# ART. XIII.—*Geology of the Waikato Heads District and the Kawa Unconformity.*

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Communicated by J. A. Bartrum.

[*Read before the Auckland Institute, 15th December, 1920; received by Editor, 31st December, 1920; issued separately, 27th June, 1921.*]

Plates XX, XXI.

CONTENTS.



## INTRODUCTION.

THE entrance to the Manukau Harbour and the lower part of the Waikato River separate three notably distinct topographic and structural regions. That to the north of the Manukau is characterized by a broad range of hills of resistant rock, deeply dissected by streams. The middle area is constituted by a line of ancient sand-dunes facing the ocean, and is considerably worn by streams, moderately low country rising behind it to the east. The third area, that south of the Waikato River, is a broad minutely-dissected upland of more varied structure than the others, and it, with the second or middle area, forms the subject of this paper.

## PREVIOUS WORK IN THE DISTRICT.

Hochstetter (1867) in 1859 collected fossils from the Waikato South Head, as well as from the plant-beds near Oruarangi Point, some four

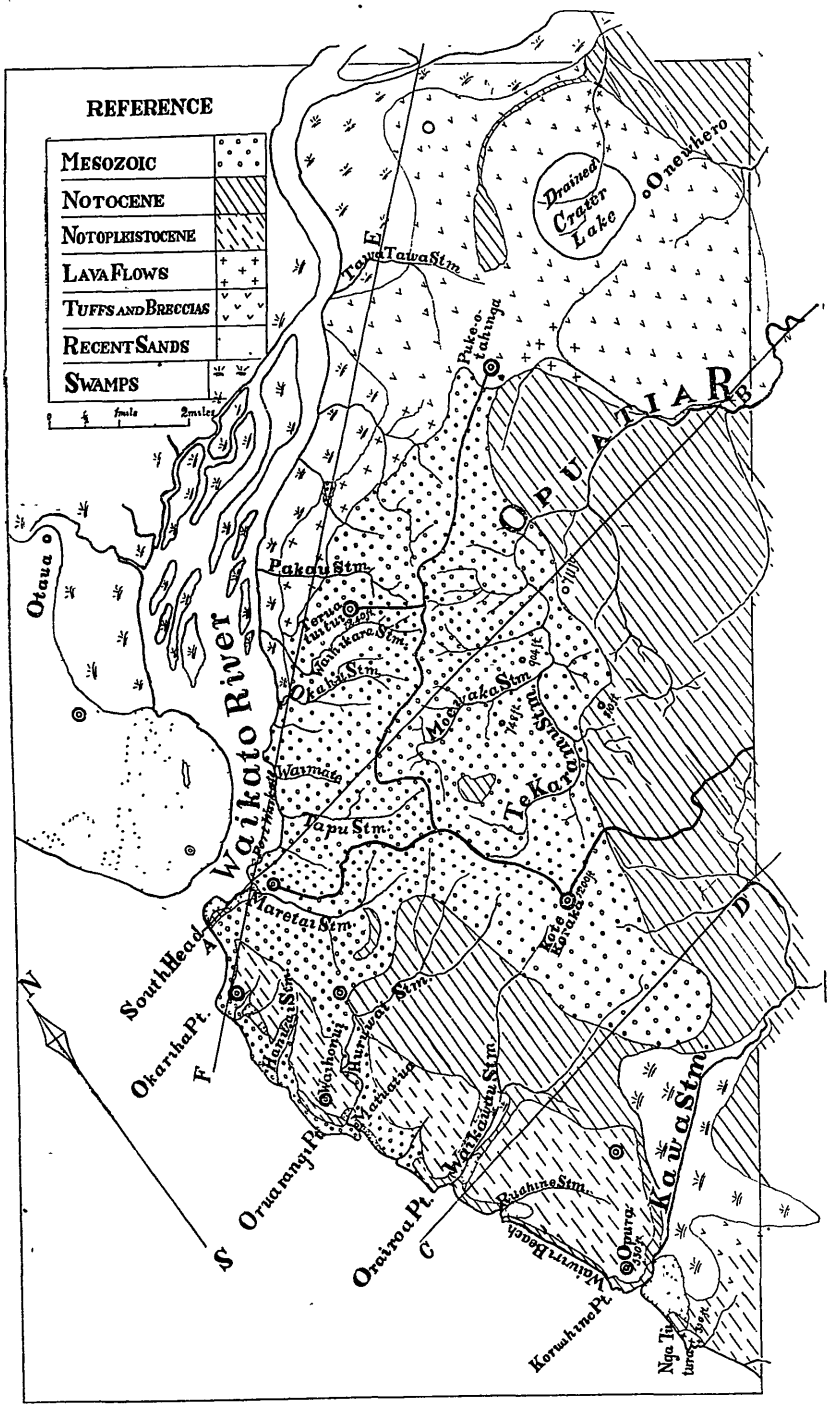


FIG. 1.—Geological map of Waikato Heads district.

miles farther south, and classed the beds containing them as Neocomian. The sand-dune area was briefly described by him, and the structure illustrated by a section across the sand-dunes near the northern end.

Park (1910) alludes to the dune formation of the sandhills, and further calls attention to the oxidation of the ironsand into hard bands of limonite.

Cox in 1876 journeyed south along the coast from the mouth of the Waikato River, but so hurriedly that he appears to have failed to observe a conspicuous unconformity in the Tertiary strata at the Kawa Stream (fig. 11) and a less noticeable one at the Waikawau Stream (fig. 9), though in his report he expressed the conviction that an unconformity existed at the base of the beds he called the "*Cardita* beds," and classed as lowest Eocene in age.

Hutton (1867) had reported on the same district, and would seem to be misunderstood by Cox (1877, p. 16) when the latter quotes him as classing the *Cardita* beds with the Waitematas, in which he distinctly says he could find no fossils (1867, p. 16). Cox's report is somewhat confusing.

One of the most valuable contributions to the knowledge of the geology of Port Waikato district is that by the late E. A. Newell Arber (1917), who allocated the plant-beds of the Mesozoic sequence to the Neocomian. A feature of particular interest is his discovery of leaves of the angiosperms *Artocarpidium Arberi* Laur. and *Phyllites* sp., thought by him to be amongst the earliest dicotyledons yet discovered, and, as Dr. L. Laurent says, "it is hardly possible to attach too much importance to the discoveries."

Bartrum (1919B) described a fossiliferous bed at the Kawa Creek, some fourteen miles south of Waikato Heads. He published a list of fossils collected from the bed, and described six new species discovered there by him (Bartrum, 1919A).

Almost the only other reference of any importance to the geology of the area studied is one by Bartrum (1917) to the discovery of several types of volcanic rocks in pebbles of conglomerates in the Mesozoic strata.*

## THE COASTAL AREA BETWEEN MANUKAU ENTRANCE AND WAIKATO RIVER.

From the Manukau Harbour to the Waikato River, in a belt averaging five to six miles in width, stretch now deforested hills, which for twenty miles form a straight coast-line of almost continuous cliffs averaging 500 ft. to 600 ft. in height, broken only by the narrow valleys of a few streams draining to the west. Immediately behind these hills is a belt of low country bordering the Waiuku Creek, and forming the Akaaka Swamp in the south. East from this belt the land rises gently, forming undulating country of subdued topography, the highest point being the volcanic cone of Pukekohe Hill, some 710 ft. high.

The characteristic cross-bedding of wind-deposited sands is conspicuous from top to bottom along the line of cliffs facing the sea (Plate XX, fig. 1). The beds vary in texture from a fine to a fairly coarse sand, and many consist of a large proportion of magnetite with grains of feldspar and some quartz. Certain very fine beds appear to be pumiceous. The contained magnetite has been oxidized to the brownish hydrated oxide of iron

* Whilst this was in press reference to the geology of the district appeared in a report by Dr. J. Henderson on the Huntly Subdivision, which was published in *14th Ann. Rep. N.Z. Geol. Surv.*, 1920, and distributed early in 1921.

(limonite), forming tough, resistant, anastomosing bands, or more frequently lens-like or irregular beds of considerable thickness, which constitute the most resistant parts of the nearly vertical cliffs, and in a few cases, as at the Fishing Rock, opposite Waipipi, form reefs running a short distance out to sea.

From the general proximity of the watershed to the line of cliffs, and the longer and more gentle easterly slope towards the Waiuku Creek, and from the loftiness of the cliffs, which have been cut back by the waves almost to the watershed, and the character of some of the lower beds, it is evident that these hills at one time extended much farther seaward—probably several miles at least. Except in the extreme south of this area the sand of these hills is much limonitized and consolidated, while the surface on the easterly (or landward) slope is decomposed to a yellowish-red clay to a depth often of 6 ft., and is covered with a fairly good soil.

Near the Waikato River and the "gaps" or stream-valleys opening west the surface is composed of loose sand travelling inland. This is particularly well shown at Lake Pokorua. Only in a few places, such as the Waiuku and Pokorua gaps, is there convenient access to the beach.

A mile south of Pokorua Stream outlet a bed of lignite outcrops for a distance of 100 ft. at the foot of the cliffs. It is about 5 ft. above high water, but rises gently to the south. The only other bed of lignite outcropping on the coast is a small one in a short stream-valley two miles south of Manukau Heads. The only other lithologic feature deserving of mention is a bed of sand from 3 ft. to 6 ft. thick, near the foot of the cliffs close to the outcrop of lignite, which is a fine, light, white sand, evidently pumiceous.

*The Area East of the Sand-dunes.*

To the east of the sand-dune range, bands of lignite 18 in. thick can be seen on both sides of Waiuku Creek, just above or at high-water mark Beds which are either pumiceous or of very fine light sandstone occur above the lignite. On the east bank a coarse conglomerate sometimes occurs. A short distance to the north of Awhitu Wharf a bed of lignite occurs intercalated in sand. Stream-bedding is noticeable in most of these deposits of sand along the Waiuku Creek.

Hochstetter (1867, p. 272) furnishes a section which seems too generalized in respect of the lignite formation. The occurrence of but two small bands, the larger not more than 100 ft. long, in a length of sea-cliff extending twenty miles hardly warrants the use of the name "lignite formation" to include the western lower beds on the coast range in which these two bands occur. Their very frequent occurrence in the sand and silt-beds along the Waiuku Creek, however, amply justifies the name so far as it is applied to the low-lying area east of the coast range. The undulating country east of Waiuku Creek and of the Akaaka Swamp consists of an extensive deposit of basaltic breccia—the "basaltic boulder formation" of Hochstetter (1867, p. 268), Hutton (1867, p. 7), and Cox (1877, p. 17)—mixed with much red loam resulting from decomposition of the breccias and tuffs.

The most extensive lava-flow is that at Waitangi Stream, two miles from Waiuku; whilst the volcanic tuffs become very prominent in the Koraka district, near Drury. On the south side of the Waikato River, at Pakau Stream, and at Tauranganui, three miles to the north-east, lava-flows occur associated with volcanic breccia similar to that forming several small isolated hills in the Akaaka Swamp. Evidence of stream-bedding has been observed in the tuffs and breccia at Tauranganui.

*A Suggestion of Origin of the Sand-dunes and of the Lignite-beds.*

North of Manukau Harbour is a strongly resistant coast-line which has retrogressed considerably owing to wave-attack. Similarly, south of the Waikato River all evidence points to considerable sea-cliff recession. The writer's belief touches entirely new ground, and it is this: that regularity of coastal outline was reached between Waikato Head and Manukau North Head by spit or perhaps barrier-beach formation in the not distant past, when the relative level of sea and land approximated the present, and that a great estuary of the Waikato River was formed behind this barrier, in which pumice-silts were deposited and bands of lignite formed. This beach supplied the material raised by wind into lofty sandhills, which have been cut into by the waves as the shore-line advanced towards maturity.

Mr. J. A. Bartrum, in mentioning to me that this accorded with his own view, called my attention to a fact which I have since been able to confirm—namely, that there are similar sand-ranges west of Helensville, going north along the western margin of the Kaipara Harbour. He further pointed out that in that district there is every evidence of former uplift in elevated erosion-plains.

This theory of the origin of the sand-ranges with an extensive estuary of the Waikato River behind them readily accounts for the origin of the pumiceous silts and the lignite bands west of the ranges, for it is believed that the silts were formed in the estuary by the deposition of fine material, largely pumiceous, brought down by the Waikato River from the great pumice lands of the middle of the Island. There are pumice-silts at Mangere, opposite Onehunga, at Otahuhu, and near Drury and Papakura. They are thus very widespread round the shores of Manukau Harbour, the waters of which cannot have supplied the material. The Waikato River, then, appears to be the only source of origin that can satisfactorily account for these silts. Well-borings in various places around Waiuku and the Aka-aka Swamp support the view that an extensive estuary existed. The lignites at and above high-water mark along the Waiuku Creek, and exposed in railway-cuttings between Otahuhu and Papakura, would be formed in this estuary by the accumulation of vegetable material in the swamps.

The two lignite bands at the foot of the sand-dunes on the coast contain fragments of wood, undecomposed or slightly carbonized, and, amongst other vegetable remains, the abundant long leaves of the raupo (*Typha angustifolia*). They were probably formed in shallow lakes or lagoons occurring in the hollows of the sandhills in their early stages, just as the remains of similar vegetation are accumulating at the present time around the swampy raupo-covered margins of Lake Pokorua, north-west from Waipipi, and other lakes even in the shifting sand-dunes near the Waikato River. It is possible, however, that they had an origin similar to that of the Waiuku bands—that is, in the swamps marginal to the early Waikato estuary, which have since been covered up by the inland advance of the dune-belt, and then re-exposed by sea-cliff recession in conformity with the general retrogression of the coast both north and south of this area.

*Sub-recent Oscillations of Level: Origin of Manukau Harbour.*

The bands of lignite exposed at frequent intervals along the banks of Waiuku Creek are either at or slightly above high-water mark, and are covered to a depth of from 5 ft. to 20 ft. by silts. They thus furnish evidence of sub-recent minor oscillations of the district. In the arm of

Manukau Harbour that penetrates to Otahuhu—indeed, in most of the harbour's ramifications—similar evidence is available. These silts are now being cut back rapidly by wave-action at high-water,* and present low cliffs that rise to no great height above high-water level.

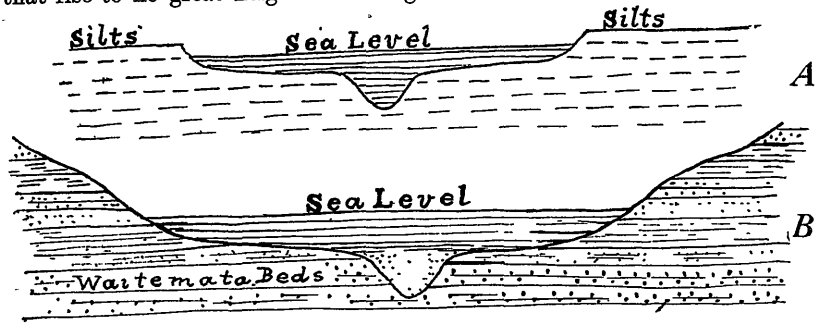


FIG. 2.—A. Manukau Harbour. B. Waitemata Harbour (Grafton Gully continuation).

The story they unfold is briefly as follows: After their deposition, uplift over the whole Auckland area occurred, of which local evidence is found also in the Waitemata Harbour.† Following the uplift the silts were dissected by the various streams emptying into the Manukau Harbour, such as the Waiuku, and the present channels thus formed. Depression soon followed, admitting the tidal waters into the stream-courses. (See fig. 2, A.)

*Mutual Relations of the Areas North and South of the Waikato River: an Hypothesis of Major Faulting.*

It is believed that the northern shore of the Manukau is roughly coincident with a fault-line running east and west, and that the Waikato River in the last few miles of its course traverses another fault-line parallel with the first, cutting the Mesozoic rocks at right angles to their strike. This latter has been called the Waikato fault. The country between is deemed faulted down at least 2,000 ft., leaving the eroded Mesozoic rocks on the south standing 12,000 ft. above sea-level.

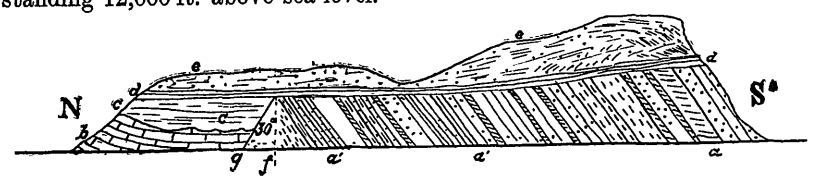


FIG. 3.—Coast section, Waikato South Head. *a'*, belemnite marly shales; *a*, sands and shales; *o*, sandy limestone; *c*, brown sands and silts; *d*, gray clays and silts; *e*, red clays and sands; *f*, zone of comminuted shale; *g*, fault.

Though no conclusive evidence of the faulting could be obtained, the south bank of the Waikato River presents the appearance of a deeply dissected fault-scarp; and, further, at the South Head there is a nearly vertical fault,

* Tidal interval at spring tides, 14 ft.

† I am indebted to Mr. J. A. Bartrum for pointing this out to me, and for a sketch of the continuation of Grafton Gully into the harbour, which he drew from data supplied by the Harbour Board, and which is reproduced in fig. 2, B.

heading 30° to the north and striking 30° north of east, roughly along the line of the river, and traceable for some 50 yards. The limestones on the north must be downthrown 200 ft. to 300 ft. at least. This fault may very well be one of the step-faults of the zone of faulting referred to above. Brown sands and sandy limestone are here brought in contact with Mesozoic shales (belemnite-beds) dipping 45° south west and striking 30° west of north, forming the southern (or upthrow) side of the fault. The shales are finely comminuted in a band some 20 ft. wide along the line of the fault.

The most important reason for suggesting faulting is the abrupt termination of the older rocks along a fairly definite line, and their replacement by an area of much later sedimentation. Along the maturely dissected scarp of the Waikato fault between Maretai Stream and the South Head, wave-attack has in places produced typical sea-cliffs, above which are hanging valleys.

It is possible, though unlikely from their position, that river-planation, and not wave-attack, was responsible for the wearing-back of these cliffs.

## THE AREA SOUTH OF THE WAIKATO.

### *General Description.*

The country to the south of the Waikato River dealt with herein is an upland, 600 ft. to 1,200 ft. above the level of the sea, consisting of uniformly resistant rocks, except along the sea-coast, where the upper portions are much less resistant than the lower. This upland is deeply dissected by stream-valleys running north-west and east from the main watershed, which sends out numerous sharp spurs, so that the surface is very uneven and rugged,

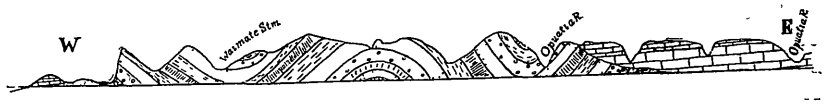


FIG. 4.—Section along line AB of map.

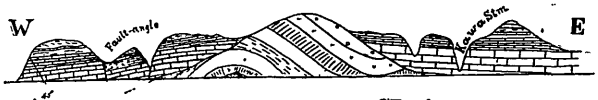


FIG. 5.—Section along line CD of map.

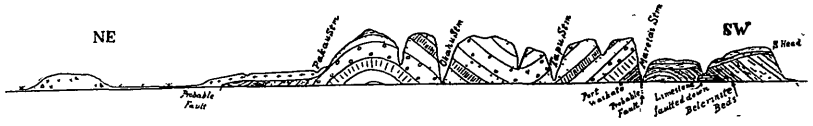


FIG. 6.—Section along line EF of map.

presenting few level tracts. The rocks consist of a basement (herein called the "older-mass") of symmetrically folded sediments, on the eroded and weathered surface of which in many places the younger-mass beds* rest horizontally, and therefore unconformably; these latter consist of moderately resistant marine sediment. They again are covered unconformably along the coast by less resistant Pleistocene and Recent† clays and sands.

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* Part of the Notocene of Thomson (1917, p. 408).
† The Notopleistocene of Thomson (1917, p. 411).

### *Drainage of the Southern Area.*

The Opuatia River, with its upper east-flowing tributaries, cuts across the strike of the rocks of the Mesozoic older-mass where these are exposed in its upper course. This indifference to the strike of the folded rocks can be explained by supposing these streams to be superposed consequents. On account of having had their courses shortened by coast-recession, the streams flowing west from the watershed are shorter than those to the east. Those flowing north-west, having maturely dissected the fault-scarp facing the Waikato River, are obviously streams consequent on the deformation. Their courses are short and their drainage areas small.

From Port Waikato the main watershed runs in a south-easterly direction for forty miles or more.

The Maretai Stream, flowing north into the Waikato River, has cut its way down to grade along what is believed to be a fault-line, on the west side of which the beds of the older-mass are strongly downfaulted, the scarp on the upthrow (or eastern) side being immaturely dissected. This fault probably extends a long distance south-west. A sunken outlier of the younger-mass at Newdick's, on the western side of the stream-valley, appears to owe its position to the effect of the faulting along this line.

Most of the streams flowing east or west are graded, and the Okahu and Maretai Streams, flowing north-west, are similarly graded in their lower courses. The Waikawau Stream, seven miles south from the Waikato River, is graded for some two miles of its lower course. Its middle course is between the high vertical walls of its limestone gorge, which soon widens out to a broad valley, the floor of which is covered by flood-plain and delta deposits.

The Kawa Stream, still farther south, has a comparatively bottle-necked outlet to the sea. In its middle course it flows across extensive flood-plain swamps, which cover a broad depression, believed to have originated in the foldings and dislocations of the beds of the older-mass and younger-mass alike, which are made evident in the coast sections from the Waikawau Stream along the Waiwiri Beach to the Kawa Stream. Solution may have played its part, as in the Waikawau and upper Huruwai valleys. The writer's first impression was that it represented a gigantic sinkhole.

### *The Older-mass of the Southern Area.*

It has been pointed out above that the southern area consists stratigraphically of a younger-mass unconformably overlying an older-mass. The writer considers that the sediments of the older-mass are folded in fairly symmetrical waves measuring four miles from crest to crest, the strike of the axes of the folds being about 30° west of north. The limbs of the folds have an average dip of about 30° and a maximum of 45°. The average is that of thirty-two determinations in different localities. These sediments are therefore not less than 7,000 ft. thick in those portions above sea-level. The conclusion as to the symmetry of the waves is deduced from the evidence of strike and dip of the beds along the Waikato River, as well as from those along the Opuatia and Huruwai Streams and the coast sections.

In the deepest part of the anticline, which is exposed in a good section at the South Waikato Head, the lowest beds visible are the belemnite shales—a fine, slightly calcareous mudstone containing some thin, light-coloured, highly calcareous bands. In these, but more conspicuously in

all the higher beds in this formation, plant-remains are abundant, though rarely in other than fragmentary form. Tree and fern trunks and large roots are abundant, more particularly two miles south of the Heads in a very thick bed of concretionary sandstone.

The following is roughly the sequence, in ascending order, of the beds as shown in the coast sections from south of the Huruwai Stream to the Waikato Heads. (See Plate XXI, fig. 2.)

(1.) 700 ft. of dark marly shales containing marine fossils (Cox, p. 20), and herein spoken of as the "belemnite-beds."*

(2.) Hard grey sandstone with shaly beds.

(3.) Thick beds of concretionary sandstone, containing tree-trunks in abundance, amongst which could be recognized some resembling tree-ferns. These beds thin out laterally, rapidly giving place to thin bands of shale and sandstone.

(4.) Shales with bands of a hard, shiny, black, impure coal 1 ft. and 1½ ft. thick, dipping seaward at an angle of 35° to west. These outcrop on the strike coast near Hanwai Stream.

(5.) Alternating beds of hard shale and sandstone, the shale bands outcropping at Oruarangi Point, about five miles south of Waikato River, being rich in well-preserved plant-impressions.

(6.) Bands of shale interbedded with sandstone and containing thin coaly bands.

(7.) Fine conglomerate.

(8.) Coarse sandstone, stream-bedded, with large fragments of wood, outcropping on the beach south of Huruwai Creek.

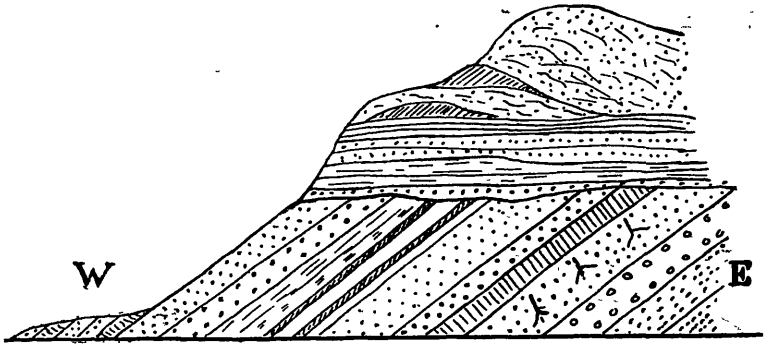


FIG. 7.—Observed section north of Hanwai Creek. Height of section, 200 ft.; length, 100 yards. *Mesozoics* (strike 25° west of north, dip 35° to west) overlain by horizontal Notopleistocene beds.

Though the strike of the main axes of the folds is 30° west of north, it occasionally changes locally to north-and-south and east-and-west, for there is much local distortion, notably in the axis of the syncline where the Waimate Stream enters the Waikato River, about two miles above its mouth.

* A similar series of shale-beds, though unfossiliferous, appears at the top of the watershed between the Okahu and the Moewaka Streams, where deep weathering has increased their friability.

A little north of Orairoa Point, six miles south of Waikato River, the basal sedimentaries disappear under the seaward-dipping beds of the younger-mass, and are not found again north of the Kawa Stream, though they are said to outcrop farther south.

From the South Head to the Waikawau Stream the Mesozoic beds form locally a prominent strike-coast—*i.e.*, the coast follows the strike of the seaward-dipping beds, leaving here and there a promontory of very resistant sandstone beds presenting precipitous bluffs to the fierce attacks of the violent Tasman Sea.

### *The Marine Fossiliferous Shales or Belemnite-beds.*

As stated above, the shale-beds at the Waikato South Head contain marine fossils. Cox (1877, p. 19) reported having obtained the following: "*Aucella plicata, Inoceramus haasti, Inoceramus* (sp. ind.), *Belemnites aucklandicus, Halobia* sp., *Placunopsis striatula,* and other species not determined."

As the result of many hours of patient search, the writer recently gathered from these shales numbers of belemnites, which are abundant, and eight or ten other fossil species not yet determined, but the majority apparently not previously reported from this locality. All that can be said is that amongst the species found at Waikato Heads shales are brachiopods, pelecypods, and gasteropods.* (See Plate XXI, fig. 1.)

### *The Fossil-plant Beds.*

From 2,000 ft. to 3,000 ft. higher up in the conformable sequence occur the beds near Oruarangi Point first collected from by Hochstetter (1867, p. 278). These are alternating sandstones and shales, and contain abundant well-preserved plant-fossils.

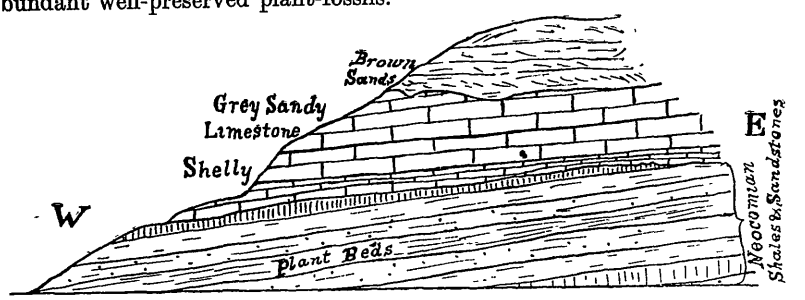


FIG. 8.—Probable section at Oruarangi Point (near plant-beds).

Newell Arber (1917, pp. 18, 20) in a recent palaeontological bulletin describes and figures a number of fossil plants from these beds.

After a careful comparison of the plant-fossils gathered on two visits to these plant-beds, and of others gathered by Mr. J. A. Bartrum from

* Mr. J. A. Bartrum has informed me since the above was written that he forwarded a selection of the fossils from these beds to Dr. C. T. Trechmann, of Durham, and amongst them the following forms were determined by him (accompanying remarks are those made by Dr. Trechmann): *Arca (Parallelodon) egertonianus* Stoliczka (found in Spiti shales, India, and in Somaliland); *Arca blandfordiana* Stoliczka; *Aucella* cf. *spitiensis extensa* Holdhaus; *Limea* sp. (two); *Pyrgopolon* (?) (? a serpulid); *Serpula* sp. (the *Serpula* is rather like *Serpula convoluta* Goldf. from the Dogger: see Zittel-Eastman, p. 138); *Trigonia* sp. Several other forms, notably lamellibranchs and a serpulid, though generically unidentifiable, furnish additions to the above list.

the same place, with those figured by Arber, a selection was made of types that appeared to be new, and forwarded by Mr. Bartrum to Arber for determination, but his death occurred before he was able to examine them.

On the banks of the Waikato River near Waimate Creek, at about high-water mark, well-preserved plant-impressions can be obtained from various beds, especially from one of fine white sandstone about 1 ft. in thickness. Some 6 ft. above this bed occurs a bed of coal 12 in. to 18 in. thick associated with a similar fine sandstone. These beds, occurring in the axis of a syncline, are not less than 2,000 ft. above the belemnite-beds, from which they are distant two miles across the general strike of the sequence, the effect of downthrow along the Maretai fault-plane being taken into account.

*Age of the Older-mass.*

Arber (1917) classes the upper plant-beds at Oruarangi Point in the Neocomian, as did Hochstetter (1867) originally. The fossil plants in the beds mentioned above at Waimate, about two miles up the Waikato River from its mouth, are apparently the same as those at Oruarangi; the beds containing them are therefore Neocomian, and hence the lower belemnite-beds are most probably of Jurassic age.

*General History of the Coastal Area South of the Waikato River.*

Mid-Cretaceous uplift and folding of the Jurassic and early Cretaceous sediments (here spoken of as the "older-mass") was followed by dissection and by planation to a greater or less degree; depression then ensued, and was succeeded by a long period of sedimentation, during which most of the beds of the younger-mass were laid down. Subsequent deformation of the older-mass, involving warping and dislocation of the beds of the younger-mass, and general though unequal uplift, initiated a long period of erosion, during which movements of elevation continued, and the younger-mass was stripped from much of the higher portions of the uplifted area, whilst the older-mass was deeply cut into by superposed consequent streams. At the same time, too, the fault-scarp along the line of the Waikato River, a product of the deformation which followed the conclusion of deposition of the younger-mass, was maturely dissected.

During the period when the beds of the younger-mass were being laid down slight uplift took place, at least in some localities, as at the Kawa, where the movement was sufficient to bring about sea-planation of certain impure limestones after they had been slightly warped. With slow depression, again, other beds were laid down unconformably above the warped and planed limestones; local volcanic activity occurred, depositing beds of ash and lava. These were again covered by swamp-silts, and, upon uplift, by wind-blown sands.

*Relation between the Mesozoic Older-mass and the Younger-mass (or Notocene) Beds.*

The Notocene beds, using the name suggested by Thomson (1917, p. 408) for the "covering strata" or "younger rock-series" of New Zealand, were deposited on the eroded surface of the folded older-mass. (See figs. 3, 4, 5, 6, 7, and 8.)

An outlier of Notocene beds at Pa Brown, high up near the source of the Moewaka Stream, a tributary of the Opuatia, is of great importance as indicating the former greater extent of these beds. This small outlier, covering about a quarter of a square mile, consists of 40 ft. to 50 ft. of platy bands of an extremely hard limestone, containing abundant large

oyster-shells, sharks' teeth, and small indeterminate shell-fragments, underlain by a thick layer of calcareous sandstone, very similar lithologically to that in the bed of the Opuatia Stream four to five miles farther east. A short distance to the west the Mesozoic rocks of the watershed rise 100 ft. to 200 ft. higher.

An examination of the upper parts of the valleys of the Maretai, the Huruwai, and the Waikawau Streams reveals the same phenomenon as the Opuatia Valley—namely, that the Notocene suddenly appears deep down in troughs in the Mesozoic older-mass. The lowest beds there observable are calcareous sandstone, passing upwards into a hard, scantily fossiliferous, platy limestone, which changes in facies with great rapidity. Again at the Waikato South Head there is a downfaulted block of the Notocene beds which owes its preservation to its resistant character. (See fig. 3.)

No shore-line deposits have been found in these valleys or depressions to support the view that the Notocene beds were laid down in deeply eroded valleys into which the sea penetrated when the land was depressed, although fragments of Mesozoic rocks were found in a basal bed of the younger-mass near Orairoa Point, half a mile south of the Huruwai Stream. The upper Notocene beds are often of hard, pure limestone, and must have been deposited in deep, clear water at a distance from land. Having in view the fact that the Notocene beds have suffered very considerable erosion, the final conclusion is that they covered the whole area—even the more elevated tracts occupied by the Mesozoic rocks, where now no trace of them is left. They covered a broadly truncated surface of the Mesozoic rocks, and when later uplift set in would be removed most readily from the uplifted areas. As pointed out, the Notocene beds in several places occupy valley-like depressions in the Mesozoic strata, either as the result of faulting or owing to involvement in the folding of the Mesozoic older-mass that occurred subsequent to the deposition of these younger-mass beds. The latter supposition appears the more probable explanation, although a more careful examination of the district is needed to settle the point.

### *The Younger-mass (or Notocene) Beds.*

The beds of the younger-mass dip slightly to the south along the coast, and their sequence from their lowest upwards is not easy to determine. The following is the probable upward sequence:—

(1.) At the base algal tabular limestone. It contains angular fragments of the underlying Mesozoic rocks where it rests on the latter at Orairoa Point, north of Huruwai Stream. This limestone seems to rest on still lower blue sea-muds, and to lose both its tabular and brecciaceous character.

(2.) Grey calcareous sandstone, 300 ft. thick in places such as the Opuatia Stream valley and the upper Waikawau, changing to a blue sea-mud at the base of the outcrops on the coast between the Waikawau and Kawa Streams.

(3.) Tabular limestones. At the Waikawau and the Ruahine Streams, and along the northern half of Waiwiri Beach, the upward succession is of alternating calcareous sandy beds, and thin, hard, marly limestone, all becoming tabular, sandy, or even shelly limestones farther back from the coast and south from the Ruahine Stream. They appear as a pure, hard, coarsely crystalline limestone in a large cave two miles from the coast on the north bank of the Waikawau Stream. Half-way up this series of thin beds a discontinuity occurs in the Waikawau section.

Minor faulting and some planation, probably by wave-action, occurred, and was followed by the deposition of a dark-greenish sandy bed containing many easily gathered marine fossils. Other similar but less fossiliferous beds follow, being interbedded with thin, hard, closely-jointed, more calcareous layers, the whole attaining a thickness of 130 ft. to 150 ft.* They are called the "blue marls" or "*Cardita* beds" by Cox (1877), from the presence in them of "a large *Cardita* that cannot be distinguished from '*Cardita planicostata*' of Europe [see Hector, 1877, p. viii], and are probably of Lower Eocene age." They are correlated with what has been spoken of earlier in this paper as the tabular limestones of Pa Brown and other localities.

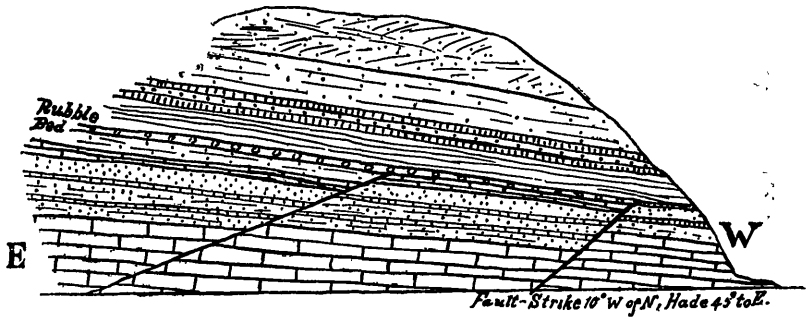


FIG. 9.—Observed section at South Head, Waikawau.

The exposures of the Notocene beds along Waiwiri Beach show some warping and frequent faulting on a small scale, with possibly a much more powerful fault at a point where the sea-cliffs are temporarily interrupted. (See fig. 10.)

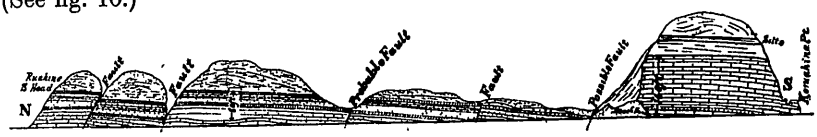


FIG. 10.—Coast section along Waiwiri Beach (two miles).

The beds of Koruahine Bluff, at the south end of Waiwiri Beach, which could not be definitely correlated with others either north or south in this section owing to the rapid changes in the facies of the limestones, furnished numerous fossils, among which were abundant echinoids, a few brachiopods, several species of *Pecten*, and abundant Foraminifera, with occasional sharks' teeth. They are not like the fossils of the "*Cardita* beds," which are prominent along Waiwiri Beach, but rather resemble those of the shelly bed at the Huruwai Stream and of the tabular limestone at Waikato South Head. These beds probably correlate with the warped and sea-planed beds of the syncline at the base of the Kawa section, for their fossil content is somewhat similar. Thomson has expressed the opinion after examining them that the brachiopods are typically Oamaruian.

* On revisiting the Waikawau in February of 1920 the writer found an immense slip had recently occurred, obscuring the features of the section here referred to, but facilitating the collection of fossils from a very fossiliferous band higher up the cliff than the rubble-bed.

The glauconitic greensands of the south Kawa section (see fig. 11) were not traced north of the Kawa Stream.

(4.) Above the tabular limestones appear fine light-coloured silts and clays. These close the Notocene sequence.

(5.) Brown sands. As pointed out already, the Notocene beds show folding, and on their eroded surface rest the younger beds.* In most of the sections the brown sands follow the tabular limestones unconformably. However, near the Hanwai Creek and the Waikato South Head they rest on beds of fine light-coloured silts and clays, called by Hochstetter (1867) "Pleistocene silts," which contain no fossils. (See figs. 3 and 7.) The brown sands show the characteristic irregular bedding of wind-blown sands, except where bands of silt are interbedded with them in their lower parts.

(6.) Shifting sands of recent date close the sequence.

## The Kawa Section.

The most important section shown along this coast is that to the south of Kawa Stream, and referred to herein as the "Kawa section." The well-marked unconformity in the sequence of its strata, the evidence of volcanic activity, and the pumice-bed, 170 ft. to 180 ft. above sea-level, possibly

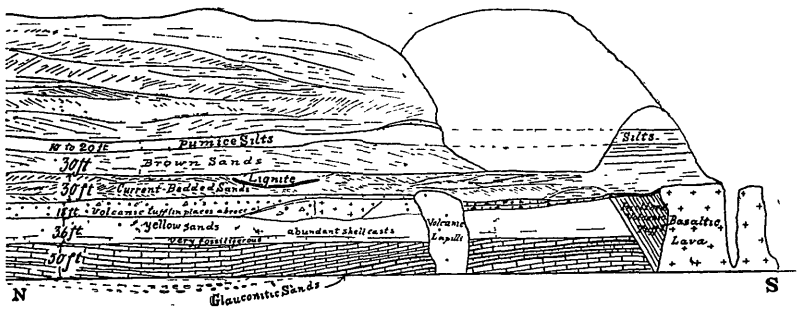


Fig. 11.—Coast section south of Kawa Stream.

connecting these beds with the history of the Waikato River, are the features which give it this importance. It was described in detail by Bartrum (1919B). The following brief description contains a few facts not recorded by him.

*Order of Ascending Sequence.* (See fig. 11.)

1. Blue calcareous sea-muds.
2. Glauconitic greensands (15 ft. to 20 ft.).
3. Above the glauconitic greeesands come 50 ft. to 60 ft. of thin calcareous sea-muds. These thin beds, after deposition, were affected by movements of compression, resulting in faulting and gentle folding, and accompanying uplift. Then followed a period of planation by the sea which cut their upper surface into a plane of marine denudation.
4. Fossiliferous yellow sands to a depth of 36 ft. were now deposited by the sea on the marine-planed surface of the slowly sinking land. Mr. J. A. Bartrum has published a list of fossils from this bed and has described some new species (Bartrum, 1919A and 1919B).

* The Notopleistocene beds of Thomson (1917).

5. Volcanic ash, breccia, and basaltic lava. The marginal portions of the plug contain included fragments of the calcareous beds through which it was extruded. The volcanic-ash bed contains large fragments of the underlying calcareous beds, and varies from a coarse ash in the north to a breccia or agglomerate as it approaches the neck of the volcano. These beds are distinctly unconformable to the underlying fossiliferous sands.
6. Stream-bedded sands, 30 ft. thick, follow; they include a band of lignite 8 in. thick. In proximity to agglomerate which is above the volcanic lava-plug they appear locally to overlie beds of included tuff of which the upper limit is a sharply marked erosion-plane coincident approximately with the upper level of the yellow fossiliferous sands.
7. Brown sands (30 ft.) follow, whose lower layers are horizontally bedded, whilst higher up they are composed of peculiar lenses encrusted by limonitized ironsand. The thin encrusting layers show an interlacing tendency typical of wind-blown sands where the winds change direction frequently, and so form confused series of ripple-marks. It is not easy to explain why the encrusting layers alone should become limonitized, leaving the sand between loose and unaltered.
8. Pumice-bed (10 ft. to 20 ft.). This is a white, light, slightly plastic clay band, its very thinly bedded nature indicating deposition in the fairly still water of a swamp or lake. It is undoubtedly a fine pumice, enclosing large fragments of the same material. Non-pumiceous silts of irregular thickness replace the pumice to the south, above the volcanic conglomerate which covers the remnant of the lava-plug.
9. 200 ft. of brown, oxidized, wind-blown sands rich in limonite concretions.

*The Kawa Pumice-bed in Relation to the Waikato River.*

The occurrence of this bed of pumice-sand, containing coarser fragments of pumice, 180 ft. above high water, so far south of the mouth of the Waikato River makes one hesitate to ascribe its origin to transport by that river of material from the pumice plateau through which it flows for so much of its upper and middle course. No other origin, however, readily suggests itself, whilst this theory has several facts to support it:—

(1.) There is no other visible source whence the material may be derived.

(2.) The characteristic deposits made by the Waikato in the Bay of Plenty district and in the Hauraki Plains are largely rhyolitic pumice-silt which resembles the Kawa deposit.

(3.) Not only has the coastal area risen, but the whole country to the east and south-east as far as the middle Waikato basin, including the southern portion of the Hauraki Plains, across which the river flows in a north-westerly direction, has also been elevated with reference to sea-level since the course of the Waikato River was diverted from its old channel leading through the Hinuwera Valley to the Hauraki Gulf. There has thus been regional uplift. At the point below Maungatautari Gorge where the river enters the middle Waikato basin the surface of the plain is 300 ft. above sea-level. According to Henderson (1918, p. 60) this plain was formed by loose pumice of fluviatile origin whilst the land was depressed. About this time also the river changed its course from the Hinuwera Valley to the north-west across its own alluvial plain. (See Henderson 1918, pp. 112–15; and Cussen, 1889, p. 409, and 1894, pp. 401–10). The pumice of the Kawa beds must have been brought down at that time and deposited in a depression forming a swamp on the borders of a large estuary or low-lying coastal land such as then existed. When elevation ensued the tendency would be for the river to deepen its bed, and this has been done across the middle Waikato basin, the deepening here corresponding approximately to the uplift of the

Kawa pumice-bed, above which all the beds are subaerial deposits. (See Cussen, 1889, p. 413.)

4. It might be suggested that wave transport may have brought the pumice from far-distant localities; but the nature of the material and its bedding negative such a suggestion.

It may be mentioned that Mr. Bartrum (1919A, p. 104) similarly is inclined to ascribe the origin of this pumice-bed to the Waikato River.

### Structural Plateau near the Coast.

The Notopleistocene formations along the coast form a structural plateau governed by the bedding of the horizontal sheet of limonitized sands forming the uppermost beds and now acutely dissected by the westerly streams. The residual ridges between these streams are all about the same height, and, seen from the northerly geodetic station, Waihonui, they are remarkably uniform. These divides are sometimes, as at Waihouni and Opura, small tablelands, remnants of the old platform.

### Slipped Country above Waiwiri Beach.

For a quarter of a mile back from the Waiwiri beach the country has slipped along parallel lines, presenting seaward-facing scarps 10 ft. to 30 ft. or 40 ft. high. The whole area between these scarps and the sea-cliffs is tossed into hummocky mounds. Only the upper or sandy beds appear to be affected, and these are being slowly pushed over the cliffs on to the beach. The scarps form a rude semicircle facing the sea for a distance of over a mile. They are said to be as fresh-looking to-day as they were forty-five years ago. The scarps reveal cross-bedding everywhere.

The composition of these beds is a light, dull, black sand, the blackness not being due to grains of magnetite, which is not abundant, but to dull, light grains of material probably owing its origin to the erosion of shale-beds of the Mesozoics. They are unlike any of the other beds north or south that occupy a higher horizon than the *Cardita* beds or tabular limestone. The *Cardita* beds appear to have formed the base of a plain of marine denudation in this locality, possibly contemporaneous with that at the Kawa, or perhaps more recent, when the yellow and brown sands, &c., were removed by wave-action.

### Sinkholes.

Close to the ridge above the great area of slipped country are several sinkholes, or swallow-holes, vertical cavities formed by the internal running of the sands beneath the surface, which then subsided. Similar sinkholes can be observed in the pumice lands near Hamilton. One at Pa Brown, due to solution of the limestone beneath the surface, is of much larger dimensions than those between the Ruahine and Kawa Streams.

### Microscopic Characters of some of the Rocks.

*The Kawa Basalt.*—In a holocrystalline pilotaxitic groundmass consisting of long microlites of feldspar, showing good flow-structure, with less prominent prisms and grains of augite and olivine and very numerous fine specks of magnetite, occur separate phenocrysts of augite and olivine, and some glomero-porphyritic phenocrysts of olivine and augite with associated chlorite. The augite is usually colourless, but sometimes has a pink border. The olivine phenocrysts show the mesh-structure characteristic of alteration to serpentine along lines of fracture and around the edges. A secondary fibrous mineral, chlorite, is formed in numerous cavities. Large olivine nodules, up to 2 in. in diameter, are numerous in this basalt.

FIG. 1.—Showing the characteristic dune-bedding in the consolidated sands close to the bed of lignite near the Fishing Rock, on the coast north-west of Waiuku.


FIG. 2.

FIG. 3.

FIG. 2.—Photomicrograph of algal limestone north of Te Orairoa Point. The section shows the structure of the algae very clearly, but on so fine a scale that the photograph reproduces it poorly. *a*, an alga (? *Lithothamnion*); *b*, Polyzoa; *c*, a foraminifer, probably *Amphistegina*. × 24.

FIG. 3.—Photomicrograph of fine *Globigerina* limestone, Koruahine Point. × 24.

(Photomicrographs by J. A. Bartrum.)

*Face p. 112.*]

FIG. 1.—Mesozoic shales and sandstones of the "strike coast," a little south of Okariha Point.

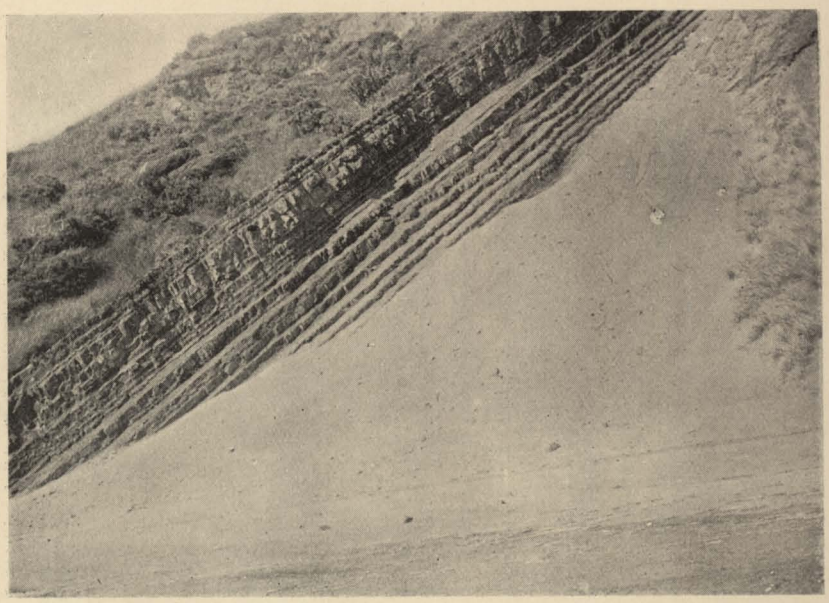

FIG. 2.—The belemnite shales (Mesozoic) at the South Head, Waikato River.

*Waitangi Bay Basalt.*—A couple of miles to the north of Waiuku there occurs a basaltic lava-flow which can be traced along the bed of the Waitangi Stream. Elsewhere it is covered deeply in a ferruginous clay resulting from the decomposition of basalt, so that its extent could not be ascertained. At one time the rock was quarried for road-metal at Waitangi Bay, where the stream enters Waiuku Creek. Here it is coarsely columnar. Examined under the microscope this rock is seen to be quite similar to the basalts common round Auckland City. It consists of a holocrystalline, pilotaxitic groundmass of long feldspar laths and small granular interstitial augite and olivine, enclosing numerous large phenocrysts of olivine and pale to colourless augite. The feldspar is mainly a basic labradorite, some of the twinned crystals being fairly large laths. Subsidiary iron-ore (magnetite) is scattered about in short streaks.

*The Pakau Basalt.*—About seven miles up the south bank of the Waikato River is a lava-flow across which several streams, including the Pakau, flow in relatively shallow valleys after leaving the deep, gorge-like valleys their headwaters have cut in the Mesozoic rocks of the Waikato fault-scarp.

At a point about a mile to the east of the Pakau Stream, where another stream forms a waterfall over the edge of the basaltic lava-flow, the Mesozoic sandstones and shales are seen in direct contact unconformably underlying the lava-sheet. This lava-sheet and the associated basaltic breccia to the east are believed to be of the same age as the basaltic flows and breccias spread over a wide area to the north of the Waikato River and eastward of Waiuku, and to be more recent than the Kawa flow.

At the Opuatia Bridge and in the environs of Puke-o-tahinga the lava rests directly on the Notocene calcareous sea-muds. Behind the Onewhero store and Post-office is a circular basin one mile in diameter, originally a crater and subsequently a lake, which has been insilted to the level of its present floor and now forms good farm land. It was drained by a stream through a breach in the north-eastern margin of the crater. This stream exposes the original lava-flow beneath the tuffs of the lip and for a mile farther on, till finally, where its waters tumble into a deep gully, the lava can be seen to occupy a trough representing an old stream-valley in the Notocene calcareous sea-muds.

The Pakau basalt, microscopically, consists of numerous large phenocrysts of olivine with less important colourless augite, in a pilotaxitic groundmass. The groundmass is made up of twinned feldspar microlites of basic labradorite with abundant augite and olivine granules and subsidiary iron-ore scattered about in large and small grains.

*Algal Limestone.*—South end of Matuatua Beach. This limestone occurs at the base of the cliffs less than a mile south of the Huruwai Stream, and near Te Orairoa Point. Examined in microscopic section it is seen to consist mainly of algal concretions, fragments of echinoid shells and shell-plates and spines, corals, Foraminifera, and a good many polyzoans. (See Plate XX, fig. 2.)

*Glauconitic Limestone.*—From same locality. Associated with the coarse-looking algal limestone, and probably above it, is a glauconitic type, composed of numerous grains of glauconite with tests of Foraminifera and a few angular grains of quartz. Recrystallized calcite forms a finely granular mosaic filling some of the interstices between the organic fragments.

*Marly Limestone.*—North Kawa Head. This limestone consists chiefly of the tests of *Globigerina*, of which the chambers are frequently detached, and other Foraminifera. Small granular calcite often fills the foraminiferal chambers.

Globigerina *Limestone.*—Koruahine Point, south end of Waiwiri Beach. *Globigerina* shells almost entirely constitute this rock, which may therefore

be considered a *Globigerina* ooze. In the section examined there were, in addition, other foraminiferal remains, and an echinoid spine, together with some grains of iron-pyrites. (Plate XX, fig. 3.)

## Summary and Conclusions.

South of the Waikato River occurs a folded older-mass of Mesozoic age, on the broadly truncated erosion-surface of which was laid down a younger-mass of Tertiary strata showing unconformity, or at least discontinuity of deposition between some series, as at the Kawa.

North of the Waikato River is an area of younger (Quaternary) sedimentary strata with a line of elevated sand-dunes fronting the coast.

Along lines of major dislocation coincident with the northern limit of the Manukau Harbour in one case, and, in the other, with the line of the lower Waikato River, considerable differential movements resulted in uplift of the areas to the north and south relatively to the middle (or Manukau) area. The latest considerable movement of the southern area appears to have been uplift to the approximate height of 180 ft., and to have occurred since the Waikato River began to discharge itself by its present outlet.* Minor oscillations have occurred in sub-recent times, especially in the middle area.

The Manukau sand-dune range originated in a spit or barrier beach which created a broad estuary of the Waikato River.

The Manukau Harbour owes its origin to streams, during minor uplift, cutting into the silts deposited in the former Waikato estuary, whilst subsequently the area subsided slightly, allowing the sea to penetrate into these stream-courses and rapidly push back the low sea-cliffs cut in the unconsolidated silts

The ages of the Tertiary strata and the importance of the physical unconformity and stratigraphical discontinuity in the Kawa beds cannot be decided definitely without further palaeontological evidence, which it is hoped will be available in the near future.

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* This estimate is based upon the data furnished by the pumice-bed in the section exposed south of Kawa Stream.