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THE ACTIVE VOLCANOES OF NEW ZEALAND

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The northern island of New Zealand has, at the present time, five volcanoes which show more or less activity, besides a large number of others which have been active since Miocene time and are now dormant or extinct. This island has experienced much more volcanism during late geological time than the southern island, which consists largely of sedimentary and ancient metamorphic rocks. After traveling through North Island the writer was impressed by the simple statement of the Maori guide living near Mount Tarawera, who said, "New Zealand has been turned over and over."

The active volcanoes are White Island, in the Bay of Plenty, which displayed fresh activity in the autumn of 1914; Tarawera, near Rotorua, which suffered a terrific explosion in 1886; Ruapehu, which is in the solfataric stage and almost extinct; Ngauruhoe and Tongariro, which are in the solfataric stage, but still suffer explosive outbursts, those of Ngauruhoe being of considerable violence at times. The three last-named volcanoes are situated close together on the plateau in the central portion of the island.

There seems to be a close relationship among all these five volcanoes, as they are arranged along an almost direct line, indicating a zone of fissuring of immense proportions, known as the

Whakatane fault. Speight considers that this line continues from Ruapehu through Tonga and Samoa toward Hawaii along what he

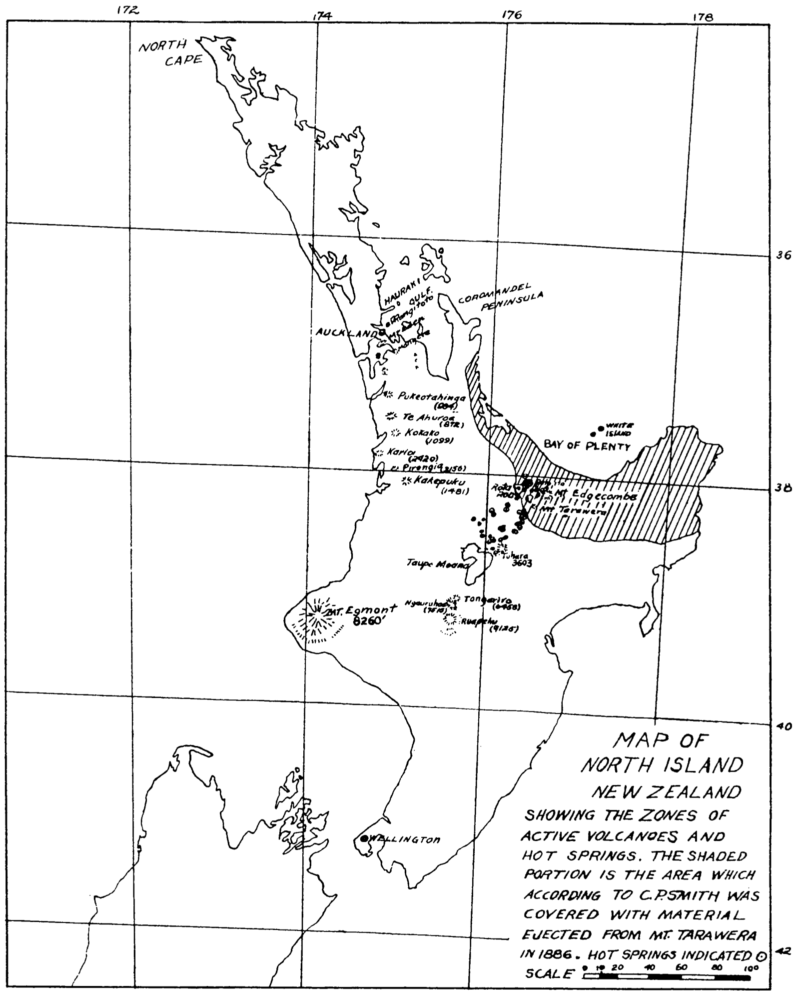

FIG. 1.—Map of North Island, New Zealand, showing the zones of active volcanoes.

calls the "Maori" line, since the Maoris probably migrated in a general direction along that line.[1] The "Samoan" and "Hawaiian"

[1] R. Speight, "Geology," *Report on a Bot. Sur. of the Tongariro National Park* (Dept. of Lands, N. Z., 1908), p. 9.

lines are supposed to cross the "Maori" line at their respective points of greatest volcanic activity. Running practically parallel to the fissured zone mentioned above, there is another zone containing numerous extinct or dormant volcanoes stretching along the eastern border of the island from the great Mount Egmont through the Auckland district, where over sixty craters, mostly of small magnitude, appear. There seem to have been, also, another line of disturbance and a great fault running from the north-central

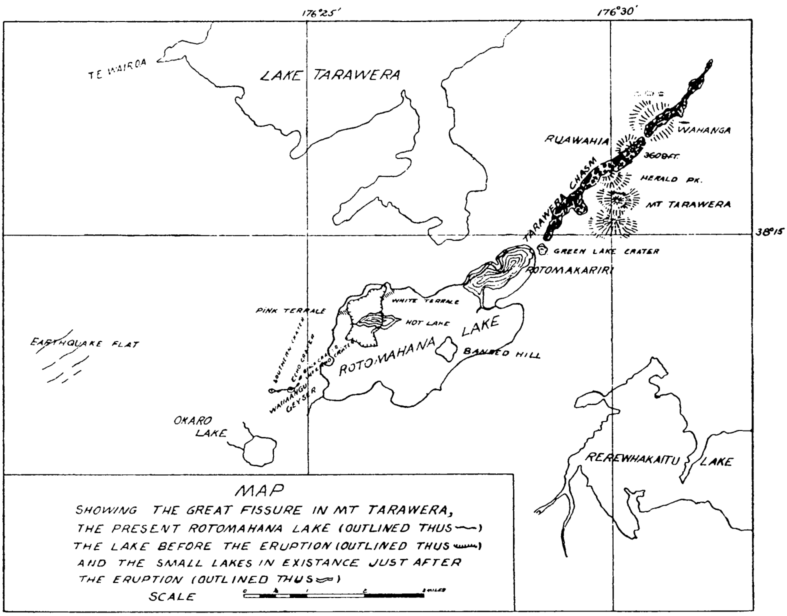

FIG. 2.—Map showing the course of the great fissure

part of the island nearly northwest to Hauraki Gulf and passing through the Waihi mining district. The prominent scarp of this fault may be seen from Morrinsville Junction in going from Auckland to Rotorua, and it is necessary to ascend this steep slope to reach the plateau before arriving at Rotorua. The streams descend rapidly over this scarp, which is a prominent physiographic feature of the landscape. This *graben* fault has aided in producing the lowland stretching from Hauraki Gulf toward the central portion of the island.

These major zones of disturbance run parallel to the main structural features of the islands resulting from the orogenic and epirogenic movements which produced New Zealand and the adjacent islands.

HISTORY OF THE LATER VOLCANIC ACTIVITY OF NEW ZEALAND

There seems to be a general agreement among New Zealand geologists that there were extensive post-Jurassic and pre-Mioeene movements, resulting in much folding and in bringing the islands nearly to their present geographical condition. The rocks formed up to this time indicate, according to Marshall,[1] that the present islands occupied a zone along the border of a continent now lost to sight. The folding raised the mountain ranges from the sea bottom and determined the major structures of the islands. There have been numerous oscillations since that time, but these have not materially altered the main structural features. Following these great disturbances, which may be correlated with those of America and Europe, there was inaugurated an important stage of igneous activity which became very prominent in the Miocene and has continued, more or less actively, since that time. There was some igneous activity during the Jurassic, and even then hypersthene-andesites, so common in later periods, began to make their appearance. Igneous rocks of this age are found, according to Park,[2] in the Hauraki Peninsula, while the andesites and rhyolites of the Canterbury district in South Island are regarded by some geologists as Jurassic.

The greatest period of activity seems to have opened in the Middle or Lower Miocene and to have extended into the Pliocene, and even into the Recent, in North Island. During the Miocene, which was also characterized by extensive orogenic and epirogenic movements, the main centers of activity were the Otago, Banks, and Hauraki peninsulas. The rocks of these areas generally rest on Omaru sediments, which are regarded as Early Miocene. In the Otago Peninsula the alkaline rocks were erupted at this time; in the Banks Peninsula, rhyolite, andesite, and basalt; and in the

[1] P. Marshall, *Geology of New Zealand* (Wellington, N. Z., 1912), p. 188.

[2] James Park, *The Geology of New Zealand* (Whitcombe & Tombs), p. 82.

Hauraki Peninsula, andesites followed by rhyolites. Probably the andesites extending north of Auckland up to North Cape were contemporaneous with those mentioned. The important gold veins of the Waihi mines are connected with this period of eruption as a later phase of the activity.

The great volcanic plateau occupying the central portion of North Island consists largely of rhyolite and pumice with the later extrusions of andesite and related rocks breaking through the rhyolites. The first evidence of the activity which produced the plateau is found in the rhyolite gravels of the Miocene, but the main eruptions are believed to be of Pliocene age because much of the pumice is found resting on early Pliocene strata and some is interbedded with them. The earliest igneous rocks of this plateau are, therefore, rhyolite and the latest andesite. As to the source of these acid rocks, there are factors which point to the Taupo area as the center of the eruption. While the writer did not have the opportunity of visiting Lake Taupo, he is convinced, after visiting other lakes in this region and reading descriptions of the Taupo basin, that these larger lakes in the central portion of the island are old craters modified by faulting. There is so much in common between such depressions and many of those of crater origin in the Hawaiian Islands that their origin can scarcely be in doubt.

The early andesite eruptions of Ruapehu, Tongariro, Egmont, Edgecombe, and related volcanoes occurred in the Pliocene, while the basanites of the Auckland area are probably of Pleistocene age.

PETROGRAPHICAL PROVINCES IN NEW ZEALAND

There is such a close relationship between the rocks of the Ruapehu–White Island and Egmont-Auckland zones that they may be justly regarded as belonging to one province. The rocks of Mount Egmont consist of hornblende-andesite and hornblende-augite-andesite; those of the Auckland region of basanite, poor in nepheline and probably lacking in this mineral in some cases; those of Ruapehu of augite-hypersthene-andesite; and those of White Island of hypersthene-andesite.

On the Coromandel Peninsula there were first eruptions of andesites of various types followed by rhyolite and these again by hypersthene-andesite. It is probable that the great rhyolite extrusions of the central plateau were contemporaneous with those of the Coromandel Peninsula, and that the early andesite extrusions of this region did not occur in the plateau area. There are dacites in both areas.

Park considers that there are two other petrographic provinces in New Zealand of late Miocene or early Pliocene age, these being found on the Otago and Banks peninsulas.[1] In the former peninsula the rocks consist of an earlier series of phonolite, dolerite, trachydolerite, andesite, basalt, and basanite; and a later series, erupted on the eroded surface of the first, consisting of basalt with probably andesite and phonolite. Cutting the lavas of the first series are dikes of nephelite-syenite, augite-dolerite, and tinguaite. Professor Marshall, who has made a detailed study of this area, states that no regular order of eruption and no definite system of differentiation in these various rocks have, so far, been recognized.

On Banks Peninsula there was a period of rhyolite eruption followed, after considerable erosion, by andesites and basalts.

From the evidence presented there does not seem to be any regular order of eruption followed by rocks of the various types, except that in practically all cases there is a tendency for the volcanism to cease with the eruption of intermediate rocks, as andesites.

RUAPEHU, NGAURUHOE, AND TONGARIRO

These three large volcanoes are located near the center of North Island at the southern end of the rhyolite plateau. Their craters lie along a direct line, within a distance of less than fifteen miles, and if this line be projected northeastward it will pass also through Pihanga and Tauhara, volcanoes now extinct; then through Tarawera, Edgecombe, and White Island. Ngauruhoe is situated between the other two and almost on the side of Tongariro, in such a way as to indicate that it has arisen in the later stages of Tongariro as a subsidiary cone to this great volcano.

The rocks of all three of these volcanoes are similar, and consist of augite-andesite with augite-hypersthene-andesite. The early activity produced extensive flows of these rocks followed by

[1] Park, *op. cit.*, p. 147.

alternating lava flows and fragmental deposits of the same material. Ruapehu has not been in active eruption since early in the Recent period, but Ngauruhoe and Tongariro continue to suffer regularly weak outbursts. Evidence of this may be seen in Fig. 6. According to Marshall there has not been a flow of lava from a New Zealand volcano in historic times, but Park and Speight believe that in 1869 a lava flow escaped from the northwest side of Ngauruhoe and that the fresh appearance of this lava attests its recent origin.

FIG. 3.—Ruapehu (9,175 feet) from the Waiouru-Tokaanu road eight miles distant. Looking across the Onetapu Desert covered with volcanic sand and cinders.

Ruapehu.—This is an enormous mass of red to dark-gray lava and scoriae rising from a plateau region. Its height has been placed by various writers at 8,878 feet to 9,175 feet above sea-level, and the latter may be considered as the more correct figure. It has a large crater, approximately a mile in diameter, cut into on the south-southeast side by a great ravine, so that the rim of the crater consists of a series of prominent peaks. The crater is occupied by a glacier which surrounds a small, hot lake said to be about 600 feet in diameter. According to various reports, the water sometimes boils, and apparently it is the sulphur water from this lake which issues from the northeast side of the mountain.

The writer was unable to reach the lake on the date of his visit in October, 1914, owing to the steepness of the ice walls between the point where he reached the crater and the location of the lake, and from the brink of the crater no sign of it could be seen in the snow field within the crater.

The sides of the cone are covered with masses of andesite from the disintegrated lava flows and with fragments of large bombs. In some cases columnar structure is well developed in these flows.

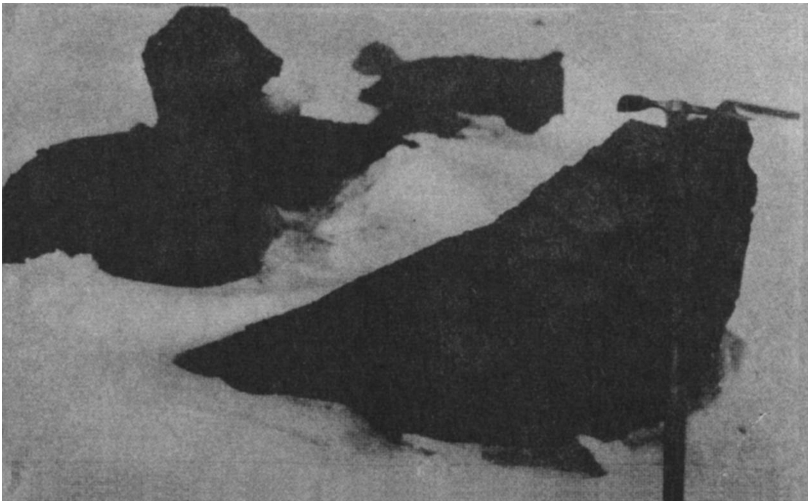

FIG. 4.—Bread-crust structure in a portion of a large bomb near the foot of Ruapehu.

In a fragment of a large bomb lying near the foot of the mountain and almost buried in the snow and cinders, an excellent example of bread-crust structure was found (Fig. 4). Small glaciers hang on the cone, extending, in some cases, as low as 2,000 feet below the crater rim.

Ngauruhoe.—This is a beautiful and symmetrical cone resting on an upland base which was probably largely developed by Tongariro before Ngauruhoe was of much importance. The elevation of this mountain is placed at 7,481 feet by S. P. Smith, and at 7,515 feet by Marshall. It is made up of a base of andesite flows on which rests the cone, consisting of alternating lava flows and beds of tuff and agglomerate, with bowlders up to ten feet in diameter. Some interesting examples of flows which appear to have split, passing above and below beds of agglomerate and tuff,

FIG. 5.—Ngauruhoe from a point near the foot of Ruapehu. This view shows how the cone is built on an upland largely developed by Tongariro.

FIG. 6.—Ngauruhoe (7,515 feet) showing the usual cloud of steam and sulphur fumes rising from the crater.

may be seen on the east side of the cone (Fig. 7). These are found, on close examination, to be due to the viscous lava piling up and becoming brecciated in movement, so as to resemble a bed of tuff and agglomerate.

There was considerable snow and ice on the mountain when the writer visited it in the spring season, early in October, but this disappears in the summer and no glaciers remain here, as on Ruapehu.

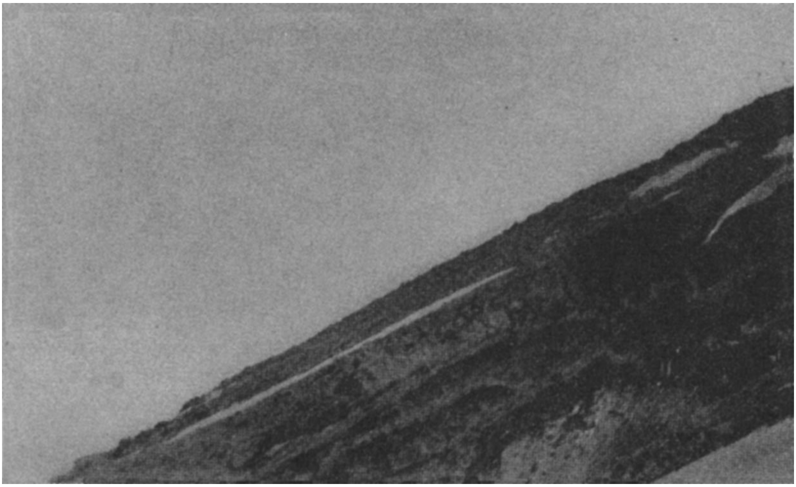

FIG. 7.—Apparent splitting of lava flows. This seems to be due to the viscous lava becoming brecciated in movement so that it resembles tuff and agglomerate. The liquid lava then flows over the fractured layer.

The crater may be entered on the north side, where the rim is broken away and it is comparatively level on the bottom except for two mud volcanoes on the floor and a deep depression on the west side, the depth of which cannot be estimated since it is always full of fumes. The diameter of the main crater is about 500 feet and the height of the perpendicular walls on three sides of it was estimated at 200 feet in the higher portions. In the small crater there is a great deal of activity. Large clouds of steam mingled with sulphur dioxide rise continuously, and at times detonations like the crack of heavy rifle-fire may be heard. Considerable dust is intermittently shot up from this crater and, as seen from Fig. 8, these explosions are occasionally quite violent. The explosion which threw out the cloud seen in the photograph, and which occurred on October 3, 1914, was said by some of the residents of Waiouru, twenty-five miles distant, who witnessed it, to be one of the strongest outbursts observed for at least two years. Up to the time this occurred, on the date mentioned, no sign of activity was seen around the mountain top, until at 9:30 A.M. this cloud was suddenly shot up about 1,000 feet before being drifted away

FIG. 8.—Cloud of dust and steam blown from Ngauruhoe, October 3, 1914. This explosion was much more violent than usual.

by a terrific wind, which was blowing at the time and prevented the cloud from rising to a great height.

Fumaroles occur around the steep walls of the main crater and well down the north side of the cone. On the northeast side of the cone was seen some reddish, highly vesicular, ropy lava, which has every appearance of being quite recent. As mentioned above, it has been stated by a number of writers that this stream was erupted in the year 1869, but not all New Zealand geologists are in accord on this subject.

Tongariro.—There are many features which make it appear that Ruapehu and Tongariro are major volcanoes with Ngauruhoe subsidiary to the latter. Tongariro is an immense volcano, but with a cone of much less altitude than that of either of the others just described. The history of this mountain has been very

FIG. 9.—Looking from Ngauruhoe into the center of the crater of Tongariro and showing the Red Crater in the foreground.

FIG. 10.—One of the later flows of andesite from Ngauruhoe

similar to that of Ruapehu. According to all the descriptions given, the lavas are andesites, mostly of the augite-hypersthene type, with small amounts of the hornblende-hypersthene type in some of the earlier flows. The cone consists of alternating lava flows and beds of scoriae. According to Speight[1] the height of the cone was greatly reduced by a terrific explosion, which was followed by extensive lava flows, and which blew 2,000 to 3,000 feet off the mountain. The crater rim now has a maximum altitude of 6,458 feet and is made up of a number of peaks surrounding several minor craters. One of these, known as the Red Crater because of the red color of the lava, is situated near the center of the main crater. Another, called Te Mari, lies on the northeast corner, and a third known as Tama is southeast of Ngauruhoe. Tama is believed to be part of the old crater rim, even if it lies beyond Ngauruhoe, and this is proof of the subsidiary character of the latter crater. All these craters are in the solfataric stage, but Te Mari is said by Speight to suffer explosive activity at times and to throw out ashes and stones. It was from this crater that the flow of andesite poured down through the forest on the flank of the mountain, and the conditions indicate that this eruption occurred at a comparatively recent date, although not within historic time.

In a depression on the main crater floor there is a small lake, called Blue Lake, lying at an elevation of about 5,500 feet. This lake, Te Mari, Red Crater, and Ngauruhoe all lie in almost a straight line, and they are apparently located on a fissure, or narrow zone of weakness, in the earth's crust. The Ketetahi Hot Springs are situated a little to the east of the line mentioned and well down on the northern flank of the mountain. They exhibit very strong thermal activity. Lying between Ngauruhoe and Ruapehu there are two small lakes, which probably owe their origin to some of the explosive activities of Tongariro.

MOUNT TARAWERA

Much has been written on Tarawera but many of the original works are out of print and unavailable. Reports have been prepared for the government bureaus of New Zealand by A. P. W.

[1] Speight, *op. cit.*, p. 11.

Thomas, Sir James Hector, and S. P. Smith, while other descriptions may be found in the works of Hutton,[1] Marshall,[2] and Park.[3] The special interest in this volcano lies in the great eruption of 1886, which produced results of much scientific, economic, and humanistic importance. The opening of the yawning chasm through the mountain, followed by the distribution of ashes over thousands of square miles of country with the accompanying destruction of life and property, is a matter of interest to every traveler who approaches this region.

Mount Tarawera was a small, nearly flat-topped mountain of rhyolite about 3,600 feet high and approximately 2,500 feet above Lake Tarawera lying at its base. There are on the mountain three prominences, known as Wahanga, Ruawahia, and Tarawera, the latter giving its name to the mountain as a whole. The structure was that of almost horizontal beds of pumice and flows of rhyolite, which had been poured out of some adjacent volcano or fissure, and which made up part of the rhyolite plateau in the central portion of North Island. Up to the time of the great explosion there was no evidence of a crater in the mountain, but it is situated in the zone of fissuring which runs from Ruapehu to White Island, and previous to the eruption there were numerous hot springs and geysers in the vicinity of the present Lake Rotomahana. It is close to Lake Tarawera, which has every appearance of being an old crater modified by local subsidence. The walls are steep and the water near the shore is deep in many places. The same condition exists in Lake Taupo and it may be concluded that all the steep-walled lakes in this region are of crater origin. The whole region lying between Tarawera and Rotorua is perforated with craters, hot springs, and geysers.

THE ERUPTION OF 1886

During the night of June 10, 1886, violent rumblings were heard and minor earthquakes experienced in the region surrounding the mountain. These increased in violence until about 2:00 A.M., when

[1] F. W. Hutton, *Report on the Tarawera Volcanic District*, Wellington, 1887. Also "The Eruption of Mount Tarawera," *Quar. Jour. Geol. Soc.*, XLIII, 1887.

[2] Marshall, *op. cit.*, p. 107.

[3] Park, *op. cit.*, p. 166.

the main eruption commenced and the great fissure began to open in the mountain, commencing at the north end in the hump called Wahanga. It passed through Ruawahia toward the basin now occupied by Lake Rotomahana and formerly containing the small lakes, Rotomahana and Rotomakariri. It opened under the lakes about 2:30 A.M. with a terrific roar and a cloud of steam which rose over 15,000 feet high.[1] This no doubt was due to the water rushing into the heated zone and producing a great explosion of steam. The result was the opening of a large pit, now occupied by Lake Rotomahana, while the débris was scattered widely over the country. The finer materials were carried out to sea over the Bay of Plenty, as indicated on the accompanying map (Fig. 1). It has been estimated that from the great fissure from 520,000,000 to 620,000,000 cubic yards of material was thrown out and this was spread over an area of almost 6,000 square miles, of which 1,500 square miles were damaged more or less severely from the agricultural standpoint. All habitations within four miles of the mountain were destroyed and 116 people killed. Most of these were natives, and while the majority of them were killed by the falling materials burying them, some around Rotomahana, where the natives often gathered, were literally carried away by the explosion. At Te Wairoa the buildings were crushed in and all vegetation destroyed or very severely damaged. There is still very little vegetation near the mountain, but it is interesting to see how quickly it has re-established itself at Te Wairoa, where the eucalypti are already fourteen to fifteen inches in diameter and other trees of less rapid growth are eight inches. The fern, like the braken of this country, establishes itself very quickly and flourishes on the acid soil. In many places the charred remains of trees are found, not only in the ashes of this eruption, but also in the ashes of earlier date.

The main eruption lasted about five hours, although the more violent part was probably over in less than an hour. Earthquakes continued for many days and there seems to have been some unusual activity in the hot springs around Rotorua. There have also

[1] According to S. P. Smith the measured height was 15,400 feet. "The Eruption of Tarawera," *A Report to the Surveyor-General*, New Zealand, 1887.

been reports of sympathetic action in Ruapehu, White Island, and other places along the volcanic zone.

Previous to the eruption of Mount Tarawera there were numerous hot springs and geysers in the area occupied by the present Lake Rotomahana, and the famous Pink and White sinter terraces were situated well within the border of the present lake.

THE GREAT FISSURE

As stated above, the eruption of Mount Tarawera began at the northern end of the mountain and progressed southward with the opening of an enormous fissure. This chasm is about 8¾ miles long, 1¼ miles wide in Lake Rotomahana, and 900 feet deep in the mountain. It is one of the most extraordinary openings to be found anywhere in the earth's crust (Fig. 11). Where it cuts through the mountain it takes the form of several deep, narrow craters in linear succession, separated by wedges of rock not blown out by the great explosions. The deepest opening is about 900 feet and it is about 1,000 feet wide at this point. In some places the crater walls are nearly vertical, but in others they have a gentle slope and can be descended to the bottom. There are a few small fumaroles, but they are no longer important. Along the brink of the chasm there is about 175 feet of highly colored, red and variegated scoriae deposited on top of the rhyolite materials thrown out of the fissure, but there is no evidence of a lava flow.

The fissure runs down the mountain side and through Lake Rotomahana, where it is 520 feet deep and has very steep walls in some places. It reached its maximum width here, where it is 1¼ to 1½ miles wide. The present lake is about 4 miles long and 2 miles wide, and it covers the areas formerly occupied by the old Lake Rotomahana and Lake Rotomakariri. In the fissure, immediately after the eruption, there was a small lake called Hot Lake, but gradually the whole depression became filled with water. The explosion completely destroyed the Pink and White sinter terraces, which were located within the present basin rim, and fragments of them may be picked up for miles around where they are mingled with the other ejectementa from the fissure. There is still much thermal activity around Rotomahana, the name of which

FIG. 11.—The great fissure through Mount Tarawera. *A*, the north end; *B*, deep central portion; *C*, looking down fissure to Lake Rotomahana. In *A* and *B* the layer of red scoriae is distinctly seen along the brink of the fissure with the lighter rhyolite underlying it.

signifies "warm lake," and steam rises from many parts of the shore, especially near the northwest corner where the terraces and other hot-spring phenomena were most prominent before the eruption. The color of the water is a sort of dirty, greenish gray, like that of glacial streams, this hue being caused, no doubt, by the large amount of extremely fine particles of mineral matter suspended in the water.

Continuing westward the fissure passes through Black, Inferno, Echo, and Southern craters, all of which exhibit considerable

FIG. 12.—Lake Rotomahana, through which the great fissure passes from end to end. Looking westward from Mount Tarawera.

thermal activity at the present day. The basin of the extraordinary Waimangu Geyser, now inactive, is located on this line a short distance from Lake Rotomahana. This geyser became active in 1900 and continued more or less irregularly until 1908, when it ceased to act. It has been reported by various reputable authorities that it often threw water and mud to a height of from 1,200 to 1,500 feet. With the extinction of this geyser the surrounding springs became more active. The Waimangu "blow hole," situated southwest of the geyser orifice, blows hot water and steam for two minutes and is then quiescent for seven. In Echo Crater the floor and walls are dotted with hot springs and fumaroles, and around some of these springs a great deal of iron pyrite is being deposited on pebbles, particularly in a spring called "The Frying Pan." The pyrite becomes disseminated in the sinter and to some extent it impregnates the thermally altered rhyolite. It seems to owe its origin to the reaction between H_2S and some iron salt, which in all probability is the chloride. The sulphide coats the pebbles with a black, smooth, waterworn layer which later tends to assume more nearly the appearance of typical pyrite. An assay was run on this pyrite deposit to determine the presence or absence of gold, and no trace of gold or silver was found. It seems probable that the pyrite in the sinters around Rotorua is of the same origin, and the large deposits of sulphur around the springs near Lake Rotorua appear to be due to the oxidation in the air of the H_2S so plentiful in these waters.

While the great fissure practically ends at the Southern Crater there are some smaller fissures and faults in Earthquake Flats which indicate the extension of the disturbance beyond the main fissure. There are lines of former movement which were again depressed a few feet.

DETAILED DESCRIPTION OF THE ROCKS OF MOUNT TARAWERA

This mountain was originally made up of interbedded rhyolite and rhyolite pumice, with streaks of dark gray to black, spherulitic obsidian running through the rhyolite. The bands often have the appearance of irregular dikes in the rhyolite, but they are probably due to the varying rate of cooling in different parts of the flows. The dark obsidian contains many fragments of the lighter rhyolite, and in some cases these have the appearance of being partly absorbed. This may be explained by the rhyolite fracturing on the cooled surface, permitting the liquid beneath to pour out around the brecciated fragments and to cool quickly. Good examples of this spherulitic obsidian were found on the road leading from Te Wairoa down to the landing on Lake Tarawera. Fragments may also be picked up among the dëbris from Tarawera, showing that the rock exists in the deeper beds in the mountain.

The rhyolite is quite fresh, brittle, and friable. Thin sections show that it contains a very deep dark-brown biotite, some augite, and, in one case, a grain of hypersthene, in addition to orthoclase, albite, and quartz which is very glassy and brilliant. The groundmass is usually mostly glass.

The obsidian consists of a brittle, dense, black glass, showing flow structure. It is full of spherulites from 0.05 mm. to 3.5 mm. in diameter. The glass contains also phenocrysts of green hornblende, orthoclase, and zonally built crystals of orthoclase and albite. The smaller spherulites consist of radiating needles of feldspar, while the larger ones are nearly solid glass around the center, with radiating dark lines and with concentric spheres

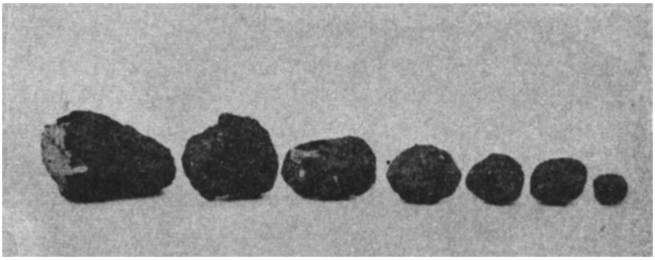

FIG. 13.—Bombs of andesite and basalt from Mount Tarawera. In two of them the light-gray cores of rhyolite may be seen ($\frac{1}{8}$ natural size).

becoming more distinct toward the exterior. These spheres are alternately brown and gray. The outer thick zone is brown and shows only a glass without crystal structure. The other zones show radiating small crystals of feldspar under the high-power microscope, but there is so little crystal structure that only a very slight darkening and brightening can be observed on rotating the section between crossed nicols, and there is almost no difference in birefringence between the spherulite and the surrounding glass. A distinct bending of the microlites in the glass around small spherulites may often be observed.

Bombs.—During the eruption of 1886 a considerable amount of intermediate to basic rock was ejected from the crater. It has been estimated that from 520,000,000 to 620,000,000 cubic yards of material was blown out of the great fissure. This was largely rhyolite, but about 175 feet of dark, reddish-brown scoriae consisting of ashes, lapilli, and bowlders of vesicular and ropy lava lies along the brink of the great chasm through Mount Tarawera. The lava, which was the last to fall on the mountain, except some material from the basin of Rotomahana, welled up beneath the chasm and was caught in the big explosion. It was blown to fragments and thin layers of the fine material are mixed with the lighter colored tuff from the rhyolites around Rotomahana. It formed irregular masses of scoriaceous and ropy lava up to two feet in length, while it quite frequently formed spherical and oval bombs (Fig. 13). These bombs occur in great numbers around the foot of the mountain. The most peculiar are those with a core of rhyolite and an enveloping coat of andesite or basalt. They owe their origin to the fact that fragments of rhyolite were engulfed in the more basic lava, and when the explosion occurred these were hurled into the atmosphere with a rotary motion so that the viscous molten material became well wrapped around the core of solid rock. As a rule, this core is not exposed until the bomb is broken open. They all show the bread-crust structure well developed owing to the shrinking of the cooling, molten coat around the solid interior. In the specimens examined there is a sharp line of contact between the two rocks and there is no evidence of fusion of the rhyolite.

An examination of thin sections of the more basic rock showed in one case much dark, grayish-brown, vesicular glass containing numerous little laths of feldspar, a little augite, and a few small phenocrysts of enstatite. In another specimen the same minerals were found, with the exception of augite. In one small bomb the feldspars were identified from their extinction angles as anorthite and bytownite, and this same specimen contained traces of quartz, possibly due to absorption of some of the acid rhyolitic material before ejection. It was carefully examined for nephelite, owing to the reported occurrence of nephelite in the Auckland lavas, but it was found to be optically positive and to lack any sign of cleavage. Very small crystals of augite were present. The rock is a quartz basalt.

Dr. Marshall mentions hypersthene-augite-andesite in the bombs from Mount Tarawera,[1] but no hypersthene has been found

[1] Marshall, *op. cit.*, p. 102.

by the writer, the orthorhombic pyroxene in all cases being like enstatite.

From the description given it is evident that these rocks vary from andesite to basalt and that they represent a much more basic phase than any rocks previously erupted in the vicinity of Mount Tarawera. The sequence is very similar to that in all the other volcanoes in this petrographic province.

GLACIATION IN THE VOLCANIC ZONE

There has been much discussion in New Zealand in recent years regarding glaciation in North Island. Outside of the comparatively small glaciers on Ruapehu the writer did not see any evidence of glaciation. Around both Ngauruhoe and Ruapehu there were many bowlders which had grooves very similar to those often made by glaciers. It was surprising to find, however, that in practically all cases these were not due to glaciation, but probably to the action of one mass of rock falling on another when hurled from the craters. This was proved by the fact that the groove would often end abruptly against the wall in a re-entrant angle in such a way that it could not have been produced by glacial action.