The Geology of the North-west Portion of Manukau County, Auckland.

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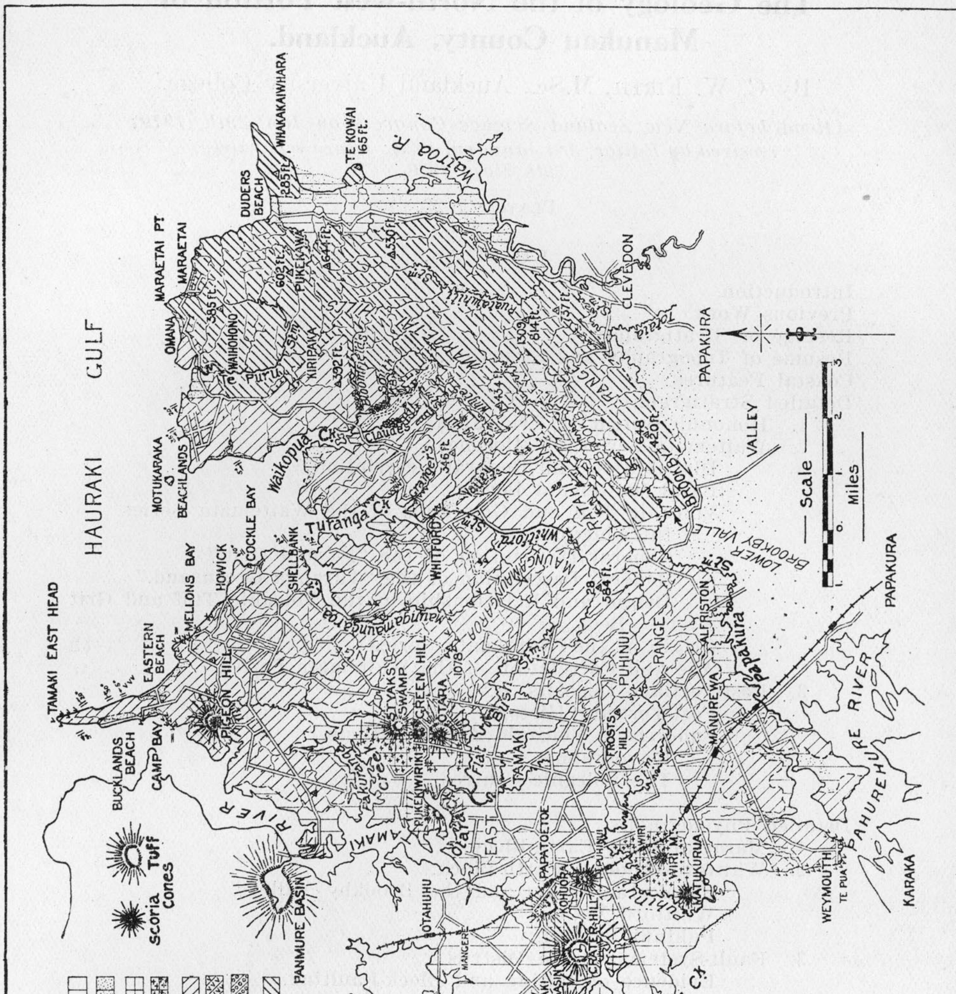
INTRODUCTION.

THE district dealt with in the present paper comprises a clearly defined area of approximately 130 square miles lying between Tamaki River, 7 miles south-east of Auckland City, and Papakura Valley a further 11 miles south-east. On its northern limits it is bounded by the eastern shore-line of Hauraki Gulf and on its western by Manu-



Sketch-map of geology of North-West Manukau, Auckland, kau Harbour. Papakura Valley is a marked tectonic depression crossing the Auckland Isthmus from Manukau Harbour near Papakura Township, to Hauraki Gulf in the vicinity of Clevedon, and therefore invests the district with a degree of structural as well as geographical unity.

The area studied consists essentially of three distinct major topographical units, which rise successively from west to east in the form of huge steps, which are bounded by prominent structural features and possess the characters of earth-blocks. The most easterly and highest of these units is composed essentially of comparatively resistant Mesozoic rock, and comprises the rugged, largely bush-clad Maraetai Hills; the central one is characterised by softer Tertiary sandstone, and displays a more subdued topography, whilst the western and lowest comprises extensive plain-like lowlands of unconsolidated Pleistocene silts bordering Tamaki River and Manukau Harbour.

The investigation was carried out in 1928 in fulfilment of the requirements of the Master's degree under the supervision of Professor J. A. Bartrum, to whom the writer's thanks are due.

PREVIOUS WORK.

As early as 1853 Hochstetter (1864)* examined the volcanic centres and underlying Pleistocene sediments of the western portion of the district, whilst in 1860 Heaphy published notes upon the adjoining volcanoes of Auckland. Apart from this, and the recent work of Bartrum (1927) relating to certain structural features of its eastern margin and to the pumiceous silts bordering Lower Wairoa River, all other geological investigation prior to that here recorded has been confined to the coastal section from Tamaki River to Waikopua Creek, and deals mainly with the controversial subject of the age of certain volcanic grits of the Waitemata Series. The published views of Hutton (1871), Cox (1882), Park (1886; 1889), McKay (1888) and Fox (1902) on this question will be summarised in a later section of this paper. A list of the fossils recorded from the fossiliferous horizons of the Waitemata Series is given by Clarke (1905), and includes specimens collected from the coastal section mentioned.

In an attempt accurately to revise the somewhat misleading geological maps already published and compiled from work of the localised nature indicated above, the writer has made a detailed study of the whole district, and has obtained sufficient data not only to describe its stratigraphy, but also to break virgin ground by discussion of its post-Mesozoic geological history and its physiographic development during post-Tertiary times. It has furthermore been possible to map, as accurately as the scale used would permit, the drainage and other topographic features of the district, and thus amplify the very inadequate information given in earlier physiographic maps.

*See list of literature cited for full reference.

Résumé of Stratigraphy.

The oldest rocks of the district are disordered greywackes, assigned by recent writers to the Hokonui system of Trias-Jura age, which are developed almost exclusively in the Maraetai hills and the hills bordering the Brookby valleys. These rocks are followed westward by beds of the Waitemata Series (? Miocene), the several members of which form an unbroken sequence from basal limestones, developed at Waikopua Creek, to heavy-bedded sandstones with intercalated tufaceous green sandstones and volcanic grits of the so-called Parnell Grit horizon, such as are perfectly exposed along the shores of Waitemata Harbour and the adjacent shores of Hauraki Gulf. The contact of this "youngermass" with the Trias-Jura "oldermass" in all cases is highly unconformable.

The absence of such beds as the "hydraulic limestone" (Onerahi Series) of probable Upper Cretaceous age, which Bartrum (1924) believes to underlie unconformably the beds of the Waitemata Series in Riverhead-Silverdale district, 20 miles north, and of the coal measures forming the base of the Tertiary sequence in Hunua district, 8 miles south, would suggest that the full post-Hokonui succession is not developed in the present area. It is possible, though not demonstrable, that post-Hokonui beds older than those actually exposed may exist under the area, buried beneath overlapping younger beds.

Fluviatile and estuarine deposits, probably of Pleistocene age, have an extensive development in the plain-like lowlands bordering Tamaki River and Manukau Harbour known throughout this paper as the "coastal lowlands." They rest unconformably on Tertiary sandstone in places along the Hauraki Coast, and on Trias-Jura greywacke adjacent to Lower Wairoa River. The youngest deposits of the area are represented by raised beaches at numerous places along the coasts, and by volcanic tuff and scoria cones, with associated basaltic flows, which rest on the Pleistocene silts of the coastal lowlands.

Resume of Topography and Structure.

As already suggested in the Introduction, three distinct major topographical and geographical units are defined by stratigraphical and structural considerations in the present district. (See Text Fig. 1).

The most westerly unit comprises the coastal lowlands, which cover some 50 square miles, and present a plain-like surface, rarely over 60 ft. above sea-level, the monotony of which is relieved by somewhat numerous small scoria cones and tuff craters. The topography of this plain is clearly due to two cycles, for the lower reaches especially of the streams which drain across the plain to the west, display clear evidence of rejuvenation in that they are sharply entrenched, to a maximum depth of 15 ft., below the very broadly convex late-mature forms of an earlier cycle. (See Fig. 29). Some of the larger streams, especially those tributary to Otara and Pakuranga creeks, which spread fan-wise across the lowlands of East

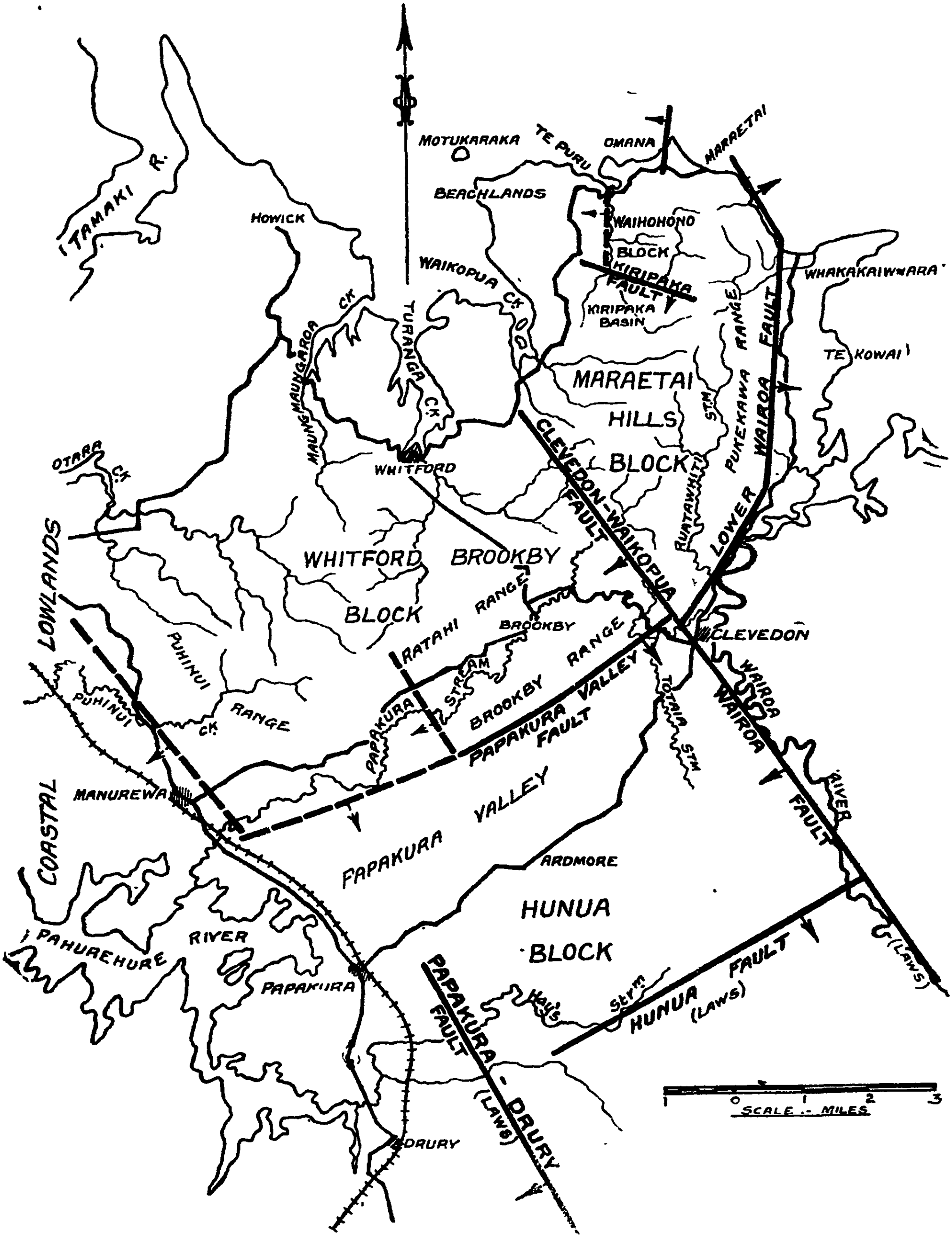


FIG. 1.—Index-map of faults in North-West Manukau and the neighbouring Papakura-Hunua District.

Tamaki district from Tamaki River to the fringing hills of Tertiary sandstone further east, have built small sharply-defined flood-plains during the second cycle, but many smaller streams have not yet adjusted themselves to the new base-level, and still flow in sharply entrenched meanders. Recent comparatively small uplift is undoubtedly partly responsible for the institution of the rejuvenation evidenced, but it is probable that deforestation of this formerly entirely bush-clad locality has been at least as potent as uplift in producing this feature.

On their eastern margin the coastal lowlands abut against abruptly-rising hills of Tertiary sandstones, which characterise the central topographic unit—hereafter called Whitford-Brookby Block—and run in a broad arc, concave to the west, from the vicinity of Howick to Manurewa township. These hills, comprising Maungamaungaroa and Puhinui ranges, rise to an elevation of 580 ft. near Alfriston, but descend gradually eastward to the low-lying Whitford and Brookby valleys. In Ratahi and Brookby ranges, which border the latter valleys, harder mid-Mesozoic greywackes replace the Tertiary sandstone with expectable changes in topography. Tertiary beds form another prominent feature in a long gently-sloping surface which gradually descends from the flanks of the lofty Maraetai hills—the mass of greywacke which constitutes the third or eastern topographical unit of the district—to an almost level area of Pleistocene deposits, about 60 ft. above sea-level, at Beachlands.

As a general rule, the Tertiary sandstone terrain presents readily recognisable features. In major detail it invariably displays comparatively coarse-textured topography, which is often accompanied by distinct stepping as a result of slight variations of hardness in the sub-horizontal strata, and by mammillary contours due to large-scale slips with sharp scarps at their upper margins, at times prominent near the crests of divides.

In contrast with such characteristics, the maturely dissected greywacke terrain invariably exhibits close-textured insequent drainage developed as a result of its remarkably uniform lithological nature and its heavy cover of impervious residual clay.

Identification of the various geographic units does not depend, however, solely on details of minor topography, but is simplified by the fact that the area described consists of two very distinct earth-blocks, differentially uplifted with respect to each other and to the neighbouring tectonic depression of Papakura Valley. The higher eastern Maraetai Hills Block culminates in a height of 820 ft. near Clevedon, and is bounded eastward by a steep scarp-slope which is believed to be due to a great fracture herein called Lower Wairoa Fault, as is suggested by Bartrum (1927, p. 246). The lower or Whitford-Brookby Block rises to a maximum height of only 580 ft., and is separated from Maraetai Hills Block north-east of it by a prominent scarp, developed by what is here designated the Clevedon-Waikopua Fault. On the south-east it descends abruptly by the scarp of Papakura Valley Fault (Laws, MS.) to the Papakura Valley lowland, whilst it is possible that its south-western margin may have been determined by a north-west extension of the Papakura-Drury Fault of Laws (*loc. cit.*). (See Text-Fig. 1).

All these fractures will be considered in detail later. For the present it will suffice to state that their average orientation in two directions—north-east to south-west and north-west to south-east respectively—is in close agreement with that of the major fractures responsible for the blocking out of the whole Hauraki area, in common with other parts of Auckland Province north of the Rotorua-Taupo volcanic zone (Henderson, 1924 a). Structurally, therefore, it is apparent that the district is in keeping with the generalisation of Cotton (1916, p. 319) that New Zealand as a whole may be regarded as a "concourse of earth-blocks of varying size and shape."

COASTAL FEATURES.

The coastal topography displayed on the coasts both of Hauraki Gulf and of Manukau Harbour is essentially that of a comparatively recently submerged area of low relief, modified subsequently by erosion to give the approximately stable coastal outlines of the present day.

It is apparent that, following submergence, extensive cliffing took place even along the shores of long and narrow drowned valleys, formed by this movement, which are represented at the present time by Tamaki River, Maungamaungaroa, Turanga and Waikopua creeks on the Hauraki Gulf coast, and by Pukaki, Puhinui and Pahurehure creeks of Manukau Harbour. This cliffing has, however, long ceased except at certain points in the creeks of the Manukau coast, and has been followed by the gradual infilling of bay-heads by débris derived by stream and wave erosion, so that at the present time prominent abandoned sea-cliffs are general with extensive mud-flats seaward of them.

Progradation of the shore-line has advanced still further in some cases. For example, the mouth of Maungamaungaroa Creek is partly closed by a prominent recurved shell spit marking the zone of conflict of the currents in this creek with those of the nearby main channel of Turanga Creek, whilst low barrier beaches enclosing swampy flats are common in the wide open mouths of Turanga and Waikopua creeks. Similar conditions hold near the mouth of the Wairoa River, where deltaic deposits constantly reduce the slope of the off-shore profile, and thus produce the requisite conditions for progradation by a series of barrier beaches, as is admirably shown by the infilling of the formerly deep embayment between the greywacke residuals, Whakaiwhara and Te Kowai, of this locality. (See Fig. 5).

Simultaneously with progradation in the drowned valleys, the intervening exposed portions of the initial coasts have suffered very extensive retrogradation. In the sandstone terrain from Tamaki River to Omana Beach this has resulted in the development of even lines of sheer cliffs, fronted everywhere by extensive wave-cut platforms (Fig. 6). These cliffs attain a height of 80 ft. near Howick, whilst the shore-platform near Beachlands extends well beyond Motukaraka, a large, flat-topped, cliff-encircled stack which lies half a mile off-shore from the mainland. The results of selective erosion along the lines of cliffs are clearly demonstrated in the not unusual definite association of pocket beaches with zones of marked contortion of the sandstone strata, and in the cutting of small sea-caves along fault-lines or in the weaker members of highly tilted strata. The greywacke terrain east of Omana displays a much less advanced stage of shore development, and is characterised by a series of deep crescentic bays and steep beaches, separated by comparatively subdued headlands which are continued seaward as jagged reefs.

Well-defined remnants of raised beaches backed by abandoned sea-cliffs form a constant feature of all sheltered sections of the coasts of the district, and clearly demonstrate a small relative uplift in recent times. Evidence of this is particularly clear in the comparatively immature coast of the greywacke terrain, where elevated wave-cut benches are also preserved on certain of the headlands, and corroborate the evidence of the raised beaches at the heads of the bays (See Fig. 7). Further details of these will be given when dealing with post-Tertiary history.

Manukau Harbour presents several special features in its coasts. Consequent on the rapid erosion by waves of the soft Pleistocene beds of the plain-like, low-lying area by which it is bordered, this harbour at the present time is little more than a series of mud-flats, whilst its shore-line has been greatly simplified. Minor details of the coast are now determined by the relative proximity, one to another, of the channels crossing the mud-flats. Thus the original trench-like valleys that were drowned by submergence are still being widened by wave-erosion, and along their courses and near their mouths present lines of low, sheer, crumbling cliffs, though elsewhere, in the protection afforded by wide stretches of mud-flat, progradation by low barrier beaches has recently been instituted.

Detailed Stratigraphy.

As stated previously in the resumé of stratigraphy, three very distinct rock-groups are developed in the present district, and will now be discussed in some detail under the following headings:—

(1) Hokonui System (? Trias-Jura).
(2) Waitemata Series (? Miocene).
(3) Post-Tertiary Deposits.

(1) Hokonui System (? Trias-Jura).

Rocks referable to the Hokonui System outcrop over 30 square miles in the north-east portion of the district studied, and, as far as can be seen, are an unbroken series of fine to moderately coarse-textured greywackes of uniform character, so closely jointed as to obliterate all traces of original bedding planes, and apparently entirely unfossiliferous. Closeness of joints has so facilitated weathering that a deep cover of stiff, yellowish-white or reddish residual clay is general, with the result that outcrops of all but greatly weathered rock are confined to the more youthful stream valleys and to the coast-line.

Fine-grained greywacke, in which occasional angular fragments of plagioclase and quartz are the only recognisable minerals, characterises the Maraetai Hills and predominates also in the hills bordering the Brookby Valleys. Not uncommonly it is so closely jointed as to crumble under the hammer, but in some cases, as at Whakakaiwhara, it is rendered very hard and resistant as a result of the filling of the joints fissures with siliceous material.

Rock appreciably coarser in grain and with a much wider spacing of joints has a very limited occurrence, and appears to be restricted to the vicinity of Trig. 648, in Brookby Range, and to the summit of Ratahi Range, immediately opposite on the northwest side of Upper Brookby Valley. In the former locality it is indicated only by numerous spheroidally weathered boulders of up to 3 feet in diameter, but in the latter locality it is also seen *in situ* in an outcrop which, however, is too limited to display any evidence of structure other than jointing.

Under the microscope this rock (Fig. 35) is seen to consist of an even-grained mosaic of fragments of plagioclase—probably andesine—and orthoclase, in sub-equal amounts, with less abundant angular grains of quartz, minor augite and green hornblende and occasional grains of magnetite and zircon. Chlorite is a common alteration product, whilst the orthoclase is usually sericitised. Fragments of pre-existing andesite as much as one-eighth inch in diameter, and of a dense, fine-grained, indeterminate volcanic rock, are also moderately plentiful, together with occasional tiny pellets of fine-grained sandstone.

The only other variation from the predominating fine-grained greywacke is seen in an interesting occurrence on the eastern side of the upper valley of Te Puru Stream, where outcrops of a comparatively resistant pinkish-white quartzose vein or stratum form a series of prominent bare ridges which are roughly aligned for nearly one mile, in a direction slightly east of north. The true nature of the occurrence of this rock is obscure. In its upper levels the "reef" is predominantly quartzose, yet exhibits close jointing identical with that of nearby fine-grained greywacke. Further, in a tributary of Te Puru Stream that has cut through it to a depth of nearly 200 ft., it appears to pass down into a highly siliceous greywacke which is with difficulty differentiated from flanking dense normal greywacke. This fact suggests that the upper quartzose portions are to be regarded rather as the cap of a band of such rock cemented by silica supplied by the weathering of still higher, now-removed portions of the same band, than as a vein-filling or a metasomatic replacement of original greywacke adjacent to a fissure. If this explanation is correct, the roughly-aligned quartzose outcrops must be regarded as representing a definite sub-vertical stratum, at least 20 ft. thick, which strikes a little east of north.

Liberal coatings of manganese oxide or hydrate occur on some outcrops of dense fine-grained greywacke in the vicinity of the above "reef." The parent rock on sectioning is also found to be crossed by veinlets filled with quartz and a mineral which is probably prehnite, but which unfortunately is not sufficiently well crystallised to allow conclusive tests to be made.

By reason of their unfossiliferous nature and the elimination of all evidence as to internal structure, the Hokonui rocks of the district unfortunately throw no new light on the question of the age or structure of the system to which they are allocated. Neither do they offer any evidence as to their origin, except that they show that the land mass from which they were derived was constituted in part of crystalline rocks.

(2) Waitemata Series (? Miocene).

Distribution and General Description.

Beds of the mid-Tertiary Waitemata Series—a term introduced by Hochstetter (1864) for "the horizontal beds of sandstone and marls which form the cliffs of the Waitemata"—lie west of the rocks of the Hokonui System on the western flanks of the Maraetai Hills and of Ratahi Range, and occupy the whole of the central portion of the district. Still further west they pass under the Pleistocene beds of the coastal lowlands facing Tamaki River and Manukau Harbour.

The normal beds of the series are alternating beds of unfossiliferous, fine-grained, yellow-brown sandstones and thin bands of fine gray mudstone. The latter are never more than a few inches thick, but invariably contain numerous fragments of wood and bark, which, however, are generically indeterminate and therefore of no value palaeontologically. Eminent cross-bedding on a fine scale is common in the sandstone members. These also show occasional gritty phases and rare, small pyritous nodules, and frequently incorporate lenses or pebbles of sandstone which apparently have resulted from contemporaneous erosion.

Thin, hard, irregularly-concretionary bands which have resulted from cementation by calcareous material are general throughout the series. A special phase of this is shown north of Buckland's Beach (Fig. 9), where numerous perfectly-rounded concretions up to 18 ins. in diameter have weathered from the adjacent cliffs. Deposition of calcareous cement around small pebbles of mudstone is indicated in broken specimens, in which fractures lined by calcite crystals are also seen to be common. This type of concretionary sandstone is the "cannon ball sandstone" of Cox (1882).

Interbedded with the normal beds of the Waitemata Series are thick strata of a volcanic grit of variable texture—the "Parnell Grit." In addition, however, there are two sets of beds which by reason of their fossiliferous nature render the present district specially important: (a) the so-called "Turanga greensand" of early writers (b) greywacke conglomerates and impure limestones which form the base of the Waitemata Series at Waikopua. These beds will be considered in some detail in the following pages.

Basal Waitemata Beds.

At distances varying from one-quarter to one-half of a mile east of Whitford-Maraetai road, in the beds of Bloomfield's Stream, South Branch, and Claude's Stream—the three largest streams draining into the head of Waikopua Creek—there are some very interesting but limited outcrops of impure limestones (Fig. 10), lime-cemented greywacke-breccias and calcareous green sandstones which

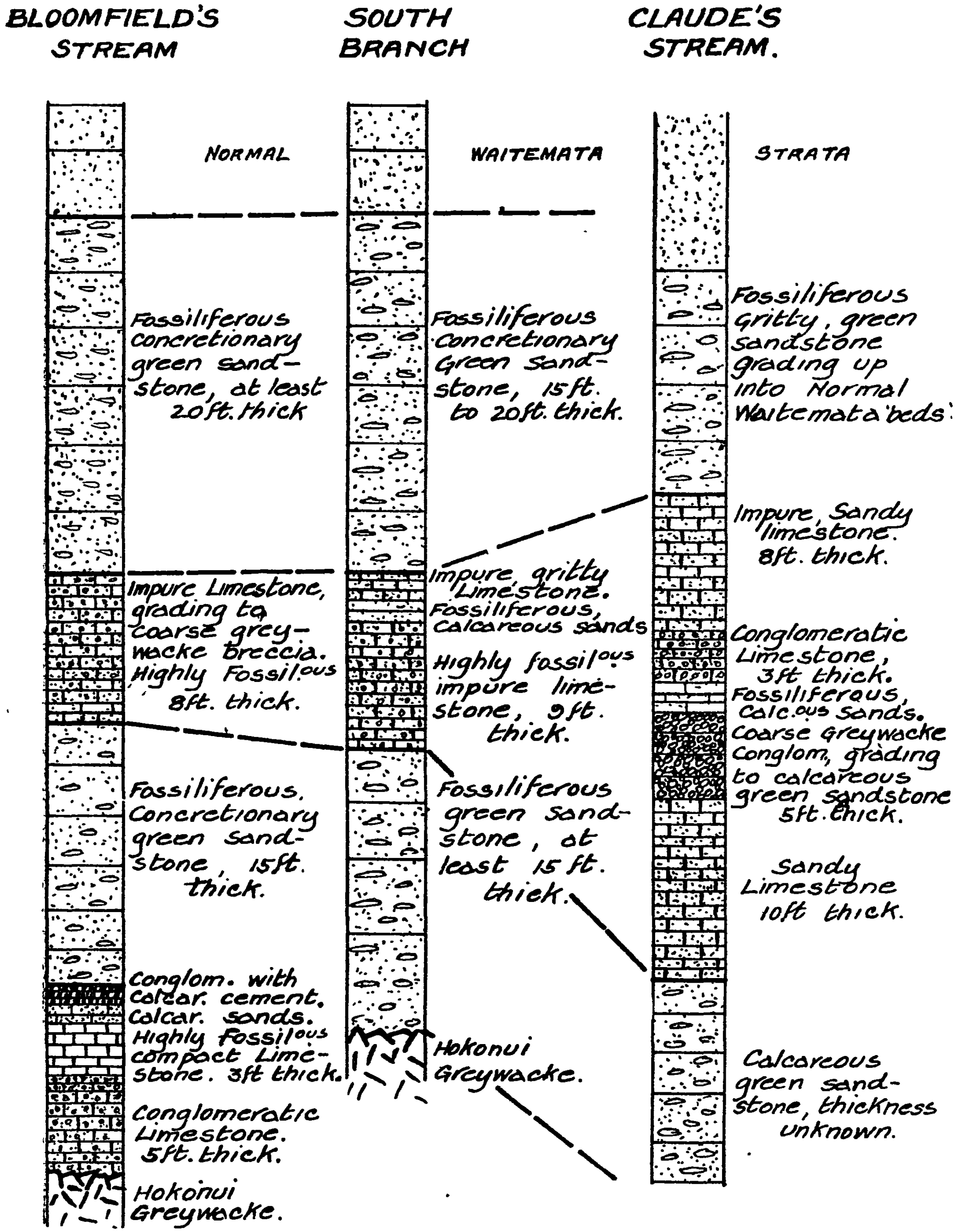


FIG. 2.—The main sequences of basal Waitemata beds exposed at Waikopua.

rest highly unconformably on Hokonui greywacke, and are followed conformably by normal beds of the Waitemata Series. These beds are the oldest exposed members of the "youngermass" in the present area, but in spite of their palaeontological and stratigraphical importance the only published account of them is a generalised description made by Park in 1886, who correlated them with the beds of the so-called Papakura Series of Hutton (1871, p. 246), developed at Hay's Creek, Papakura, which he showed to be the basal members of the Waitemata Series.

Considerable variation in facies occurs in the several outcrops at Waikopua, but nevertheless certain strata appear to be sufficiently constant throughout the main outcrops to suggest the following general succession, which varies in some respects from that given by Park:—

6. Normal Waitemata beds
5. Concretionary green sandstone
4. Impure limestone; coarse greywacke conglomerate
3. Concretionary green sandstone
2. Conglomeratic limestone
1. Hokonui greywacke.

The complete sequences exposed in the several streams are given in Text-Fig. 2. So far as is known that at Claude's Stream has not been previously recorded or described.

The main or downstream outcrops in all three streams display strata with a constant dip to the north-west of from 5° to 8°, which brings successively lower beds of the sequence into view for approximately 10 chains. They end abruptly against steep, narrow ridges of greywacke, upstream of which are further more circumscribed outcrops which occupy pockets between similar greywacke barriers. The only connection between the beds of the main outcrops and these upstream outcrops lies in the fact that both are followed conformably by normal Waitemata beds which over-ride the intervening barriers of greywacke. The "basal" beds exposed in the upstream outcrop at Bloomfield's Stream are coarse, poorly-cemented conglomerates which grade upstream into gritty, impure limestone. Of two similar outcrops at South Branch, one shows a limited occurrence of gritty green sandstone and the other, 5 chains upstream from the first, a prominent band of limestone which is exceptionally pure in places and consists almost entirely of an open-textured mass of polyzoa, foraminifera, algae, brachiopods and echinoid fragments; above the limestone there is about 40 ft. of green sandstone. At Claude's Stream the only "upstream" representative is a band of poorly-cemented, roughly-sorted greywacke breccia, at least 8 ft. thick, which coarsens upstream until included fragments as much as 9 in. in diameter are common.

The green sandstone members of these basal beds are generally fine-grained and contain sporadic small greywacke pebbles. The limestones are much coarser in texture, exhibit cross-bedding on both fine and coarse scales, and thin out laterally in the form of lenses. Evidence of minor faulting or down-sagging at or adjacent to steep contacts with the greywacke of the "oldermass" is complete in

FIG. 5.—Typical bay-filling between Whakakaiwhara and Te Kowai (right centre). The barrier-beach behind which this filling has taken place is clearly seen on its seaward margin. Remnants of an earlier barrier-beach are still preserved immediately to the right of this view.

FIG. 6.—Typical wave-cut platform and cliffs (in distance) of the Waitemata sandstone terrain, western portion of Omana Beach. The well-defined terrace behind the present storm beach (foreground) is a characteristic raised beach.

Face p. 96.

FIG. 7.—Uplifted shore-platform 8 ft. to 10 ft. above high-water mark cut in greywacke at the promontory between Omana and Maraetai Beaches.

FIG. 8.—Typical raised beach deposits resting on a wave-planed surface of Pleistocene clays; eastern portion of Omana Beach.
[*Photo., J. A. Bartrum.*

FIG. 9.—Concretions eroded from "cannon-ball" sandstone on the wave-cut platform north of Buckland's Beach.

FIG. 10.—Impure limestone conformably overlying green sandstone; main outcrop, South Branch, Waikopua.

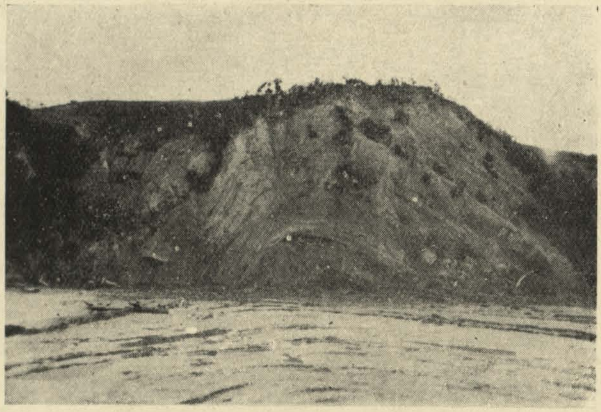


FIG. 11.—Anticline in Waitemata strata of sea-cliffs between Tamaki East Head and Eastern Beach.

FIG. 12.—Thrust-fault in Waitemata strata between Eastern Beach and Mellon's Beach.

Fig. 13.—Conformable relations of Parnell Grit (shore-platform and base of cliffs) and horizontal sandstones and mudstones of Waitemata Series west of Mellon's Beach.

Fig. 14.—Typical Parnell Grit at the north end of Camp Bay. Tufaceous sandstone shows above the Grit at the top of the cliff.

Fig. 15.—Kiripaka Basin from the hills above Kiripaka scarp, looking south across the denuded greywacke floor to Waikopua divide (middle distance) and the main range of Maraetai Hills beyond.

[*Photo., R. W. Firth.*

Fig. 16.—Fossil pothole in Waitemata sandstone at base of Pleistocene beds in bay east of Beachlands Wharf.

[*Photo., J. A. Bartrum.*

FIG. 17.—Material of the "30 ft. to 35 ft." terrace at road from Clevedon to Duder's Beach. Grey muds at the base followed by greywacke conglomerate and then light-coloured pumiceous silts.

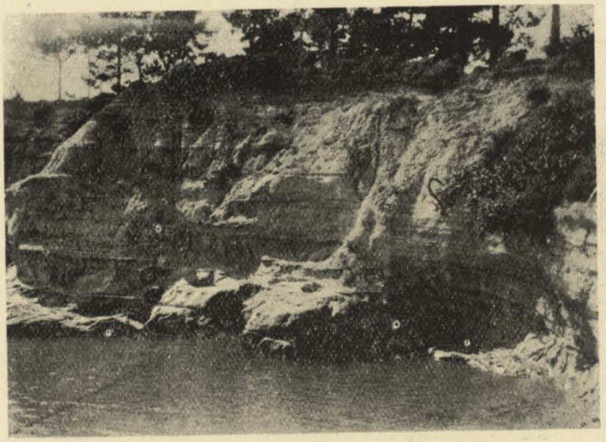


FIG. 18.—Normal fault intersecting Waitemata and Pleistocene strata near Beachlands Wharf.

[*Photo.*, *J. A. Bartrum.*

FIG. 19.—Main crater, Mount Mangere; a small scoria-cone rises from its floor with a tiny shallow crater at its left (west) margin and another (invisible) on the right. There is a smaller, deep crater in breached rim of main cone, near the middle group of trees.

FIG. 20.—Mangere Basin, viewed from Mount Mangere, with small scoria-cone as the central island. Maungataketake (A) and Otuataua (B) volcanoes in distance on right.

FIG. 21.—Scoria-cones on floor of crater of tuff-cone of Waitomokia. Otuataua rises above tuff-ring in distance on left.

FIG. 22.—Otuataua (Quarry Hill) from the soutn.

FIG. 23.—Pukaki Basin from the west. Its caldera is occupied by a marine swamp with its outlet in distance to the right of centre.

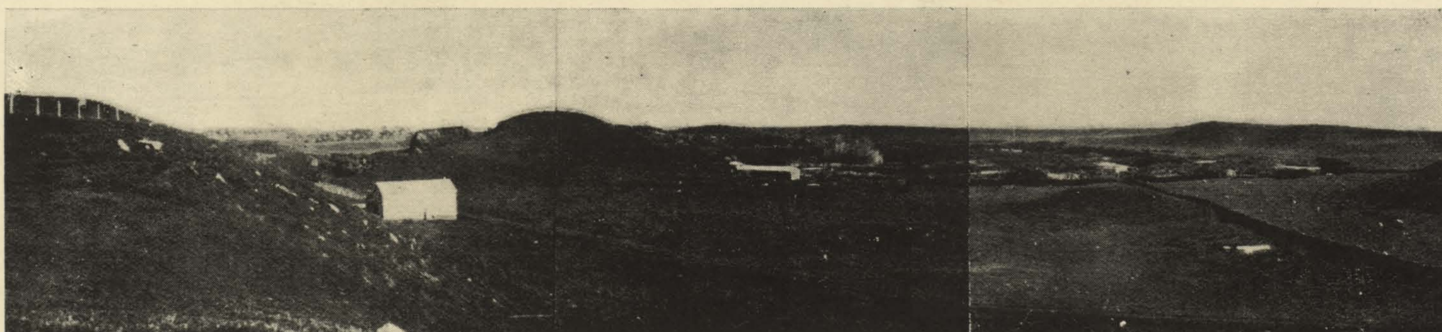


FIG. 24.—Panorama of Crater Hill, Papatoetoe, from north-east portion of encircling tuff-cone. Swamp-filled sink in lava floor of crater at centre, with scoria-cone to left of it.

FIG. 25.—Overlooking breached eastern lip of crater of Otara to scoria mounds beyond. Part of tuff-ring behind the mounds, and Tertiary sandstone hills of Maungamaungaroa Range in the distance.

FIG. 26.—Part of scarp of Clevedon-Waikopua Fault. A small tributary of Hog Hill Stream at base of scarp is working headwards in Waitemata sandstone rendering the capture of Whyte's Creek imminent.

FIG. 27.—View looking south-east along middle section of scarp of Clevedon-Waikopua Fault.

FIG. 28.—Looking north-west near Clevedon along line of Clevedon-Waikopua Fault. Transverse scarp of Lower Wairoa Fault on right half, that of Papakura Valley Fault off-set to north-west on left half. Filling of fault-angle-depression of Papakura Valley in foreground.

FIG. 29.—Shallowly entrenched meanders of a tributary of Tamaki River near Papatoetoe.

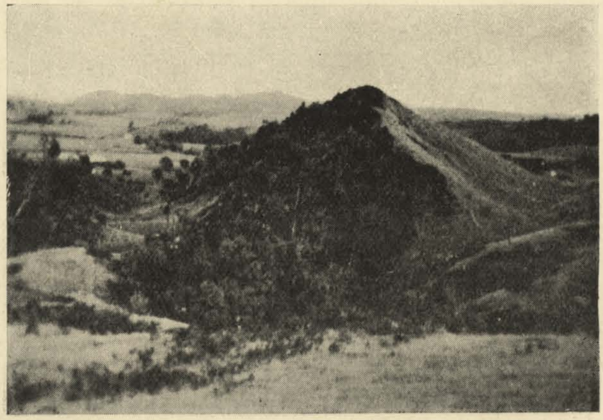


FIG. 30.—Conical hill at debouchure of Papakura Stream (on left) from Maraetai Hills Block on to Upper Brookby Valley (distance). Small stream on right beheaded at middle distance by recession of scarp of Clevedon-Waikopua Fault.

FIG. 31.—Back-slope (distance) of tilted Hunua Range Block viewed from north-west across alluvium-filled fault-angle-depression of Papakura Valley (middle distance). Dissected scarp of Papakura Valley Fault in foreground.

FIG. 32.—Spur-facets of middle section of scarp of Kiripaka Fault. Photographed from distance of 300 yards with $4\frac{1}{2}$ in. lens.

FIG. 33.—Low scarp exposed by waves at faulted contact of Pleistocene beds (shore-platform in foreground) with greywacke (in scarp) at east end of Omana Beach. Elevated beach-deposits rest on wave-planed surface of greywacke.

[*Photo., R. W. Firth.*

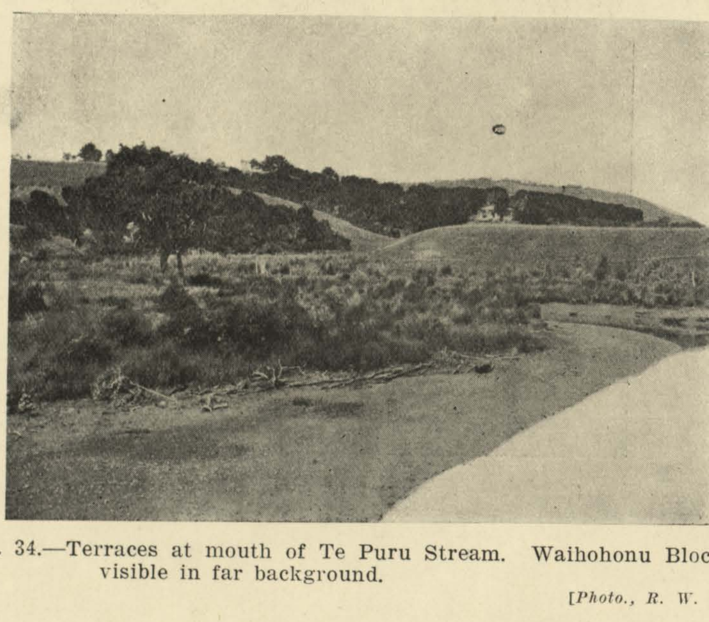


FIG. 34.—Terraces at mouth of Te Puru Stream. Waihohonu Block is visible in far background.

[*Photo., R. W. Firth.*

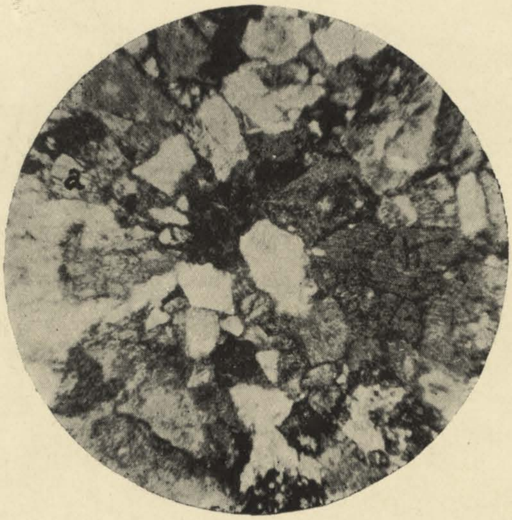


FIG. 35.—Coarse-grained greywacke from Trig. Station 648, Brookby Range. Ordinary light; magnification 46 diams. Quartz is sparse and weathered feldspar abundant. Grains of hornblende (h) and augite (a) are visible.
[*Photomicrograph by J. A. Bartrum.*

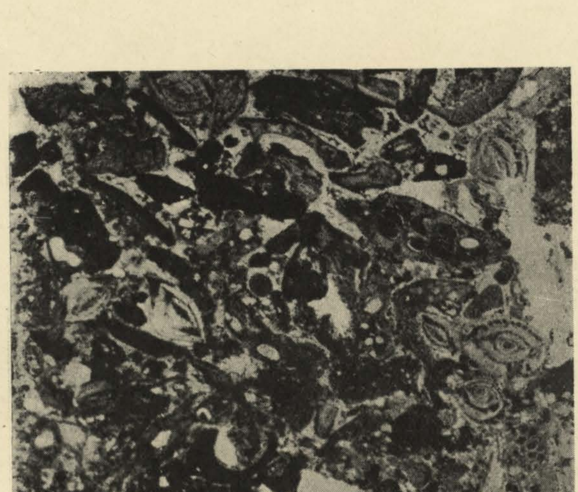


FIG. 36.—Section of typical Tertiary limestone from Waikopua, with abundant foraminiferal, polyzoan and algal remains. Magnification, 10 diams.
[*Photomicrograph by J. A. Bartrum.*

FIG. 37.—Coarse-grained basic olivine basalt, Green Hill Quarry. Large idiomorphic phenocrysts of olivine appear in groundmass of augite, plagioclase and magnetite. Ordinary light; magnification, 46 diams.

[*Photomicrograph by J. A. Bartrum.*

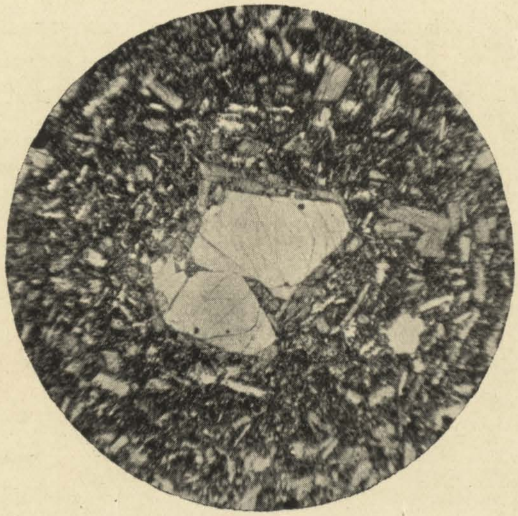


FIG. 38.—Fine-grained highly basic basalt from small flow on west side of Maungataketake. Note the cluster of crystals of augite around the central phenocryst of olivine. Ordinary light; magnification, 46 diams.

[*Photomicrograph by J. A. Bartrum.*

several cases, but is explicable merely by the shrinkage on consolidation and drying of a moderate thickness of beds.

The nature of the basal deposits described above suggests that the beds of the main outcrops were deposited in open water offshore from a rugged, youthful coastline, in a regular succession that suggests certain fluctuations of the strandline but the maintenance of moderately shallow-water and locally-sheltered conditions for some time prior to the deposition of the rapidly-accumulated sands and muds that characterize the main mass of the Waitemata Series. Highly-variable conditions of deposition must have held in embayments of this youthful coastline, in which the effects of minor fluctuations of the strand would be much less apparent than in open water; such fluctuations would give rise to the beds of the "up-stream" outcrops and account for the lack of connection between these and the succession of the main outcrops.

The palaeontology of these beds at Waikopua is as yet imperfectly known. The limestones are highly fossiliferous (Fig. 36), but unfortunately much of the material is fragmentary. Polyzoa, foraminifera, and algae (? *Lithothamnion*) abound, whilst fragments of lamellibranchs, echinoids, gasteropods, and brachiopods, and occasionally shark teeth, are plentiful. Portions of the shells of *Ostrea* are common in some coarse conglomerates. In the green sandstones foraminifera are particularly abundant, with less frequent, perfectly preserved brachiopods (*Hemithyris antipoda*), small Pectens (*P. fischeri; P. polymorphoides; Amussium zitteli*) and small gasteropods.

Through the kindness of Mr. W. J. Parr, of Caulfield, Australia, who most generously undertook the identification of the foraminiferal fauna both of limestone and green sandstone from Waikopua, the writer is able to supply lists of the foraminifera of these beds and thus bring this section of the palaeontology up to date. Mr. Parr also examined samples of the Turanga greensand and Parnell Grit facies. His determinations are tabulated at the conclusion of this paper.

Volcanic Tuff and Grit Beds of the Waitemata Series.

Introduction.

The occurrence of beds of volcanic nature interstratified with normal sandstones and mudstones has been known to be characteristic of the Waitemata Series since the time of Hochstetter (1864). The work of Hutton (1871), Cox (1882), McKay (1884; 1888), Park (1886), Mulgan (1902), Fox (1902) and Turner and Bartrum (1929) has shown these pyroclastic beds to outcrop abundantly over a distance of 30 miles from Waiwera, 20 miles north of Auckland City, to Turanga Creek in the present area, and also throughout the Auckland Isthmus.

Apart from the so-called "Orakei greensand," these volcanic beds north and west of Howick vary from fine volcanic tuffs and grits—the normal facies—to coarse volcanic breccias and conglomerates, and are described collectively under the name "Parnell Grit." East of Howick, however, the Parnell Grit is replaced by much finer, but nevertheless still definitely tufaceous, highly fossiliferous beds which, under the term "Turanga greensands," have been correlated by earlier writers with the "Orakei greensand." In frequent association with the Turanga greensand, though by no means so obviously tufaceous or fossiliferous, are fine-grained, often thinly-bedded yellow-green or brownish-yellow sandstones to which, for convenience in description, the term "tufaceous sandstone" is here applied. These appear to be intermediate between the more definitely volcanic beds and normal Waitemata sandstone.

In addition to the Parnell Grit previously recorded on the Hauraki Gulf Coast of the present district between Eastern Beach and Mellon's Bay, and to a narrow band only 2 ft. thick, which dips across the face of the cliffs a few chains north of Cockle Bay, several outcrops of it also occur at Buckland's Peninsula.. This peninsula is occupied by a sharp anticline, the axis of which trends north-north-west, parallel to the coast, and has a constant plunge to the north (Fig. 11). Outcrops of the "Grit" occur on both sides of the peninsula, namely in an extensive reef one-quarter of a mile off-shore from Eastern Beach, in the cliffs at both ends of Camp Bay, Tamaki River, where a gradual transition from grit to normal sandstone through tufaceous sandstone is suggested, and in four outcrops, developed from repetitions of the same bed by normal faulting, near its extremity.

The same type of rock also outcrops at several places in Maungamaungaroa and Puhinui Ranges, and in the coastal lowlands occurs extensively at Weymouth, on Manukau Harbour, and also in the bed of Flat Bush Stream in East Tamaki district. In the vicinity of Papatoetoe it has been recorded in well borings 100 ft. below sea level, whilst lumps of it up to 1 ft. in diameter are found incorporated in Recent volcanic tuffs in Crater Hill.

General Description of the Parnell Grit.

Most earlier writers have agreed that the Parnell Grit everywhere shows certain distinctive characteristics, and that the facies of different outcrops differ one from another mainly in texture. The normal grit consists of angular or roughly rounded fragments of volcanic material, Waitemata sandstone, and a "peculiar, black, carbonaceous shale," generally from ¼ in. to ½ in. in diameter, welded together by finer particles of similar material cemented by calcite. In the rare cases in which the volcanic material is determinable it has been found to be an augite andesite. Lumps of such rock up to 4 in. in diameter are common in an outcrop of the Grit at Weymouth, on Manukau Harbour. Worn crystals of augite and plagioclase abound at the base of the outcrop near Camp Bay, Tamaki River.

Broken fragments of polyzoa, small Pectens and other lamellibranchs, corals and echinoderms are general throughout the Grit but are usually indeterminable specifically. Foraminifera are occasionally well preserved, but have not yet been satisfactorily worked up.

The normal occurrence of the Parnell Grit in the Waitemata beds appears to be in the nature of large lenticular masses, from 15 ft. to 25 ft. thick, probably the result of false-bedding on a large scale. In those cases where bedding is at all clearly shown the Grit itself is also false-bedded, and often incorporates near its base lenses of sandstone or aggregations of lumps of sandstone which demonstrate that variations in deposition and contemporaneous erosion have occurred.

In spite of the fact that intense deformation of normal Waitemata beds associated with the Parnell Grit is almost general, and that many of the visible contacts are faulted ones, there are enough clear sequences in the present district to show that no unconformity exists between the two sets of strata (See Fig. 13).

When exposed to sub-aerial weathering agencies the Grit readily disintegrates into small fragments and generally displays spheroidal weathering, initiated by the narrow, rather widely spaced and irregular joints which characterise the rock (Fig. 14). The major joints are frequently filled with calcite, which stands out prominently on exposed faces.

General Description of the Turanga Greensand.

Beds described by earlier writers under the name Turanga Greeensand have been recorded by them from only two localities:—(1) Near the mouth of Maungamaungaroa Creek (2) Turanga Creek, near Whitford. These beds are typically moderately fine-grained, deep-green sandstones which generally occur in thick beds with a maximum thickness of 30 ft., but otherwise exhibit the jointing, concretionary structure, and type of weathering on exposed faces characteristic of the Parnell Grit. They are definitely tufaceous but to a highly variable degree, and are usually richly fossiliferous. Polyzoa, foraminifera (see Appendix) and small Pectens are abundant, especially in the coarser, more tufaceous beds, and even the finer more sandy phases contain plentiful foraminifera and broken shell fragments.

Under the microscope the more tufaceous beds are seen to contain small but readily recognisable crystals or fragments of hypersthene, augite, plagioclase and green hornblende, with occasional glauconite and a few minute flakes of biotite. Small pebbles of greywacke are general in all beds of Turanga greensand facies.

The investigations of the writer have shown beds of Turanga greensand facies to have a much wider distribution than hitherto recorded, for they outcrop frequently in Maungamaungaroa Range in the valley of Maungamaungaroa Creek, Whitford Stream and Flat Bush Stream, and also in many places along Turanga Creek. These outcrops are far too numerous to describe fully, but from the fact that beds intermediate in character between the two types, "Parnell Grit" and "Turanga Greensand," are common, and that in many cases gradation from one type to the other, or to tufaceous sandstone, is complete, it appears that the greensand is but a finer phase of the grit, and that the separation of the two as distinct horizons, as held by earlier writers working on the coastal sections only, is untenable.

Brief descriptions of a few of the more important and characteristic outcrops will suffice to illustrate this point. Structurally Maungamaungaroa Range appears to be a moderately sharp anticline, with its axis plunging north-north-west, which is probably a continuation of that of Buckland's Peninsula. This fact, with due consideration for the characteristic sharp local dislocations so common in Waitemata strata, explains the disposition of the numerous outcrops of the hinterland.

At an elevation of 200 ft. near Trig. 1078, a clear section shows very coarse Parnell Grit grading rapidly upwards into beds of Turanga greensand type. Nearby, at an altitude of 400 ft., determined by local distortion of the strata, similar grit grades through fine-bedded tufaceous sandstone into normal Waitemata strata.

Another perfect sequence is displayed in the headwaters of Whitford Stream one-quarter of a mile west of the crest of Whitford—East Tamaki road, where a 25 ft. face shows a thin stratum of coarse grit grading upwards through Turanga greensand to tufaceous sandstone. It may be of interest to mention that highly fossiliferous bands in the Turanga Greensand here contain numerous thick-domed *Amphistegina* up to $\frac{1}{8}$ in. in diameter.

Again at Weymouth, the conditions of occurrence of coarse Parnell Grit, beds of Turanga Greensand facies, and tufaceous sandstone grading into normal sandstone, are such as to suggest that all belong to the one horizon. This important outcrop will be dealt with more fully later.

Origin and Relationship of the Volcanic Tuff and Grit Beds.

The chief characteristics of the pyroclastic beds under consideration are, in the writer's opinion, fully explained by the theory put forward by Turner and Bartrum (1929) that they incorporate material ejected from a series of small andesite vents connected with a common magmatic source, and deposited by currents in the form of lenses throughout a thickness of strata so small in comparison with the 1200 ft. thickness to which the Waitemata Series is known to attain in the Kaipara District, as to constitute a fairly definite horizon —the Parnell Grit horizon. The known rapid and irregular variation of these beds in texture and thickness does not appear reasonably explicable on the assumption of a single centre of eruption.

Much has already been written on the question of the relative positions of the Parnell Grit and the Turanga Greensand. The latter, it will be remembered, has been correlated with the Orakei Greensand, which is considered to underlie the Parnell Grit at Orakei Bay. (Cox, 1882; Turner and Bartrum, 1929).

In greatly weathered outcrops in road cuttings on the west side of Maungamaungaroa Gorge in the present district, what is apparently a limited band of Grit appears to follow coarse Turanga Greensand with the interposition of approximately 20 ft. of normal Waitemata beds. This is no more than what is to be expected in certain cases, if the above theory of origin holds, for differences of magnitude and duration among the several outbursts postulated could readily explain such seeming anomalies, without detracting in any way from the essential unity of the Parnell Grit horizon.

The majority of early writers regarded the eruptions that ultimately raised the Waitakerei Hills, 12 miles west of Auckland City, as being the most probable source of the greater part of the volcanic material of the Parnell Grit horizon. Although this theory has support in that augite andesite similar to that of the Grit also characterises these hills, it is discredited by the fact that the Waitakerei fragmentals are now considered either to close the Waitemata sequence or else to lie unconformably above it (Bartrum, 1924).

Fox (1902) went further than other workers and made subdivisions of the horizon, mainly on the grounds of variation in texture and thickness. He considered the Parnell Grit—using the term in a much more restricted sense than that usually accepted—to be younger than the Turanga Greensand, and to have derived its material from the Coromandel volcanic zone 30 miles east, but his petrographical evidence for this is certainly faulty. He correlated his other subdivisions with different stages in the development of the Waitakerei Hills.

Fox's conclusions affect the present area, for he groups an extensive outcrop of thick beds of tufaceous sandstone alternating with thin mudstone bands that occurs between Howick and Mellon's Bay with his "Wairau tuff." The actual relationship of this outcrop to normal Parnell Grit exposed in and west of Mellon's Bay is unfortunately obscured by faults, but similar interbedded tufaceous sandstones and mudstones are prominent not far distant at Shellbank, and there grade laterally into typical Turanga Greensand. Fox further groups a 2 ft. band of typical grit exposed near Cockle Bay with his "Tamaki tuff," mainly by reason of its thinness.

Much of the palaeontological evidence used by several earlier writers in support of their contention that the Parnell Grit and Turanga Greensand represent two distinct volcanic horizons has been discredited by a more complete understanding and general extension of the time ranges of the fossils concerned. Even at the present time, however, the palaeontology of these beds is too imperfectly known to warrant their correlation with other Tertiary horizons in New Zealand; nevertheless the list of foraminifera determined in the Turanga Greensand by Mr. Parr that is published at the end of this paper will prove a most important aid to future correlation.

It is also necessary to point out that earlier workers often placed undue reliance, when making correlations of separated beds, upon the maintenance of observed strike and dip throughout obscured portions of sections, for sharp dislocations very commonly affect the Waitemata strata of the district (See Figs. 11 and 12).

Fairly conclusive demonstration that the several rock facies comprising the Parnell Grit have resulted from outbursts not from one main source but from a series of small volcanic centres is afforded by the great variety of beds of this horizon exposed in low cliffs facing Manukau Harbour at Weymouth. The eruptive centre responsible for these particular beds must have been close at hand, for very coarse

Parnell Grit outcrops between Weymouth Wharf and Te Pua Point, and contains frequent lenses of water-worn pebbles of vesicular, highly feldspathic andesite up to 4 in. in diameter. This Grit passes up into a jumbled mass of very coarse sandstone breccia which also contains occasional pebbles of andesite. The facts suggest that the volcanic eruptions were accompanied by or caused local warpings or uplift which brought the earlier-deposited sediments into the zone of erosion either of waves or streams. It is especially clear at all events that deposition took place in waters that had perceptibly shallowed, for there is ubiquitous evidence of contemporaneous erosion, illustrated by the well-developed cross bedding and alternating lenses of gritty sandstone containing numerous strings of scoriaceous andesite and fine tufaceous sandstone, that characterise an outcrop stretching for nearly one mile from Te Pua Point in the direction of Puhinui Creek. There is also indication that the volcanic material was distributed from the south, for, as it is followed towards Puhinui Creek, this outcrop becomes progressively less tufaceous, and grades gradually into normal Waitemata sandstone.

In the vicinity of Weymouth Wharf a well-bedded series of alternating bands of Parnell Grit, normal Waitemata sandstone, highly tufaceous Turanga Greensand, and thin bedded "tufaceous sandstone," point to deposition of material from the same source under comparatively sheltered conditions, and are so obviously of one horizon as to suggest that a similar relationship holds for the disconnected outcrops of beds of tufaceous character in the northern parts of the district.

The andesite incorporated in the Grit at Weymouth consists essentially of phenocrysts of plagioclase—moderately basic labradorite, Ab_{35} An_{65}—set in a fine matrix of minute, irregularly-disposed plagioclase laths and magnetite grains. Colourless augite was apparently moderately plentiful in the original rock, but has now been largely altered to chloritic material.

Origin of the Waitemata Series.

In explanation of the general characteristics of the beds of the Waitemata Series, Turner and Bartrum (1929) suggest that they represent the deltaic deposits of a large stream or streams draining a land mass probably situated some distance north-west of the Waitemata area. That this land mass must have been of considerable extent is apparent when it is considered that even at the present time, after having suffered extensive erosion, Waitemata rocks outcrop over an area at least 70 miles long and 20 miles wide, and are known to attain a thickness of 1200 ft. in the Kaipara district.

It is apparent that the sediments were deposited in an extensive shallow sea at a rapid rate—so rapid as to produce conditions altogether unfavourable for the existence of marine life—during a period of progressive subsidence interrupted at rare intervals by minor negative movements seldom important enough to occasion more than slight contemporaneous erosion. Seasonal control of the rate of supply of the sediments under the conditions suggested fully explains the alternation of thick sandstones and minor mudstones characteristic of the series.

Prominent shore-line conglomerates of greywacke pebbles and impure limestones which constitute the base of the series and rest on the Hokonui basement at Cape Rodney, Kawau Island, Tiritiri Island, Motutapu, Motuihi, Waikopua and Hunua suggest that the shore-line of early Waitemata times extended from Cape Rodney, 40 miles north of Auckland, approximately in a direct line to Hunua Range, 20 miles south-east of Auckland.

The following events probably immediately preceded and accompanied the deposition of beds of the "youngermass" in the mid-Auckland area. The Hokonui (Trias-Jura) rocks that constitute the "oldermass" suffered extensive erosion after having been closely folded during the lower Cretaceous orogeny that brought Hokonui sedimentation to a close. In late Cretaceous times, the portion of this eroded mass lying north of the site of the present Waitemata Harbour, and perhaps part of it south of this, was submerged beneath seas of moderate depth and extensively covered by beds of the Onerahi Series. These beds suffered elevation and extensive erosion in early Tertiary times, and, if ever deposited upon the present area or districts further south, were now completely removed from them.

Renewed submergence, approximately during early Miocene times, apparently commenced first in the south, for brown coals and associated beds at Hunua and Drury which form the base of the Tertiary sequence thin out to the north (Laws, MS.) and are absent at Waikopua, whilst, as stated by Hutton (1871), the "Papakura Series," which overlies these coals conformably and is correlated with the basal Waitemata beds at Waikopua, increases in thickness to the south. During the early stages of submergence, rugged greywacke coasts at places such as Waikopua afforded sufficiently sheltered conditions to permit the formation of impure highly fossiliferous limestones of shallow-water facies but, as the transgression continued and the whole mid-Auckland area became submerged, deltaic deposits comprising the Waitemata Series and derived from the continued erosion of land surviving in the north-west gradually enveloped the whole area, including what is now the area of the Maraetai Hills, in a sheet of sediment.

During this phase of sedimentation, probably at the same time as the upper green sandstones at Waikopua were being deposited, for these, as pointed out by Park (1885), are slightly tufaceous in places, a series of volcanic eruptions broke through the floor of the shallow Waitemata sea, and supplied the volcanic material of the Parnell Grit horizon. It has generally been considered that this horizon is low in the Waitemata Series, but it is shown from the occurrence of Parnell Grit at an elevation of 400 ft. near Trig. 1078, and by considerations of dip at Buckland's Peninsula that the thickness of underlying sandstone—equivalent to the limestones and associated beds at Waikopua—is fairly considerable.

The deposition of Waitemata strata was brought to a close, probably in early Pliocene times, by the initiation of the great differential uplifts and minor flexures of the Kaikoura period of orogeny (Cotton, 1916) which culminated in the production of the great earth-blocks, bounded by profound fractures, that largely control the present structure of New Zealand. The various earth-blocks of the present district arose along their bounding faults at this time, with the result that the Waitemata beds were uplifted to a great extent and have suffered almost continuous erosion ever since.

With regard to the nature of the Waitemata-Hokonui contact in the present area, it is probable that here, as elsewhere in New Zealand, the rocks of the "oldermass" were reduced to very low relief subsequent to the late-Mesozoic orogeny (Cotton, 1916), for a plain-like greywacke surface, stripped of its Tertiary cover, is preserved in the down-faulted floor of Kiripaka Basin (Fig. 15). At Omana, Waikopua, and in Ratahi Range, however, moderate relief at the time of submergence is suggested. It is possible that the uplift of early Tertiary times which resulted in the erosion of Onerahi beds further north-west may have affected the present area to an extent sufficient to produce strong youthful features in the marginal portions of the old land-mass, and that Waitemata transgression interposed before rejuvenation of topographical features was felt much beyond the lower reaches of the streams of that time.

Age and Correlation of the Waitemata Series.

The palaeontology of the Waitemata Series is still imperfectly known, pending the revision by competent workers of the lists of fossils published by Fox (1902) and Clarke (1905); it is therefore futile at present to attempt correlations with the stages of the well-established Oamaru sequence, and impossible to do more than assign the series provisionally to the Miocene.* In view, however, of the importance of the present area in this connection, the following resumê of the opinions of early writers on the question of the age and correlation of the Waitemata Series is of interest.

Following a study of foraminifera and polyzoa from the Orakei Greensand, Hochstetter (1864) placed the Waitemata Series in the Miocene, and with it, on the basis of their both containing *Pecten fischeri, P. zitteli* and *Vaginella,* correlated the limestones and associated beds to which Hutton later gave the name Papakura Series.

Hutton (1871) reported two unconformities in the Tertiary sequence south of Auckland City, one between the Brown Coal Series of Hunua and Drury and his overlying Papakura Series, and the other between the Turanga Greensand, which he included in his Papakura Series, and the overlying normal Waitemata beds. He disposed of Hochstetter's correlation of the Waitemata Series with the Papakura Series by proving a wider time range for the fossils concerned.

The work of the officers of the early Geological Survey in the mid-Auckland area appears to have been influenced by the Cretaceo-Tertiary hypothesis brought forward in 1867 and more fully defined in 1877 by their Chief, Sir James Hector, in an attempt to solve the problem presented by New Zealand post-Hokonui beds. The Geological Survey considered *Pecten zitteli* to be a typical Cretaceo-Tertiary fossil, and the presence of this form and certain stratigraphical evi-

*Since this was written a paper by Powell and Bartrum (1929) has appeared in which the basal Waitemata beds at Waiheke Island are correlated with the Hutchinsonian stage of the Oamaruian.

dence near Mercer led Cox (1877; 1877a) to classify the Waitemata beds and the Papakura limestone—placed by him above the Waitemata beds—as Cretaceo-Tertiary. In 1881, Cox altered his opinion and gave the age of the " whole Waitemata Series " as Lower Miocene, for, at Komiti (Pakaurangi) Point, Pahi and other localities in the Kaipara district, he found Waitemata strata containing *P. zitteli* and *P. fischeri* " associated with a great preponderance of Lower Miocene forms," resting unconformably on typical Cretaceo-Tertiary chalk-marls and hydraulic limestones (now referred to the Onerahi Series). In his Progress Report of that year, however, Hector (1881) insisted on dividing the Waitemata Series at the top of the Parnell Grit, for he still considered this horizon and underlying beds, which at that time included the Orakei and Turanga Greensands, to be Cretaceo-Tertiary and separated from the succeeding Waitemata (Miocene) sandstones and marls by an unconformity, as demanded by his hypothesis. On being sent to elucidate this point, Cox (1882); and later McKay (1884; 1888) concurred with Hector and Hutton as to the existence of an unconformity above the greensand at Turanga Creek.

In 1885 Hutton strongly attacked the inclusion in the Cretaceo-Tertiary of the Papakura Series, which was made to embrace, in addition to other beds, the Turanga and Orakei Greensands, for he considered the Orakei beds to be younger than the Turanga ones, and had proved the time-range of *Pecten fischeri* and *P. zitteli* to be greater than that held by the Geological Survey. He reasserted his view of 1871 that the Papakura Series was probably Oligocene and the Waitemata Series (including the Orakei Greensand), which he believed unconformably to overlie the earlier series, Upper Miocene.

Park (1886; 1889) made a distinct departure from the views of his colleagues of the Geological Survey by showing that there is an unbroken sequence from the base of the "Papakura Series" of Hutton to the top of the Waitemata Series, and classed the limestones at Papakura and Waikopua and the greensands at Turanga Creek and Orakei Bay as Lower Miocene, and the Parnell Grit and succeeding normal Waitemata beds, Upper Miocene. Support for Park's claim of conformity throughout the mid-Auckland Tertiary succession is given by Clarke in a contribution to a paper by Marshall, Speight and Cotton (1911), and still more recently by Laws (MS.), who has recorded for the Papakura-Hunua area a broadly conformable sequence from marine sandstones below the Brown Coals, through the Papakura Series, to the top of the Waitemata Series.

(3) POST-TERTIARY DEPOSITS.

Varied deposits, both sedimentary and volcanic, have accumulated in the present area subsequent to the extensive erosion suffered by Waitemata strata consequent on the Pliocene Kaikoura orogeny (Cotton, 1916) which terminated the Waitemata period of deposition.

Of most importance among the sedimentary deposits are the extensive pumiceous sands, silts and clays of the Manukau-Tamaki coastal lowlands, and the similar more localised deposits at Buckland's, Omana, and Wairoa Estuary. No internal evidence as to the age of these beds is available, but inasmuch as they rest unconformably on Waitemata strata—though occasionally, as at Wairoa Estuary, on Hokonui greywacke—and are not affected by the sharp dislocations produced in the older rocks by the Kaikoura orogeny, their provisional relegation to the Pleistocene is largely justified.

Other post-Tertiary deposits include large, low-lying pockets of clays in Waitemata strata near Whitford, partly or wholly Recent ubiquitous raised beaches and associated deposits, and such alluvial deposits as those of the Brookby Valleys, Whitford Valley, and the terraces at the mouth of Te Puru Stream.

Volcanic accumulations—tuff craters, flows of basalt, and scoria cones—attain some importance in the coastal lowlands, where they rest unconformably on the eroded surface of the Pleistocene sediments mentioned above. This relationship, supported by the fact that near Auckland City, as pointed out by Marshall (1908), the lava flows occupy the valleys of the present cycle, and by the freshness of the lavas and the well-preserved nature of the cones, justifies the allocation of these products of igneous action to either Recent or sub-Recent times. It may be remarked, however, that Turner and Bartrum (1929) hold the view that the volcanoes of the Takapuna-Shoal Bay area on the north shore of Waitemata Harbour were active at a time prior to the present cycle. This also appears to be the case for some of the tuff-cones of the present area.

Post-Tertiary History.

Before proceeding with a description of the sub-Recent volcanic accumulations it is proposed to attempt to trace the post-Tertiary history of the area and the development of certain of its present day topographical features from the evidence given by the post-Tertiary sedimentary deposits, and by comparisons with work done in adjacent districts.

Turner and Bartrum (1929), dealing with the Takapuna-Silverdale district, which has its southern and northern limits 10 miles and 20 miles respectively north of the present district, have interpreted the evidence available as indicating that, subsequent to the Kaikoura orogeny, prolonged erosion reduced the mid-Auckland area to a peneplain. Peneplanation was succeeded by long-continued uplift which resulted finally in a relative lowering of the strand-line by at least 600 ft. This uplift was broken by several periods of standstill of sufficient duration to allow the streams of that time to become graded with respect to the current sea-level, and to develop benches, still partially preserved, at elevations of approximately 350 ft., 100 ft. to 120 ft., 40 ft. to 60 ft., and 15 ft. to 20 ft. above present sea-level. The movement culminated in a rapid uplift of the order of from 150 ft. to 200 ft., as a result of which the streams of that time became entrenched in narrow, steep-sided valleys, and was closely followed by a negative movement of the land which resulted in the drowning of these youthful valleys and initiated the embayed coastline so characteristic of the western shores of Hauraki Gulf to-day. The only movement since this drowning has been an uplift of from 5 ft. to 8 ft. in Recent times, clearly indicated by well-preserved raised beaches at numerous localities (See Figs. 6 and 8).

The course of events outlined above holds generally throughout the whole neighbourhood of Auckland City (Bartrum, 1922), and possibly, as indicated by the work of Smith (1881) and Henderson (1924), over a much wider area. By comparing all such evidence of post-Tertiary movements throughout New Zealand, Cotton (1916)*, Benson (1924) and Henderson (1924) have reached the conclusion that these were singularly constant, and of an epeirogenic rather than of an orogenic nature. Though this generalisation undoubtedly holds in major detail, considerable difficulty is experienced in connecting minor details of adjacent districts. Bartrum (1927) suggests that this is due either to incomplete evidence, or possibly to local variations produced as a result of dying movements of the Kaikoura orogeny along the original fracture lines. A small normal fault which cuts both Waitemata and Pleistocene strata near Beachlands Wharf (Fig. 18) gives support for the latter contention, for it may possibly have resulted from a final adjustment of the blocks produced during this orogeny, and indicates that similar processes may have been at work in other localities during the Pleistocene.

Evidence bearing on early post-Tertiary history is scanty in the present area, but there is a moderately strong suggestion of an old erosion-level at an elevation of from 350 ft. to 380 ft. above sea-level in the sandstone hills immediately north of Great South Road between Wiri and Manurewa. The earliest period of standstill of which definite evidence is available is a minor one indicated by certain alluvial deposits exposed at an altitude of 180 ft. near the northern boundary of Manurewa Township, which appear in road cuttings as coarse-grained, frequently cross-bedded, thin strata containing plentiful roughly-rounded pebbles of hardened mudstone, and resting unconformably on beds of the Waitemata Series.

As elsewhere near Auckland City, a lengthy period of standstill is clearly indicated in the present area by erosion surfaces and alluvial and possibly fluvio-marine deposits at from 100 ft. to 120 ft. above present sea-level. Beds referable to this stage which are generally finer in grain but otherwise somewhat similar to those just described, appear along the base of Puhinui Range, passing from Wiri through Manurewa to a continuation in an extensive distinct terrace in the vicinity of Alfriston, 30 ft. above the level of the adjacent floor of Papakura Valley. It is to this stage also that Bartrum (1927) refers the formation of terraces of pumiceous silts, 80 ft. to 100 ft. above sea-level, on the west coast of Firth of Thames and the east bank of the estuary of Wairoa River, the material of which he believes to have been deposited in sheltered waters as the top-set beds of an ancient delta of Waikato River at a time when its course was through Hinuera Gorge and across the present Hauraki Plains to Hauraki Gulf (Cussen, 1889; 1894).

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*Cotton has introduced the term "post-Kaikoura movements" for these post-Tertiary oscillations of land and sea.

It is of interest to note that at the present time the central portion of the floor of Papakura Valley (Fig. 31) is at an elevation of 90 ft. above sea-level, but that towards both Hauraki Gulf and Manukau Harbour this is reduced gradually to approximately 50 ft. above sea-level. The greater part of this extra elevation appears to have been attained by the accumulation of successive comparatively recent swamps, which often entomb large forest trees, so that it is reasonable to assume that at the period under consideration a strait of the sea connected Hauraki Gulf with Manukau Harbour by way of the fault-angle depression of Papakura Valley. No wave-cut benches or other signs of such occupancy are, however, visible on the valley walls, though it is possible that a distinct terrace of appropriate elevation which partly occupies the floor of Lower Brookby Valley may represent an ancient delta of Papakura Stream formed at this time, whilst the existence of this strait would readily account for the presence of occasional strings of fine-grained pumiceous silts in the "100 ft. to 120 ft." deposits along the base of Puhinui Range, for, as has been shown above, Waikato River at this time flowed into Hauraki Gulf.

A further period of standstill co-ordinated with deposits and erosion-surfaces from 40 ft. to 60 ft. above sea-level is admirably shown by the deposits of the extensive Tamaki-Manukau coastal lowlands, by the Pleistocene beds at Omana, Wairoa Estuary, and Beachlands, and by an erosion-level clearly demonstrated not only on the mainland at Beachlands and Buckland's, but also in Motukaraka, Motuihi, and other islands nearby in Hauraki Gulf.

During this phase the Waikato River appears to have made one of those changes in its course noted by Cussen (*loc. cit.*) and, leaving Firth of Thames, flowed into an immense shallow estuary, now partly represented by Manukau Harbour, depositing therein the series of finely-bedded, fine-grained, soft pumiceous sands or silts which characterise the coastal lowlands. These beds grade from unconsolidated sands of almost pure pumice and occasional bands of fine pumiceous conglomerate, to plastic clays containing considerable plant material and, though everywhere cross-bedded on a fine but distinct scale, are essentially horizontal throughout. Certain coarse alluvial deposits incorporated with the finer-grained ones, such as are exposed at the railway bridge over Papakura Stream, probably represent the deltaic accumulations of small streams draining into this shallow estuary from the adjacent hills of Tertiary sandstone.

Other distinctive associated beds are certain "peat-like lignite bands" which are extensively exposed on the banks of Tamaki River, north of Panmure Bridge. They were first recorded by Hochstetter (1864, p. 62), who regarded them as so characteristic that he gave the name of "Lignite Formation" to the whole series of pumiceous beds filling this early estuary of the Waikato.

Interesting sidelights upon the early history of the present area may be drawn from certain features of the beds belonging to this "40 ft. to 60 ft." series of terraces at Beachlands, on the Hauraki Gulf coast. Near the wharf, about 15 ft. of thick greenish clays, interbedded with two thin bands of pure pumiceous silt, underlie the plain-like surface of the area at an elevation of about 40 ft. above sea-level, and rest highly unconformably on the denuded edges of underlying Waitemata strata. In the bay to the east, however, these Pleistocene beds grade down through fine-grained conglomerates to rapidly-changing lenses of stream-derived greywacke gravels and coarse sandstone conglomerates which rest on a water-worn surface of Waitemata sandstone in which are preserved several perfect "fossil" pot-holes up to 18 in. in diameter and 6 in. in depth (Fig. 16). It is apparent that this surface, which is approximately at present day high-water mark, was cut by the same stream that later deposited the overlying gravels. Further, it could only have been carved when the sea-level was the same or lower than that of to-day, and it therefore appears that the uplift subsequent to the formation of the "100 ft. to 120 ft." benches and terraces must have continued till the strand-line was at approximately the same elevation as at present, with consequent appropriate down-cutting of the streams of the time, and that subsidence then intervened and continued until the strand reached an elevation consistent with the "40 ft. to 60 ft." deposits. At the eastern end of the bay, a bed of lignite, composed almost entirely of sedges (Raupo or *Typha angustifolia*), and obviously representing an old swamp accumulation, occurs at the base of the series and corroborates the evidence of the fossil pot-holes. The low disposition of these deposits is clearly shown to be quite unrelated to sub-Recent fault movements.

Turner and Bartrum (1929) have found similar evidence in the Pleistocene beds bordering the upper reaches of Waitemata Harbour, of comparable fluctuations of the strand-line prior to the formation of the "40 ft. to 60 ft." terraces.

The beds of the so-called "30 ft. to 35 ft." terrace of Lower Wairoa River are also to be correlated with those of the coastal lowlands, and are characterised by fine, closely-laminated and cross-bedded pumiceous silts, grey muds, and occasional bands or strings of fine pumiceous conglomerate (Fig. 17). At the present time this terrace forms a practically continuous fringe along the base of Pukekawa Range, which follows the line of Lower Wairoa Fault from Clevedon to Duder's Beach, and terminates abruptly eastward against the low swampy flats of the modern delta of Wairoa River. It is apparent, therefore, that movement along Lower Wairoa Fault, which defines the eastern limit of the Maraetai Hills block, had ceased before these Pleistocene beds were deposited, for they lie in a distinct re-entrant, cut most probably by wave erosion, in the face of the greywacke hills near Clevedon. Sandy beds containing numerous rounded pebbles of greywacke are common amongst the material of this terrace, and undoubtedly represent fans deposited by streams draining the scarp during the time of the accumulation of the pumiceous silts.

Bartrum (1927) has traced this same terrace from Clevedon along the east bank of Lower Wairoa River, and has also identified it at several places along the western shores of Firth of Thames.

Although it is probable that at this time Papakura Valley was still occupied by a strait of the sea in which beds of the same series as those of the coastal lowlands were deposited, it is not necessary to postulate that the pumiceous material of these "30 ft. to 35 ft." terraces was transported across this waterway from the ancient Manukau estuary. During the uplift subsequent to their deposition, the older pumiceous beds of the "80 ft. to 100 ft." terraces recorded by Bartrum (1927) from the Clevedon area undoubtedly suffered enormous erosion, and their upper portions were entirely removed from the base of Pukekawa Range. The material thus set free would be available for re-deposition elsewhere at lower levels, while many of the "30 ft. to 35 ft." terraces were probably directly carved out of the earlier pumiceous deposits either by stream or wave erosion.

After the deposition of the pumiceous beds just discussed, uplift recommenced, but was interrupted by a minor period of standstill when the sea stood approximately 20 ft. lower than previously, and probably 20 ft. above that of to-day. It then continued rapidly until it attained a maximum of perhaps 200 ft., causing sharp entrenchment of the streams of the time, and was almost immediately succeeded by depression of approximately the same magnitude, which produced extensive drowning of the rejuvenated valleys, and laid the foundation of the major modern coastal features.

The history of Manukau Harbour is largely bound up with the sub-Recent movements of the land subsequent to the deposition of the deposits of the plain-like coastal lowlands that have been discussed, for much of its extent is due to the rapid erosion by waves of these soft deposits subsequent to the drowning of long, deep valleys cut across them as a result of the uplift which closed the period of their deposition. The long tidal estuaries of the modern Manukau Harbour coastline represent merely the upper reaches of the original drowned valleys, and have themselves been greatly widened by wave erosion. It would appear that the Waikato River was localised in its present course at the southern margin of its ancient estuary at some time during these movements by outpourings of basaltic lavas in the Lower Waikato Basin.

The only other diastrophic movement to affect the district has been a minor uplift of from 4 ft. to 8 ft. in Recent times. This is clearly shown by raised beaches backed by abandoned sea-cliffs in the majority of the bays and other sheltered sections of both the Hauraki Gulf and Manukau Harbour coasts, and by occasional benches of alluvium bordering certain of the streams. A particularly fine example of these raised beaches stretches almost across the base of Buckland's Peninsula. It is one mile long and as much as one-quarter of a mile wide, and everywhere displays shell deposits characteristic of fairly steep beach débris. Similar shell beds form an extensive slightly-elevated strand-plain bordering the whole length of Duder's Beach.

At the eastern portion of Omana Beach, old beach deposits of this stage are exposed resting, with the interposition of about one foot of coarse, iron-cemented greywacke beach-conglomerate, on a bench two or three feet above high-water mark which has been carved by wave-erosion upon a local occurrence of estuarine muds and associated beds of the "40 ft. to 60 ft." stage (Fig. 8). These shell beds merge to the east into a corresponding wave-cut platform 100 ft. wide which is carved in the greywacke of Maraetai Point (Fig. 7) and is there succeeded upwards by a remnant of an earlier bench cut at that period of standstill mentioned on an earlier page when sea-level was 20 ft. above that of the present day. Similar juxtaposition of evidence of these two periods is to be seen in two clearly-defined terraces of appropriate elevation at the mouth of Te Puru Stream (Fig. 34), which probably are remnants of deltas developed with respect to these two base-levels.

Sub-Recent Volcanic Accumulations.

Of the 63 separate points of eruption recorded by Hochstetter (1864; 1867) within a 10-mile radius of Auckland City, 17 are located in the coastal lowlands of the present district. Of these latter, 7 are grouped in Mangere-Ihumatao area, 5 are in the vicinity of Papatoetoe, and 4 more form a group at East Tamaki.

The normal order of events in the history of these volcanic centres appears to have been (1) The formation of an explosion-crater surrounded by a low tuff-ring. (2) Outpourings of basaltic lavas. (3) The building of numerous scoria cones. This complete sequence is to be seen at Puketutu, Maungataketake, Crater Hill, Otara, and Pigeon Hill, but considerable variation from it is shown by other centres. Thus Mangere Basin and Waitomokia have small scoria cones rising out of the floors of explosion craters; Pukaki Basin, Kohuora, Styak's Swamp and Pukekiwiriki are only tuff cones, whilst lava flows associated with scoria cones, with no evidence of an original explosion crater, are to be seen at Mount Mangere, Puke-iti, Otuataua, Wiri Mountain, Matukurua, and Green Hill. Brief descriptions of each of these points of eruption will be given later.

As stated previously, it would appear that this volcanic activity generally took place in sub-Recent times, but there is, however, evidence in at least two localities that it probably commenced either prior to or contemporaneously with the building of the "40 ft. to 60 ft." terraces of post-Tertiary times. Turner and Bartrum (1929) have demonstrated this possibility in the case of two calderas at Shoal Bay, on the north shore of Waitemata Harbour, whilst in the present area, in the vicinity of Panmure Bridge, the surface of tuffs derived from Panmure Basin—a large caldera west of Tamaki River—is so perfectly continuous with that of Pleistocene beds of the Tamaki-Manukau coastal lowlands as to suggest that this is more than mere coincidence, as it must be if the tuffs are truly sub-Recent. It is clear that the eruption from Panmure Basin preceded the major final phase of uplift of the area that was followed by the important sub-Recent submergence to which the present coastal features are primarily due, for Tamaki River represents a valley, drowned by this submergence, that has been incised in the tuffs in common with the adjacent pumiceous beds. It will be shown later that similar evidence is afforded at Pukaki Creek.

In this connection it is of interest to note that Shrewsbury (1892), following Hochstetter (1864; 1867), explained the perfect bedding displayed throughout the tuff-cones in the vicinity of Auckland

City by suggesting that the outbursts—probably paroxysmal—which formed them were largely submarine, though in shallow water. In certain cases this may be correct, for shells have been recorded from some of these tuffs, but the bedding can be equally well explained as the result of subaërial settling, in the vicinity of the vents, of the débris ejected by the explosions.

Petrography of the sub-Recent and Recent Lavas.

Samples from practically all of the basaltic flows in the present district have been studied in thin section under the microscope and have shown the lavas to be closely similar to, though on the average more basic in composition, than those further north nearer to Auckland City. They are typically holocrystalline, olivine-rich basalts, in which prominent sub-idiomorphic phenocrysts of olivine and augite, in sub-equal amounts, are set in a groundmass of plagioclase laths, augite, and grains or small well-formed crystals of magnetite. Augite is the only mineral to occur in two generations. It is of the titaniferous variety, characteristically shows hour-glass structure, and not infrequently occurs in aggregations or intergrowths of numerous small idiomorphic crystals. The plagioclase appears to be moderately basic labradorite, and normally occurs in comparatively long, slender, irregularly-arranged laths, which are often ophitically enclosed by augite or are squeezed between small augite crystals. A moderate amount of residual glass occurs in the groundmass of basalt from Otuataua.

As is to be expected, great variations in texture occur in different flows, and also in different parts of the same flow. The lavas of Green Hill (Fig. 37) and Crater Hill are sufficiently coarse-grained to enable approximate micro-analyses to be made, the results of which indicate them to be normal basalts, though with a somewhat low iron-ore content. Both rocks show large idiomorphic crystals of olivine and augite set in a coarse groundmass of irregularly-arranged long slender laths of plagioclase, small crystals and grains of augite, and subordinate magnetite.

A Wentworth recording micrometer was used in making the analyses, and traverses were made across the slides at intervals of 0.5 mm. The results obtained must be regarded as approximate only, for in places the grain of the groundmass is too fine for accurate measurement, and occasionally lack of definition of magnetite not only makes determination of this mineral difficult, but also clouds the limits of adjacent augite and plagioclase. Further, both rocks are vesicular, and in some cases it is not certain whether holes in the sections are original or due to fritting of phenocrysts during grinding. With olivine, therefore, which occurs in one generation only, the interpretation placed on the nature of these holes may greatly affect the final result. Nevertheless, it is believed that the following figures indicate fairly closely the composition of these rocks. In obtaining them, the compositions of the various minerals have had to be assumed. The only analysis available of the minerals of Auckland sub-Recent basalts is that of olivine from nodules at Takapuna (Turner and Bartrum, 1929). This has been adopted for the olivine in the present slides. For the augite, the mean of six analyses of titaniferous augites given on p. 361 of Dana's "A System of Mineralogy; Descriptive Mineralogy," 6th edition (1909), has been taken. Plagioclase has been taken as being labradorite $Ab_1\ An_2$, a procedure justified by extinction angles of up to 35° on albite twin-lamellae, and its composition has been worked out from analyses on p. 327 of Dana's book.

The results obtained are as follows:—

Green Hill Basalt.

		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	TiO_2
Augite ...	(50.90%)	24.35	2.68	3.01	2.64	5.76	11.08	—	1.38
Olivine ..	(15.43%)	6.51	0.07	0.02	1.33	7.42	0.05	0.02	0.01
Plagioclase ...	(27.18%)	13.96	8.47	—	—	—	3.72	1.03	—
Magnetite ...	(5.79%)	—	—	4.00	1.79	—	—	—	—
	(99.30%)	44.82	11.22	7.03	5.76	13.18	14.85	1.05	1.39

Crater Hill Basalt.

		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	TiO_2
Augite ...	(51.37%)	24.56	2.71	3.07	2.66	5.81	11.17	—	1.39
Olivine ...	(9.69%)	4.09	0.04	0.01	0.84	4.66	0.03	0.01	0.01
Plagioclase ...	(32.28%)	16 58	10.06	—	—	—	4.41	1.23	—
Magnetite ...	(6 08%)	—	—	4.20	1.88	—	—	—	—
	(99.42%)	45.23	12.81	7.28	5.38	10.47	15.61	1.24	1.40

Exceptionally basic or limburgitic basalts, of no great extent, however, occur at Maungataketake (Fig. 38) and Matukurua. Both rocks show scattered phenocrysts of augite and olivine in a fine-grained groundmass consisting essentially of augite and magnetite. Though the groundmass is too fine-grained to test for analcite by ordinary methods, yet the almost complete absence of plagioclase is sufficient to indicate limburgitic affinities. An extensive flow of moderately coarse-grained basalt from Puke-iti also appears to be more basic than the average. In this rock olivine phenocrysts are abundant, whilst in the groundmass plagioclase is subordinate to augite, and magnetite, usually in well-formed crystals, is plentiful.

Marshall (1908), in a resumé of the sub-Recent basalts of mid-Auckland, classed them all as basanites as a result of gelatinization and staining tests made on samples collected over a wide area from Auckland City south to Waikato Basin. A doleritic basanite does occur at the Domain, Auckland, but otherwise, in the vicinity of Auckland City at least, there appears to be little support for Marshall's generalization.

The Volcanic Centres.

Brief descriptions of the various volcanic centres, which may readily be located by reference to the accompanying map, will now be given, commencing with those in the Mangere district.

Mount Mangere.

This is the largest cone in the district; its eastern wall is extensively breached, but its western rim is intact and rises to a height of 350 ft. above sea-level; a considerable portion of its centre is occupied by a large, splendidly preserved crater, from the floor of which rises a perfect small cone (Fig. 19) with two minor explosion pits. A smaller, deep crater occupies a position at the northern margin of the breached eastern wall of the main cone, whilst a shallower one occurs nearby on its northern flanks. Stretching eastward from the breach there are a series of jumbled mounds of scoria and tumuli of scoriaceous basalt, beyond which is a small, localised flow of basalt, whilst at the base of the mountain, on its north-east side, there is a small cone of well-bedded scoria which also appears from the bedding to have been breached to the east. On its western side the main cone rises abruptly above a wide, low-lying, gently-sloping surface apparently underlain by highly scoriaceous basalt and occasional tuffs which represent the initial stages of activity.

Mangere Basin.

This basin (Fig. 20) lies at the southern base of Mount Mangere and is a distinct shallow caldera 600 yds. in diameter. Its low tuff-ring has been breached on its south-western side and its crater has been filled almost to high-water mark with marine muds which encircle

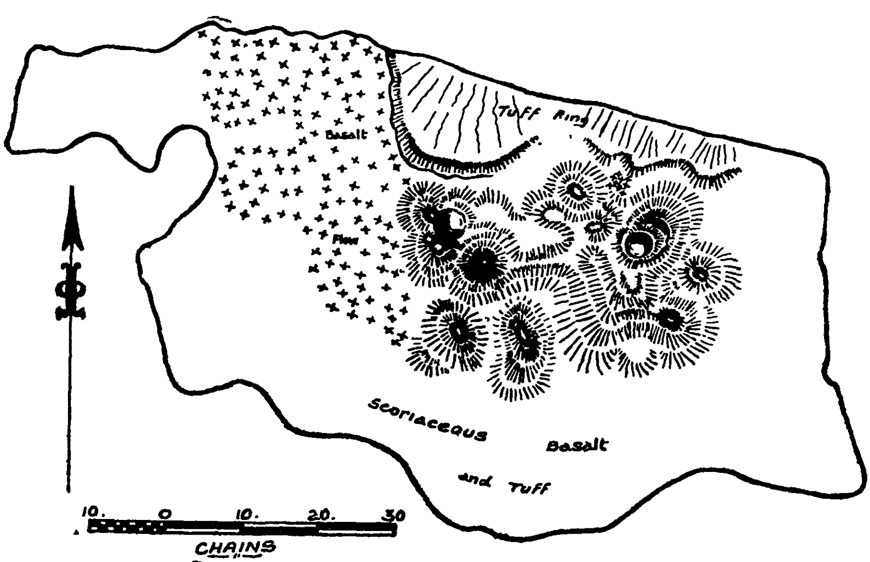

FIG. 3.—Sketch-map of the volcanic accumulations of Puketutu.

a low scoria cone, 20 ft. high, which forms an island in the centre of the circular crater floor. Tuffs derived from this centre of activity are widespread, well bedded and generally fine-grained, and contain an amount of volcanic lapilli which is large as compared with that of sedimentary débris.

Puketutu (Week's Island).

The sketch-map of Text-Fig. 3 shows the general arrangement of the various volcanic accumulations of this island, which is one of the most interesting localities of the district.

The first phase of activity was apparently the production of a large explosion crater and tuff-cone, the sole surviving evidence of which are certain fragments of the tuff-ring preserved along the northern side of the island, where as much as 30 ft. of tuffs are exposed. These are similar to those at Mangere Basin, but also contain occasional blocks of scoriaceous basalt. At several points along the southern shore, however, the tuff is again visible, though overlain by irregular flows of scoriaceous basalt which form an extensive low-lying gently-sloping border to the island.

Near the centre of the island an interesting series of scoria cones rise above this floor of scoriaceous basalt, the highest reaching 260 ft. above sea-level; they are obviously not the products of a single eruption. Except for two sharp, craterless cones on the south of the group, the several cones are connected and form a somewhat confused series of scoria peaks and ridges, the westerly members of which form the southern rim of a shallow crater, now breached on its north margin.

The most interesting cone of the series is at the north-east corner of the group. A well-defined crater at one time occupied its crest, but was later largely obliterated by a small cone, cupped by a shallow crater, which rises from its interior and over-rides the earlier crater rim to the south-west, leaving only a north-east remnant of this latter.

A moderately extensive basaltic flow occupies the western end of the island, whilst large blocks of basalt are plentiful in the westerly members of this group of scoria cones and ridges, though fine scoriae alone characterise the easterly members.

Waitomokia (Gabriel Hill).

Waitomokia is a perfect tuff-ring almost one-half mile in diameter which rises 70 ft. above sea-level and encloses a crater, now occupied by a swamp, in the centre of which there is a group of three small scoria cones (Fig. 21). These latter attain an elevation of 120 ft. above sea-level, or 80 ft. above the crater floor, the crest of the most southerly one possessing a deep, symmetrical crater. The tuff comprising the crater-rim is similar to that at Puketutu, and at Oruarangi Creek is overlain by extensive basaltic flows from Puke-iti.

Puke-iti.

This is a low, symmetrical, saucer-shaped scoria hill with its crest entirely occupied by a comparatively wide but shallow crater. An extensive lava flow extends from it northward to Oruarangi Creek and westward to the shores of Manukau Harbour.

Otuataua (Quarry Hill).

Otuataua (Fig. 22) is a scoria cone rising 200 ft. above sea-level immediately south of Puke-iti. A small shallow crater, breached to the north-west, occurs near its summit, whilst a thick but limited flow of basalt, apparently overlying that from Puke-iti, extends west from its base to Manukau Harbour. The constituent well-graded and well-bedded scoriae are well displayed in a large quarry on the south face of the cone.

Maungataketake (Ellett's Mountain).

This is a double cone three-quarters of a mile south-west of Otuataua; a sharp craterless peak 230 ft. high has risen out of and largely obliterated the extensive shallow crater of an earlier but much lower cone, overlapping the eastern rim of the older crater, whilst the distinct western portion of the rim is cupped by a subsidiary crater. Blocks of scoriaceous basalt litter the slopes of the lower cone, but the only visible flow is a small one on its western side, near Manukau Harbour. A low tuff-ring partially encloses Maungataketake on the north, and it is traceable by frequent exposures of tuff and volcanic agglomerate at sea-level also on its southern and western margins. It evidently was formed during a very early phase of activity at this centre.

Pukaki Basin (Motor Speedway).

This is a splendid sub-circular caldera (Fig. 23), approximately 600 yds. in diameter, which is flooded by the sea at high water, and drains into Pukaki Creek through a narrow gap in its south-east margin. The mangrove swamp which now occupies its floor is enclosed by almost sheer walls of tuff 30 ft. to 40 ft. high, which are succeeded north-westward by higher ground rising to an elevation of 100 ft.

The tuffs forming the crater-rim are well-bedded, reddish-brown in colour, and usually contain some comminuted sandstone and other sedimentary material greatly in excess of volcanic matter, though there are occasional bands wholly composed of rounded scoriae ½ in. in diameter. In some cases the volcanic material is very dense and glassy, approaching tachylyte in nature, and undoubtedly represents rapidly cooled drops of lava thrown out liquid during the eruption. At several points around the base of the inner crater walls, the tuffs are seen to rest on pumiceous silts which represent the pre-volcanic basement.

Crater Hill.

This centre of eruption (Fig. 24), 1½ miles west of Papatoetoe, is one of exceptional interest. Its history appears to have been (1) the formation of a large explosion crater 500 yards in diameter and of an encircling perfect tuff-ring at least one-half mile in diameter (2) the upwelling of basaltic lava into the crater to form a level rock-floor (3) foundering of a considerable portion of the centre of this floor, leaving a distinct frozen ledge 2 chains or 3 chains wide against the tuff-rim. This was a result of withdrawal of lava in a manner reminiscent of events at Kilauea, perhaps by the initiation of activity at neighbouring volcanic centres.* (4) the building of a cone of fine, well-graded and well-bedded scoriae rising perhaps 70 ft. above the floor of the crater immediately north-west of the foundered section. This may have preceded stage (3) and its building have contributed to the withdrawal of lava evidenced by the foundering of the floor, but from the smallness of the cone it appears unlikely that this has been the only factor concerned.

The tuff-ring of Crater Hill rises to an elevation of 120 ft. above sea-level and is from 30 ft. to 50 ft. above the crater floor. The tuffs themselves are splendidly bedded in layers from ½ in. to 3 in. thick which dip towards the crater on the inside of the rim, though radially outwards elsewhere, and consist dominantly of rounded basaltic lapilli with subordinate sedimentary material, though large blocks of scoriaceous basalt are occasionally met with adjacent to the crater. Other inclusions noticed in well-exposed sections around the shores of Pukaki Creek include small spheroids of basalt enclosing fragments of sandstone, and lumps of Parnell Grit roughly rounded by attrition. The former rarely exceed 2 in. in diameter, but the latter are in some cases as much as 6 in. These Pukaki Creek sections are also interesting in that they show the tuffs resting on a somewhat irregular erosion-surface of the pumiceous silts which varies in altitude from sea-level to about 10 ft. above this latter. Two interpretations of this relation are possible: either that the pumiceous beds had been built up to their normal greater height above sea-level and then eroded by streams prior to the volcanic outburst, or that this latter took place before deposition of the subjacent silts had developed the higher remarkably level plain normally constituted by these beds. Topographic evidence in favour of the first alternative is absent, and it appears preferable, therefore, to conclude that here, as at Panmure Bridge, there is evidence that certainly not all of the volcanic eruptions of the Auckland district are as late an event as is generally believed.

In places, the clays beneath the tuffs show definite prismatic structure at the contact and thus indicate that these latter were ejected as showers of hot ashes.

The foundered section of the crater floor of Crater Hill is now occupied by a swampy lake of unknown depth, with its shores constituted by vertical walls of lava 10 ft. high and with a small residual island at its north-west corner. The upwelling of the lava did not precede the formation of the tuff-ring, for, had no barrier existed, a thick flow such as that which occupies the crater floor would inevitably have escaped to the much lower ground on the outer confines of the tuff-cone, and no trace of such lava has been found. In addition, the relations of the wide central rock-bench to the tuff-cone can be reasonably explained only if the sequence of events has been as suggested.

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*The general petrographical uniformity of mid-Auckland basalts indicates their connection with one common source of supply, probably a large sill under the area, as suggested by Marshall (1912, p. 106).

Kohuora.

This name is applied to two somewhat irregular depressions and their encircling subdued hills which occur immediately south-west of Papatoetoe township. These depressions are undoubtedly explosion-craters, for although the material comprising the surrounding hills is generally ill-assorted and so deficient in volcanic material as scarcely to warrant the term volcanic tuff, yet the presence in it of occasional well-defined thin bands containing dominant small scoria fragments, as revealed in adjacent railway cuttings and in well-borings, and the fact that the hills rise appreciably above the general level of the coastal lowlands is at least suggestive if not definite proof of their volcanic origin. Not far distant there is a perfect, small explosion-crater little more than 50 yards in diameter and only 10 feet deep, which occurs immediately west of the railway midway between Papatoetoe and Puhinui railway stations. At Kohuora and also at Pukaki Basin, activity must have taken the form of steam explosions mainly confined to shattering the sedimentary beds above subjacent liquid rock.

Wiri Mountain (Manurewa).

This elevation is a scoria cone, 300 ft. high, which is now considerably defaced by quarrying operations. It is surrounded by extensive basaltic flows, whilst the remnant of a small summit crater is still to be seen at the head of the main quarry on the north-east face of the mountain. This quarry also reveals irregular masses of highly scoriaceous basalt traversing the scoria in the vicinity of the old vent, and at its entrance shows a sub-horizontal sheet of basalt overlying steeply-inclined, well-bedded scoriae. This is unusual in the local cones, and demonstrates that there have been periods of cone building alternating with outpourings of lava in the history of the mountain.

Matukurua (McLoughlin's Hill).

This is a scoria cone rising approximately 200 ft. above a somewhat limited, low-lying floor of scoriaceous basalt, one mile south-west of Wiri Mountain, and immediately beyond the basaltic flows from that centre of eruption. The symmetry of the cone is broken by a large, extensively-breached crater which occupies its southern face, and by a jumbled group of scoria mounds which stretch from this breach to the mouth of Puhinui Creek. The constituent material of the cone, as displayed in a small quarry on its north face, is seen to be well-bedded scoriae and numerous irregular, twisted masses and ill-formed bombs of highly scoriaceous basalt which attest to the ejection of lava in a semi-plastic state. The surfaces of the larger bombs are frequently studded with lumps of scoria, apparently caught up by the plastic masses as they rolled down the flanks of the growing cone.

Otara (Smaile's Hill).

Otara is a scoria cone (elevation 320 ft.) showing perfect contours when regarded from the west, but flanked on the east by a group of irregular scoria mounds apparently produced by the breaching of the eastern rim of a small crater near its summit. The eastern half of the hill is margined by a typical, low, tuff-ring (Fig. 25), which merges into its northern slopes, whilst the southern end of the ring, on which historic Smaile's church is situated, is connected with the main cone by a low scoria mound. Small flows of basalt pass around the southern extremity of the tuff-cone and extend a short distance out on to the neighbouring lowlands. Several strong springs of water issue from under the lava at the base of the western slope of the main cone.

Green Hill.

Like many others, this hill has been greatly defaced by quarrying operations upon the evenly-bedded, well-graded scoriae of which it is composed. The summit of the main cone is at an elevation of 260 ft., and is partially occupied by a shallow, symmetrical crater. A smaller, craterless cone is situated immediately north of the main one, whilst a third, little more than a mound, lies at the base of its eastern face, and is separated from it by a low-lying, shallow crater. An extensive flow of coarse-grained basalt, approximately 15 ft. to 20 ft. in thickness, extends from Green Hill to Pakuranga Creek, and at Green Hill "bluestone" quarry, one-half mile west of the cone, is seen overlying Pleistocene pumiceous silts.

Styak's Swamp.

This centre of activity, which is situated immediately north of Green Hill, is a small perfectly-preserved explosion-crater, approximately 100 yds. in diameter, with its floor occupied by a swamp and enclosed by a continuous tuff-ring not over 20 ft. in height. The tuff is typically in very thin beds and contains numerous fine-grained sandy bands. The included volcanic material is never greater than ¼ in. in diameter.

Pukekiwiriki.

The name Pukekiwiriki is applied to a low, subdued hill on the north bank of Otara Creek, near the confluence of this stream with Tamaki River; it rises definitely above the general level of the surrounding coastal lowlands, which fact, in conjunction with the evidence given by beds of sandy volcanic tuff which overlie Pleistocene beds along the adjacent shores of Otara Creek, immediately suggests that it is of volcanic origin. The centre of eruption appears to have been a small, low-lying explosion crater, now largely destroyed by stream-erosion, which lies alongside Otara Creek on the south-east flanks of the hill now described. Tuffs erupted from this point have only minor development on its south-east margin.

Pigeon Hill.

This is a small scoria cone situated immediately east of Tamaki River 3 miles from its mouth; it rises to a height of 180 ft. above sea-level, and is partially encircled to the north-east by a well-defined tuff-ring. A small crater, breached to the west, occupies its western flanks, and reveals the coarse, ill-graded scoriae and irregular sheets and dykes of scoriaceous basalt of which the cone is comprised. No marginal flows of basalt occur at this centre.

Detailed Physiography.

The generalised physiographic description of the present district given previously needs amplification in order to bring out more fully interesting peculiarities of certain areas; this will be done by detailed reference to the various physiographic units, which, with their bounding fault-fractures, have already been introduced.

1. Maraetai Hills Earth Block.

The state of homogeneity to which the greywacke that forms the basement rock of the Maraetai Hills has been reduced by its prevalent close jointing is such that the effects of all structural features, other than strong fractures, are negligible. With the exception, therefore, of such cases as Waihohono Block and the middle reaches of Ruatawhiti Stream, where, as will be shown later, structural control is apparent, the drainage pattern of the block is typically dendritic, and the streams insequent. The whole block is maturely dissected, the topography fine-textured, and the streams typically in the stage of late youth or early maturity in that they display series of short, graded reaches separated by falls or rapids which are usually associated with master-joints in the greywacke. Normally the slopes of the valley walls are graded, and the valley cross-profiles moderately sharply V-shaped, but in deforested areas extensive slipping of the residual clay cover is general, exposing the decomposed underlying rock.

The central portion of the Maraetai Hills exhibits a special feature in that, over a moderately large area, the summits of divides show a close accordance to a level of approximately 500 ft. above sea-level, which is accentuated by the fact that the surrounding hills, especially to the north and south, rise a further 100 ft. to 200 ft. This feature is apparently an example of what Cairns (1912) has termed "equiplanation," for the conditions obtaining agree with those believed by Davis (1923) to be essential for such a development, namely, a maturely dissected area drained by more or less equally spaced and equally dimensioned streams—in this case, headwater tributaries of Waikopua, Papakura, and Ruatawhiti Streams—the valley slopes of which are in a graded condition and have equal declivities.

2. Whitford-Brookby Earth Block.

The chief modifications of the general physiographic features already described as characterising this topographical unit arise along the course of Papakura Stream—in the Brookby Valleys—in Whitford Valley, and in the valley of Puhinui Stream, and will therefore be dealt with under these locality headings.

Papakura Stream and the Brookby Valleys.

Papakura Stream, which is by far the largest in the present district, rises in the Maraetai Hills, and leaves this elevated block in a narrows which cuts across the scarp of Clevedon-Waikopua Fault and displays sub-mature features in strongly developed meanders incised in the greywacke basement. On entering the eastern corner of the Whitford-Brookby earth-block the stream has developed two intermontane valleys, known respectively as Upper Brookby Valley, which is roughly 2½ miles long and half a mile wide, and Lower Brookby Valley, only one mile long, which lie from 200 ft. to 350 ft. below the crests of the bordering Brookby and Ratahi Ranges, and are separated, one from the other, by a low greywacke ridge breached by the stream in an unimpressive, narrow, but shallow gorge.

The course of Papakura Stream from the Maraetai Hills to its mouth is characterised by profuse meanders and occasional cut-offs and small ox-bow lakes, and shows a marked tendency to swing to the north-west against the bases of Ratahi and Puhinui Ranges.

The downstream margin of Lower Brookby Valley is defined only by the roughly-aligned, sudden terminations of the abruptly-rising greywacke hills of Brookby Range to the south-east, and of low greywacke foothills of Ratahi Range to the north-west. It is worthy of note that no greywacke appears in Ratahi Range or Puhinui Range south-west of this line or its continuation, and this suggests the possibility of a fracture at this point, trending roughly parallel to Clevedon-Waikopua Fault, the downthrow side of which is also to the south-west. However this may be, the immediate result of this rapid change in rock facies is that on leaving Lower Brookby Valley, Papakura Stream, again expressing its tendency to migrate to the north-west, has formed a deep embayment into the sandstone hills of Puhinui Range, from which it returns further downstream, still skirting the hills, to the approximate line of Papakura Valley Fault as given by the south-east scarp-face of Brookby Range. This embayment is continuous with the encroaching lowland plain of Papakura Valley, from which also the floor of Lower Brookby Valley is but imperfectly separated.

Upper Brookby Valley presents all the features of an aggraded depression, filled mainly by Papakura Stream—a flood plain of this stream constitutes the main floor—and to a lesser extent by gently sloping piedmont alluvial fans developed by tributaries draining across the valley from the bordering hills. The cross-profile of the valley is distinctly unsymmetrical as a result of the proximity of Papakura Stream to its north-west margin, and the consequent limitation of the fans on this side. The main floor rises at a gradually increasing gradient from an elevation of 120 ft. above sea-level at its downstream margin to 250 ft. against the Maraetai Hills. The steeper upper portion represents an extensive fan of Papakura Stream, which has been built sufficiently rapidly to force the lower courses of several adjacent tributaries down the main valley, and in one case has produced minor ponding.

From the evidence available it would appear that the depression now occupied by the Upper Valley originated during the period of block-faulting which gave rise to the several earth-blocks of the district, as a result of back-tilting of a valley of the pre-faulting surface against the rising Maraetai Hills Block in consequence of a general tilt to the north-north-west given to the Whitford-Brookby Block at this time. Evidence of such a tilt is fairly complete, and will be given in a later section. The depression was undoubtedly originally occupied by a lake, which overflowed across the low ridge forming its downstream border, but which was soon obliterated by débris from the adjacent elevated Maraetai Hills poured into its head by the ancestral Papakura Stream. Filling would then proceed by the formation of alluvial fans and flood-plains until a graded profile, such as approximately has now been attained, was established throughout the length of the valley. Lowering of the outlet has at no time been able to keep pace with, much less to exceed the rate of deposition of alluvium, for nowhere are these deposits terraced as would undoubtedly be the case had this condition held. The level of the adjacent floor of Lower Brookby Valley would, in any case, exercise a controlling influence on the extent of degradation at the outlet gorge of the Upper Valley, and at the present time is only 10 ft. lower than the floor of the Upper Valley immediately upstream of the intervening barrier.

The early history of Lower Brookby Valley was probably similar to that of the Upper Valley, for the presence in the middle of its downstream margin of a low mound 15 ft. high which is probably composed of greywacke, indicates the existence at this point of a now-buried spur. In more recent times, however, its development must have been affected by such movements of the strand-line as have been indicated when dealing with the post-Tertiary history of the district. It has been shown that at one time the sea stood approximately 100 ft. above its present level and that at this period the present site of Papakura Valley was occupied by a strait of which Lower Brookby Valley probably formed a sheltered arm. Bordering Papakura Stream near the downstream margin of the Lower Valley and rising from 6 ft. to 8 ft. above its present flood-plain, which is continuous with the floor of Papakura Valley, there is at the present time a distinct terrace at an elevation of approximately 100 ft., which grades gradually into piedmont alluvial fans along the valley walls and occupies the greater part of the floor of the valley. This is believed to represent a delta of Papakura Stream formed during this period. During ensuing uplift the stream would cut a trench through these deltaic deposits, but in Recent times, as a result of the extensive filling in of Papakura Valley by alluvial and swamp deposits, it has been forced to aggrade this section of its course until but little trace of this trench now remains, and the surface of the ancient delta constitutes a distinct terrace only a few feet above the present flood-plain of the stream.

Whitford Valley.

Whitford Valley is a narrow lowland, 2 miles long, situated immediately south-east of Whitford Township. It is occupied by two tributaries of Turanga Creek, the larger of which, Whitford

Stream, flows north from the northern slopes of Puhinui Range, and the other, Valley Stream, follows the course of Whitford Valley and is fed by two streams—Hog Hill Stream and Whyte's Stream—which rise in the elevated Maraetai Hills, 1½ miles to the north-east.

Whitford Stream and its tributaries are confined to the sandstone terrain and generally display the characteristics of streams of such areas. The valley of the main stream is, however, distinctly unsymmetrical, especially in those reaches where its trend is north-east and south-west, for in such cases the south-east walls of the valley have a gentle and regular slope, whilst on the north-west bank there are steep, bush-clad bluffs. These bluffs, in some cases at least, express the presence of comparatively resistant bands of green sandstone interbedded with softer normal Waitemata strata. The appearance of two-cycle topography as a result of the discovery by streams of these bands of green sandstone is a common feature of the western portion of the Whitford-Brookby earth-block.

Hog Hill Stream, and Whyte's Stream further to the south-east, flow south-west in roughly parallel courses three-quarters of a mile apart, and cross the scarp of Clevedon-Waikopua Fault at the border of the Maraetai Hills block by gorges displaying series of picturesque falls and cascades in the greywacke basement. Abrupt reduction in gradient on entering the lower Whitford-Brookby block has caused both streams to build extensive fans of greywacke débris at their debouchure from these gorges, but further downstream the streams have courses of widely different natures. Half a mile from the Maraetai Hills, Whyte's Stream plunges over a 50 ft. face of greywacke, which it has caused to recede some distance, and from this point to Valley Stream shows greywacke continuously in its bed. Hog Hill Stream, however, exposes Waitemata sandstone everywhere in the corresponding section of its course, which, further, is remarkably straight, is roughly graded with respect to the level of Whitford Valley at its confluence with Valley Stream, and lies in a valley of highly unsymmetrical cross-profile, with long, even south-eastern slopes and steep short north-western ones. It is worthy of note that greywacke is revealed in the headwaters of certain of the larger tributaries draining the long south-eastern slopes of the valley of this stream, though the divide appears at higher levels to be wholly Waitemata sandstone. Similar asymmetry is also revealed on a much less prominent scale in Whyte's Stream, and, as previously noted, characterises the Brookby Valleys still further south-east. A section taken across Whitford-Brookby earth-block parallel to and adjacent to the scarp of Clevedon-Waikopua Fault is therefore a series of saw-tooth ridges.

A most interesting case of stream-capture is imminent at the base of Clevedon-Waikopua fault-scarp, where a tributary of Hog Hill Stream (Fig. 26) working along the soft Tertiary sandstone of the lower block has reached a point within 4 chains of Whyte's Stream, which is retained by the greywacke in its bed further downstream at a height of 170 ft. above Hog Hill Stream, half a mile away. At the present time the sandstone divide to be removed before capture of Whyte's Stream by this tributary can be effected does not rise more than 30 ft. above stream level.

Whitford Valley itself presents many interesting features. Its floor is composed of a narrow strip of terraced alluvial deposits which border the south bank of Valley Stream and merge gradually into the long gentle slopes which form the southern margin of the valley. A line of prominent steep, bush-clad bluffs, at the base of which Valley Stream flows in an approximately graded course, forms the northern wall of the valley, so that once more marked asymmetrical conditions prevail. These bluffs range from 100 ft. to 150 ft. in height, and are continuous with the steep north-west slopes of the valley of Hog Hill Stream. Greywacke outcrops in them and along the south-eastern margin of the valley in the vicinity of Whyte's Stream, but elsewhere they are composed entirely of thick beds of Waitemata sandstone.

Two flights of terraces, approximately 20 ft. and 40 ft. respectively above sea-level at the confluence of Whitford and Valley Streams, are well defined throughout the length of Whitford Valley, whilst a third, 5 ft. to 10 ft. above sea-level, appears downstream from this point. These terraces no doubt reflect the changing base-levels instituted by fluctuations of the strand-line in later post-Tertiary times.

Puhinui Stream.

Puhinui Stream rises in the high hills of Tertiary sandstone comprising Puhinui Range, and flows thence in a general westerly direction to Manukau Harbour. Like many other streams of Whitford-Brookby earth-block, the cross-profile of its valley is decidedly unsymmetrical in its upper reaches, for its northern wall is short and abrupt whereas the southern slopes are low and even. Bands of tough calcareous mudstone and gritty sandstone are partly responsible for these steep northern slopes, and have also caused the formation of a series of falls and gorges in a tributary from the vicinity of Frost's Hill.

On leaving the sandstone hills, Puhinui Stream follows a profoundly meandering course in a wide, clearly-defined flood-plain 20 ft. to 30 ft. below the level of the plain-like coastal lowlands, which has been developed with respect to a local base-level instituted by volcanic débris from Wiri Mountain and Matukurua. In its lower reaches the stream skirts these volcanic accumulations and parallels the coast for some distance before entering Manukau Harbour. This suggests that the stream was established before the volcanic outbursts took place.

3. Fault Systems of the District.

Evidence of Tilting and Block-Faulting.

As already indicated, the presence of two systems of faults which trend approximately north-east by south-west and north-west by south-east respectively is clearly demonstrated in the eastern portion of the present area, and has resulted in the existence of at least two well-defined differentially-uplifted earthblocks. (Text Fig. 1). The connection between the major structural features of the eastern margin of the district and those of the Hunua and Wairoa districts further east has been traced by Laws (MS.) and

Bartrum (1927), who have shown that the lowland of Papakura Valley occupies a fault-angle depression between the unmistakable fault-scarp of the Papakura Valley Fault, which forms the south-east face of Brookby Range, and the back-slope of a sharply-tilted block which forms the Hunua Ranges to the south-east. These authors also regard Clevedon-Waikopua Fault of the present paper to be a continuation of their Wairoa Fault, which determines the middle course of Wairoa River, whilst Bartrum (*loc. cit.*) anticipated the view held by the present writer that the abrupt eastern boundary of the Maraetai Hills is also a fault-scarp, developed by a deviated continuation of Papakura Valley Fault which for convenience in description is herein called Lower Wairoa Fault.

The Maraetai Hills Block, bounded roughly east and south-west by Lower Wairoa and Clevedon-Waikopua Faults respectively, repeats the definite north-west tilting of the back-slope of the Hunua Ranges. This is clearly demonstrated in distant views by a long even surface which rises gradually from lowlands at Beachlands, along the crests of the Maraetai Hills, to Trig. Station 1309 (814 ft.) near Clevedon. At closer quarters the tilt is indicated by the persistent north-west dip of basal Waitemata beds at Waikopua, and by the tendency displayed by the south-westward flowing waters of the upper reaches of the Te Puru Stream and the middle reaches of Ruatawhiti Stream to migrate to the north-west.

The valley of this section of the course of Ruatawhiti Stream is of further interest in that at its upper end it opens out into a flat floor with a maximum width of 3 chains. The gradient of the stream at this point is sufficiently steep to suggest that this, as also a similar but narrower feature farther downstream, is merely a flood-plain developed in the course of normal stream degradation, but nevertheless, the deep precipitous nature of the narrows through which the stream crosses the scarp of Lower Wairoa Fault to join Wairoa River indicates the possibility that reduction of gradient, or even ponding, consequent on such a tilt of the block as is here postulated may have had some genetic influence.

In the north-west corner of Maraetai Hills Block there is a very distinct subsidiary down-faulted area known as Kiripaka Basin (Fig. 15), to the north of which lies a correspondingly elevated block—Waihohono Block—which appears to have been titled to the south-west rather than north-west. This is indicated by the prevalent south-west dip of Tertiary sandstone at Omana Beach and Te Puru Estuary at and adjacent to its contact with greywacke that comprises this fragment of the major block.

The extent of the relative uplift of Maraetai Hills Block along Lower Wairoa Fault is certainly not less than 800 ft. near Clevedon, for down-faulted greywacke appears in the bed of Wairoa River at this point. In the vicinity of Duder's Beach, 5 miles north of Clevedon, however, a movement of the order of only 400 ft. is indicated, for Whakakaiwhara, the larger of two masses of greywacke—peaks of the otherwise submerged downthrow block to the east of this fracture—which rise island-like above the Pleistocene and Recent deposits at the mouth of Wairoa River, attains an elevation of 285 ft., whereas the maximum elevation of the neighbouring Pukekawa Range of Maraetai Hills is 644 ft.

Along Clevedon-Waikopua Fault the lower or Whitford-Brookby Block has been relatively down-thrown to the south-west to an extent that varies from approximately 200 ft. to 250 ft. at the Waikopua end, to from 350 ft. to 400 ft. at the Clevedon end, adjacent to Trig. Station 1309.

Whitford-Brookby Block is clearly defined along its north-east boundary by the scarp of Clevedon-Waikopua Fault (Fig. 27)), and along part of its south-east boundary by that of Papakura Valley Fault (Fig. 28), but all evidence of other possible bounding fractures has been lost in the subdued faces of the hills of readily eroded Waitemata beds which characterise other marginal areas. Nevertheless it is probable that the south-west continuation of Papakura Valley Fault is responsible for the alignment of the eastern base of Puhinui Range with the scarp-face of Brookby Range, whilst similar evidence suggests that the south-west limits of the block, delineated from the Manurewa district to Wiri by the Great South Road, may have been determined by a north-west continuation of the Papakura-Drury Fault of Laws (MS.). It is of course possible that in the sandstone terrain these fractures may have merged into monoclinal folds, but scarcity of outcrops prevents confirmation of this possibility. Differential uplift, whether by monoclinal folding or by faulting, appears undoubtedly to have occurred, for beds of the Parnell Grit horizon occur at sea-level at Weymouth and yet are uplifted to an elevation of 180 ft. in Puhinui Range near Manurewa. On this interpretation the coastal lowlands facing Manukau Harbour rest on a third, still lower earth-block, a view which is supported by the opinion of Gilbert (1921) that Manukau Harbour occupies a down-faulted area.

Mention has already been made of the alignment of the sudden termination of Brookby Range with the greywacke foothills of Ratahi Range across the mouth of Lower Brookby Valley, and with the abrupt replacement of greywacke by Waitemata strata still further north-west near the crest of Ratahi Range. This alignment may be due to a minor fracture, roughly parallel to Clevedon-Waikopua Fault and dying out in the sandstone terrain to the north-west, but definite proof of this view is not available.

The tilt so clearly manifested in the eastern or Maraetai Hills Block is much less definite in the lower block now described. Nevertheless, observations of the elevations of outcrops of beds of the Parnell Grit horizon, together with the few reliable observations of dip and strike that are available, demonstrate the presence of a broad anticline in the western portion of the block, the axis of which runs roughly from Buckland's Peninsula, through Maungamaungaroa Range to Puhinui Range — approximately parallel to Clevedon-Waikopua Fault—and has a constant plunge to the north-north-west. That this tilt is general throughout the Whitford-Brookby Block is indicated by the fact that practically all streams flowing in an appropriate direction have developed valleys of definitely asymmetrical cross-profile, the steeper slopes of which rise to cuesta-like divides invariably to the north or north-west, as previously described when dealing with the Brookby Valleys, Whitford Valley, and Puhinui Stream. Such a tilt would also fully explain the origin of the intermontane Upper Brookby Valley as a consequence of the resulting ponding of a section of the course of an ancestral Papakura Stream, and later filling of the basin thus formed by alluvium.

Clevedon-Waikopua Fault (Figs. 26-28).

This fault is represented by a youthful scarp which presents a practically straight and unbroken wall of greywacke trending in a direction 30° west of north from the immediate vicinity of Clevedon Township to a point a short distance south of Waikopua Creek, over 4 miles away, where topographical expression of displacement is soon lost when soft Waitemata strata displace greywacke on the western flanks of the Maraetai Hills. The scarp, if not truly a fault-line scarp, must be classed as a composite fault scarp, as defined by Cotton (1922), for the complete stripping of the Tertiary covering beds of the relatively downthrown block from their basement in Brookby Range indicates that much if not all of its present face has been revealed by erosion. Though stripping of the Tertiary cover from the upper block is far more extensive, yet remnants of it persist at an elevation of 700 ft. near the headwaters of Whyte's Stream.

Small longitudinal streams (Fig. 26) tributary to such strong transverse streams as Hog Hill, Whyte's, and Papakura Stream, follow the greater part of the length of the fault-line, and receive small streamlets which cross the scarp and have developed thereon splendid spur-facets, not uncommonly from 200 ft. to 300 ft. in height, whilst the face of the scarp is everywhere encumbered with greywacke débris in the form of steep alluvial fans and talus deposits.

Several interesting features in addition to those already described during discussion of Whitford Valley and Upper Brookby Valley, are presented by the streams draining the scarp and its vicinity. For example, in the gorge by which it leaves Maraetai Hills Block, Whyte's Stream plunges over a 30 ft. fall, exposing there a clearly defined band of crush-breccia which marks the line of a fracture parallel to Clevedon-Waikopua Fault and shows that the relative displacement of the adjacent earth-blocks has been distributed probably along several parallel faults. Near the debouchure of Papakura Stream into the head of Upper Brookby Valley there is a curious isolated sub-conical hill (Fig. 30), with its south-western face forming part of the scarp of Clevedon-Waikopua Fault; the gorge cut by Papakura Stream near the scarp forms a semicircle about it on the east, whilst it is bounded on the north-west by a steep-walled wind-gap. This interesting wind-gap most probably developed as the scarp was eroded back from the fault-line and continuously beheaded the valley of a small stream flowing north-east to Papakura Stream. Another possibility is that it represents an old course of Papakura Stream across the scarp, but this finds little support in the evidence available.

Several interesting features are connected with a short, vigorous tributary of Totaia Stream which has cut a gorge as much as 100 ft.

in depth along the base of the scarp of Clevedon-Waikopua Fault near its Clevedon limit, and is rapidly working headwards towards Upper Brookby Valley. This stream turns sharply south-west, roughly parallel to Papakura Valley Fault, when but a short distance from the intersection of this fracture with the north-west fault under discussion, and flows in this direction for from half a mile to three-quarters of a mile across a small aggraded basin before again turning sharply to cross the scarp of Papakura Valley Fault in a moderately widely-open valley and emerge on the lowlands of Papakura Valley. The pattern of its course is perhaps explained by splintering of the north-east corner of Whitford-Brookby Block as a result of the intersection of its two powerful bounding fractures, with the consequent production of a shatter-belt which afforded an even easier route for the stream than along the base of Clevedon-Waikopua scarp.

The scarp of Clevedon-Waikopua Fault continues one-quarter of a mile south-east beyond the line of Papakura Valley Fault, and is terminated abruptly in the immediate vicinity of Clevedon by its intersection with Lower Wairoa Fault (Fig. 28), which takes up the differential movement of, and in this locality is roughly parallel to, Papakura Valley Fault. The significance of this off-setting of these powerful north-east fractures will be discussed later, but in the meantime a clearer conception of the relationships of the several earth-blocks and their bounding faults near Clevedon may be obtained from Text-Fig. 4.

Papakura Valley Fault (Fig. 28).

The scarp of this fault is clearly preserved in the straight, steep south-east face of the greywacke hills comprising Brookby Range, which ends abruptly at Ardmore Road and thence runs in an E. 35° N. direction for 3½ miles to the south-east corner of Maraetai Hills Block. The hills immediately behind this sharply-rising and imposing front-slope attain an average elevation 300 ft. higher than the aggraded plain of Papakura Valley, which occupies the fault-angle depression between it and the back-slope of the tilted Hunua Block further south-east (Fig. 31). As already stated, it is possible that Papakura Valley Fault continues south-west along the base of the sandstone hills of Puhinui Range from Alfriston to Manurewa.

Since the relatively downthrown area has been aggraded, the scarp is evidently a true fault-scarp (Blackwelder, 1928, p. 300). It is sub-maturely dissected by numerous short, steeply-graded transverse streams which have cut deep steep-sided notches into the hills and have built extensive piedmont fans of greywacke débris at the base of the scarp. Along the outer edge of the fans there is a swampy strip drained by a sluggish stream which flows north-east roughly parallel to the scarp, and joins Totaia Stream near Clevedon.

At Ardmore and Hunua, across the fault-angle depression of Papakura Valley, Tertiary sandstones cover Mesozoic greywacke similar to that comprising Brookby Range, and dip under the intervening alluvial and swamp deposits which form the floor of the depression (Laws, MS.). From this fact and the disposition of similar Tertiary beds on the western flank of the masses of greywacke which outcrop in the eastern portions of both Maraetai Hills

Block and Whitford-Brookby Block, there is little doubt that prior to faulting a sheet of Tertiary strata continuous with that of the Waitemata area completely covered the present district, and thence extended unbroken in a south-east direction at least as far as the site of the Hunua Ranges.

The extent of the differential movement along Papakura Valley Fault is difficult to estimate. The hills of Brookby Range rise to a maximum height of 450 ft. above the floor of Papakura Valley, and have been stripped of Tertiary covering beds probably several hundred feet in thickness. The depth of post-Tertiary deposit upon the downthrown block is not known but must be fairly considerable, so that on a conservative basis the movement must be in excess of 600 ft. or even 700 ft.

Lower Wairoa Fault (Fig. 28).

Although the major topographical features in the neighbourhood of the mouth of Wairoa River certainly indicate differential movement on a large scale, the orientation of the fractures by which this has been accomplished is indicated only in a general way. The Maraetai Hills are everywhere clearly differentiated from the lowland across which Wairoa River meanders to join Hauraki Gulf, and for at least 2 miles north of Clevedon their eastern bush-clad face undoubtedly represents a maturely dissected fault-line scarp trending north-north-west. North of this section, however, clear demonstration of a scarp is obscured by far-reaching erosion, and continuation of the fault is suggested only by the sub-meridional alignment of spur ends which project on the lowlands bordering Wairoa River. The relief here is much less than that near Clevedon, and the subdued lower slopes of the face of the hills grade into extensive, low-angle, confluent fans which themselves merge into the lowlands.

It is possible that the remarkably straight middle reaches of Ruatawhiti Stream may reflect the direction of major fracturing in this locality. Such a feature is so unusual in the Maraetai Hills as immediately to suggest as its cause the presence of a fracture or shatter-belt apparently orientated in a direction roughly the mean of those determining the eastern limits of the elevated block from Clevedon to Duder's Beach.

For 1½ miles north of Duder's Beach, greywacke cliffs 40 ft. to 50 ft. high form a remarkably straight shoreline which is suggestive of faulting, though it must be admitted that the features presented could equally well be explained by wave-erosion. The streams in the hills immediately to the west, however, show a marked tendency to flow parallel to this coast in a south-south-west direction and to develop, along with others at right angles, a trellised drainage-pattern which is paralleled by the headwaters of Te Puru Stream still further west. This suggests the presence of N.N.W.-S.S.E. and possibly E.N.E.-W.S.W. fractures or shatter-belts—fold structures in the "incompetent" greywacke can safely be ignored in this case—and lends support to the classification of this length of coast as a fault coast.

It therefore appears probable that the whole of the eastern boundary of Maraetai Hills Block is determined by a fault or series of faults, here called Lower Wairoa Fault, which, bending continuously more and more to the west as it is followed north, trends north-north-east near Clevedon and north-north-west beyond Duder's Beach. This is quite in accord with what Henderson (1929) considers to be the usual condition in the case of major faults.

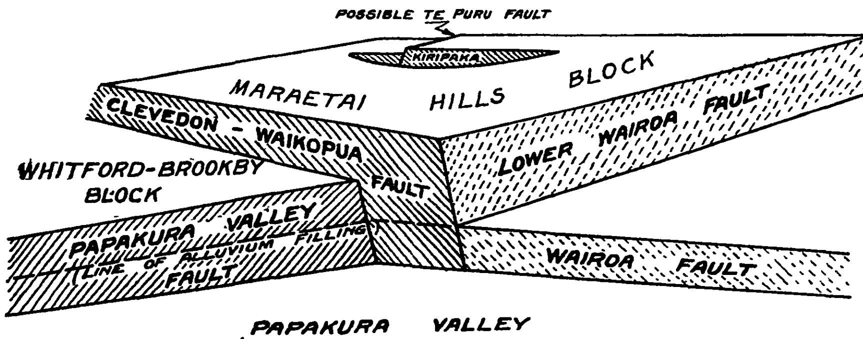

Fig. 4.—Block-diagram to illustrate the relationship of the several earth-blocks and their bounding fractures in the vicinity of Clevedon Township.

The significance of the one-quarter of a mile off-set of the sub-parallel scarps of Papakura Valley and Lower Wairoa Faults along Clevedon-Waikopua Fault deserves some consideration. The relationship of the several fractures and of the earthblocks determined by them is, as far as can be seen, as shown diagrammatically in Text Fig. 4. It is highly probable that the four faults shown are not independent, and that in reality only two fractures exist. The first trends north-west and includes Clevedon-Waikopua Fault and Wairoa Fault of Laws (MS.), the latter continuing the course of the former across Papakura depression into the middle section of the course of Wairoa River. The second major fracture is a flatly-curved one, concave to the north-west, and trends on the average north-east by south-west. It is represented by Papakura Valley and Lower Wairoa Faults. This view is supported by the fact that Laws' estimate of a downthrow of 400 ft. to the south-west along Wairoa Fault agrees with that indicated at the Clevedon end of Clevedon-Waikopua Fault, whilst a downthrow of the order of 800 ft. to the south-east along Lower Wairoa Fault, which is suggested near Clevedon, compares well with a corresponding movement of at least 600 ft. or 700 ft., and probably much more, which has been deduced for Papakura Valley Fault. If this interpretation of the fault systems is correct, in order to explain the off-setting that has been noted, it is necessary to postulate that the north-east by south-west fracture originated first, and that its scarp was later displaced by movement along the more recent north-west fracture. Support for this is forthcoming in that youthful features characterise the scarp of Clevedon-Waikopua Fault, whereas the scarps of Papakura Valley and Lower Wairoa Faults are sub-maturely or even maturely dissected.

Kiripaka Basin and Waihohono Block.

These two interesting topographical features of the north-western portion of the Maraetai Hills area form respectively the downthrow and upthrow members of a fault, here called Kiripaka Fault (Fig. 32), which trends 30° north of west and is traceable by a well-displayed scarp which begins at a point one-half mile east of Maraetai-Whitford Road, and continues for nearly a mile eastward. Kiripaka Basin itself is bounded on the north-east by this scarp, but its other limits are less clearly defined, though they suggest that the key to the structure of this area is differential down-warping relieved in the north-east by fracture.

The floor of Kiripaka Basin (Fig. 15) rises in a gentle, regular slope to the south until it gains the divide north of Bloomfield's Stream, Waikopua, and there culminates at what is probably the axis of warping. At its eastern margin it merges into rather abruptly rising high hills of greywacke, without, however, definite topographic signs of fracturing, whilst its western limit is defined by a subdued ridge of Tertiary sandstone which is followed by Maraetai-Whitford road. Tertiary sandstone outcrops extensively beneath the upper western slopes of the floor of the basin and in isolated outliers further east, but for the most part it has been entirely stripped from the underlying greywacke basement. The streams that cross the floor apparently were originally consequent upon the surface of the sandstone cover, and have later been superposed upon the older greywacke.

The central section of the scarp of Kiripaka Fault is followed at its base by the middle reaches of Te Puru Stream, and exhibits splendid spur-facets, some as much as 100 ft. high, marked off by short, hanging streams (Fig. 32), whilst it further displays two sharp displacements to the north, one 3 chains and the other 1 chain in depth. Both north-west and south-east of this, true scarp features rapidly disappear, and the impression is given that displacement gradually dies out in these directions. To the north-west additional grounds for this belief are afforded by an abrupt uplift of the greywacke floor of this corner of the basin, as a result of which Te Puru Stream has been compelled to turn abruptly to the south, and to cut a deep outlet-gorge across the line of the scarp. As this outlet was lowered, there were pauses of sufficient length to allow the stream to carve three terraces in the greywacke of the lower portions of the floor of the basin. The highest of these is a broad bench about 100 ft. above sea-level; 20 ft. below this there is a narrower bench as much as 6 chains wide, and again 30 ft. below this, adjacent to the stream, there is another terrace carved in greywacke crush-breccia.

Waihohono Block, on the north of Kiripaka Basin, is bordered on three sides by Te Puru Stream and has a most striking trellised drainage-pattern incised on its surface; the streams flow in remarkably straight courses in one or other of two directions approximately normal one to the other—either roughly meridional, as in the case of the upper and lower reaches of Te Puru Stream itself, or else parallel with the scarp of Kiripaka Fault. This suggests that the stresses associated with the downfaulting and downwarping of Kiripaka Basin were in a measure relieved by minor fractures in Waihohono Block, and that, in addition to controlling the courses of the streams draining this area, these also imparted to the block a slight tilt to the south-west. Direct evidence of such minor faulting is indeed present in the north-east corner of the block, for a low scarp of greywacke, 5 ft. high, there forms the western edge of a long low reef at Maraetai Point, and has been exposed as a result of the removal by wave-erosion of overlying soft Pleistocene beds from its westwards dipping surface (Fig. 33). Along the base of the scarp there is a band of completely crushed and slickensided greywacke which trends 10° east of north and is closely aligned with the straight upper portion of Te Puru Valley.

In support of the contention that the Waihohono Block is a relatively uplifted unit, it should be mentioned that the general level of the hills west of it is very decidedly below that of its surface, whilst a mass of greatly-crushed greywacke with elongated lenticles of uncrushed rock that is exposed in a quarry on the western bank of Te Puru Stream, one-quarter of a mile above its mouth, appears to represent friction-breccia produced by the fault that is believed to form the western boundary of the block.

There is a possibility that Te Puru Stream originally drained from Kiripaka Basin across a low col in the divide followed by Maraetai-Whitford Road, maintaining the direction of Kiripaka Fault, and finally entered Hauraki Gulf south of Beachlands. If this be so, its present course may be explained as the result of capture of the earlier stream by another working south along the zone of crushing or fracture that determines the western limits of Waihohono Block. At the present time, however, the hypothetical elbow of capture is at an altitude at least 130 ft. below that of the col mentioned, whilst this latter shows no clear evidence of earlier occupation by a stream, so that this hypothesis cannot be extended beyond the realms of conjecture.

Resumé of the Geological History of the District.

During Trias-Jura times a great geosyncline occupied the greater part of New Zealand, and in it were deposited enormously thick sediments, now represented by Hokonui (Trias-Jura) strata, derived from a land-mass of which the exact location is not known, but which, on the evidence of the greywackes of the mid-Auckland district, was largely composed of crystalline rocks.

This long period of deposition was brought to a close by an orogenic period in early Cretaceous times, as a result of which the sediments in the Mesozoic New Zealand geosyncline were thrown into a series of sharp folds and suffered great erosion prior to ensuing submergence in the late Cretaceous, when beds of the Onerahi Series were deposited throughout North Auckland and possibly in the present district as well. However, as a result of erosion following a late Cretaceous or early Tertiary orogenic movement which closed the Onerahi transgression, such Cretaceous beds, if present, were completely stripped from the underlying basement of Hokonui strata in North-West Manukau, so that, in a subsequent submergence in Miocene times, Waitemata strata were here deposited directly on Hokonui greywacke..

During the Waitemata transgression, rivers from a land which appears to have been situated north-west of Auckland City (Turner and Bartrum, 1929) built an extensive delta on the gradually subsiding floor of the shallow Waitemata sea, and this finally extended to and ultimately completely covered Hokonui strata which now form the Maraetai Hills, where, in the early stages of submergence, sufficiently sheltered conditions held in certain localities to enable the formation of impure limestones such as those now seen at Waikopua. Further, during the deposition of Waitemata strata, a number of small andesitic vents more or less simultaneously broke through the floor of the Waitemata sea and gave rise to the volcanic tuffs of the Parnell Grit horizon.

In early Pliocene times differential uplifts of the Kaikoura orogeny of Cotton (1916) caused the cessation of deposition of the beds of Waitemata Series, and great fractures, oriented in two series, one roughly at right angles to the other and trending approximately north-west by south-east and north-east by south-west respectively, gave rise in the present district to two distinct elevated earth-blocks, both of which display a definite tilt in an approximately north-west direction.

This uplift resulted in such great erosion of the Tertiary covering-beds that in some districts the underlying Hokonui greywacke became exposed over large areas. It was followed by a movement, generally of uplift but broken by several periods of standstill and by at least one minor positive movement, which continued till comparatively recent times, when a sharp positive movement caused extensive flooding of deep, youthful valleys cut during the preceding uplift, and thus initiated the embayed coastline of the vicinity of Auckland City and the present erosion cycle.

At some period of sub-Recent times commencing probably prior to this final submergence, volcanic activity which resulted in the building of tuff and scoria cones and the outpouring of basaltic lavas broke out in the western portions of the district and continued into comparatively Recent times.

The complicated history sketched above was brought to a close by a slight uplift of a few feet after the establishment of the cycle of erosion to which the modern topographic forms are due, but its effects away from the coast-line are almost inappreciable.

FORAMINIFERA FROM WAIKOPUA AND THE PARNELL GRIT HORIZON.

Identifications by Mr. W. J. Parr, Caulfield, Victoria, Australia, are listed below.

Mr. Parr states that the most characteristic foraminifera in the samples supplied were the *Amphisteginae, Lepidocyclinae* and *Miogypsinae,* and that a thick-domed species of *Amphistegina* with affinities to *A. lessoni* d'Orb, was common in all of them. A species of *Lepidocyclina* (sub-genus *Nephrolepidina*) from Whitford Stream is described as new to New Zealand, whilst *Cristellaria* (now *Lenticulina*) *mamilligera* has not been recorded from New Zealand Tertiary since Karrer described it in 1859. *Siphonia australis* has recently been described from the older Tertiary of Victoria.

Several of the species represented are probably new.

The numbers to the columns below refer to the following localities:—

1. *Bloomfield's Stream, Waikopua.* From base of green sandstone above upper limestone, north bank.
2. *Bloomfield's Stream, Waikopua.* From green sandstone below upper limestone, south bank.
3. *South Branch, Waikopua.* From base of green sandstone over the limestone, south bank.
4. *South Branch, Waikopua.* From boulder of limestone in bed of stream.
5. *Granger's Stream, Whitford.* At limit of tidal waters. Specimen intermediate between Parnell Grit and Turanga Greensand facies.
6. *Granger's Stream, Whitford.* 100 yards up-stream from 5. Turanga Greensand facies.
7. *Whitford Stream.* ¾ mile north-east of Trig .28. Turanga Greensand facies.
8. *Whitford Stream.* Headwaters of western tributaries. Turanga Greensand facies.
9. *Maungamaungaroa Creek.* East bank, ¾ mile up-stream from road bridge. Turanga Greensand facies.

In the following lists *f* indicates fairly common, *c* common, and *vc* very common.

	1	2	3	4	5	6	7	8	9
Ammodiscus sp.		x							
Placopsilina cenomana d'Orb.		x							
Textularia gibbosa d'Orb (Short var.)		x	f	x	x		x		f
,, *goesii* Cushman			x		f				
,, *rugosa* (Reuss)			x	x					f
,, sp. aff. *trochus* d'Orb.							x		
,, sp. aff. *catenata* Cushman					f				
,, *sagittula* Defr. (long var.)	x		x	x	x				
,, sp. aff. *carinata* d'Orb.					c				
,, *gramen* d'Orb.		x	x		x		x		
Gaudryina triangularis Cushman									x
,, *quadrangularis* Bagg			x		f				
,, *pupoides* d'Orb.					f				
,, *reussi* Stache			x		x				x
,, sp. with excavated sutures				x					
,, sp. (elongate, sharp angled)			x		c		f		
Clavulina communis d'Orb.					x				
,, *antipodum* Stache	x		f		x		f		f
Quinqueloculina lamarckiana d'Orb.					?		x		
Lenticulina gyroscalprum (Stache)					x		?	x	x
,, *duracina* (Stache)							x		
,, *orbicularis* (d'Orb.)					?				
,, *mamilligera* (Karrer)						x	x		
,, *gibba* (d'Orb.)						x			
,, sp. aff. *crepidula* (F. & M.)							x		
,, *schloenbachi* (Reuss)					x				
,, sp.					x				x

	1	2	3	4	5	6	7	8	9
Nodosaria (*Dentalina*) *obliqua* Linné							x		
„ „ sp. aff. *obliqua*									
(Linné)					x				
„ „ *consobrina* (d'Orb.)				x	x				
„ „ *consobrina* var.									
„ „ *emaciata* Reuss ...									x
„ „ *soluta* (Reuss) ...							x		
Nodosaria radicula (Linné), slender var.					x				
„ *scalaris* (Batsch)					f				
Vaginulina legumen (Linné)			x		f				
Lagena orbignyana (Seguenza) ..					x				
Guttulina communis d'Orb.					x		x		
„ *problema* d'Orb.									x
Polymorphina sp.					x				
Sigmoidella elegantissima (Parker and									x
Jones)					x				
Nonion depressulus (W. & J.)									x
„ *scapha* (F. & M.)			x		x				
„ *umbilicatulus* (Montague)					x				
Dimorphina striata (Schwager) ...					c		x		x
Elphidium macellus (Fichtel & Moll.) ...					x				
„ *craticulatus* (F. & M.) ..	x				x				
Bulimina affinis d'Orb.						x			
Bolivina robusta Brady					f				
„ sp. aff. *textilarioides* Reuss ...	x								
Uvigerina sp. aff. *pygmaea* d'Orb. . .	x				x				
„ *schwageri* Brady					x				
Discorbis bertheloti d'Orb. (var. *complanata* Sidebottom)					x				
„ *bertheloti* (d'Orb.) var. ...					x				
Discorbis (?) sp.					f				
Gyroidina soldani d'Orb.					x				
Eponides repandus (F. & M.)		x		x	f				
„ (?) sp.				x			x		x
Rotalia clathrata Brady									x
„ sp. nov. (1) (aff. *clathrata*)			x		c				
„ sp. nov. (2) (aff. *calcar.* d'Orb.)				f	x		f		x
„ sp. nov. (3) (domed form, aff.				f		x	c		c
clathrata)									
„ sp.					x				
Epistomina elegans (d'Orb.)	x								
Siphonina australis Cushman							x		
Amphistegina sp. aff. *lessoni* d'Orb.					f				
„ *hauerina* d'Orb.	x	c	c	c	f	vc	c		c
Calcarina sp. aff. *calcar* d'Orb.			x	x		x		x	x
Cassidulina subglobosa Brady							x		
„ *crassa* d'Orb.		x							
„ sp. nov. aff. *pacifica*; Cushman & *subglobosa* Brady					?				
Ehrinbergina mestayeri Cushman					f				
Globigerina bulloides d'Orb.					x				
„ sp. aff. *inflata* d'Orb.		x	f		x				
„ probably sp. nov.					x				
Cibicides refulgens Montfort	c	x	f		c				
„ sp. between *refulgens* and	f	x		x	x				
ungerianus (d'Orb.)	f	x	x						x
„ *ungerianus* (d'Orb.)					x		x		
„ *tenuimargo* (Brady)					x				
„ sp.	x				f				
Gypsina globulus (Reuss)					x				
Carpentaria proteiformis Goes							x		x
Lepidocyclina (*Nephrolepidina*) sp.								x	
Miogypsina irregularis (Mich.)							x		

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