place and water was got at the same depth, and this has continued to supply houses in the neighbourhood successfully.

The new bore is 11 ft. off the old bore, and does not seem to affect it. This bore is about 1 chain off the river-bank on the right bank of the river.

Before, this a trial bore, 14 chains down the river and 4 chains off the bank, was put down by Mr. Walker to 610 ft., but no successful water-supply was got, and no solid papa stratum was reported there.

The following notes were given to me by Mr. Walker:—

From surface to 60 ft., sand and pumice.
60 ft. to 66 ft., sand.
66 ft. to 105 ft., clay.
105 ft. to 117 ft., sand (wood at 110 ft.).
117 ft. to 127 ft., shingle.
127 ft. to 130 ft., sand.
130 ft. to 138 ft., shingle.
138 ft. to 144 ft., coarse grit.
144 ft. to 183 ft., sand.
183 ft. to 183½ ft., hard seam (taking five hours to bore).
183½ ft. to 185 ft., fine sand.
185 ft. to 239 ft., papa.
239 ft. to 260 ft., sand.
260 ft. to 540 ft., papa.

At 540 ft. water came up strongly, after boring through a hard seam. The water was got in sand intermixed with fine pumice, into which the rods were put down to 553 ft. The bore is piped with 313¼ ft. of 4 in. pipe, the top of last length being 15 in. below the surface (the rest of the bore has no pipe). A strong volume of water was got, with a good pressure.

Art. XLV.—*The Volcanic Beds of the Waitemata Series.*

By C. E. Fox.

[*Read before the Auckland Institute, 24th February, 1902.*]

Plates XXXVIII.-XL.

1. Introduction.

The Waitemata series is a group of strata developed round the shores of the Waitemata Harbour, from which it derives its name. The upper limit of the series is well defined, since a complete unconformability exists between its shales and sandstones and the overlying tuffs and lava-streams, which are of Pliocene or later age. The lower limit is not so certain. In this paper it is taken to be the Papakura limestone, which crops out along the Palæozoic ranges to the east of the Waitemata Harbour, lying unconformably on the upturned and denuded edges of ancient slates and phyllites. This limestone is considered by Captain Hutton to be Oligocene in age, while the beds in the vicinity of Auckland are classed as Lower Miocene. If this classification be accepted the volcanic beds with which this paper deals are Lower Miocene, some of them Oligocene perhaps.

Above the limestone lies a thick group of greensands. These are succeeded by sandstones and shales, evidently deposited in somewhat shallow water, for ripple-marks and current bedding may frequently be observed in them. There is some doubt as to whether an unconformability exists between the greensands and the overlying beds, Captain Hutton and Mr. S. H. Cox, F.G.S., both holding that there is one,* while Mr. James Park, F.G.S., believes the evidence to point to a regular succession.† At least the unconformability cannot be very great if we judge by fossil evidence.

About the time when the limestone was being formed to the east of the Waitemata there rose through the Oligocene sea to the westward a long line of volcanic vents, now denuded and overgrown with dense forest, and known as the Waitakerei Range. There is no means of ascertaining its exact extent or the nature and position of the vents. These Waitakerei outbursts gave rise to a thick bed of coarse volcanic fragments. As the bed occurs typically at Cheltenham, it may be called the Cheltenham breccia. This is the oldest of the volcanic beds of the series.

Twenty or thirty miles to the eastward another line of vents became active at nearly the same time, on Coromandel Peninsula. The Coromandel eruptions, however, would seem to have commenced rather earlier than those at the Waitakerei, and to have continued for some time after the western vents had become quiescent. The *débris* from the Coromandel volcanoes was spread over the floor of the sea, and possibly it was these eruptions which supplied the material for the Parnell grit, the youngest volcanic bed of the series.

Between these two main beds, the Cheltenham breccia and the Parnell grit, there are other but less important beds of volcanic origin which seem to have been all derived from the Waitakerei outbursts. Each of these seems to be less coarse

* Trans. N.Z. Inst., 1884.
† Trans. N.Z. Inst., 1889.

than the preceding one; and they mark, I believe, the gradual dying-out of volcanic activity along the Waitakerei Range.

The general evidence for the age of the beds is of a threefold character. In the first place, there are the fossils contained in the beds themselves—the palæontological evidence. This alone would show that the Cheltenham breccia cannot be Pliocene, as the Geological Survey contends. In the second place, there is the composition of the contained lava. In New Zealand, as in other places, there seems to be frequently a regular succession. The earlier eruptions are sometimes basic. These, however, are succeeded by acid lavas, and these again by more basic, the lava of a "petrographical province" growing more and more basic till the cycle is completed. The lavas of Pliocene age in Auckland are olivine basalts. The lavas of the volcanic beds of the Waitemata series are pyroxene-andesites; and, since the Eocene lavas are generally rhyolites, the evidence seems at least favourable to a Miocene or Oligocene age for the Waitemata lavas. The exceptions to this rule make it impossible, however, to rely on the lithological evidence alone—or, indeed, to lay much stress upon it. The last line of evidence is the position of the beds—the stratigraphical evidence. At Orakei Bay there is a very fossiliferous greensand of whose Miocene age there can be little doubt. It will be shown that the volcanic beds are all below the greensand, with the exception of the Parnell grit, which is above it.

Generally the beds of the Waitemata series are either horizontal or dipping in long gentle anticlines and synclines; but in places they are distorted and dislocated, and may even be thrust over each other. It has been generally supposed that these strains and the numerous faults are due to the volcanic forces which produced the basalt puys, scattered in scores round the Waitemata. Sometimes, perhaps generally, the distortions occur in proximity to a puy. At other times no such apparent connection is visible, and the strata may be disturbed far from any basalt cone, or may lie horizontally quite close to one. It may be that the small puys are no true measure of the magnitude of the volcanic forces that formed them, and that, as in Scotland, when denudation lays bare the underlying rocks great sills will be found whose contents never reached the surface.*

In working out the stratigraphy of the Waitemata series the volcanic beds are invaluable. They are widespread, and their lithological characteristics are much more distinct than those of the sandstones and shales. Moreover, some of the

* Sir A. Geikie: "Ancient Volcanoes of Great Britain," vol. i., p. 458.

tuffs are comparatively rich in fossils, whereas the sandstones and shales are generally lacking in organic remains.

2. Previous Observers.

Hochstetter was the first to describe the Waitemata series, in a lecture delivered to the Auckland Institute in 1859: "The horizontal beds of sandstone and marl which form the cliffs of the Waitemata and extend in a northerly direction to Kawau belong to a newer Tertiary formation, and, instead of coal, contain only layers of lignite. A characteristic feature of this Auckland Tertiary formation is the existence of beds of volcanic ashes, which are here and there interstratified with the ordinary Tertiary layers."*

Captain Hutton showed in 1870 that the beds could be followed in an easterly direction to the Hunua and Wairoa Ranges, composed of Palæozoic slates. He thought that the estuarine sandstones forming the upper part of the series were separated by an unconformability from the greensands and limestone to the east †

Mr. S. H. Cox, of the Geological Survey, traced the beds to the north some ten years later. At Komiti Peninsula he found Lower Miocene fossils associated with the forms found in the Orakei Bay greensand. He therefore concluded that the Waitemata series was Lower Miocene.‡

Sir James Hector, Director of the Geological Survey, thought that the series should be divided at the Parnell grit; the beds below this he classed as Cretaceo-tertiary, those above it as Lower Miocene. This seems to have been the first occasion when the importance of the Parnell grit as a stratigraphical guide was realised.‡

Mr. McKay, of the Geological Survey, examined the district in 1883. He agreed with Sir James Hector in the division of the series; considered the "Fort Britomart" shales the equivalent of the Orakei Bay greensand, and showed the Parnell grit lying unconformably on the former; and identified the Cheltenham breccia with the Parnell grit on stratigraphical grounds.§

Captain Hutton, in 1884, showed that there was no evidence of an unconformability between the Orakei Bay greensand and the Parnell grit; that there was no evidence that the latter was younger than the former; and that the Orakei Bay bed was of Miocene age.‖

Mr. James Park, of the Geological Survey, made an

* "Reise der 'Novara': Geology," i., p. 34.
† Trans. N.Z. Inst., vol xvii, p. 307.
‡ Geological Reports, 1879–80.
§ Geological Reports, 1883–84.
‖ Trans. N.Z. Inst.

examination of the district in 1885. He collected a great deal of new evidence as to the stratigraphical position of the Parnell grit, which he was inclined to think inferior to the Orakei greensand; identified the Parnell grit with the Cheltenham breccia on palæontological grounds; traced the whole series eastward to the Papakura limestone; and concluded that the Waitemata series was unconformable to the Cretaceo-tertiary beds. His final classification was as follows:—

Upper Miocene.

1. "Fort Britomart" shales.
2. Parnell grit and Waitakerei breccias.

Lower Miocene.

3. Turanga greensands.
   Orakei Bay greensand.
4. Papakura limestone.
   Cape Rodney grits.*

Sir James Hector still thought the series should be divided at the Parnell grit. He dissented from Mr. Park's view that the Cheltenham breccia was the northerly extension of the Parnell grit, considering the Cheltenham breccia and the other volcanic beds to the north of the harbour of Pliocene age, and quite unconformable to the Waitemata series.†

Mr. Park, in 1889, upheld his views as given above.‡

Since 1889 nothing of importance has been published on the volcanic beds of the Waitemata series. The view adopted in the present paper has been already indicated in the introduction.

3. The Volcanic Beds of the Series.

As the volcanic beds at Cheltenham and Parnell are the thickest, most fossiliferous, characteristic, and widely spread beds of the series, and their stratigraphical position and age have been a subject of much dispute, most of the paper will be devoted to a consideration of them. The evidence tends to show that they are distinct beds, though Mr. McKay and Mr. Park consider them identical, and Mr. Park writes that he has "conclusively proved" their identity. Sir James Hector considers the Cheltenham breccia to be Pliocene, so that it will be necessary to give in some detail reasons for supposing it to be Lower Miocene, or even Oligocene. With regard to its source, I will give evidence tending to show that it probably came from the Waitakerei vents. The chief point

* Geological Reports, 1885.
† Geological Reports, 1885–86.
‡ Trans. N.Z. Inst., 1889.

of interest with regard to the Parnell grit is whether it is above or below the Orakei Bay greensand, because the latter is a fossiliferous bed which is allowed to be Miocene. Mr. Park felt inclined to place it below, although admitting the evidence inconclusive, and he has since classed it as Eocene.* But a large amount of new stratigraphical evidence will be given which leads me to think that it is really above the Orakei greensand, and therefore Miocene. Its source is an open question; it may have come from the Waitakerei, but there is evidence in favour of its having come from the Coromandel vents. There are at least two other volcanic beds. One of these really consists of a group of tuffs separated by thin layers of shale. They are well developed at Wairau Creek, and so I have called them the "Wairau tuffs." The other bed is a feldspathic tuff, developed best at Ponsonby, and called throughout the "Ponsonby tuff." These can be dealt with more shortly.

I consider that the thick volcanic breccias on the west of the Waitakerei Range should really be included in the Waitemata series, but I have not been able to examine them sufficiently to include a discussion of them in this paper.

4. Are the Cheltenham Breccia and the Parnell Grit distinct Beds?

The study of the volcanic outcrops at these places has led me to the conclusion that these beds are distinct. The evidence is considerable, consisting of a number of facts which are cumulative. Before giving them it will be advisable to give the evidence in favour of the identity of the beds.

Mr. Park, in 1885, came to the conclusion that the outcrop at Cheltenham, on the north side of the harbour, was simply a northerly extension of the outcrop at Parnell, on the south side. Sir James Hector dissented from this, and wrote: "The Parnell grit, which has been much relied on in discussions concerning the Waitemata formation, has in many cases been confounded with the volcanic grits and conglomerates in other parts of the district"†—*i.e.*, with the Cheltenham breccia. Mr. McKay, too, who had been the first to suppose the beds identical, wrote: "As a consequence of my admission that the Parnell grit does or should pass under the Fort Britomart and Calliope Dock beds, and of the observed fact that the breccias north of Cheltenham Beach overlie them, I am forced to agree with Sir James Hector that the Parnell grit and Cheltenham breccia do not

* "Thames Goldfields": Park and Rutley, 1897.
† Geological Reports, 1885–86.

occupy the same horizon, and that the Parnell grit is the older."*

This led Mr. Park to defend his views.† To Mr. McKay he replied that the Cheltenham breccia might quite possibly underlie the Calliope Dock beds, because a basalt cone of more recent date lay between the two and obscured their stratigraphical relations. This was, so to speak, negative evidence; but he added that at Parnell, in the lower 2 ft. of the grit, he was fortunate enough to find some fossils (a *Pecten*, a *Cerithium*, a *Teredo*. and several small corals), and he wrote: "The *Cerithium*, *Pecten*, and corals are the same as those found in the breccia at Cheltenham, thus proving conclusively that the Parnell grit is the southern extension of that stratum, deposited at the same time and under the same geological conditions." Mr. Park made good use of his fossils. As he does not give even the generic names of the corals they need not be considered. Surely it is possible for two beds of nearly the same age to have *Pecten polymorphoides* and an unknown *Cerithium* associated together, especially as *Pecten polymorphoides* has a wide vertical range and is a common Miocene fossil.

As far as I know this is all the evidence in favour of the beds being identical. Since, however, the beds are both volcanic breccias and similar, and there is a stretch of water two miles in width between the two, it is reasonable to suppose them identical unless there is good reason for thinking them distinct. The evidence for the latter view is as follows:—

(1.) The beds are not entirely similar in lithological characters. In the case of the Cheltenham breccia the bed consists almost entirely of volcanic fragments, some of them (though this is rare) 8 in. in diameter. In the Parnell grit most of the fragments are greensand, slate, &c., while only in the lower layers do we find volcanic fragments of any size, and these are rounded, well-worn scoria, generally oxidized, and never more than 1 in. in diameter. There are other minor differences, but the difference in texture is the point which I wish to emphasize: in the one bed numerous lumps the size of an orange, hard, black, and angular; in the other, red, rounded, scoria fragments not larger than marbles. This difference is brought prominently before one when trying to obtain a suitable fragment at Parnell from which to make a microscopic section. It must be remembered that the Parnell outcrop is not more than two miles and a half from the Cheltenham outcrop. It is in that distance that the texture

* Geological Reports, 1888–89.
† Trans. N.Z. Inst., 1889.

alters so remarkably. This line of argument is immensely strengthened by some outcrops hitherto unrecorded. The most interesting of these are some reefs in the harbour which are uncovered at lowtide and may then be examined. I cannot do better than represent these various outcrops diagramatically. The positions are shown by an X and Y respectively, the Y standing for the bed with coarse texture and the X for the bed with fine :—

Birkenhead. X — Cheltenham. Y

← to the Waitakerei.

X Shelly Beach. — X 1st reef.

X Judge's Bay. — Y 2nd reef.

↑ — X St. John's College.

Now, it can be shown that very probably the coarse bed is derived from the Waitakerei vents, and it is difficult to see how such a distribution as that shown above could be effected. How is it that none of the large blocks reached the spots marked with an X, while great numbers reached those marked with a Y? Supposing this due to currents, those currents must have been somewhat peculiar ones. But this argument from variation of texture does not stand alone ; it is supported by much stronger ones.

(2.) The fossil contents of the beds are different. I have examined more than half a dozen outcrops of the coarse bed at widely separated localities, and more than a dozen outcrops of the finer bed at spots equally far apart. In every one of the former fossils are plentiful, especially *Bryozoa* and *Pectens*, the total number of fossils in the coarse outcrops amounting to more than forty species. In more than twice as many outcrops of the latter I found scarcely any fossils, a species of *Bryozoa* (*Fasciculipora ramosa*) being the only usual one. Moreover, the fossils of the coarse bed* show a blending of Miocene and Oligocene forms just as we find in the Papakura limestone, while the fine bed can be shown on independent evidence to be decidedly Miocene.

(3.) The stratigraphy gives direct evidence in favour of the beds being distinct. I cannot mention all the minor facts which receive an explanation on this hypothesis and become difficulties on any other. I shall merely mention the two clearest indications that the beds are distinct.

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* List on page 468.

(*a*.) At Lake Takapuna (Wairau Creek), about 30 ft. above the outcrop there of the coarse bed, are the black-banded Wairau tuffs. At St. John's College black-banded tuffs, apparently the same, occur some 70 ft. below the fine bed. Neither section is completely exposed, but I could see no sign of a break.

(*b*.) At the Manukau Harbour, where the occurrence of these beds does not seem to have been hitherto observed, two outcrops occur, a quarter of a mile apart. One is a coarse bed with fossils, ten species of the *Bryozoa* being also found at Cheltenham, as well as *Pecten burnetti* and *Rhynchonella nigricans*. The other is a fine-grained bed, in every way resembling the bed at Parnell, except that its fragments are slightly smaller and its thickness rather less. The coarse-grained bed has larger fragments than at Cheltenham, which is natural enough if the Waitakerei vents were the source; so that the difference in texture between the two beds is accentuated (Plate XXXVIII., fig. 1).

The section cannot be seen in a direct line since two small bays occur at x and y; but there is no break possible except at one point, the head of the inlet at y, where there has been a fall of *débris*, so that no section can be seen. This slip may mark a line of fault, but as the beds have the same dip on both sides of it and are similar, and there is no sign of distortion of the strata, there seems no reason to suppose one. The coarse bed is here about 30 ft. thick, the other perhaps 12 ft.

I wrote that the evidence was cumulative—*i.e.*, the stratigraphy and the palæontology both point to two beds. In fact, it seems to me improbable that so many fossils should be preserved invariably in the coarse bed and never in the fine; that the texture should vary so rapidly; and that the stratigraphical relations given above, sometimes fairly clear, sometimes obscure, but always indicated, should be always misleading.

Accepting, then, the conclusion that the beds are two distinct formations of different date, it will be well to consider them separately; and, first, the Cheltenham breccia, because it is the older.

5. The Cheltenham Breccia.

The Cheltenham breccia presents usually a bedded appearance, due to the arrangement of fragments of approximately the same size in roughly parallel bands. The coarsest band is usually about a third of the way from the bottom, and the angular fragments scattered through this band are as large as apples. These fragments are imbedded in a matrix of smaller *débris*, which forms the rest of the bed. Next to this main band the lowest layers are the coarsest, those above shading off very gradually into a tufaceous sandstone. From these facts it seems probable that the main outburst took place some little while after the vents had become active, and was succeeded by outbursts less and less powerful. The thickness of the bed varies, of course, with its distance from the source: the thickness seems to average about 25 ft. at ten or twelve miles from the Waitakerei Range When we consider the thickness (3 ft.) of the ash which the violent outburst of Tarawera produced in 1886,* we cannot but be impressed with the magnitude of the eruptions necessary to lay down this coarse and thick breccia. The fossils contained in the bed are generally found either at the top or bottom.

The bed weathers to a black or brown colour when exposed to the air, but in the finer parts is bluish-grey on a fresh fracture. The surface is very irregular, owing to the fact that the lava fragments weather out of the matrix. Near vegetation—along the top of a cliff, for instance—all the colour is generally leached out, the result being a creamy loam; or, if there has been much oxidation, a bright-red stratum forms a band along the summit of the cliff. Zeolite veins running through and through the bed are not uncommon. These veins are not more than $\frac{1}{10}$ in. in width, but extend for yards, and when the rock is weathered they sometimes stand out on the face of the cliff like a network of miniature dykes.

The material of which the bed is composed consists almost entirely of rounded fragments of lava set in a matrix of finer volcanic *débris*. Sometimes the fragments are rough and angular. Occasionally blocks of sandstone or shale are included, and these are sometimes several feet in diameter. Some small fragments of porcellanite also occur.

Besides these constituents there are very numerous crystals of feldspar and augite, sometimes broken, but often retaining very perfect crystalline shape. These, no doubt, were separated from the lava in which they were contained at the time of the explosions. The feldspars are bright glassy forms in little oblong crystals, showing good cleavage. The augite crystals are of two sizes. The smaller and less perfectly formed resemble those in the lava; but occasionally much larger forms may be found up to 1 in. in length, distinguished from the former both by their larger size and more perfect crystalline form. Large crystals, and especially large augite crystals, appear to be frequently observed in tuffs deposited at no great distance from a vent. Their origin is obscure, and

* "Eruption of Tarawera," Professor A. P. W. Thomas.

Sir A. Geikie remarks*: "The conditions under which such well-shaped idiomorphic crystals were formed were probably different from those that governed the cooling and consolidation of ordinary lavas." These crystals, however, were found at a greater distance from the vents than is usual, since they must be at least ten miles in a direct line from the Waitakerei Range.

The typical lava of the Cheltenham breccia is an andesite, usually an augite-andesite, but hypersthene-andesite is also present, as is the case at the Coromandel, a parallel line of activity of much the same age. There is occasionally a tendency to ophitic structure, but it is never pronounced, and the ground-mass is typically hyalopilitic. The specific gravity varies from 2·5 to 2·8, but in the majority of cases does not exceed 2·7. This is the more remarkable since a few of the rocks are basalts (but without olivine). This somewhat low specific gravity may be accounted for, however, by several considerations. In the first place, there is frequently a fair amount of dark-brown glass in the ground-mass. Teall gives the specific gravity of andesites as ranging from 2·54 in a glassy to 2·79 in a crystalline state.† In the second place, some of the specimens are highly amygdaloidal, the amygdules forming a large percentage of the rock. They generally consist of chabasite, which has a specific gravity ranging from 2·06 to 2 17, so that the specific gravity of the whole rock fragment would be much lowered. On the whole, then, they may be taken as typical andesites, while a small percentage are basalts without olivine. Except in one doubtful case I have seen no olivine; but a highly basic serpentine, containing 0·47 per cent. of nickel, has been described as occurring at Manukau North Head, so that olivine-basalts may yet be found in the lavas if not in the ejected fragments.

Besides the more basic fragments there are others presenting the appearance of true trachytes, pale-grey in colour, with a specific gravity of 2·54. Occasionally fragments of acid pumice are also present. It is possible that this did not come from the Waitakerei vents. At the Tamaki Gulf, a few miles from Auckland, there are pumice beds, which I consider to be of Pliocene age. They lie unconformably on the Waitemata series, and are due, I believe, to the fact that the Waikato River then flowed into the Auckland sea.‡ Before this, however, it flowed into the sea near Tauranga, in the Bay of Plenty, and it cannot be supposed that it was flowing into the Auckland sea so long ago as Miocene times. Except

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* "Ancient Volcanoes of Great Britain," vol. i., p. 62.

† "British Petrography."

‡ Trans. N.Z. Inst.

the Waikato, I see no source from which pumice is likely to have been derived by transport, and it does not occur in the beds below or above the breccia. If the pumice is really part of the ejected matter, we have a large range of lava from basalts to rhyolites, indicating probably a long period of volcanic activity. In the present state of our knowledge, or lack of knowledge, of the Waitakerei lavas it is scarcely safe to generalise, but it is interesting to note that no rhyolites have yet been found *in situ* at the range, though andesites are abundant and andesitic basalts still more common. It is possible that the acid lavas rose in the vents but never flowed out as lava. Dykes and necks are frequently more acid than the lava-flows, and this seems here to be the case.*

I have drawn some sections of the lava as seen under the microscope, but the drawings are merely diagrammatic (Plates XXXIX. and XL.). The shaded portion represents the ground-mass (which is usually opaque, but sometimes consists of a brown glass). Owing to this fact the phenocrysts appear in the diagrams to stand out from the ground-mass more than they do in the rock. The shading, moreover, is not quite true to nature, especially in fig. 1, where the difference in shade between the two generations of augite is accentuated. The mosaic of granules in fig. 2 is only seen, of course, under polarised light.

Fig. 1: St. Heher's Bay.—The ground-mass consists largely of brown glass partly devitrified, and containing numerous laths of feldspar and magnetite. The phenocrysts are chiefly augite, in two generations. The smaller crystals present irregular rounded outlines, and are yellowish-brown in colour; the larger crystals present more regular six-sided outlines, are dark-green, and contain inclusions, especially of magnetite. The phenocrysts of feldspar frequently consist of an outer shell, enclosing brown glass. Others show perfect zonal structure. Striping is absent. There are a few amygdules.

Fig. 2: Deep Creek.—This is a highly amygdaloidal rock, the secondary mineral, which in this case is chalcedony, not only filling the vesicles but also replacing the phenocrysts, none of which appear under the microscope. With polarised light the pale amygdules break up into a mosaic of granules, greys and yellows of the first order being the colours. Each amygdule is bordered by a row of minute granules very regularly arranged, the centre consisting of granules of a larger size. Sometimes streams of small granules connect separate amygdules. Feldspar laths are not numerous in the opaque

* Sir A. Geikie: "Ancient Volcanoes of Great Britain," vol. i., pp. 61, 62.

ground-mass. A large fibrous mass of yellowish-brown pleochroic bastite appears in the centre of the section. It gives straight extinction along the planes of schillerisation. Under a high power it is seen to be a very pale-yellow mass, with deep-brown prisms arranged in parallel lines, and giving the fibrous appearance. Sometimes little prisms are arranged crosswise, giving a scalariform appearance.

Fig. 3: Cheltenham.—This is a hypersthene-andesite. The ground-mass is hyalopilitic, but the feldspar laths are not very numerous. Grains of magnetite are thickly distributed. The phenocrysts consist chiefly of large striped feldspars, whose extinction angle shows them to be labradorite. Augite also occurs, associated with a rhombic pyroxene, which is probably hypersthene. The colour is paler, however, than in the drawing.

Fig. 4: Onehunga.—This is a very amygdaloidal rock. In the hand specimen it is black, spotted with white amygdules of chabasite, which show under the microscope beautiful fibrous forms. The ground-mass is augitic, with feldspar laths and a little magnetite. The phenocrysts are numerous, especially large striped crystals of labradorite or andesine. Augite is the usual pyroxene, forming very large green six-sided prisms; but pleochroic brownish crystals of hypersthene are also present.

Fig. 5: Wairau Creek.—The ground-mass is typically hyalopilitic, with numerous elongated laths of feldspar, showing flow-structure. Augite is also present in the ground-mass in abundant pale-yellowish grains. Magnetite grains are numerous. The rest of the ground-mass consists of a deep-brown glass, perfectly isotropic.

The phenocrysts consist of plagioclase, but, though binary twinning is common, multiple twinning is very rare, and some of the feldspars are untwinned. Zonal structure is very general. Augite phenocrysts are not very numerous, occurring as pale-green six-sided prisms. The augite and the feldspar contain numerous inclusions of glass and magnetite grains. Magnetite also occurs as large three-sided crystals.

The rock closely resembles an "andesitic basalt," from the Waitakerei Range, which is in the collection of the University College laboratory, the only difference being that multiple twinning is more common in that rock. It also somewhat resembles an "andesitic basalt" from Eskdalemuir, described by Sir A. Geikie.*

Sir James Hector has always distinguished between the Parnell grit and the Cheltenham breccia, but he placed the latter above the former on the strength of a supposed uncon-

* Proc. Roy. Phy. Soc. Edin., vol. v., 1880.

formability.* He wrote: "Great potholes, similar to that now occupied by the North Shore Lake [Lake Takapuna], were formed, and these were filled by Pliocene beds composed chiefly of volcanic agglomerates"*—*i.e.*, by the different outcrops of the Cheltenham breccia, each outcrop marking, I suppose, the site of a former lake. Sir James Hector also gave a section at the Wairaù Creek to show that the breccia lay unconformably on the Waitemata sandstones. I have repeatedly examined this spot and can find no section closely resembling the one given, so that I think some other locality was probably intended. The breccia does, indeed, occur at the Wairau Creek, but it appears unconformable to the sandstones from which the fine specimen of *Pentacrinus* now in the Auckland Museum was obtained. This appearance of unconformability is, I believe, deceptive, partly due to the effects of current-bedding at the base of the breccia, partly to a series of small faults which obscure the section, and partly to distortion of beds of unequal hardness, which is the reason given by Mr. Park. Mr. Lamplugh has shown how a "crush breccia" may be formed where the strata shade off into one another. Here, however, we have beds of quite distinct hardness, and in that case an appearance of unconformability is generally the result of crushing.

In reply to Sir James Hector Mr. Park wrote: "It should, however, be pointed out that wherever the strata occupy a horizontal or undulating position the breccia is seen to be interbedded with and quite conformable to the adjacent beds, and at its base is frequently more or less false bedded with the underlying clays and sandstones. On the other hand, at points of severe local disturbance where the breccia is present the softer and more yielding clays and soft sandstones have in many instances been crushed and contorted and often turned over the more compact, heavy, and unyielding ash-bed, thus giving rise to apparent unconformity."

Mr. Park's section shows how an inverted-trough fault may produce an appearance of unconformability in beds of markedly unequal hardness. On the weathered face of the cliff the faults and fault breccia are by no means as prominent as they are in his drawing. C is the bed from which *Pentacrinus* was obtained. In a spot where the underlying sandstones were exposed an inverted-trough fault might still more easily cause a deceptive outline.

It is also quite true, as Mr. Park observes, that the unconformable appearance generally coincides with an area of distortion; but this is not universally the case, as at the Manukau Harbour.

* Geological Reports, 1885, p. xxxviii., woodcut.

I believe that the real reason for this deceptive appearance is to be found in current-bedding. The ancient sea which washed the flanks of the Waitakerei hills was probably studded with islands, of which few now remain. The proximity to the surface, however, of the Palæozoic quartzites and silky slates, some of which the Cheltenham breccia did not cover, is evidence of their former existence. This may have produced violent and conflicting currents which deposited the breccia on the earlier sands and mud-flats in a somewhat irregular way. The Waitakerei hills were not very far distant, and the isthmus of Auckland was then a narrow strait.

The argument for a Pliocene age rests entirely on the supposed unconformability. The argument for a Miocene age rests on overwhelming fossil evidence and also on stratigraphy. The unconformability might not, in any case, be serious, and the appearance may be otherwise explained; but Oligocene fossils, unless derivative, could not be found in a Pliocene bed.

The stratigraphy points to an Oligocene age for the Cheltenham breccia. It may be shown that the breccia is stratigraphically below the Parnell grit; that there is no volcanic bed between the Parnell grit and the Orakei greensand; and that the Cheltenham breccia is consequently inferior to the Orakei greensand—a Lower Miocene bed. It may further be shown that the Orakei greensand is the equivalent in position and fossil contents of the upper parts of the Turanga greensands which overlie the Papakura limestone; and it follows that the Cheltenham breccia is either the equivalent of the lower greensands at Turanga (and therefore at the bottom of the Lower Miocene) or of the limestone at Papakura (and therefore at the top of the Oligocene). The evidence for each of these propositions is given below.

(*a*.) The breccia is below the Parnell grit. This has been incidentally shown in discussing the question of their identity; but it will now be necessary to give the evidence which leads me to consider the coarse beds at Wairau Creek, Cheltenham Beach, and the White Bluff to be all outcrops of one bed In lithological contents the beds are very similar, differing almost wholly in the varying size of the lava fragments of which they are mainly composed. The arrangement, too, is similar, the coarsest fragments being about a third of the way from the bottom. The agreement in fossil contents is shown in three parallel columns on pages 468–9.

At the White Bluff I had not more than ten minutes to collect, but was fortunate enough to come upon a very fossiliferous patch of *Bryozoa*. With a more careful search I think it very probable that other *Pectens* at least would be found; but, at all events, the fossil contents are very similar. The identifications were made chiefly by a comparison with the plates and descriptions in Zittel and Stolickza's "Orakei Bay Fossils,"* Waters's papers on "Australian Bryozoa,"† and Tenison-Woods's "New Zealand Corals and Bryozoa."‡ No attempt was made to identify numerous indistinct remains.

(*b.*) There is no volcanic bed between the Parnell grit and the Orakei greensand. The evidence for this will be given when the Parnell grit is described.§ It may also be noted that if the Cheltenham breccia were between the two it must have been erupted at Orakei since the greensand was, or else it must appear in section between the two, but nearer the Parnell grit, at the Orakei Stream.‖ It does neither. The breccia therefore underlies the Orakei greensand.

(*c.*) The Orakei greensand is the stratigraphical equivalent of the upper greensands of Turanga. The evidence for this is given better later, and it will be sufficient here to say that the Parnell grit slightly overlies both. Mr. Park found numerous fossils in both, which he compares.¶

I have slightly rearranged Mr. Park's list. A difficulty, however, confronts us in supposing the Cheltenham breccia and Papakura limestone equivalent beds. How is it that the Parnell grit, a thinner bed, extends to the Turanga greensands and the limestone, while the Cheltenham breccia, a thicker bed, does not? If it were certain that the former came from Coromandel and the latter from Waitakerei a sufficient reason is given in that their origins lay in opposite directions. But this is not certain, and I am inclined to offer a different explanation. It will be noticed that round the Waitemata, in early Oligocene times, sandstones and volcanic beds were laid down, while round Papakura limestones and greensands were deposited; so that the two areas have different types of sedimentation, and must have been laid down under different conditions. When, however, we come to Lower Miocene times the same type prevails over both areas, and when a volcanic bed is deposited, as in the case of the Parnell grit, it is deposited over limestones and sandstones alike. In other words, the conditions of deposit had become the same in both areas. This points apparently to a separation, in the earlier period, of the two areas, probably by a land mass; and there is some independent evidence for this. At Mount Wellington, a basalt puy, the Rev. Percy Smallfield found fragments of Maitai slate which had been erupted by the puy; so that the slates are probably at no great depth in this locality.

* "Voyage of 'Novara,'" vol. ii.
† Q.J.G.S., 1885, &c.
‡ Part iv. of the "Palæontology of New Zealand."
§ See page 485.
‖ See page 482.
¶ Geological Reports.

At Tamaki West Head, in the tuff (or volcanic neck?) of another basalt puy, large angular blocks of Maitai slates, quartzites, and phyllites occur. Lumps of Parnell grit have also been ejected. Some of the Maitai blocks are several feet in diameter, and the rocks must be quite close *in situ*. Farther east Motutapu is an island consisting mainly of Maitai slates. Much to the west, near the south head of the Manukau Harbour, Maitai slates have also been found. These points may be connected by an almost straight line, and, bearing in mind the lithological evidence and the fact that the Cheltenham breccia seems never to have passed this line, it seems reasonable to infer that in Oligocene times there existed a Palæozoic ridge or chain of islands, whose sunken summits are still traceable, which acted as a barrier to the western deposits. In Lower Miocene times it had sunk beneath the sea, and the Parnell grit spread over the whole area.

The fossil evidence for an Oligocene age is strong. The forms appear to me to represent a position somewhat intermediate between the Orakei greensand and the Papakura limestone; but, as the conditions were somewhat different, the Cheltenham breccia and Papakura limestone may really be contemporaneous. Below I give a list of the fossils so far obtained from the beds. Those marked with an "x" have not hitherto been named as occurring in them. I have not given in full the list of *Foraminifera* from Orakei, because the Cheltenham forms were not distinct enough to warrant identification. The *Barnea* from the Cheltenham bed I could not identify, nor was the Orakei *Barnea* identified by Mr. Park.

Name of Fossil	Papakura.	Cheltenham.	Orakei.
Ostrea nelsoniana	x	..	..
Ostrea wallerstorfi	x	..	..
Terebratella cruenta	x	..	..
Waldheimia gravida	x	x	..
Terebratella dorsata	x	x	..
Rhynchonella nigricans	x	x	..
Cidaris sp. (corals)	x	x	..
Retepora beaniana	x	x	x
Pecten hochstetteri	x	..	..
Pecten burnetti..	x	x	..
Pecten fischeri	x	x	x
Pecten polymorphoides	..	x	x
Pecten zittelli	..	x	x
Pecten convexus	..	x	x
Idmonea giebeliana	..	x	x
Idmonea radians	..	x	x
Idmonea serialis	..	x	x
Idmonea inconstans	..	x	x

Name of Fossil.	Papakura.	Cheltenham.	Orakei.
Hornera pacifica	..	x	x
Hornera lunularis	..	x	x
Spiropira verticillata	..	x	x
Spiroporina immersa	..	x	..
Heteropora grayana	..	x	x
Fasciculipora mammillata	..	x	x
Fasciculipora ramosa	..	x	..
Fasciculipora intermedia	..	x	..
Celleporaria gambierensis	..	x	x
Celleporaria globularis	..	x	x
Escharifora lawderiana	..	x	x
Filiflustrella pacifica	..	x	x
Eschara aucklandica	..	x	x
Semieschanpora porosa	..	x	x
Biflustra papillata	..	x	x
Porina dieffenbachiana	..	x	x
Salicornaria margintata	..	x	x
Salicornaria ovicellosa	..	x	x
Filispara orakiensis	..	x	x
Entotophora nodosa	..	x	..
Cellaria punctata	..	x	..
Crisinta sp. (Foraminifera)	..	x	x
Barnea sp. (Cerithium)	..	x	x
Hornera striata	..	..	x
Mesenteripora rerehauensis	..	..	x
Bidiastopora toetoeana	..	..	x
Entolophora haastiana	..	..	x
Sparsiporina vertebralis	..	..	x
Crisina hochstetteriana	..	..	x
Cellepora inermis	..	..	x
Eschara monilifera	..	..	x
Flustrella denticulata	..	..	x
Flustrella clavata	..	..	x
Vincularia maorica	..	..	x
Melicerita augustiloba	..	..	x
Stegenepora atlantica	..	..	x
Vaginella	..	..	x
Turbo	..	..	x
Rissoa	..	..	x
Nucula	..	..	x
Leda	..	..	x
Cardita	..	..	x
Carduum	..	..	x
Dosinia	..	..	x
Turritella	..	..	x
Ostrea	..	..	x
Rhynchonella	..	..	x

I have endeavoured to group them as far as possible so as to show the blending of the faunas of the first and third beds in the second. It will be seen that the Papakura limestone and the breccia have five forms in common, but the former bed probably contains more *Bryozoa* than *Retepora beaniana*, which may add considerably to the list. Twenty species of

Bryozoa are common to the greensand and the breccia. *Pecten fischeri* and *Retepora beaniana* are common to all three beds.

The stratigraphical and palæontological evidence are thus both in favour of an Oligocene age. There is evidence also in favour of the supposition that the breccia had its source in the Waitakerei vents; and, since those vents are considered Oligocene, such an origin for the breccia strengthens the above arguments.

My reasons for believing that the source of the Cheltenham breccia was the Waitakerei line of vents are briefly as follows: Firstly, the bed is Oligocene and the vents are Oligocene; undoubted Waitakerei breccias contain a fauna similar to that in the Cheltenham breccia; and the lava in the range is very similar to the lava in the breccia. Secondly, the Waitakerei vents are the only Oligocene vents not far from the breccia, which can be shown to have had a not distant source; and the bed grows coarser in this direction, but does not extend to the east. Thirdly, this supposition explains some anomalies in the distribution of the bed.

I have already given my reasons for considering the breccia Oligocene. With regard to the range I must rely on the observations of others, since I was not able, in the absence of roads and especially in the winter, to explore its forest-clad slopes for myself. The most important observations on the age of the Waitakerei vents are those of Mr. James Park.*

Mr. Park wrote that his work in 1886 tended to show that the Manukau (= Waitakerei) breccias "originated during submarine volcanic outbursts of an intense character, some time during the deposition of the Orakei Bay beds, most probably at the horizon of the Parnell grit and Takapuna [= Cheltenham] ash-bed. At Komiti Peninsula, and further north, on the Wairoa, marine beds, containing characteristic fossils of the Orakei Bay horizon, are interbedded with heavy deposits of volcanic breccias, tufas, and agglomerates, and occasionally sheets of solid lava, consisting of dolerites rich in olivine, hornblende, and augite-andesites. These can be traced southward to the Hoteo and Kaukapakapa, and an examination of the bush country south of the latter will probably show that they are connected with the breccias of the Waitakerei Range."

The classing of the Orakei greensand, the Parnell grit, and the Cheltenham breccia as "Orakei Bay beds" is somewhat confusing, and I am ignorant as to what "the characteristic fossils" were to which Mr. Park refers; but, since the out-

* Trans. N.Z. Inst., 1889.

bursts were "most probably at the horizon of (the Parnell grit and) the Takapuna ash-bed," I infer that they were those species which are common to the Orakei greensand and the Cheltenham breccia—very probably *Pectens* and *Bryozoa*. I have not had an opportunity of examining the Waitakerei breccias, but I am informed that immense numbers of *Bryozoa* are found in them; and this is the most striking and characteristic feature of the Cheltenham breccia.

A description has already been given of the Cheltenham lava. Besides examining the slides of the Waitakerei lava in the Auckland University College laboratory, I made several myself from lava *in situ*, and found the lava very similar to that contained in the breccia. Naturally, all the outcrops of the bed are not likely to owe their origin to the same vents, since several vents along the chain were, no doubt, active simultaneously. Where, however, we can ascertain approximately the position of the vent from which the materials of the bed at any one outcrop were derived the lava *in situ* shows a striking resemblance to the lava in the bed, which is all we can expect. Till the Waitakerei eruptions have been studied, more than a general similarity need not be looked for. I may, however, give one case of more certainty, and therefore more interest.

The outcrop of the breccia at the White Bluff is not many miles from the range, and is, moreover, at the southern end of the chain, so that the southern vents may be considered as its source. In the bed there are several varieties of lava, but the commonest are—(1) A purple earthy rock with abundant phenocrysts of kaolin; (2) a black amygdaloidal rock with bright unaltered feldspar phenocrysts; (3) a dark-brown or chocolate rock of a somewhat holocrystalline appearance since the phenocrysts of feldspar are very numerous, and large black phenocrysts of pyroxene also occur. These three kinds of lava are found to be plentiful *in situ* in various localities between Big and Little Muddy Creeks, about six miles to the westward.

The Waitakerei Range is, moreover, the only chain of Oligocene vents near at hand, and the breccia cannot have come from a distance. The size of the included fragments, varying from 1 ft. to 4 ft. in diameter, is, it seems to me, conclusive. I have also found numbers of elliptical or round volcanic bombs, which are not likely to have come a great distance. The bed cannot often be seen in successive outcrops, each nearer than the last to the Waitakerei Range, but where this can be observed the nearer outcrops are always the coarser. St. Helier's Bay, for instance, is about twice as far from the vents as the White Bluff, and the coarseness at the latter is much more marked than at the former spot.

Lastly, such a source as I suppose explains anomalies of distribution which I shall now describe. Mr. Park wrote that the ash-bed had a linear extension from Parnell to Whangaparaoa Peninsula, thirty miles from Auckland, and I shall assume that the volcanic breccias of that peninsula are really extensions of the Cheltenham bed. In that case the coarsest outcrop of the breccia is at the White Bluff, but at Wairau the breccia is coarser than at Cheltenham, which lies midway between White Bluff and Wairau. Again, it is coarser at Deep Creek than at Wairau or Okura, yet Deep Creek lies midway between Wairau and Okura. Or let us consider the variations in thickness. At White Bluff it is 30 ft., at Cheltenham 25 ft., at Wairau 30 ft., at Deep Creek 40 ft., at Okura 4 ft., at Whangaparaoa 20 ft., each of these places being farther north than the preceding one.

It seems to me that these wide variations in both thickness and coarseness must be due to a variety of sources, in a chain of vents. Until we have far fuller fossil evidence than we at present possess it seems impossible, or at least inadvisable, to attempt to separate these beds, which we may judge from their coarseness to have all come from the Waitakerei vents, the fossils in the beds, from White Bluff to Onehunga, confirming this. To attempt the separation it would be necessary to know the position of the vents, of which we are quite ignorant. In the meanwhile we may group the beds together as the "Cheltenham breccia," regarding this really as a number of breccias formed at much the same time under much the same conditions, but derived each from its own vent or group of vents; for we know that the Waitakerei Range extends northward at least as far as Whangaparaoa, and that there are other andesitic volcanoes beyond that which may be of the same age. If we accept this origin for the breccia our difficulties vanish. The volcanoes of the Waitakerei chain were not equally active, equally powerful, or exactly synchronous. Some outcrops of the resulting breccias would be thick and coarse, others thinner and finer, while here and there breccias of different origin would be mingled together. Nor would the vents be quite in a line; some might be to the east of it, some to the west. Some would throw out mainly scoria; others, with greater explosive energy, would eject large blocks. The thickness would probably vary more than the coarseness, since no outcrops are far from the main line, and this we find is actually the case. I believe the Okura breccia may pretty safely be separated from the Cheltenham, but beyond that it is impossible to go; and perhaps it is better, on the whole, to use the term "Cheltenham breccia" for the present in the wide sense I have given to it.

The outcrops of the breccia at White Bluff and Wairau have already been described in sufficient detail. The other outcrops now to be described are as follows: (1) St. Helier's Bay; (2) Cheltenham and Narrow Neck; (3) Deep Creek; (4) Okura; (5) Whangaparaoa.

The outcrop at St. Helier's Bay is a reef, covered at high-tide, about 20 yards from low-water mark. It is a coarse bed, with large rounded and angular fragments, and contains *Pecten zittelli*, *Pecten burnettii(?)*, and *Bryozoa* too much weathered for identification.

Cheltenham Beach is the first outcrop north of the harbour, and is the typical one (Plate XXXVIII., fig. 2.) The bed has an easterly dip, and comes down along the face of the cliff, which extends at right angles to the above section. The breccia is thus exposed for several hundred yards. The cliff then again turns east and west, and at the head of the bay the dip has increased from 30° to 70°. Round the headland there is violent dislocation and a fault. Beyond this the sandstones show a beautiful example of a dome, the centre of which is at the middle line of the beach. A few hundred yards beyond, the north-westerly dip brings down a volcanic bed. This is much thinner than the bed at Cheltenham—only about a quarter of a mile distant in a direct line. It is, however, equally coarse, and I see no reason to suppose it to be a separate bed. The only fossils obtained were some weathered *Bryozoa*. This outcrop is very remarkable, owing to the fact that in the breccia as seen in the face of the low cliff there is evidence of very complete decomposition, while where it is exposed to the waves it is quite fresh and hard. At the former place it has weathered to a creamy white and is clayey to the touch; the lava is pale-grey, scarcely distinguishable from the matrix, and quite soft and rotten, so that the bed might be mistaken for a mudstone. As one follows it towards the water's edge it hardens and darkens, till at low-water mark it exactly resembles the outcrop at Cheltenham, the lava here being dark-grey or black, and giving a ringing sound when struck with the hammer, though at the cliff one may pull it to pieces with one's fingers.

Crossing the bay, along the shore of which there is nothing more than a bank a few feet high, the dip continues regular, till at the north headland the breccia is again met with in a long reef separated from the cliffs by a fault. It runs out into the sea for several hundred yards. I found no fossils except *Bryozoa*. It seems quite possible that the reef may be an extension of the fault. The outcrop at Wairau Creek has been mentioned in discussing the age of the bed. It is the next outcrop.

About seven miles from Wairau Creek there is another outcrop of the breccia. The strata near Deep Creek have a southerly dip, which brings up the volcanic bed at the south head of the bay. At the north head it forms the mass of the cliff, and also a small island 50 yards from the shore, which is completely composed of it. The actual thickness is nowhere seen, as a fault occurs beyond the bay, but the bed must be more than 30 ft. thick. It is rather coarser than at Cheltenham, and contains numerous *Bryozoa*. The weathering of the upper parts is very noticeable. The upper 8 ft. weathers to a rich red earth with concentric markings (Plate XXXVIII., fig. 3).

On the north bank of the Okura River there is an outcrop of a coarse volcanic breccia interbedded with shale and sandstone. In texture it resembles the Deep Creek bed, but it is not more than 4 ft. in thickness. The dip takes it up above the cliff-line. The Okura River forms a kind of V with the Wade River, the apex being directed seawards. On crossing the Wade River one is at the foot of Whangaparaoa Peninsula.

Whangaparaoa Peninsula, thirty miles from Auckland, is about thirty miles round. This journey had to be done in a day along a rugged coast, where it was sometimes difficult to get along the rocks, so that I had little time for observations. Unfortunately, too, being pressed for time, I omitted the end of the peninsula from the journey, and this apparently was the locality from which Hochstetter's section was taken. The cliffs on the south are composed of hard sandstones with layers of shale, and at intervals a volcanic breccia resembling in all respects the Okura breccia is interbedded with these. It is perhaps slightly coarser than at Okura, but the thickness is very regular—about 4 ft. The first point at which I observed it was in the cliff opposite Kohanui Island. Large blocks have fallen from the breccia, which lies on a shale bed about 30 ft. from the foot of the cliff. No doubt the shale has become slippery, allowing large blocks of the hard breccia to slide away and form an admirable protection at the foot of the cliff. The fragments of lava contained in it are a compact grey rock with feldspar phenocrysts. It is apparently an augite-andesite, and resembles fragments from Cheltenham breccia. At Korimai Bay there is a very similar outcrop of the same bed, and there are occasional outcrops of the bed on the northern shore, but part of this coast I examined in twilight. Along the beach I noticed occasional fragments, well water-worn, of augite-andesites.

Mr. E. Wilson informs me that at Mahurangi Heads, about ten miles to the north of the peninsula, there is an outcrop of a very similar bed; but it is coarser, lumps of lava "from the size of an orange downwards" occurring in a "clayey matrix." Some of the fragments were forwarded to me. Most of these are augite-andesites, but one specimen appears to be a dolerite. The augite-andesites closely resemble the andesites in the peninsula breccia. I am informed that this coarse breccia is conformably overlain by sandstones, and may be traced seven or eight miles farther north, cropping out at Omaha and Matakana.

In addition to these coarse beds, I observed in the cliffs of the peninsula ash-beds of a much finer grain, not unlike the Wairau tuffs.

In conclusion, I add Hochstetter's remarks on this locality: "The peninsula of Whangaparaoa, which I visited from Auckland, consists principally of the same Tertiary strata which constitute the isthmus of Auckland. The steep cliffs in the hills show the horizontal strata clearly exposed: at the bottom generally fine-grained sandstone in layers 6 ft. to 8 ft. thick, and over these a thin stratum of clay marl. Very frequently there are intermediate strata of volcanic tuff, which is partly developed as a fine-grained sandstone, and partly coarse-grained as a breccia, consisting of fragments of trachyte, dolerite, and basalt. At the places where coarse-grained breccias and conglomerates appear very striking local disturbances of the strata are noticeable. A very instructive section is afforded by the north (north-east?) shore of the peninsula.* *a* is a tuff mass showing in places a very coarse-grained conglomerate of fragments of volcanic rocks, and containing much augite in little shining crystals, and, besides augite, little twin crystals of glassy triclinic felspars. This mass appears as an eruptive formation which has penetrated between the sandstones *c* and clay-marl *d*, torn them asunder, broken them by lateral pressure to the westward, and forced them out of their original horizontal position At *b* the tuff is fine-grained, and in places full of *Foraminifera* and *Bryozoa*. A smooth *Terebratella* (*Waldheimia lenticularis*) was also found here enclosed in the tuff, so that there can be no doubt we have in these volcanic tuffs the products of submarine eruptions, with which the volcanic outbursts commenced in the Tertiary period."

I have quoted this passage at length, because it gives so admirable an illustration of the manner in which these Tertiary breccias may be distorted. An equally good example will be given when the Parnell grit is described. Hochstetter does not attempt to explain how the volcanic breccia was injected, and I am at a loss to explain it.

From the description of this bed, and its contained fossils,

* "Reise der 'Novara,'" quoted in Geol. Surv. Repts., 1885, p. xxxvi.

and my own examination of the peninsula breccias, I cannot but think that, though these are doubtless outcrops of a volcanic bed which owed its origin to Waitakerei Oligocene vents, those vents were not identical with that which produced the Cheltenham breccia. Probably it was equally near (for the lava fragments are quite as coarse), but from the thinness of the bed one is led to infer that the vents which formed it were smaller, or that they continued active for a comparatively short period.

The Parnell Grit.

The Parnell grit, like the Cheltenham breccia, presents a somewhat bedded appearance, due to the linear arrangement of fragments of similar size. In this case, however, the bands are much more regular, and the coarsest fragments—the size, perhaps, of marbles—are all at the bottom, from which point the bed grows gradually finer till it shades off into a sandstone. The outcrops of the Parnell grit everywhere present the most beautiful examples of the shading-off of one rock into another. The red rounded lapilli of the lowest layers are gradually replaced by smaller ones, and these by yet smaller, till at length they can no longer be observed with the naked eye, and on a fresh fracture the rock has all the appearance of a blue sandstone; nor is it possible to say where the sandstone begins and the breccia ends. The lapilli are very uniform in size in each layer, which seems to indicate a distant origin. The average thickness of the bed is about 18 ft. Fossils do not seem to be as abundant as in the older beds.

The weathering is extremely characteristic and useful. In the coarser parts it is similar to that of the Cheltenham breccia, but in the upper parts concretionary or spheroidal structure is usually developed. Round the shells of brown iron-oxide the dark colour which the bed usually presents is absent, so that the concentric layers are plainly visible. This type of weathering seems to be almost confined to this bed, none of the Waitemata sandstones exhibiting it; and it is invaluable as a means of detecting the presence of the bed in inland outcrops, where the colour has generally all been leached out and the bed is left an (apparently) white crumbly sandstone. Under sea-water neither this bed nor the Cheltenham breccia weathers more than a few inches, and the feldspars remain comparatively fresh.

As at Cheltenham, a very common feature of the bed is the occurrence of zeolite "dykes," dividing the surface of the grit into irregular polygonal plates. These dykes, when split, frequently show beautiful dendritic manganese markings. The markings closely resemble those formed by moist emerypowder when, after grinding a section, one slowly withdraws the slide at right angles to the iron plate, the markings occurring both on the plate and on the slide. Possibly the dendritic markings on the zeolites were formed in an analogous manner.

The lava fragments are so small and so oxidized that I was not successful in making any microscopic sections. My sections of the grit were scarcely more successful, the rock crumbling away before it was thin enough to be of much service. In one or two instances fragments of lava could be recognised in the sections, containing feldspar and six-sided augite phenocrysts and probably an augite-andesite.

Among the crystals in the tuff corroded quartz grains occur, which may be due to the mingling of sandy sediment, or, since Sir James Hector says that the grit contains fragments of trachytes, may be derived from them or from more acid rocks. By far the most numerous crystals are small oblong feldspars sometimes altered and milky, at other times fresh and bright, with good cleavage. These are very plentiful throughout the bed. A few broken fragments of augite crystals are also present, but the large perfect augites described as occurring in the Cheltenham breccia are conspicuous by their absence. The grit is largely composed of fragments of greenish sandstones and slates which may be Palæozoic rocks. Large blocks of sandstone are absent, and current-bedding is unusual. Iron-pyrites is plentifully disseminated in bright-yellow flecks. The black matrix is often studded with scarlet scoria and white feldspars, and forms a handsome rock. From the plentiful occurrence of feldspar and augite the grit may be best described as an augite-andesite tuff.

I do not consider the source of the Parnell grit by any means as certain as that of the Cheltenham breccia, but, on the whole, the evidence is perhaps in favour of a source near Cape Colville. Before giving what evidence there is in support of this I must freely admit that the grit may have come from the Waitakerei vents, like the other volcanic beds of the series. But in the first place it is a good deal younger than the Cheltenham bed, as is shown by the fact that it crosses the Maitai ridge, which apparently was above water when the former bed was deposited; and so it is quite possible that the Waitakerei vents may have become quiescent. In the second place, it is a bed with a very wide distribution, extending from Ponsonby to Turanga Creek, from Manukau to St. Helier's. Yet it is not a coarse breccia. Such a widespread bed must have been, one would think, the result of very violent eruptions, and if the eruptions at Waitakerei were very violent the bed at the Manukau ought to contain some coarse lumps. But, if it came from Coromandel, a great outburst might result in just such a bed at so considerable a distance. In the third place, it grows coarser, on the whole, in an easterly direction. At the Manukau the bed at the White Bluff, though evidently the same, is yet rather finer than at St. John's, to the east. I cannot say that I have observed any increase of coarseness between Ponsonby and Parnell, but between Parnell and St. John's College there is a distinct increase. At Tamaki Head the bed is coarser than at St. John's, while the outcrop in the reef is, on the whole, intermediate between the two. It is very noteworthy that Mr. Park was so struck by the increase of coarseness at Howick that he described the bed there as "much coarser" than at Parnell. Had he seen the outcrops at St. John's, St. Helier's, and Tamaki Head he would hardly have noticed the increase, so gradual is it; but it becomes noticeable when we compare places far apart. Ponsonby is eight or nine miles from Howick. At a spot between Little Muddy Creek and Avondale I found what appeared to me an outcrop of the Parnell grit. The bed weathered in concretions, and was, as usual near vegetation, leached of its colour, and crumbly. It was much finer than near Auckland, and only 10 ft. thick, and the sandstones with which it was interbedded seemed to be lying on Waitakerei lavas, but this I could not decide. It is so like the usual outcrops of the Parnell grit that I see no strong reason for doubting its identity. If this be accepted, the Parnell grit evidently did not come from the Waitakerei vents; and I think the evidence from coarseness is entirely in favour of its having come from the east, not the west. Lastly, we have the opinion of so excellent a geologist as Sir James Hector, already quoted: "The Parnell grit, as far as I have seen, contains no fragments of the volcanic rocks of the district, but is greensand, with well-rolled pebbles of cherty slate, quartzite, and other Palæozoic rocks, and occasional fragments of old trachyte and basic rocks of Cape Colville." I might add that the volcanic inclusions are invariably in the form of lapilli, full of steam-vesicles, such as one would expect to have come from a considerable distance.

The age of the Coromandel volcanic gold-bearing series is a matter of dispute; but Mr. Park, who has studied them, is evidently convinced that they are about the same age as the Parnell grit. He had in 1889 placed the grit in the Upper Miocene, but for some reason he changed his mind, and wrote in 1897: "Judging from the fossiliferous Parnell bed in the Upper Eocene Waitemata marine series, on the shores of the Waitemata, with its contained fragments of andesite and coarse ash, the author is of opinion that the eruptions which originated these gold-bearing rocks began in the Upper Eocene and continued down to the Lower Miocene period." In my opinion, Mr. Park is here confusing two beds; but, be that as it may, he seems to consider that the Coromandel Peninsula eruptions began at the horizon of the Cheltenham breccia, but lasted for a long while, and this is all that is required in the supposition that the Parnell grit came from Coromandel.

Its Age.

The most interesting question relating to the Parnell grit is its stratigraphical position. Most observers have supposed that the grit overlies the Orakei greensand, but apparently on no very good evidence. Captain Hutton contributed a paper in 1884 to the New Zealand Institute in which he concluded that the relative position of the beds was uncertain, and he even wrote: "To the east of Parnell, between Resolution Point and Hobson's Point, there is a break across Hobson's Bay in which nothing definite can be seen. It is therefore quite impossible to say from stratigraphical evidence whether the beds at Hobson's Point are above or below the Parnell grit.* It is not really at all impossible, and it seems to me that Captain Hutton implied as much when he assumed that the Hobson's Point fossiliferous greensand is an extension of the Orakei bed. No one doubts this; but it is evident that if the greensand may be traced from Orakei to Hobson's Point it may be traced farther, and thus new evidence may be supplied. The Parnell grit may also be found cropping out farther east. As a matter of fact, both the greensand and the grit do occur at many localities eastward.

Before giving this new evidence it will be well to review Mr. Park's opinion, which was the reverse of that here adopted. Considerable support is given to Mr. Park's opinion by the sections which he published, but I am unable to agree with Mr. Park's interpretation of the stratigraphy. The dips are, in my opinion, sometimes the reverse of those given by Mr. Park, who wrote in 1889†: "As bearing on the relation of the Parnell grit to the Orakei Bay bed, I may mention that during my last visit to St. George's Bay I found a number of Orakei fossils in the flat irregular calcareous gritty cornstones at the foot of the cliff on the west side of the bay. These cornstones are only exposed at low water, and occupy a position some 15 ft. or 20 ft. above the Parnell grit. The fossils collected at D were *Pecten fischeri, Vaginella, Orbitolites*, and a number of small corals. The occurrence of Orakei Bay fossils in this position would tend to show that the Parnell grit is inferior to the Orakei Bay beds; but, if the

* Trans. N.Z. Inst., 1884.
† Trans. N.Z. Inst., p. 399.

evidence is not sufficient to prove this, it shows that these two horizons are at least not far separated from the Orakei greensand."

Now, in the first place, *Pecten fischeri* might occur at any horizon from the Oligocene limestone at Papakura to the Miocene greensand at Orakei, if it has not a greater vertical range. But, be that as it may, I cannot agree with Mr. Park that the Parnell grit underlies the cornstones, as shown in his section.

Mr. Park was of opinion that the bed could be seen dipping under the Mechanics Bay beds; but, although the grit may certainly be seen in the floor of the bay, I think that a fault separates it from the beds at Mechanics Point. This fault dips, I believe, as Mr. Park's section shows it (only the plan can actually be seen), but I would make it a normal fault, Mr. Park a reversed one; and, in my opinion, the grit is superior to the Mechanics Bay beds.

But the most important point in which I differ from Mr. Park is the amount and direction of the dip at B in his section. A photograph was taken for me, which shows that the dip is a low westerly not a high easterly one.

Mr. Park shows another section of less importance at Hobson's Bay, where, again, I must differ from him, not as regards the amount of dip so much as the direction, which here, again, I consider to be the reverse of that given in his section.

At Hobson's Bay, however, there is no fossil evidence, and the dip which Mr. Park gives to the grit is suggestive of a position inferior to the Orakei greensand at C of his section, but only suggestive; and Mr. Park did not seek to establish that position from this section.

My observations do not prove that the Parnell grit lies above the Orakei greensand, for there is a mile of mud-flat (covered at hightide) between Morrin's Point and Resolution Point. If this were all the evidence a superior position for the Parnell grit would be only suggested; the fuller evidence lies to the east, where both the grit and the greensand may be followed for several miles.

Mr. Park found a bed "resembling" the Parnell grit at Howick, but apparently doubted the identity. He says it is coarser; so that the grit seemed to him to get coarser in two opposite directions—Cheltenham and Howick. Besides, he found "lumps of limestone" at the base of the bed, and thought it Kaipara limestone. Kaipara is to the north-west, very much nearer the grit at Parnell and Cheltenham than at Howick, so that it was difficult to see why the limestone lumps were not at the former places, although found at Howick.

Except for this notice the Parnell grit has not hitherto been described to the east of Point Resolution. I have been successful in finding seven new outcrops in this direction, and they supply a good deal of new stratigraphical information. Some hitherto unrecorded outcrops to the west are also full of interest.

Round Point Resolution the cliffs grow low, and are covered with scrub. Here and there, however, an outcrop of the strata may be seen along the cliffs to Newmarket. The beds all have a westerly dip. Not far from Newmarket the Parnell grit can be seen, so that it is apparently well above Morrin's Point beds here, and rising in that direction.

Leaving this doubtful locality, we come to outcrops where the evidence for a superior position is more important. There is, near St John's College, a very fine exposure of the Parnell grit. The College itself stands on a high ridge 300 ft. above the sea. Numerous small streams have cut their way down in a north-westerly direction to the old crater-lake of Orakei. The chief stream rises at the College, and, cutting down through shales and yellow sandstones, which are dipping as the bed of the stream, but at a lesser angle, reaches the Parnell grit. Here there is a considerable waterfall: the underlying shales have been eaten away much more rapidly than the hard volcanic bed. It is at this waterfall that the grit is so well exposed. It is from 15 ft. to 20 ft. thick, and rather coarser, in the lower parts especially, than at Parnell. There is a large amount of iron-pyrites in it, and very numerous laths of feldspar. I could not find any fossils. The grit is overlain by the yellow-and-white sandstones, and overlies conformably, with no sign of current-bedding, a layer of shale. Beneath this is a calcareous grey sandstone, very hard and full of fantastically shaped concretions. In the concretions of a very similar sandstone at Kohimarama I obtained some well-preserved lamellibranch shells, about the size of *Venus*, which I have not been able to identify. These sandstones are at about the same horizon.

Plate XXXVIII., fig. 4, shows the position of these beds. At 4 in the section occurs the waterfall; the stream has cut right through the grit here, just before the latter rises north-west. The outcrop between A and B is not easy to find. It may be seen in a well close to the Presbyterian Church. There is one break in the section, at 5, where a modern tuff volcano has covered the beds and distorted them close to the point of eruption. I do not think, however, that this eruption disturbed the general dip of the beds. The Orakei greensand should come in between beds 2 and 4. Everything there is covered with very dense gorse. The Wairau tuffs are seen in the bed of the creek when the tide is out and a freshet has scoured away some of the mud.

I examined the Orakei tuff to see whether it would throw any light on the question. It is chiefly composed of fragments of basalt (Mr. Park mentions trachyte; I could only find hard black scoriaceous lava, with olivine), but here and there are fragments of grey sandstones and shales, and occasionally of the Wairau tuffs. There are no fragments, as far as I could see, of the Parnell grit. If this thick bed had been below the Orakei greensand, fragments would in all probability have been thrown out. A beautiful illustration of such an event occurs in the case of a similar outburst at Tamaki Gulf, where a modern volcano has broken through the Parnell grit and contains large fragments of it scattered everywhere through the tuff. The Parnell grit is an easy rock to recognise, and as it is hard it would not be blown to dust if the Wairau tuffs escaped. But fragments of these tuffs are included. Now, these are below the grit, so that the grit was, no doubt, all denuded away before the outburst—at least, that portion of it above 5. In that case it must have been at a good elevation, and therefore probably above the Orakei greensand. It was at C that Hochstetter collected from the greensand.

The outcrop of the Parnell grit, forming a reef in the harbour near the Bean Rock Lighthouse, throws no light on the stratigraphy.

The next outcrop is at the west head of the Tamaki. Before referring to this it will be advisable to trace the Orakei greensand in the same direction. At the bridge which crosses the outlet of the sunken Orakei crater to the sea the rocks exposed in the low cliffs are the Orakei tuff beds. These are seen a little further on to be quite unconformable to the Waitemata sandstones. Interbedded with these is the Orakei greensand. Here it is a greenish sandy bed which thins out completely in both directions—a lenticular mass; but it appears again at a little distance on both sides. This patch is the most fossiliferous outcrop, yielding more than forty species of fossils in a few yards, though the bed is only a couple of feet thick. Proceeding round the cliffs towards St. Helier's Bay the bed is next seen, beyond a fault, as a reef separated from the shore by 30 yards of deep mud and covered at hightide—here, again, richly fossiliferous. A little beyond the west head of Okahu Bay the strata have a westerly dip, which brings up the greensand in a gentle slope across the face of the cliff. *Pecten zittelli*, *Pecten fischeri*, Gastropods, and *Bryozoa* are the commonest forms contained in it. A fault exists in the middle of Okahu Bay, or the dip changes, for on the east side of the bay the bed is seen dipping easterly, and is again seen at the Bastion, where it has an easterly dip and passes down below the water. From this point to Tamaki West Head I have not observed any outcrop, so that I cannot say with certainty that the beds are identical. I think, however, we may fairly assume that they are. The lithological characters are the same, and peculiar to these beds; both are somewhat gritty greensands with small red patches of volcanic fragments. The fossils at the Tamaki Head bed are *Pecten zittelli*, *Pecten fischeri*, and most of the Orakei *Bryozoa* named by Hochstetter in the "Voyage of the 'Novara.'" The bed can be seen at intervals along the cliffs of the Tamaki Gulf, till towards Panmure we reach pumice sands unconformable to the Waitemata series. In these outcrops I have only found *Bryozoa*, but they are much more numerous than at Orakei even, though the same species.

I have given a somewhat full description of this bed—First, because it is, so to speak, a central line in the Waitemata beds from which other horizons may be worked out; and, secondly, because, though it is undoubtedly best described as a sandstone, it yet contains volcanic fragments, and is therefore connected with the volcanic beds of the Waitemata series.

At Tamaki West Head occurs one of the most interesting sections in the vicinity of Auckland. It is interesting from several points of view. In the first place, it supplies a section in which the Parnell grit and the Orakei greensand both occur, and is the only section I know of in which they do. It is also the spot whence Major Heaphy's section was taken, a section which has since appeared in most text-books on volcanoes. Moreover, it is in this locality that the volcanic neck(?) occurs, with large blocks of Maitai slates and quartzites.

Mr. Park has given a section of this most interesting locality.* Here, again, however, I am not able to agree with him regarding the dip of the beds at the west head. A photograph kindly taken for me by Mr. W. Satenby will exemplify my views. Mr. Park, moreover, omits from this part of his section the most prominent bed, the Parnell grit, and also the Orakei greensand. On the western part of his section he omits the high sandstone cliffs, and therefore, of course, the Parnell grit. He also writes that the beds are "undulating gently"; but, in my opinion, this is one of the most contorted spots on the whole isthmus.

In Plate XXXVIII., fig. 5, A on the section is the Tamak West Head, B a bluff not far from St. Helier's Bay. At C there is distortion and small anticlines, not shown in the section because they are on a small scale though very perfect. 1 is the Parnell grit, 2 the Orakei greensand, 3 sandstones and shales (but the beds are more numerous in the actual section), and 4 a recent tuff crater. This section is an extremely

* Geological Reports, already cited.

interesting one. It is said to be the one drawn by Major Heaphy* to show the strata through which a vent is forced, dipping down towards the vent. If it is the same, denudation must have been very active, since the crater is gone and the levels altered. I know, however, of no similar section in the Auckland cliffs, and the blocks shown in Judd's "Volcanoes" present much the appearance of the great blocks of Maitai and Parnell grit and sandstone which have been emptied at 4, or perhaps are the relics of the agglomerate in the old volcanic neck. 4 is the tuff. Numerous landslips have occurred here, obscuring the relations between the more recent tuff and the Waitemata beds. A plan of this tuff cone is given by Hochstetter.† It forms a beautifully stratified cone, each layer composed of basalt fragments in a clayey matrix; and, as already mentioned, the agglomerate of the old neck(?) consists largely of green Maitai slates and phyllites often siliceous, and Parnell grit. There can be no doubt that the basalt vent burst through the grit. This forms a reef parallel to the shore opposite the cone, and at A the reef has curved round to the shore and dips up towards the cone. The chief interest in the section, however, lies in the fact that here at last we have the grit and the greensand together. But, unfortunately, even here their relation is obscured.

Near B the grit is quite white and crumbly, but weathers in characteristic spheroidal fashion, so that it can easily be recognised from below. Near A I am at a loss to account for the appearance of the beds. Just below the grit is a sandstone, and the grit seems to lie unconformably on this sandstone, which is several feet thick at the first fault, and thins quite out at the second. Stranger still, though the greensand is lost at the fault, and, so far as I have seen, does not appear below the grit towards B, at A the grit passes right over the fault without any dislocation, and, rapidly increasing in dip to over 50°, passes down to the sea round the head. The only explanation I can give is that the eruption has driven the harder bed over the softer ones for some distance. The objection to this supposition is that, although the appearance in the section seems to fit in with it, just round A the grit seems quite conformable to the underlying sandstone, which in turn is only a few feet about the greensand. But I think such a position for the grit impossible, for then at Orakei we should see it above the greensand, while at Parnell we might expect to see the greensand below the grit. As we do neither there must be a considerable thickness of beds between them —at least 50 ft., I should say—and the appearance beyond A

* Judd: "Volcanoes," p. 165.
† "Voyage of the 'Novara,'" vol. i., Geology.

must be deceptive. However we explain matters, it seems certain, at any rate, that the grit is above the greensand. It is, perhaps, possible that this bit of the sea-floor was above water for a short time in the Miocene period, and that the grit is really unconformable; but I am inclined to think the explanation lies in the proximity of the basalt vent.

The grit forms the face of the cliff round the point, and this is probably one of the best places near Auckland for seeing its structure. The zeolite veins are well developed in particular. The fault is only inferred from the horizontal position of the sandstone at B, as landslips have covered the face of the cliff.

There is one other spot at which light is thrown on the relative positions of the grit and greensand—Maungamaungaroa Bridge. Mr. Park concluded from the fossils found here that these greensands were the equivalent of the Orakei greensand. I do not know at what spot exactly Mr. Park found these fossils, but interbedded with yellow sandstones and shales, and above the greensands, occurs an outcrop of the Parnell grit, very much weathered and easy to miss, containing *Fasciculipora ramosa.*

It may, then, be considered as highly probable that the Parnell grit is above the Orakei greensand, and even probable that it is considerably above. This fixes the age of the grit, since by a consensus of opinion the Orakei greensand is classed as Miocene, the Geological Survey alone considering it earlier.

Professor Rupert Jones, who examined the *Foraminifera,* thought them to indicate a "late Tertiary age" for the bed.

Herr Karrer, in the palæontological section of the "Voyage of the 'Novara,'" made the bed the equivalent of the Vienna basin—*i.e.*, Miocene.

Professor Martin Duncan identified them with the Mount Gambier series in Australia—Miocene.

Professor Hutton, the first of New Zealand palæontologists, examined the evidence generally, and came to the conclusion "that the evidence, both stratigraphical and palæontological, is altogether in favour of the Orakei Bay beds belonging to the Pareora system."

Since these beds are almost universally classed as Miocene, and from the Papakura limestone to the highest Waitemata sandstones the series apparently has no break, the greensand may fairly, I believe, be put at about the middle of that series. In that case the Parnell grit is Upper or Middle Miocene.

In dealing with the source and age of the grit I have already had occasion to describe some of the outcrops.

These I shall not again refer to. The following is a list of the outcrops: (1) Shelly Beach, (2) St. George's Bay, (3) Judge's Bay, (4) Newmarket, (5) St. John's College, (6) St. Helier's Bay, (7) Tamaki West Head, (8) Howick, (9) Maungamaungaroa Bridge, (10) White Bluff, (11) Cape Horn, (12) Little Muddy Creek, (13) Point England. (14) Blockhouse Bay(?).

At Shelly Beach the grit forms a synclinal. It has been described by Mr. Park, and I have nothing to add except with regard to the fault on the east of the section. I do not feel at all sure that this fault dips easterly, but I could not see the line of fault, owing to landslips and the fact that the bank is not high at Shelly Beach Road.

At Acheron Point, half a mile to the east, occurs the Ponsonby tuff. To that bed the dip is regularly west, so that there is at least 100 ft. of strata above the Ponsonby tuff at Shelly Beach. Now, the stratigraphical relations of the Ponsonby tuff are very puzzling, but it will be shown later that it is probably a little above the Cheltenham breccia, and therefore much below the Parnell grit. But here, if the Parnell grit is above it, it must be at least 100 ft. above. I see no objection to this, and am therefore inclined to think the Parnell grit is above the horizontal strata which form the Auckland hills, near the wharves, at Freeman's Bay, Hobson Street, Fort Britomart, and Mechanics Bay. Mr. Park strengthened this supposition by finding a few fossils, also found at Orakei Bay, in the Mechanics Bay bed. Both Professor Hutton and Mr. Park, however, believe that the grit overlies these beds.

Round St. George's Bay the grit dips under the sea. On the west of the following bay (Judge's Bay) the beds are much contorted. A section is given by Hochstetter. On the east of the bay the Parnell grit is beautifully exposed. This is the best locality for seeing the gradual shading-off of the coarser grit into a blue compact sandstone. Blocks have fallen from all parts of the bed, and every variety of texture may be observed. There are numerous zeolite veins running across the bed.

The next point at which the grit occurs (omitting places already described) is a reef not far from the Bean Rock Lighthouse. At the lighthouse itself the rocks are scoriaceous Auckland basalt. This cannot, I think, be derived from the North Shore puys or Rangitoto Island (a basalt volcano), since there is a deep channel between in each case, so that it probably marks the site of an ancient puy, perhaps a submarine one; but more likely its present position is due to the submergence of the old Waitemata River, which has led to the formation of the Waitemata

Harbour. This puy stood, perhaps, on the bank of the river near its mouth.

About a quarter of a mile to the east and nearer the shore a long low reef is exposed, which I visited in a boat, with the object of seeing whether the outcrop of the Cheltenham grit was here. The reef proved, however, to be the Parnell grit, lacking, as usual, coarse fragments, and unfossiliferous except for a few *Bryozoa*, which my friend Mr. E. K. Mules discovered, but which were too weathered for identification. There is a second smaller reef parallel to the first and only a few yards distant. The second reef is probably only another part of the grit. This outcrop of the grit is about as coarse as that at St John's College.

The next easterly outcrop is at Howick. The Tamaki Gulf is crossed by a bridge at Panmure, about three miles from the mouth. Crossing this bridge, and making for a point near the mouth, it is easy to miss a long headland of cliffs which forms the east head of the gulf. Viewing this headland from the terminus of the road, it seems a small one, and the strata appear horizontal, so that Mr. Park, observing it doubtless from this point, wrote that the strata "are horizontal to the Tamaki, and consist of sandstones." I fell into precisely the same error, and it was not until several weeks later that I had an opportunity of seeing the real extent and position of the beds from the harbour. Unfortunately, I was too far distant to make exact observations, and I was not able to revisit the spot. but it was evident that not only are the beds much disturbed, but that at intervals there occurs a bed much resembling the Parnell grit.

Beyond the bay to the east of these cliffs occurs an undoubted outcrop of the grit. Mr. Park, who examined the same bed rather farther along, says that it is coarser than the Parnell beds, and "contains lumps of limestone in its lower parts." It certainly is coarser than the grit at Parnell, but very little coarser than the grit at the other side of the Tamaki, which Mr. Park did not observe. It is about 20 ft. thick, and traversed by veins of calcite. These in places have thickened into lumpy masses, and have fallen frequently in this form to the foot of the cliff, and are possibly what are described as "lumps of Kaipara limestone." In some places the veins are beautifully crystalline, containing large crystals of calcite in dog-tooth spar form. At other times the calcite crystals are small (requiring a lens to distinguish their outline) but very numerous, and forming a white sparkling surface to the black grit.

The grit lies in all places conformably on the underlying sandstones, and is also overlain by sandstones in a perfectly conformable manner. The first outcrop, however, occurring at the end of the bay, is a most peculiar one. The grit thins out abruptly. This appearance is due, I believe, to currents, which have produced "contemporaneous erosion," and is not an example of "current-bedding."

The thickness is about 15 ft., but apparently the bed thins out abruptly. This strange resemblance to an injected lava (there is, however, no alteration, of course, of the surrounding beds) is frequently found in outcrops of the Cheltenham breccia, but not so frequently in those of the Parnell grit.

Sir A. Geikie, who gives a similar section, writes: "It shows a deposit of shale which, during the course of its formation, was eroded by a channel into which sand was carried, after which the deposit of fine mud recommenced. . . . It is evident that erosion took place, in a general sense, during the same period with the accumulation of the strata. . . . We may reasonably infer that erosion was due to the irregular and more violent action of the very currents by which the sediment of the successive strata was supplied."

There is an example of "injection" in the Ponsonby tuff which cannot be explained by current-bedding, as will be seen later; but current-bedding is sufficient explanation of many of these unconformable appearances.

From Howick to Turanga Creek there is no outcrop of the grit along the cliffs. At Turanga Creek the greensands were found by me resting unconformably on Maitai slates, without any Papakura limestone between the two.

Along the cliffs of the Manukau Harbour the beds, as a rule, are almost horizontal. In places, however, they have been inclined at high angles, and here and there much disturbed. It is generally at these spots of distortion that the volcanic beds crop out.

There is a wharf about a mile or a mile and a half from Onehunga. At low water more of the grit can be seen, as it forms the base of the cliffs between the fault and the White Bluff. Round the White Bluff the Parnell grit rises somewhat steeply; but that section has already been drawn and described in dealing with the question of the identity of the two breccias. The Parnell grit is here about 12 ft.–15 ft. thick, and it is not as coarse as in the eastern outcrops.

About two miles beyond the bluff the Parnell grit is again met with, and may be followed for some distance along the base of the cliffs round Cape Horn, where its hardness has been of great service in protecting the cliffs from the effects of marine denudation (Plate XXXVIII., fig. 6). The section shown in fig. 7 is taken about three miles from Little Muddy Creek, where the last section of the grit to the west was observed. The dip of the sandstones near 2 is not actually seen. The grit here is about 8 ft. thick. Lapilli, however, are rare in it, and in some respects its general appearance does not resemble that of the grit. This may be due simply to the fact that it is a very westerly outcrop. On the other hand, it is possible that the bed seen here is a distinct one, possibly an outcrop of the Ponsonby tuff, to be presently described.

7. THE OTHER VOLCANIC BEDS.

Having dealt at length with the Cheltenham breccia and the Parnell grit, something must be said of the other volcanic beds. I have already said that I do not consider the coarse breccias containing *Bryozoa* as all identical beds, but find it impossible at present to distinguish between them. The finer tuffs of the same, or nearly the same, age may, however, be separated. Two of them are here described as the Wairau tuffs and the Ponsonby tuff. I should also mention that other beds contain occasional volcanic fragments, but not enough to constitute them tuffs. The Orakei greensand is a very good instance, for in that bed patches of scoriaceous lava the size of a pin's head may be detected with a lens. On the shores of the Tamaki, near Panmure, there are also pumice sands, but I believe these are Pliocene or later beds, unconformable to the Waitemata series, and derived from the pumice plateau in the centre of the North Island.

The Waitakerei breccias and conglomerates on the west coast and therefore on the other side of the vents, I have not visited; but they must, I believe, be classed with the Waitemata series.

It is interesting to compare the Wairau tuffs with that formed at the eruption of Tarawera. Except that the former were submarine, the resemblance is considerable; but, judging from their thickness and distance from the vent, the eruptions which produced them were larger. It is interesting to note that there are three or four tuffs separated in each case by a few inches of shale, so that the eruptions succeeded each other at only short intervals. These eruptions took place some time after those which produced the Cheltenham breccia, and were not, apparently, so violent.

Wairau Tuffs.

I have given this name to volcanic beds which are best developed at the Wairau Creek, near Lake Takapuna. There are really several beds, each separated from the next by a thin layer of shale. The distinction between a tufaceous sandstone and a sandy tuff is not very easy to draw, and some of these beds are decidedly sandy. The lowest, however, is distinctly volcanic, with, occasionally, fragments of scoria as large as a pea.

The position of the Wairau tuffs appears to be above the Cheltenham breccia and below the Orakei greensand. I am uncertain whether they are above or below the Ponsonby tuff, since they seem everywhere to be above it; but at Ponsonby, where the section is clear, either they are not above it or they must be more than 100 ft. above it, a most unusual position.

The group of tuffs is more sandy than the Parnell grit, but the scoria can easily be seen with a lens. At the Wairau Creek I discovered a fragmentary Gastropod shell near the base of the second bed. It is very minute, not as large as a pea, and several whorls are evidently missing; but I believe it is a species of *Littorina*. Elsewhere I have not been able to detect any fossils.

Since there are no fossils, it will be advisable to give the reasons for identifying volcanic beds at Howick, St. John's College, the Tamaki, and Manukau Harbour, with this bed at the Wairau. In the first place, the beds do not resemble the ordinary Waitemata sandstones, which are blue or grey, while these tuffs are brown or black, with a tendency sometimes to spheroidal weathering. In the second place, although there is a little scoria present occasionally in other beds, it is never so abundant. In these beds, too, occur veins of calcite, with large crystals sometimes ½ in. long (dog-tooth spar); and there are also veins of zeolites. And, moreover, these beds always occur as a well-defined group of black bands in the cliff, the lower being the more tufaceous.

At the north head of Castor-oil Bay the tuffs are separated by bands of sandstone, as at St. John's College. Generally they are separated by thinner layers of shale.

In the first section I observed the bed was about 8 ft. thick. Across Castor-oil Bay no section can be seen, the ground being low. In the floor of the bay nothing can be seen, owing to the covering of yellow sand. If there is no break—and there is no reason to suppose one—the Wairau tuffs are here about 30 ft. above the Cheltenham breccia.

To the north of the Wairau (Castor-oil Bay) I saw nothing of the tuffs, but some of the finer tuffs at Whangaparaoa resemble them.

On the southern side of the harbour there is no outcrop of the tuffs until St. John's College is reached, the reason being that younger beds occur along the cliffs. At St. John's College they are seen in the floor of the stream when the tide is out and a freshet has scoured away the mud. The bed of the stream is obscured farther up by a raupo swamp, and the hillsides are thickly covered with gorse. Wherever the strata can be seen they are, however, sandstones, so that it seems fairly certain that the Wairau tuffs are here about 70 ft. below the Parnell grit, which coincides with the supposed general position of the beds. The tuffs are more sandy and thinner than at Wairau.

The Wairau tuffs occur at the Tamaki, near the west head. Apparently they are above the Orakei greensand, but faults make it impossible to say with certainty.

At Howick the Wairau tuffs again crop out, this time in numerous thick bands separated by several layers of shale, and shading off into sandstones. Here they are traversed by numerous zeolite veins. They occur not far from the last outcrop along Howick cliffs of the Parnell grit, but the relation between the two is obscured by several faults.

At Maungamaungaroa Creek there is another outcrop, and, judging from the dip, these beds should be nearly at the lowest horizon of the Turanga greensands, the Parnell grit occurring a little above the greensands.

As seen in a section, close to Onehunga, on the Manukau Harbour, the tuffs resemble the outcrop at Howick.

With regard to the Wairau tuffs, I am inclined to think that, just as in the case of the Cheltenham breccia, it is a group on the whole synchronous (and probably marking a gradual quiescence of the Waitakerei chain), but derived from different vents along the chain, just as in the former case.

Tamaki Tuff.

At the Tamaki and at Maungamaungaroa Stream there occurs a thin tuff (2 ft. thick), with numerous small lapilli, traversed by veins of large calcite crystals. Its position is 30 ft. below the Orakei greensand, as seen at the Tamaki Gulf, some distance from the west head. I have not seen it elsewhere.

The Ponsonby Tuff.

The Ponsonby tuff is a most interesting bed. In the first place, it is quite a thin bed, and yet has a wider distribution than any bed in the Waitemata series. In the second place, it shows some peculiar results of distortion. It is nowhere more than 2 ft. thick, yet it occurs at the Tamaki, at St. Helier's Bay, at the Manukau, at Ponsonby, at Cheltenham, at Narrow Neck, at Wairau Creek, and at Deep Creek. When unearthed it is a blue soft bed, rather sandy to the touch, speckled with white flakes of kaolinised feldspar. These flakes are thickly crowded together, sometimes as many as 500 in a square inch. Occasionally a small red patch of scoria is seen. The rock weathers to a pale-yellow in which the white feldspars are still visible.

On the whole, the bed grows thicker and coarser in a north-westerly or westerly direction, and I believe it came from some explosive outburst of a Waitakerei volcano. At the Tamaki it occurs as a thin bed 1 ft. thick not far from the west head. There is a bay and two faults at least between it and the Parnell grit. At St. Helier's Bay it occurs at Watson's Point, the westerly head of the bay, among very much contorted strata. It is not very far from the reef of the Cheltenham breccia. At the Manukau it occurs near the Wairau tuffs. Here it has been drawn out in a most curious fashion. The spot is near an area of distortion. All the lumps are elongated in the direction of the dip of the beds.

At Cheltenham it occurs near the breccia, much crushed. At Wairau Creek it occurs on the bank of the creek in the most distorted part of the cliff, and has been crushed out completely, occurring as a lenticular mass.

In all of these localities it seems to be a little above the breccia.

Across the neck on the North Shore no section can be seen, but the dip continues regular. The tuff would therefore seem to be more above the breccia than is usually the case, and some fault may be present.

In the section at Acheron Point the relative positions of the beds are quite clear, but it is not so certain that there is present an extension of the Cheltenham breccia seven or eight miles away. The question of its position at Acheron Point has already been dealt with in describing the Parnell grit.

8. Conclusion.

I have now described all the volcanic beds of the Waitemata series, and (to recapitulate) have come to the following general conclusions: That in late Oligocene times, in the shallow sea near Auckland, there rose a long line of vents, which were at first very powerful and gave rise to several coarse breccias, laid down amid conflicting currents on the fossiliferous sea-floor. But, as usual, after these first violent eruptions, from which were derived the Cheltenham breccia and the Whangaparaoa breccia, and no doubt several others, besides the massive breccias found on the west coast, there were other manifestations of volcanic activity, on the whole more feeble, but some explosive eruptions on a large scale; and it is to these we must look for the source of the Wairau tuffs and the Ponsonby tuff. Meanwhile the whole area gradually sank, till, towards the close of the Miocene period, the Palæozoic islands and ridges were mostly covered by the waves of the advancing sea, which laid down in regular succession shales and sandstones, even on the older lava-streams of the Waitakerei vents. But at the same time, and probably earlier too, volcanic outbursts were taking place on the Coromandel Peninsula, some of them of sufficient magnitude to scatter their *débris* over the floor of the Auckland sea; and it is to these we owe the Parnell grit. At a later period the volcanic forces became quiescent, the Miocene strata were raised and extensively denuded, and between the two former lines of volcanic activity arose scores of puys, which covered the older strata with tuffs and basic lavas, and distorted the beds, raising them sometimes, perhaps, from the sea; though I believe the majority of these puy cones arose on the land. One conclusion of interest is that these areas of volcanic disturbance were areas of subsidence, not elevation.*

It is possible that the Waitakerei outbursts were at first submarine, and the opening phase may have been one of elevation. But while the vents discharged their contents the sea-floor gradually sank. It was only when volcanic energy had completely died away that the consolidated sandstones, shales, and tuffs were thrown into long gentle anticlines and synclines, to be denuded by the atmospheric forces, until, after another phase of volcanic history of quite a different type, they again began to sink beneath the waves.

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* See Sir A. Geikie: "Ancient Volcanoes of Great Britain," vol. ii., p. 470.