Art. XXXI.—*The Auckland Volcanoes.*

By Hugh Shrewsbury, M.A.

[*Read before the Auckland Institute, 2nd November, 1891.*]

Plate XXXV.

The isthmus which separates the Waitemata and Manukau Harbours, and upon which stands the City of Auckland, has an average breadth of six miles; but at its narrowest part, between the eastern shore of the Manukau and the Tamaki River, it is not more than a mile and a half in width; and, again, between the Whau River and the Manukau its breadth is only about two miles. Small as this tract of land is, however, it is thickly studded with extinct volcanoes, there being no less than sixty-three separate points of eruption within a radius of ten miles, in many places so close together as to merge into one another. The greater number of these volcanic cones are in a very perfect state of preservation. It is true that many of them have been deeply terraced by the Maoris for purposes of fortification; many also have been cut into to obtain supplies of road-metal; but from weathering and denudation these hills have suffered little, and are remarkably well preserved. They present the form of cones of low altitude, Rangitoto, the highest of them, being only about 920ft. in height, and the slope of their sides being about 30° or 40°. The majority of them are dome- or mound-shaped rather than conical. Classifying them according to their mode of formation, we may divide them into three classes: (1) tuff cones and craters, (2) scoria cones and craters, (3) lava cones.

1. *Tuff Cones and Craters.*—Instances of these are Lake Takapuna and the Orakei and Panmure basins. They are readily distinguished from the scoria-cones by their shape, being wider and flatter, with much larger craters. The material composing them is not, as in the case of the scoria-cones, entirely scoria and lava, but consists of a mixture of sand and grit of non-volcanic origin, derived from the Waitemata beds, with volcanic blocks, scoriæ, lapilli, and ash, in some cases the former, in others the latter, class of material predominating. Some of the tuff-craters have been partly filled up by scoria-cones thrown up by subsequent eruptions—for example, Mount Wellington and the North Head—and it is probable that many of the scoria-cones stand upon older tuff-craters, which, however, are hidden from view by the great quantities of lava and scoria ejected by the later eruption.

The tuff-cones were evidently formed prior to the scoria-cones, and, as stated by Hochstetter, appear to have been formed under water, for, where cut across by roads or opened up by gravel-pits, their materials are distinctly stratified. A very good instance of this bedded structure can be seen at Lake Takapuna, where a scoria-pit in the northern wall of the crater shows a thick bed of black scoria, succeeded by a bed of sand and scoriæ mixed. This sandy bed is stratified and banded, and has every appearance of having been laid down in water. When the volcanic action commenced, therefore, the isthmus, or parts of it, must have been under the sea. We will return later on to a discussion of the condition of the land at the time of the first eruptions.

What is the reason of the essential difference between the tuff-cones and the scoria-cones? Why is it that the former are so much wider and flatter, and contain so much more non-volcanic material, than the latter? The reason, I think, is twofold. In the first place, the earliest eruptions, by which the tuff-cones were produced, would naturally be more violent than those succeeding—clearing away obstructions, rending and reducing the superincumbent rocks to fragments, and opening up a way by which the subsequent eruption of volcanic material would be comparatively easy. Such violent paroxysmal outbursts, as stated by Judd, produce flat cones, of low elevation, with wide craters, such as these tuff-craters; while the steeper and smaller scoria-cones are the result of more moderate but long-continued volcanic action. In the second place—and in this probably lies the chief reason of the difference—the presence of water in abundance would largely increase the violence and suddenness of the first eruptions, for we know that the chief factor in volcanic explosions is steam, and we can readily imagine that the sea-water would not only enter the fissures formed at the commencement of volcanic action, but would also percolate through and fill the pores of the sandstones, &c., of the Waitemata beds. The conversion of this water into steam, when the tension became so great as to overcome the weight of the overlying rocks and water, would not only add to the sudden force and intensity of the eruption, but would also cause the comminution of the sandstones, and thus account for the large amount of non-volcanic material in these earliest-formed craters.

Some of the tuff-craters are situated in close proximity to the sea-shore, and in such cases we generally find that the side of the crater nearest the sea has given way, and the crater has become filled with mud and sediment carried in by the sea. This is seen at the Orakei and Panmure basins, which at low water are mere mud-flats and mangrove swamps, connected with the sea outside by narrow channels cut through the mud by the ebb and flow of the tide. There are two of these crater-basins near Northcote, which are remarkable from the fact that they contain, in the material of their walls, certain olivine nodules which are extremely interesting as affording a parallel to the nodules of that mineral found in some Tertiary basalts of Europe. They are small—the largest I have found measure only about 1½in. by 1in. They fracture with an uneven, crystalline-granular surface, and are sometimes so loosely coherent as to be easily crumbled down to a coarse powder; most, however, are harder and more compact, requiring a pair of pincers or a hammer and chisel to break them. The olivine is of a pale yellowish-green colour, and remarkably fresh. In some of the nodules a few of the grains are coloured a dark-grey, almost black, by vast numbers of grains and fine thread-like or needle-shaped inclusions of magnetite and dark-coloured glass. Most of these inclusions are so minute as to appear as short, fine, hair-like bodies when examined with a magnifying-power of 300 diameters, and are arranged in parallel lines or rows closely crowded together. More interesting, however, is the appearance of fluid inclusions in this olivine. Their presence points to the deep-seated origin of the nodules, and so exactly illustrates the words of Teall in his "British Petrography" that these words may be quoted here: "If we consider the distribution of fluid inclusions in the different classes of rocks, we are struck by the fact that they are especially characteristic of the plutonic rocks, such as gabbro, diorite, and granite, and the crystalline schists. They are rare or absent in rocks of the volcanic group. . . . We do occasionally find glass and stone inclusions in the minerals of certain granites, and fluid inclusions in those of volcanic rocks, as, for instance, in the olivine and leucite of certain lava-streams; but it must be remembered that in these exceptional cases the minerals in question have probably been developed before the actual eruption of the lava." This is just what appears to have occurred here. The olivine nodules must have crystallized out or segregated from the magma some time before it was erupted—while it was still deep below the surface—and were afterwards ejected along with the scoriæ and ash formed by the comminution of the surrounding magma. That they are segregations from the basalt itself, and not inclusions of foreign matter, is, I think, almost certain; they do not contain penetrating veins of basalt, nor possess a thin easily-removed coating or shell of basalt, as exhibited by the foreign inclusions occurring in the scoria which will be presently described. Moreover, the olivine is exactly similar to that occurring so abundantly in smaller crystals in all the Auckland basalts. Their origin, therefore, is to be explained by the "segregation hypothesis" put forward by Roth, Rosenbusch, and others in explanation of the olivine nodules occurring in the Tertiary basalts of Europe already referred to, rather than by the "inclusion hypothesis" held by Bischof and Daubree with respect to the same.

2. *Scoria Cones and Craters.*—Passing on to the second class of these volcanoes—the scoria-cones—we find they are more numerous than the visible tuff-cones. They are steeper than the tuff-cones, but only moderately steep, the angle of their sides varying from 30° to 40°. Now, in many of the hills which have been cut into for the supplies of rough metal for the roads, the back or sides of the cuttings have been sloped down in the course of removal of the material, so that the scoriæ are resting at their natural angle of repose. This angle is found to be about 36°. In other words, the slope of the hills as we see them is approximately the same as the slope of loose scoriæ which have assumed a position of rest. This proves that the hills have not been disturbed to any great extent by either elevation or subsidence since the materials composing them first settled down after eruption.

The walls of several of the cuttings show a rude semblance of bedding in their materials, which is rendered more apparent where layers of different degrees of coarseness alternate with one another. This stratification or bedded structure affords a further illustration of the words of Judd (*vide* "Volcanoes," chapter v.): indeed, these cones form a very perfect parallel in nature to the artificial cone described by him. The layers or beds of volcanic material slope at an angle which gradually increases from the bottom to the top of the hill. Of course, a single cutting is usually too small a section of the beds to show this clearly; but this we do find: that in cuttings near the bottom of any of the hills the beds dip at lower angles than in cuttings at a relatively higher position—for example, near the foot of Purchas Hill the dip of the beds is about 20°, whereas about half-way up Mount Wellington the dip is over 30°. The reason of this is that the volcanic cone is formed by repeated and successive additions of ashes and lava to its surface, the material ejected falling thicker and faster towards the centre of eruption. As the cone grows, therefore, the ashes and lava are laid down upon progressively-steeper slopes. This structure accords with the remarks of Professor Geikie and other geologists on the growth of volcanoes; but there is this discrepancy: In sections illustrating this formation (for example, Geikie's diagram section of a normal volcano*) the material is usually represented as in fig. 1 below—that is, in beds sloping at a *constant* angle. Such a structure as this would imply that the eruptive force

---

* "Textbook of Geology," 2nd ed., p. 225, fig. 47.

was extremely weak at first, scattering the material to such a short distance from the centre of eruption that a very minute cone (as *a a′*) was formed, and that the force gradually and uniformly increased as the eruption progressed, reaching its maximum intensity as the eruption began to die out. Such a state of things is not suggested, and would be difficult to imagine as actually occurring. Indeed, if anything, the first eruption would probably be of greater intensity and violence than those succeeding it, clearing away obstructions and forming a vent by which subsequent ejection of material would be more easy, and attended by less violent explosions. Of course, after the slope of the sides reached about 35° the material would no longer remain in a state of repose where it was laid down, but would slide and roll downwards, so that the angle of slope would then become constant, or slightly decreasing. A section of a normal volcano would therefore present something of the form shown in fig. 2.

Fig 1

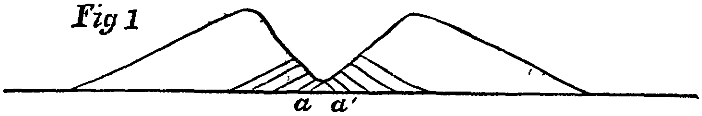
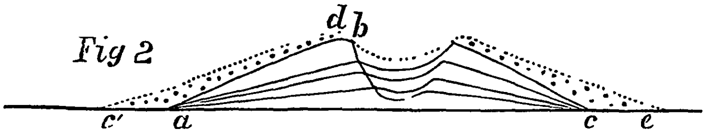


Fig 2



a, *b*, *c*. The cone when its sides have attained an angle of 35°, and before the materials have begun to roll to any extent. *c′*, *d*, *e*. The cone after this angle is passed. The lines show the cone at progressive stages in its growth, and represent the beds sloping at a constantly-increasing angle.

3. *Lava-cones.*—Rangitoto is an example of this class. Only its upper part consists of scoriæ and ash, the whole of the lower slopes being formed of lava-streams. It rises at a low angle (from 5° to 10°) to the foot of the peaks or scoria-cones forming its summit. These dip at the usual angle of 30^{c} to 35°.

Having described the three classes into which these volcanoes may be divided, we may now pass on to consider the material of which they are composed. This is in every case a basalt very rich in olivine, and showing great similarity at all the points of eruption. The scoriæ are of all sizes, from dust and small cinder-like fragments to large masses weighing several tons. The smaller fragments are generally highly vesicular, so much so in some cases that, though a heavy basic rock, the enclosed air enables it to float on water. Bombs and curiously twisted and contorted fragments of lava are of frequent occurrence. Inclusions of olivine (nodules) do not occur in the scoria-cones, but inclusions of clay, sandstone, &c., and of silica are not infrequently met with. The former are fragments of the Waitemata beds which have been caught up by the lava in its expulsion as scoriæ, and altered by the heat to which they have been subjected. This alteration has been carried to very varying degrees: in some cases the fragments have been greatly hardened, have assumed various shades of grey, red, and black, and have acquired a porcelain-like appearance, whence they are known as porcellanites; in others very little change has been produced, and the inclusion consists of soft sandstone, just like the unaltered rock of the Waitemata beds. They are generally somewhat rounded, and the exterior is either partly or wholly covered with adhering scoria, sometimes in thick lumps, sometimes as a thin semi-vitreous coating which can usually be readily cracked off. As a rule the lava has not penetrated to any extent; some of the porcellanites, however, show minute veins of penetrating lava. A microscope section which I have prepared from the outer part of such a porcellanite shows in an interesting manner the gradation from ordinary basalt on the exterior to an almost perfect glass at the furthest limit of the vein. Occasionally these porcellanites display a very interesting columnar or prismatic structure, due to contraction on cooling. Since they are more or less spherical in form, and contraction-jointing took place at right-angles to the surface of cooling, the columns or prisms radiate from the centre. They can be more or less readily separated from one another, giving rise to a number of curved and tapering fragments.

The inclusions of silica are smaller and less common than those of the preceding class. They are fragments, generally somewhat rounded, but sometimes angular, of nearly pure quartz, in the form of a crystalline-granular aggregate, crumbling almost with a touch. Except when stained with ferric oxide, they are colourless or white. They generally, like the porcellanites, show a loosely-adhering coating of basalt; many also contain small beads and threads of glassy basalt, which has penetrated them from the lava as it surrounded them. It is difficult to account for the origin of these quartz-inclusions. It is improbable that they are derived from the slates and greywackes which underlie the Waitemata beds, for these do not, where exposed near Auckland, contain free quartz, except in minute quantities; and, moreover, no fragments of the slates themselves are found in conjunction with the quartz, as we should certainly expect to find if this was the origin of these fragments. The Waitemata beds themselves contain no free quartz or quartz-veins. Whence, then, is this quartz derived? To this question I am unable to give any satisfactory answer, but may perhaps venture to put forward two theories, at the same time acknowledging that, in the absence of actual proofs in their support, they afford but a possible explanation. One is that these inclusions are fragments of silicified wood which have been caught up by the lava in its ascent, fused, and ejected with the scoriæ. This idea suggested itself to me on finding a specimen in which the penetrating veins of vitreous or semi-vitreous lava had taken the form of thin parallel plates and threads bearing some resemblance to fibres, as if the lava had been intruded into cracks or fissures formed in the direction of the *grain* of the original wood. The other theory is that this silica represents fragments of diatom earth, deposits of which occur near Auckland—as, for instance, at Mount Albert. Whatever their origin, the occurrence of fragments of free quartz in so basic a rock as the Auckland basalt is very remarkable.

The lava appears to have flowed rapidly—to have been, in fact, fairly liquid, certainly not very viscid—for the streams present, for the most part, a rough, clinkery surface, strewn with loose blocks and fragments, and not, except in a few places, the smooth, "ropy" surface exhibited by slowly-moving lava. The surface of Rangitoto Island, for instance, is exceedingly rough and uneven, being broken up by deep clefts into blocks, some of them of enormous size, which are covered with jagged, cindery projections. Another proof of the liquidity of the lava, and therefore of the large amount of steam given off from its surface while cooling, is afforded by the presence on Rangitoto of small cones—miniature volcanoes —of lava, thrown up on the streams, just as was the case with the extremely liquid lava erupted by Vesuvius in 1872. The small thickness of the streams in proportion to their length and breadth, also, I think, points in the same direction. And, indeed, we can well understand this lava to have been thoroughly liquid, owing to its very basic composition.

As regards its physical character, the lava from all the points of eruption is very similar in general appearance, in structure, and in composition; and, though varieties of microscopic structure are to be found in it, yet no variety characterizes the lava from any particular hill; on the contrary, the different kinds of structure can be seen in different parts of one and the same lava-stream, and are, in fact, merely the results of different conditions and circumstances of cooling. The texture, of course, varies according to the depth at which the rock solidified, being vesicular and porphyritic near the surface of the streams, becoming more granular and microscopically holocrystalline the further it is from the surface of cooling.

The olivine occurs as small crystals in the groundmass of the rock, but far more abundantly as porphyritic crystals or aggregates; sometimes, as in the lava-streams of Lake Takapuna and in the blocks of basalt in the tuff at Northcote, reaching ½in. or more in diameter. These crystals are somewhat granular and irregular in shape, having no doubt been rounded since their formation by the solvent action of the magma before the lava actually flowed at the surface. We must here, however, distinguish between the macro-porphyritic and the micro-porphyritic olivine, for the latter often shows very perfect and regular crystalline form. Except at the surface, where it has been exposed to weathering, the olivine is perfectly fresh and unaltered, unless the rock is very porous; very often, indeed, the olivine crystals stand out almost unchanged by the corrosive influences of the atmosphere on the very surface of the lava-streams.

The augite is also porphyritic in the Lake Takapuna and Northcote basalt, but not, so far as I am aware, elsewhere; nor have I observed either of the other constituents occurring porphyritically.

In describing the microscopic structure of this basalt it will be convenient, I think, to divide it into three classes, according to the depth at which it solidified and the relative arrangement of its constituents. The classification being one of degree rather than of kind, there is no hard-and-fast line between the three classes—they shade imperceptibly into one another—but it will serve to define the three main varieties in the microscopic structure of the rock, from which the numerous intermediate forms and gradations are derived Since a description of a large number of sections would entail repetition, and become tedious, I will merely describe the three sections of which I have appended sketches, and which illustrate respectively the three classes into which this basalt is divided. These classes are,—

1. Basalt which has cooled comparatively rapidly at or near the surface.—The rocks of this class are more or less glassy, usually dark-coloured, and finely porous or scoriaceous to a varying degree. The abundance of magnetite, especially in the darker varieties, renders the micro-sections very opaque till they are brought down very thin, when it is seen to be matted together, as it were, with the feldspar microliths, minute augite grains, and glassy matter. Rock-section 70 (Pl. XXXV.) is typical of this class: the olivine is both macro- and microporphyritic, surrounded by a base composed of small feldspar microliths, minute augite grains (colourless and almost indistinguishable except with polarised light), a large quantity of magnetite as grains and fine dust, and glassy matter. It is very pale yellowish-green, almost colourless, and is exceedingly fresh-looking, being unaltered even at the margin and along the cracks. It contains numerous inclusions of magnetite and glassy base, showing that some of the magnetite began to

crystallize before the olivine. A few small grains of olivine also occur in the groundmass.

The augite is not abundant; it is mostly in the form of small irregular grains in the groundmass, but a few large crystals occur (2, rock-section 70, Pl. XXXV.). In this particular section these crystals are not well developed, but in some sections of the basalt belonging to this class an occasional very regular augite crystal occurs.

The feldspar is in the form of small crystals, giving the usual lath-shaped sections. They are all minute and approximately equal. There are no microporphyritic crystals of this mineral present.

A half-developed flow-structure is observable in this section. The greater number of the olivine crystals and the feldspars are arranged with their long axes pointing in one direction (the direction of flow), and the groundmass separates into two currents at the porphyritic crystals, flows past them, and unites beyond. This structure is of somewhat frequent occurrence in the basalt of this class; also, though to a less marked degree, in the basalt of class 2; but not in that of class 3, where the lava had ceased to flow at all rapidly before the rock began to solidify.

2. Basalt which has cooled less rapidly than that of class 1, but yet in most cases while the lava was still in motion.—This class includes all those varieties in which, as in the preceding class, there is a well-defined base between the larger crystals, but it is more crystalline and less glassy than in rocks included in that class. These basalts, being intermediate between, show greater variety than, the basalts of the other two classes, but rock-section 17 (Pl. XXXV.) is fairly representative of class 2. It illustrates the large amount of augite frequently occurring in the groundmass of rocks belonging to this division. A glance at the illustration will suffice to show the smaller proportion of magnetite and glassy groundmass in this as compared with the preceding section.

The olivine is similar to that just described. The augite in this section is of a pale yellowish-purple tint, slightly dichroic, and is mostly in the form of rounded grains or plates of irregular shape. Some of the feldspar laths reach a fair size, and in some of the rocks of this class (*e.g.*, sections of basalt from One-tree Hill and the Three Kings Hills) are very regular and perfect in outline.

3. Basalt which has cooled comparatively slowly—that is, which has crystallized near the centre or bottom of the stream.—The olivine occurs mainly micro-porphyritically, its crystals being relatively smaller than in the preceding classes. The ingredients are more equal in size, and there is but little glassy or semi-vitreous groundmass; the structure is, in fact,

almost holocrystalline, owing to the pressure under which the rock crystallized, and the comparatively long time it took to cool. The olivine in this case (rock-section 72, Pl. XXXV), is seen to be, for the most part, unaltered, but in places has yielded ferruginous products.

Besides the well-defined crystals (of which there are two in this figure), there are small irregular patches of this mineral (as at *a*) which with ordinary light can hardly be distinguished from the augite. The latter occurs in fair-sized plates and irregular crystals.

With regard to the feldspar, there is a marked difference in its mode of occurrence in typical sections of the two extreme classes. In the first, or semi-vitreous, it is wholly in the form of minute laths and bars mingled with the magnetite dust and glassy matter (as in rock-section 70, Pl. XXXV.); in the last the crystals are larger and broader, and there is, in addition, a development of *plates* of this mineral, intercrystallized with the other constituents more after the structure of the diorites and plutonic rocks generally. The magnetite also occurs not as fine dust, but as large crystals or plates.

Between the types of rock of which these sections are taken as illustrations a complete gradation can be traced, and the transition followed from a semi-vitreous rock on the one hand to the more holocrystalline state of the same or a similar rock on the other. In other words, all these basalts, though their appearance varies under the microscope, merely represent differently-cooled portions of one and the same molten mass. The constituents are everywhere the same, the olivine, magnetite, and glassy matter decreasing, and the feldspar increasing, as we recede from the surface of cooling; and no particularly-glassy or particularly-crystalline variety characterizes the lava from either of the hills.

In speaking of the constituents, I have throughout referred to the pyroxenic constituent under the general name of "augite;" and this appears to be the only form of pyroxene present. I have examined the optical characters of this mineral in a number of sections of the basalt under consideration, and have been unable to detect any rhombic pyroxene: in other words, the pyroxene apparently occurs only in the monoclinic form. It remains to decide to which of the monoclinic pyroxenes the mineral in question belongs. Unfortunately the crystals are nearly all very irregular and imperfectly developed, with no definite outlines or cleavages. They are, in fact, rather grains or granules. Where, however, individuals are sufficiently well developed they can be identified as augite, showing the short prismatic forms characteristic of that mineral. Long columnar forms, on the other hand, such as are almost invariably assumed by diopside and acmite, are rare or absent. Moreover, as already mentioned, the pyroxene in these rocks is frequently of a pale violet or wine colour, in which case it exhibits distinct dichroism, changing from pale yellowish-brown or yellow-violet to brownish-violet. This character is not, I think, met with in any of the pyroxenes except augite, none of the others showing any approach to a violet or purple colour. On the whole, therefore, the evidence, though not conclusive, seems to show that augite is the only kind of pyroxene present.

The feldspar of these basalts is in too minute a form to be isolated and its nature determined by Szabo's method. I have therefore employed the method of determination by measurement of the angle of extinction referred to the length of the microliths; and, where the feldspars are twinned, by measurement of the angle between the directions of extinction in two adjacent lamellæ. These angles in nearly every case are high—sometimes very high—the average observed in the case of the twin crystals * being 33°; and in the slides examined by me the crystals in which this angle was lower than 20° were in the proportion of only 2 in 45. Further, in many of the slides the angles given by laths from all parts of the section are very close, indicating a uniformity in the composition of the feldspar throughout. This mineral, therefore, must belong to the labradorite-anorthite group. In most cases it probably consists entirely of anorthite.

Before leaving the microscopic structure of this basalt we may notice a slight variation which occurs in the blocks containing the large porphyritic groups of olivine at Northcote. The groundmass is seen under the microscope to contain a large quantity of augite and a little olivine, in the form of almost circular grains distinctly separated from one another by the rest of the groundmass, and not, as is usually the case, intercrystallized irregularly with it. I have noticed above the similarity between the mode of occurrence of the olivine in this rock and in some of the lava at Lake Takapuna; and, on examination with the microscope, a further resem-

---

* The following are some of these angles:—

Rangitoto Scoria-cone.	Mount Hobson.	Mount Eden.	One-tree Hill.	Mount Smart.	Tamaki.	Three Kings.	Takapuna.
24°	32°	37°	43°	25°	25°	40°	37°
22°	41°	41°	25°	26°	32° 30′	35°	27° 30′
27°	33°	36° 30′	39°	28°	30°	30°	29°
26° 30′	22°	30°	40°	38°	23°	30°	16°
26°	21°	20° 30′	34°	40°	..	34°	42°
25°	38°	28°	29°	44°	..	23°	41° 30′
30°	37°	28° 30′	32°	25°	..	24°	38°

SECTION 17.

—Basalt – Mt. Eden . Auckland. —

SECTION 72.

—Basalt – Rangitoto . Auckland. —

SECTION 70.

—Basalt – Mt. Eden . Auckland. —

—— REFERENCE . ——

1. Olivine . 3. Felspar . 5. Ferric oxide .
2. Augite . 4. Magnetite .

H. S. del.

C. H. P. lith.

blance is seen, the latter rock showing the same peculiarity in the arrangement of circular augite crystals in the base. The groundmass, indeed, in these two rocks is almost identical. It is very probable, therefore, that the Northcote tuff-craters and Lake Takapuna are closely connected, and drew their supplies of lava from the same point.

A more interesting peculiarity occurs in a small basalt-dyke which has been exposed in one of the scoria-pits at Mount Eden. This rock shows to the naked eye numerous small crystals which have the shape and general appearance of olivine, but are black. The microscope shows that they are in reality olivine crystals almost entirely filled with magnetite grains and dust. This magnetite is partly scattered irregularly through the crystals, partly arranged in parallel rows, and in lines crossing one another at right-angles. It may have been produced in either of two ways. It may be the result of weathering: the first stage of decomposition would then be marked by the production of ferric oxide, which on further weathering would be converted into magnetite. Examples of this are frequently met with in volcanic rocks, the olivine being altered round the margin and along the cracks, and even for some distance on either side of them, into red ferric oxide, which sometimes shows a fibrous arrangement similar to that assumed by the magnetite in the present instance. A further change takes place in the centre of the cracks and at places most exposed to decomposing influences, and the red ferric oxide becomes at these places converted into the black oxide or magnetite. A crystal of olivine under these circumstances shows the fresh unaltered mineral in its central parts, changing to red oxide of iron towards the edges and fissures, which in its turn changes to black oxide in the cracks themselves and round the margin of the crystal. It is more probable, however, that the magnetite in this case was formed at the time of the cooling and incipient crystallization of the lava, and is not the result of weathering, for the olivine in question does not contain any of the red oxide, but, on the contrary, the crystal substance between the grains of magnetite, as well as the spaces clear of them, are fresh and quite unaltered. It seems, therefore, that this magnetite is not a secondary product, but began to crystallize out before the olivine, and was subsequently caught up and included by that mineral in the course of growth of its crystals. This view is strengthened by the fact that, although the octahedra are so imperfectly developed that the magnetite is for the most part in the form of mere irregular grains, yet the lines in which the grains are arranged are in many cases those assumed by skeleton crystals of magnetite, such as are frequently met with in basaltic rocks.

These, however, are mere local variations in form or structure. The constituents which build up the lava, from whatever point erupted, are invariably the same—felspar, pyroxene, olivine, and magnetite; and, moreover, it appears that the felspar may in every case be referred to the labradorite-anorthite group, while the pyroxene probably occurs throughout in the form of augite only. No other mineral enters into the composition of these basalts at any point: on the contrary, the accessory ingredients found in some basalts are not met with in this rock. The internal structure of the lava is similar at all points at which it has cooled and consolidated under similar conditions, and what differences there are lie not in the constituents themselves, but in their form and mode of development. Moreover, with regard to such differences, we have seen that no variety characterizes the lava from any focus of eruption, but that the differences in texture, relative arrangement, and proportions of the component crystals, are observable in different parts of the lava from one and the same volcano, and pass by insensible gradations into one another. We have seen also that the basalt which occurs in the form of scoriæ and fragmentary material is the same rock as that which flowed as streams of lava; in short, that in composition, colour, and general outward appearance, as well as in microscopic structure, the materials ejected from all the points of eruption so closely resemble one another that the lava in all cases may be considered identical in origin. We have seen that the lava is basic—so much so, in some cases, that the olivine has separated out, or crystallized, to an unusual extent before the actual eruption of the lava, and in at least one instance was ejected in the form of nodules. The conclusions to be drawn from these facts are that the eruptions are not distinct, but closely connected with one another, and belong to one period—that, in fact, they originated from a common point or focus of activity; and, further, that this focus was not situated near the surface, but at some depth—possibly beneath the oldest rocks in the neighbourhood. All the volcanoes were probably connected with one and the same reservoir of molten rock, which, instead of escaping at a single point with one great explosion, was expelled through a great number of minor vents.

All the points of eruption may be included in an elliptical area, the long axis of which has a general north-east and south-west direction. Moreover, a line joining the principal volcanoes—Rangitoto, Mount Eden, One-tree Hill, Mount Elliot (Mangare), and the three volcanoes situated in a line with one another, and known as Moerangi and Maungataketake—also trends to the north-east. This line, if produced in a north-easterly direction, joins the "line of volcanic activity" which passes through the New Hebrides and New Guinea, and then forks, one branch being continued northwards through the Philippine, Japan, and Kurile Islands to Kamtchatka, the other westward, through Java and Sumatra. New Zealand therefore represents a continuation in a south-westerly direction of this volcanic belt, and the elevation of the North Island was probably due to volcanic activity. It is now well known that in the majority of cases volcanic eruptions commence with the formation of a fissure or fissures in the earth's crust. It is probable, therefore, that previous to the outburst of volcanic activity* in what is now the isthmus of Auckland disturbances took place in the direction of the line above stated, and a deep fissure was formed running in that direction, from which numerous minor fissures branched off at right-angles.

As regards the conditions attending the earliest eruptions and the surface-features at the time, we have seen above that most of the tuff-craters were formed under the sea. On this point Hochstetter says, "The first outbursts, as a closer examination shows, were probably submarine; they took place at the bottom of a shallow muddy bay, little exposed to waves and wind." He fails to notice, however, that, though the earliest eruptions were submarine, dry land had previously existed—that, in fact, the land was submerged only just previously to the commencement of volcanic activity. That this is so is shown by the presence at the Panmure basin of a bed of vegetable matter (in composition intermediate between peat and lignite) immediately underlying the volcanic tuff. Logs, stumps, flax, &c., have also been found under the tuff at other points on the isthmus. The bed at Panmure is several feet in thickness, and contains stems and branches of trees, some of them of considerable size. This points to a luxuriant vegetation covering the ground at the time the first eruptions took place, and proves that dry land must have been in existence for a long period before the submergence took place and volcanic action began. The sequence of events therefore seems to have been this: After their original upheaval the Waitemata beds suffered the usual weathering and denudation, and became covered—at least in places—with vegetation; subsequently, just previous to and probably as a result of the same earth-movements as produced the eruptions, a depression took place, until parts of the isthmus were submerged beneath the sea. A fissure was then formed, and volcanoes burst out under the sea in various places, forming the tuff-craters. Then, as stated by

---

* This period of volcanic activity must not be confused with the antecedent period of activity during which the Manukau and Cape Colville breccias were formed, and the distribution and contour of the land were very different from the features now existing.

Hochstetter, "With the beginning of volcanic action, by which the tuff-cones were formed, a slow and gradual upheaving of the whole isthmus seems to have taken place, so that the latter eruptions"—by which the scoria-cones were formed—"were supramarine."

There remains one question of interest which I should like to notice—the question of the age of these volcanoes. On this point we may be certain that, although the last of them was probably extinct before the advent of the Maori, still they are of comparatively modern date. They distinctly overlie all other formations in the neighbourhood, being the latest or surface-deposits, and containing, mingled with their materials, fragments of the Waitemata beds upon which they rest. The fresh and recent appearance of the scoria and lava, the unaltered angle of slope of the sides of the hills, the fact that the lava-streams have everywhere followed valleys and depressions in the surface of the land which exist at the present day, all show that these volcanoes are of geologically recent date, and that since the cessation of volcanic activity the general contour and surface-features of the land have remained unaltered. We conclude, therefore, that this activity dates from Pleistocene, if not later or recent times.

Art. XXXII.—*On the Prospects of finding Workable Coal on the Shores of the Waitemata.*

By James Park, F.G.S., Lecturer, Thames School of Mines.

[*Read before the Auckland Institute, 22nd June, 1891.*]

The recent reported discovery of a thin, irregular seam of coal in the cliffs near Northcote has again directed attention to the probable existence of workable coal in the vicinity of the City of Auckland. The great economic importance of this question has long engaged the attention of the Director of the New Zealand Geological Survey; and during the past ten years a number of surveys have been undertaken by the officers of his department with the view of collecting sufficient data to definitely determine the relation existing between the Waitemata beds and the New Zealand coal-bearing series.

In the years 1879, 1880, and 1881 Mr. Cox, late New Zealand Assistant Geologist, examined the country extending northwards from the Auckland isthmus to Whangarei on the east coast and the Upper Kaipara on the west. He arrived at the conclusion that the Waitematas, as typically developed