# The Geology of the Takapuna-Silverdale District, Waitemata County, Auckland.

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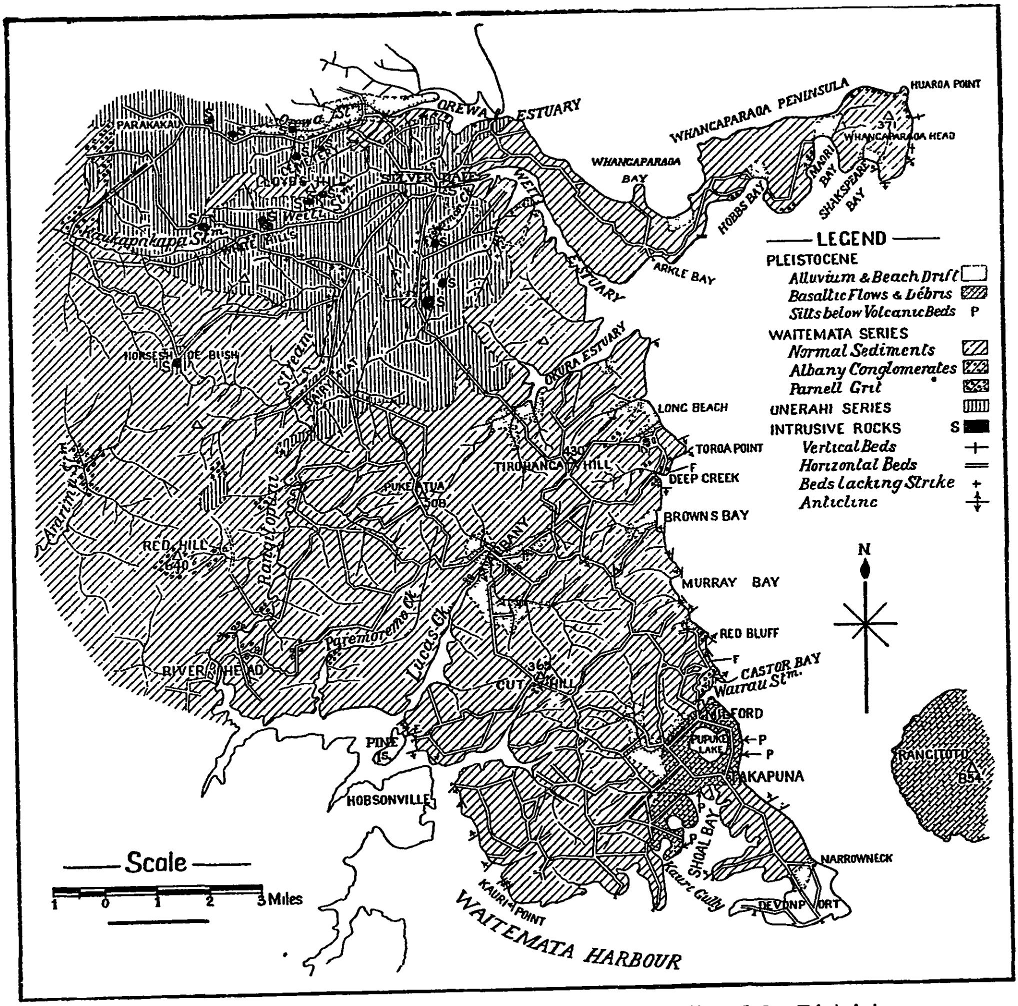
## Introduction.

The district described in this paper covers an area of about one hundred square miles between the northern shore of Waitemata Harbour and Orewa Stream, about fifteen miles north of the latter. On the east it is bounded by the western shore-line of Hauraki Gulf, and on the west joins up with the Riverhead-Kaukapakapa area




**Sketch-map illustrating geology of Takapuna-Silverdale District.**

described by Bartrum (1924). In order to shew the continuity of the rocks of this area with those further west, part of Bartrum's map has been added to that now published.

A small part of the district was early visited by Hochstetter (1864, pp. 13-14), but the first important work upon it was that of McKay (1884; 1884a; 1888), who made two hurried examinations of the eastern coastal portion of the area, parts of which were also surveyed by Park (1886; 1887). In 1902, papers on the volcanic grits and breccias of the Waitemata Series were published independently by Fox and Mulgan, while more recently, facts bearing upon the geology of the district here described have appeared in two papers by Bartrum (1920; 1924) which deal with the region further west. The most northerly part of the area has recently been mapped by Mr. H. T. Ferrar of the New Zealand Geological Survey, to whom both authors are greatly indebted for generous co-operation in the field-work, and hospitality at his camp during Easter 1926. Only a brief summary of the results of his work are at present available (Ferrar, 1925a).

### General Description of Area.

The greater portion of the Takapuna-Silverdale area consists of typical North Auckland "gum-land," namely an unforested upland of moderate relief, intricately dissected by insequent streams flowing sluggishly in swampy valleys between scrub-covered hills rising to between 400 ft. and 600 ft. The wide open valleys typically are graded throughout almost their whole extent, and almost invariably contain a swampy filling of alluvium resulting from soil-wash accentuated by ancient deforestation and more recent burning off of scrub. Further, there is so considerable a depth of superficial leached residual clay that outcrops of fresh rock are scarce, except along the sea-coast and, especially where remnants of forest remain, at the steeper headwaters portions of some of the streams.

The coast of the district shows, on the south and east, the long tidal estuaries and other deep embayments characteristic of a recently submerged region; these are perfectly exemplified by the drowned valley-system which now forms Waitemata Harbour, and by the estuaries of Okura, Weiti, and Orewa Streams further north. Subsequent to the submergence, wave-attack has caused the retreat of the more exposed headlands and thus developed stretches of high cliffs, which are separated by crescentic beaches in the intervening bays.

## STRATIGRAPHY.

### Synopsis of Stratigraphy.

Though such rocks do not occur *in situ* actually within the district mapped, there is no doubt that, as elsewhere in North Auckland Peninsula, the basement is constituted by the greywackes, argillites, and jasperoid rocks of probable Triassic or Jurassic age, to which the name Waipapa Series has been applied by Ferrar (1924) in the contiguous Rodney district, following Bell and Clarke's (1909) early usage for similar Whangaroa rocks. These are separated by a strong unconformity from a thick series of green sandstones, siliceous mudstones, and argillaceous limestones, which are grouped by the writers in the Onerahi Series of Ferrar (e.g. 1925) of probable Upper Cretaceous age, and which represent the earliest rocks actually exposed in the area described. They are invaded by serpentines and allied intrusive rocks, which apparently fail to pass upward into succeeding strata. Above the Onerahi rocks—the writers believe unconformably—there are sandstones, mudstones, and grits of middle Tertiary age, which have long been referred to the Waitemata Series. As closing members of the sequence there are basaltic lavas and tuffs and bedded silts and gravels, all of Pleistocene age, which lie unconformably on the older rocks.

The sequence of deposition or of intrusion may be summed up as follows:—

1. Waipapa Series (Trias-Jura).
2. Onerahi Series (? Upper Cretaceous).
3. Post-Onerahi and pre-Waitemata ultrabasic and basic intrusives (? Eocene).
4. Waitemata Series (? Miocene).
5. Lavas, tuffs, silts etc. (Pleistocene).

THE WAIPAPA SERIES (TRIAS-JURA).

Though the strata of the basement series do not outcrop within the area, pebbles worn from them occur in Pleistocene and Tertiary conglomerates, and much shattered and folded greywackes of this formation are exposed in many nearby localities, as on the neighbouring islands of Tiritiri, Motu Tapu, and Waiheke. Bell and Clarke (1909) grouped similar rocks of the Whangaroa district in their Waipapa Series, to which Ferrar in more recent years (1925; 1925a) referred the greywackes of the Whangarei-Bay of Islands Subdivision as well as the rocks at present under consideration. In the absence of palaeontological evidence these Waipapa rocks have been included tentatively on lithological grounds in the Trias-Jura Hokonui System by most modern workers. (See for example Ferrar, 1925, p. 34).

THE ONERAHI SERIES (? UPPER CRETACEOUS).

*General Distribution and Content.*—The rocks included here in the Onerahi Series broadly form a large inlier in the northern portion of the district. On the north side of Okura Estuary they emerge from beneath the covering Waitemata sandstones and thence extend north and west, through Silverdale (Wade) and White Hills, to the northern limit of the area shown on the map. West of Silverdale they cover the country drained by the upper tributaries of Orewa, Weiti, Rangitopuni, and Kaukapakapa streams. On the western side of Rangitopuni Valley they pass beneath Waitemata rocks which continue far to the west and south, and they are similarly covered by an extensive mass of these younger beds at varying distances north of Orewa Stream.

The Onerahi beds of the area described fall into two distinct sub-series here described as the Lower Beds—concretionary green sandstones with shattered black shale and mudstone—which have limited extent, and the Upper Beds, which include much more widely-developed argillaceous limestones, siliceous claystones and mudstones—beds which may be regarded as the typical facies of the Onerahi Series.

*The Lower Beds.*—The rocks of the lower group were found at only four localities: a narrow strip bordering the southern foreshore of Orewa Estuary for about three-quarters of a mile west from Orewa.

Heads; in the banks of Weiti Stream about one mile west of Silverdale, where the Silverdale-Kaukapakapa road crosses the stream; along the banks of Weiti Stream about five chains east of Silverdale Township; finally, a small triangular area on the eastern side of Duck Creek, where it enters Weiti Estuary, about two miles downstream from Silverdale.

The predominant rock is a micaceous glauconitic sandstone with a peculiar grey-green colour, with which are associated fine-grained black shaly mudstones, and soft green and blue clays. All are much shattered and, wherever strike and dip are observable, appear to dip at steep angles in varying directions. The glauconitic sandstone contains large calcareous septarian and other concretions, some of which are four or five feet in diameter. As already noted by Ferrar (1925a), fragments of *Inoceramus* occur in some of these concretions at Orewa Estuary, whilst indefinite broken plant-remains are often abundant. In all localities of their occurrence, the rocks of the greensand group appear to underlie the argillaceous limestones and siliceous mudstones of the upper sub-series, though whether conformably or otherwise it is impossible to say.

*The Upper Beds.*—In contrast with the limited outcrop of the lower beds, that of the upper or main portion of the Onerahi Series includes practically the whole of the area mapped as covered by strata of this series. Its rocks consist of a fine-grained white, grey or bluish argillaceous limestone—the North Auckland "hydraulic limestone"—with very variable content of lime, and fine-grained grey and white siliceous mudstones, or brown and purple aluminous shales which show a gradation towards the limestones in several localities. The presence of these rocks in the present area was first noted by McKay (1884a), who correlated them with his "Cretaceo-Tertiary" Mahurangi limestone. Lithologically they are exactly similar to limestones and claystones which have long been known to outcrop widely in North Auckland Peninsula, and which have been described by Ferrar (1920; 1924; 1925; 1925a) and included in his Onerahi Series. Bartrum (1924) also describes rocks of this formation in the contiguous Parakakau and Dairy Flat areas, so that little further description is necessary here.

The limestone is a very fine-grained rock, which, in the purer varieties (e.g. the rock from Okura quarry), is composed almost entirely of tests of *Globigerina* and other foraminifera, with which are a few skeletons of radiolarians and grains of glauconite or of disseminated argillaceous material (Fig. 1). Though recorded by Marshall (1917), Bartrum (1924), and others, in the hydraulic limestones of other North Auckland localities, diatoms were not distinguished in sections cut from limestones of the present area. Apart from the lowly forms mentioned, the Upper Beds are devoid of fossils. Flints are infrequent, though at Mappin's quarry, Silverdale, there is a well-marked band of flint nodules which have been intensely shattered and then re-cemented with calcite.

The siliceous facies of the Upper Beds are more widely represented than the argillaceous limestone, into which they appear to grade both laterally and vertically. The predominant rock is a very fine-grained, highly-siliceous mudstone, with its numerous joint surfaces stained brown and black with hydrates of iron and manganese. Like the limestones, the siliceous beds are always intensely shattered, and whenever the dip is observable it appears to be at a high angle. The shattering appears to be due to pressure rather than to shrinkage of drying sediment, since even the flint nodules of Mappin's quarry, as well as the serpentines which invade the series, shew similar disruption.

Completing the facies of the Onerahi Series there are fairly thin-bedded shales apparently barren of all fossils, which constitute a type of rock which is not usually found among the beds of this formation in other North Auckland localities. They are exposed along the Silverdale-Parakakau road, two miles west of Silverdale, and again near Parakakau. In contrast with the usual conditions, the disposition of the beds is easily observable, and in all cases the dip appears to be at a steep angle in directions varying from north-west to south-west. Owing to their thin-bedded weathered state, the purple and brown shales which outcrop two miles west of Silverdale are difficult to distinguish, in the absence of palaeontological evidence, from beds of the Waitemata Series. A significant fact points, however, to their inclusion in the Onerahi Formation, namely, that at adjoining localities, such as Lloyd Hill, Waitemata sandstones rest on rocks of this series and have horizontal disposition which contrasts with the persistent inclined bedding of the latter, which can be followed at intervals for some miles across the general line of strike between Orewa and Parakakau, and preserves a steep dip in the same general westerly direction.* Substantial horizontality, or, at most, gentle inclination, is the dominant structural characteristic of the Waitemata beds; zones of acute folding are very limited in extent. On the other hand, wherever structure is decipherable, the Onerahi strata seem to be disposed at high angles.

*Correlation and Age.*—Ferrar (1925a) has correlated the *Inoceramus*-bearing green sandstones of the Orewa-Silverdale area with the lithologically similar beds of the Central Kaipara region grouped by him (Ferrar, 1924, p. 6) in his Otamatea Series, and by Marshall (1926) in his Batley Series, from which come abundant ammonites of Upper Cretaceous age (Marshall, *loc. cit.*). Ferrar (1925a) follows Park (1887) in postulating unconformity between his Otamatea beds and the overlying argillaceous limestones and other beds of the Onerahi Series, but the present writers find no evidence suggestive of unconformity in their district. In other areas of North Auckland, for example the Central Kaipara, the Narrows of Hokianga Harbour, the north-east portion of Mangakahia Survey District and Parengarenga, there is such very general association of ammonite or *Inoceramus*-bearing sandstones of Otamatea facies with argillaceous and siliceous limestone of Onerahi type under conditions which in no case suggest unconformable inter-relations of the two sets of beds, that the writers prefer to group both provisionally in the one series (Onerahi Series) characterized by the two facies—the lower or Otamatea and the upper or Onerahi.

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*Cox (1882, p. 24) records similar relations of beds at Mahurangi which evidently belong to the two series discussed.

No fresh evidence bearing upon the controversial subject of the age of the beds grouped here as the Upper Beds of the Onerahi Series has been unearthed by the present work. Marshall (1916; 1917; 1924) has ably advocated an early Tertiary age, basing his argument largely upon the apparent superposition of the "hydraulic limestone" upon greensands at Pahi, from which definitely Tertiary mollusca have been collected. The writers' experience of the hydraulic limestones tends to indicate that structurally they are highly disturbed, and it is possible, therefore, that the Pahi section is inverted by thrusting in conjunction with folding. They hesitate to accept Marshall's view for two reasons: first, because of the close association of beds of Onerahi facies with Upper Cretaceous ammonite and *Inoceramus* beds; secondly, because of the fact that, as will appear in a later Section, they believe, with Ferrar and others, that important unconformity separates the Onerahi strata from the overlying Waitemata ones. Judged by investigations of mollusca now being made by Mr. A. W. B. Powell and one of the authors (Bartrum), these latter beds appear to correlate with either the Awamoan or the Hutchinsonian of the Oamaruian sequence. Thus, following Benson (1921) and Bartrum (1924), Ferrar's allocation of the beds here classed as the Upper Beds of the Onerahi Series to the Upper Cretaceous is provisionally accepted in this paper, though it is admitted that some of them may range upwards into the early Tertiary. As already stated, they are here believed conformably to overlie the Upper Cretaceous Lower Beds, or green sandstones of Otamatea facies.

*Intrusive Rocks associated with Onerahi Sediments.*

*Distribution and General Petrography.*—Numerous scattered outcrops of small intrusions of serpentines and other intrusive rocks of basic or ultrabasic character were located in the northern part of the area occupied by rocks of the Onerahi Formation, whilst others probably await discovery in the dense scrub and fern.

Serpentine is the commonest type of intrusive rock and outcrops of it occur at the following localities:—

1. At Matthew's quarry alongside the East Coast Road, three miles south of Silverdale. A fairly extensive mass is enclosed in siliceous claystones. Impure argillaceous limestones outcrop on the road a few chains west.

2. Two unobtrusive outcrops, probably of the same mass as that at the quarry, occur a quarter of a mile north of the latter in Matthew's Gully, a headwaters tributary of Duck Creek.

3. About ten chains east of the East Coast Road, one and a-half miles south of Silverdale, two good exposures of serpentine occur at the head of Fisherman Creek in the vicinity of outcropping limestone and mudstone of the Onerahi Series.

4. Floaters of serpentine are present on the divide between Weiti Estuary and the outlet of Orewa Estuary.

5. On the southern scrub-covered face of the Orewa-Weiti divide, about fifteen chains east of Lloyd Hill trigonometric station, serpentine is exposed in a deep shaft which was sunk by the early settlers in quest of gold, as well as at the surface close by. The serpentine

must originally have been covered by Waitemata sandstone which has since been removed by erosion, for this latter rock is visible in a horizontal drive about 30 ft. below the outcrop of serpentine and about 7 chains east of it. Sandstone of this series is also exposed in a pit sunk as a coal-prospect on the northern side of the divide about half a mile north-west of the last outcrop, and forms a continuous cap upon the Onerahi strata along the crest of Lloyd Hill.

6. A quarter of a mile south of the last exposure, serpentine again outcrops, well hidden in scrub, on the almost flat top of the spur which leads down from Lloyd Hill to Mr. Davidson's farm. Here a short deep trench was excavated in the serpentine many years ago.

In addition to the above outcrops, there are others already described by Bartrum (1924) quite close to the last two mentioned, namely in the vicinity of White Hills School and Major Jolly's farm, and in the neighbourhood of Wainui Cemetery and of Mr. David Jack's property on the Orewa side of the Lloyd Hill divide. In every case the enclosing strata appear to be those of the Onerahi Series, and the serpentines themselves are generally much shattered and slickensided.

Basic igneous rocks, which appear to represent the same period of activity as that during which the serpentines were intruded, are also known from the northern part of the district. They are seldom found *in situ,* but usually the masses are of such a size that the parent mass cannot be far distant. They include epidiorite, dolerites, and allied amygdaloidal volcanic rocks. Epidiorite has already been described (Bartrum, 1924) from near the unformed road on the east side of Wainui Cemetery, where it occurs as loose boulders. Masses of similar rock outcrop with other basic rocks near Orewa Heads; boulders of them strew the foreshore for a few chains east of the bridge. Dolerites have also been noted (Bartrum, 1920a; 1924) from the swinging basin near Silverdale Wharf, and from the bed of the Upper Orewa Stream, not far west of Wainui Cemetery, whilst they are also plentiful amongst the boulders on the foreshore at Orewa Heads. In association with them at this latter place, there are masses of altered amygdaloidal volcanic rocks which probably represent effusive equivalents of the doleritic rocks.

As a special phase of the occurrence of these doleritic rocks may be mentioned fragments found with larger ones of greywacke and of a schistose metamorphic rock, as xenoliths in the serpentine at the head of Fisherman Creek. This suggests that some at least of the doleritic intrusions were earlier than the serpentines. The schistose inclusions represent fragments of a coarse-grained strongly-metamorphic rock with large idioblasts of strongly-pleochroic brown hornblende. (See Section on Petrography). They have probably been derived from metamorphic rocks underlying the basement Trias-Jura Hokonui strata, for similar schistose xenoliths are abundant in intrusive andesitic rocks at Whangarei Heads, and are believed by Bartrum (1921, p. 121) to represent now-deeply-buried earlier Palaeozoic terrain.

*Origin and Age of the Intrusive Rocks.*—In his first report on the serpentines, McKay (1884) gives his opinion that the outcrops examined by him belong to three slightly converging dykes with approximate north and south trend. Park (1887) illustrates conditions at Matthew's quarry by a section, and states that the serpentine occurs in the shaly clays which immediately underlie the " hydraulic limestone." He considers that the ultrabasic intrusives are associated with " Carboniferous or Devonian " greywackes (now referred to the Trias-Jura Waipapa Series), and evidently has mistaken some of the weathered shattered serpentine which is exposed in the vicinity of " Bond's farm " (now Major Jolly's property) for these latter rocks.

In 1888, McKay arrived at the conclusion that the serpentines constituted a definite horizon beneath the hydraulic limestone, and published the theory that they were ophicalcites derived by metamorphism of the greensand strata which lie beneath the limestone.

The writers have observed, however, that the serpentines frequently invade the Upper Beds of the Onerahi Series, and thus cannot constitute a definite horizon towards the base of this latter, whilst microscopic characters indicate that they are normal alteration products of dunites, harzburgites and other peridotites. The evidence of their intrusive character is thus complete. McKay's earlier suggestion that the serpentines constitute three long north and south dykes proves unacceptable, for the intrusions are arranged in quite haphazard fashion.

So far as date of injection is concerned, there are three possibilities: it may be pre-Onerahi, or post-Onerahi and pre-Waitemata, or post-Waitemata. Thus Park (1887) suggested, as already noted, that the serpentines were injected in pre-Onerahi times into sediments now grouped in the Waipapa Series, but their vertical distribution through a considerable thickness of the Onerahi beds, in conjunction with the lack of outcrop in their vicinity of the Waipapa rocks, is against this hypothesis, for it necessitates the assumption that during the Waipapa-Onerahi interval erosion removed the resistant Waipapa greywackes and left the serpentine projecting as residual ridges. This is highly improbable, for the serpentine is so poorly resistant that its outcrops generally have inconspicuous relief even in contrast with the soft Onerahi rocks.

The third possibility, namely that the period of intrusion was subsequent to Waitemata sedimentation, is negatived by the field-evidence, for though exposures of serpentine are very numerous amid Onerahi beds, they have not yet been found invading the Waitemata strata which enclose the Onerahi beds on every side. It is true that at Lloyd Hill, as noted, sandstone of the Waitemata Series outcrops at a lower level than adjacent serpentine, yet the maximum uprise of the serpentine above the base of the sandstone probably does not exceed 30 ft., and can very readily be explained as due to the irregularity of the erosion-surface carved from Onerahi beds and associated intrusive bodies, prior to the initiation of Waitemata sedimentation.

Benson (1926) has ably shewn that the intrusion of serpentines generally accompanies moderately intense orogenic diastrophism. As has already been shewn, there is evidence that the little-deformed Waitemata beds rest upon the steeply-inclined edges of the Onerahi ones. These conditions suggest unconformity between the two series for which other evidence is not lacking, and the writers therefore believe that the peridotites and the doleritic and other intrusive basic rocks invaded the Onerahi strata as an accompaniment of an orogeny which occurred at the interval between Onerahi and Waitemata times, and folded the newly deposited strata. Subsequent erosion uncovered some of the intrusive masses before the Tertiary beds were laid down, not only in the present area but elsewhere, for pebbles of silicified dunite-serpentine have been discovered in conglomerates apparently of Tertiary age at Mangawhio Point, Whangarei Harbour (See Bartrum, 1925). The epidiorites, dolerites, and other basic rocks which have been mentioned earlier in this Section are the usual cognate associates of ultrabasic intrusions.

THE WAITEMATA SERIES (? MID-TERTIARY).

*Distribution and Petrography.*

*Normal Sediments.*—Beds of sandstone and mudstone which have long been grouped as the Waitemata Series, marginally overlie the Onerahi rocks on all sides, and extend many miles north, west, and south of the area here considered. Small outliers of Waitemata strata also cap the Onerahi limestones and mudstones at Lloyd Hill and again in the vicinity of Matthew's farm, about three miles south of Silverdale, and are evidently the remnant of a continuous sheet of such beds now largely removed by erosion.

The total thickness of Waitemata beds is difficult to estimate, but in the hilly country further north, between Cape Rodney and Kaipara Harbour, horizontal strata of this series appear to reach a thickness of at least 1200 ft.

The typical rocks of the series are brown and yellow feldspathic sandstones with which are interbedded thinner layers of fine gray mudstone. A not infrequent bed is composed of concretions a few inches in diameter, and is similar to a bed further north which was called by Cox (1882, p. 22) "the cannon-ball sandstone." This is generally about 2 ft. in depth and is especially well exposed on the sea-coast north of Castor Oil Bay, at the northern end of Long Beach, and between Hobbs and Maori Bays on Whangaparaoa Peninsula. The concretions generally contain a central pebble of fine-grained sometimes calcareous shale, and microscopic examination shows that the surrounding accreted matter has a calcareous cement enclosing angular grains of sand, which are exactly similar to those making up the bulk of the associated sandstone. It appears that precipitation of cementing calcite has been inaugurated and aided by the central pebble.

At times the sandstones pass into grits, and in some localities, as for example near Okura South Head and on the southern shores of Whangaparaoa Peninsula, into thin irregular lenses of interformational conglomerate. These latter contain pebbles of earlier-deposited sandstone of the same series, derived by contemporaneous erosion, along with others of a white marl which shews tests of *Globigerina* in thin section, and appears to have been derived from rocks of the Onerahi Formation.

The beds of bluish-grey mudstone intercalated in the general sandstone range from about 6 ins. to 1 ft. in thickness and shew the usual minute curved shrinkage cracks on exposed surfaces. They frequently contain abundant fragments of carbonized wood, whilst small concretions of pyrite are often common.

*The "Albany Conglomerates."*—Two bands of marine beach-conglomerate containing material foreign to the district are exposed interbedded with the normal finer-grained Waitemata sediments in the bed of Lucas Creek, not far below Albany. Similar conglomerates are extensively developed north-west of the present area and attain a maximum thickness of not less than 700 ft. They have been described by Bartrum (1920; 1924) in some detail, so that brief description of their nature will suffice here.

All the pebbles and boulders of these beds, which may be called the Albany conglomerates, are well-rounded and smooth, and though generally not more than 1 ft. in diameter, are sometimes as large as 8 ft. The rock facies include varied sediments—many with probable prototypes in the Onerahi Series—and greatly-varied igneous rocks. Though andesites are the dominant types of some localities, and are usually the largest masses, the most distinctive and abundant rock throughout the whole formation is a granulated diorite which often grades into a dioritic gneiss. An isolated round boulder of norite discovered by Bartrum (1920a) in Waitemata sandstones at the mouth of Wairau Stream, Milford, probably represents material similar to that of the conglomerates further north, which was entangled in drift-wood and so carried well away from the shore.

Bartrum (1920) noted the occurrence of a band of much-weathered conglomerate in a deep road-cutting at Cut Hill, three miles south of Albany on the road to Birkenhead. Recent excavations have exposed somewhat less-weathered material, and shew that the conglomerate dips south-east at about 70°. At the north end of the cutting there is a mass of inclined cross-bedded fine-grained sands and mudstones, which continue south for about 20 yds., and then give place to a bed 6 ft. thick of coarse-grained conglomerate which contains rounded boulders, up to 2 ft. in diameter, of siliceous material probably derived from the Onerahi Series. Finally a finer-grained conglomerate, with pebbles averaging about 2 ins. in diameter, comes in above this bed and extends for 20 yds. to the south end of the cutting. Most of its pebbles or boulders are of weathered sandstone apparently worn from earlier Waitemata beds during a phase of contemporaneous erosion. There are also a few pebbles of siliceous material similar to those of the lower band just described, whilst larger masses, as much as 1 ft. in diameter, of a greatly-weathered igneous rock resembling andesite are scattered throughout this and other beds of the conglomerate at this locality. The diorites characteristic of the Albany conglomerates are entirely absent.

In discussing the origin of the Albany conglomerates it is necessary to draw attention to the fact that beds similarly containing pebbles of plutonic rocks which are often affected by pressure have been described from Mesozoic and Tertiary strata in a number of localities in the North Island, as, for example, the central portion or King Country (Park, 1893), near Kawhia (McKay, 1884c, p. 145), on the East Coast near Gisborne (McKay, 1887; 1884b, p. 72), Great Barrier Island (Bartrum, 1921) and at Mangapai and Onerahi on the Whangarei Harbour (Bartrum, 1921a; 1924a).

Occasional dioritic boulders also occur at Kaipara Harbour (Marshall, 1917), in the North Cape area (Bartrum and Turner, 1928) and, as determined by a recent visit of the authors, near the mouth of Waimamauku Stream south of Hokianga Harbour and at Hokianga South Head, in conglomerates which are dominantly andesitic in character and have been unhesitatingly correlated with the Waitakerei fragmental volcanic beds. These latter are generally accepted as constituting a horizon above the sedimentary facies of the Waitemata beds near Auckland. This fact of the distribution of the diorites raises the interesting question whether the North Cape conglomerates in particular, in view of their somewhat plentiful dioritic pebbles and intercalation in fossiliferous normal Tertiary sediments, should not be regarded rather as the equivalent of the Albany conglomerates than of the Waitakerei "breccias." Such a correlation is further supported by the stratigraphic position of the Hokianga conglomerates, which appear to lie at no great distance above the basement of Onerahi limestones.

The origin of the pressure-affected plutonic and other pebbles is of particular interest in view of the fact that no plutonic rocks have been discovered *in situ* within very considerable distances of outcrops of Albany conglomerate. Bartrum (1920) has discussed the facts fully, and there is no need to add to his statements regarding the known occurrence of coarse-grained batholithic or other intrusive masses, beyond the fact that the present authors have recently found that the gabbroid masses described in association with peridotites by Bell and Clarke (1910) have local gneissic facies, and that small batholithic masses of basic intermediate or basic composition are not infrequent over a wide area both north and south of Hokianga Harbour.

Conclusions summarized elsewhere may well be quoted " The granulated and sheared plutonic rocks are believed to be representatives of a buried terrain which was in existence before and during the deposition of Trias-Jura sediments exposed in neighbouring areas, which are the oldest rocks so far discovered *in situ* in the North Island of New Zealand. This terrain apparently persisted into Tertiary times, for the Miocene conglomerates appear not to be a rewash of mid-Mesozoic ones." (Bartrum, 1924b).

*"Parnell Grit" Horizon of the Waitemata Series.*

*General Description.*—A further variation from the normal sandstones and mudstones of the Waitemata Series is shewn in bands of fine-grained volcanic grits, tuffs, and in some places coarse-grained breccias and agglomerates, which outcrop freely along the east coast north of Takapuna, and have been described by earlier writers as the "Parnell Grit" or "Cheltenham Breccia." Detailed descriptions of the material of the beds have been given by Fox (1902) and Mulgan (1902) to supplement the more general statements of Hochstetter (1864), Cox (1882), Hector (1886), and Park (1889). Outcrops of material distinctive of this horizon were noted within the present area at the following places along the eastern coast:—

1. Castor Oil Bay, Milford. At the south head of the bay there is typical coarse material. At the north head fine tuffaceous material probably represents the same horizon.

2. Red Bluff.
3. On both sides of the bay at Deep Creek.
4. Beside the road to Tirohanga Hill, one mile inland from Long Beach.
5. On the western side of Hobbs Bay, Whangaparaoa Peninsula.
6. On the western side of Maori Bay, Whangaparaoa.
7. Along the north coast of Whangaparaoa Head.

Fox (1902) also mentions an outcrop on the north side of Okura Estuary, whilst other outcrops may exist west of Manly on the northern shore of Whangaparaoa Peninsula, for this area was not examined. Similar beds have been recorded by McKay (1884a, p. 104) and others from as far north as Puhoi.

For so wide-spread a bed the " grit " is fairly uniform in material, though subject to variation in texture. It typically consists of angular fragments, about one-quarter to one-half inch in diameter, of andesite and Waitemata sandstone set in numerous interstitial particles of the same materials partially cemented by calcite. Larger masses of sandstone and andesite from 3 ins. to 3 ft. in diameter are often scattered sparsely through the rock, especially where it is a little coarser in texture than usual. In several places, as on the southern side of Castor Oil Bay, there are enclosed blocks of carbonaceous mudstone which are possibly derived from subjacent Onerahi beds.

By far the greater proportion of the volcanic material is comprised of porphyritic and often vesicular andesitic rocks, though more acidic trachytic ones have been recorded (Bartrum, 1917). Isolated crystals of augite and plagioclase are sometimes numerous. Abundant varied Bryozoa occur in almost every locality where the grit is developed, though unfortunately they are unfavourable for exact determination, since perfect specimens are hard to obtain.* Other fossils of Parnell Grit horizon include Foraminifera and the broken remains of lamellibranchs, corals, echinoderms and crustaceans.

Cross-bedding is a prevalent feature in most of the bands of " grit," and lenticular beds shew transition both laterally and vertically from coarse to fine facies in the most abrupt fashion. Wide-spaced joints are usually well displayed, with the fissures occupied by veinlets of calcite which sometimes exhibits good rhombohedral and scalenohedral crystals. Fox (1902, p. 461) records veinlets of zeolites, but none was noticed by the present writers. The contact between the " grit " and underlying Waitemata beds is often a faulted one; where the sequence is uninterrupted, however, the volcanic beds appear conformably to overlie the normal sediments (Fig. 2). There is often interdigitation of lenses of sandstone in the basal portion of the grit, indicating a transition from one set of beds to the other, though Ferrar (1925a) considers that in some cases slight unconformity is indicated at this horizon. Hector (1886) similarly held that such unconformity exists, and removed the beds above it from the Waitemata Series.

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*Fox (1902) lists a number of species obtained near Auckland, but his determinations have not yet been revised by competent workers upon this group.

Coarse-textured breccias which occur in the high sea-cliffs of the northern and eastern coasts of the small peninsula known as Whangaparaoa Head, which terminates Whangaparaoa Peninsula itself, constitute an important special phase of the Parnell Grit. Interbedded with acutely-disturbed sandstones, they outcrop almost continuously for about three miles, and at the most northerly point of the peninsula, about three-quarters of a mile west of Huaroa Point, take the form of a very coarse breccia or agglomerate. The included fragments here average about 3 ins. or 4 ins. in diameter, whilst many of the constituent blocks of andesite—the prevailing rock-type—are as much as 3 ft. across. An interesting and important feature is the occurrence in the breccia of large angular fragments of limestone, as much as 5 ft. in greatest dimension, which consist mainly of Bryozoa, *Amphistegina* and other Foraminifera and echinodermal remains (Fig. 5). In constitution it thus resembles closely the Whangarei limestone (see Marshall, 1916, p. 91), and that near Papakura, the former of which has been placed by Ferrar (1924; 1925) near the base of the Tertiary sequence in that area, whilst the latter has long been placed at or near the base of the Waitemata Series (see, for example, Park, 1886).

Other interesting inclusions in the breccia of Whangaparaoa Head are occasional boulders about 3 ins. in diameter which contrast strikingly in their well-polished nature with the general angular material. Petrographically they consist of greywacke and of andesites and gneissic diorites indistinguishable from those of the Albany conglomerates. In addition, a pebble sectioned proved to be a fine-textured submarine tuff (Fig. 6) containing fragments of pyroxene and of a dark aphanitic rock set in a calcareous matrix in which remains of broken pelecypod shells and tests of *Rotalia* and other Foraminifera could be distinguished.

The explanation of the incorporation of these boulders in the agglomerate, along with the masses of limestone and sandstone mentioned above, lies undoubtedly in their disruption from subjacent beds by volcanic eruptions (evidently at no great distance) which supplied the andesitic débris constituting the main mass of the deposit. The existence of limestone beneath the sandstones of the area is what might be expected in view of its outcrop near the base of the Waitemata Series on nearby islands, but it is especially interesting to have the suggestion, if not demonstration, of the extension of the Albany conglomerates far east of their surface outcrop.

*Horizon and Origin of the Parnell Grit.*—Much has been written by earlier workers regarding the stratigraphic position and origin of the Parnell Grit, but the evidence is by no means conclusive. Cox (1882, p. 25) points out that it overlies the foraminiferal beds at Orakei Bay, Auckland—a fact certainly supported by recent disclosures of the grit in the railway cut near Orakei Basin—but this by no means delimits its position in the whole series. He is further inclined to regard the deposit as material spread on the floor of the shallow Waitemata sea by the earliest of the eruptions which had their culmination when the rocks now consituting the agglomerates, breccias, and conglomerates of the Waitakerei Hills were hurled out to form a mass nearly 1000 ft. in thickness. Park (1886) similarly correlates the Parnell Grit with the Waitakerei breccias and places both near the top of the Waitemata Series.

On the other hand, near Mahurangi Heads (Fox, 1902, pp. 474-475), beds which are referred to these grits lie not far above limestone belonging to the Onerahi Series, whilst the writers' observations on the Auckland-Riverhead section make it clear, in spite of complications introduced by local sharp corrugations and dislocations, that the tuffaceous beds at Parnell Point are overlain by several hundred feet of sandstone. It thus appears certain that the eruptions which spread this volcanic débris were not limited to the final stages of Waitemata sedimentation.

Fox (1902) subdivides the Parnell Grit, using the term in the comprehensive fashion adopted here, into two phases which have different sources and dates of origin, but this is unsatisfactory, since the correlation of beds only a few feet thick and often many miles apart is based only on variations in texture combined with minor lithologic changes. He suggests that his "Cheltenham Breccia," which includes most of the Parnell Grit in the present area, derived its andesitic débris from the line of vents which gave source to the Waitakerei Hills about 15 miles west of the Takapuna-Silverdale coast-line, an opinion more or less shared by Mulgan (1902) and in agreement with that of Park (*loc. cit.*) and others.

Two objections may be urged against this view. First, the Waitakerei breccias have been accepted by all workers on the geology of the Auckland district as at the top of the Waitemata beds (see Cox, 1882; Park, 1886); most writers regard them as conformably above these latter (see, for example, Marshall, 1908), though Bartrum (1924) finds evidence near Kaukapakapa suggestive of unconformity, which is strengthened by that now available from the Huia tunnel recently excavated in connection with Auckland water-supply. The tunnel follows a thin slightly lensoid bed, often only about 2 ft. in thickness, which is interbedded at the west end of the tunnel with sandstones of Waitemata facies. This bed consists of fine-textured angular volcanic débris, with occasional well-rounded pebbles of greywacke and andesite, and contains poorly preserved molluscan shells, a few Foraminifera, and other fossils. Towards the eastern mouth of the tunnel this material appears to grade into coarser débris of the Waitakerei breccia formation, the contact between the two sets of beds being indistinguishable. These facts appear to indicate that the Waitakerci breccias rest upon an uneven erosion surface of the Waitemata beds.

In the second place, the irregular variation in texture of the "grit" from place to place, the lensoid nature of the beds, their rapid change in thickness in any particular locality, and the total absence of any trace of a former large central vent, all lend support to the view that the component andesitic material was supplied from a number of small centres of eruption rather than from a single major one. Nevertheless the petrographic uniformity of the included volcanic débris points to a common magmatic source for it all, and it is therefore believed that the Parnell Grit, though not a continuous stratum, consists of a series of lenses which occur, in the main, approximately at the same horizon in the Waitemata Series, though similar material may also be found at other levels within that series. As already suggested, it is probable that a considerable lapse of time separated the deposition of the greater portion of the Parnell Grit from that of the Waitakerei breccias.

*Basalt Entangled in Waitemata Beds at Whangaparaoa.*—A large horse of columnar basalt about 20 ft. in diameter has been entangled, along with large blocks of Parnell Grit, in highly dislocated Waitemata strata three-quarters of a mile west of Huaroa Point, Whangaparaoa Head. From its microscopic characters it is possibly the basalt, said to have come from Wade (Silverdale), which has been described by Sollas and McKay (1906, p. 158), and believed by them to belong to the same period of eruption as the Pleistocene or sub-Recent basalts near Auckland. The present writers prefer to regard it rather as approximately coëval with later Tertiary basaltic intrusions at Sugar Loaf, near Matakana, and Ti Point (Bartrum, 1920a) about 20 miles to 25 miles further north. The main evidence in favour of this view is the fact the altered olivine of the Whangaparaoa rock contrasts strikingly with the unaffected mineral of the Auckland basalts, but strong support is added by the knowledge that these latter were not erupted until long after all important movements connected with the orogeny by which the Waitemata beds were disordered had ceased. The Whangaparaoa basalt, on the contrary, preceded this period of stress.

*Structure of the Waitemata Series.*—Viewed broadly, the beds of the Waitemata Series of the present district resemble those of other areas in their simple, gently-inclined or horizontal disposition, though superposed upon this simple structure there is local complexity shewn by relatively narrow zones of acute folding and fracture. Park (1910, pp. 133-135) summarizes these facts, publishing a diagram illustrative of the complex local dislocation of the beds, and ascribes this latter to "thrust exerted by the comparatively recent volcanic outbursts." Though this certainly is suggested by the section at the west head of Tamaki Inlet, near Auckland, where a dissected basaltic cone is associated with considerably-disordered Waitemata beds, yet it is entirely negatived by the clear evidence that the Auckland basalts have everywhere buried topography carved subsequent to deformation.

It is exceedingly difficult to systematize the structural disposition of the Waitemata strata in the present area, because of the constant local complexity. Between Milford and Ohura Estuary, however, there is synclinal arrangement of the beds which was early pointed out and figured by McKay (1884, p. 103). This can also be distinguished, with superimposed minor corrugations and fractures, in the section along the shores of Waitemata Harbour from Kauri Point to Lucas Creek. The axis of the syncline appears to trend approximately north-east and south-west, for a north-east strike is very general.

Another fairly large area over which the general attitude of the beds is relatively simple is Whangaparaoa Peninsula, with the exception of its extreme eastern portion, for a slight westerly dip is very constant.

Turning, however, from these areas to those where faulting or corrugation is evident, it is almost impossible to unravel the tangled skein of facts—facts so numerous that their incorporation in this paper is impracticable. Normal faults, reverse faults with associated overturned folds, and possibly also flaws, constantly succeed one another and trend with directions so diverse that their maze almost obliterates evidence of structural control in their creation. It is indeed probable that a N.E.-S.W. disposition of such fault and fold axes is dominant, a fact which is in keeping with observations recently summarized by the present writers (1928, pp. 135-137), which shew that the structure of the Auckland area and of North Auckland Peninsula is governed by two series of great fractures arranged in rectangular pattern, of which the lesser trends north-east and south-west. It is also possible to co-ordinate the broader features of the two most extensive and intensive zones of compression traversing the present area. One of these (Figs. 7-9) is perfectly portrayed in the sea-cliffs between Wairau Creek, Milford, and Red Bluff, about two miles further north, and the other is at Whangaparaoa Head (Figs. 11-14).

The Milford section exhibits an example of thrusting which invariably proves a delight to all geological visitors. The base of the visible section shews that the beds below the lowest thrust 'sole' have been crumpled and overturned by frictional drag. Above them there are at least two thin lensoid overthrust sheets, followed by a much thicker one with a minimum thickness of at least 30 ft. (See Fig. 7). The edges of its strata are indragged in most interesting fashion at the thrust-plane (Fig. 8), and it is interrupted by two narrow zones from 15 ft. to 25 ft. in width in which sub-vertical beds are entangled (Fig. 9).

The writers had early attempted to refer these zones of sub-vertical strata to intilting along faults developed subsequent to thrusting from a south-west direction, but could not find this explanation satisfactory. Nor did the hypothesis that these zones followed the course of flaws prove more acceptable, and they are indebted to Dr. Leon Bossard for a suggestion which explains the facts more satisfactorily than the other hypotheses. This is that the sharply-tilted strata represent beds forced against a resistant foreland at the toe, somewhat arcuate in plan, of an overthrust mass advancing approximately from the south-west. This latter was compelled to develop temporarily sub-vertical reverse faults, and then to over-ride the obstructing mass at higher levels. Particular support is afforded this hypothesis by the fact that the over-ridden beds include especially rigid strata in a band of Parnell Grit approximately 15 ft. in thickness, 'horses' of which have been included in one of the zones of disturbance (Fig. 7). As will be pointed out later, there is further suggestion from elsewhere that the Parnell Grit frequently provides a resistant mass upon which the weaker normal facies of the Waitemata Series are overthrust or piled up in close folds.

Corroborative evidence is yielded also in the drag of the edges of the beds of the major overthrust sheet down the plane along which the most pronounced dislocation has occurred, which, further, appears to die out seaward, a fact which suggests that actually it merges into a sharply arcuate, variably-inclined fracture bounding the front of an advancing sheet.

The incidence of pressure at Whangaparaoa is perhaps even more remarkable than at Milford, but its features are not so familiar on account of its comparative inaccessibility. Highly detailed mapping is necessary before the full scheme of events can be unravelled, and this was impossible in the limited time available. Nevertheless, a major rock-sheet, which has been thrust apparently from a more or less southerly direction, is clearly recognizable for a distance of about half a mile north and a similar distance south of Huaroa Point. Lenses of Parnell Grit are thrust one over another, whilst normal faults have combined with the thrusts to render the disposition of the strata such that it can only be described as chaotic (See Figs. 13, 14). Certain details of structure displayed in the almost uninterrupted sea-cliffs and broad cut-platforms are well worth brief record. On the northern side of the isthmus which separates Maori Bay from the northern coast, the beds undulate gently, but trend uniformily about E.N.E. Passing east, however, Parnell Grit soon appears, affected by intense faulting movements which have displaced lenses of the grit itself, brecciated the sandstones and indragged them along the fault zone. Moderately complex folding is exhibited for about half a mile further eastwards (See Fig. 11) and then, about three-quarters of a mile west of Huaroa Point, the pressure finds its expression in the development of overthrust sheets amongst which large masses of coarse volcanic breccia and one of the columnar basalt described in an earlier section are entangled. A quarter of a mile further east, upward shearing is perfectly displayed, and there begins also the major sub-horizontal thrust from a southerly direction which has already been noted. South of this zone of thrusting, folding again becomes the most noticeable expression of the disturbing forces, and such close folds are displayed that the beds stand vertical for distances of several chains across the strike. Beds of coherent sandstone 2 ft. or more in thickness may be bent through almost 180°, close examination alone revealing that the displacement has been adjusted along innumerable tiny fractures.

One of the most noteworthy characteristics of the intense local deformations prominent in the Waitemata beds is the fact that they are almost always best developed in association with coarse or moderately-coarse beds of the Parnell Grit. This applies to other districts near Auckland in addition to that now described. Hochstetter (1864, p. 13), with his characteristic acumen, remarks on this at Whangaparaoa, and, in explanation, as quoted by Hector (1886, p. 39), advances the theory that the grit ". . . . is an eruptive formation which has penetrated between the sandstones and clay-marl strata, torn them asunder, broken them, and by lateral pressure to the westward forced them out of their original situation."

This association of the grit with zones of complex yielding to compressive forces is too frequent to be merely a coincidence. An explanatory suggestion which may present itself is that the grit is low in the Waitemata sequence and comes to the surface only when brought there by folding or thrusting. There are good reasons for believing that this is not so, for at Whangaparaoa, as explained previously, there is evidence that beneath the grit there are the Albany conglomerates, which appear to be distributed through a considerable depth of strata (Bartrum, 1924).

A preferable explanation, which is supported very strongly by the phenomena of the overthrust at Milford, is based on the massive comparatively unyielding character of the bed or beds of Parnell Grit. Its lensoid strata have acted as obstructive masses against which more yielding beds have been piled up in folds by lateral pressure, and, when the limits of its own resistance to shearing have been exceeded, it has itself been piled up in small overthrust sheets.

On summarizing the facts, it must be emphasized that no physiographic evidence of fractures of the N.W.-S.E. series which are so important near Papakura and Brookby about 15 miles to 20 miles south-east from Takapuna, can be obtained in the present area, nor could it, perhaps, have been expected, in view of the poorly-resistant nature of the underlying strata. Nevertheless, facts have been set forth which shew that there has been moderately intense compressional force acting from a south-western direction, which has given origin to thrusts representing a special phase of the same post-Waitemata orogeny (the Kaikoura orogeny of Cotton, 1916) as is evidenced by the major faults near Papakura, sub-horizontal movements having temporarily superseded vertical.

The inference drawn by the authors is in accord with their views of the structure of North Auckland Peninsula (Bartrum and Turner, 1928, pp. 135-137). They believe that their area represents a laterally compressed member of a series of elongated sub-parallel blocks rising along a N.W.-S.E. fold-axis delineated long previously in early Cretaceous times. It would appear that its structure, in a broad way, is anticlinal, with the strike of the accompanying thrusts sub-parallel to the anticlinal axis.

Special complications have arisen, however, in response to the presence of structural elements of the complementary N.E.-S.W. series. It has been shewn earlier that these are indicated in the disposition of the strata, and it can now be stated that physiography also indicates control of this kind. That this is so is suggested by such phenomena as the direction of Whangaparaoa Peninsula and the very general N.E.-S.W. trend of streams of the district and of certain cuesta-like divides which are by no means uncommon, especially both east and west of Lucas Creek.

In addition to the structural characteristics of the Waitemata beds which have been described and discussed, there are others which are not without their interest. Amongst them is the presence of interformational dislocations and folds, which are generally present on a minute scale, and are then limited to a layer not over 1 ft. in depth. One of the best examples is near the sewerage discharge about three-quarters of a mile south of Takapuna Beach, where a bed about 2 ft. 6 ins. in depth is complexly corrugated. The probable cause is subaqueous gliding of delta-beds down the slope of the delta, when growth has caused over-loading, for the local examples exactly resemble those figured by Grabau (*Principles of Stratigraphy*, 1913, p. 783, Fig. 167) from Canada.

*Relation of the Onerahi and Waitemata Series.*—The question as to whether or not unconformity separates the Waitemata beds from the Onerahi rocks below them has given rise to much discussion ever since Cox (1881) first suggested that the series are unconformably related. Whilst members of the present Geological Survey (e.g. Ferrar, 1924; 1925) support the view that the Waitemata Series rests on the eroded surface of the Onerahi Formation, Marshall (1917) has expressed the contrary view that the hydraulic limestones of North Auckland (part of Ferrar's Onerahi Series) lie between the Waitemata beds and the Early Tertiary Whangarei limestone, and form part of an unbroken Tertiary sequence. In 1924 he again affirms the Tertiary age of the hydraulic limestones.

A number of indications that unconformity does exist may be observed in the area here described ,and may be enumerated briefly as follows:—

1. Pebbles lithologically similar to the more siliceous members of the Onerahi Series are found in many of the bands of conglomerate which are widely scattered through the Waitemata Series, especially in those at Cut Hill. Other pebbles, such as some from the Albany conglomerate and the Parnell Grit at Whangaparaoa, include *Globigerina*-bearing marl which resembles closely the Onerahi hydraulic limestone.*

2. The rocks of the Onerahi Series universally shew intense shattering in contrast with the unshattered massive beds of the Waitemata Series. That this shattering is the result of pressure, and not merely of shrinkage during drying of the beds, is clearly shewn by the presence of similar fractures in a band of siliceous nodules included in the limestone at Mappin's quarry, Silverdale.

3. When their stratification is discernible, the Onerahi beds always dip at steep angles, in marked contrast with the normal gently-undulating or sensibly-horizontal disposition of the Waitemata strata.

4. In some localities horizontal Waitemata beds rest on the Onerahi rocks at heights above sea-level which vary widely at points relatively close one to another. This may be explained by faulting in any specific case, but such occurrences are so frequent over a wide area, which includes not only the present district but most of North Auckland, that the best explanation is afforded by the assumption that a highly irregular erosion-surface separates the two series.

5. It has already been shewn that ultrabasic rocks invaded the Onerahi strata prior to the deposition of the Waitemata Series. Benson (1923, p. 53) remarks on this, and suggests that they are coëval with serpentines which were injected into the rocks of New Caledonia during an important Early Tertiary orogeny, for New Zealand and New Caledonia shew considerable structural similarity and lie on the same great fold-arc.

There is in addition strong presumptive evidence that long-continued erosion superseded the orogeny, for, as has been shewn, at Lloyd Hill serpentine, intrusive into the Onerahi beds, appears to have been denuded of its cover prior to the Waitemata transgression.

6. In areas south-east of Auckland, and in others north and east of the district described in this paper, the Waitemata strata rest on

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*Similar evidence has been adduced from neighbouring districts by Cox (1881), Henderson (1914), Bartrum (1924, pp. 143-144), and others.

a basement of the Hokonui (Trias-Jura) greywackes, though, in numbers of other localities, often not far distant from the first, they lie on Onerahi strata. It is true that the absence of these latter beds near Auckland and south of that city may be explained by differential subsidence of the area of deposition in Onerahi times, subsidence beginning earlier in the north than in the south, but further north such an explanation cannot hold, for the changes of the basement series are too rapid. Further, in conjunction with these changes the undoubtedly great, though unknown, thickness of the Onerahi beds and their wide extent are greatly against an explanation of the facts on the basis of overlap of the Waitemata beds upon lower strata as the uppermost members of a conformable sequence, and the hypothesis of unconformity remains as the more satisfactory alternative.

After due consideration of the evidence adduced, the writers are inclined strongly to the belief that Onerahi sedimentation was terminated by uplift associated with acute stress which had as accompaniment the injection of basic and ultrabasic intrusions. Erosion intervened for a sufficient time to permit the removal of the soft Onerahi cover from areas that were relatively uplifted by folding or warping, and underlying Hokonui rocks were bared, to sink in their turn beneath the transgressing Waitemata seas.

*Origin of the Waitemata Series.*—The gritty nature of many of the sandstones, the frequent development of bands of beach-conglomerate, often of great thickness, the presence of thin lenses of interformational conglomerate, and the abundant fragments and even whole tree-trunks of carbonized coniferous wood which occur in many of the mudstones, render it evident that the rocks of the Waitemata Series originated as delta-deposits laid down rapidly in a shallow sea. Ripple-marks are very constant, and help to indicate the shallowness of the water. From the rarity of marine fossils it appears that the rivers brought in such floods of waste that the waters near shore were unfavourable for molluscan and other similar life. The area of deposition was relatively extensive, for in spite of long-continued denudation subsequent to uplift, the Waitemata sediments to-day are present over an area approximately twenty miles wide, which extends from forty or fifty miles north of Auckland to a considerable distance south of that city, and in some localities are as much as 1200 ft. thick.

The exact location of the Tertiary land-mass from which this sediment was unloaded is difficult to fix, but the coarse-grained nature of the sandstones and wide development of conglomerates north-west of the district here described, suggest that the bulk of the material came from that direction. In the vicinity of Wainui Hill east of Kaukapakapa, in particular, fragments in the Albany conglomerate attain truly remarkable size, many exceeding 7 ft. in diameter. The larger of them are mainly andesite, but occasional dioritic masses at least 4 ft. in average diameter can also be found, whilst smaller boulders include greywackes and other sediments as well as varied igneous rocks. This indicates clearly that a greywacke terrain, varied locally by protruding dioritic batholiths, younger sediments, and andesitic and other eruptives was close at hand, drained by rapid streams which built up deposits upon the sinking sea-bottom which include a lensoid mass of coarse gravels over 600 ft. in maximum depth.

There is very clear evidence that the material does not come from an eastern land in the nature of the basal beds of the series on its eastern margin. These include beach-conglomerates lying hard upon the Mesozoic greywackes from which they have been worn, above which are plant-bearing quartz-sandstones and fireclays with which bands of coal are associated at Hunua, Drury, and Bombay. Above this there are marine beds sometimes in the form of foraminiferal shales, but more often as sandstones. At Maraetai, the Papakura-Clevedon area and Kawau Island—this last far separated from the other more southerly localities—there are more or less impure flaggy limestones, built of broken bryozoan, algal, and echinodermal remains, with foraminifers and occasional brachiopods and molluscs, which closely follow the basal conglomerate. Shorewards they grade into calcareous sandstones and evidently represent deposits formed in relatively clear water at some distance from the growing Waitemata delta. Later, however, the advance of this latter inaugurated the ubiquitous succession of sandstones, with intervening narrow layers of mudstones, which cover the limestones.

The phase of sedimentation which has been outlined was punctuated by an outburst of volcanic activity during which, it is believed, andesitic cones rose above the seas of Waitemata times in the region now occupied by the western part of Hauraki Gulf, and gave rise to the tuffs and breccias of the Parnell Grit. These cones were soon removed by erosion, and deposition proceeded as before.

Before Pliocene times the general transgression became reversed at the initiation of the Kaikoura movement of uplift, and the sedimentation soon ceased, to be followed shortly by the emergence of wide areas of Waitemata beds along the fractured flanks of the great anticline of North Auckland. Long-continued erosion upon the compressed and fractured blocks has subsequently developed the major features of the present topography.

## POST-TERTIARY DEPOSITS.

Post-Tertiary deposits include volcanic and alluvial and other sedimentary beds which have accumulated in restricted parts of the area, especially in the south, during Pleistocene to sub-Recent times.

The volcanic rocks include basaltic flows and sheets of tuff and lapilli found in the south-eastern part of the district, where three broad, picturesque, shallow tuff craters are grouped near the head of Shoal Bay, an arm of Waitemata Harbour. The flows are restricted to the margins of Lake Pupuke, which occupies the caldera from which they were poured out, and are prominently exposed along the shore between Takapuna and Milford Beaches (Fig. 18) overlaid by beds of fine-textured material which form a continuous sheet encircling the lake as a low-angle cone. A beautiful section of the tuff and unconsolidated lapilli of this sheet is afforded by quarries on the west margin of the lake (Fig. 16), where they are not less than 50 ft. in thickness and shew especially regular bedding in their upper portions. The remaining two caldera are on the western shores of Shoal Bay, and are breached to admit the sea at high-water to their extensive mud-filled sub-circular basins (Fig. 15). The material of the encircling cones is relatively consolidated and coarser than at

Takapuna, for it includes many large angular fragments of Waitemata sandstone and of basalt, in addition to the finer débris of these rocks.

The period of activity of the Takapuna and Shoal Bay volcanoes may be taken to be approximately that of those of Auckland Isthmus, where the perfect preservation of the cones and craters, the freshness of many of the flows which still show plainly such surface characters as ropy structure, and the manner in which many of the flows have occupied valleys of a very late erosion cycle, all testify to the comparatively recent date of these eruptions. This may best be referred to the later Pleistocene or to sub-Recent times.

Post-Tertiary sediments have only minor importance in the Takapuna-Silverdale area, and for the most part take the form of veneers of flood-plain gravels covering limited river terraces. In the Shoal Bay-Takapuna district, however, there are pre-volcanic estuarine silts of Pleistocene age. Discussion of their origin opens up questions of considerable physiographic interest, so that they will be considered in greater detail in a later Section.

## DRAINAGE AND PHYSIOGRAPHIC DEVELOPMENT.

### PRESENT PHYSIOGRAPHY.

Inspection of the map shows drainage which is generally insequent, although, as noted, the valleys of Okura Stream and of the eastern tributaries of Rangitopuni Stream, Lucas Creek, and several other streams, appear to shew structural control in their N.E.-S.W. alignment. Another though different suggestion of such control is afforded immediately south of Albany by two cuesta-like divides each of which has a long gentle slope northward, and a steep scarp approximately 150 ft. in height facing the south. The strike of the rocks from which the divides are carved is transverse to the trend of the latter, and in addition their resistance to erosion does not appear to be superior to that of other rocks of the vicinity, so that it appears probable that the steep faces represent fault-scarps, especially as the north-east trend of the northern one and the south-east direction of the southern accord with the directions of the two dominant fault-systems of Auckland Province (see Bartrum and Turner, 1928, p. 136).

In the present area relief and topographic detail frequently have the usual sympathetic relation to the underlying rocks. The Onerahi rocks generally develop forms which contrast in their subdued nature with the stronger relief of areas of Waitemata beds, especially when the latter comprise the more resistant massive sandstones. In the Silverdale-Dairy Flat district, therefore, where Onerahi beds have their main distribution, the valleys generally are widely flaring and have broad low terraces margining the streams. Where siliceous phases of Onerahi strata outcrop, however, their topographic recognition is impossible. The intrusive serpentines usually fail to cause any noticeable disturbance of the simple contours of the Onerahi beds they invade, although they are sufficiently resistant to protrude in inconspicuous outcrops.

Towards Takapuna, there is rapid descent from high-level maturely-dissected uplands to small bay-head plains along the east