Jura rocks at Balclutha and typical schists at Beaumont, and between them there is an almost continuous section yet no unconformity could be detected; but a gradual transition from unaltered rocks to the completely foliated mica schist as the river was ascended. Similar results were obtained on the Blue Mountains from south-east to north-west, and again along the Dome and Hector Mountains from Lumsden to Kingston. Another section along the gorge of the Greenstone river gave a similar result. A gradual change is to be seen along the coast from the Nugget Point to the Taieri mouth and on the northern fringe between the Kakanui and the Waitaki. Such remarkably concordant observations show that the stratigraphical evidence almost compels one to place the Trias-Jura and the Otago schists in the same series.

There is further evidence of a lithological nature. It is admitted that the Maitai system lies on both sides of the schist. If there is an unconformity, elements of the schists should form the most important constituent of the Maitais. Careful search has failed to find any fragments of schists in the conglomerates and sandstones and shales of which the Maitai sediments are formed. Everywhere fragments of plutonic rocks compose the conglomerates. Felspars and quartz grains from plutonic rocks form the sandstones and finer grains of the same minerals constitute the shales. This is in marked contrast with the nature of the Cainozoic rocks where they occur in the neighbourhood of the schists. Conglomerates and sandstones of schist quartz are here the only rocks composed of fragmentary material. The absence of material derived from the schists in the Trias-Jura series is a proof that at the time of their deposition the schists had not been exposed to denudation, in other words that no unconformity exists.

Results of a precisely similar nature have been obtained on the western slopes of the Southern Alps. The route over the Fitzgerald Pass, down the Copland and Karangarua valleys to the west coast shows a gradual transition from greywackes at the divide, through phyllites and mica schist to highly crystalline schists and in places even to gneiss. The same transition was found by Bell[40] in the section from the head of the Wilberforce over Browning's Pass and down the Arahura valley. In the section a possible unconformity is indicated; but it is said that there is only slight evidence of a structural break. A great thickness of argillites and greywackes is said to follow the schists on the east conformably.[41] The age of the Arahura series, as the schists and the unaltered argillites and greywackes are collectively classed, is said to be Maitai, though in the meantime no exact meaning is given to the term.

The neighbouring district to the south has more lately been closely examined by MORGAN[42] who has again classed all the conformable rocks whether metamorphic or unaltered in the Arahura series which is tentatively placed in the Maitai or Carboniferous, the latter being considered equivalent with the Maitai in accordance with Hector's work. These statements show that in the Southern Alps as in Otago the schists and the neighbouring greywackes and shales are of the same age. Apparent continuity along the strike with Maitai rocks of HECTOR has caused all geologists to assume that these greywackes are of the same age as the well known Maitai sediments of Nelson. Although this continuity has never been proved in detail no facts are known to the contrary, and it is reasonable to assign them to the same age, that is to the Trias-Jura system in the classification here adopted.

All the palaeontological evidence that we have is in favour of this view: though this evidence has been very differently interpreted by different authorities. Thus the fossils at Mt. Potts in the Rangitata basin were said by HAAST to be classed with the Carboniferous by McCOY[43] though the ferns in the conformable series further east in the Clent Hills were classed by him as Jurassic. HECTOR placed the Mt. Potts beds[44] in his Kaihiku or Permian formation though bones of marine reptiles *(Ichthyosaurus?)* occur there quite plentifully. Species of *Halobia* are also found there, and in neighbouring beds at Tank Gully *Phyllopteris, Alethopteris* and *Baiera* occur. This certainly justifies the placing of these beds in the Triassic, which has already been done by PARK; but who has changed this to Permo-Trias in the Geology of New Zealand 1910, p. 68. The fossils that have been found at Mt. St. Mary have not yet been identified. The fossiliferous beds at the Nugget Point should certainly be classed here for they contain *Halobia* and *Trigonia.* The other fossiliferous localities are admitted on all hands to be of Mesozoic age. Amongst these are the Hokonui Hills and the Moonlight Range, Clent Hills, Ashley Gorge, Cheviot, Okuku Range.

McKAY in the Upper Wairau reports an unconformity between HECTOR's Triassic and Maitai but no junction of the two series was observed.[45] The Kaikouras are classed with the Maitai (Trias-Jura) solely on lithological grounds; but it is a correlation that has been accepted by all geologists.

There is a large district of sandstones, shales and schists between the recognised Maitai of Nelson and the Wairau valley.

HOCHSTETTER[46] described them as palaeozoic. HECTOR and HUTTON always regarded them as of great age. McKAY[47] was the last geologist to report on them. He classifies them as Silurian and Devonian; but states that there is no unconformity between them. The rocks are all unfossiliferous and their stratigraphical relations have not been very closely examined. Close to Nelson they are separated from the acknowledged Maitai by the intrusive ultra-basic plutonics; but this hardly justifies a chronological separation from the Maitai, especially as in their western portions they are lithologically similar to the Maitai sediments.

No unconformity has been found between them and the coarser sediments of Starveall and more western localities, nor between these and the schists, or still further eastward between the schists and unaltered rocks. There is then at present no lithological, stratigraphical, or palaeontological reason to prevent the inclusion of the schists of the Queen Charlotte and Pelorus area in the Maitai (Trias-Jura) formation, a result that is in agreement with the conclusions adopted for the schists of Otago and Westland.

North Island.

Here again the older sediments are largely destitute of fossil evidence as to their age, and reliance has once more to be placed on what stratigraphical and lithological evidence is available.

The great series of rocks forming the mountain ranges Rimutaka, Ruahine, Tararua, Kaimanawa and high country thence to the east side of Poverty Bay were classed by HECTOR[48] as Maitai and HUTTON with some protest followed his lead[49]; but this opinion was entirely based upon a lithological comparison with the Maitai rocks of Nelson. Certain parts of this formation have however been regarded as of earlier or later date; for instance McKAY[50] describes the Devonian, Carboniferous and Triassic rocks as all represented in the neighbourhood of Wellington. The only fossil found was the *Torlessia mckayi* BATHER which is regarded as Carboniferous by HECTOR, though BATHER admits that it may as well be Jurassic.[51] HECTOR mentions the existence of Triassic rocks near Wellington, and also between Cape Palliser and Palliser Bay.[52]

Fossiliferous rocks with Triassic and Jurassic types are well developed at Kawhia and Waikato Heads. In the Reise der Novara Vol. I, p. 29 the following species are described: *Belemmites aucklandicus* HAUER, *Ammonites novo-zelandicus* HAUER, *Aucella plicata* ZITT., *Inoceramus haasti* HOCHST., *Placunopsis striatella* ZITT. and *Polypodium hochstetteri* UNGER. Descriptions of some cephalopods from these beds and from others in the Hokonui Hills have recently been published by MARSHALL, Trans. N. Z. Inst., Vol. XLI, p. 143. HECTOR described the belemnites, T. N. Z. I., Vol. X, 1878, p. 484. The rocks extend eastward as far as Waignaro. The other outcrops of folded rocks in the Hauturu, Tuhua and Rangitoto mountains and in the Mokau valley are all called Maitai by HECTOR and are here classed in the Trias-Jura system.

It has long been recognised that folded sedimentary rocks are present in the Coromandel Peninsula and in the Great Barrier Island; but for a long time no fossils were found in them and they were referred to the Maitai. McKAY has recently[53] separated them into three systems Devonian, Carboniferous and Triassic. No unconformable junctions were observed and the division is based upon lithological evidence that is far from conclusive. A single fossil remain showed that part of the rock series at any rate was definitely Triassic.

Still more recently FRASER has described this district[54] and he too divides the rock series into three systems. The division is admittedly tentative and is based upon slight stratigraphical and lithological evidence; but again is somewhat unconvincing. The highest of the three divisions is undoubted Jurassic age for typical fossils similar to those at Kawhia were found. Thus the only definite evidence we have is that Triassic and Jurassic rocks are present. The outcrops are relatively small and when the great breadth of the Trias-Jura outcrop elsewhere is remembered, a very definite unconformity must be recorded before the division into three series is justified. Folded shales and sandstones occur again at Whangarei and somewhat extensively at the Bay of Islands and Cape Brett. Here they are often contorted and sub-metamorphic, but no fossils have been found in them. Lithological characters justify their inclusion with the Trias-Jura system, until definite evidence to the contrary is forthcoming. Similar rocks crop out at the entrance to Whangaroa Harbour and at the Cavalli Islands and again at Hokianga, but they are not fossiliferous. In the extreme north outcrops are found at Cape Camel and the North Cape. Near the latter McKAY found some fossils of a Mesozoic nature.[55]

All through the country the unaltered rocks of the Trias-Jura formation have very similar characters. There are occasional conglomerates sometimes rather coarse. The pebbles in them consist mainly of plutonic rocks mostly granite. The conglomerates grade into sandstones formed of minerals of such rocks, and they grade into the shales often extremely fissile—the argillites of the geological survey. The sandstones are usually dark grey but often with a greenish tint and sometimes quite green. This colour is due to the presence of serpentine and chlorite for such sandstones consist mainly of the detritus of basic igneous rocks. The argillites are black bluish green and sometimes conspicuously red, and in the last case are nearly always associated with some amount of manganese oxide. This led HUTTON to suggest[56] that they were of abyssal origin. This is not supported by their microscopic structure and in hand specimens the frequent alternation of red and green bands 1 cm thick strongly opposes it. There are occasional bands of limestones but as a rule they do not contain distinct fossils. The commonest of them at Nelson are fragmentary remains of a very fibrous shell called by Hector *Inoceramus*. It is apparently similar to that described by Chapman from the Queensland Cretaceous[57]. Argillites and sandstones succeed one another irregularly so far as present observations show. In almost all parts of the country all the rocks are penetrated by numerous small quartz veinlets. On the margins of the metamorphic areas the greywackes pass quite gradually into schists: The felspar first becomes cloudy; muscovite forms from it and a silvery sheen is the result and the argillites change into phyllites. In them minute grains of haematite and epidote are formed and in some places there are large cubes of pyrite. The schists themselves do not show a great variety. Muscovite schist is by far the commonest. It consists almost entirely of quartz and muscovite with a little epidote. Occasionally biotite or actinolite take the place of muscovite and garnet may be present in extremely small crystals. Bands of chlorite schist (chloritoid) with magnetite are more common.

In Westland the structure often becomes gneissic; garnet is found in much larger quantity; the actinolite is coarse and a great deal of epidote and felspar may occur. The foliation is not often distorted and over large areas is practically horizontal especially in the central districts of Otago. Distortion of the plane of foliation is very noticeable in the Shotover valley, at Brighton and in the gneisses on the north side of the Franz Joseph glacier.

The cause of the metamorphism is somewhat obscure. So strongly did the difficulty of explaining the structure appeal to Hutton, that he concluded that it was original and relegated the schists to the Archaean[58]. There is at any rate no indication of the presence of plutonic rocks to which contact action could be due. Hutton stated that the horizontal position of the foliation planes, and the absence of distortion proved that dynamic action could not be responsible. However the structure and mineral composition indicate dynamic action, and the schists occupy the central position of a large folded mass of rock; it therefore appears to be reasonable to ascribe the metamorphism to the pressure to which the folding and elevation of the whole region was due. In Westland the schistose rocks occur on the western slopes of the main range and they are most completely metamorphic (gneissic) where they are nearest to granite intrusions. This at least suggests that the metamorphism is here in part the result of contact action, but the rocks are so folded and in places the foliation is so distorted that it is evident that dynamic action has also been important. The metamorphism of the Westland schists is ascribed by Bell[59] to contact action and dynamic agencies and Morgan[60] came to the same conclusion. The area of schists in the Queen Charlotte region has not yet been closely examined, but it appears to be more analogous to the Otago area than that of Westland.

Igneous rocks of the Trias-Jura.

While the sediments are composed almost entirely of crystals and mineral fragments derived from plutonic and other igneous rocks, it remains true that there is not much evidence that volcanic action was in progress during the period.

On the western margin of the Canterbury Plains from the Rangitata to the Waimakariri there is a large series of volcanic rocks which is most prominent in Mt. Somers. Rhyolite and pitchstones, often with almandite, are the commonest types; but there are many types of andesite mostly pyroxenic, though some have mica. Much of the pyroxene is orthorhombic. A very different kind of rock is found at Nelson and at Orepuke. It consists of thick tuffs, scoria beds and lava flows of a basic rock now most properly classed with the melaphyres. It is of a dark green colour.

These melaphyres under the name greenstone ash and diabase ash were classed by HECTOR in the Devonian[61] because they were supposed to underly the Maitai at Nelson.[62]

The association of some of these greenstones with the ultra-basic rocks of the Dun Mountain has led to the classification of these too in the Devonian. There is however no doubt that the ultra-basic rocks are intrusive into the Maitai for the shales have suffered distinct contact action in places. Petrographic similarity leads to the supposition that the ultra-basic rocks of the west of Otago are of the same age. In the extreme north of New Zealand there are other masses of intrusive rocks in sediments classed as Maitai. At the North Cape gabbros, norites and harzburgites are found in considerable bulk, and at Ahipara and Mongonui there are also large intrusions, for the most part diorites.[63] Dr. BELL has recently discovered serpentines derived from harzburgites at the Wairere falls on the Mokau.

5. Oamaru system.

Under this head are classed the Lower Greensand, Cretaceo-tertiary, Eocene, Lower and Upper Miocene of HECTOR[64] or the Waipara, Oamaru and Pareora of HUTTON[65] or the Upper Cretaceous and Miocene of PARK as well as some of his Pliocene.

The question of the correlation of these rocks involves many difficulties because of the isolation of many of the outcrops, the intense local earth movements to which they have in places been subject, and more important of all because of the great difference between the fossils of different members of the series. This last feature has naturally been used by HECTOR and HUTTON as an indication of a difference of age of the various series. The author's view is that these differences are partly due to differences of station which resulted from the rapid depression of the area, and partly to the rapid replacing of the fauna which had become archaic through long isolation, and partly to the slow rate of deposition of the greater part of the strata.

As here classified the rocks occur very widely in New Zealand. They are usually marginal on the older rock formations to which they are notably unconformable. They also occur in many isolated patches within the recesses of the mountain ranges in the South Island, where local conditions of structure or physiography have protected them from erosive agencies.

In the extreme south-west they are found at Preservation Inlet. They are well developed in the Waiau valley and reach nearly to the head of Lake Te Anau. From Gore the outcrop is practically continuous as a marginal formation as far as Cape Campbell and Cloudy Bay. There is a small outcrop at Nelson, and at Takaka a marginal deposit extends to Cape Farewell and bending south fronts the west coast as far as Hokitika and throughout this distance it reaches some miles up the river valleys. The belt expands widely in the upper valley of the Buller river, where in the Maruia tributary the series is found at a height of 4000 feet above sea level. A similar altitude is found at Lake Te Anau, and at Lake Wakatipu there is a small strip, and on the Gouland Downs there are isolated patches at a high altitude.

In the North Island there is a still more general distribution. All the eastern side of the Trias-Jura rocks is occupied by this Cainozoic material, and on the west side there is a still larger area that forms all the stretch of country that lies between Mts. Egmont and Ruapehu. Bounded on the south by the Manawatu River and on the east by the Ruahine Mountains and the volcanic plateau it stretches northward over and between the denuded Trias-Jura, and passing through Auckland is found as far as the North Cape thus connecting in the far north the isolated outcrops of Trias-Jura rocks.

In the east Cape district the rocks dipping but slightly to the east rise to 4000 feet above sea level. A similar elevation is attained on the western side of the Trias-Jura rocks of the Kaimanawa range near Ruapehu.

Usually the rocks are nearly horizontal or they dip outwards at low angles towards the coast. Locally however they are much disturbed. Thus they form a good syncline at Lake Te Anau. At Wakatipu they are almost vertical, lying along a fault plane. In the Trelissick basin behind Mt. Torlesse they are considerably folded and in the Puketoi Hills near the east coast of the North Island they are contorted. Quite a regular succession of rock types is found in most parts of the country. At the base of the series there is a conglomerate often with coal seams. Above this greensands often concretionary in many places followed by grey sands. The green sands in their upper strata become calcareous and finally pass into a chalky limestone which followed upward shows an argillaceous character and passes into a bluish grey marl which is finally succeeded by sandy and shelly beds of various kinds. This series has a different development in different parts of the country. Thus in Otago the marls are seldom present while at Amuri Bluff they are 630 feet thick and in the North Island more than a thousand feet thick. In many localities there are no coal seams near the base; for example at the Waipara River and Amuri Bluff though there are generally carbonaceous shales. At Cape Farewell the conglomerates are 1000 feet thick and in the Aorere valley they are almost absent. The lower limestone at Amuri Bluff is more than 600 feet thick, at Dunedin it is represented by sandy beds with foraminifera in plenty. At Kawhia there are no greensands, but a glauconitic limestone represents them.

There is also a great difference in the fossils in these localities. This must be expected when it is remembered that the whole series was deposited on a sinking shore line, and that this sinking was apparently associated with the removal of barriers to the distribution of marine organisms. The lowest beds were obviously formed at very different times in various parts of the country; thus the coal beds

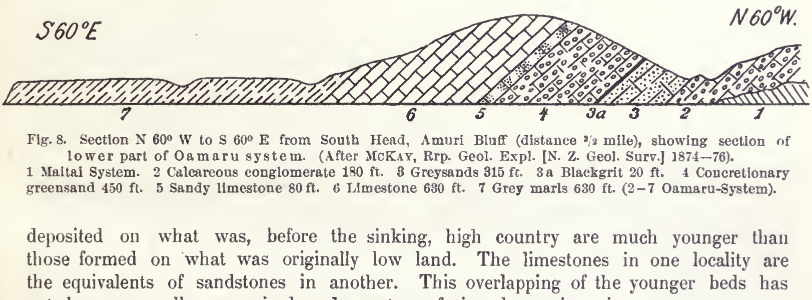

Fig. 8. Section N 60° W to S 60° E from South Head, Amuri Bluff (distance ³/₂ mile), showing section of lower part of Oamaru system. (After McKay, Rrp. Geol. Expl. [N. Z. Geol. Surv.] 1874—76).
1 Maitai System. 2 Calcareous conglomerate 180 ft. 3 Greysands 315 ft. 3a Blackgrit 20 ft. 4 Concretionary greensand 450 ft. 5 Sandy limestone 80 ft. 6 Limestone 630 ft. 7 Grey marls 630 ft. (2—7 Oamaru-System).

deposited on what was, before the sinking, high country are much younger than those formed on what was originally low land. The limestones in one locality are the equivalents of sandstones in another. This overlapping of the younger beds has not been generally recognised and great confusion has arisen in consequence.

In addition to this it is evident that with a rapidly sinking shore line there must have been great differences in the bionomic condition of the stations at which the deposits accumulated. Thus at some stations there were littoral conditions while simultaneously at others the conditions must have been almost oceanic.

It is believed that these considerations not only explain the rather striking diversities in the fauna but even make it necessary that such diversities should have existed. It may be as well here to indicate the more important of these diversities.

At the base of the whole series at Amuri Bluff and the Waipara the rocks contain fossils that are distinctly Mesozoic in their affinities. *Belemnites, Trigonia, Inoceramus, Baculites, Gryphaea, Conchothyra*[66], *Aporrhais* as well as a great variety of marine saurians have all been recognised. In the Greta beds, the highest stratum in the Weka Pass section, Hutton gives a list of 46 species of organisms the great majority of them Mollusca; of these 66 per cent are recent species[67]. This illustrates the two extremes found in a single section. Fossiliferous beds are common in all parts of the country.

The following are the more important species in the different classes of organisms.

Mammalia: *Kekenodon onemata* Hector; *Squalodon serratus* Davis.

Whale remains are quite frequent but no other specific identifications have been made.

Aves: *Palaeudyptes antarcticus* Huxley, Moa Remains.[68]

Reptilia[69]: Hector gives the descriptions of seven species of *Plesiosaurus* and one each of *Leiodon* and *Ichthyosaurus*. He also gives descriptions of species of the new genera *Mauisaurus* and *Taniwhasaurus*.

Pisces: Remains of fish especially teeth of sharks are very abundant. Collections sent from New Zealand were classified by Davis.[70] He described twenty nine species of which twentyfour were sharks. *Carcharodon angustidens, C. megalodon, C. robustus;* eight species of *Lamna;* four of *Odontaspis;* eight of *Oxyrhina;* and three of *Notidanus* comprise the list of sharks.

So far as the age of the rocks in which these remains occur is concerned Davis makes no suggestions based on his identifications. He remarks that all the genera are represented in the Tertiary strata of the Oamaru formation of Hector; but most of them also occur in the Lower Cretaceous, though only in its upper portion.

Crustacea: *Harpactocarcinus tumidus* H. Woodward, a crab, is fairly well represented but other crustacean remains are infrequent.

Pollicipes aucklandicus Benham of very unusual size for a cirrhipede comes from Auckland.

Mollusca.

Cephalopoda: *Belemnites australis* Phill. occurs plentifully in the lowest beds of the series at Amuri Bluff and at the Waipara. An exfoliated form of a fusiform shape perhaps *Actinocamax* is much more common. *Ammonites* are recorded from the Amuri Bluff and the east coast of Wellington.

Aturia ziczac is found in the upper beds.

Gastropoda: The most characteristic are: *Scalaria lyrata* Zitt.; *S. browni* Zitt.; *Cassidaria senex* Hutton; *Scaphella corrugata* Hutton and many other species; *Struthiolaria papulosa* Martyn. There are many closely allied species. *Natica zelandica* Quoy and Gaimard. A very great variety of species of this genus including some very remarkable thick shelled forms such as *Natica solida* Hutton; *Turritella rosea* Quoy and Gaimard, several other very closely allied species. *Siphonalia orbita* Hutton. This genus is well represented. *Ancilla australis* Sowerby; *Calyptraea monoxyla* Martyn; *Pleurotoma fusiformis* Hutton; *Crepidula monoxyla* Lesson.

Pelecypoda: *Ostraea wullerstorfi* Zittel, very abundant with several allied species. *Anomia alectus* Gray; *Pecten triphooki* Zittel. (This genus is very well represented. Generally the species have both valves ribbed but *Pecten hochstetteri* Zitt. has one valve smooth and *Pseudamusium huttoni* Park, a highly characteristic form, has both valves smooth.) *Cucullaea alta* Sowerby. Three or four variable species are common. Of these *C. ponderosa* Hutton is very large. *Limopsis aurita* Brocchi; *Glycimeris globosa* Hutton. Several other species are quite common. *Lima palaeata* Hutton; *Panopaea orbita* Hutton; *Mactropsis trailli* Hutton; *Cardium spatiosum* Hutton; *Crassatella ampla* Zittel. Many other species and genera occur somewhat less commonly.

Scaphopoda: *Dentalium giganteum* Hutton. This and several other species are found almost everywhere.

Complete lists of fossils will be found in the "Detailed catalogue and guide to the geological exhibits in the New Zealand court. Indian and Colonial exhibition, London 1886". Descriptions of species will be found in Hutton's "Catalogue of the Tertiary Mollusca and Echinodermata of New Zealand, Wellington 1873."

Echinoderms: Tate[71] examined a collection of typical specimens of this class of animals. Twenty five species were distinguished including two species of *Pentacrinus. Lovenia tuberculata* Zittel; *Pericosmus compressus* McCoy; *Schizaster rotundatus* Zittel are the most characteristic species. In regard to the correlation of the strata Tate says "There is no doubt that the Oamaru formation is correlative with the Lower Murravian of Australia." This he says is comparable with the European Eocene with a slightly more Cretaceous complexion.

Corals and Bryozoa: Tenison-Woods[72] examined a collection of species of these groups. He distinguishes twenty nine species of corals of which nine belong to the genus

Flabellum which is still represented in New Zealand waters by two species. Of the fossil species *Flabellum radians* TENISON-WOODS is perhaps the commonest. Corals are seldom conspicuous in the Oamaru formation. *Isis dactyla* is found more frequently than the others. As to the indication of the age of the beds offered by the corals TENISON-WOODS says:—"I have no doubt that from the fossil corals the formation at Oamaru and that at Mt. Gambier (Australia) were contemporaneous." The age accepted by him for the latter is a stage later than the Upper Eocene.

Of the *Bryozoa* he distinguished eighteen species. They are generally small and inconspicuous. *Eschara ampla* TEN. WOODS and *Celleporaria nummularia* BUSK. are perhaps the most abundant. In his general remarks TENISON-WOODS says:—"At Mt. Gambier there are immense masses of limestone composed of fossil *Bryozoa* with very few shells and the corals always occur as casts. Precisely the same features are visible in such fragments of the Hutchinson quarry stone as I have seen."

Foraminifera: STACHE [73] who examined the Novara collections from Raglan and Papakura distinguished 266 species. He says they are of the same age as the Neogen Tiefenfauna of the Vienna basin; more precisely they correspond with the upper Oligocene of North Germany. CHAPMAN has contributed more information on this subject in the Geology of New Zealand by PARK, p. 122.

Sponges: At Oamaru sponge spicules are often extremely common. Some of these have been examined by HINDE and HOLMES.[74] One hundred and ten species were recognised and it is stated that there are probably many more species represented. A noticeable feature is that monactinellid sponges are practically absent and that *Hyalonema* is represented though recent species are most common at a depth of 1000 fathoms and they range to 3000 fathoms. The authors agree with HUTTON that the age of the deposit is Oligocene or Upper Eocene.

Diatoms: From the same deposit the remains of diatoms are obtained in abundance. GROVE and STURT [75] have found as many as 283 species represented in this material.

Plants: VON ETTINGSHAUSEN [76] examined collections of fossil plants from several localities. He has described a large number of species belonging to genera not now represented in the New Zealand flora. Of these *Quercus, Alnus, Myrica, Acer, Ulmus* and *Fagus* are the most striking; though the last is represented by numerous recent species in the country none of them are deciduous or large leaved types. In accordance with his well known views he found that the New Zealand Tertiary flora was a part of the universal Tertiary flora, and that only one part of this Tertiary flora has developed into the living flora. From the specimens sent to him he recognised some localities as Cretaceous but the majority as Tertiary. As dicotyledonous remains are present in his Cretaceous localities they cannot be older than the Upper part of that formation.

From these statements it will be seen that there is a general consensus of opinion that the rocks are of older Cainozoic age, perhaps Eocene. It is however fairly evident that any classification that can be satisfactory must be based on the characters of the mollusca which occur far more generally than any other class. Here too it is unsatisfactory to compare the species or even genera with those of definitely known geological periods in Europe; for in such a distant part of the world homotaxial considerations must be weighed with great care. A comparison of the recent molluscan fauna of New Zealand with that of Europe shows marked differences even of a generic character. It appears then that it is only by comparing the Oamaru fauna with that of the present day that a reliable idea can be formed of the age of the rocks of this period. The percentage method however is here more than usually unsatisfactory, for the greensand and limestone deposits at least were formed in deep water and little is known of the fauna of the localities where similar deposits are now being laid down.

HUTTON found that in his Oamaru (Oligocene) system 9 to 10 per cent of the mollusca belonged to recent species; and in his Pareora system 20 to 45 per cent.[77] PARK however asserts that at the typical locality at Oamaru the Pareora (Miocene) fauna is sandwiched in between two different fossiliferous strata of the Oamaru series and in different localities finds that from 22 to 38 per cent of the Oamaru species are recent. The author has obtained somewhat similar results in the north-west of the Nelson province and at Gisborne. Such estimations however require expert conchologists with an accurate knowledge of the exact characters of the recent fauna, before they can be accepted as altogether reliable. In the meantime these percentages merely indicate the close resemblance of this Oamaru fauna to the recent one. When the isolation of the country and the oceanic barrier to the migration of littoral species are born in mind, it becomes apparent that such percentages cannot rightly be employed in correlating the Oamaru fauna in the upper strata with any of the European divisions of the Cainozoic age.

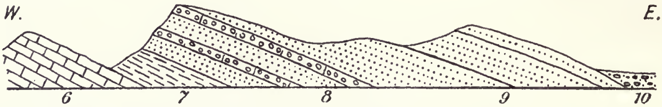

Fig. 9. Section of Weka Pass, North Canterbury (distance 1½ miles), showing upper part of Oamaru system. 6 Limestone. 7 Greymarls 100 ft. 8 Mt. Brown beds with calcareous conglomerate 570 ft. (Eocene HECTOR, Miocene HUTTON, PARK). 9 Pareora beds 250 ft. (Miocene HUTTON and HECTOR, Pliocene Park). 10 Pleistocene gravels.

The rocks that are here classed in the Oamaru system were divided by HECTOR into the following series (1) Lower greensand, (2) Cretaceo-tertiacy, (3) Upper Eocene, (4) Lower Miocene, (5) Upper Miocene. He shows no unconformity between the two lowest in the Coverham section.[79] In the Progress Report of the Geological Survey 1890—1891. p. LI. he states explicitly that "the Lower Greensand formation (is) almost universally followed conformably by the Cretaceo-Tertiary formation and that too in a manner that but little supports the idea of any unconformity separating the lower beds and the higher beds of the two formations". There is no unconformity at Amuri Bluff. The unconformities between the Cretaceo-tertiary and the Eocene have not been accepted by HUTTON and PARK and the author after going over the typical sections has failed to see them. The Lower Miocene and the Eocene are represented as conformable.[80] He gives no section showing the relation between the Upper and Lower Miocene; but presumably they are conformable. It appears then, that the only unconformity that he recognises in the whole series has not been recognised by any other observer.

HUTTON divided the system into three series: Waipara (Cretaceous), Oamaru (Oligocene) and Pareora (Miocene). The unconformity between the first two is the plane that separates the two limestones.[81] This was vigorously opposed by McKAY[82] and HECTOR, HAAST and PARK failed to see it. The author in five localities has been unable to see it in perfectly clear sections. A specific instance of unconformity between the Pareora and Oamaru is recorded in the Weka Pass.[83] This is not noticed by any one else and is certainly a fault as first supposed by HUTTON.

PARK[84] recognises three formations in this series. Waipara (Upper Cretaceous), Oamaru (Miocene) and Te Aute (Older Pliocene).

The limit of the first formation occurs above the upper limestone, a plane of discordance also suggested by HAAST. This supposed unconformity was not noticed by HECTOR, HUTTON and McKAY. It is admitted that no section shows this unconformity. Careful work over the whole district has convinced me that there is no break in the series. The other section showing the break between the Miocene and Pliocene also appears to me to have been misread. Previously[85] PARK had stated that the beds formed a complete sequence from the base of the Cretaceo-tertiary to the close of the Pareora.

For the reasons briefly indicated above but which it is impossible to enter into fully in this place, the author, who has had opportunities of examining the post-mesozoic strata in nearly all parts of the country, is strongly of opinion that all the strata here classed as Oamaru belong to a single conformable series. Subsequent work may of course show that this is an error but all statements hitherto made appear, when closely examined on the field, to fail completely in attempting to show that unconformities exist.

The general rock succession has already been described and the base was said to consist of conglomerates and coal seams.

Hutton always vigorously opposed the classification of all the New Zealand coal seams in one formation; the Westport and Greymouth fields in particular he placed in the Cretaceous system. The stratigraphical information hitherto published in regard to these fields is of a meagre nature. Hector however did not see any reason to separate them from the Cretaceo-tertiary formation. Coal is not found everywhere at the base of the system but is yet of wide occurrence. The following are the most noteworthy localities: Preservation Inlet, Nightcaps, Kaitangata, Green Island near Dunedin, Shag Point, Ngapara, Mt. Somers, Malvern Hills, Pakawau, Puponga, West Wanganui, Westport, Reefton and Greymouth in the South Island. Whangarei, Kawakawa, Ngunguru, Hikurangi, Huntly, Mokau and the Upper Wanganui in the North Island. It is not intended to be asserted here, that all these coals are of the same age, but that they were formed during the continuance of the same period of depression in different low lying localities near the coast line, as it gradually extended shorewards and forced the strata deposited later to overlap the earlier deposits. Nor can it be asserted that the coals now lying at the same level were contemporaneous; for the reelevation of the country after the great Cainozoic depression was not accomplished by simple upward movements but was uneven in different localities and in many places was accompanied by rock folding. Morgan has recently stated that an unconformity separates the bituminous and the brown coal measures at Greymouth. The evidence for this break is found in the presence of pebbles of coal supposed to be derived from the lower rocks in the conglomerates of the upper series. No break has been seen in any natural section.

Locally volcanic rocks are of importance though for the most part their eruption took place after the Oamaru formation had appeared above the surface of the ocean. At Oamaru there is a remarkable breccia in which fragments of tachylite are embedded in a calcareous cement. This was evidently formed during a submarine eruption on a sea floor that was then covered with a foraminiferal ooze. In the neighbourhood there are tuff and breccia beds, and lava flows interbedded with the Oamaru sediments. The many basaltic cones between Oamaru and Dunedin and further inland were of this age.

At Dunedin the extensive series of volcanic rocks, trachytes, phonolites, basalts, kenytes and basanites rest on the eroded surface of sandstone of this age. The mass of volcanic rocks that forms Banks' Peninsula probably belongs here though direct evidence of its age is wanting. The rocks are mainly basic types of andesites as well as basalts. In the North Island evidence of contemporaneous volcanic action is to be seen in the interbedded pumice and tuff beds in this series near Gisborne; but these are not known to be represented on the western side. At the Coromandel Peninsula there is a highly important series of tuff beds and lava flows of an andesitic nature. They rest on calcareous sandstones in places and vary somewhat in nature—from dacites to pyroxene andesites. Nearly all the auriferous quartz veins of the mining field traverse this series. Massive breccia formation of a similar kind of rock are found in many other localities further north. The best known localities are Waitakerei close to the north of Manakau Harbour, Whangarei Heads, Whangaroa and North Cape, but in these districts they are not associated with any auriferous deposits. Several of the outlying islands:—the Hen and chickens, Little Barrier and most of the Great Barrier are formed of the same kind of rock, and are probably of the same age. At Auckland, beds of tuff are found in the Waitemata series, which are the upper beds of the Oamaru formation. These tuffs have been correlated by Fox with the eruptions at Coromandel and Waitakerei.

In the Coromandel Peninsula Fraser[86] distinguishes three Cainozoic periods of eruption. Of these the first took place at the close of the Eocene for the rocks rest on beds there classed as Eocene though here placed in the Oamaru series. The second period is classed as Miocene for an unconformity is described between the two series and certain plant remains are said to point to a later Cainozoic age. The rocks of the third period of Fraser are more acidic but it has not been shown that they are unconformable to the other series. Marshall[87] has classed two other series of igneous rocks in the North Island as of the same age as the Coromandel andesites. One series includes the older basalts of Kerikeri which occur over a large area north of the Bay of Islands. The other series contains the dolerites of Kerioi and Pirongia two large denuded cones near the west coast.

The only exact measurement of the thickness of the rock series in this system is that made by McKay at the Amuri Bluff.[88] In that locality the thickness to the top of the grey marls is 2300 feet (700 m). In the Waipara the beds that rest on the top of the grey marls are certainly an additional 2000 feet (610 m) thick. At Lake Te Anau at the entrance to the north arm the series is over 3000 feet (915 m) thick, but it appears probable that at no place are the rocks thicker than 5000 feet (1524 m) though of course, if the maximum thickness of each different formation as developed in typical localities is added together, the total would be very much greater. Exceptions to this statement are found in the great thickness of the basal conglomerate in some places. This is 7000 feet thick near Greymouth, 3000 feet thick at Shag Point and perhaps more than 1000 feet at Cape Farewell.

In conclusion the following may be given as a summary of the reasons for classing all these younger rocks in the same system.

1. The clear conformable stratigraphical sequence at the Waipara in North Canterbury, and though somewhat less distinctly at the Weka Pass. This sequence extends from the lowest beds with a Cretaceous fauna to the highest with a Pliocene or Upper Miocene fauna.

2. The fact that the stratigraphical sequence is so similar in all localities; viz. conglomerates, sandstones, greensands, limestones, greensands, grey marls, brown sands.

3. In no district is there any instance of the typical development of the one series resting on the typical development of another. At the Waipara in particular, where a succession of three series has been described, the middle system has a very different development from that of its stated equivalents elsewhere.

4. In no district have coal measures been found above the basal conglomerate which rests directly on the Trias-Jura or older rocks, and in no district are there two limestones in the same section.

5. All previous observers have differed from one another as to the positions in the series in which they place the unconformities they describe.

6. Wanganui system (Pliocene).

All authorities are agreed that the fossiliferous sands at Wanganui and at Petane near Napier are of Pliocene age. The very high percentage of living species in the fauna—at least 90 per cent—is in itself sufficient to establish this point. In the North Island the rocks are marginal and do not appear to cover a very large area. In the South Island it is doubtful whether there are any marine sediments of this age, unless those at Awatere and Motanau, which are correlated with the older Pliocene by Park.[89]

Hutton remarked that the marine beds of the North Island are represented by thick unfossiliferous gravels in the South Island which are exceedingly difficult to separate from gravels of Pareora age.[90]

A similar classification was adopted by Hector. In addition to the marine fossiliferous beds of the North Island and the gravels of the South Island there is no doubt that a large portion of the volcanic plateau of the North Island is of Pliocene age.

Hutton asserts that there is an unconformity between the Pareora and Wanganui sediments in the North Island, but this is opposed to the author's observations and Park[91] in the

Wanganui and Cox[92] in the Hawke's Bay district deny the existence of unconformities; and McKay does not definitely state that one is present.

Of all the localities that of Wanganui is best known, for the sediments are highly fossiliferous there and are somewhat varied in their nature. There is however some doubt as to how many of the Cainozoic rocks there should be included in the Pliocene series, and where the dividing line between the Pliocene and lower sediments should be placed. There is however no doubt that all the strata exposed at Shakespeare's cliff at Wanganui except superficial drift should be placed here, while the strata near Parakino should be placed in the upper part of the Oamaru formation. It appears however that there is no unconformity between this system and the Oamaru system. Similar beds to these extend south eastward to the slopes of the Ruahine at Pohangina and on the eastern coast they cover a large area near Napier. The sands at the Manukau Heads and the pumice plains in the upper Waikato Basin and east from Taupo are placed in the Pliocene by Hector.

Park in his Geology of New Zealand (p. 157) classes practically all the sediments that extend from the coast to the volcanoes, and to the mountain range of the North Island in the Pliocene. He does not state whether these rocks are conformable to his underlying Karamea System of Miocene age.

In the South Island the great mass of gravels forming the Moutere Hills between the Motueka and Waimea valleys are probably of Pliocene age for they contain occasional fragments of Oamaru rocks. Other areas of gravel that Hector classes as Pliocene are found in the Mackenzie country near Lake Ohau; in the upland basins of Otago —Manuherikia, Maniototo, Idaburn—also the gravel areas between the Mararoa River and Lake Te Anau as well as a portion of the plains of Southland. It is however well to recognise that there is no special reason for this classification except in the case of the inland basins of Otago where some Pliocene fossils have been found.

Hutton always thought that the glacial extension of which there is so much evidence in New Zealand took place during the Pliocene. His opinion was based on several very distinct considerations. He first gave proofs that the glaciation took place, when the country was more elevated than now. Then he made a comparison between the fauna and flora of the North and South Islands and between these and the animals and plants of the outlying islands, which would have been connected with New Zealand if such an elevation as that which he believed to have been associated with the glaciation had actually occurred. The notable generic and specific differences that exist he regarded as so important that they could not have arisen within the limits of Pleistocene times. Although Hutton's reasoning and conclusions are not altogether to be gainsaid, geologists at the present time are inclined to regard the glaciation as occurring in Pleistocene times and therefore to correlate it with glacial advance in Australia, Tasmania and elsewhere.

In the typical locality at Wanganui the lower members of the system are blue marls with a large number of shells of *Rhynchonella, Ostraea, Pecten* and *Solenella*. The upper beds are brown and yellow sands often extremely micaceous. Hutton mentions[93] 279 species of Mollusca and states that 77 per cent of these are recent. This percentage has been increased in recent years as the result of dredging off the coast. The Foraminifera from Petane have been examined by Vine, but he has made no comparison between these species and those of other deposits. Pliocene plant remains are not uncommon especially in the lake beds of Otago. Amongst other species represented are fruits of Hakea which have been found also in lignites at Gore. These plant beds have not yet been properly described.

The identity of the fossils with living species renders it unnecessary to give lists. It is however noticeable that Hector says that the following species found in the Wanganui beds are now extinct: *Struthiolaria frazeri, Lutraria solida* Hutt., *Pileopsis uncinatus* Hutt., *Pleurotoma tuberculata*.

As in other countries Pliocene deposits are local and vary much from point to point; consequently no general succession of strata that accords with all the outcrops can be stated. At Wanganui there are bluish grey marls at the base, brownish micaceous sand rest on these and coarser and finer bands of these alternate and there are some bands of shell limestone. At Napier there is a similar association of brown sands and shelly limestone.

In the old lake basins of Otago quartz gravels are followed by brown gravels, than by clays, and there are some beds of lignites. These beds may belong to the Oamaru system. At Gore there are some lignites interstratified with Pliocene gravels. In some of the old lake basins of Otago especially near the margins of the deposits they have been disturbed by earth movements and are now vertical. Similar disturbances have been recorded by Hector in Pliocene rocks bordering the Ruahine Mountains. Certain sandy strata in Central Otago and elsewhere are now white quartzites. They are merely portions of ordinary sandy beds cemented by secondary silica. This is apparently similar to the surface quartzites of South Africa.[95]

Volcanic rocks.

There is no definite evidence of volcanic action in the South Island though the eruptions at Otago Peninsula and Hyde and other areas of basic rock may have extended into this period. At Timaru the fact that the dolerite rests on the surface of gravels similar to those that form the Canterbury Plains is almost proof that its age is Pliocene. If this is the case the moa bones described by Forbes cannot be older than Pliocene, but even so they are of great interest.

In the North Island volcanic action was extensive. At first the eruptions appear to have been associated with acidic rocks, for pumice is found in the Pliocene and no andesitic matter has been found in that series. Fraser's third volcanic series in the Coromandel Peninsula is of Pliocene age. The outpouring of rhyolitic lavas was extensive over the whole volcanic plateau from Te Kuiti on the west to near the Bay of Plenty, and from Lake Taupo on the South to Mercury Bay on the north. For the most part these great lava flows rest almost horizontally. The eruption of these was probably a continuation of the volcanic disturbances that began at the close of the Oamaru period. I know of no absolute proof that the eruptions to which Ruapehu and the other andesitic cones of the North Island were due began during this period. At Wanganui the andesitic gravels rest unconformably on the Pliocene sediments, and the same appears to be the case throughout the coastal region. General considerations based on the bulk of the mountain, the great erosion that has taken place and the great amount of material that has been transported to the coast line appear sufficiently weighty to justify the statement that eruptions had commenced in the Ruapehu area at this time. There is no reason to suppose that the eruptions of Mt. Egmont were not commenced at this time. The close of the Pliocene then appears to have witnessed the commencement of the volcanic activity to which the most prominent mountain crests of the North Island are due.

The lower part of the Waikato valley is covered with sheets of dolerite and sometimes basanites, but only small cones are visible. These probably date from the Pliocene. The fact that the lava flows have undergone great weathering and decomposition is the only reason for considering them older than the Pleistocene.

These volcanic rocks were first examined and classified by Hochstetter[96] who divided them into two series: — an older and a younger but without giving any exact geological age for either class. Recently the whole series of volcanic rocks has been more closely examined by Marshall, who[97] has divided them in accordance with the views here stated.

7. Pleistocene.

At Wanganui and elsewhere along the coast on the west of the North Island there is a stratum of so-called drifts which rests unconformably upon the surface of the Pliocene strata. The Pleistocene age is ascribed to these. The parallel inclined stratification noticeable in many places shows that the gravels accumulated on a beach. Fragments of wood are included in the gravel and the formation reaches to 400 feet above the sea level at Kaiwhaiki, twelve miles from the mouth of the Wanganui river. Raised beaches have been recorded on many parts of the coast.

Hutton gives the following list[98]:—Thames 10—12 feet, North Head Manukau 10—12 feet, Tauranga 25 feet, Hick's Bay, Taranaki 150 feet, Cape Palliser 200 feet, West Coast South Island 220—400 feet, Amuri Bluff 500 feet, Conway River, Motunau 150 feet, Entrance to West Coast Sounds 800 feet.

Recent elevation is also indicated by the remarkable river terraces in most of the valleys in the South Island. In addition to these gravels the fine clays that cover the surface of the Canterbury Plains are classed with the Pleistocene. These clays are not restricted to the level land but cover the downs at Timaru and Oamaru and extend up to 1000 feet on the flanks of Bank's Peninsula on both the landward and seaward side. These clays Hutton classed as marine silt, but Haast considered it to be a loess. The vertical tubular structure, uniform fineness, rounded nature of minute grains, general independence of topography, absence of stratification and absence of marine fossils all point to the correctness of the latter explanation and Haast's opinion is the one now generally adopted.

The majority of New Zealand geologists place the glacial moraines among the Pleistocene deposits. These are very abundant in the South Island where immense accumulations are found far beyond the terminal faces of the present glaciers. On the western side no moraines are to be found in the south; for it appears that in this region of high precipitation, the debris was either floated away seawards by icebergs or the moraines have since their deposition been submerged far beneath the sea level. Further north moraines form the coast line in many places between Milford Sound and Hokitika and hills of moraine cumber a large part of the low country. Further north they retreat inland and in the Nelson Province are not found below the level of 2000 feet at the foot of Lake Rotoiti. Lake Guyon, Tennyson and others have moraines at their eastern extremities. In the Waimakariri valley glacial deposits are widely extended and moraines have even been described on the western margin of the Canterbury Plains. The same is true of the basin of the Rangitata and Rakaia, while in the Waitaki basin glaciers extended at least as far as the southern ends of the Lakes Tekapo, Pukaki and Ohau. In Central Otago there are moraines at Clyde and Alexandra, while at the Taieri mouth a large moraine occurs within three miles of the present sea margin and reaches below the sea level. This moraine however is at the point, where the western high land approaches most closely to the east coast, and as it is inclined landwards at an angle of 15—25 degrees important land movements have evidently taken place since its deposition.

A great moraine is found at the south end of Lake Wakatipu and at the south-east end of Manapouri and Te Anau but none have been described nearer to the seacoast in the south-east, nor have any erratic boulders, or ice worn surfaces been described between the moraines and the coast, though the fact that the rock of the interior is mica schist and that of the coast line volcanic rock, limestone or sandstone would make it extremely easy to detect them. These facts show, as was long ago pointed out by Hutton, that the glaciation was restricted to the highlands and was rather of the nature of separate glaciers than a continuous ice sheet. A map showing the probable extent of former New Zealand glaciers was published by Marshall.[90] (See Fig. 13).

Park[100] has recently stated that New Zealand was covered by an ice sheet in the Pleistocene and that this was connected with an extension of the ice from South Victoria Land; but he gives no sound reason in support of this but bases all his suggestions on the supposed thickness of the ice in the Wakatipu region.

Since this was printed a number of illustrations of fragmental accumulations supposed by Park to be of glacial origin have been published T. N. Z. I. Vol. XLII. and Geology of New Zealand. In the opinion of the author these accumulations are either of fluviatile origin or are due to landslips. Other features of the shores of Cook Strait ascribed by Park to glaciation are thought by the author to be the effect of normal marine or sub-aerial erosion.

In Stewart Island the only glacial moraines known to occur are on the slopes of Mt. Anglem.

Highly important Pleistocene deposits are the peat swamps with moa bones which occur not infrequently especially on the western border of the Canterbury Plains particularly where small streams reach the plains from the hills. One at Hamilton[101] contained the remains of 400 birds. Another at Glenmark perhaps 1000. With the *Dinornis* there are remains of *Harpagornis* (an eagle), *Apteryx, Cnemiornis* and of *Sphenodon*, also the fresh water shells *Thalassia obnubila* (*Flammulina igniflua* Reeve) and *Limnaea leptosoma* Hutt.

Hutton thought that these remains were due to the collecting agency of streams during a period of high eccentricity of the earth's orbit which caused cold winters and heavy floods. Haast thought that the deposits occurred on the routes of moa migration, and that those birds that wandered from the track were engulfed in the swamp. Others have thought that natives drove the birds by fires and weapons into the swamps where they were easily attacked and dispatched. Each of these explanations is in some essential respect unsatisfactory.

The absence of gravel and rolled bones is a serious difficulty in connection with that offered by Hutton. The fact that the bones of an individual moa are seldom or never found in association tells against the suggestion of Haast. The absence of marked and broken bones disproves the last. It appears that at the present time there is no satisfactory explanation of the occurrence of these remarkable collections of bones.

The literature of the *Dinornithidae* is somewhat extensive.[102] Owen[103] distinguished twelve species but included them all in the same genus. Hutton distinguishes six genera and twenty-six species.[104]

Haast described a quaternary race of men that he thought has existed in New Zealand and was responsible for the extermination of the moa.[105] His opinion was based on the supposed occurrence of two series of kitchen middens the lower of which contained numerous moa remains and the weapons found in them were nearly all of chipped stone. Cranial characters were also said to indicate a race with melanesian affinities. The nature of rock paintings in South Canterbury was supposed to support this view. This race did not have a domesticated dog and did not possess greenstone implements.

It is now generally believed that several migrations of Polynesians reached New Zealand before the great heke of 500 years ago[106], and that the earlier migrations exterminated the moa.

Many species of birds now extinct or restricted to outlying islands existed on the mainland in the Pleistocene, *Harpagornis moorei* Haast was a large bird of prey; *Cnemiornis*, a goose, was apparently widely distributed, *Notornis hochstetteri* Meyer was abundant; the tuatara lizard *Sphenodon punctatum* Groy still lived on the main islands. The kakapo extended its wanderings to the east coast.

But little is known of the plants of the Pleistocene though it is fair to conjecture that the kauri spread over much of the country that lies to the north of Auckland for the gum, apparently of considerable age, is found in localities where now there is no indication of the former existence of forest. It is possible that much of the treeless area of Central Otago was then covered with forest, for in many places trunks of trees have been found in large numbers on the surface of the ground.

Volcanic rocks.

The rocks of Ruapehu and the adjacent volcanoes which were partly formed in Pliocene are also in part of Pleistocene age. Though the gravel drifts at Wanganui and elsewhere on the west coast consist mainly of andesitic rocks, there is no reason to suppose that the volcanoes had at that time attained their present form and grandeur. Erosion took place as accumulation progressed. Some of the lavas do not appear to have suffered from erosion; others seem to have been almost entirely removed. These remarks are also in general true of Egmont and Tongariro and the other volcanoes of the volcanic plateau. Throughout the Pleistocene andesitic rocks were the lavas emitted. The fact that in many places rhyolitic rocks rest on the andesitic material does not militate against this statement. The eruptions of Tarawera in 1886 though associated with an andesitic magma scattered rhyolitic pumice far and wide, and in places it fell over andesitic rock thus giving the impression that the last eruptions were acidic though the pumice was in reality derived from the superficial covering of this material of greater age. It is probable that in the past similar spasmodic eruptions have taken place and that the interstratification of rhyolitic pumice and andesitic lavas is to be thus explained. There is no knowledge whether basaltic eruptions were in progress in the Waikato basin at this time or not. It may be that the action commenced at this time though it is more probable that the Pliocene marked the commencement and that the action continued during the Pleistocene. There appears to have been no volcanic action during the Pleistocene period in any part of the South Island.

8. Recent.

Sand dunes, river gravels and volcanic cones constitute the geological formations of this period. Sand dunes are very extensive on the exposed coasts of both islands. Their extent is however greater on the west coast of the North Island than elsewhere for here they are found eight or ten miles from the beach and rise to 300 feet above sea level. They are remarkably developed in the extreme north and even unite together various masses of Trias-Jura rocks that otherwise would be islands. The North Cape district, Hohoura and Mt. Camel are all bound to the mainland by rolling wastes of sand dunes. In the sand dunes Maori kitchen middens are frequent, and from time to time the onward movement of the dunes reveals to daylight the remains of moas that have been covered up ages before. The fact that native races fed on the moa is clearly shown by the great abundance of moa bones and egg shells in the middens. Complete egg shells have been obtained during gold saving operations in the river gravels of Otago, Moa feathers and dried muscles have been found in caves in the dry districts of Central Otago.

River gravels of recent age are to be found in a great many valleys, but they are not to be distinguished from those of Pleistocene age by any special characters. Deposition in most of these valleys has taken place more or less continuously since at least the beginning of the Pleistocene. In many places the rivers have cut their way through gravels that they previously deposited, and have extended the deposit seawards. Recent gravels are perhaps best seen at the head of Lake Wakatipu and Lake Pukaki.

Volcanic action in the centre of the North Island has continued through the Recent period. There is little doubt that the volcano Ngauruhoe dates from the recent period and that flows of lava have issued from Tongariro and even Ruapehu in the Recent, though none of the lavas of Mt. Egmont appear to be sufficiently unaffected by weathering action to be rightly classed here. Violent volcanic action has taken place within the last 25 years at Mt. Tarawera by which pumice and dust were scattered over a great area of country and with this material there were many volcanic bombs of andesite. No lava flow has issued from any volcano in New Zealand during the period of colonisation. The statements that lava issued from Ngauruhoe in 1866 appear quite erroneous.

The very perfect form of the volcanic craters near Auckland and the Bay of Islands negatives the idea that they could be of greater age than the recent period. Many of the lava flows streamed into the present valleys and the displaced water now flows at the side or below the usurping lava. The surface of the lava at Rangitoto Island is quite unaffected by weathering. Hutton mentions perfect cones on the Great Barrier and on Arid Island, a small outlying island to the west; the age of these is however not stated.

III. Geological History.

Manapouri period.

The rocks of the Manapouri system as at present known tell us nothing of the geographical conditions at the time of their deposition. They are entirely crystalline and are mainly plutonic in their nature. Some, especially those at the entrance to Milford Sound, appear to be metagneisses but even this is not known for certain. Until a greater amount of exact work has been done on these rocks it is useless to speculate as to the geological conditions that attended their formation.

Aorere period.

Limestone is the lowest rock of this system in Nelson, but its completely crystalline character has entirely obliterated any structures that might have given a clue as to its origin. The very pure nature of the rock perhaps justifies the suggestion that it was formed in deep water uncontaminated by sediment. The fine shales that rest on it contain graptolites and were evidently formed in deep water. These are succeeded by greywackes and quartzites but no facts are yet known that could be of any assistance in determining the source of the sediments or the direction from which they were derived.

No volcanic material is known to occur in this series of rocks but they are intruded by the great mass of granite of which the Gouland Downs are mainly formed. Orogenic agencies are said to have affected this system of rocks before the deposition of the Trias-Jura (Maitai Hutton, Haupiri Bell). The metamorphic action to which the rocks have been subjected probably took place at this time.

Baton River period.

Little is yet known of the rocks in the typical districts Reefton and the Baton River. Impure limestones, shales and greywacke are the rock types; so it is safe to assume that they were deposited on a shore line. Where the land existed and what was its nature is at present quite unknown. If the unconformity that has been described between the Maitai rocks and this system really exists, it is evident that elevation and rock folding must have succeeded the deposition of these rocks, and if any of the Westland schists are of this age as believed by Hector the rock movements must have been associated with the action of metamorphic processes. The author however sees no reason to class any of the schists with this system.

No volcanic or plutonic rocks have yet been described from this rock series but in the Baton valley there is a large intrusion of diorite.

Maitai period (Trias-Jura).

Geographical conditions are far more clearly marked out in the Maitai sediments than in the earlier periods. There is no doubt that the whole series was deposited on a continental shore line. Where the continent was situated is not at present known certainly. Efforts to locate it by identifying a rock formation with the fragments found as pebbles in the coarser sediments have largely failed. There are at present no rock masses in New Zealand that closely resemble the pebbles. An exception must be made of the small intrusive mass of granophyre at Ruggedty Point, Stewart Island, which is apparently quite similar in nature to many of the pebbles and boulders in the Maitai conglomerates.

The criterion of the relative coarseness of the sediments also fails in some measure. Haast for instance insists on the coarseness of the conglomerates in Puddingstone Gully near the Rangitata Gorge and concludes from this that the continent was eastward. Hutton states that the sediments are coarser on the western side and concludes that the continental land stretched to the west of New Zealand. Nor is much light thrown on the matter by considering the present position of ancient rock masses in New Zealand. The rocks of the Manapouri system and of the Aorere and Baton River systems cannot have been the source whence the sediments were derived, nor were the granite at the Bounty Islands (which is of unknown age) or the schists of the Chatham Islands. In the North Island there are no known rock series older than the Maitai.

The point of greatest importance in this connection is that the flora appears to bear a somewhat close relation to the flora of the later Gondwana period in Australia and India. *Baiera, Otozamites, Rhacophyllum, Taeniopteris* and *Macrotaeniopteris* are represented as well as many other genera of ferns. This may justify the conclusion that the continent lay to the west of New Zealand and was perhaps a part of Gondwanaland.

That the coast line was close at hand is abundantly proved not only by the coarseness of the sediments but also by the frequent occurrence of floated fragments of wood. In one locality in the extreme south—Waikawa—there was actually a portion of the accumulated sediments above sea level for a time and on this material was growing a luxuriant forest the remains of which are still to be seen in the numerous petrified tree stumps that project from the stratification.

The general conclusion that it seems fair to draw is this:—During the Trias-Jura period the present position of New Zealand was a shore line of a continent that stretched far to the westward and probably united New Zealand with Australia.

The conditions of sedimentation were simply those of an ordinary shore line. For the most part sandy beds were deposited and but few animal remains are to be found in them, as is usual in sandy beaches at the present day. In the conglomerates however such as those of the Hokonui Hills we have evidence that fluviatile deposition played its part. On the other hand fine shales formed apparently at some distance from shore are also frequent but in no case is limestone, apart from a few shell-beds and some argillaceous beds near Nelson, found in any locality. Amongst the shales are some conspicuous red bands often associated with manganese ores. It was suggested by Hutton that these strata represented abyssal red clays; but the stratification of the rocks, the absence of calcareous oozes, and their microscopic and chemical characters do not support this suggestion. Some of the upper rocks are marly and contain large concretions often with an organic centre.

There was not much volcanic disturbance during the Maitai period. At Nelson and Riverton the occurence of large masses of melaphyre ash and lava show that basaltic eruptions were somewhat widespread, for similar rocks are found in several intermediate districts. Hutton mentions interstratified volcanic rocks at the Hurunui. There is a large series in the Mt. Somers and Clent Hills districts. Here rhyolites often containing almandine garnet are the commonest type; but there are many andesites mainly of hypersthene and augitic varieties.

There is a great abundance of intrusive rocks though in all cases there is no actual knowledge of the period of intrusion. At Nelson the ultra basic intrusive rocks of the Dun Mountain consist of dunite and harzburgite with dykes of websterite and rodingite (a rock composed of diallage and grossularite). Many of these are partly or wholly changed into serpentines. There are similar rocks over a large area near Martin's Bay. At intervals on the western side of the Southern Alps there are large masses of granite. Near these the sediments are metamorphic and there is some doubt as to their age. In the Coromandel Peninsula there are many intrusive rocks, diorites and porphyrites, but none of there intrusions are large.

In the extreme North intrusive rocks are of great importance. At Mangonui there is a large mass of diorite and at the other side of the island at Ahipara an olivine-norite which extends to a distance southward in the Maungataniwha range. There are also intrusive rocks at the North Cape. Harzburgites, serpentines, norites and gabbros are found there and apparently at Hohoura as well.

These intrusives have not caused much contact action as is well seen in the Dun Mountain area where comparatively small "islands" of greywacke—not more than 40 yards across—show hardly any trace of change under the microscope. In the field the loss of stratification planes and the irregular cracked and baked appearance alone indicate the effect of intruded igneous rocks. In Westland on the other hand the granites are bordered on the east by a great thickness of schists which may have been formed by their intrusion. If that is the case there is in this region some evidence in regard to the relative age of ultra basic and granitic intrusions, for the ultra basic rocks are represented by serpentine and talc schists, and if the metamorphism is due to the granitic intrusions it is evident that the granite must be of a later age than the ultra basic rock which at Nelson is itself intrusive into Maitai sediments.

Orogeny. The close of the Trias-Jura is on all sides regarded as the critical period in the geological history of New Zealand. A great earth pressure acted at its close and all the areas of Mesozoic sediments were folded and apparently greatly elevated. The strike of the folds is remarkably uniform throughout the greater part of the country. From Mt. Cook through the northern part of the South Island, and through the North Island from Cape Terawhiti to Poverty Bay the direction is constantly north-north-east. Throughout this distance it hardly varies, except in the immediate vicinity of igneous intrusions such as the ultra basic mass of Nelson. Further south than Mt. Cook the strike bends considerably and is north-west to north-north-west from Nugget Point to the Takitimo Mts. There is a similar regular strike on the north side of the axis in the Waitaki valley. It has been previously pointed out that no unconformity has yet been found between the fossiliferous Trias-Jura and the schists of Central Otago, though the district is rocky and mountainous with abundant natural sections. Until such unconformities have been found it is obviously advisable in the absence of palaeontological evidence to regard the schists as metamorphic Trias-Jura rocks.

The structure of the schists is somewhat indefinite.

Hutton records a very general strike from north-west to north-north-west though occasionally varying to south-south-west. Park in 1909 gives a general north-north-east to north strike in the Wakatipu district.[107] At Cromwell the dip is given as west or east and the strike is therefore north.[108] In the Alexandra district[109] no mention is made of the strike or dip. From this it appears that in the Central Otago district the strike is north-west to north. Further westward the strike is north in the upper part of the Rock burn and at Big Bay is north-east. In Canterbury the strike is very generally north-east. Between these two relatively well known districts it has always been assumed that the strike gradually bends round.[110] Suess says of this structure:—Two independent unilateral chains meet here in syntaxis.[111] This statement is based on Hutton's paper and diagram and from what has been said it is evident that a great deal more detailed work is necessary before it can be definitely accepted. So far as our knowledge goes at present, it can only be said that it is highly probable. The country referred to however is extremely mountainous and rugged and will probably remain practically unknown for many years. Hutton shows some subsidiary branching folds, but these are not properly known at present.

All we are justified in saying at present is that in Otago there is a broad mountain axis directed north-west and south-east, formed of unaltered Mesozoic rocks on both flanks, but with a core of schists probably of Mesozoic age. From the Haast Pass along the axis of the Southern Alps there is a continuous mountain axis directed north-north-east; it is composed of Mesozoic rocks from its eastern margin to the axis, and on its western slopes schists and granite occur; but even here indications are not wanting that a similar development of Mesozoic rocks extend westwards. These have been examined in considerable detail by Bell and Morgan as well as earlier workers. The former does not attempt to define their age but calls them the Kanieri series[112] and remarks on their lithological similarity to the rock of the Arahura series here called Trias-Jura. Morgan[113] calls them the Greenland series and again remarks upon their similarity in composition, and probably in origin to some of the rocks of the Arahura series. Morgan says that the rocks of the Greenland series have been folded by a pressure antecedent to that by which the main chain of the Southern Alps were formed.

It is important to notice that the western rocks here mentioned have not been found in contact with those of the main series and that they are nearly always separated from them by granitic intrusions.

The Kaikoura Mountains appear to be formed of folded rocks with the same general strike as those of the main range.

In the North Island the main axis from Cape Terawhiti to Motu is composed throughout of shales, argillites and greywackes apparently similar in all parts of the range and as far as known not fossiliferous. The isolated outcrops in the Hauturu, Tuhua and other small ranges[114] are also of a similar nature. At Kawhia the rocks are more marly and strike north-east; here they contain a great abundance of Triassic and Jurassic fossils; the same is true at Waikato Heads, but at the Wairoa and Waiheke they contain no fossils though in the Coromandel Peninsula Jurassic fossils have recently been found. Whether these outcrops are portions of one great anticlinorium now eroded, depressed and with the eroded portions covered up with volcanic detritus is not yet proved, but it is the belief of Hutton[115] and of Suess[116]. The isolated outcrops of these rocks further north are also supposed to be a portion of this structure. The strike certainly appears to remain constant. Thus it is north at the Coromandel Peninsula.[117] At the Bay of Islands and near Ahipara it is somewhat doubtfully north-east.[118] At Whangaroa two anticlinoria appear[119]; one of these—the inner—is directed north-north-east and that near the coast strikes west-north-west. These facts appear to afford ample justification for Suess' view "The north-western coast therefore in no way represents the actual trend of the mountains".[120] Several smaller folds more or less inclined to the main axis are represented by Hutton but there is no certain knowledge in regard to them.

Periods of folding. Morgan gives reasons for thinking that a north-west—south-east series of folds was formed at an earlier period than the main north-east south-west system and that the main system was of early Cainozoic age.[121] Hutton however strongly maintained that the later Jurassic was the true period of folding and this opinion is founded on such good grounds that it cannot be refuted. The fact that everywhere the Cainozoic rocks are but slightly disturbed and rest on the denuded edges of the Maitai sediments is quite conclusive.

The folding force appears to have been directed from the north-east in Otago and from the south-east in Canterbury, Marlborough and Nelson. In Otago the rocks situated near the resistant plutonics of the foreland (Ruapuke, Stewart Island and Manapouri) are not metamorphic and in the east are almost horizontal. Possibly the plutonics are so close to the surface there and offered such effective resistance to the forces that caused folding that they protected the sediments that rest on them. North of Catlin's River they are strongly folded and north of the Taieri River they are quite metamorphic, and this condition extends right across Central Otago. That this metamorphism was due to dynamic action is certain, but how the pressure acted, is not known. The area is large and the rocks over a large portion of it rest horizontally, and are apparently far less disturbed stratigraphically than neighbouring rocks that are not metamorphic. Further north all metamorphic effect is confined to that portion of the formation that is nearest to the foreland. Morgan[122] regards the structure here as a huge overthrust, but thinks that the metamorphism is due to dynamic action though modified by thermal action near the granitic and ultra basic intrusions. Further north in Nelson the western part of the main axis is free from metamorphism though there are large granitic and ultra basic intrusions there.

Gregory has in different publications insisted upon the evidence of two periods of folding in New Zealand. The older of these is found in the south east bend of the axis in Otago and in the north of the North Island. Since in the former locality the rocks with Jurassic fossils are affected this distinction does not appear to be justified though it has been adopted by Park in the Geology of New Zealand.

The mountain axis of the North Island has not yet had its structure investigated. Hector[123] gave generalised sections in his map but these do not give definite information as to the actual structure nor as to the direction of the folding force, for nearly all the Trias-Jura rocks are represented as vertical. In the South Island the mountain axis of the north is continued in the Kaikoura mountains. McKay has worked at these in detail. He describes a series of immense reversed faults along which the Maitai (Trias-Jura) rocks have been thrust over Miocene sediments.[124]

There is no reason to suppose that the period of folding in the North Island was different from that in the South. The general absence of folds of Cainozoic rocks involved in the Trias-Jura structures is strong evidence that this folding and accompanying elevation preceded the deposition of Cainozoic rocks.

Faults. Apart from the overthrust described by Morgan in Westland and those of the Kaikoura mountains described by McKay no faults of great structural importance have been mentioned. Hutton indeed separated the Manapouri system from the rest of the country by a huge fault but this does not rest on actual observation. Bell and Morgan both mention the fact that very numerous faults exist in Westland but the date of their formation is not mentioned. Clarke represents a fault along the axis of Whangaroa Harbour in the North Island. In general the absence of well marked stratification and lithological changes renders it a difficult matter to distinguish the effects of faults especially in rocks that are so greatly shattered. Mention must again be made here of the faults in the Wairoa gorge, Nelson, described by McKay. They are represented as parallel to the strike of the folds and he thought that they brought into contact rocks of very different ages. The author does not think that they exist.

Hutton suggested that a fault of great importance traversed Cook Strait and having its downthrow to the north accounted for the absence of schists in the North Island. There is at present no independent evidence that such a structure exists.

Fauna and Flora. The Trias-Jura rocks contain rather a curious assemblage of animals and plants. The Baton River organisms had apparently quite disappeared. Comparatively few reptilian remains have been found. At Mt. Potts there are many bones that apparently represent *Ichthyosaurus,* and similar remains have been found at Wakefield near Nelson. No traces of terrestrial reptiles have yet been found.

Mollusca are well represented, but there was a very mixed assemblage when judged by European standards. Thus *Orthoceras* occurs from top to bottom of the series. Nautiloids and ammonites are not infrequent. In a single stratum in the Hokanui Hills *Orthoceras,* ~~*Nautilus*~~, ~~*Brancoceras*~~*?* and *Arcestes* have been found. *Belemnites* occur rarely in the lower rocks but abundantly in the upper.

The lamellibranchs show somewhat similar features. At Nelson *Trigonia* is found below beds in which *Monotis* and *Halobia* occur. At the Nugget Point *Trigonia* and *Halobia* occur in the same stratum. At Kawhia the *Monotis*-beds are not separated by an unconformity from the Jurassic rocks that contain *Inoceramus.* The gastropods are less represented and so far as known give little information of value.

The brachiopods are well represented. Spiriferids of great variety are found in several places. Hector classed many of them in new genera which however require full description. *Terebratula* and *Rhynchonella* are represented by several species. Of other groups worms are represented by the widely occurring *Torlessia mckayi* and by tracks of annelids. The comparative poverty of these rocks in fossils must be ascribed to the conditions under which they were formed. For the most part there were shifting sands and rough beaches conditions which would be unfavourable to the existence of animal life.

Ferns and conifers are well represented in the upper part of the formation in all parts of the country. Hochstetter first collected them near Waikato Heads and his specimens were afterwards described as *Asplenium palaeopteris* Ung. and *Polypodium hochstetteri* Ung. The latter now generally regarded as an *Alethopteris* is a common type in New Zealand. *Taeniopteris* is abundant in the south as well as *Sphenopteris. Macrotaeniopteris* and *Camptopteris* occur, but the species have not yet been identified or described. *Baiera* is found at Mt. Potts and silicified coniferous wood is quite abundant in many places and its frequent association with the foliage of *Podocarpus* suggests that it belongs to species of that genus. These rocks contain the first record of plant life in New Zealand and from what has been said it is evident that vegetation was then luxuriant and varied. In the coast lands at least there were sturdy and dense coniferous forests while the ground was carpeted with many ferns and some *Cycadofilices(?)* with which grew a varied assortment of cycads.

Climatic changes.—The nature of the flora gives in the majority of instances a more accurate idea of the climatic conditions of the past than the fauna. It is however questionable how far we are justified in assuming that plants of the past required similar climatic conditions to those necessary for their congeners of the present day. If we can assume that cycads have always required the same climate as members of that group do now, it is at once evident that the climate of New Zealand in the Trias-Jura must have been warmer than now for cycads do not grow in the open air in New Zealand at the present time. Other members of the flora indicate little difference between the climatic conditions of the Maitai and that of the present day. The very distinct annual rings in the silicified wood show that the seasonal changes were as sharp and complete then as now.

Oamaru Period.

As explained elsewhere the Cretaceous of Hector, Hutton and Park is here regarded as the lower part of a great Cainozoic formation the lower part of which contains fossil remains indicative of the continuance of Mesozoic forms of life while the upper part is distinctly Upper Miocene so far as European equivalents are concerned.

The critical period of New Zealand geology, during which the great thickness of Mesozoic sediments was elevated and folded, was in all probability also a period during which the confines of the land were immensely extended. On this elevated land surface all the destructive agents of geology had free play; the result was that a land surface was developed on which mountains, stream valleys and marine platforms were well represented. The material derived from the land waste was carried to the shore and now rests beneath the surface of the ocean far beyond the present limits of the land. We have therefore no record of the actual position of the margin of the land though we have some reason to believe that it extended beyond the present position of the 500 fathom line. Even this elevation would extend the land south to the Campbell Island, east to the Chathams and north-west nearly as far as New Caledonia.

This great elevation was succeeded by nearly as great a depression. The majestic mountain ranges were gradually lowered until nothing but a chain of islands showed above sea level. To what a great extent this movement prevailed is seen at Lake Te Anau, where the Oamaru formation some 3000 feet thick rises to the tops of the mountains. At Wakatipu and in the Rangitata valley the Oamaru rocks are found in the recesses of the mountains. In the Trelissick basin and between the masses of the Kaikoura ranges there was deep water. The valleys of the tributaries of the Buller are filled with the Oamaru sediments; while on the Gawler Downs patches of these rocks with marine fossils tell us that these too were submerged beneath the surface of the ocean.

In the North Island the sea floor of this period is now in places 4000 feet above sea level. In the extreme North rocks of this age still separate the stumps of the old land as completely as the sea did when its level was 1000 feet higher.

Character and condition of sedimentation. The information as to this is somewhat definite and precise. Almost everywhere the base of the series consists of conglomerates and beds of carbonaceous shale which in places become important seams of coal. Obviously these coals are not strictly contemporaneous, for as the depression gradually proceeded the sea margin crept further and further inland; new areas became swamped out and new beds of coal were formed. Above the shale or coal there are more conglomerates, then sands and finally glauconite sands, which are often very concretionary. Limestones, chalky, foraminiferal or polyzoan succeed these. Above these there are extensive beds of marl in which concretions often of large size are found. The series is generally closed with layers of beach sands. (Fig. 10).

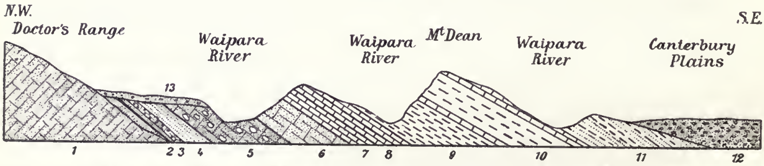

Fig. 10. Oamaru Series, Waipara, N. Canterbury, from NW. to SE., distance 3 miles.
1 Greywackes and shales (Trias-Jura). 2 Coal grits and coals. 3 Gravel with Trigonia, Ostraea etc. 4 Quarz sands. 5 Concretionary greensands with reptilian remains. 6 Greensands. 7 Amuri limestone. 8 Weka Pass limestone. 9 Grey marls. 10 Mt. Brown beds with pebbly limestone. 11 Pareora beds. 12 Pleistocene gravels. 13 Terrace gravels (Pleistocene).

This definite sequence is found with its members developed in greater or less degree throughout the country. Where coastal action was great and severe, or where rivers entered the Oamaru sea, the conglomerates attain great thickness as at the west coast and at Cape Farewell. In many places no limestone was deposited while in others it is most characteristic. Sometimes the grey marls are absent and in others they are 2000 feet (610 m) thick. The extent to which submergence proceeded may be roughly guaged by comparing these rocks with deposits now being laid down on the ocean floor around New Zealand.

Glauconite is a characteristic mineral of the middle strata and it is noteworthy that this material is formed "along high and bold coasts where no rivers enter the sea and where accumulation is less rapid, glauconite appears in its most typical form and in its greatest abundance"[125]. Again: Glauconite occurs below the lower limits of wave, current and tidal action; in the neighbourhood of the mud line, that is at depths of 200—300 fathoms, typical glauconite is most abundant, though it is found to a depth of 2000 fathoms. None is found in littoral or sublittoral zones. It is also asserted that glauconite is only formed off continental shores and never beyond the limit of terrigenous material. Its general ocurrence in the middle members of the series therefore tells us that much of the present land was during this period 1200 to 1800 feet below the sea level; that the coast line was bold and the rivers small, though the land remained of considerable extent. This is exactly the nature of a land surface developed as described in these pages and depressed after long continued erosion.

Limestone succeeds the greensand and indicates deeper submergence and probably the climax of the movement, for it is succeeded by grey marls or papa with occasional shell beds which is evidently equivalent to the blue mud now being deposited everywhere off the New Zealand coasts within the limits to which fine sediment is abundantly carried.

The occurence of greensands and limestones all round New Zealand shows that the land was much circumscribed in all directions.

Episodes of volcanic disturbance. During the deposition of these rocks volcanic action was at first quiescent but locally became of great importance before its close. In many parts of the country both north and south there was much volcanic activity towards the close of the period when the great elevation by which it was closed had commenced. At Oamaru volcanic breccias are interstratified with the limestones, and submarine flows of basalt rest on them. Although most typical at Oamaru similar volcanic action took place at many localities between the mouth of the Kakanui River and the Trelissick basin. In the Clarence valley there is a similar association. At Auckland the higher members of the system—the Waitemata beds—have andesitic breccias interstratified with them. Pumice beds of this age are found at Table Cape and in many parts of Poverty Bay.

It was however after these rocks had been raised above the sea level that volcanic outbursts became most pronounced. In the South Island there was an active centre at Dunedin, where an extensive series of basic and alkaline rocks rests on the denuded surface of calcareous sandstones that are probably the local reprensentatives of the Oamaru limestone. The outflow of the andesitic and basaltic rocks of Bank's Peninsula was probably commenced at this time. In the Coromandel Peninsula there were tremendous eruptions of andesitic rock of great variety, and there were somewhat similar emissions on a smaller scale at Waitakerei, Whangarei, Whangaroa and many other places to the north of Auckland.

Orogeny. The movements of elevation and depression that succeeded this period or took place during its continuance were apparently of an epeirogenic nature, for the rocks are not folded or contorted in the same sense as the older series. In many places they are horizontal even when raised to an elevation of 3000 feet (914 m). More usually they occur in broad synclines or anticlines as at Te Anau, North Canterbury and Amuri. Occasionally they are sharply folded and contorted, especially when in the recesses of the mountain ranges, as in the Trelissick basin and sometimes away from the ranges and near the coast, as in the Puketoi Hills. The very recent nature of the upper rocks of this system appears to be sufficient proof that the elevation did not take place until the Cainozoic era was well advanced.

It is noticeable that the rocks of this system are found at a greater elevation inland, than they are near the coast. This of course may indicate a differential elevation, though another explanation might be offered. This would be based upon the probability that the sea floor sloped away from the land and that though elevation has been equal everywhere the floor of the shallower water has naturally been raised to a greater height than that of the deeper sea. That the former suggestion is the more satisfactory is seen when attention is drawn to the fact that almost everywhere the beds dip seawards, and that the present marginal rocks do not appear to have been deposited in water much deeper than those that occur further inland.

How far the elevation proceeded is of course not known, but it was probably considerably greater than now. The deep inlets in the north of the land and in many places along the coast, the deep valley of the Wanganui (600 feet below the sea level), the old soils 600 feet below the present surface of the Canterbury Plains, and the far reaching inlets of the Queen Charlotte Sounds all prove that the land has been much more elevated within times that are geologically not far distant.

Characters of the fauna and flora. Fossil remains of both plants and animals occur in some abundance in the rocks of the Oamaru system and they show that great biological changes were in progress. Even in the lowest rocks dicotyledons are more abundantly represented than other plants and they show considerable variety. They have been studied by von Ettingshausen who recognised two different floras which he regarded as of Cretaceous and Cainozoic ages respectively. Both of them however consist mainly of remains of dicotyledonous plants. Amongst the localities in which the former occurs are two localities classed by Hector and Hutton as Cretaceo-Tertiary and Oligocene respectively. No stratigraphical work has yet shown that the rocks distinguished by von Ettingshausen as Cretaceous are unconformable to others which he distinguished as Tertiary. It is agreed that in the Nelson Province there is a complete conformity between the various members of the younger series of rocks that rest on the granites and on the Aorere system. It must not however be supposed that all the younger rocks are of the same age. The gradual depression of the land would reduce successively higher portions to the condition of littoral marshes and the plant beds formed at the climax of the period of depression would differ materially in age from those that would be formed at its commencement. The flora is sufficiently remarkable when compared with the present New Zealand plants. Remains of *Quercus* and deciduous species of *Fagus* are numerous, but remains of plants similar to those at present growing in New Zealand are relatively rare. von Ettingshausen regards the flora as composed of a principal element, and of co-elements from the former of which the present flora of New Zealand has been developed.

Difficulties similar to those encountered when considering the flora of this period are met with when the animal kingdom is passed in review. In certain localities notably at the Amuri Bluff the lowest beds of the series contain the remains of such genera as *Belemnites, Trigonia, Inoceramus* as well as a few Cainozoic forms. With them are found bones of *Plesiosaurus, Mauisaurus, Leiodon* and other saurians.[126] The rocks that contain these remains have however been shown by Haast, McKay and others to be perfectly conformable to the Cainozoic rocks that rest on them at Amuri Bluff, Gore Bay and the Waipara and with these observations the author absolutely agrees. For these reasons the strata that contain the upper Mesozoic forms and those that contain Cainozoic fauna are here classified together and the great change in faunal and floral characters is believed to be a result of the depression that followed the great Mesozoic elevation which had erected a barrier to the migration of marine species. When the early Cainozoic depression commenced this barrier was pierced and a new fauna speedily replaced the old Mesozoic forms. The reptiles apparently soon became extinct and their place was taken by Zeuglodont whales, *Squalodon* and *Kekenodon*. *Palaeeudyptes,* a large penguin, is the earliest bird; it is found in the upper series. Sharks became excessively numerous for their teeth are abundant in the greensands and limestones. The Mesozoic forms in the mollusca too soon disappeared; the belemnites became extinct and the Trigonias and other genera of Mesozoic age were succeeded by others that are distinctly Cainozoic.

Echinoderms soon become abundant and Polyzoans and corals build up large masses of rock. The surface waters were soon filled with *Radiolaria* and *Foraminifera,* while siliceous sponges were numerous on the floor of the sea. Finally, when the upward movement ceased, the flora and fauna had been so changed that there are no great differences between its appearance and that of the New Zealand plants and animals of the present day.

Climatic changes. Specimens of fossil wood show that seasonal changes were well marked. The fact that apparently throughout this period *Dammara* or a closely allied genus grew in most parts of the country suggests a milder climate than now for at the present day it is restricted to that part of the land that lies to the north of the 39th parallel of latitude. The palm nut that occurs at Mangonui indicates the same thing. On the other hand deciduous trees such as *Fagus* were an important element of the fauna even in the Waikato as well as the southern parts of the land.

Our present knowledge does not allow us to make any statements in regard to the climate based on the occurrence of belemnites and saurians. However the large size of many of the species of *Mollusca* in the limestone strata strongly suggest that the limestones accumulated in relatively warm waters. *Cardium spatiosum* Hutt., *Ostrea wullerstorfi* Zitt., *Cucullaea ponderosa* Hutt., *Turritella gigantea* Hutt. and *Crassatella ampla* Zitt. were all of large dimensions. On the other hand the littoral formations that occupy the highest levels contain an assemblage of shells of dimensions no larger than those that may now be found on a New Zealand beach.

Wanganui Period.

In the typical locality there appears to be complete conformity between the rocks of this system and those on which they rest. It is probable therefore that they were deposited in the same sea round the margin of the land that had been slowly rising since the deposition of the greensands and limestones that mark the climax of the depression. In this case the Wanganui system must be regarded as merely the upper series of the Oamaru system. The geographical configuration of the land does not appear to have been very different from its present form; though it is certain that there was a beach connection between Cape Farewell and Wanganui, for the sands of this age found in the latter place, are identical with those of which the long Farewell Spit consists, which are derived from the destruction of the mass of granite between the Karamea and Kahurangi Point. There appear to have been relatively large inland lake basins in Otago at this time and they are now filled with deposits that may be of the Wanganui age. To what extent the large gravel formations of the South Island are of this age is at least doubtful. They were evidently deposited after a period of prolonged elevation for they often fill basins and valleys that penetrate far into the mountains. This period appears to have been the last stage of the depression that lasted right through the Cainozoic era.

Conditions of sedimentation. Those deposits that are certainly of Wanganui age are mainly of littoral origin. The lower part of the formation at Wanganui is a blue clay not distinguishable lithologically from the similar clays on which it rests. On these rest beach sands or gravel with here and there a small band of carbonaceous shale or lignite. Pebbly limestone composed largely of shells occur in many places and at Napier. McKay contends that the limestone at Scinde Island should be referred to this age. There are however no formations that indicate deposition in deep water.

Fig. 11. Map showing areas of igneous rocks, South Island.

Volcanic action. Eruptions of pumice still continued in the central part of the North Island for pumice has been found in the deposits at Wanganui and at Napier. Hill [127] describes pumiceous sands as important in the structure of Scinde Island, There is however no direct evidence that Ruapehu and his neighbours were yet in eruption, though this is certainly probable. It has often been stated that eruptions took

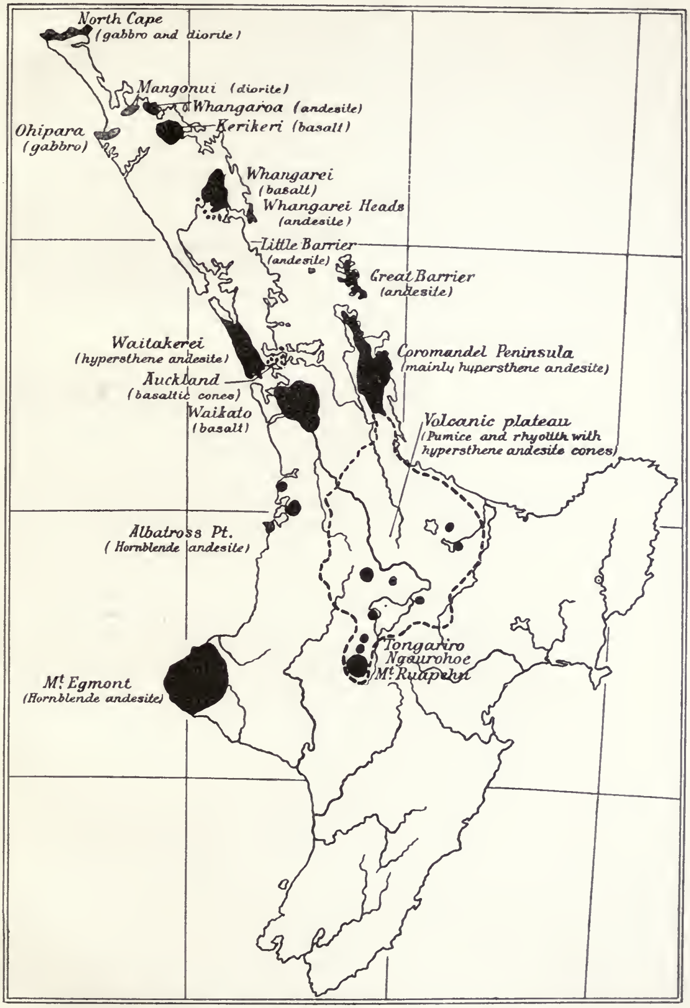

Fig. 12. Map showing areas of igneous rocks, North Island.

place in the Ohinemuri district for the rhyolites of Waihi are classed here. In the Waikato the heavy flows of basanite probably belong here, but they are restricted to the north-west of the Trias-Jura ridge that extends from Pirongia to Waiheke Island.

Further north the andesitic eruptions ceased and were succeeded by the extensive flows of basalt in the Kerikeri district and in other more northern localities. In the same district there are a few outcrops of more acidic rocks, but their age relative to the basalts is not known.[128]

The eruptions of Mt. Egmont probably continued during this period. The lavas of which this cone is formed consist of hornblende andesite, very different from the hypersthene andesite of which Ruapehu and its neighbours are formed. The ejection of these materials at nearly the same time and also the basanites of the Waikato basin seems to prohibit the idea that they were derived from the same magmatic reservoir for there cannot have been sufficient time for differentiation. Their distribution does not suggest that they were related to any single earth movement. Taken alone the lineal arrangement of Ruapehu and the other central volcanoes is strikingly parallel to the folds of the Kaimanawas or to the "grain" of the country, and the rocks of which they are formed are similar in composition. Rocks very similar to those of Mt. Egmont are found near Albatross Point and this may indicate another volcanic line nearly parallel to that of the Ruapehu line. On the other hand the basic rocks of the lower Waikato and Kerikeri are not in any way related to one another nor to the other lines in the composition of the rocks, and the structure of the country also is quite different.[129]

Orogeny. There appears to be no evidence of rock folding during the Wanganui period though it is certain that elevation was in progress. Locally the rocks may be faulted as at the Languard Bluff at Wanganui. It has lately been suggested that the mountains of Central Otago are block mountains formed by movements of faulting that took place towards the end of the period. This matter however requires fuller investigation. The statement was made by Park that the basins were graben formed by infall. In the Geology of New Zealand however he states that the mountains have been thrust vertically up. Hutton regarded the basins between the mountains as due to glacial erosion.

Characters of fauna and flora. There is practically no indication of the nature of the flora except in the lignites of the lake basins of Otago (St. Bathans). These have not yet been fully examined, but it appears that the fruits of Hakea are quite numerous and these are also found in lignites at Gore. This genus is not now comprised in the New Zealand flora though an Australian species grows freely to the perjudice of the native plants in the west of Nelson and in the north of Auckland.

The *Mollusca* are almost identical with those now found on the coast. Hector mentions four extinct species—*Struthiolaria frazeri, Pleurotoma tuberculata, Pileopsis uncinatus* and *Lutraria solida.*

The remains of vertebrates are of small number. Bones of a moa from below the dolerite at Timaru may be of Miocene age though more probably Pliocene. Moa footprints have been found in Wanganui rocks near Napier and in other rocks near Gisborne; but there is no evidence that the moa was abundant at this time.

Climate. Hutton always maintained that the glacial extension took place in the early part of the Wanganui period in New Zealand. His opinion was based rather on circumstantial evidence than on direct observation of the stratigraphical position of the glacial deposits. There is at any rate no evidence that any important organic migration was caused by a climatic change during this period; but this is not a matter of great importance because the amount of glaciation to which New Zealand was subjected does not imply a great refrigeration of the climate. The evidence that we possess in regard to the climate of the period is that it was little different from that of the present day but on the whole slightly warmer.

Pleistocene Period.

Geographic changes. The elevation of the late Cainozoic was continued into the Quaternary era. The period of erosion was prolonged and the country judging from the drowned valleys at Dunedin and elsewhere was deeply dissected. Stewart Island, Marlborough, Kawhia and North Auckland stood for some time at an elevation 1500 feet (450 m) higher than now. It is probable that at this time New Zealand was united with the outlying islands and extended over the whole of the New Zealand plateau. After this prolonged elevation depression took place and the glaciers that had extended far, retreated, and the rivers proceeded to fill up the valleys that the glaciers had eroded, with gravels, but the smaller valleys at the coast were simply drowned and changed into inlets of the sea. The depression lowered the land below its present level and about the end of the period the submergence was considerable in many places. Beach gravels of this period are found at many localities on the coast; at Taranaki 130 feet (40 m), Cape Palliser 200 feet (610 m), west coast South Island 220—400 feet (120 m), Amuri Bluff 500 feet (150 m). Other terraces that appear to be of marine origin near Preservation Inlet extent to 1500 feet (450 m) above sea level.

The great depression has been followed by continuous elevation which locally at least is still in progress. This elevation has had great effect upon the surface. To it must be ascribed all the river terraces which are so prominent in many parts of the country particularly on the western border of the Canterbury Plains. Speight however ascribes the formation of these terraces to a diminution in the supply of waste to the rivers.[130]

The elevation has not been uniform. The narrow gorges of all the rivers of the eastern side where they enter the low country implies that the elevation was more pronounced inland than near the coast, and this greater elevation perhaps was due to movement along thrust planes such as those described by McKay in the Kaikoura district. Direct evidence of such a movement is to be found in the Waipara gorge.

The gravel deposits laid down in the middle Pleistocene have in places been enormously eroded. In Nelson their remnants form the Moutere Hills 1000 feet (305 m) high. At Wanganui they cap hills 500 feet (152 m) high. In the Rangitikei valley they are 200 feet above the present river level. In Otago similar gravels are 100 feet above the present bed of the Waianakarua river. Near Gore gravels are 200 feet above the Mataura.

Conditions of sedimentation. When the depression reached its maximum in the Pleistocene, relatively deep water formations must have been deposited over quite a large portion of the present land surface. The depression apparently was so short lived that the thin deposits formed were removed as the land rose. Hutton however maintained that the loess of Otago and Canterbury was a marine deposit laid down at this time. When the land was most elevated the glacial extension was considerable and moraines were laid down in many valleys as much as fifty or sixty miles away from the present terminal faces or ice covered slopes. Generally the moraines are found in valleys, but on the west coast of the South Island they now form large bluffs on the coast line, sometimes as much as ten miles away from the mountain ranges. Evidently here there were piedmont glaciers. Near the mouth of the Taieri river on the eastern side there is a large moraine five miles away from the mountains. Here however important earth movements have taken place and the exceptional position of the moraine can be ascribed to this.

Volcanic action. It is probable that the eruptions of Egmont and Ruapehu continued throughout the Pleistocene. That immense emissions of lava had taken place before the Pleistocene is certain for at Wanganui the Pleistocene gravels contain a large number of fragments of andesitic rocks, and since the Pliocene gravels of the

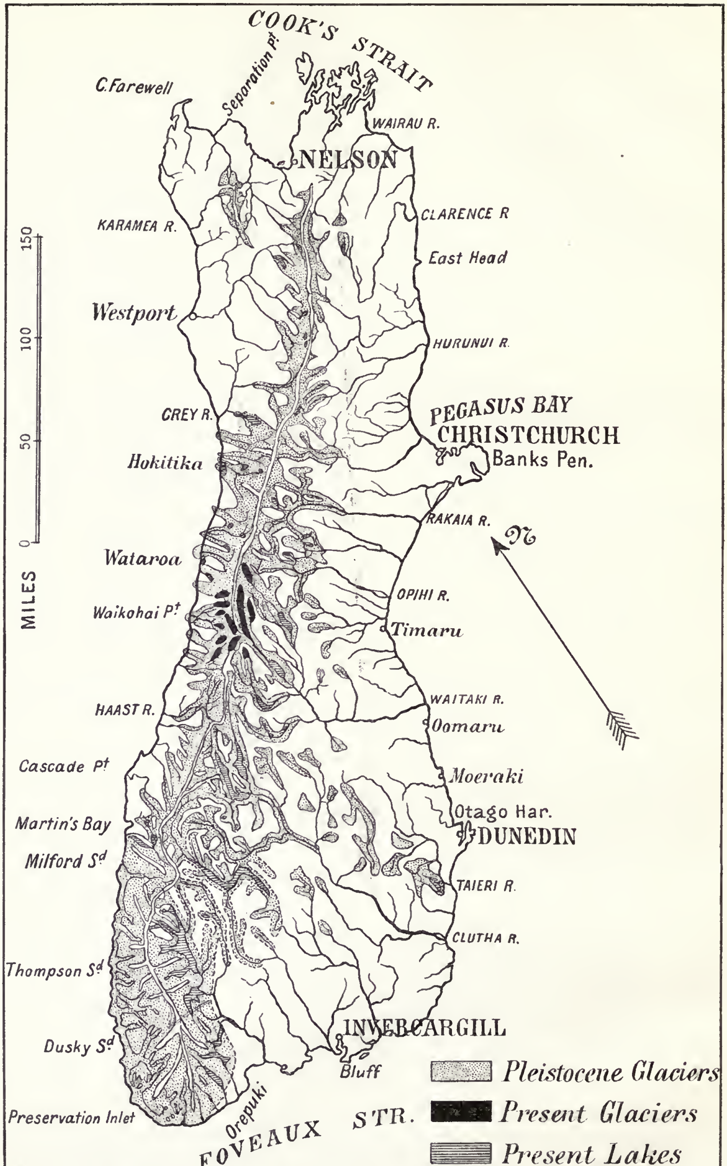

Fig. 13. Map of South Island of New Zealand, showing extent of pleistocene glaciation.

same place contain no andesitic matter it is evident that a new phase of volcanic action had commenced in the central region. There is no definite information as to Pleistocene volcanic action near Auckland or to the north of that town.

Orogeny. Nearly all the Pleistocene rocks rest horizontally, but the great elevation at the beginning of the period was associated with differential movements of the older rocks, for the Oamaru strata are usually somewhat folded where they abut against the older series. The Taieri moraine is inclined landwards at an angle of about 18 degrees. This is certainly due to differential land movements since its deposition and this perhaps explains its singular position at the sea level on the eastern coast though all the other glaciers on the eastern slope ended far from the present coast.

Characters of flora and fauna. There are practically no plant remains other than wood in the gravel deposits. It is probable that at this time the flora and fauna of New Zealand acquired many of their present features. The great Pleistocene elevation connected New Zealand with some of the northern tropical islands, and birds, land-molluscs and insects trooped down in some numbers, while *Quercus* and other genera disappeared from the flora. On the other hand this elevation did at the least produce a shallow water connection with Antarctica and many plants such as *Sophora, Acoena,* and *Fuchsia* reached New Zealand. Many marine birds and shells reached us at the same time.

Hutton's argument in regard to the Pliocene age of glaciation was largely based on the amount of faunal change that has taken place since the glaciation which he rightly regarded as contemporaneous with the last period of elevation. This must have united together all the outlying islands and the plants and animals would become the same throughout. The changes that have taken place since that time as cited by him are as follows.

a) Six different kinds of birds are represented by distinct species in the two islands.

b) One third of the land birds of the Chatham Islands and 15 per cent of the plants are endemic.[131]

In addition stress has often been laid on the presence of a flightless duck in the Auckland Islands and the feebly flying parrakeet and snipe and fern bird in some of the outlying islands. The flora of these islands has lately been closely investigated by Cockayne who finds that about ten per cent of the species are endemic and forty per cent have New Zealand affinities.[132]

Such facts as these do not, in the present state of our knowledge, justify the assertion that the islands have been separated since the older Pliocene. The rate of variation of plants and animals is largely unknown, and these outlying parts of the larger elevated Pleistocene land may have possessed a flora and fauna different in important respects from that of the more northerly and easterly portions.

Climatic changes. The most notable evidence of climatic variation in the Pleistocene is to be found in the greater extension of the glaciers. Hutton as stated before referred this extension to the early Pliocene and while it is not easy to controvert his arguments geologists are generally agreed that the extension took place in the Pleistocene.

The amount of glacial advance was considerable (Fig. 13). In the Te Anau and Wakatipu basins where now no glaciers exist there were then streams of ice 70 miles long. The western fiords which radiate from mountains where now there are but few patches of permanent snow were filled with huge ice masses. The glaciers of the Tasman valley were greatly extended. The whole of that portion of the Rakaia, Waimakariri and Rangitata valleys that lie within the mountain valleys were the beds of glaciers. In the Nelson province ice eroded and filled the basins of Rotoiti and Rotoroa lakes and at an altitude of 4000 feet reached as far north as Tasman Bay. In the North Island there is no evidence of glaciation. Park (Trans. N. Z. Inst. 42 and Geology of New Zealand) has described boulder beds near the high volcanoes in the North Island as glacial deposits. This view has been opposed by Marshall who thinks that:

1. There are no signs of glacial erosion. 2. The deposits occur in river valleys. 3. There are no signs of terminal moraines. The elevated position of the gravels is due to the rapid corrosion of rivers as the country was elevated a total amount of 3000 feet since the Pliocene.

The early Pleistocene was a period of great elevation and it is at once suggested that this too was the period of ice advance. On the one hand it is probable that elevation alone was not the full and sufficient cause to account for the amount of glaciation that took place. On the other the present flora and fauna of the country is evidence, that there was no great refrigeration for it is probable that New Zealand has been isolated ever since that time and cannot have received migrations of any kind since then.

The general conclusion is that though the country was more elevated the temperature at the sea level was also lower than now.[133]

Hutton frequently stated that a reduction of temperature could not have been the cause of the glaciation. In support of this he quoted the distribution of plants and animals in New Zealand and maintained as is probable that their distribution indicates a reduction of temperature as the latest change. It appears that if the early Pleistocene was the period of glaciation and elevation that there would be time for an increase of temperature between the period of glaciation and the present day. If the glaciation was due to elevation it would not have affected the distribution of the life forms to any important extent.

The distribution of the loess certainly indicates that the eastern coastal portions of the land were subjected to a drier climate during the later Pleistocene. This is borne out by a consideration of the development of the foliage of the plants that grow there, for the habit of the plants is distinctly xerophytic. Such a difference in climate might be a simple result of the greater elevation of the land.

Recent period.

Geographic changes. The great depression of the Pleistocene was succeeded by elevation and this has been maintained in the recent period. Everywhere on the coast line are to be seen raised beaches. How many of them should be classed as Pleistocene and how many as Recent is at least doubtful; but some are certainly of recent age. The elevation accounts for the extreme shallowness of many of the inlets on the coast line such as those of Otago Peninsula. The most notable effect of the elevation inland is the formation of river terraces. Generally these consist of gravels but near Nelson they are rock terraces in the valleys of the Wairoa, Roding and Maitai streams. Their extent shows that there was a long cessation of the upward movement while the streams eroded laterally to considerable distances. The last upward movement has been so recent that these streams have not yet reached the new base level of erosion.

The coast line has within recent times been much modified by the formation of sand dunes and gravel bars that have been piled up against projecting headlands and have formed long bars across bays.

Volcanic action. Ngauruhoe is probably a volcano of the Recent period. Ruapehu and Tongariro have maintained their activity intermittently throughout, and still show indications of renewed activity in the future. It is probable that the many small cones near Auckland and at the Bay of Islands have been entirely formed since the Pleistocene; a statement that is based upon the very recent appearance of the lava of Rangitoto and of some of the other cones. The eruption of Tarawera that took place in 1886, when half a cubic mile of volcanic material was scattered over an area of 2500 sq. miles, suggests that many of the andesitic cones of the North Island have been built up in the recent period and that some at least of the lake basins have been formed by volcanic explosions within that time, for in 1886 the basin occupied by Lake Rotomahana was enlarged to three times its previous dimensions by explosive action and since then has become filled with water. The activity of hot springs and geysers has been constantly maintained notably at Rotorua, Wairakei, Taupo, Orakei and many other localities and the crater of White Island has continued its solfataric action.

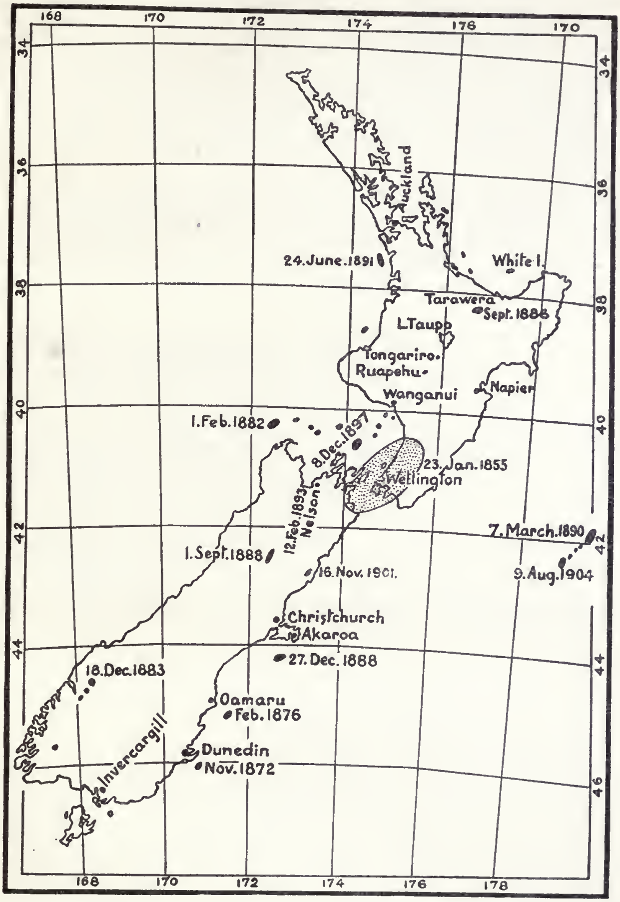

Fig. 14. Earthquake origins in New Zealand. (After HOGBEN in MARSHALLS Geography of New Zealand.)

Orogeny. Earthquakes. The frequency of earthquakes shows that rock movements are still in progress but there is little knowledge as to their amount and nature. Since the arrival of colonists an important movement has taken place on the shore of Cook Strait. In 1848 an earthquake was associated with the formation of a fissure running southward from White Bluff in Cloudy Bay.[135] In 1855 there was a still more important movement. At the time of a violent earthquake the shore of Wellington

Harbour rose 5 feet. The rise was 9 feet in Palliser Bay and it diminished to nothing on the West Coast. On the south side of Cook Strait there was a depression of five feet in the Wairau valley. This is stated by Suess to be the one authentic record of an actual elevation of the land. Other earthquakes of considerable intensity in Marlborough have been investigated by Mc Kay [136] who has traced the earth rents on the surface for a considerable distance generally in a north-north-east direction. He describes these rents as the lines of faults and thinks that they afford evidence that the movements along the huge faults of the Kaikoura mountains described by him have not yet ceased. [137] The very recent character of raised beaches and rock terraces at Amuri Bluff, Oamaru and many other localitities at least suggest that elevation is still in progress though there is no positive information on this matter at the present time.

Fauna and flora. There is no reason to suppose that the plants have undergone much change since the beginning of the recent period. The fact that round the hot springs species of ferns such as *Gleichenia* are found that are unknown in other parts of the land may indicate that other plants requiring the same high temperature but unable to withstand the strong sulphurous gases of that region have disappeared.

The animal life on the other hand has undergone most important changes. Remains of the moa are quite abundant in the sand dunes of the coast and they are still more numerous in certain peat swamps. It is therefore well known that a great variety of these struthious birds roamed over the land. As many as 26 species belonging to seven genera have been recognised. The structure of the bird shows that its habitat was the open grassy land, and this was in all probability far more extensive during the Pleistocene elevation, for the high ranges of the western mountains would deprive the prevailing wind from the west of so much of its moisture that the rainfall over the eastern flat land would have been insufficient to support forest growth, and would have imparted to the land a steppe or desert like appearance. This view is supported by a consideration of the nature of many of the plants that grow on the eastern slopes. The leafless condition of *Discaria, Carmichaelia* and *Muhlenbechia* and the hard thorny leaves of *Aciphylla* adapt these plants for growth in a climate far more dessicated than that of New Zealand at the present day.

The species of moa were not all the same in the two islands. Seventeen have been recorded from the South Island and twelve from the North, and remains have been found in Stewart Island and in the Chathams. The earliest known remains are those that were found under the dolerite at Timaru, though but little is known of the development and specialisation of the moas during the Pleistocene.

The great source of material in regard to the moa is the peaty swamps on the western border of the Canterbury Plains. Here veritable mortuaries have been found. From one of these Hutton obtained seven tons of bones which represented 400 birds. In a similar deposit at Glenmark Haast found the remains of 1000 birds. Hutton refers these swamp deposits to the Pleistocene, but there is some doubt as to whether this is the right period; for the basins in which the swamps are situated are excavated in loess which is here regarded as deposited in the early Pleistocene.

About the cause of the aggregation of the moa bones in swamps see p. 32.

No satisfactory explanation of these occurrences has yet been offered. The apparently rapid development and variation of the moa has been explained by Hutton in the following way. The great Cainozoic depression would have reduced New Zealand to the condition of an archipelago. Isolation on different islands would have allowed of divergent modifications which if the isolation were sufficiently prolonged might result in the establishment of different species. The reelevation of the land he supposed allowed of the mingling of the species. Hutton supported his views by an analogy of the South Pacific islands on which four or five different species of cassowary are now to be found.

Within the recent period the *Sphenodon* and *Notornis* were common on the mainland. Within the period of colonisation the quail, stitch bird and huia and some other birds have become practically extinct.

The affinities of the flora and fauna of New Zealand have been widely used by different authorities as a basis of their views in regard to the past arrangement of land and ocean areas in the western Pacific. Wallace[137a] held that there was no evidence of previous land connections. Forbes[137b] in 1893 included New Zealand in an immense Antarctic Continent. This had been previously advocated by Hutton and others though they described a continent of much smaller dimensions. In 1884 Hutton[137c] advocated a connection between New Zealand and South America by a mid Pacific continent. This in 1904[137d] he reduces to a chain of coral islands. Hedley[137e] in 1899 states that there is no evidence whatever of an American migration can be traced in the Central Pacific. He connects New Zealand with New Caledonia and other northern groups of islands and with the north of Australia. Benham[137f] states that the earthworm fauna of New Zealand appears to date from the early Cretaceous period.

As stated at some length in an earlier portion of this work it is the author's opinion that no great elevation of the land except in the early Pleistocene has taken place since the land had continental dimensions during the critical period in the late Mesozoic. Hutton in accordance with his views of the stratigraphy of the younger rock series of New Zealand believed that there were three periods of elevation:— Eocene, Early Miocene and Early Pliocene.

Climate. The only evidence of variation of climate within the recent period is to be found in the present distribution of plants and perhaps of some animals. Thus Hutton mentions that *Lotorium spengleri* Lam., *Astralium subeolum* Mart. and *Scalaria zelebori* Frfld. now occur in Foveaux' Strait though really characteristic of much more northern habitats. Similarly *Rhopalostylis sapida* Wendl and Drude occurs at Banks' Peninsula, *Lomaria frazeri* A. Cunn. near Westport and *Cyathea medullaris* Swartz at Milford Sound. Also there is a parrakeet at the Antipodes Island and tree ferns at the Auckland Islands. Lingering examples of tropical ferns *Gleichenia dichotoma* Swz., *Nephrodium molle* Desv. and a few others are found near the hot springs. From these examples it appears that the climate within recent times has become somewhat cooler.

IV. Orographic Elements.

The following features will be considered under separate headings in this chapter:—

A. Main Islands of New Zealand.

1. The gneiss range of the south-west.
2. The Southern Alps with the south-east bend in Otago.
3. Northerly continuation of the Southern Alps.
4. The Tasman Mts. in the north-west of Nelson.
5. The Kaikoura Mts.
6. The North Island range.
7. Isolated mountain groups to the north and west.
8. The hills of the Cainozoic country.
9. The volcanoes.
10. The volcanic plateau.
11. The gravel plains.

B. Outlying Islands of New Zealand.

A. Main Islands of New Zealand.

I. The gneiss range of the south-west.

Formations present. The rocks in this area are almost entirely the plutonic gneissic members of the Manapouri system. Here and there Cainozoic rocks rest in synclines as at the upper end of Lake Te Anau. In the extreme south there are Ordovician shales and sandstones. It is believed that the gneisses are of Archaean age, but Park classes them with the Otago schists in the Cambrian (N. Z. Geology p. 27).

Structure. So far, as is known, these rocks strike to the north-west and dip steeply and somewhat uniformly to the south-west. This statement however is based upon the position of foliation planes. The period of elevation is not known. No junction has yet been described between the gneisses and the folded rocks to the

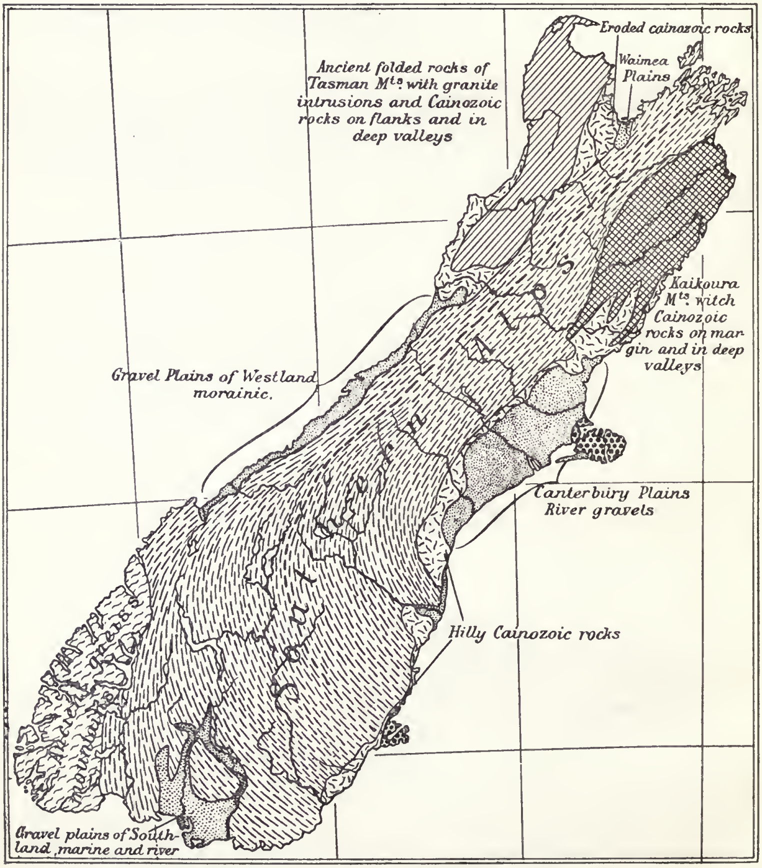

Fig. 15. Map showing topographical divisions of South Island of New Zealand.

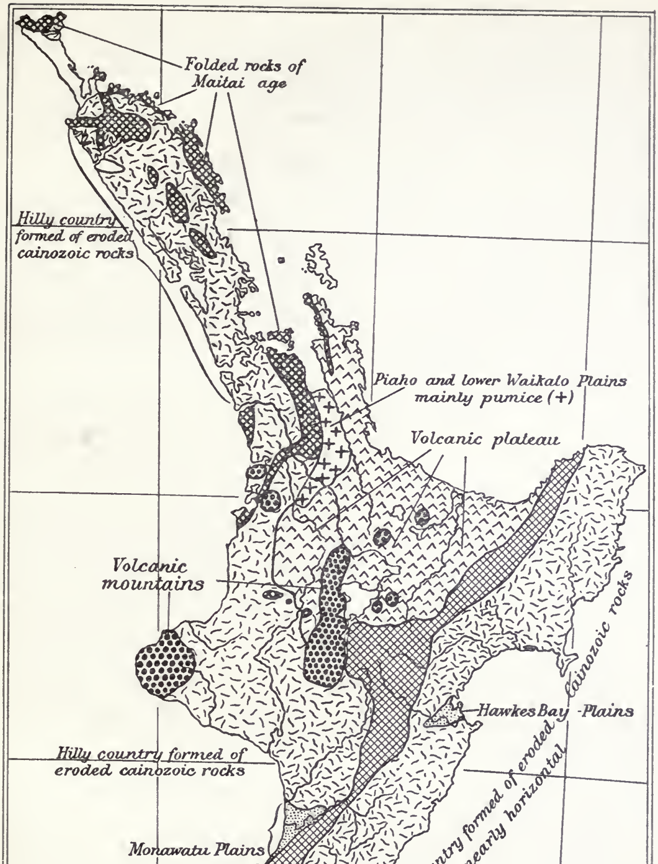

Fig. 16. Map showing topographical divisions of North Island of New Zealand.

east of them. Hutton thought that they were separated from these by a fault. It is believed that their elevation preceded the great Mesozoic depression; but important movements of elevation and depression have affected them since their first elevation.

Physiographic features. These are most marked. The mountains are scoured with deep U-shaped valleys, and their flanks rise with remarkable steepness in their lower portions. The valley floors are flat or rise in steps. Hanging valleys are frequent. There is no doubt that the district owes its final sculpturing to ice. The relatively sloping form of the mountains above 4000 feet (1200 m) and the truncated spurs have been supposed to prove the existence of valleys before the glaciation. [138] While it is probable that such valleys existed, it is not improbable that these slopes were formed above the surface of the main ice stream. E. Suess regards this as an older range that requires further investigation. [139] Gregory's old range may consist of these rocks. [140]

2. The Southern Alps.

These mountains form the dominant feature of the physiography of New Zealand. They consist of a series of greywackes and shales from the western borders of the plains to the main divide about twenty five miles from the west coast. A metamorphic structure then developes and on the western foot the rocks are gneissic. Intrusive granite is apparently in contact with these and beyond the granite is another small series petrographically similar to the greywackes and shales of the east but there is no palaeontological evidence as to their age. [141] All the rocks of the range are here included in the Maitai system because it is believed that no proof of a stratigraphical or palaeontological nature has yet been forthcoming to justify the division into six series (Silurian, Devonian, Carboniferous, Permian, Triassic, Jurassic) as was done by Hector or into three as was done by Hutton.

Structure. This has at present not been closely investigated. von Haast [142] and Hutton [143] always stated that the structure is that of a huge anticline and that the western part has been removed by denudation. von Haast stated that the folds were repeated several times and were crumpled in places. Hector regarded the structure as a synclinal one. [144] Mc Kay has described movement along thrust planes as the cause of the formation of the Kaikouras and has suggested that the formation of the Southern Alps may be due to the same cause. [145] This has been further developed by Morgan [146]; but Bell had previously described the structure near Hokitika as ordinary folding. Morgan insists that the presence of folded rocks to the west of the granite with a strike different to that of the rocks to the east proves that the anticlinorium of Haast and Hutton never existed. Bell [147] in the Browning Pass district shows a complex folded structure and states that "broadly viewed the whole series may be regarded as forming a huge synclinorium probably including in the region of pronounced metamorphism many isoclinal folds".

The strike of the strata throughout the greater part of the Southern Alps is from north-east to south-west but at Mt. Aspiring it is thought that the strike bends round to the south-east in a wide curve, and the axis reaches the east coast at Dunedin. Gregory regards this south-east curve of the range as part of an older mountain system. It will be noticed that the strike of the rocks throughout the portion of the range, that is directed to the north-east, is quite parallel to the direction of the range. In Otago the direction of the mountain ranges is nearly at right angles to the strike.

The strata are everywhere steeply inclined but as a rule they are not much contorted. The width of the belt of metamorphism varies greatly; in Otago it is 100 miles (161 km) wide, near Mt. Aspiring 20 miles (32 km), near Mt. Cook 10 miles (16 km), and the rocks are here quite gneissic on the west side, at Browning's Pass 5 miles (8 km), in the Teremakau valley 2 miles (3 km). At the head of the Motueka valley in Nelson there are no schists and at the head of the Pelorus Sound they are 15 miles (24 km) wide.

Granite intrusions are found in many places along the western side of this range, and though they are of great importance near the Teremakau river in Westland they attain their greatest development at Lake Rotoroa in Nelson where they are 16 miles (26 km) wide. The greywackes and shales of which this range is composed are traversed by many divisional planes and they break down easily under the action of erosive agencies. The result is that huge scree slopes cumber the mountain sides in all the drier regions. The uniformity in the petrographical nature of the rocks and the absence of fossils renders the actual interpretation of the structure of this mountain range a matter of peculiar difficulty. In the present state of our knowledge it appears that a series of steeply inclined isoclinal folds most nearly represents the actual structure. Besides the granites there is another very interesting series of plutonic intrusives of an ultrabasic nature. These are typically developed at the Dun mountain in Nelson but the outcrop is larger in the region of Lake Rotoroa and there is another large mass near Mt. Aspiring.

In this work the mountain district of Otago is regarded as an extension of the Southern Alps; the mountains themselves are thought to be due to the erosion of streams that run through the country which was a peneplain before the recent elevation. Park has recently described them as Block Mountains at the bases of which he says that faults of great magnitude can be distinguished.[148] Still more lately he has ascribed great importance to glaciation as a deforming agent of this region. In the „Geology of New Zealand" he states that the mountains have been thrust up. Suess represents the two ranges as meeting in syntaxis and does not discriminate between them in age or structure.[149]

3. Northerly continuation of the Southern Alps.

One looks in vain for a mountain range in the North Island which might be regarded as a continuation of the dominant range of the south. The country along this direction is occupied first by the thick horizontal Cainozoic sediments of the Wanganui area, and afterwards by the volcanic plateau. The only important relief is afforded by the line of great volcanoes. Suess believes that this portion of the great mountain chain has sunk; and Hutton remarks that the arrangement suggests that there is an important fault in Cook Strait, of which however there is no independent evidence.

4. The Tasman Mountains and the chain in the north-west of Nelson.

The direction of the folds in the northern part of this range the Whakamarama Mts. is directed a little west of north, though it varies considerably. The main structure is defined as a great synclinorium in which isoclinal folding makes the folds pitch north and south.[150]

The structure is further complicated by the intrusion of plutonic rocks round which the folds bend. The Tasman Mts. themselves have been very little investigated. A reconnaisance by the writer showed that the structure is somewhat similar to that of the Whakamarama range but the strike is somewhat more westerly, and the whole arrangement complicated by the intrusion of the large mass of porphyritic granite on the west. The Tasman and Pikikiruna Mts. unite at Mt. Arthur; the strike of the strata here is a little to the north of north-west. In the Baton River McKay gives the strike north-east[151] while further south near Mt. Murchison Haast found the strike nearly north.[152] The range must either be regarded as stopping at Mt. Hope or as crossing the Buller River and finding its continuation in the rugged country to the west of Lake Rotoroa. There is at present very little information in regard to this matter.

The mountains are composed of strata of greater age than those of any other of known age in the country. Some of them are certainly of Ordovician age, some are older and some are Silurian. The strata have a varied lithological composition: quartzites, greywackes, shales, marble and a great variety of schistose rocks. On the western side there is a granite intrusion 40 miles (64,3 km) long and 15 miles (24 km) broad, but near the coast it is covered in places by Cainozoic sediments.

The only point that appears to be certain about the period at which these rocks were folded is that the movements took place before the deposition of the Cainozoic rocks. Hutton thought that Carboniferous and Hector that Devonian rocks rested on the eroded surface of the older rocks. Bell however sees no proof of a stratipraphical break.[153] Consequently this upper series throws no light on the question of the period of the folding.

5. The Kaikoura Mountains.

Suess points out that Hochstetter was right in regarding the North Island mountains as a continuation of the Kaikouras.[154] There are three parallel ranges separated by profound valleys the highest point rising to 9000 feet. McKay[155] has stated that a series of thrust planes separates the different mountain ranges from one another and from the Southern Alps. The planes of these movements are now the river valleys. In them a series of Cainozoic strata is found and in the Clarence a number of basaltic outflows have taken place. McKay's description was endorsed by Hector, but no other geologists have visited the region. The rocks are strongly inclined and strike north-east but no analysis has yet been published of the nature of the folds. McKays description makes these mountains extremely youthful, for the Mesozoic sediments are described as being thrust over Miocene rocks. There is no doubt that these mountains are formed of rocks similar to those of which the Southern Alps are formed and that they were subjected to folding movements long before the supposed thrust movements took place.

6. The mountain range of the North Island.

This is formed of the following separately named ranges:—Rimutaka, Tararua, Ruahine, Kaimanawa, Raukumara and Huiarau. It thus extends continuously from Cape Terawhiti almost to Cape Runaway. Its direction is north-east in continuation of that of the Kaikoura mountains, and it is composed of the same rocks as that range. No fossils have been obtained and in their absence it is assumed that the rocks are of the Trias-Jura age. As in the South Island they are strongly inclined and no analysis of the folds has been made. The sections displayed along the shore of Cook Strait show that the structure is of a most involved nature.

In places Cainozoic rocks are in contact with the older rocks and they have undergone a slight amount of folding also. The great earthquake of 1855 is said to have rent open a fissure at the base of the Ruahine Mts. extending north from the Mukamuka cliff for a distance of 90 miles.[156] The foreshore near Wellington and at Cape Palliser is conspicuously terraced. With the exception of the disturbance caused by the peculiar course of the Manawatu River the range constitutes the watershed of the country as far north as Lake Taupo, but further north it forms the western slope only and finally ends near Cape Runaway.

This is clearly shown by Hector and his conclusions are supported by the observations that the author has made.[157]

The period of folding of these rocks was probably late Jurassic, that is the same as that of the Southern Alps and of the Kaikouras. It was nearly completed before the deposition of the Cainozoic rocks though earth movements of elevation and depression have affected the range since then.

7. Isolated mountain groups to the north and west.

There are in the North Island several outcrops of folded rocks apparently of the same age as the range last described.

a) The most important starts at Kawhia and extends rather interruptedly to Wairoa and Waiheke Island. In the southern portion the rocks are distinctly of Trias-Jura age[158] but no fossils have yet been found north of the Taupiri gorge. The rocks strike to the east of north.

b) Another distinct line forms the core of the Coromandel Peninsula. Some of the rocks here also contain Jurassic fossils. Strike almost due north.[159]

c) A small area of folded rocks extends from Whangarei to Russell. They are intensely folded at Russell and are not known to contain fossils. Strike perhaps east of north.[160]

d) Around Whangaroa, Mangonui and Ahipara there are small outcrops again as yet unfossiliferous and striking north. These rocks contain intrusive masses of gabbros and diorites.[161]

e) At the North Cape there are again outcrops of similar rocks with basic and ultra basic intrusions.[162] Fossils that indicate a Triassic age were found by McKay at Spirits Bay. There is no information as to the strike of these rocks.

It will be seen that there is no evidence other than that of a petrological nature for classing these rocks together.

There is some difference of opinion as to the relation of these mountain fragments to the great orographical features of New Zealand. Thus Gregory regards them as the result of an earlier period of folding during which the south east bend of the southern alps were formed.[163] The fact that Jurassic rocks are included in these folds at Kawhia and at Coromandel disproves this. Suess[164] regards them as "isolated fragments of the sunken range." "The north west coast therefore in no way represents the actual trend of the mountains." With this latter view the author agrees. The observation of the strike of the rocks is still very incomplete, but it appears to agree with what Suess has written. More recently however he has expressed himself in somewhat less definite sentences. "All the arcs and fragments are so arranged within the Kermadec line that they seem to whirl toward the bifurcation of northern New Zealand." "Thus the plan assumes the form of a virgation proceeding from New Zealand and opening out towards the north-west and west."[165] This view makes the Auckland Peninsula of great structural importance.

In all cases the folds of these ranges were formed before the deposition of the Cainozoic rocks and it is probable that the period of earth movement was that of the later Jurassic and Cretaceous periods, in other words between the Maitai and Oamaru systems of New Zealand geology. This may reasonably be called the critical period of New Zealand geology.

8. The hills of the Cainozoic country.

It is only locally that these rocks are folded and still more rarely that they form orographical features of any importance. One such locality is in the Puketoi Hills of the east of Wellington where though but 2000 feet (610 m) high they form the main watershed of this part of the island. Elsewhere these sediments are often sharply inclined, where they are in contact with older rocks, especially if situated in inland basins such as the Trelissick and Te Anau areas. This clearly shows that there have been rock movements since the main folding and elevation of the land in the critical period. The great extent to which such movements have extended is seen in the peculiar involvement of a thin stratum of Cainozoic rock in the inclosing schist through a vertical distance of 4000 feet (1219 m) in the Wakatipu district, an example that has long been known to New Zealand geologists.

Apart from folds some districts of Cainozoic rocks which have been considerably elevated have been so dissected that the watersheds between adjacent valleys are now hills of considerable altitude. The tops of the hills are often nearly flat though the sides are steep, as the blue marls of which the country is chiefly formed stands well in very steep slopes. The last important movement of elevation has been so recent that the streams flow in the steepest gorges lying in the flat floors of the valleys, formed when the land was at a lower level. This dissected hilly country is most characteristic of the western side of the North Island from Palmerston to Kawhia. The same structure is also conspicuous on the eastern side from East Cape to Castle Point. It is much less general in the South Island.

9. The volcanoes.

Cones of striking magnitude are found in the central part of the North Island. It has long been remarked that Ruapehu, Ngauruhoe, Tongariro, Pihanga, Tauhara, Edgecumbe and White Island stand in a line that is nearly straight and presumably indicate the presence of an important line of crustal weakness. In many places along this line thermal activity is still shown in the numerous hot springs. West of this line there are many volcanoes though with the exception of Egmont of less imposing dimensions. In addition there is as yet no certainty as to the position of the vents whence the immense outflows of rhyolite issued as well as the showers of pumice that were scattered over the country.

It is noteworthy that the volcanic line mentioned is parallel to the range of folded rocks and is directed towards the Kermadecs and Tonga where the volcanic rocks are somewhat similar to the andesites of the North Island volcanoes. In Tonga there are islands of elevated limestone lying to the east of the volcanoes, a condition that would be practically repeated in New Zealand in the east coast region, if the country were lowered some 3000 feet.

Elsewhere with the exception of Pirongia and Karioi near the west coast, the Coromandel Peninsula and the Great and Little Barrier Islands, all of which are of relatively considerable age, the volcanoes are of insignificant dimensions, though they are numerous in the Lower Waikato, Auckland, Whangarei and the Bay of Islands.[166]

In the South Island the relatively old volcanic masses of Otago and Banks Peninsula are the only volcanic hills of any importance.

10. The volcanic plateau.

The surface of the interior of the North Island which lies for the greater part at a higher altitude than 1500 feet (450 m) is covered with pumice and rhyolite and may aptly be called the volcanic plateau. From this plateau the volcanoes rise. The surface of the plateau is nearly flat, but flat topped hills such as Horohoro near Rotorua rise from it. They are portions of rhyolite lava flows that have resisted the agents of denudation. Gregory describes the sides of these mountains as marked out by fault planes.

11. The gravel plains.

From the eastern bases of the mountains in the South Island plains that are nearly level extend to the coast, especially in the centre in Canterbury. Another area extends north from Foveaux Strait and stretches far into the valleys that separate the mountainranges from one another, and terminates only at the extremities of the great lakes Wakatipu and Te Anau. In Westland the plains have a less regular surface and are largely morainic in origin as against the purely fluviatile origin of the Canterbury Plains. Such plains are less noticeable in the North Island, but are to be seen along the western base of the Ruahine Mts. from Otaki to Palmerston, and on the eastern side near Napier. These plains all have a strongly inclined surface and in Canterbury the western margin is 1500 feet above sea level.

B. Outlying Islands of New Zealand.

Chatham Islands.

Lat. 44° S, Long. 177° W.

They lie 480 miles E.S.E. from Wellington and have an area of 375 square miles. Their surface is hilly but not mountainous. Our knowledge of the geology of these islands is chiefly due to HAAST[167] and DIESELDORFF.[168] The former recognised schists, basalts and limestones among the specimens collected by TRAVERS. The same types are mentioned by DIESELDORFF with the addition of tuff and trachytic pumice.

The schists occur mainly in the north especially on the extreme west and extreme east of the main island Waitangi. They strike SW.—NE. and dip 30°—50° SE. They have been correlated with the schist rocks of New Zealand which are here classed as metamorphic equivalents of the Maitai system (Trias-Jura). Volcanic rocks and tuffs cover the larger part of the main island as well as Pitt Island. DIESELDORFF states that hornblende heaving feldspar basalt is the commonest rock though there are mica basalts as well. A limburgite with hornblende is also widely distributed. Trachytic tuffs occur near Waitangi settlement at Mount Engst and on Pitt Island.

The limestones are somewhat variable. An outcrop on the SW. side of the lagoon consists of crystalline rock. HAAST suggested that this was of Palaeozoic age. DIESELDORFF however records remains of *Cidaris* which causes him to class it as Cainozoic. The other limestones at the North of the island and elsewhere are sometimes calcareous tuffs sometimes concretionary and sometimes with glauconite. The tuffaceous limestones appear to form the base of the series. In Pitt Island brown coal is found at the base of this series. The following fossils are mentioned by DIESELDORFF as occurring in the limestones:

Waldheimia lenticularis DESH. *Pectunculus aff. lenticularis* TATE. *Terebratula. Pecten aff. laticostatus* GRAY. *Pecten tenuicostatus* MICHELS. *Gryphaea cf. tarda* HUTTON. *Cidaris verticillata* LAM. *Spiropora, Vincularia. Lichenopora* and *Desmopora.*

HUSTEDT states that the Bryozoa indicate a Senonian age.

There is no reason to refuse to correlate the limestones with the limestone of New Zealand which forms an important member of the Oamaru system as here treated. It thus corresponds with HECTORS Cretaceo-Tertiary, HUTTONS Oligocene and PORTIS Miocene.

Geological History. The presence of schists implies the existence of an old eroded land surface. When this was submerged limestones were deposited. Volcanic action commenced and afterwards elevation took place. If HECTORS statements are correct, elevation took place in the early tertiary after volcanic action had ceased. The formation of peat and accumulation of sand has taken place continuously since then.

Snares Islands.

Lat. 48° S, Long. 166° 53′ E.

These are wholly formed of a muscovite granite with some tendency to a gneissic structure. The rock contains a little garnet. The surface of the island rises precipitously on nearly all sides to a moderately flat summit 400—500 feet above sea level. This is an erosion surface probably due to marine action but the thick covering of peat obscures all the details of the structure.

Bounty Islands.

Lat. 47° 40′, Long. 179° E.

These also consist entirely of granite. The islands are numerous but small and rise to only 290 feet above sea level. The rock is an ordinary biotite granite consisting of quartz, orthoclase, a little albite, biotite, some muscovite and needles of apatite.

Antipodes Islands.

Lat. 49° 40′, Long. 178° 40′ E.

The dimensions are five miles NW. to SE. by three miles in breadth. Its surface has the form of a rough undulating plateau which rises to 1320 feet. Only volcanic rock has been accurately described though sedimentary types have been stated to exist. Most of the rock appears to be scoria but there are also large lava flows. The rocks are basalt glasses and porphyritic basalts. Fragments of coal have been obtained but they appear to be merely coked peats. The island is bounded everywhere by high cliffs.

Auckland Islands.[169]

The main island is 25 miles long and 17 wide. It lies in lat. 57° S. and long. 166° E. Nearly all our geological knowledge of the group is due to Speight. Besides the main island there are Adams Island in the South, Ewing and Rose Islands in the North and Disappointment Island in the west. The surface is elevated and hilly. It is higher near the west than the east. It is often more than 2000 feet an elevation that is reached also by the ridge of Adams Island. The hills are generally flat topped.

The valleys are deep with steep sides and semicircular cirque like terminations. The streams all flow eastward and enter the heads of deep inlets by which the eastern coast is indented. Similar inlets and of greater extend are found in the north and south. The watershed of the Island is often at the crest of the western cliffs. Between the inlets the cliffs are steep and the straight coast line of the west rises without break to 1500 feet almost throughout its length.

The surface features are ascribed to the action of glaciation a conclusion that is strongly supported by the occurrence of moraines in some of the valleys and of a moraine damned lake. Speight however lays emphasis an the absence of all indications that an ice sheet passed ower the island.

The rocks are all of igneous origin. In Cornley Harbour in the south there are masses of granite and of olivine gabbro. The granite is penetrated by numerous small intrusions of alkaline trachytes which also form lava sheets which are separated from the granite by trachyte tuffs. A remarkable breccia composed of plutonic rocks rests on the trachyte. There is an older basic series of rocks which is associated with dykes of dolerite, diabase and porphyrite and lastly a younger series of basic lava flows with dykes of diabase and basic porphyrites.

The trachytes, conglomerates, and older basic rocks are said to be precainozoic and the youngest series is almost certainly of middle or late Canoizoic age.

Disappointment Island is formed of diabases and melaphyres similar to those of the older basic series of the main land, but they are intersected by rhyolitic dykes. An erosion platform 10—15 feet above high water at Ewings Island appeared to the author to indicate a recent movement of elevation.

Campbell Island.

Filhol wrote a detailed geological description of this island which lies in 52° 30′ S. and 169° 8′ E. It has since been more accurately described by Marshall. The main island is nearly 30 miles in circumference and the other islets are mere rocks. The surface is somewhat elevated rising in Mount Dumas to 1650 feet. In the southern portion the peaks are isolated but in the northern part the island is uniformly elevated to about 1000 feet. The eastern coast line is intersected by two deep inlets —Perseverance and North East Harbour. Filhol mentioned the occurrence of schist and granite neither of which were found by Marshall in the localities indicated by Filhol. The oldest rock is a normal olivine gabbro which occurs in the south-west and forms the mass of Mount Menhir. On its eroded surface there rests a series of

Cainozoic rocks which have a quartz conglomerate with carbonaceous matter at the base. The quartz is derived from metamorphic rocks. The conglomerate grades into sandstone which is succeeded by limestones with flints. These dip eastward very slightly and are traversed by faults. The following fossils were obtained from this rock:

Pentacrinus stellatus Hutton. *Micraster sp.*? *Conchothyra parasitica*? Hutton. *Pecten delicatulus* Hutton. *Pecten polymorphoides* Zittel.

The mass of the limestone is formed of tests of *Globigerina, Nodosaria, Textularia, Cristellaria.* In the most the limestone is crystalline and forms marble. The series of Cainozoic rocks is penetrated by a series of dykes which are particularly

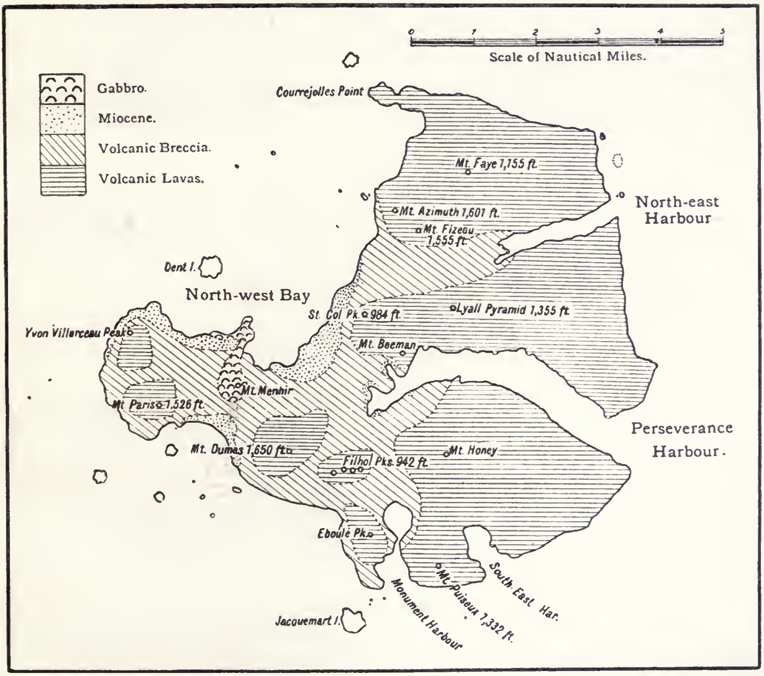

Fig. 17. Geological map of Campbell Island. (After the work «Subantarctic Island of New Zealand».)

numerous near the west coast while those on the shore of Perseverance Harbour radiate somewhat irregularly from a point to the west of the island. A volcanic breccia rests on the limestone. It is of submarine origin and contains the following fossils:

Magellania lenticularis Hutton. *Pecten triphooki* Zittel. *Luna colorata* Hutton. *Glycimeris Chambersi u. sp.* *Venericardia australis* Quoy. *Meretrix multistriata*? Sow. *Flabellum sphenoideum* Ten. Woods.

This corresponds roughly to the upper Miocene of New Zealand.

Volcanic lavas rest on the breccia. They are mainly trachytes dipping sligtly to the east. Basalts are well represented and there is a phonolite with mosandrite as well as melilite basalt. A coarse porphyry with mica, anorthoclase, perowskite and zircon in large crystals has a limited occurrence.

The island is covered everywhere except on steep rocky slopes with a thick growth of peat sometimes 40 feet thick.

The surface features of the island are ascribed to glacial erosion by radiating glaciers. There is no evidence that an ice sheet passed over the island, but many facts are in opposition to this.

The area was eroded in precainozoic times, submerged for a considerable time. Volcanic action broke out and elevation took place in the later Cainozoic and since then the island has remained above sea level.

Macquarie Island.

Lat. 54° 30′, Long. 158° 30′ E.

Though this island has been frequently visited we have but little geological knowledge of it.

A photograph published by the British Antarctic expedition shows a well developed marine platform 100 feet wide at the base of grass covered cliffs. The island rises to 2000 feet with an average height of 500 feet. The longer axis lies NE.—SW.

Volcanic rocks only are known and those collected by the Discovery expedition are dolerites and basalts, but Marshall has previously described a basaltic glass, diabase and porphyrite from specimens obtained by A. Hamilton. All the rocks dip about 10° NW. A few dykes were noticed on the coast line, and in a stream valley a terrace was seen about 20 feet above the present bed. This may be a raised beach or an incised delta. Most of the surface of the island is covered with peat.

V. Economic Geology.

The exploitation of mineral substances for commercial purposes has been confined to comparatively few materials. Of these gold, silver, coal, kauri gum and scheelite are the most important. Gold is obtained from beach sands and river gravels as well as quartz lodes. Silver occurs with gold in some of the important fields. Coal occurs in a great many localities in the North and South Islands. Much of it is strongly hydrous and little better than a lignite. There are however highly important coal fields in Westland where the coal is entirely bituminous in its character. The kauri-gum is found in superficial deposits in the north part of the North Island only. Scheelite is found in Otago.

The Metals.

Gold. In the early days of the industry gold was derived mainly from the alluvial deposits; the greater part is now obtained from quartz mining. The alluvial drifts have been most productive in Otago and in Westland. While no nuggets comparable in size to those found in Australia have been obtained in New Zealand the gold in several localities such as Tuapeka and Baton River has been coarse. In 1909 a nugget weighing 101 oz was found at Ross.

Much discussion has taken place as to the age of the alluvial deposits in Otago. As they are unfossiliferous it is difficult to arrive at any exact conclusion. McKay ascribes different members of the alluvial deposits to periods between the Cretaceo-tertiary and the Recent.[170] Park apparently regards all the gold bearing drifts as younger than the Pliocene.[171] The source of the gold is also somewhat obscure. The quartz-lodes found in the schists are often auriferous but seldom rich. Unless denuded portions were much richer an enormous amount of material must have been removed in order that such large amounts of gold should have been derived from them.

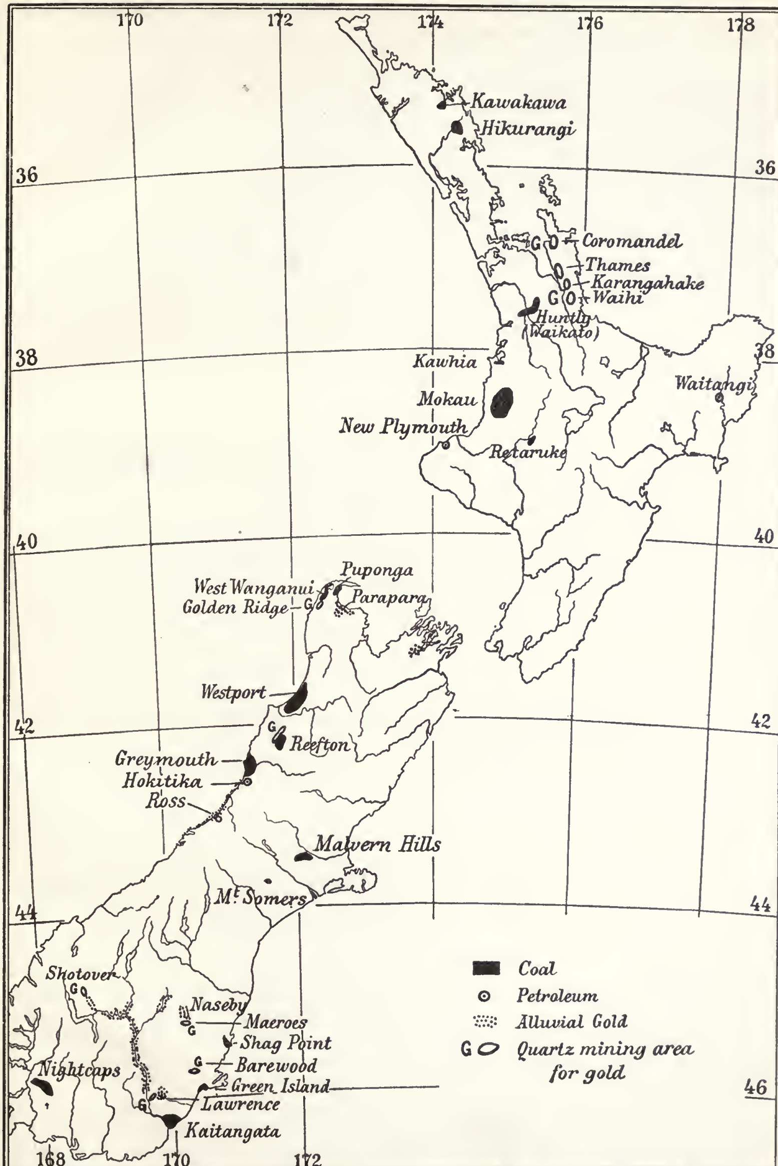

Fig. 17. Chief areas of gold, coal and petroleum in New Zealand.

Ulrich has suggested that the gold was partly derived from quartz lenticles in the schist.[172] This suggestion is not supported by assays.

Gold occurs in notable amount in the gravels of the present river beds and within the last decade much has been obtained by dredging, and many gravels are still worked by sluicing. About six million ounces of gold have been obtained from alluvial deposits in Otago. The Westland alluvial deposits are comparable in many respects to those of Otago. Again in most of the alluvial country of Westland auriferous reefs are conspicuously absent from the ranges from whence the rivers flow. At Ross some rich deposits have been worked 100 feet (30 m) below sea level.

In the middle of last century gold was obtained in some quantity from the gravels in the north-west of the Nelson Province. The industry has now dwindled down to the activity of a few sluicing claims. Beach sands were highly auriferous at Hokitika and many other places on the west coast in the early days of exploration and patches of sand are still rich enough to pay for working. Auriferous gravels are of very slight extent and importance in the North Island.

Quartz mining has been an important industry for a long time. Several lodes are still worked in Otago in the chlorite and mica schist the age of which is here taken as Trias-Jura. The lodes sometimes contain scheelite and they are somewhat irregular and mullocky.

At Reefton quartz lodes penetrate sediments of Maitai (Trias-Jura) age. They run parallel to the bedding and have been worked to a depth of 1500 feet (457 m) and the amount of gold obtained has been considerable.

The most important gold mining district is the Ohinemuri-Coromandel area. Some of the Thames mines when first exploited yielded exceptionally large bonanzas notably the Caledonian and within the last few years the Waiotahi. The Wauroki mine at Coromandel was famous for a similar reason. Some of the ore bodies are of remarkable size notably in the Waihi mine, where the ore is payable throughout a thickness of 80 feet in places. From this mine £ 8000000 of gold has been obtained within the last 20 years. Nearly all the lodes of this district penetrate volcanic rocks which are probably of middle Cainozoic age. The volcanic material is mostly andesitic rock of various kinds. The quartz is said to be richer where the lodes traverse hypersthene andesite than in other types. Here the origin of the lodes is ascribed to the escape of magmatic waters.

The value of the gold obtained from all the fields in 1908 was £ 2082000 and the total that has been obtained in all the years of gold mining is £ 74000000.

Silver. The bullion obtained from the Thames mines always contains more silver than gold, and assays of the ore show that the amount of silver is four times greater than that of the gold. The silver mineral in the ore is argentite. Silver also occurs with galena and other minerals in the neighbouring district of Te Aroha but metallurgical difficulties have hitherto prevented systematic work from being done. Silver ores have also been found at Puhipuhi near Whangarei but there is a scarcity of silver lead ores in the country. The value of the silver produced in 1908 was £ 175000, and the total amount that has been produced has the value of £ 1266000.

Platinum. Sands at Orepuki contain a small amount of platinum, iridosmine and other allied minerals though little metal has been obtained from them. Similar minerals occur with gold in the alluvial deposits near Takaka in the Nelson province. There is no special reason to suppose that these metals have been derived from peridotite rocks.

Copper. Comparatively little of this metal has been mined. Deposits of various copper ores occur in the peridotite region of the Dun mountain near Nelson. Some native copper has been obtained from there and attempts have been made to work the sulphide ores which are mostly pyrrhotite. A small amount of copper pyrites is found at Whangaroa, Great Barrier, Lake Wakatipu and Kawau, but no success has been achieved in the attempts that have been made to exploit these.

Antimony. At Endeavour Inlet there is a lode that contains a high percentage of stibnite, and other deposits have been found near Alexandra in central Otago. The fluctuating price of the metal has hitherto prevented these mines from being worked profitably. Good crystals of stibnite are found in some of the Thames lodes.

Arsenic has been obtained from some of the gold mines in the Coromandel district.

Iron. No success has yet been attained in working the iron deposits though ores are found in considerable quantity. The best known are those of Parapara near Cape Farewell, and the beach ironsands of Taranaki. The former consists almost entirely of limonite which is in close association with limestone of early Palaeozoic age. There is a large quantity of the ore which is extremely pure.[173] The average composition is:

SiO_2 9.56; Al_2O_3 3.36; Fe_2O_3 71.25; FeO 1.94; MnO 0.65; CoO 0.51; MgO 0.10; TiO_2 0.63; P_2O_5 0.35; SO_3 0.21; CO_2 0.10; Alk. 0.08; H_2O 11.83 = Sa. 100.58.

Bell ascribes the origin of this ore to the action of acid sulphurous and chalybeate waters derived from pyrite in the surrounding rocks on the calcium carbonate of the Palaeozoic limestones.

Good steel can be made from the ore and attempts are now being made to work it on a commercial scale.

The Taranaki iron sand consists chiefly of magnetite with which there is some ilmenite and basic minerals. Good steel has been made from this ore, but it appears that modifications of the ordinary processes of metallurgy are necessary for success.

Chromium. The peridotite rocks of Nelson contain some chromite which is often concentrated in masses of considerable size. Analysis shows that the ore should be called a picotite for its composition is: — Cr_2O_3 56.54, Al_2O_3 12.13, FeO 18.01, MgO 14.08, MnO 0.46, CoO, NiO trace. The ore is an original impregnation in the rock and a similar substance is found in the ultra basic rocks of the west of Otago. Some thousands of tons of this ore were exported from Nelson in the middle of last century.[174]

Manganese. Mixed oxide and hydroxide ores of this metal occur in many places in association with dark red shales of Maitai age. They have been mined at the Bay of Islands and at Waiheke but never in important quantities.

Tungsten. Scheelite is found in lodes in schist in Otago and Marlborough. It is always associated with quartz and some gold is found in the lodes. Finlayson regards these lodes as formed of material derived from hypothetical magma below the schist as a result of differentiation and ore segregation that had taken place in the magma.[175] The value of the mineral exported in 1908 was £ 6 000.

Nickel. The only ore of this metal that is known to occur is awaruite an alloy with iron. It is found in the gravels and sand of several small rivers on the west coast of Otago.

The Non-metals.

Coal. Bituminous coal of high grade is found in the west coast coal field. Greymouth and Westport are important mining centres. The coal is near the base of the Oamaru series which in the greater part of the district rests on the granite. It occurs in an extremely thick formation of a granitic conglomerate sometimes as fine as sandstone. Plant impressions show that the coal forming plants were for the greater part Dicotyledons. These beds have been classed as Cretaceous by Hutton, and by Hector possibly Lower Greensand in age. Park considers them Eocene. As however no unconformity has yet been shown between these coals and the Cainozoic rocks which rest on them they are here included as the lowest member of the early Cainozoic as previously described.

Morgan who has recently examined these rocks closely thinks that the inclusion of pieces of coal in the overlying Cainozoic sediments conclusive evidence of the existence of an unconformity. If this implies any unconformity it must be a most important stratigraphical break but of this there is no direct stratigraphical evidence in the many natural sections. It is also quite a usual thing to find resin embedded in the overlying rocks and carbonised fragments of wood in the conglomerates. This suggests that the coal fragments were wood when entombed in the mud and that they have been changed into coal in situ. It is also possible that there was some contemporaneous erosion of the coal measures. Associated sediments contain but few marine fossils and these have not yet been shown to be older than the Cainozoic.

The amount of this class of coal that is mined is considerable. In 1908 671000 tons were exported from Westport and 375000 tons from Greymouth. A mine in this district lately opened produces semi-anthracite coal. Throughout this district the seams are thick and continuous.

Less valuable coals are found in many localities. They can be collectively classed as brown coals, though as the analyses show they are of many grades. The deposits are always found near the base of that development of the Oamaru system that is found in the district. In the South Island there are the following localities:—Preservation Inlet, Nightcaps, Kaitangata, Green Island, Shag Point, Mt. Somers, Malvern Hills, Pakawau, Puponga, West Wanganui, Heaphy River, Reefton. In the North Island Mokau, Retaruke, Waikato, Hikurangi, Ngunguru, Kawakawa. The separate coal bearing areas are often relatively small, and quartz pebbles of relatively large size are often found embedded in the coal. This suggests that the vegetable accumulations were formed in swampy ground and that detrital matter formed at least some part of the mass.

A large series of analyses of New Zealand coals has recently been completed[176]. In this report they are classified as follows:—semi-anthracite, bituminous, glance and brown coals and lignites. The glance coals appear to correspond with the semi-bituminous coals of Hector which were however divided by him into glance and pitch coals.

The following are typical analyses of the different classes of coal mentioned.

	Fixed carbon	Hydro-carbous	Water	Ash	Sulphur	Coke
Semi-anthracite (Paparoa) . .	78.90	16.93	0.40	3.77	0.37	82.67
Bituminous (Westport) . . .	55.73	40.08	2.37	1.82	0.55	57.55
Glance coal (Hikurangi) . . .	44.56	47.17	4.06	4.21	5.81	48.77
Brown coal (Kaitangata) . .	38.00	39.96	18.22	3.82	0.40	—
Lignite (Alexandra)	18.78	43.10	32.62	5.50	0.84	—

In 1908 the total production of all classes of coal was 1860000 tons, and the total production is now 27000000 tons.

Petroleum. Exudations of petroleum have long been known to occur in three districts in New Zealand. The best known of these is at Moturoa near New Plymouth where a fair flow of oil is now obtained from a bore 2331 feet deep. The other localities are at Waitangi Hill near Gisborne and Kotuku near Greymouth.

The following analyses show the composition of these oils:

	(1)	(2)	(3)
Benzene b. p. below 150° C. .	20.2	4.1	0.00
Kerosene b. p. 150—300° C. .	42.8	42.4	25.2
Lubricating b. p. over 300° C. .	22.1	47.8	71.8
Paraffine	10.3	5.2	3.0
Pitch	4.6	0.5	

(1) Moturoa. (2) Kotuku. (3) Waitangi.

Oil shale. Deposits of this are found at several places. The best known is at Orepuki where attempts have been made to work the material on a commercial scale but hitherto without success. The deposit is in strata of Oamaru age and it contains a large amount of paraffin.

Kauri gum. This material is the exudation of the kauri pine *Dammara australis*. It is found in superficial deposits only and usually in places where no kauri forest is now growing. The mineral is obtained by digging rather than mining. The value of the export amounted to £ 375.000 in 1908 and altogether the value that has been exported since the colonisation of the country is £ 14.500.000.

Phosphate. An earthy form of apatite is found in localised patches on the margin of a limestone of Oamaru age. It appears to have its origin in the leaching action of percolating water, which has concentrated the calcium phosphate contained in the teeth and bones that were originally embedded in the limestone.

Building stones. Limestones are well represented but those of great age, the marbles of the Pikikiruna range, have not yet been utilised. The Cainozoic limestones are seldom sufficiently compact for economic uses. An exception is found at Oamaru, where especially near Weston a great thickness of stone of uniform quality and of great purity is found free from all division planes. The defect of all this Cainozoic limestone is a relatively high porosity but it has been largely used for building with great success and it is admirably adapted for use in interior carvings. Similar stone is quarried at Mt. Somers.

Volcanic rocks are used for building in many places. In Dunedin andesites, dolerites and phonolites are utilised. At Christchurch andesites and basalts. In Auckland basalts are used. A few blocks of diorite from the extreme south have been used as ornamental polished bases or foundation stones, and the tonalite from Cabbage Bay in the Coromandel Peninsula has been similarly used. A granite from Tonga Bay near Nelson has lately been used for building; but none of the other New Zealand granites have been used.

A volcanic breccia of Cainozoic age is quarried to some extent at Port Chalmers and it is largely used for the basements of buildings. A Jurassic sandstone has been quarried at Mataura in Southland. Mica schist has been employed for many buildings in Otago.

Cement. The materials for this can be obtained in great quantity from the Cainozoic rocks. At Dunedin cement is manufactured from the limestone quarried at Millburn mixed with marl obtained locally. In Golden Bay it is prepared from Cainozoic marls and limestones near Takaka. In Auckland there are works with a large output at Whangarei.

Precious stones. None of any value have yet been discovered. The only gems found so far are a variety of corundum which occurs in boulders of mica rock at Rimu near Hokitika. The corumdum grains are small and of a purplish colour and are not suitable for polishing.

VI. Literature.

Abbreviations: Trans. N. Z. Inst. or T. N. Z. I. or Trans. = Transactions and Proceedings of the New Zealand Institute. Rep. G. S. = Report of geological explorations, New Zealand Geological Survey, Sir J. Hector, Director. Qu. J. G. S. = Quarterly Journal of the Geological Society of London. N. Z. G. S. = New Zealand Geological Survey.

A.

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[171] Geology of the area covered by the Alexandra sheet. Geology of the Cromwell subdivision Western Otago. N. Z. G. S., Bull. 2 and 5 (New series).
[172] Geology of Otago and Southland, p. 158.
[173] Bell, The Geology on the Parapara subdivision Karamea Nelson. N. Z. G. S., Bull. 3 (New series), p. 81.
[174] Dana, Syst. of min. sixth ed., p. 228.
[175] Finlayson, The Geology of the quartz veins Otago Goldfields. T.N.Z.I., Vol. XLI., p. 84.
[176] Rep. Col. Lab. 1907, p. 46 etc.

Contents

Additions and Corrections.

Page 2. Line 5 from bottom for „east“ read „west“.
Page 7. Under Recent include andesites and basalts.
Under Pleistocene include andesites and basalts.
Page 17. Line 17. Insert after „same“ „as those“.
Line 21. For Triassis read Triassic.
Page 19. Line 2. For structural read stratigraphical.
Page 20. Line 5. For Poverty Bay read Bay of Plenty.
Page 24. Line 23. After and insert it has been found.
Before Echinoderms insert Brachiopoda. Hutton has recently classified the fossils that represent this group. Magellania is the most abundant genus; 7 species of it are mentioned. Terebratula, Terebratella, Bouchardia, Terebratulina occur as well. Altogether 24 species are described.
Page 26. Line 21 from bottom. After limestones read the so-called Amuri-limestone foraminiferal and Weka Pass stone glauconitic. See fig. 10.
Page 39. Line 9. The Nautilus and Brancoceras have kindly been identified by Dr. Prof. Boehm as Grypoceras and Prochydonautilus and the Arcestes as Proarcestes.
Page 43. Line 22. For fauna read flora.
Page 46. Line 20 from bottom. For Hakea read Podocarpus. This identification has been made at Kew.
Page 49. Line 6 from bottom. For valleys read ranges.
Page 61. Line 11. For heaving read bearing.
Line 19 from bottom. For Portis read Park's.
Page 63. Line 9. For most read west.
Line 6 from bottom. For Luna read Lima.
Page 66. Line 25. For Wauroki read Hauraki.