XXVI.—*A Visit to the New Zealand Volcanic Zone.* By HENRY
M. CADELL, of Grange, B.Sc., F.R.S.E., F.G.S. (Plates V.-X.)

(Read 16th April 1896.)

To the Scottish geologist, whose acquaintance with volcanic phenomena in the field is confined to eruptive rocks old and cold, deeply buried, perhaps, beneath Palæozoic strata, or associated with fossils of the far-off Miocene age, and everywhere greatly denuded and covered with marks of hoar antiquity, a visit to a region where volcanic action is still rife is a profoundly interesting and instructive experience. To see the ground rent by eruptions and split open by recent earthquakes, and to follow the outcrop of a fault perhaps only ten years old, and trace it across a valley and up a hillside, as one might trace a furrow or the track of a cart across a field, is a geological luxury that cannot be enjoyed in our solid old country. In text-books we read of the effect of a fault crossing a valley and throwing a wide part down against a narrow part higher up stream, producing a waterfall at the crossing, and a sudden widening of the glen immediately below it. Such a thing is unknown with us, where the inequalities of the surface due to large displacements have long ago been smoothed away by denudation. In the Thames Valley this very phenomenon, which will again be referred to, is distinctly visible, and many others of an equally interesting character can be studied all along the volcanic zone of the North Island. The limits of the volcanic area and the principal hot-springs, geysers and active or dormant volcanoes are indicated in red on the accompanying general map of the North Island (Plate IX.).

The North Island, which I visited in September 1895, is almost entirely volcanic in character, and the eruptive rocks are all of Tertiary or Recent age. The beautifully-situated town of Auckland is surrounded on all sides by evidences of recent volcanic activity. Happily its volcanoes are all extinct now, but during the later Tertiary or the Pliocene period the whole district was a seat of intense eruptive energy. From the top of Mount Eden, an old crater behind the town, a multitude of small cones and craters can be descried, some of them scattered like large molehills over the mainland, and others on islands or headlands surrounding the magnificent harbour.

In the Hauraki Peninsula, which is separated from the Auck-

land district by the Firth of Thames and the Hauraki Gulf (see Map, Plate IX.), volcanic energy appears to have first manifested itself in the Upper Eocene period. A great series of submarine eruptions took place, by means of which a bank of volcanic materials was built up on the ocean floor. Associated with these lava beds is a band of ash known as the "Parnell Grit," containing fossils which indicate the period of the first volcanic outbursts. In course of time many of the volcanoes rose above sea level, and the land surface, during a temporary cessation of volcanic activity, became covered with a luxuriant growth of vegetation. When the subterranean fires again burst forth with renewed energy, the forests were overwhelmed and covered by hundreds of feet of ashes and lavas, first of a semi-basic and then of a trachytic character. During the subsequent time of diminished volcanic activity the embedded trees were in many cases converted into wood-opal by the petrifying action of thermal springs. Great earthquakes were no doubt prevalent in the district, while the cracking of the rocks as they cooled and contracted gave rise to numerous deep-seated parallel fissures running in a general north-and-south direction. Heated vapours, sulphuretted hydrogen, steam and acid gases rose through these channels, and appeared as solfataras and fumaroles, such as are still abundant in the Rotorua and Tarawera districts. These chemical reagents permeated the rock and gradually decomposed it more or less completely, until its original character was quite altered. Mr James Park, F.G.S., lately director of the Thames School of Mines, believes that the metallic constituents and silica were carried in solution along the fissures, and that these seem to have acted like voltaic cells in which a strong electro-chemical action was set up. The basic solutions were thus apparently decomposed and their metallic constituents deposited, the base materials and part of the silver as sulphides, and the gold, together with most of the silver, as metallic alloy.

Since the last of these eruptions ceased, the greater part of the Hauraki district has remained undisturbed by volcanic action, and the agencies of denudation have during the remainder of the Tertiary epoch been busy wearing down its surface and eroding its stream-channels. The decomposition of the volcanic rocks has made them very soft and friable, so that they offer comparatively little resistance to the action of the rain and running waters. When visiting the Yellowstone National Park in America, which in many ways resembles this part of New Zealand, I was much struck with this softening action of heated springs and fumaroles on hard volcanic rocks. The magnificent cañon of the Yellowstone river has been eroded out of hard

WAIROA TOWNSHIP BEFORE THE ERUPTION.

Lake Tarawera in distance.

SITE OF WAIROA AFTER THE ERUPTION.

rhyolite at a comparatively rapid rate, the rock having become completely rotted away by heated waters and vapours percolating through it from below. Little puffs of steam were visible issuing from cracks in the cañon walls, and the hard rhyolite within their vicinity was so soft that it could at places be crumbled away by the fingers, so that the river had little difficulty in scooping out its channel.

Volcanic activity, although apparently extinct in the Hauraki district proper, was only dormant for a time in the central parts of the island. In newer Pliocene times it burst forth with prodigious energy, and huge floods of acid lavas were vomited forth over hundreds of square miles of country, while dense clouds of light pumice, ashes, and dust were belched into the air to fall in thick beds over half the island. Excellent examples of the younger volcanic cones are, as already mentioned, conspicuous all over the Auckland district, and further south the great volcanoes of Ruapehu, Tongariro, and others are still in a state of modified activity. The solid products of these eruptions reached as far north as Paeroa and Waihi, while the ash-beds are found hundreds of feet thick in the Upper Thames valley and the Upper Waikato. The old valleys were filled up in many cases, a circumstance of importance from a mining point of view, as the outcrops of the reefs were also covered, and a correct knowledge of this fact is essential to successful prospecting wherever the newer rhyolites occur. The well-known Martha Hill at Waihi, through which the celebrated lode of the Waihi Company runs, was surrounded but not quite covered by thick masses of rhyolitic breccias and lavas. The outcrop of the lode outside the company's property cannot, therefore, be traced on the surface of the ground, and must be sought for by mining operations underneath the latest rhyolitic lavas.

The auriferous reefs are found in bands or belts of "propylite" or decomposed andesite, separated from each other by hard bands of solid andesite-lava, or indurated tuffs passing into coarse breccias. This propylite is locally known as "sandstone," and is spoken of by the miners as the "kindly rock" of the country, in which reefs may be most confidently expected to occur. The reefs are of the segregated class, having derived their metallic ingredients from the solution of the rock in their immediate vicinity.

Gold is a very widely disseminated metal, and occurs in minute quantities in sea-water as well as in various minerals. In many goldfields, such as those of Victoria and Western Australia, the best gold reefs are found in a clay-slate "country," and this has been explained by supposing that the slate was originally a marine deposit which enveloped small quantities of

gold at the time of its deposition during the Palæozoic epoch. The action of aqueous solution has subsequently resulted in the leaching out of the gold with other minerals and the re-deposition of them along fissures in the rock.

In the case of the Hauraki district, the gold occurs under peculiar conditions and in reefs of Tertiary age, so that here the marine theory is quite inapplicable. The propylites are the gold-bearing rocks, and wherever the reefs pass from this decomposed rock into the fresh rock (or andesite) or into the tuffs and breccias associated with them, they become poor or sterile in character. The inference seems sound that the source of the gold and silver is to be sought in the pyroxenes of the original andesite, which have elsewhere been found to contain small quantities of the precious metals. It may be mentioned that when visiting the geyser and hot spring district of Rotorua, I was told that small quantities of gold were known to occur in the sinter-deposits produced by the geysers, which helps to substantiate the theory that the reefs were originally due to hydrothermal action.

The minerals associated with the gold are principally iron pyrites, after which come copper pyrites, zinc-blende, stibnite, and ruby silver, as well as galena, manganese oxides, calcite, pearl-spar, and occasionally metallic arsenic, specimens of the last-named metal are often found in the Kapanga mine at Coromandel. Before turning from the gold-bearing rocks, it is of importance to note that after much scientific investigation it has been clearly ascertained that the auriferous propylites of the Hauraki district are the same as the volcanic rocks of the famous Comstock lode and Washoe districts of North America, and are also similar to the "country rocks" of the ancient mines of Hungary and Transylvania.

After the district had passed through the changes described, and most of the fissures had become completely mineralised and filled up by quartz-reefs, a new set of geological phenomena arose. The infilling of the fissures was not quite complete, it may be mentioned, as it is common in the mines of the Thames district to find extensive empty cavities, where the fissures are still open and gaping for hundreds of feet at a time perhaps, or again to strike water-channels or acidulated springs following the course of the rents. Most of the reefs, however, were completely mineralized when the district was again dislocated by earthquake-cracks, such as are still produced during the earth-tremors at other parts of the island.

Two large faults were originated in the Thames gold-field, and their courses are very clearly marked by the alteration they have made on the surface of the country, as well as by

From Photo. by Mr J. Martin, F.G.S. Auckland.

ERUPTION OF THE WHITE TERRACE GEYSER,

22ND NOVEMBER 1885.

their important influence on the distribution of the reefs in that district.

The best known of these is the Moanataiari fault, which crosses the trend of the reefs at right angles, and runs along the face of the mountains from Hape Creek to the shore, a short distance west of Grahamstown or Thames. The effect of this displacement is to produce a distinct terrace or step on the mountain-slope, as its downthrow side is towards the sea. It fades to the south-west at a uniform angle of 45 degrees, and it has been calculated that it must have a vertical downthrow of about 400 feet. The fault forms an abrupt barrier to the mining operations on its seaward side, and to regain the truncated reefs on the upthrow side extensive cross-cutting is necessary. When it was first crossed it shed so much water that operations had to be abandoned for a time, and when again the north-eastern cross-cut from the 640-feet level of the Big Pump shaft at Thames reached its face, a huge mass of soft plastic clay rolled down the drift with great velocity, causing the workmen to flee for safety. The lateral displacement is so great that reefs which have been followed from the seaward side have never as yet been recovered on the footwall or landward side. The recent age of the fault is shown by its effect on the surface of the ground, where its course can be distinctly traced. Where it crosses one of the mountain-gulleys it has the effect of suddenly contracting the glen above and lifting the former bed of the stream up opposite the wider mouth of the part below. A broad part is thus thrown against a narrow portion, and a marked and sudden contraction on the upthrow side is clearly visible. Where the fault has been cut in the mines it has, moreover, been found to contain masses of rotten wood, fern-roots, and decayed vegetable matter in the soft "pug" and clays lying under its hanging wall. These circumstances point to the newer Pliocene, or even later age, of this important displacement.

The Hauraki Peninsula, as shown on the map (Plate IX.), is outside the zone of recent vulcanicity, but the Coromandel mountain range, which forms the backbone of the peninsula, extends southwards along the eastern side of the Thames valley to Te Aroha, where the first of the hot springs are to be found. Te Aroha, a pleasant sanatorium, nestles snugly at the foot of the forest-clad mountain of the same name, and its warm sulphur baths are much sought after for their medicinal virtues. To reach the heated region we must continue our journey southwards to Rotorua, the centre of the geyser district.

Rotorua, a township on the flat shore of Lake Rotorua, forms the railway terminus, and as we approach it the smell of

sulphur in the air, and the clouds of steam circling lazily upwards through the ti-tree bush, show that we have reached a place where the crust is dangerously thin, so that we can hardly consider ourselves standing on *terra firma* proper any longer. Lake Rotorua, a sheet of water about 20 miles in circumference and 1000 feet above sea-level, is, next to Taupo, the largest lake in the North Island. It lies in a roundish depression, not more than about 30 feet deep, which may have been produced by a volcanic subsidence. Abundant signs of thermal activity appear along its shores in the shape of hot springs, boiling mudholes, fumaroles, and sulphur baths, greatly valued by invalids. The surrounding country is uneven and hilly, and is covered by a dense growth of the ti-tree or manuka bush, which in winter has a warm russet brown hue like heather, but is spangled with white blossoms when the bloom is on.

The principal geysers are grouped together at the native village of Whakarewerewa, two miles south of the township of Rotorua. These are exceedingly interesting, but are not nearly so fine or so imposing in their performances as the splendid geysers of the Yellowstone. The art of soaping the geysers, which was accidentally discovered in the Yellowstone Park, is practised here when an eruption is wanted to order; and after trying the experiment, by means of a bar of soap cut up into small pieces and thrown into the funnel, we were successful in inducing Pohuto, one of the principal spouters, to favour us with a very creditable performance. At the sanatorium of Rotorua, on the shore of the lake, some interesting experiments were made a few years ago by Mr Camille Malfroy, C.E., the engineer in charge of the Government works there, after the eruption of Mount Tarawera.¹ These experiments were designed to illustrate Mr Malfroy's theory of geyser action, and went to show that the difference between a fumarole, hot spring, mud volcano, and a true geyser is very small, and depends on the shape of the funnel and the facilities for the descent of water to the heated cavities below. The practical result led the author to conclude that geysers can be regulated and controlled to some extent, and hot springs can be converted into geysers by certain mechanical arrangements, and made to play at will. In proof of this, the hot springs supplying the baths at Rotorua were converted into small geysers at Mr Malfroy's suggestion, and have continued to play regularly for the entertainment of visitors. It may appear sacrilegious thus to interfere with curious natural phenomena, and thrust iron pipes and concrete into the throats of beautiful boiling springs. To my mind,

¹ For an account of these experiments see Mr C. Malfroy's paper, "On Geyser Action at Rotorua."—*Transactions* of the N.Z. Institute, 1891.

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however, the charms of nature can in this way be greatly enhanced, and one can only regret that the geysers of Whakarewerewa have not been improved a little in their working. There is ample room for scientifically embellishing both their sinter deposits and their surroundings; but the Maoris, to whom they belong, do very little beyond drawing toll from visitors (which is done on correct and most scientific lines), and squatting in the warm pools with their wives and families. A feeble attempt has, it is true, been made to build up the sinter, so as to produce in time a far-off imitation of the lost Terraces, but much more might be effected in this direction, both at Whakarewerewa, Wairaki, and at other places, were the custody of the geyser basins in more intelligent hands. Soaping the geysers has been prohibited in the Yellowstone Park, and other regulations have very properly been strictly enforced for the preservation of their amenity; and perhaps at some future time the Government may see fit to acquire the New Zealand Wonderland in the same way, and improve it for the benefit of the public in all time to come.

Mount Tarawera is about twenty miles by road from Whakarewerewa. The first ten miles are covered on horseback *via* the old road through the Tikitapu bush to the ruined village of Wairoa. Before the eruption, when the shores of Lake Tarawera were inhabited, and there was a well-populated township at Wairoa, the road was used for vehicles, but it is now merely a bridle track, the greater part of it having been destroyed by the eruption, washed away, or allowed to go to decay for want of use. For the first few miles the road runs along a flattish plain that slopes gently from the high ground towards the shore of Lake Rotorua, and is clad with a bosky mantle of ti-tree bushes. The ground is all made up of volcanic ash of various ages, most of it being light yellow or grey pumice, the product of old eruptions. The ash of Mount Tarawera is dark gray or nearly black, and it is thus an easy matter to tell when we are within the area affected by the eruption. At first the traces of the eruption are only apparent to the trained eye of the native of the district, but soon the layer of dark material becomes evident to the most careless observer. The limits of the ash have been carefully mapped out by Professor Thomas, of Auckland University College, who investigated the district immediately after the eruption, and published a valuable report on it in 1888. As the wind was from the south-west when the outburst took place, most of the ash was blown in a north-easterly direction towards the sea, and scarcely any fell so far west as Whakarewerewa and Rotorua. After leaving the plain the path turns southward through the once luxuriant Tikitapu

Bush, and follows for part of the way a small valley, on either side of which the hills rise to a considerable height. Moerangi, the highest summit, has an altitude of 2240 feet, and rises steeply from the shores of the Tikitapu and Rotokakahi lakes, whose waters once sparkled like sapphires in the sunlight, but are now as dull as milk, or at least as white as opals without the "fire." The fine bush along their margin is blasted and blackened, and although the luxuriance of the vegetable growth is, after ten years of repose, beginning to reassert itself, and clothe the landscape with some of its former verdure, many years must elapse before the first rude traces of the catastrophe become hidden from view.

One effect of the shower of ash on the physical geography of the district interested me exceedingly, and brought into prominence a phenomenon that can seldom be observed, from its rare occurrence. Where the fall of ash exceeded 6 inches, the whole ground was covered with a dense black skin, which, when saturated with rain, turned into an impervious bed of clay, that overspread hill and dale like a waterproof sheet. Before the eruption the rain fell upon ground thickly overgrown with vegetation, and a great part of the rainfall was thus retained for a time, absorbed, or allowed to trickle into the lakes or percolate slowly and quietly into the porous soil. After the coat of volcanic mud was put on all was changed. The heavy rains no longer fell on a bosky, absorbent surface, but were precipitated on a smooth, watertight cover which, like the slated roof of a house, shed the drops as fast as they fell. The water ran in streams down the slopes, and these united to form fierce torrents in the flat bottoms of the valleys between the hills. These hollows had, in former days, been occupied by small rills that warbled quietly down to the lakes without scooping out deep channels or notably wearing away their mossy sides. When these brooks gave place to roaring torrents that rushed along with wild fury whenever a heavy shower fell, and dried up as soon as the clouds rolled away, quite a new effect was produced on their beds. The waters quickly dug out deep channels, and in a short time their courses were marked by gorges or small cañons with perpendicular sides, which were undermined and further excavated by each fresh spate. The ground rock being of soft, light pumice fragments, with little coherence, excavation was not a difficult matter.

As we approached Lake Tikitapu the road followed one of these stream courses, and we gradually ascended the valley for a few miles riding close to the edge of the cañon cut out during recent floods. Our Maori guide, A. Warbrick, said that the gorge in the middle of the valley had been almost entirely

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formed within the last five or six years, and had no existence before the eruption. It was at places more than 60 feet deep, and the sides were perpendicular or even dangerously overhanging. At one place where the hillside above sloped rather steeply down to the chasm, the path, only about 2 feet wide, ran along the very brink. This was at a bend in the stream where its eroding power was greatest and the depth was 50 or 60 feet. I dismounted and led my horse past it, not relishing the idea of a possible fall over the edge on horseback. If the path were to give way under us it would probably be more comfortable to fall separately. After passing the critical place I looked round and found that the cañon wall was really overhanging, and I made up my mind that when we came back

another way past must be found out. When we did return in the evening there was no need of impressing this caution on our guide, as the path had disappeared during our absence into the chasm! The above sketch, which was taken a short distance further up the stream, illustrates roughly the appearance of this last product of the eruption. The walls of the gorge reveal an excellent section of the stratified pumice beds with which the old valley was filled, and at the time of our visit the weather was fortunately dry, so that the bottom of the stream channel was quite bare.

The steepness of the walls shows that the process of excavation is rapid, and that the natural disintegration by the atmosphere

and rain is quite insignificant compared to the erosion by the stream, just as it is on an infinitely greater scale in the celebrated Grand Cañon of the Colorado. The old valley, on the other hand, is shaped like a roofing tile, showing that the tendency to crumble away at the sides was formerly greater than the tendency to undergo deepening through the stream's action. An excavation of this sort starts at first by the stream eating down its bed near the lower end, where it debouches on flat ground and has a "free toom," as we say in Scotland, or available space to deposit its burden of detritus in the shape of a fan or delta. The gorge begins at the apex of the cone, and when once started eats its way steadily backwards up the valley, deepening and widening its section as it grows in length; and so long as the fall is great enough to let the stream carry away all the detritus, the process will go on. As we proceeded on our way this was made quite clear, for the chasm grew smaller and narrower, so that at last we could step across it, and it finally dwindled down to a mere fissure a yard or two deep, with vertical walls entirely bridged over at places by the vegetation. In this case there is evidence that the original fissure was partly produced by an earthquake crack, but the quantity of material washed out of it by water showed clearly that it is to the action of the stream that its present size is due.

This is only one, and perhaps not the best, example of a process that is going on all over the ash-covered district. Professor Thomas told me of other and much deeper gorges produced in the same way. Now it is interesting to note that this is only a temporary phase of the physical evolution of the region. Provided no fresh eruptions occur, the ashy covering will be gradually washed off the hills, or at least the deposit will disappear under the growing vegetation, so that the sudden torrents will diminish in force and erosive power. The sides of the gorges will fall in, as it is not natural for soft strata to stand long in the form of vertical cliffs where the climate is moist and the rainfall abundant. Small but regularly flowing streams will again occupy the channel, and these will not be able to transport all the stuff that falls into them, so that in time a smaller tile-shaped valley will be formed inside the greater, and a step-like feature along the hillsides will be all that remains of the original perpendicular cañon walls shown on the sketch.

In the Taupo volcanic district the tributaries on the right bank of the Waikato river, which is far beyond the area of the Tarawera ash, have cut cañons with vertical sides 200 feet or more in height. Professor Thomas points out that the preservation of the walls is largely due to the porous nature of the pumice strata, which allows the rain to sink into the ground

From Photo. by Mr J. Martin, F.G.S., Auckland.

THE WHITE TERRACE CUPS, LAKE ROTOMAHANA.

MINERVA TERRACE, MAMMOTH HOT SPRINGS, YELLOWSTONE PARK.

instead of streaming over the surface and wearing away the margin of the cañon. The preservation of the walls of the Grand Cañon of the Colorado is due, on the other hand, to the very small rainfall of the part of America across which the greater part of the river has formed its bed. The absence of frost is also conducive to the preservation of sharp natural features of this sort, since soft, porous cliffs would, in a wet region nearer the Poles, be particularly liable to disintegration by the winter's frosts.

The native township of Wairoa was, up till June 1886, a smiling village, beautifully situated in a valley, amid luxuriant forests and well-tilled land, on the banks of the stream that falls from Lake Rotokakahi into Lake Tarawera. It is now a blasted and blackened waste, with ruined houses half buried under ashes (Plate V.); and the solitary inhabitant that met us was a brown cat, the only resident that had, after escaping with a whole skin, apparently thought the place still attractive enough for a permanent residence. The trees were partly burnt and partly overthrown by the fury of the indraught of wind caused by the eruption; but these are now sprouting again, and the dull, leaden grey of the landscape is becoming enlivened with spots and patches of warm russet brown or green. Professor Thomas has calculated that Wairoa is situated at the outer edge of the area over which the ash fell on the average 3 feet deep, and as we approach the volcano the depth of course continually increases. A fall of from 2 to 3 feet of ashes and mud may not seem a very serious matter, but it was quite enough to crush in the frail roofs of the houses and cause the death of over a dozen persons. The eruption took place suddenly in the small hours of the morning, and in the pitchy darkness it was impossible to escape. The two native villages of Te Ariki and Moura, on the shores of Lake Tarawera, near the volcano, whose sites are indicated on the accompanying map of the district, were entirely overwhelmed, and not a soul was left to tell the terrible tale of their destruction. Altogether 111 natives and Europeans were killed, the majority of the inhabitants of Wairoa having survived the eruption, which, though terrific while it lasted, happily did not last long, as it was all over, so far at least as the ash shower was concerned, in about five hours. Although large volumes of steam continued to rise from the newly-formed vents for months afterwards, no fresh explosion has since taken place, and the mountain has been steadily cooling down for the last ten years, almost no steam being now emitted from the craters.

We left our horses at Wairoa, and clambered down the steep path past the charming waterfall at the head of an arm of Lake Tarawera, to the white beach of pumice and obsidian sand, where our Maori guides had a boat ready to take us to the volcano on

the opposite shore. As we rowed across the milky waters our boatmen related how, eleven days before the eruption, the inhabitants of the native settlements on the shores had been startled by the form of a huge phantom war-canoe moving stealthily over the lake, coming from an unknown port, and going no one knew whither. The meaning of this apparition was not understood at the time; but after the catastrophe was past, the few survivors were convinced that this had been an omen from the world of spirits to warn them of the approach of the destroying angel.

The length of our little voyage was about eight miles, and we landed in a bay where a torrent had cut out a gorge in the black scoriæ and spread out the detritus in the form of a broad fan sloping gently downwards to the beach. The configuration of the ground has here been entirely changed by the eruption. For miles around, the shores of the lake, once decked with luxuriant vegetation, are now deeply buried under a leaden-grey coating of volcanic mud and scoriæ. The surface of the ground is cut up with multitudes of deep, wavy furrows, as if it had been raked all over with gigantic combs. At places these furrows are so deep and numerous that they resemble glacier crevasses, and make the country quite unpassable for man or beast. They can be seen miles away from the neighbouring hills radiating outwards and sweeping in regular curves corresponding with the changes in the slope of the ground. A good impression of the remarkable appearance of the district may be gained by looking at the hill shading on some of our ordnance maps, whose black radial hatchings bring to mind the black, sharp groovings in the scoriæ hills round Mount Tarawera.

Mount Tarawera is an ugly, flat-topped mass that rises steeply from the lake, and at the water's edge terminates in abrupt cliffs. The lake is about 1000 feet above sea level, and the mountain rises over 2700 feet higher, so that the climb is not a matter involving much expenditure either of time or muscle. The upper part of the mountain is entirely made up of black or reddish scoriæ, lapilli, and dark rounded bombs or "fireballs" of augite andesite lava, with a vesicular spongy core and a hard shell rather smooth at times on the surface. In many cases, however, the core is seen to be a lump of white, hard rhyolite, the rock of the original Mount Tarawera. This has been blown into fragments, many of which were wrapped round with a skin of the black andesite lava during the progress of the late eruption.

On reaching the crest of the ridge a strange scene presented itself. After climbing the steep, ashy slope, we came suddenly to the brink of the great chasm that has cleft the mountain into two parts. This huge fissure extends for a distance of over nine miles through the top of Tarawera and the site of Lake Rotoma-

MAP OF TARAWERA DISTRICT IN SEPTEMBER 1895.
SHOWING THE NEW LAKE ROTOMAHANA AND LINE OF THE GREAT FISSURE

hana at its base, on whose shores the Terraces were situated. The eruption produced a row of deep craters along this line, and these are separated by a series of bridges or partitions, some of which are quite sharp and thin at the top, and others are several hundred yards in breadth. The accompanying map, taken from accurate surveys by Mr S. Percy Smith, F.R.G.S., shows the line of the great fissure and the craters along its course. (Plate X.).

The sides of the chasm reveal an interesting section of the mountain, which is seen to be made up of cream-coloured rhyolite lava beneath, with deep red or dark grey stratified ash-beds at the top, and here and there a dark, slaggy patch of the new lava plastered on to the side, or lying like a saddle on the back of the separating bridges. With the exception of these isolated splashes, there is no sign of any lava stream among the products of the eruption. The eruption produced nothing but ashes and scoriae, and this is to be explained by the fact that there was so much water present that the molten rock beneath was blown to fragments by the sudden expansion of the steam imprisoned in its pores before ever it rose to the edge of the craters. There was, no doubt, lava at a certain depth, and some of it can be seen in the bottom of the deeper craters, and the fact of its existence proves that a true volcanic eruption took place, and that the explosion was not due merely to the pressure of highly-heated steam. Small volcanoes are sometimes produced by steam explosions, but in such cases the materials thrown out are found to be composed of shattered fragments of the rock beneath, unaccompanied by matter of a genuine eruptive character.

The eruption of Tarawera did not last long—only about five or six hours—but while it lasted the explosion was one of tremendous energy. A long row of craters, some of them over 800 feet in depth, were blown out of the solid rock, and from these was ejected a shower of stones, mud, and ashes, estimated by Professor Thomas to have a bulk of 1,960,000,000 cubic yards, or nearly two-fifths of a cubic mile. The ash fell over an area of more than 6000 square miles on land, and a good deal was carried away seawards by the south-west wind, to fall into the Bay of Plenty.

The observations of Mr Percy Smith, Assistant Surveyor-General, who has from time to time published very accurate maps and reports on the volcano and its surroundings, show that the effect of the accumulation of ash was to raise the summit of Tarawera to 3770 feet, which is 164 feet above its original altitude.

The most important change in the topography of the district

is the formation of the new Lake Rotomahana at the western base of the mountain, and about half a mile south from the nearest part of Lake Tarawera. The general appearance of the new lake is shown on the accompanying topographic sketch, and on the right a small part of the Tarawera lake comes within the view. The crater lake of Rotomahana has steep sides, and covers the hollow in which were situated the small Lake Rotomakariri, and the larger hot lake Rotomahana, whose shores were adorned by the terrace formations. The surplus waters overflowed into Lake Tarawera by a small stream which has been obliterated by the eruption.¹ During the explosion the lake was entirely blown up, and a huge hole formed with a small pool in the bottom about 400 feet below its original surface. The line of the great fissure (shown on the map) ran straight through the top of Mount Tarawera and the bed of Lake Rotomahana, and a row of craters mark its course across the country. Another crater lake further along the line of the chasm, and close to the foot of the mountain, was produced at the same time, and was named Rotomakariri, after the original tarn of that name. Both lakes have gradually been filling up, and now, instead of together occupying an area of about twenty-five acres, which they did in August 1886, they have joined into one imposing sheet of water, three miles in length, 5600 acres or more in extent. The level of the water was found, from surveys made in 1893, to have risen 420 feet during eight years, and at the time of my visit in 1895 it had crept up still further, and covered up some of the features shown on Mr Percy Smith's map published in 1894. When it rises to 1080 feet above sea-level, or 95 feet above its level in 1893, it will either find a subterranean outlet through the porous soil, or it will overflow the ashy ridge, and again find an outlet to Lake Tarawera. A channel in the soft scorïæ will again be excavated, by which a considerable part of the water will be drawn off, and the surface of the lake will, after reaching a maximum, begin to decrease in area, leaving no doubt a small notch or terrace round its margin to show the line of high-water mark.

The accompanying topographic sketch from near the top of Tarawera shows the appearance of Lake Rotomahana and the country to the west and south on the 27th September 1895. The day was happily very clear, and we were fortunate in catching a glimpse of the top of Ngauruhoe and Tongariro, about ninety miles off on the south-western horizon; and as the clouds lifted for a few minutes, the steam issuing from the cone of Ngauruhoe (7841 feet) was distinctly visible.

¹ These original topographical features are shown in red lines on the map of Tarawera. (Plate X.)

VIEW SOUTH-WESTWARD FROM MOUNT TARAWERA, SHOWING THE NEW LAKE ROTOMAHANA.

A sharp pointed rock, known as the Pinnacle, formed a prominent landmark on the north or right side of the Rotomahana crater after the eruption. As the water rose, the Pinnacle became an island, and gradually diminished in size until nothing but the tip appeared above water. This was shown on Mr Percy Smith's panorama, taken in 1893, and published along with his latest report in the following year, and at the time of my visit the continued rise of the lake was clearly proved by the diminished size of the Pinnacle, which is shown on the sketch as a mere speck, and may by this time have completely disappeared. The Pinnacle was close to the White Terrace and near the head of the Kaiwaka stream, by which the old Lake Rotomahana overflowed into Lake Tarawera. The course of this stream is still marked approximately by the storm channel shown on the sketch.

The view north-eastwards along the volcanic belt was equally clear. The following sketch gives a glimpse of the Tarawera chasm and the craters and bridges between them, and on the horizon on the left is seen, far out to sea in the Bay of Plenty, the great fumarole of White Island, seventy miles distant, from which clouds of steam are constantly rising. The panorama from Mount Tarawera thus embraced a distance of 160 miles, and included the entire length of the volcanic zone, between whose extremes nearly all the curiosities of the New Zealand Wonderland are to be seen.

Reference has been made in this paper to the Yellowstone National Park, and nobody who has seen the "wonderlands" of both New Zealand and the United States can resist making comparisons between the kindred phenomena of these two volcanic regions. The phase of declining volcanic activity indicated by hot springs, solfataras, fumaroles, and mud volcanoes, is only a temporary episode in the history of an old volcanic area, and but few places are known to us which are passing through this phase at present. Geyser action in the Yellowstone is evidently on the decline, and even within the last twenty-five years several of the geysers and hot springs have notably decreased in power, while all the volcanoes have been extinct for many centuries. The geysers of the Yellowstone are more powerful than those of New Zealand, and since the destruction of the Terraces of Rotomahana, the "Minerva Terrace" (Plate VIII.) at the Mammoth Hot Springs, with its exquisite ornate cups and basins, is probably finer than anything that has been discovered of its kind elsewhere. The Terraces of New Zealand were precisely similar to, but far more magnificent than, those of the Yellowstone Park. Fortunately we have ample descriptions and photographs of the lost Terraces, and I

VIEW NORTH-EASTWARD FROM THE EDGE OF THE TARAWERA CHASM.

obtained several views taken by Mr J. Martin, F.G.S., of Auckland, from some of which the accompanying illustrations are reproduced. Mr Martin was engaged with his camera on the 22nd November 1885 at the White Terrace, when suddenly the geyser at the summit burst forth in an eruption of unprecedented violence. The steam ascended in a column five times as high as the cliffs above the basin, and as these are 200 feet in height the altitude of the pillar of cloud must have been at least 1000 feet. Mr Martin told me he was successful in getting a photograph of the eruption, but his camera was not large enough to take in the whole of the vast column of steam. The accompanying block (Plate VI.) is a very poor reproduction of this photo. of one of the premonitory signs of the explosion of Tarawera seven months later. The photo. of the "White Terrace Cups" (Plate VII.) is from another of Mr Martin's plates, and the exquisite sinter formation so clearly represented here is identical in configuration with many parts of the Mammoth Hot Springs geyser deposits of the Yellowstone. For purposes of comparison, a photo. of the Minerva Terrace at the Mammoth Hot Springs is appended. (Plate VIII..)

The New Zealand volcanic zone, whose outline is indicated on the accompanying map (Plate IX.), also abounds in sulphur deposits of brilliant hue, and seething mud holes of awesome aspect, whose dark and viscid contents are constantly bubbling and spluttering like thick soup or porridge in a pot. At many places the mud is so thick that it has been built up into conical mounds with steaming craters at the top, which resemble diminutive volcanoes of the most weird and grotesque appearance. Mud volcanoes and "paint pots" of white or coloured clay are also common in the Yellowstone Park, but in number and size their New Zealand relatives far surpass them. One of the largest I noticed had the size and shape of a hayrick. It was 12 or more feet in height, and consisted of dark slate-coloured clay, with a shallow crater on the top in which the viscid fluid was bubbling languidly, as if the fire had gone low and the water was about to go "off the boil." In other cases the fire had gone quite out, and the extinct mud volcano was represented by a dirty mound in the midst of the ti-tree bush, soon to be worn away by denudation and obliterated by the rapid growth of vegetation.

These and many other manifestations of the proximity of the subterranean fires make "Infernal New Zealand" a place of unusual interest to the physical geologist. The sudden and terrible eruption of Tarawera shows, however, that the region is in a state of more or less unstable equilibrium, and another explosion might at any time take place between Tarawera and the Taupo district.

MAP SHOWING THE VOLCANIC ZONE OF NORTH ISLAND, N.Z.