1922.

NEW ZEALAND.

MINES DEPARTMENT.

GEOLOGICAL SURVEY BRANCH

(SIXTEENTH ANNUAL REPORT (NEW SERIES) OF THE).

Laid on the Table of the House of Representatives by Leave

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LETTER OF TRANSMITTAL.

SIR,— Geological Survey Office, Wellington, 30th June, 1922.

I have the honor to transmit herewith the sixteenth annual report of the Geological Survey Branch of the Mines Department. This report covers the work of the Geological Survey for the twelve months ended 31st May, 1922. In addition to brief reports on the districts examined by the field officers, various special reports are appended.

I have, &c.,

P. G. MORGAN,

Director, Geological Survey.

The Hon. G. J. Anderson, Minister of Mines, Wellington.

DIRECTOR'S REPORT.

Summary of Field Operations.

During the field season of 1921–22 detailed topographical and geological surveys have been conducted in the following districts:—

(1.) North Auckland district (Dargaville Subdivision), by Mr. H. T. Ferrar, M.A., F.G.S., Geologist, assisted by Mr. W. H. Cropp, A.O.S.M.

(2.) Tokomaru - East Cape district (Waiapu Subdivision), by Messrs. M. Ongley, M.A., B.Sc., and E. O. Macpherson, Assistant Geologists.

(3.) Ohura-Aria-Taumarunui district (Ohura Subdivision), by Mr. L. I. Grange, M.Sc., Assistant Geologist.

(4.) Waihi district (resurvey of part of Waihi-Tairua Subdivision), by the Director, Mr. P. G. Morgan, assisted by Mr. H. A. Ellis, A.O.S.M.

Owing to the reduced amount of the Geological Survey vote, detailed surveys have been conducted on a somewhat more restricted scale than in 1920–21.

Brief visits for various purposes were made by the Director to the following localities: New Plymouth (reported on in the last annual report), Greymouth, Te Puke, Maratoto, and Waiotapu. Dr. J. Henderson, Mining Geologist, visited and reported on the Progress Mines (Reefton) and the Chertsey oil-bore (Canterbury). He also spent six weeks in the East Cape district examining critical sections in the Waiapu Subdivision. Mr. J. Marwick, Geologist and Palæontologist, visited the Maraekakaho district, west of Hastings, where he made extensive fossil collections and examined some of the limestone-deposits.

Progress of Areal Survey.

During the twelve months ended 31st May, 1922, an area of about 1,523 square miles was geologically surveyed in detail. Of this area 543 square miles is in the Dargaville district, 540 square miles in the Tokomaru - East Cape district, and about 400 square miles in north Taranaki. In addition about 40 square miles was resurveyed in the Waihi district.

The present state of the detailed geological survey is given in the following table:—

	Square Miles.
Surveys completed and work published, on the scale of 1 in. to the mile	8,884
Surveys completed and work published, on the scale of ½ in. to the mile ..	325
Surveys completed but work not yet published	5,509
Surveys in progress—area actually surveyed	1,553
Total area surveyed	16,271
Area in which work is suspended (Heaphy)	293
Area resurveyed (Whatatutu and Waihi)	352

Dargaville Subdivision.

During the past field season Mr. H. T. Ferrar, Geologist, assisted by Mr. W. H. Cropp, examined in detail an extensive area in North Auckland near Dargaville. The cinnabar-deposits of the Puhipuhi district and several coal-bearing areas in the Whangarei - Bay of Islands Subdivision were further examined.

The soils of the Dargaville district, as well as the deposits of limestone, kauri-resin, and coal, received due attention. Coal occurs near Avoca, a few miles north of Tangowahine, but unfortunately the seam is vertical and extends over only a small area.

Waiapu Subdivision.

The Waiapu Subdivision, which includes the area called Tokomaru Subdivision in last year's annual report, extends northward from Tokomaru Bay nearly to East Cape, and contains almost the whole of Waiapu County, together with parts of Waikohu, Uawa, and Matakaoa counties. Numerous escapes of inflammable gas and several oil-seepages, as well as many outcrops of rock containing petroleum in small quantity, occur in the district. That the structure of the strata of the possible oilfield should be understood is of the greatest importance, and the work of the Geological Survey in the Waiapu district has been directed mainly to this end.

Since oil-seepages are known north of the area so far explored, and since from time to time specimens of copper-ore have been received from the Cape Runaway district, the further extension of the survey is recommended in order that these occurrences may be thoroughly examined.

Ohura Subdivision.

The survey of the Tangarakau district, begun in November, 1920, by Messrs. Ellis and Marshall, was continued this season by Mr. L. I. Grange eastward and northward across the wide Ohura basin to the Auckland–Wellington Railway.

The whole of the known outcrop portion of the North Taranaki Coalfield has now been examined. The coal-measures cover an area of more than a hundred square miles within the subdivision. Throughout the southern half of this area the coal-seams, so far as known, are thin and unworkable at a profit under present conditions; but in the northern half thick coal outcrops at many points, and as soon as a railway has been built mining on a large scale will be practicable.

Waihi Goldfield.

During the years 1908–11 the Waihi district, together with a large area to the north, was examined in detail by Dr. J. M. Bell, at that time Director of this Survey, and Mr. Colin Fraser, formerly Mining Geologist. Their report (Geological Survey Bulletin No. 15), published in 1912, fully describes the Waihi district and mines. For various reasons a re-examination of the Waihi district and a revision of its geology were urgently required, and therefore, in November last, I began a resurvey of the Waihi Goldfield. In this work I was assisted by Mr. H. A. Ellis, A.O.S.M.

The principal object of the resurvey was to ascertain if geological reasoning would point to the presence or absence of ore-bodies either in depth or in areas laterally outside the country already explored by the mining companies. The re-examination has not yet been completed, but an interim report has lately been published in the *New Zealand Journal of Science and Technology*, and the preparation of a detailed report and of maps is well under way.

Important geological data have been obtained, and from them inferences favourable to the future not only of the Waihi mines, but also of several other parts of the Hauraki Goldfield, may be drawn. So far as Waihi is concerned, there seems to be a fairly strong probability that ore formed by "secondary enrichment" exists at depths greater than yet reached in the western part of the Waihi Mine, and perhaps also in the western section of the Grand Junction property. Similar ore may occur in depth in the lodes of the Rosemont–Silverton hills. New bodies of "primary" ore may possibly also be found by deeper exploration. Further, the principal ore-bodies are now known to be enclosed in flows of quartz-andesite, and not in an intrusive mass as supposed by Dr. Bell and Mr. Fraser. This view of the geological relations justifies the exploration of the quartz-andesites outside the area at present known to contain ore-bodies.

Palæontological Work.

During the past year Mr. J. Marwick, M.A., Assistant Geologist and Palæontologist, has been engaged mainly in examining the Tertiary Mollusca of the Geological Survey collections. He has also examined some Cretaceous and older Mesozoic fossils, and has made many identifications for the field geologists.

Most of the fossil collections sent to England about 1913 have now been returned to New Zealand. Although arrangements for the examination of all the material by specialists could not be made, nevertheless a considerable portion has been studied by experts. Three valuable memoirs, by Mr. Henry Woods, the late Dr. Newell Arber, and Dr. Otto Wilckens respectively, have already been published; the manuscripts of two other reports have been received, and two collections are still in the hands of English scientists. Mr. F. Chapman, of the National Museum, Melbourne, having completed his work on the Foraminifera and Ostracoda of New Zealand, has returned the material, and has furnished a full and most valuable report.

Publications and Manuscript Reports.

The only publications* issued by the Geological Survey during the year were the Fifteenth Annual Report, and Bulletin No. 23, entitled "The Geology and Mineral Resources of Western Southland," by Professor James Park, F.G.S., F.N.Z.Inst. In addition the following articles and reports by officers of the Survey have appeared in the *New Zealand Journal of Science and Technology*:—

"The Status of Areal Geological Survey Mapping in New Zealand." (Vol. 4, No. 5.) By P. G. Morgan.

"Notes on the Geology of New Zealand." (Vol. 5, No. 1.) By P. G. Morgan.

"Preliminary Report on the Resurvey of the Waihi Goldfield." (Vol. 5, No. 2.) By P. G. Morgan.

"On the Geological Survey of the Whangarei and Bay of Islands Subdivision." (Vol. 4, No. 6.) By H. T. Ferrar.

The following reports by specialists have been received:—

"The Fossil Cirripedes of New Zealand," by T. H. Withers, F.G.S.

"Contributions to the Palæontology of the New Zealand Trias," by Otto Wilckens, Ph.D.

"The Cretaceous and Tertiary Foraminifera of New Zealand, with an Appendix on the Ostracoda," by F. Chapman, F.Z.S.

These memoirs, which are accompanied by illustrative plates and text-figures, will, it is hoped, be published at an early date.

A bulletin entitled "The Geology of the Mokau Subdivision," by J. Henderson and M. Ongley, is now in the press, and the manuscripts of several other areal bulletins are ready or nearly ready for printing. These are as follow:—

"The Geology and Mineral Resources of the Collingwood Subdivision," by M. Ongley and E. O. Macpherson.

"The Geology of the Whangarei - Bay of Islands Subdivision," by H. T. Ferrar and W. H. Cropp.

"The Geology of the Huntly-Kawhia Subdivision," by J. Henderson and L. I. Grange.

Office-work, etc.

The office-work for the year has been of the usual character. Two highly technical reports by experts have been edited. Information on many matters, some not of a geological nature, has been supplied to the Mines Department, to other Government Departments, and to members of the public. The cores of the diamond-drill bores sunk to prospect the coal-measures of the Hikurangi district have been reported on; samples of coal from seams some two miles south of Glenhope have

* The memoir by Dr. Otto Wilckens, mentioned under the heading of "Palæontological Work," was issued after the end of the year dealt with in this report.

been examined; many rock specimens and minerals have been identified; and samples of clays from various parts of New Zealand have been received. The more important of the specimens have been handed to the Dominion Analyst. The Geological Survey is especially indebted to the Laboratory for the comprehensive analyses of a suite of rock-specimens collected by Professor R. Speight from Banks Peninsula, and for similar analyses of igneous rocks from the Whangarei and Waihi districts.

During the year Mr. G. E. Harris, draughtsman, drew eleven survey-district maps, four detailed geological maps, and several sections and plans to be reproduced by photo-lithography. In addition he prepared twenty-two field sheets and thirty-two tracings and drawings.

Library.

During the year numerous publications were received in exchange for Geological Survey bulletins. The library, which now contains about 6,500 volumes in addition to a large number of pamphlets, is invaluable for reference purposes to the members of the staff. A considerable proportion of the clerk's time is occupied in the care of the library and in the listing of additions to it.

Office and Laboratory Accommodation.

Ever since its reorganization in 1905 the Geological Survey has been cramped for accommodation. Seeing that the principal work is, or should be, research, the accommodation needed is not so much ordinary offices as laboratories—that is, workrooms. Adequate library and storage space is also needed. As time goes on, the methods of scientific research become more and more elaborate, and the need of equipment more pressing. Officers of the Survey are at present compelled to restrict research to lines that need little special plant and equipment. The reduction in efficiency resulting from this cannot be measured, but it is considerable. Probably opportunities to make valuable discoveries have already been lost; and it is certain that without up-to-date equipment the Survey cannot keep abreast of modern science, or be, as it should, a great factor in the development of the natural resources of this country.

SPECIAL REPORTS.

1. DARGAVILLE SUBDIVISION.

(By H. T. Ferrar, Geologist, and W. H. Cropp.)

Introduction.

The systematic survey of the North Auckland Peninsula, commenced by the senior writer in 1919, was continued during the past season. An area of some 543 square miles was surveyed at comparatively small cost, field expenses being considerably reduced, the work accelerated, and other economies effected by having two geologists with one field-party. The following survey districts—namely, Ruakaka, Tangihua, Maungaru, Kaihu, and Kai-iwi—in Whangarei and Hobson counties, were mapped between the 4th October, 1921, and the 8th May, 1922. This area will form part of the Dargaville Subdivision.

Physiography.

The area mapped is a strip of country, 12½ miles broad from north to south, stretching westwards across the North Auckland Peninsula from Marsden Point on the east coast to Bayly's Beach on the coast west of Dargaville. Physiographically, the area is a dissected peneplain of limestones, claystones, and sandstones, with an average height of 500 ft. above sea-level. From this plain rise fault-block mountains of greywacke and igneous conglomerates, which in part have been stripped of their covering of younger sedimentary rocks. The greywacke blocks are approximately 1,000 ft. high, but the igneous-conglomerate ranges rise steeply to heights of more than 2,000 ft. The higher peaks and more secluded valleys still retain their forest cover, but the greater part of the area has been almost completely denuded of timber. Where the soils are fertile the country is well grassed and forms excellent pasture, but where the land is poor it lies idle, the kauri forests having given place to fern and tea-tree.

The drainage of the area is simple in the main, but intricate in detail. The watershed between the east and west coasts lies close to the east coast, the main drainage eastward being by way of the Ruakaka and Waipu North rivers. The Waiotama, Tangihua, Tauraroa, Waiotira, and Mongonui streams drain the middle of the subdivision. The Northern Wairoa, draining the western portion, receives the Kirikopuni, Tangowahine, Awakino, and Kaihu streams from the north-west, and at Dargaville it broadens to an estuary, which merges into the northern part of Kaipara Harbour.

General Geology.

Prior to the present survey the area had been traversed by Hector in 1866 and by Cox in 1879. Their views as to the relative positions of the different rock formations require to be modified by the results obtained during the last few years. The account of the stratigraphy as detailed in last year's annual report holds good for the area under review. The uncertainty that still exists as to the precise age of the various beds will gradually diminish as the survey is extended. In order to solve several economic problems it is necessary to establish the sequence of the rock formations.

The oldest rocks are the greywackes of the Rangiora and Kukunui ranges, belonging to the Waipapa formation, which is regarded as of Trias-Jura age. These ranges lie in Ruakaka Survey District, near the east coast, and the formation soon disappears westwards beneath the covering of Notocene claystones and sandstones, which overlie the greater part of the subdivision.

The claystones and limestones of the Onerahi formation have yielded no further internal evidence as to their age. These beds are correlated with the Waiparan of other parts of New Zealand and tentatively regarded as Cretaceous. The formation, which covers comparatively large areas in the eastern and western parts of the subdivision, is present in small amount in the central part. Usually the deposits of Onerahi age are claystones, which give rise to very poor land, but occasionally they pass into argillaceous limestones, in places hard enough to serve as roadmaking-material.

The Whangarei formation is usually a somewhat barren sandstone, locally passing into crystalline limestone, the age of which has been determined as Miocene. The formation is correlated with the Oamaruian of the South Island. The sandstone, especially where it is calcareous, forms a soil which supports a good pasture. At two points seams of coal are present. The limestone-deposits form the most valuable mineral resources of the district.

Gravels and consolidated wind-blown sands, in places containing lignite, are correlated with the Purua beds of the Whangarei - Bay of Islands Subdivision, and are considered to be of Pleistocene age. The gravels occur mainly in the Wairoa Valley; the sand-dunes cover the area between the Kaihu Valley and the west coast. Recent deposits are represented by fertile alluvial tracts in all the valleys eastward of Dargaville, and in the area between Dargaville and the west coast by swamps containing kauri-resin.

Two types of igneous rock occur in the district. The Tangihua and Maungaru ranges, near the middle of the subdivision, and the Angiangi peaks, in the Kaihu Survey District, consist of igneous intrusions and conglomerates of post-Onerahi but pre-Whangarei age. The Tangihua and Maungaru ranges are block mountains probably formed during the Pliocene orogenic movements. The second type of igneous rock includes the basaltic lava-flows and scoria cone of Maungakaramea. To these rocks the high productivity of the soil of this prosperous district is largely due.

Economic Geology.

The systematic survey of the Dargaville Subdivision has shown that minerals of high commercial value are practically absent. In North Auckland the coal-measures have a sporadic development; and in the area dealt with in this report small quantities of coal are known to occur in two localities only—namely, near Waipu, and at Avoca, fifteen miles from Dargaville. The examination of those localities has shown that the coal-outcrops are of little economic value. That near Waipu is a remnant capping an isolated hill: it is of small extent, and is thin and impure. The Avoca outcrop is a small remnant of a once extensive seam. The greater part of the accessible coal here has already been marketed, and only a few cartloads of shattered material remain in sight.

Of first importance to settlers are the deposits of high-grade limestone occurring in different parts of the district. These deposits have been mapped, and estimates of the quantities available have been made. Notable localities are Takahiwai, on Whangarei Harbour; Waipu Caves; on the railway-line near Waikiekie; and in the Avoca district.

Large areas of hydraulic limestone suitable for cement-making have been traced inland from Wilson's (N.Z.) Portland Cement Works, and similar deposits in Hobson County have been partly delineated.

In the country to the west of Dargaville the swamp lands containing kauri-resin (commonly called "kauri-gum") have been differentiated from the consolidated dune-sands on which they rest. The resin-deposits are recent surface accumulations: they are not found intercalated in the aeolian sandstone beds. The mapping of this district provides a means of estimating the areas of those lands which contain kauri-resin in payable quantity, and which, when drained, will become productive dairy lands, and also the areas of land that could be made available for afforestation.

Since the productivity of the various soils of the subdivision depends largely upon the underlying rock formations, the geological map is virtually a soil-map. Six types of soil, each of which requires different treatment, are recognized.

Clays useful for brickmaking, and sands suitable for glassmaking and other industries, have been located during the course of the survey. In some localities roadmaking-material is difficult to obtain; the nearest source of road-metal for any particular point may often be determined by examination of the geological maps, which show the boundaries of the different rock formations.

2. THE WAIAPU SUBDIVISION.

(By M. Ongley and E. O. Macpherson.)

Introduction.

In the annual report for 1921 the survey districts of Arowhana, Tutamoe, and Hikurangi were reported on under the name of the "Tokomaru Subdivision"; to that area the districts of Tokomaru, Mata, Waipiro, Mangaoporo, and Waiapu have now been added, and for this larger area the name "Waiapu Subdivision" has been adopted. The following brief notes, based on evidence collected during the field season, may be added to the account given in last year's report.

It may be as well to mention in the first place that the geologist does not pretend to any mysterious power of finding mineral wealth or of indicating oil-well sites with gushers guaranteed, but proceeds by studying the rocks and indications exposed at the surface and comparing them with old-established mines and productive fields to estimate the probability of payable deposits being

found. In oil geology in particular, which is one of the youngest branches of economic geology, the geologist cannot guarantee payable production; but from a study of surface conditions he can estimate whether boring is justified, and what parts of the field are more favourable. If the best sites in a field are tested and found barren, then the field may be abandoned; but if, as in the Gisborne-East Cape district, a few wells located at hazard have not produced payable oil there remains a practically untested field.

From October, 1921, to June, 1922, the writers were in the field, and surveyed 540 square miles, which, with the addition of the 470 square miles examined in the previous season and the 1,102 square miles reported on in Bulletin No. 21, makes an area of 2,212 square miles examined in detail in the Gisborne-East Cape district. A relatively small area of possibly petroliferous country between East Cape and Cape Runaway has still to be explored.

Physiography.

The western part of the Waiapu Subdivision contains the crest and the eastern slopes of the Raukumara Range, which in places is more than 4,000 ft. high. East of the range hilly country from 2,000 ft. to 1,000 ft. high extends to the east coast. The even crests and flat tops of the ridges in the eastern half of the district indicate erosion from an extensive plateau. Above the general level the rugged peaks of Hikurangi (5,606 ft.), Aorangi (4,091 ft.), Wharekia, and Taitai (2,012 ft.) stand up sharp and steep.

General Geology.

The district consists of Mesozoic and Tertiary sedimentaries which contain many shallow-water beds and vary considerably laterally. The rocks can be divided into five series: Tawhiti Series, Te Arai Series, Taitai Series, Tapuwaeroa Series, and Raukumara Series.

The lowest rocks seen, the Raukumara Series, are dark, evenly banded greywacke, argillaceous sandstone, and arenaceous mudstone, folded into close meridional folds in the south-west, but in other places with open folds trending east and west. They form the Raukumara Range and the western part of the subdivision. The beds generally contain broken pieces of *Inoceramus*, in some places concentrated into bands of shell rock 1 ft. thick; occasionally large shells up to 3 ft. long were observed. As no underlying rocks were seen, the total thickness of these beds cannot be estimated, but in some places they are 8,000 ft. thick. Towards the top they vary. One conspicuous bed in the upper part is a thick massive or poorly bedded blue mudstone which contains occasional red bands. The beds pass upward into greenish- and light-coloured mudstones and argillaceous sandstones. The rocks of this series are moderately indurated and contain indefinite plant-remains; but they only exceptionally show traces of oil, and are regarded as lying below the main oil-beds.

In some places these rocks grade into the overlying series, but in others conglomerate bands containing pieces of the Raukumara beds form the base of the Tapuwaeroa Series. The rocks of this series are dark fissile shales, of which the more arenaceous bands are twisted and contorted, and the more argillaceous bands crushed and polished. With these occur bands of dark carbonaceous shale and coarser sandstone bands smelling of oil. In the Waiorongomai Valley and east of it the Raukumara beds are overlain by a series of grits, greenish and light shales, carbonaceous shales, and fine conglomerates, the equivalents of the dark fissile shales to the west and south. The Tapuwaeroa beds vary in thickness from 800 ft. to 1,800 ft., and cover large areas east of Ihungia Stream, and in the valleys of the Aorangiwai, Tapuwaeroa, and Waiorongomai rivers. Fossils collected from these beds indicate that they are Upper Jurassic in age.

In the Tapuwaeroa Valley coarse conglomerates with igneous boulders and hard dark sandstone, 2,000 ft. thick, lie unconformably above the dark fissile shales. These rocks, here called the "Taitai Series," form the summits of Hikurangi, Aorangi, Wharekia, and Taitai. The sandstone occurs again at the foot of Whakoau, in Hauturu Creek, in Ihungia Creek, at Puketiti, and close to Te Puia. Above it lie, in ascending order, dark mudstones, greenish and light shales, fine conglomerates and grits, light-blue mudstone, greensandstone, and chalky limestone. These beds are thought to be of Cretaceous age.

Tertiary strata, in places more than 10,000 ft. thick, unconformably overlie the Cretaceous rocks. They consist of a lower argillaceous series and an upper arenaceous series.

Oil-indications.

The Taitai and Tapuwaeroa beds generally, but the Upper Jurassic and Tertiary only exceptionally, show evidences of oil. In addition to the indications mentioned in last year's annual report, the following are worth noting:—

(*a.*) *Seepages of Oil.*—An oil-seepage has been known at Rotokautuku for more than half a century, and led the Southern Cross Petroleum Company to bore there in 1881–83. At the present time gas and salt water are rising from the old shaft, and each gas-bubble brings to the surface a film of oil.

(*b.*) *Asphalt Deposits.*—In sandstone at the top of the Tapuwaeroa beds thin irregular cracks, $\frac{1}{20}$ in. thick and several inches long, are filled with a dark pitch.

(*c.*) *Evolution of Gas.*—Many small gas-vents occur scattered throughout the subdivision. Samples from twenty of these have been analysed, and all are "wet," the ethane they contain ranging up to 22 per cent. A "wet" gas contains appreciable quantities of hydrocarbons higher in the series than methane, while a "dry" gas consists almost entirely of methane. Wet gas is everywhere considered a favourable indication of oil. "It is obvious that the heavier and wetter a gas the more favourable the evidence of the presence of oil in the neighbourhood. Though there may be steady and brisk flows of gas or gas-wells at a locality, it does not necessarily prove that oil

can be obtained by drilling there; but, should the gas be heavy with a fair percentage and a strong odour of hydrocarbons higher in the series than methane, the prospector will be justified in concluding that a body of liquid hydrocarbon is somewhere in the neighbourhood."*

(*d.*) *Outcrops of Bituminous Strata.*—Throughout the district sandstone bands and dark carbonaceous shales smelling of oil occur plentifully in the Tapuwaeroa and Taitai beds. Exceptionally, near the contact with the oil rocks, the basal Tertiary and upper part of the Raukumara Series smell of oil.

(*e.*) *Manjak, Ozokerite, &c.*—Ozokerite, the solid residue from the inspissation of paraffin oil beneath the surface, has been reported to occur at Rotokautuku. Skey† showed that it is not ozokerite, but a grease formed out of some of the constituents of petroleum by oxidation and absorption of water, and gave it the name of "dopplerite."

These oil-indications justify the conclusion that a body of liquid hydrocarbons exists in the district. Whether the oil is concentrated in payable quantities can, of course, be determined only by drilling. Haphazard drilling is, however, too risky and too expensive; and modern oilfield practice is based on geology as the only means in advance of drilling by which anything of the underground conditions can be ascertained.

The work so far done has eliminated the country covered by the lowest (Raukumara) rocks and by the highest (Te Arai and Tawhiti) rocks as unfavourable, and has shown that the middle (Tapuwaeroa and Taitai) rocks, although not folded into broad domes or gentle anticlines or other simple ideal structures, are in places favourably disposed for the accumulation of oil in quantity.

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3. OHURA SUBDIVISION.

(By L. I. Grange.)

Introduction.

During the field season which lasted from October, 1921, to the middle of May, 1922, the following survey districts were examined in detail: Aria, Tangitu, Rangi, Piopiotea West, and parts of Waro and Ohura, containing in all about 400 square miles. This area, together with the adjoining "Tangarakau Subdivision" examined last year by Mr. H. A. Ellis, is now termed the "Ohura Subdivision." This season Mr. Ellis was in the field from October to the middle of November.

Physiography and Structure.

At the close of the Tertiary period the rocks of the subdivision were considerably faulted. Two main faults, each of large throw, divide the area into three north-westerly-dipping blocks and determine in part the boundary of the coal-bearing strata. These are the Ohura fault, which, trending north-eastward, can be traced from immediately west of Ohura Township to Matiere and Waimiha; and the Aria fault, which extends south-south-west from Morgan's Greencastle Mine, in the north-west of the district, to the head of the Panirau Stream. Many faults striking north-east and north-north-east traverse the major earth-blocks. Denudation subsequently destroyed in great part the physiographic evidence of structure. The area consists chiefly of uplands of moderate altitude produced by later elevation and erosion.

General Geology.

The oldest rocks of the Ohura Subdivision are Tertiary mudstones and alternating sandstones and mudstones continuous with the Mahoenui beds of the adjacent Mokau district. They are followed by massive sandstone layers, which are in turn succeeded by argillaceous sandstones. The whole series, which corresponds with the Mokau Series of the Mokau Subdivision, is over 1,000 ft. thick. In the western part of the district the massive sandstones contain coal-seams which, in at least parts of the area, thin to the east. Where the coal-measures are absent there is evidence of an unconformity at the base of the series. Overlying the Mokau Series, in most places conformably, are beds placed in the Mohakatino Series. In Tangitu, Rangi, and Piopiotea West survey districts an erosion interval is indicated at the contact by a band of conglomerate averaging 9 ft. in thickness, made up of sandstone and mudstone boulders and a few greywacke pebbles, as well as by the slightly uneven surface of the underlying beds. Fully 700 ft. of strata, consisting principally of mudstone, in which occur bands, lenses, and nests of andesitic tuff, compose the Mohakatino Series. The Tertiary sequence is closed by argillaceous sandstone, 70 ft. thick, which outcrops in two small areas in the north-west of Aria Survey District. This represents the Tongaporutu Series.

The rhyolitic breccia of the Ongarue Valley, near Waimiha, and of the high ridges farther west, the weathered brown pumice sprinkled over many of the upland slopes, and the white unconsolidated pumice of the terraces of the Ongarue and Wanganui rivers, form the Pleistocene and Recent deposits.

Economic Geology.

Coal.—The outcrop portion of a large coalfield, an extension of the coal-measures of the Mokau and Tangarakau districts, has been mapped in the Waitewhena, Panirau, Paraheka, and Mangaohutu valleys. The field extends almost continuously from the north to the south of the subdivision. Except for small areas capping high ridges, it is bounded on the west by the Aria fault; but to the east, at no greater distance than four miles from this fault, the coal thins out and is not present farther eastward, although what is believed to be the coal-horizon was observed at many points. The coal-measures are about 70 ft. thick, and in places contain several seams, of which the lowest is always the main seam, the upper seams rarely exceeding 5 ft. in thickness.

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* E. H. Cunningham Craig: "Oil-finding," p. 165, 1920.

† Trans. N.Z. Inst., vol. 14, pp. 397–99, 1882.

In the Waitewhena Valley, north of Ohura, the thickest coal occurs on the western side. Marco Creek and Mangarohe Stream show a practically continuous outcrop of a seam nowhere less than 10 ft. thick. From the Mangarohe Stream north to the bridge over the Waitewhena the thickness varies from 12 ft. to 9 ft. Directly east of Wa Trig. the coal thins to less than 6 ft., but thickens to 12 ft. at Knight's Mine, 38 chains north-east of the trig., and extends 60 chains farther northward with an average thickness of 9 ft. Near the source of the Waitewhena Stream the coal, here from 5 ft. to 10 ft. thick, as it approaches the Aria fault has a strong dip to the east. In the Pura Stream, immediately south of Marco Creek, most of the outcrops show more than 6 ft. of coal, but south from this locality the seam is usually less than 6 ft. in thickness. On the eastern side of the Waitewhena Valley a thick seam can be traced from the mouth of Awawaro Stream for 55 chains to the south, but elsewhere few exposures of coal are more than 6 ft. thick.

The headwater streams of the Panirau, a large branch of the Mokau River, rise on the main ridge west of Waitewhena Valley. In this locality are many outcrops of coal, almost all over 6 ft. and most of them at least 10 ft. thick. From north to south, as the crow flies, these outcrops occur over a length of four miles. There is a large amount of workable coal in the ridge between the Waitewhena and Panirau basins.

In the Paraheka Valley the best outcrops extend from 14 chains north-north-east of Pukerewa Trig. south along the edge of the Aria fault to east of Munro Trig., a distance of about one mile. Here five outcrops of 8 ft. or more were observed. The seam dips strongly to the east, and in a short distance passes below drainage level. Two miles eastward, where the coal-horizon is again brought to the surface by faulting, no coal is present. In this locality the amount of workable coal to the dip can be determined only by boring.

At a point in the Mangaohutu Valley, about two miles and a half south-east of Aria, a coal-seam fully 17 ft. thick has been worked by Mr. A. Morgan from adits. A few chains from the entrances to the mine the seam is cut off by a north-north-east-striking fault, east of which it has not yet been found. An outcrop showing 6 ft. (no roof observed) of coal, 50 chains west-south-west from the mine and 230 ft. above it, probably belongs to the same seam. Fifteen chains north from this outcrop a seam at the same high level is indicated by fragments of coal; but farther to the north no trace of coal was observed at or near this height. The evidence indicates either that the higher seam has thinned just north of the coal-fragments and that the seam worked in Morgan's Mine is in a down-thrown block, or that another fault lets down the strip of country between the fragmentary coal and Morgan's Mine to below the level of the worked seam. Owing to the covering of bush and heavy fern and manuka, prospecting is difficult.

Roadmaking-material.—The subdivision is poorly supplied with good roadmaking-material. At present the bulk of it is obtained from the beds of the Mangakara Stream and of the Ongarue and Wanganui rivers. In the Pura Valley a bed of conglomerate lying above the coal, consisting of greywacke pebbles loosely held together by sandstone, is now being opened up by the Ohura County Council. A similar deposit in the Weraroa Stream is four miles and a half from a road. The bands of mudstone and sandstone cemented by calcite, outcropping near the end of the Waitetaura Road, Tangitu Survey District, would make a fair road. A concretionary band at the base of the sandstone of the Mokau beds, where the coal is absent, and the conglomerate at the base of the Mohakatino beds contain too many comparatively soft sandstone boulders and pebbles to form a good road-surface.

4. TE PUKE GOLDFIELD.

(By P. G. Morgan.)

Between the 24th and 28th November the writer visited Te Puke in order to examine the area south-west of the township where mining is at present being carried on by Muir's Gold-reefs (Limited). The new treatment plant, consisting of a 20-stamp battery with five tube mills and a modern cyanide plant, had just been erected, and crushing with three shifts began about the 1st December. The battery is situated a little to the north-east of the main adit (No. 2 level), and is approximately 440 ft. above sea-level.

The area containing the lodes worked or proposed to be worked by the company is included in the Te Puke Mining District as demarcated by J. A. Bartrum.* In his report Mr. Bartrum describes the rocks enclosing the Te Puke lodes as consisting wholly of hypersthene augite andesite, but samples of the wall-rock of Muir's reef, the lode now being worked, appear under the microscope to be quartz-andesite (or dacite) tuff, more or less silicified. One section shows fragments of spherulites. The sections have not been closely examined, and possibly in part they represent lavas brecciated during or after consolidation rather than true tuffs. This question is of little account from a mining point of view, but the presence of quartz-grains and of spherulites, linking the rocks examined with the dacites, is noteworthy. Of equal or even greater importance is the occurrence of the variety of potash feldspar known as "valencianite" in the little veinlets that traverse the sections, and the almost total conversion of the original lime-soda feldspars into secondary potash feldspar. Thus the wall-rocks of the Te Puke lodes are found to have undergone exactly the same kind of alteration as the wall-rocks of the Waihi lodes.

Muir's lode, as seen in the bottom or No. 2 level, in the intermediate level, and in No. 1 level (about 200 ft. above No. 2), is a promising ore-body. It strikes a little east of north, and dips at

* J. A. Bartrum: "The Geology of the Te Puke District," N.Z. Geol. Surv. 7th Ann. Rep., C.-2, pp. 133–42, 1913, with map.

80°–85° to the east. The usual thickness appears to be 3 ft. to 5 ft., but in places it widens to 14 ft. or more, and at the north end of the various levels is small. At the north end of No. 2 level the ground is disturbed, and at the present south end there is a considerable fault.

The lode has been opened up for a length of perhaps 800 ft. at No. 2 level, the mouth of which is, roughly, 440 ft. or 450 ft. above sea-level. Payable ore is reported to occur for almost the whole of this length. A winze sunk from No. 2 level to a depth of 101 ft. is also stated to carry payable though not rich ore. The quartz in places is much stained by black oxides of manganese; some is almost pure-white, some cream-coloured or brownish. Much of the quartz shows wavy bands of varying colour; some is fibrous-looking, some flinty. Every variety has its counterpart at Waihi, and, in short, the quartz so greatly resembles the oxidized ore of the Martha Hill at Waihi that hand-specimens from the two localities cannot be distinguished.

At the No. 1 or uppermost level a small but rich branch lode has been developed to some extent. A 6 in. vein was intersected in the main adit (No. 2 level) about half-way between the mouth and Muir's lode.

About 800 ft. west of Muir's lode is the nearly parallel Te Puke or Fleming's lode, a massive body of quartz which outcrops prominently on the crest of Fleming's Hill, and has therefore been well known for many years. It dips eastward, rather less steeply than Muir's lode, and will probably join it in depth. Fleming's lode is from 10 ft. to 60 ft. thick, and the quartz, like that of Muir's lode, is of exactly the same appearance as that of the Martha lode at Waihi. Many years ago several prospecting-adits were driven from the hillside into Fleming's lode, but the existence of payable ore in any quantity was not proved. In later years Mr. George Muir drove a crosscut through the lode not far below its outcrop, and also drove along the footwall for about 200 ft. The quartz from this footwall drive was in part payable.* Somewhere about the middle of Fleming's lode there is another band of quartz that is reported to be payable.

The further exploration of Fleming's lode is well worth while. There is a fair probability that one or more shoots of payable vein-matter will be found, and there is a possibility of both large and rich ore-bodies being found at some little depth.

Nearly a quarter of a mile south-south-west of the top of Fleming's Hill is an outcrop of bluish-coloured pyritic quartz. This is known as the "blue reef." It is probably a continuation of Fleming's lode, but does not look promising. A few chains farther south-south-westward a massive outcrop of quartz or silicified rock appears on the west side of a small rill draining to the Raparapahoe Stream. This is not known to contain more than traces of gold and silver.

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5. THE PROGRESS MINES OF NEW ZEALAND.

(By J. Henderson.)

According to instructions I recently visited Reefton and examined the plans and claim of the Progress Mines. Owing to no work having been done in the mine for some months, water had accumulated in the lowest level and foul air in all, so that I was unable to examine the mine-workings. I had, however, visited the mine on several occasions between 1902 and 1914, and have personal knowledge of most of the excavations opened up to the latter date. The amount of exploratory work undertaken since 1914 has been comparatively small, so that the geological sections prepared by the mine staff, together with the statements of Mr. R. Stewart, mine-manager, have enabled me to form an idea of the country and structures exposed in such excavations as I have not seen. This work occupied me from the 1st to the 13th September, 1921, inclusive. It has not, in any essential, altered the opinion formed fifteen or sixteen years ago, that the lode had been cut off in depth by a north-north-west-striking fault, west of which, and at a higher level than the deepest workings, its continuation must lie.

The leases worked by the Progress Mines Company are some four miles south-south-east of Reefton, and occupy part of an extensive plateau now deeply dissected by drainage-channels. In the neighbourhood of the mine the general level of the plateau is from 1,650 ft. to 1,800 ft. above the sea, although the hills near-by rise to over 2,000 ft. The leased area is drained for the most part by Devil Creek and its branches, Oriental, Progress, Union, and Fossicker creeks, which flow in narrow steep-sided valleys up to 600 ft. deep. The present company has held this ground for about twenty-five years, in which period £326,562 has been paid in dividends. A further sum of £68,780 had already been distributed by companies that, prior to 1896, held parts of the same area. In all, over a million tons of ore have been extracted from the claims, all from the Progress lode, and this ore has yielded over £2,000,000 in gold.

On the surface the Progress lode, which outcrops along the south side of Oriental Creek, has a general east-and-west trend, except at its eastern end, where the strike is nearly east-south-east. Its dip is southward at about 60°. In depth, however, the length of lode having a south-easterly course increases at the same time as that striking east decreases. Thus in No. 8 level, about 1,000 ft. below the surface, the general strike is south-east and the dip south-west. The lode, which occupies a fissure in the rocks, consists of a number of separate shoots of gold-bearing quartz; the intervening portions of the fissure are filled with crushed country traversed by small quartz veins. Where the lode strikes east the shoots extend directly down the dip. Where the shoots enter a part of the fissure striking south-east, in addition to their dip, they have a southerly pitch. Thus, in spite of a change in course of the fissure, the shoots in plan have a nearly north and-south extension. Although decidedly irregular, the shoots, in a general way, like the shoots of the other mines of the Reefton goldfield, maintain their size and gold-content to the greatest depths reached by mining in this district.

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* See Mines Statement, C.–2, p. 18, 1918.

Eight or nine shoots belonging to the Progress lode are known on the surface, but some of these have been little explored in depth owing to their consisting of low-grade quartz. Thus the most westerly shoot, known as Smith's, has not been prospected below No. 2 Old Progress adit. Next to the east is the Progress shoot, which has been mined to a depth of 1,100 ft. (from the surface to 50 ft. below No. 9 level), where it abruptly terminated. It was from 75 ft. to 200 ft. long, about 12 ft. thick, and contained good-grade ore. The Dam shoot, still farther east, averaged 180 ft. long by 12 ft. thick. It dipped regularly nearly to No. 9 level, where it flattened and, undulating gently, continued southward for over 500 ft. It extended for some distance below No. 9 level, but does not appear to have been definitely traced to No. 10 level, although some small irregularly placed ore-bodies at this horizon may perhaps be referred to it. The behaviour of the shoot between Nos. 8 and 9 levels and its termination below No. 10 level are undoubtedly due to faulting. Near the surface, east of the Dam shoot, are two shoots known respectively as the West and Middle shoots. Down to No. 5 level these are separate, but in No. 6 level they unite to form one ore-body equal in size to the combined shoots. This continued more or less regularly to below No. 9 level. Since the Middle shoot was the more important in the upper levels, this name is retained for the combined shoot found in the deeper levels. Although a large amount of high-grade ore was obtained from this shoot, much of the quartz contained too little gold for profitable working. Callaghan's block in Nos. 8 and 9 levels is evidently part of the Middle shoot, but in and below No. 8 level the shoot is much broken, so that the relation of the detached and irregularly disposed masses of quartz of the lower levels to one another and to the regular shoots is in many cases uncertain. The Pioneer block, which yielded the bulk of the ore won from Nos. 10 and 11 levels, is probably the downward extension of the Middle shoot. The Winze block and the South block are undoubtedly fragments broken by fault-movements from the Pioneer block. The East shoot, which outcrops on the surface about 150 ft. east of the Middle shoot, has been definitely traced to No. 9 level. Probably also some of the large and little-explored bodies of low-grade quartz found in the most south-easterly extensions of Nos. 10 and 11 levels belong to this shoot. In the upper levels the strike of the shoot is nearly east, but in Nos. 5 and 6 levels it is north, so that here and in the lower levels it is known as the North-and-South shoot. It consists of two or three parallel quartz-bodies, one of which in places is over 30 ft. thick, but the others are not more than 6 ft. In some levels it is 200 ft. long, but it is usually not more than 150 ft. Prospecting has shown that the shoot contains only a small amount of payable ore, and in consequence little exploration has been undertaken below No. 9 level. Another shoot outcrops about 200 ft. south-east of the shoot above described. On the surface it strikes a little south of east, but in Nos. 3, 4, and 5 levels its course is nearly north and south. Two parallel ore-bodies, called John's and Far East shoots, are known. The quartz contained little gold, and the shoots have not been looked for below No. 5 level.

In the upper levels all the shoots dip at about 60°, but in depth, with the exception of the Progress shoot, they flatten considerably. All except the two most easterly, which, on account of their low gold-content, were not explored in the deepest levels, were found to terminate in depth against a fault-zone. This fault is best exposed in No. 10 level, where it has been penetrated by four crosscuts, from each of which it has been explored for considerable distances. The position and course of this fault at the horizon of No. 10 level have thus been definitely determined. It is variously known as the Chemist Shop, West, or Main fault, and was first definitely recognized in No. 11 level, in which it bounds the Winze block on the west. Much quartz was broken from the Winze block during fault-movements, and is now distributed along the fault above the Winze block as drag-quartz. In this part of the fault drag-quartz is abundant to No. 10 level, where, in the drives from the No. 10 main west crosscut, a leading stope was taken off to ascertain if the mixture of auriferous quartz and crushed country was payable. The explorations between Nos. 10 and 11 levels proved that the fault dipped east-north-east between 65° and 70°. Further information on this point is furnished by a vertical diamond-drill hole sunk from a point in the main crosscut of No. 11 level a little over 200 ft. from B shaft. From 886 ft. to 905 ft. this bore passed through intensely crushed country, which is almost certainly part of the plane of the Main fault. The dip of the fault between No. 10 level and this point is about 67°. A belt of intensely crushed country crosses the Old Progress No. 2 adit (890 ft. above No. 10 level) about 700 ft. from the portal. This is evidently the Main fault at this horizon. No other known underground workings cross the fault at this horizon, but the fracture can readily be traced on the surface along the valley of Devil Creek above its junction with Union Creek. Southward the fault takes a south-easterly course and follows Devil Creek Valley. To the north the fault was traced on the surface over the spur between Devil and Oriental creeks and along the valley of the latter stream.

Mr. R. Bullman, formerly surveyor for the Progress Mines, in an unpublished report has suggested that the fault here considered is a reversed fault—that is, that the hanging-wall side, in this case the country east of the fault, has moved upward in respect to the footwall. All the evidence is against this view. In nearly all faults the hanging-wall is displaced downward with respect to the footwall, and such faults are called normal. The friction of one rock-mass on the other crushes the country near the fault-plane, induces fractures in the neighbourhood of the fault, and tends to cause the rock near the fault to be relatively less displaced than that farther away. Quartz broken from the ore-bodies severed by the fault is "dragged" and distributed along the fault, the direction in which it extends indicating the direction from which the known ore-body has moved. Thus drag-quartz above the south block extended from between Nos. 10 and 11 levels to No. 9 level, a distance of 150 ft. vertical. Above the Winze block it extends higher along the fault-plane than No. 10 level. Clearly the severed edges of the Winze and South blocks, which are fragments of the Middle shoot, lie, on the west side of the fault, at a higher horizon than the known Winze and South blocks. The flattening of the shoots as they approach the fault is to be attributed to bending and the distortion of the rock-mass near the fault owing to the great friction. The fact that the lode flattens as the fault is approached indicates

that the country containing the known part of the lode, and east of the fault, has been let down relatively to the country west of the fault. The numerous faults that traverse the country close to the Main fault are probably in large part subsidiary fractures produced by the distortion and shattering of the country. Some information is available in regard to several of these faults, which strike and dip in all sorts of ways, but since their nature and distribution in no wise affect the position of the lode beyond the Main fault they need not be further discussed.

There can be no doubt that the Progress lode is cut off in depth by a fault, which, striking north-north-west and dipping east-north-east, has depressed the block of country east of the fault, in which is the known part of the Progress lode, relatively to the country west of the fault and forming its footwall. The bulk of the writer's work on this visit was directed to tracing the Main fault on the surface and to ascertaining to what extent the footwall country was shattered. In Oriental Creek, west of the fault, the rocks are much crushed, as is also the case along Devil Creek from the junction of Union Creek, 20 chains down-stream, to a point 10 or 12 chains west of the Old Progress battery. The presence of this crushed country caused the writer to state some years ago (N.Z. Geol. Surv. Bull. 18, 1917, p. 159) that the belt of disturbed country west of the Progress workings was 25 to 30 chains wide. A closer examination has shown that the crushing of the strata in Devil's Creek west of Union Creek junction is due to a fault striking along the stream-valley a little north of west and dipping steeply northward. This fault is thought to have been formed at the same time as the Main fault. The west crosscut from No. 10 level west of the Main fault penetrated disturbed country, which became more broken the farther west it advanced. According to Mr. R. Stewart, the last 160 ft. of the crosscut followed an east-and-west "track" or fracture along intensely crushed strata. In other parts, however, the footwall country is relatively unbroken. Thus No. 2 Old Progress adit is driven through greywacke, solid save for a few minor pug bands. Fossicker Creek, immediately south-west of the Main fault, for more than 20 chains traverses unbroken and regularly dipping strata. The road along Progress Creek exposes a section in which the regularly dipping strata are traversed by two or three minor fractures. Thus, except for the east-south-east-striking fault along part of the valley of Devil Creek, the country immediately west of the Main fault is, on the surface, almost undisturbed. In depth, in the neighbourhood of the lode where the country is softer and less resistant, there will probably be more disturbance near the fault than at the surface. But such disturbance should offer no great difficulties to prospecting and mining, seeing that the ore was followed right up to the main fracture through a wide belt of country shattered alike on the surface and in depth next the lode.

The amount and direction of the displacement along the Main fault are important matters, and unfortunately there is little evidence bearing on these points. On direct underground evidence the vertical displacement is at least 150 ft. Surface features near the outcrop of the fault on the ridge between Devil and Oriental creeks suggest a vertical movement of about 200 ft. But this estimate is not reliable. The horizontal component of the fault-movement is not likely to be great. The change in direction of the fault forms a slight embayment in the footwall mass, from which the corresponding projection in the hanging-wall mass would not readily be displaced. For this reason the amount of horizontal movement along the fault-plane was probably small, and any horizontal movement that did take place would shift the hanging-wall mass containing the known part of the Progress lode a little northward relatively to the footwall block.

The average battery extraction from the ore of the Progress lode was about £2 per ton, and a yield of this amount from large ore-bodies such as characterize the Progress shoots is payable even with the present abnormally high costs of labour and materials. The ore won from the lode during the last dozen years has been of decidedly lower grade, for the reason that the bulk of it was mined from the Middle shoot, which, on the whole, contains a lower proportion of high-grade ore than the Progress and Dam shoots. These latter were cut off by the Main fault at a less depth than the Middle shoot, and so were exhausted earlier. It is axiomatic in mining that the largest and richest ore-body has a limit in depth. But some types, to which those of the Reefton district belong, are much more persistent than others. As far as the lodes of the Reefton mines are concerned, all have maintained the size and gold-content that characterized them near the surface.

The explanation advanced for the termination of the Progress shoots in depth could be most cheaply tested by diamond-drilling from the surface. If the mine were working, prospecting from suitable points in Nos. 9 and 10 levels would be recommended; but if the whole cost of the maintenance of a surface staff is to be added to the prospecting cost the increased depth of drilling from the surface would be more than offset. Diamond-drilling in the Progress Mine has hitherto not been found a satisfactory method of prospecting, for the reason that nearly all the drilling has been done in the much-disturbed country east of the Main fault. In such country the cost is high and cores are difficult to obtain. Better results would undoubtedly be obtained in less broken country. Two sites, one on either side of Devil Creek, and a chain or so on the footwall side of the Main fault, are suggested, so that boring through the east-south-east fault along Devil Creek may be avoided. From the boring-sites, holes parallel with the plane of the Main fault should radiate so as to explore the country west of the fault and above the points where the shoots were cut off, the bores from the more northerly position being all north of the Devil Creek fault, and those from the southern all south of it. The boring-sites will be from 1,250 ft. to 1,350 ft. above sea-level, according to the position selected. The three principal shoots terminated against the Main fault at varying depths, the Progress shoot (50 ft. below No. 9 level) at 520 ft. above sea-level, the Dam shoot (about No. 10 level) 420 ft. above sea-level, and the Winze and South blocks parts of the Middle shoot (about 60 ft. above No. 11 level) 330 ft. above sea-level. To obtain the heights at which the downward extensions of the shoots reach the fault-plane the amount of the vertical displacement must be added. This is an unknown amount, but is at least 150 ft. But it is advisable that the bores

should be extended nearly to the horizons at which the shoots were cut off. The bores should be so directed that they will not, at each of these horizons, be more than 200 ft. apart. It should be noted that the lost part of the Progress shoot lies considerably to the north-west of the Dam and Middle shoots and thus its position cannot economically be determined from bore-sites in Devil Creek. If, however, the position of any shoot of the Progress lode west of the fault should be determined the location of other shoots becomes simple.

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6. THE CHERTSEY OIL-BORE.

(By J. Henderson.)

An account of the oil-bore near Chertsey Railway-station has already been given (see N.Z. Geol. Surv. 14 Ann. Rep., C.–2c, p. 8, 1920). The well was again visited on the 15th and 16th September, 1921, and the following additional information obtained.

The well had reached a depth of 2,170 ft. when quicksand showing a little thick oil was penetrated, and rushed up the bore several hundred feet. This caused the company to abandon the well, and a general meeting of shareholders held on the 20th September passed a resolution that the affairs of the company be wound up. When visited the 2½ in. casing had been withdrawn and the 4 in. casing was being cut.

In all 230 tons of casing were used—namely, 18¼ in. casing to a depth of 220 ft., 16 in. to 319 ft., 14 in. to 680 ft., 12 in. to 895 ft., 10 in. to 1,050 ft., 9 in. to 1,220 ft., 7½ in. to 1,485 ft., 6 in. to 1,605 ft., 5 in. to 2,067 ft., 4 in. to 2,132 ft., and 2½ in. to 2,170 ft.

Log of Chertsey Bore (10 ft. below railway-station level—354 ft.). Drilled by the Canterbury Petroleum Prospecting Company, 1914–21.

Feet.	
0– 319	Loose gravel and boulders; water-level at 230 ft.; at 190 ft., clay band with little water above.
319– 515	Conglomerate gravels.
515– 534	Loose gravel; water-level at 230 ft.
534–1,056	Hard conglomerate gravel, cemented.
1,056–1,171	Clay and boulders.
1,171–1,172	Loose gravel; water-level at 360 ft.
1,172–1,355	Gravel with large boulders.
1,355–1,368	Dark blue (clay ?) with boulders.
1,368–1,370	Brown sand and clay showing gas (CO_2) and oil of tarry nature.
1,370–1,374	Sand and gravel; oil and gas (CO_2); water-level at 360 ft.
1,374–1,387	Dark-coloured sandy clays.
1,387–1,396	Sand; gas (CO_2).
1,396–1,397	Dark-coloured sand showing heavy petroleum butter and inflammable gas.
1,397–1,420	Blue clay with streaks of sandstone gravel.
1,420–1,423	Sand.
1,423–1,437	Clay and gravel.
1,437–1,443	Sandy gravel; gas and oil shows in sludge; water-level at 360 ft.
1,443–1,447	Brown clay.
1,447–1,456	Gravel; water-level at 360 ft.; inflammable gas.
1,456–1,502	Clay mixed with gravel.
1,502–1,506	Sandy gravel; gas; water-level at 360 ft.
1,506–1,512	Clay and gravel.
1,512–1,524	Gravel with large boulders; water-level at 360 ft.; gas.
1,524–1,605	Gravel mixed with clay.
1,605–1,690	Gravel with more clay in it.
1,690–1,695	Dark-coloured clay.
1,695–1,745	Hard conglomerate gravel; shows oil and gas.
1,745–1,782	Brown clay streaks, sand, and gravel; gas and oil.
1,782–1,812	Hard boulder conglomerate.
1,812–1,864	Brown sandstone grits, streaks clay, and sand; water-level at 360 ft.
1,864–1,905	Yellow clays showing streaks blue- and lighter-coloured clays.
1,905–1,998	Sandy and clayey conglomerate gravels.
1,998–2,025	Hard blue clay.
2,025–2,028	Sandy brown clay.
2,028–2,040	Blue and yellow clay with large boulders.
2,040–2,111	Blue and yellow clay.
2,111–2,124	Hard blue clay.
2,124–2,130	Grey-blue quicksand.
2,130–2,170	Hard blue clay; below 2,170 ft. quicksand with gas (CO_2) and oil shows; runs in badly; water-level at 470 ft.(?)

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7. PETROLEUM AT WAIOTAPU, ROTORUA DISTRICT.

(By P. G. Morgan.)

On the 25th January, 1922, I visited the oil-seepages occurring on the east or left bank of Waiotapu Stream, in Section 4, Block 3, Paeroa Survey District. The ford on the cross-road between the Galatea and Taupo roads is just up-stream, so that the locality is easily reached.

The oil-seepages occur on a small sinter terrace, perhaps 25 or 30 yards long and 10 or 12 yards wide, which is only a foot or two above the level of the stream. Here are numerous roughly circular holes, of an average diameter of 12 in., filled with hot water, through which rise bubbles of non-inflammable gas. The water in the holes is covered with irridescent oil films, and, as it is sufficiently hot to cause fairly rapid evaporation of the volatile and semi-volatile fractions of the oil, the supply of oil must be continually renewed. Round each of the holes is a thin ring or coating of dark material, representing the solid constituents of the oil. This is dark-brown to black in colour; the darker portions resemble pitch, and melt and ignite readily. In the stream-bed at the ford a few yards away large bubbles of non-inflammable gas rise to the surface. Each of these bubbles carries with it a little oil, which floats down-stream as an irridescent film. If the lumps of siliceous sinter and other debris on the edge of the stream are disturbed, globules of amber-coloured oil rise and float away.

Presumably the gas contains some inflammable ingredients; but many trials with lighted matches failed to give any sign of ignition, and therefore the gas must consist chiefly of non-inflammable constituents, such as carbon dioxide or nitrogen. Other gas emanations are reported to occur in the bed of Waiotapu Stream, especially toward Lake Ngahewa, to the north-west of the point examined, but I could not learn that any of these consisted of inflammable gas.

The surface rock at Waiotapu is a poorly consolidated rhyolitic tuff, which, as in many similar occurrences elsewhere in the Taupo-Rotorua district, was observed to contain numerous fragments of carbonized wood. This carbonized wood has, roughly, the composition of brown coal, and, like brown coal, on being distilled at moderate temperatures would yield more or less oil and gas. The origin of the petroleum is therefore very easily explained. The water of Waiotapu Stream is warm (temperature probably well over 90° F. on the day of my visit), and a large percentage must be supplied by hot springs, which derive their heat from the rocks they traverse. Vast masses of heated rhyolitic tuff must underlie the whole or part of the basin of Waiotapu Stream. Not far below the surface the thermal waters are well above normal boiling-point. The adjoining rocks are probably as hot, and the contained wood and other vegetal matter, subjected to this heat, give off the oil that reaches the surface. Dr. J. M. Bell, formerly Director of the Geological Survey, in a memorandum dated 21st November, 1910, suggested a similar explanation for the oil occurring in the Waiotapu district.

It follows from this explanation that the possibility of oil occurring in the immediate vicinity of Waiotapu in commercial quantities is very small.

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8. NATURAL GAS IN HAURAKI PLAINS.

(By J. Henderson.)

The whole of New Zealand within a geologically late period was at a decidedly higher elevation in respect to sea-level than at present. Then, as now, the low-lying areas were smothered in swamps. These, as the land sank, were covered by layers of sand and mud, and now form the peaty and carbonaceous bands passed through by the numerous bores drilled for water on the Hauraki Plains. Surface swamps and muds containing plant-fragments give rise to marsh-gas, and this inflammable gas continues to be produced after a swamp is covered. The "firedamp" of coal-seams shows how long it may remain imprisoned underground. Undoubtedly the inflammable gas issuing from the bores on the Hauraki Plains consists in great part of marsh-gas.

The officer in charge of the drainage-works on the Hauraki Plains, in his report for the year ended 31st March, 1910, gave the logs of two bores drilled for water, one at Pipiroa, near the mouth of the Piako, the other at Orchard, half-way between that township and Kerepehi. The first passed through 391 ft. of pumiceous sands and muds containing one 4 ft. layer of "peaty swamp," 200 ft. from the surface; the other, 435 ft. deep, penetrated similar strata containing five bands of "peaty mud."* Inflammable gas, however, is not mentioned in this report.

Similar occurrences of "natural" gas in New Zealand may be briefly described. At Horotiu, between Hamilton and Ngaruawahia, several bores were sunk about the year 1914 in the hope of reaching coal. No coal was found. The deepest bore penetrated 740 ft. of pumiceous sands and silts similar to, though more compact and probably somewhat older than, the beds underlying the Hauraki Plains. It passed through six carbonaceous layers.† Gas escaped in considerable quantity, and when lighted is stated to have continued burning for hours. When the bore was visited in 1918 inflammable gas was issuing from the pipe at the rate of perhaps 5 cubic feet per hour. It was not escaping continuously, and would not remain alight for any length of time.

In the Gisborne district inflammable gas occurs in many bores sunk for water in the Poverty Bay flats. At Makaraka, three miles from Gisborne, a dwellinghouse was lighted by natural gas for several years until the upper part of the pipe rusted away.‡ The gas in the strata underlying

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* J. B. Thompson: "Drainage Operations in Hauraki Plains." C.–8, pp. 1–6, 1910.

† J. R. Hetherington: "Record of Borings at Horotiu, near Ngaruawahia." Trans. N.Z. Inst., vol. 47, pp. 613–14, 1915.

‡ N.Z. Geol. Surv. Bull. No. 21, p. 62, 1920.

the Poverty Bay flats is almost certainly derived from the carbonaceous material contained in the surface beds, and not from the oil-bearing rocks of the Gisborne district.

Inflammable gas in small quantities is known to occur in the unconsolidated gravels, sands, and silts of the alluvial flats near Napier,* at Hanmer (?), and in the Canterbury Plains. It probably occurs in many other similar localities.

To determine the commercial value of the gas issuing from the bores in the Hauraki Plains it is necessary to find out its chemical composition, how much can be got from the strata, and the cost of production. The natural gas of America is obtained from strata connected with the oil-pools, and in no country are beds so recent as these here considered known to yield gas in commercial quantity. But there is no geological reason why the strata should not contain much gas. Indeed, deltaic beds of porous sand separated by impervious silts all containing more or less carbonaceous matter are favourable for gas-accumulation. Conditions of this kind occur at the mouth of the Mississippi, where more or less inflammable gas is emitted in connection with the well-known "mud-lumps." The collection of data, including the number of bores, their position and depth, the strata they penetrate, and the gas they yield, is desirable. If the gas is found in commercial quantity anywhere in the Hauraki Plains the area over which it may reasonably be searched for is considerable, including all the low-lying country extending from the Hauraki Gulf to Otorohanga.

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9. MINERAL RESOURCES OF THE WHANGAREI-BAY OF ISLANDS SUBDIVISION.

(By H. T. Ferrar and W. H. Cropp.)

The mineral resources of the Whangarei-Bay of Islands Subdivision were briefly outlined in the last annual report. Of the many minerals occurring in the subdivision those forming the most valuable deposits are coal, cinnabar, and limestone. Other minerals occur, but under present conditions they are not of commercial importance.

Coal.

The following notes, based on a study of the geological relations of the coal of North Auckland, summarize the known and potential coal-bearing areas of the subdivision. For convenience they are arranged according to survey districts.

Whakarara, Bay of Islands, Kerikeri, Russell, Whangaruru, Opuawhanga, Taranga, and Taiharuru Survey Districts.—The prospects of workable coal being found in these districts are nil.

Kawakawa Survey District.—The coal-outcrops in the Waitangi Valley are of no importance. Workable coal probably exists only in the extreme south-east corner of this district—that is, in the old Kawakawa coalfield. Of this field, that portion lying immediately south-west of the township is worked out; between this area and the point of emergence of the Waiomio Stream from its limestone basin the coal-seams are too thin to be of use; beneath the limestone, however, an area of workable and relatively shallow coal may exist.

Hukerenui Survey District.—Future prospects in this district are confined to the Hikurangi coalfield, the limits of which are now approximately known. In that part of the field east of the railway little coal now remains. The Waro section, between the railway and the ridge joining Carter's Hill to Hikurangi Mountain, is rapidly being exhausted. A small reserve of workable coal probably exists between the head of Perrett's Creek and the present limit of the New Zealand Portland Cement Company's mine-workings. According to bore records, the ridge above mentioned is composed of crystalline limestone overlying workable coal-seams. In the field, however, the writers thought it to be part of the claystone which underlies the North Auckland coalfields. This forms Carter's Hill and continues under Hikurangi Mountain. West of this ridge, and between these two prominences, is a small area of downfaulted coal-measures, now being developed. This area may continue under the Hikurangi Swamp and fringe the base of Carter's Hill. Boring alone can prove this, but it is improbable that coal-bearing strata underlie the main portions of the Hikurangi Swamp. Computation of the coal reserves of this field leads to the belief that at most only three-quarters of a million tons remain.

Purua Survey District.—A triangular downfaulted area of some 1,200 acres adjacent to Kamo offers considerable prospects—perhaps the best in the subdivision. Of the three faults that enclose this area one follows Waitaua Creek, the second the line joining the mouth of Whau Valley to the junction of the Hatea and Waitaua streams, and the third extends from the mouth of Whau Valley to the Kamo thermal springs. The downthrow increases as the Hatea Stream is approached, so that the active Whangarei (Harrison's) Colliery and the abandoned Kamo workings both lie in the western or least-depressed portion of the area. From a study of old bore-logs and from geological data gathered in the field, the writers believe that the portion of the field between Harrison's workings and the Waitaua-Hatea junction would well repay the cost of further boring.

The basalt sheet which stretches from the Whauwhau Coalmine westwards to Maruarua Creek probably covers at least small patches of Miocene strata, but the chances of boring being successful in finding them are problematical. Not until other coal areas in the subdivision have been exhausted will this area be worth attention.

Whangarei Survey District.—Of the two known coal-bearing areas of Whangarei Survey District that of the Kiripaka-Ngunguru area has just been exhausted. That at Whareora contains merely the remnant of a small seam. Observations at the outcrop show it to be limited along both strike and dip by a ridge of greywacke, a rock much older than the coal. A few tons might be extracted to meet the requirements of the neighbourhood.

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* R. W. Holmes: "Notes on an Artesian Trial Bore, Westshore, Napier." Trans. N.Z. Inst., vol. 49, pp. 509–12, 1917.

The basalt-flow from the cone of Pukepoto, on the Whangarei–Kiripaka Road, may conceal an area of workable coal, but this can be determined only by boring.

Cinnabar.

Cinnabar is found in several of the sheets of siliceous sinter which are present at many points throughout the Puhipuhi district. These sheets occur above lines of crustal weakness, along which arose, in the Pliocene period, siliceous thermal waters that at times carried mercury sulphide in solution. Some of these deposits, soon after being formed, were denuded by ancient streams, the gravels of which now contain cinnabar. Others were protected from erosion by the outpouring of the basalts of the Kerikeri Series, which in their advance covered both sinter sheets and cinnabar-bearing gravels. Others, again, have suffered denudation from the time of deposition. Erosion by modern streams has exposed some of the buried deposits at various points along the edge of the upper plateau.

Such is the genesis of the ore-bodies being worked by the New Zealand Quicksilver Mines and by the Rising Sun Company, and such is the derivation of the gravels from which attempts to extract the cinnabar have been made. In addition to the partly exposed deposits just mentioned, there are several fully exposed sheets scattered over the Puhipuhi district. Of these, only one—that forming "Mount" Mitchell—is at present known to contain cinnabar. Here a considerable quantity of workable ore has been discovered, and is now being developed.

Other Economic Deposits.

The subdivision has practically inexhaustible supplies of argillaceous limestones suitable for cement-manufacture. This rock has also a prospective value as a top-dressing for the soils derived from the Kerikeri basalts. These soils, particularly those of the scoriaceous lava, have excessive subsoil drainage which has depleted them of soluble plant-food and of clay. Deposits of argillaceous limestone are fairly evenly distributed throughout the subdivision. The purer limestones required in cement-manufacture and for the production of agricultural lime occur in quantities sufficient for all future needs, but many of the deposits are small, and distant from coal and transport facilities. That at Waro, however, is most advantageously situated, and will supply the requirements of the subdivision for a very long time.

Rocks suitable for making roads are well distributed, except in parts of Hukerenui and Purua survey districts. The geological maps will afford guidance in the choice of quarry-sites.

Common brick clays are plentiful. Clays suitable for special uses also occur, but research is required in order to determine their extent and the uses to which they can be put.

Deposits of manganese-ore occur at many points in the subdivision as pockets in areas of silicified greywacke. The principal deposits are at Tikiora Hill (near Russell), Otonga, and Parua Bay. The low price of manganese-ore precludes these deposits from having any value at present. When glazed pottery, faced brick, and glass industries are established in the Dominion the subdivision may supply small amounts of manganese-ore for use in glazes and in decolorizing operations.

Deposits of high-grade limonite occur near Waipapa, Kerikeri Survey District, at "Mount" Mitchell, Puhipuhi, and near Kamo. The quantity is too small for use in iron-production, but the ores have value for paint-manufacture and for coal-gas purification.

The various localities from which gold has been reported have been examined. The metal is present in small amounts in Russell and Taranga survey districts, but that workable veins will be found is unlikely.

Bands containing disseminated silver minerals occur in silicified greywacke at the northern border of the Puhipuhi plateau. Surface waters percolating through the upper parts of these bands have brought about a redistribution of the silver minerals at various points, and thus have formed small irregular bodies of rich ore. Attempts to work some of these richer portions were made many years ago, but were abandoned because of the erratic distribution of the ore, unsuitability of methods of treatment, and the difficulty of access. The known ore-bodies are too small to be of value under present conditions, but further prospecting may perhaps be justified.

A small deposit of high-grade diatomaceous earth at Pakaraka, and another of fine-grained silica-powder at "Mount" Mitchell, Puhipuhi, are suitable for the preparation of polishing-compounds for fine work. The silica might find additional uses in wool-scouring and paper-manufacture, particularly if dressed to a marketable form. Deposits of fine-grained silica sand occur in the Kaitara district near Whangarei.

Antimony minerals are known to occur at two points in the subdivision, but not in commercial quantities.

Glauconitic sandstone containing small amounts of potash and phosphoric acid are found in Kerikeri, Purua, and Taranga survey districts, and may be useful for soil-dressing.

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10. CINNABAR IN NEW ZEALAND.

(By J. Henderson.)

Cinnabar, the principal ore of mercury, is widely distributed in New Zealand. In Otago it occurs in well-defined lodes traversing schist and greywacke. In the Hauraki Peninsula it is present in small quantities in several auriferous veins, and occurs also in deposits of siliceous sinter. These latter form commercial ore-bodies in North Auckland, where also are hot springs that carry mercury sulphide in solution. Alluvial cinnabar derived from known or still undiscovered primary deposits has been recorded from many localities.

The first reference to the occurence of cinnabar in New Zealand is in "The Reports and Awards of the Jurors, New Zealand Exhibition [Dunedin], 1865," p. 404, 1866, where it is stated that "Mercury united with gold to form amalgam, and also with sulphur as cinnabar, was received from Waipori, where both occur in the auriferous alluvial deposits. . . . The cinnabar is in roundish pieces of varying size, sometimes as large as peas, soft, and occasionally almost pure; indeed, the ease with which the ore is broken up forbids the idea that it has been transported from any great distance. It is found on several of the Otago goldfields, and rolled fragments are sometimes found embedded in the older Tertiary quartz cements." The statement that grains of cinnabar occur in the Tertiary sediments has not been confirmed by later observers. F. W. Hutton and G. H. F. Ulrich give various particulars of the Waipori and Waitahuna occurrences of alluvial cinnabar in their "Report on the Geology and Goldfields of Otago," pp. 149, 186–87, 1875.

A lode from which the alluvial cinnabar found in the gravels of the Waipori and Waitahuna districts may reasonably have been derived was discovered in 1899. For further particulars concerning this deposit see—Mines Reports, C.–3, p. 28, 1901; C.–3, p. 85, 1902; C.–3, p. 139, 1903; and C.–3, p. 95, 1904: *Mines Record*, vol. 3, pp. 152 and 219, 1900; vol. 4, p. 481, 1901; and vol. 7, pp. 139–40, 1903: N.Z. Geol. Surv. Bull. No. 19, pp. 44–45, 1918.

Rolled grains and fragments of cinnabar have been found in many other localities in Otago—in the Dunstan and Obelisk ranges, Potter's Gully, and in the Serpentine, Nevis, Nokomai, and Waikaka valleys (Hutton and Ulrich, *op. cit.*, pp. 32, 149: S. Herbert Cox, "Notes on the Mineralogy of New Zealand," Trans. N.Z. Inst., vol. 14, p. 450, 1882: Mines Reports, C.–3, p. 64, 1906; and C.–3, p. 9, 1908: N.Z. Geol. Surv., 8th Ann. Rep., C.–2, p. 152, 1914).

A cinnabar-bearing lode has recently been discovered in the Waikaka Valley, in Section 6, Block XI, Greenvale Survey District. The alluvial cinnabar of this locality has probably been derived from this lode. On the surface cinnabar is found in a band of soft broken and weathered rock which from samples seen by officers of the Geological Survey appears to consist of somewhat silicified greywacke. The mineral occurs in small seams, impregnations, and grains throughout a thickness of 10 in. to 24 in. Three winzes sunk on the deposit are respectively 50 ft., 40 ft., and 25 ft. deep, and 100 ft. has been driven on the lode at a depth of 25 ft. The lode strikes 40° west of north. The prospectors intend to explore the deposit further. This lode, in its general features, seems to resemble closely that of the Waipori district.

The only other locality in the South Island from which cinnabar has been recorded is at Taipo, in North Westland, where a small fragment of cinnabar was found in 1900 (Col. Lab. 34th Ann Rep., pp. 16–17, 1901). The specimen may have come from the valley of Seven-mile Creek, a tributary of Taipo River. In 1905 a small piece of cinnabar-bearing stone shown to an officer of the Geological Survey was stated to come from that locality.

A similar occurrence is recorded from the Wairarapa district. A small boulder of greenish sandstone veined with cinnabar was found in the bed of Waiohine River (Col. Mus. and Lab. 18th Ann. Rep., p. 50, 1883; Rep. Geol. Explor. during 1887–88, No. 19, p. 4, 1888).

Cinnabar has been reported to be present in small quantity in several of the auriferous lodes of the Hauraki Goldfield. As early as 1866 it was identified by Skey as occurring in some of the Thames lodes (F. W. Hutton, "Geological Report on the Thames Goldfields," p. 7, 1867). It was found in some of the mines at Te Aroha (Col. Mus. and Lab. 19th Ann. Rep., p. 37, 1885; N.Z. Geol. Surv. Bull. No. 16, p. 91, 1913). Alluvial grains are found in the gravels of Karaka Creek (Rep. Geol. Explor. during 1868–69, No. 5, p. 21, 1869), in the Wharekawa, Homunga, and Wharekiraupunga districts (N.Z. Geol. Surv. Bull. No. 15, p. 59, 1912), at Owharoa (Trans. N.Z. Inst., p. 339, vol. 23, 1891), and at various other localities in the Hauraki Peninsula (C.–3, p. 58, 1887).

The only deposits in the Hauraki district likely to have commercial value are the siliceous sinters at Mangakirikiri Creek and near Karangahake. The first mentioned, which is in the Kauaeranga Valley, six miles from the town of Thames, was discovered in 1897. For a description of this deposit see—*Mines Record*, vol. 1, pp. 293, 445–46; Mines Reports, C.–3, pp. 59–60, and C.–9, p. 8, 1898; N.Z. Geol. Surv. Bull. No. 10, pp. 55–56, 1910. The deposit at Karangahake, found in 1906, has been mined to a small extent. A full description is given on pp. 119–121 of N.Z. Geol. Surv. Bull. No. 15, 1912.

The most valuable accumulations of mercury-ore in New Zealand occur in North Auckland. The presence of cinnabar and mercury in this district has been known for many years (F. W. Hutton, "On the Occurrence of Native Mercury near Pakaraka, Bay of Islands," Trans. N.Z. Inst., vol. 3, pp. 252–53, 1871), and many references to them occur in the geological literature (Trans. N.Z. Inst., vol. 14, p. 450, 1882: Mines Reports, C.–2, p. 17; C.–3, p. 187, 1893; C.–2, p. 15, 1894; C.–2, p. 17; C.–3, pp. 257–59, 1895; C.–2, p. 12, 1896; C.–2, p. 9, 1897: Rep. Geol. Explor. during 1892–93, No. 22, p. 53, 1894: Trans. N.Z. Inst. Min. Eng., vol. 2, p. 48, 1898: *N.Z. Mines Record*, vol. 2, pp. 311–19, 1899). The fullest account of the cinnabar-deposits of Ohacawai is in the N.Z. Geol. Surv. Bull. No. 8, pp. 87–92, 1909, and of those of the Puhipuhi district in N.Z. Jour. Sci. and Tech., vol. 5, pp. 173–77, 1922.

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