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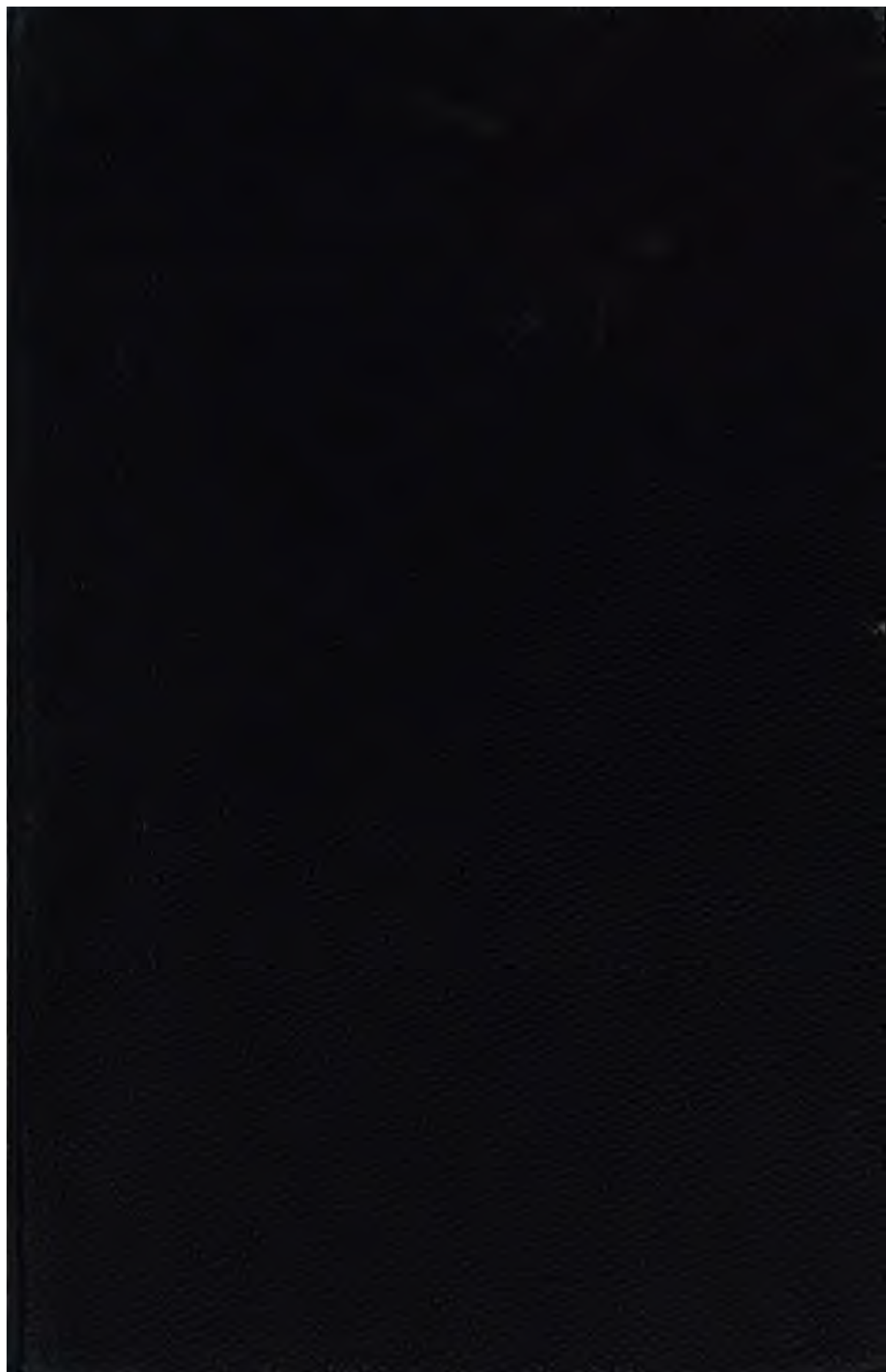
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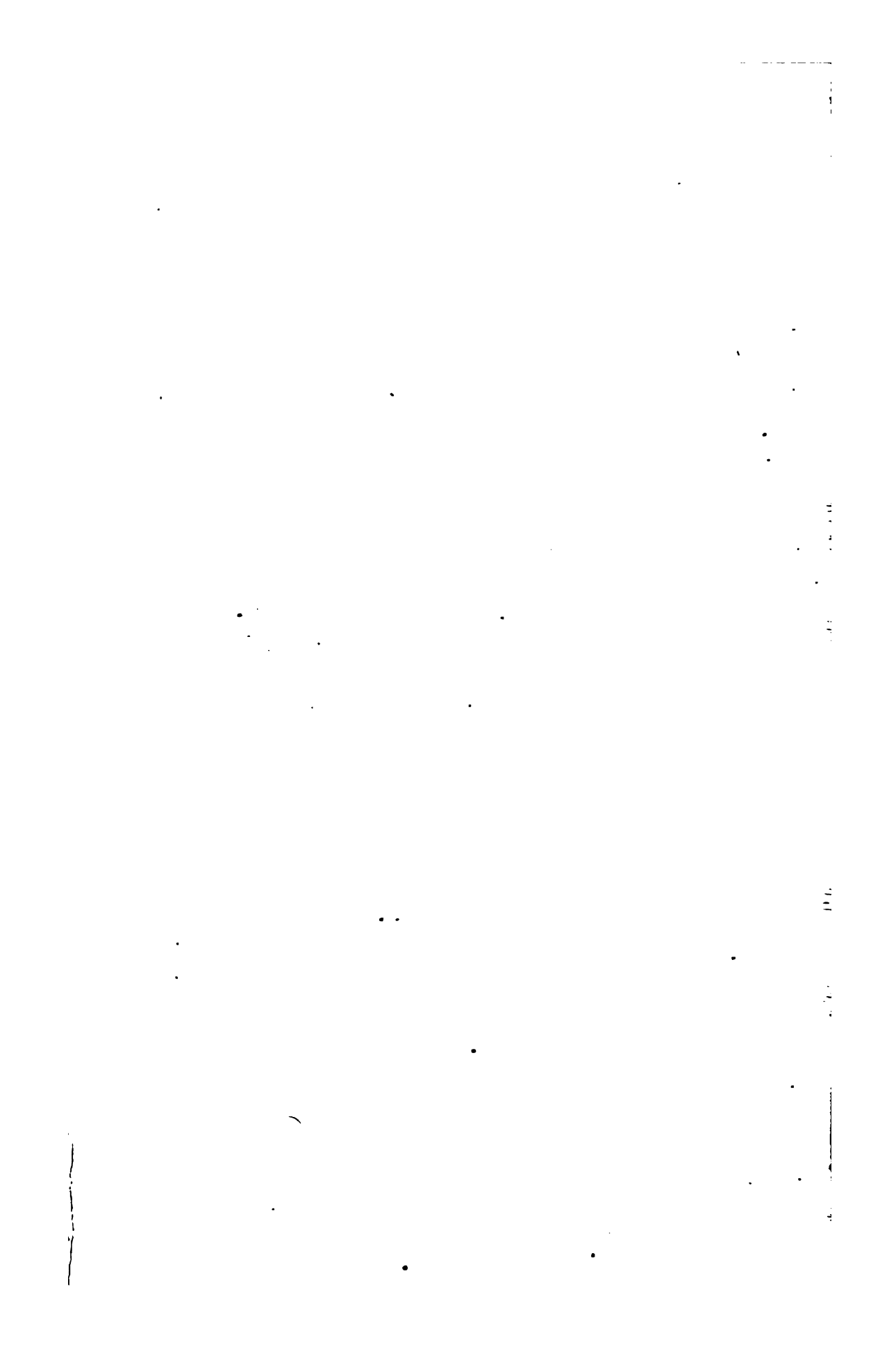
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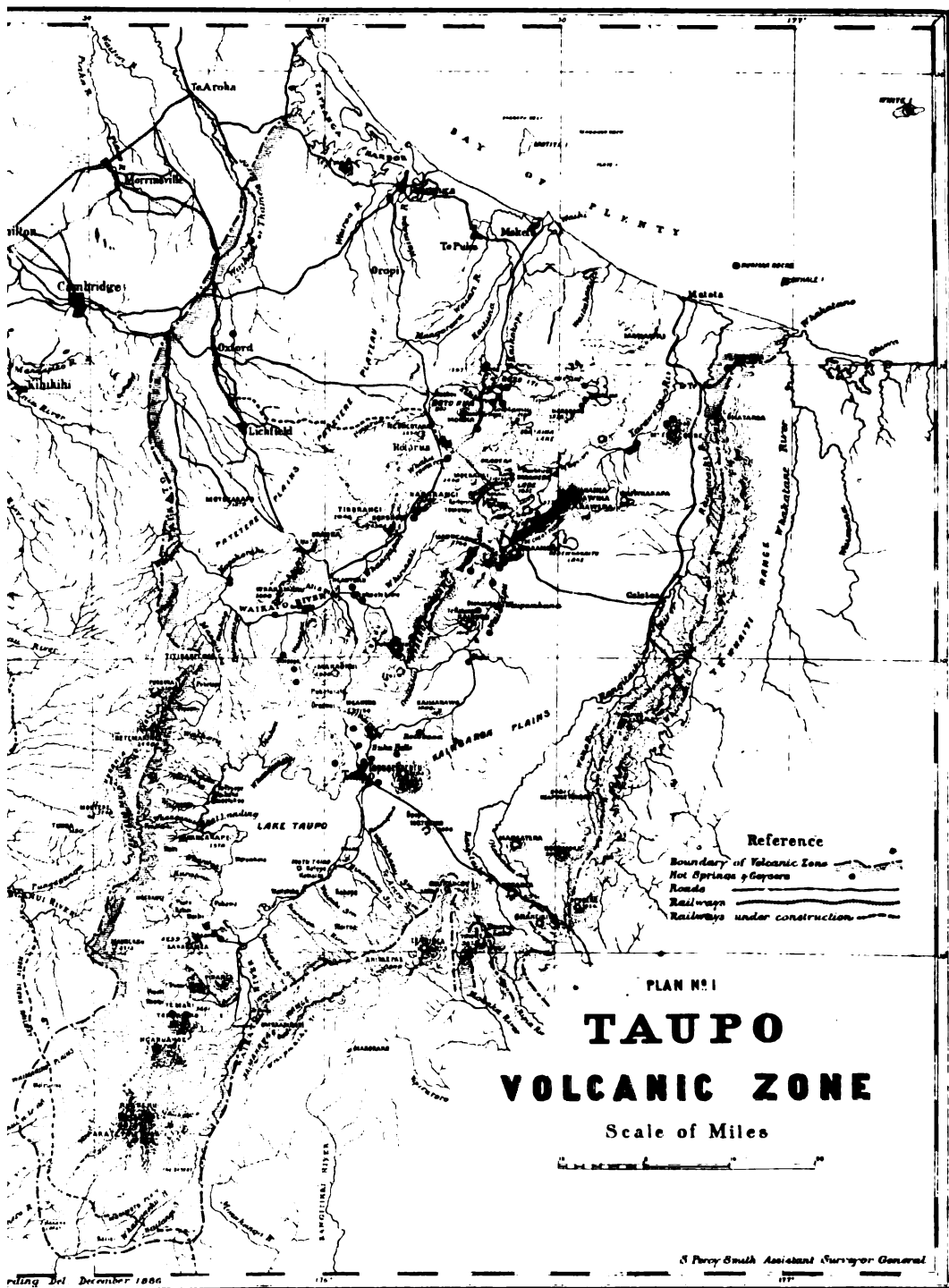
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Lindsey

THE

ERUPTION OF TARAWERA:

A REPORT TO THE SURVEYOR-GENERAL

BY

S. PERCY SMITH, F.R.G.S.,

ASSISTANT SURVEYOR-GENERAL, NEW ZEALAND.



by

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THE ERUPTION OF TARAWERA.

The ASSISTANT SURVEYOR-GENERAL to the SURVEYOR-GENERAL.

SIR,— Survey Office, Auckland, 30th November, 1886.

In compliance with the instructions contained in your telegram of the 10th June last, to the effect that the Hon. Mr. Ballance desired that I should proceed to Rotorua for the purpose of observing and reporting on the eruption of Tarawera, I have the honour to transmit herewith my final report, together with maps and drawings explanatory of the same.

In order to a clear understanding of the basis on which the report is founded, I will briefly narrate the steps that were taken to carry out your instructions.

Leaving Auckland by train on the morning of the 11th of June, I reached Oxford that afternoon, and the following morning went by coach to Rotorua, arriving at that place at 2.30 p.m. Having completed arrangements for forming a flying camp, I left Rotorua, accompanied by Mr. J. C. Blythe and Mr. C. Alma Baker, on the morning of the 13th, and formed a camp at Pakaraka, the only place where water could be found, and from there during the next three days explored as much of the country round the southern group of craters and south and west sides of Rotomahana as the thick covering of ashes and sand would allow of. Another day was devoted to the mud-covered country near the Wairoa village, and two more to visiting the hot springs around Rotorua, in order to note the changes which had occurred in them. Finding that the country near the seat of eruption was so impassable, owing to the depth of ashes, &c., as to make a visit to Mount Tarawera impossible, I returned to Auckland on the 18th June, and from there sent in my preliminary report to you. (See Appendix to Journals, House of Representatives, H.—26, 1886.)

Finer weather having set in, I again left Auckland on the 23rd July, accompanied by Assistant Surveyor E. F. Adams, and proceeded by sea to Tauranga, where we were joined by District Surveyor E. C. Gold-Smith, who went with us to Rotorua, whence, after completing arrangements for camping out, we moved on to Pareheru, a clump of wood on the edge of the ash-field, near its south-eastern side. From this camp we made daily explorations and surveys from the 27th July to the 12th August, minutely examining the whole length of the great fissure from Wahanga to Maungaongaonga, and mapping the features of the surrounding country—a work that had hitherto never been completely done. Two ascents of Tarawera and Ruawhia Mountains were made—the first on the 28th July, the second on the 6th August—when we discovered the great fissure on top, as reported to you on the 30th July by telegram. The fine weather that prevailed the greater part of the time enabled us to get quickly through the work, especially as travelling over the mud- and ash-covered hills became very good. Part of the time however, especially towards the last, it was rainy, with some snow, and a cold greater than I had hitherto experienced in this country, the thermometer going down to $19\frac{1}{2}^{\circ}$. The wet converted the ashes and sand into mud of exceeding tenacity, rendering travelling a work of extreme slowness and fatigue. I finally returned to Auckland on the 16th August.

The character of the survey is that of the ordinary topographical work performed by the department, but with more attention to detail. The points are fixed by theodolite observations from bases derived from the major triangulation, and the heights are deduced from the same source and by the same method, with the addition of a large number of aneroid levels, which were subject to constant check from the trig. stations.

It has been my endeavour in this report to describe the actual changes which have taken place, and to give as full and complete an account of the formation of the fissure as possible; for I am well aware that an opportunity is here presented of studying phenomena which are rarely witnessed—at any rate, in the stage in which it now is, or was, soon after the eruption. In carrying this out, I fear that the interest of the general reader has been sacrificed, and that the report will be considered as “very dry reading;” but, at the same time, I trust that the amount of detail given will throw light on some of the more obscure questions of the science of vulcanicity. I have to apologize for many shortcomings in the report, and my excuse

must be that it has been written, as you, Sir, are aware, in intervals snatched from the duties of carrying on the business of a large department, and therefore falls far short of what I could have wished it to be.

I feel that I am greatly indebted to Mr. C. Spencer for the permission to use his photographic views in the drawings, and also to Messrs. Valentine, Martin, and J. C. Blythe for the same.

I have, &c.,

S. PERCY SMITH,

Assistant Surveyor-General.

Jas. McKerrow, Esq., F.R.A.S.,

Surveyor-General, Wellington.

DESCRIPTION OF THE TAUPO VOLCANIC ZONE.

As it is possible that the following account of the eruption of Mount Tarawera, which took place on the 10th June, 1886, will be read by people who have no personal acquaintance with that part of New Zealand in which the outburst occurred, or have not at hand such books of reference as exist to apply to, it is deemed advisable to preface such account with a brief description of the volcanic district known as the "Taupo Zone" of New Zealand. Some advantages may be obtained by following this course, for, though traversed by Dieffenbach in 1840, by Von Hochstetter in 1859, and later by the officers of the Geological Survey Department during the last twenty years, no description exists of many parts of the district such as is necessary to a clear understanding of the relation it bears to the recent eruption. The splendid generalizations of Von Hochstetter leave, however, little to be added but the alteration of some details, and the addition of information as to points which his limited time precluded his visiting. It was the fortune of the writer to have been engaged on the trigonometrical and topographical survey of the Taupo Zone, during the course of which, and in innumerable journeys made through and across it subsequently, an opportunity was afforded of ascending nearly every hill of any note, and of forming an intimate acquaintance with all the thermal and volcanic phenomena displayed in the district. At the same time, the account professes to be mainly a topographical one, showing the changes which have taken place, the alteration in the face of the country, and the present state of the various points of activity, based on observations made during the months of June, July, and August, 1886. Furthermore, as, during the course of the late topographical survey of the district affected by the eruption, a large amount of information was obtained bearing on the actual occurrences at the outburst and prior to it, it has been thought advisable to incorporate in this account a short description of the phenomena observed, and thus make it as complete as possible.

A reference to Map No. 1 accompanying this report will show how large a part of the central regions of the North Island of New Zealand is occupied by the volcanic rocks of the Taupo Zone. Included in that term are rocks of various compositions, but all belonging to the acidic class, consisting of trachytes, rhyolites, obsidian, pumice, and the various tufas, breccias, and agglomerates derived from them, all of which belong to the younger volcanic series of Von Hoch-

stetter. They are of Tertiary age, dating from the Eocene* period, when volcanic activity seems first to have commenced in this district. And this activity has continued with varying intensity down to the present time. In the area shown on the map (4,725 square miles) none but volcanic rocks or their derivatives are to be found, and if the rocks of the same character which have been derived from this source are added, we shall find more or less volcanic matter scattered over a country nearly as large again. Within the district will be found types of volcanic action of all kinds; active and extinct craters, immense lava flows, enormous deposits of pumice, vast areas covered with volcanic mud and sands, solfataras, fumaroles, mud-volcanoes, hot springs, lakes and rivers, healing waters of various descriptions, geysers, natural hot baths and sinter-terraces, combining to make this one of the most attractive portions of the earth, either for its natural wonders or for the picturesque beauty there displayed.

To enumerate all the points of interest within this area would be beyond the scope of this paper; but some reference to a few of the most prominent is necessary to an understanding of their general character and relation to the recent occurrences.

It will be observed that the longer axis of this volcanic zone has a direction nearly north-east and south-west, and if we continue it in the former direction we shall find that the islands off the coast belong to the same volcanic series. White Island is an active volcano, though now in the solfataras stage, its crater, half a mile in diameter, being filled by a lake but a few feet above sea-level,† the water of which is warm, while along its edges arise high into the air columns of steam, which may be seen for a hundred miles round, and which deposits sulphur and other minerals in the fissures of the rocks through which it passes.

Whale Island has hot springs on it, and on the adjacent Rurima rocks steam can occasionally be seen issuing from the ground.‡

To the north-west, Mayor Island has one of the largest extinct craters in the district, the steep inside walls of which glisten with black shining obsidian in immense quantities; but even here the volcanic forces are not yet extinct, for hot springs are found on the eastern side of the island, near high-water mark.§

* Hector, "Outline of the Geology of New Zealand," Indian and Colonial Exhibition Catalogue, 1886.

† At the present time the bed of the lake is dry.

‡ Major Mair (Trans. N.Z. Inst., Vol. V., p. 15) says, also, "These islets at one time abounded in hot springs. In places the shores consist entirely of siliceous deposits, contorted in the most fantastic manner. Most of the rocks are, I think, trachytic."

§ Mr. Eric C. Gold-Smith, in his account of Mayor Island (Trans. N.Z. Inst., Vol. XVII., p. 421), says, "The crater is five miles in circumference, and is very well defined,

A line drawn from White Island south-westerly through Ngauruhoe will indicate very nearly the line of greatest activity of thermal action of this district, the principal springs, &c., being situated either on, or but a short distance from this line, and it will terminate on the summit of Ruapehu, 8,878ft. high, the highest mountain of the North Island, and which has lately proved to be in a state of activity, though hitherto always considered to be extinct. And if we pursue our inquiries back to a period preceding the present one of thermal activity, we shall find that extinct but generally perfect craters are to be found on several cones along this same line; whilst in the other parts of the district, though signs of former activity are everywhere present, no such craters are to be seen. Immediately to the north of the active mountain, Ngauruhoe, 7,481ft. high, are situated the remains of the magnificent cone of Tongariro—a name which is usually applied to its active neighbour—6,500ft. high, on the summit of which are found six craters of different ages, two of which, however, may still be said to have some life left in them, for they emit a little steam from their fissured sides; whilst on the north-west, a few hundred feet below the crater-rim, are some very active hot and sulphurous springs, called “Ketetahi” and “Te Mari,” showing by their presence that the volcanic fires are still smouldering beneath the mountain.

Standing but a short distance off on either side of this central line, and just a little to the south of Lake Taupo, are Kakaramaea, 4,258ft., and Pihanga, about the same height, near the summits of both of which traces of craters can be seen, whilst at the foot of the former a group of hot springs, lately visited by District-Surveyor Cussen, the first European to see them, denotes the presence of volcanic heat at no great depth.

Passing to the north of Lake Taupo, we find Mount Tauhara, 3,603ft. high, a fine conical hill, with crater on top, now extinct, and clothed at the bottom and western side with a forest of fine trees.

being marked out by lofty hills and ridges, which vary in height from 1,162ft. down to 100ft. The interior sides of this vast amphitheatre are very precipitous, and composed of a great variety of volcanic *débris*. Obsidian and pumice are, however, the principal minerals found; the obsidian in some places having evidently cooled in layers, which gives it a stratified appearance. At others it is found in rocks, boulders, lodes, and reefs, which, glistening in the sun's rays, produce a very pretty effect. On some parts of the sides is found a conglomeration of minerals, all of which have been in a state of fusion.” “In the north-west corner or curve of the crater there is a most peculiar hill, called ‘Tarawakoura,’ with a strong pa on its summit. It is connected with the crater-edge by a narrow ridge, and, from its appearance, has been a volcano. Its sides are not very steep, but are covered with large blocks of scoria, over which has grown a dense vegetation of stunted shrubs, &c.” “The hot springs are very small, being only little pools of warm—not hot—water, a few inches deep, scattered over about twenty-five yards of rough boulder-beach in Orongotea Bay.”

The crater-rim is very perfect on the north, east, and south sides, but the western—that directed towards the prevalent wind—has broken away. At its base, on the shores of Taupo, and along the Waikato River on both sides for some miles down, are found innumerable hot springs and geysers, all in a state of great activity, indicating the close proximity to the surface of the heated matter below.

From Tauhara northwards, the next cone with an extinct crater is situated at a distance of fifty-one miles from it. Mount Edgumbe, or Putauaki, 2,945ft. high, has on its top two craters, one of which contains a small lake, and the sides of both of which are clad with forests of very old growth. The mountain itself is a most regular cone, rising out of the plain with steep curved slopes, and without the presence of any neighbouring hills to detract from its symmetrical shape. At its base is a group of hot springs, again showing that the forces which elevated it have simply transferred their locus to a point where they more easily find a vent, and proving that they have not died out altogether.

Finally, at a distance of sixty-three miles in a north-north-west direction, is situated the extinct crater of Mayor Island, or Tuhua, already alluded to, the highest point of which is 1,274ft. above sea-level.

There are thus six extinct volcanoes in the Taupo Zone, all of which have more or less perfect craters; and although they are extinct, inasmuch as no activity (excepting on Tongariro) is found in the craters themselves, every one of them has hot springs quite close to its base, showing that the volcanic forces have simply changed their position and the character of their activity, and are not finally extinct. It is well known that this is a common phase in the life-history of many volcanoes, and is due to the decreased power of the elastic gases to force solid matter up to the higher elevations of the crater-bottoms, whilst they still have power to find a vent for the more gaseous compounds at lower levels, by the aid of the fissures so common in all volcanoes. As far as the writer's knowledge goes, all of these extinct volcanoes are characterized by rocks of the trachytic or rhyolitic formation, and no scoria is anywhere present. The lavas of Tongariro are the most recent, and are plainly visible descending the mountain-sides, sometimes ending on its steep slopes in the abrupt manner common to viscid lavas of the acidic class. In one of its craters is a beautiful example of a lava-stream which has flowed across the level bottom, and has spread out in form like a club-moss. In the other cases the lava is

generally hidden by surface decomposition, or overlaid by an earthy covering, due probably to sands and dust ejected from the vents, and now consolidated into an arenaceous rusty-coloured clay, the presence of which over extended areas of the Taupo Zone is a marked feature, and on the origin of which the late eruption has thrown much light, as will be noticed later on.

The volcanic energy to which is due the craters, active and extinct, and the thermal action briefly alluded to above, is apparently but the dying effort of an energy which in times antecedent to their formation far eclipsed them in magnitude and extent. The products of volcanic action which cannot be traced to any visible vent far exceed in bulk and extent of country covered those already described. Right and left on both sides of the north-east and south-west line of activity extend vast flows of trachytic and rhyolitic lavas, deep beds of pumice and volcanic mud, of enormous extent. Possibly the vents from which these lavas flowed have disappeared by denudation; or they may now be hidden by their own products. There are several reasons for supposing that some of the lakes have been craters. Taupo, for instance, notwithstanding its size, shows some indications of this. Possibly it consisted of a series of craters, the separate walls of which, by gradual erosion, have all disappeared. Observations made by Mr. L. Cussen, of the Survey Department, during his late hydrographical survey, tend towards this view.* The margin of the lake for seven-eighths of its circumference is formed by steep cliffs and hills of rhyolitic lava, with a generally horizontal stratification; and these cliffs at Karangahape, on the west side, rise nearly perpendicularly to a height of 1,100ft. above the lake, whilst the sounding-line dropped over the bow of the boat when its stern touched the cliff found bottom at a depth of 390ft. These cliffs are formed of alternate beds of lava and agglomerate. Motutaiko, the island near the eastern shore, formed of rhyolitic lava, rises very steeply from a depth of 400ft., and is possibly an old volcanic neck, the surrounding materials and the upper portion of which have been dispersed. Part of the eastern and northern shore of the lake is formed by cliffs of pure pumice, rising in one place to a height of 300ft. above the lake, and spreading thence north and easterly for many miles, covering the Kaingaroa Plains with a deep deposit on which nothing but a sparse vegetation of tussock-grass, tea-tree, and manoa scrub grows, and through which the copious rains filter till they reach the underlying lava and tufa, along the surface of which the water follows, appearing

* *Vide* Appendix for Mr. Cussen's official report and map.

at the edges of the plateau as waterfalls descending the face of the lava flöes.

There are also indications that some of the smaller lakes to the north may have in former times been craters or points of explosion. Such a centre is at or near Lake Tikitapu, around which for miles the rhyolitic lavas seem to have spread out in gently-inclined beds, all of which (at any rate, on the west, south, and south-east side) have a quaquaversal dip from that locality. Some evidence from the earthquake-cracks and subsidence-lines in the neighbourhood points in the same direction, as will be shown further on. The roughly circular form of the lake and the high perpendicular cliffs encompassing its southern side are suggestive also of a crater. Rotokawau, also—a small circular lake, with encircling cliffs and a hot spring on its margin—is possibly a crater of the same character as those in the Eiffel, formed by a gaseous explosion, as described by Lyell, Scrope, and others. Hochstetter, however, states that all the lakes of the Taupo Zone are due to subsidence.

Popular belief ascribes to the craters of Ngauruhoe and Ruapehu the vast mass of pumice which covers the Taupo Zone from end to end in varying depths; but it is more reasonable to suppose it to have emanated from some source nearer to where the greatest bulk of it is found. It is doubtless of different ages, and that which covers so vast an extent of country outside the Taupo Zone proper, generally as a thin sprinkling on the hills, with deeper deposits along the valleys and river-courses, may be the last effort of some of the extinct craters described, as well as of the active ones, Ruapehu and Ngauruhoe. The great depth of pumice however, around the north end of Taupo and on the Kaingaroa Plain, is more likely to have been formed at the time when the great rhyolite lava streams around that lake and the tufas to the north were exuded from vents now lost.

The north shore of the lake is formed by deep pumice-beds, but at no great depth the lava flow will be found, as witnessed at the Huka Falls, three miles below the outlet, and along the lake-coast south-westward. This lava would appear to have flowed in a northerly direction under what is now the Kaingaroa Plain, and in its extension northwards it becomes tufaceous, as might be expected, until it finally terminates in the wall-like northern end of Kaingaroa, a few miles south-east of Tarawera mountain. It is everywhere overlain by pumice more or less deep, but decreasing in amount from south to north. The manner in which this pumice-deposit wraps round the isolated slate hills in the neighbourhood of Runanga and northern end of the Kaimanawa Mountains, forming a generally level plain,

tends somewhat to the belief that it was deposited in a lake; but the evidence has not been followed out sufficiently to allow of this being stated as an ascertained fact. Large logs of carbonized wood are sometimes found in this locality, buried deep in the pumice-strata, which may have been carried there by water, unless indeed, they owe their present position to a similar cause to that which placed the logs around Rotomahana, to be referred to later on.

If a line is drawn from the summit of Ruapehu, east to within fifteen miles of the coast, and thence north-easterly towards the East Cape till it strikes the road from Gisborne to Opotiki, and thence to the coast on the Bay of Plenty by that road, whilst another is made to extend from Ruapehu northerly to near Matamata, and thence to the coast at Tauranga, we shall include an area of country of about 10,775 square miles, over the whole of which more or less pumice is found on the tops of the highest hills, with deeper deposits in the valleys. Nor is this pumice always in a fine state of division: on the hills inland of Hawke's Bay and far to the north the lumps are frequently of the size of an orange, and at the eastern bases of the mountains it has often accumulated in drifts, as if by the action of the wind blowing it over the ranges.* The Waikato River, which drains the larger part of the Taupo Zone, is noted for its perfect terraces, all formed of pumice; and many other rivers, such as the upper branches of the Wanganui, are similarly terraced to a depth of hundreds of feet—pure pumice being the formation—the bulk of which has doubtless accumulated in the lower grounds by being washed off the hills. On many of the mountains within the Taupo Zone the pumice is but a few inches deep, whilst immediately at their bases the valleys are filled to a depth of 200ft. with it, and these now form level plains, once the beds of lakes, through which the water has worn deep channels down to the bed-rock, exposing the sections of pumice, often containing large fragments of carbonized wood. A good example of these former lake-basins filled with pumice, three in number, is to be seen under Tuahu, the steep ascent on the coach-road from Rotorua to Taupo. Many of the minor plains within this district, which have level surfaces surrounded by hills with one or more low outlets from them, and the surface of which is formed of deep pumice, must have been lakes. The worn, shore-like cliffs, the stratified pumice, all point to their having been such; and the origin is in many cases due to the valleys in which they lie having been blocked, and the waters dammed back, by pumice and volcanic dust.

* For further particulars of the pumice-deposit, see Trans. N.Z. Inst., Vol. IX., page 565.

The size of the blocks of pumice varies much in different places, showing doubtless, that it originated from many points. On the shore of Taupo, 50ft. above the lake, can be found blocks containing as much as a thousand cubic feet. On a level plain (an old lake-bed probably) not many miles north-west of Runanga the ground is so covered for ten or fifteen square miles with large blocks of pumice, closely packed together, that no horse can cross it, whilst the adjacent undulating Kaingaroa Plain has few blocks of any size. The immediate vicinity of Ruapehu and Tongariro has less pumice on the surface than probably any part of the Taupo Zone: it is present in fine particles, but to no great extent, the surface being formed by a dark-brown earth or loam, forming a more fertile soil than is usual in the district.

In addition to the craters, active and extinct, the lava and pumice-beds, the district is studded with isolated hills of a characteristic shape and appearance. They take the form of a flattened plateau, or somewhat conical hill, but always encircled by steep precipitous mural cliffs of trachytic or rhyolitic lava, the decomposed portions of which form a more or less steep talus below. Good examples will be found in Ngongotaha, Haparangi, Tutuhinau, Tutukau, Ngautuku, Moroa, Tuahu, Nganiho, Tumunui, Marotiri, &c. These and other hills have all a strong family likeness and a somewhat similar height, varying from about 2,500ft. to 2,800ft. Their origin is somewhat obscure. Hochstetter, who saw some of them, believes them to be the remains of a former plateau which extended from Horohoro eastwards and southwards. The hills in question are all composed of the two lavas above mentioned, whilst the Horohoro Mountain, and the plateau extending northward from it, are composed of tufas, forming possibly the extension of the lava-plateau westward, where we should naturally expect to find this class of rock—that is, outside of the lava. It is noticeable that all the hills of this class are situated to the north-west of the great fissure to be referred to later on, and that nearly all of them are within the boundaries of the area enclosed by that and the most westward fissure.

Some indications observed from the peculiarity of their shapes in more than one instance tend to the probability that they are the denuded remains of vents or volcanic necks, formed by the harder and more consolidated portions of the lava-streams where they issued from the depths below; their extensions having disappeared by ordinary meteoric agency.

The forest-clad region lying on the west side of the Taupo Zone

north of the Waikato River, known under the general name of the Patetere Plateau, and which ends to the south in the Horohoro Mountain—whose perpendicular inaccessible cliffs are prominent landmarks over a large extent of country—is composed of trachytic tufaceous rocks, generally soft, and grey in colour, overlain by thin and local strata of pumice and the rusty arenaceous loam before referred to. Its average height is about 1,800ft. to 2,200ft., and on its western side it slopes for a long distance by easy grades towards the upper waters of the Thames River, whose numerous branches have cut deep gorges into its lower parts, and frequently formed cañons with steep sides of tufaceous rock.

The superficial rusty-coloured clay (or earth, for it has no plasticity), together with the lighter deposits of pumice, cover a very large area in the Taupo Zone; but they are generally confined to the western side of the main north-east and south-west axis. Within that area they form the subsoil, and vary somewhat in composition, being occasionally fertile, but generally only partially so. Abundant evidence is to be found that they are due to one of the latest efforts of volcanic agency in the district. The clay covers the country as with a mantle of snow, taking the same inclination as the slopes of the present hills; and frequently underneath it can be traced a former land-surface. It is, in fact, an exactly similar deposit to that ejected by the craters recently formed, with this difference: that it covers an enormously greater extent of country and is of a different colour, due, doubtless, to the action of rain-water on the iron matter contained in all volcanic ejecta. The recent deposit from Rotomahana is grey in colour; but time will doubtless alter its appearance to that of the older deposits. Its great extension has hitherto prevented a proper understanding of the nature of this deposit; but if a minor explosion such as that of Rotomahana can cause such changes in the face of the country in six hours, what would not a few similar explosions on a somewhat larger scale effect over this large district? Evidently this rusty-coloured clay fell in an exactly similar manner to the mud at the Wairoa—in the form of an exceedingly heavy rain, charged with mud. It was accompanied by simultaneous deposits of pumice; for we find this substance gathered in hollows or pockets in the loam, and these also conform to the slopes of the ground. Generally the hills are sprinkled with it to a few inches deep, showing that the ejection of pumice was the latest effort of the vents from which both deposits came.

From what has been said above it will readily be inferred that the covering of clay and pumice is, geologically speaking, of quite

recent origin. It was subsequent to the changes which have taken place in the contour and depth of some of the lakes, as is proved by finding it spread in the same equal manner over the former bed of Rotorua. Both this lake and that of Taupo have well-defined terraces, or ancient shore-lines, encircling their present basins, the former at about 120ft., and the latter at about 100ft., above their present levels.

If we turn now to a consideration of the existing points of greatest thermal activity, as exhibited in the geysers, solfataras, and fumaroles, we shall find that the same axial line from Ruapehu to White Island marks also the direction along which the greatest activity is displayed. The accompanying map (No. 1) indicates the several groups of hot springs, &c.; but it is impossible on so small a scale to show the individual springs, which may be numbered by hundreds, and of varieties innumerable. It will suffice to point out that the greatest activity in the district is seen at Tokaanu, at the south end of Taupo; at Wairakei, near the north end; at Orakeikorako, on the Waikato, but at a short distance off the line to the west; in the Waiotapu Valley; at Rotomahana, the most active point of all, and which is nearly half-way between Ruapehu and White Island; and lastly, at Ohinemutu, Whakarewarewa, and Tikitere, points much further to the west, and which are probably on another fissure, which nevertheless, has an intimate connection with the one under consideration, as will be seen later on. By varying this line very little from a strictly lineal direction, and making it a slightly sinuous one, we shall find that in addition to its denoting the region of greatest activity of thermal action, it will follow well-marked features in the physiography of the country, characterized by river-valleys, low plains, lake-margins, and the comparatively low flat water-parting between streams draining into Rotomahana and the Waiotapu. Along this somewhat sinuous line running water in considerable volume is found everywhere but on the above-named water-parting, and there it is absent for not more than half a mile. These facts, taken in conjunction with the presence of all the craters, both active and extinct, in the immediate proximity of this line, point directly to the great probability—nay, certainty—that we have here a line of weakness in the earth's crust, in which the molten matter from below is quite near the surface. A fissure doubtless exists along which the lava wells up, seeking a vent to escape the pressure of the incumbent strata, and down to which part of the water of the rivers finds its way by percolating through crevasses and fissures, its contact with the heated matter giving rise to the thermal phenomena exhibited. It would be

contrary to observed facts in other countries to suppose that this fissure takes a mathematically straight line from White Island to Ruapehu: the weight of superincumbent rocks, of different degrees of hardness or method of formation, would render it somewhat devious from a true line, though its general direction throughout varies but little from such a one. We shall see later on, that the recent eruption, although it deviates somewhat, but to no great extent, from the general direction, is on the line of this fissure. That such a fissure is deep-seated, and intimately connected with the larger and more general lines on which the two Islands are built up, is proved by its parallelism to the great mountain-backbones of both Islands. The opinion may also be hazarded that it is as ancient as the volcanic region itself, and possibly is the same from which emanated the first signs of activity in Eocene times, when it was probably submarine.

Whilst recognizing this as a great fissure of the earth, and the principal one of the district, it is quite probable that others and nearly parallel ones exist. An almost exactly parallel line drawn from the hot springs at Orakeikorako to the hot springs at the end of the eastern arm of Lake Rotoehu, indicates another line along which are a number of hot springs and fumaroles of considerable activity, and which line passes along the wall-like face of the Paeroa Range, and through the old lake-basin of Waikorua, a place which is riven by earthquake-cracks, and in which are several deep crater-like holes, probably the sites of former thermal action. The southern half of this line seems to mark a fault with a downthrow to the north-west, with the Paeroa Range, 3,244ft. high, rising on the east, and with the low undulating country of Ratoreka to the west.

Although the presence of a fissure in this locality seems to be borne out by the facts as stated, another hypothesis is possible with respect to part of it. By starting from the same place, Orakeikorako, and taking a direction somewhat more inclined to the east, slightly curving it at the north end of the Paeroa Range, it will be found to take the direction of the recently-formed fissure, and thus form a connecting-link between the two, by lines converging and meeting in Tarawera Mountain, or in Rotomahana crater.

Again, at about twelve miles to the north-west of the great fissure, and lying nearly parallel with it, a line drawn from the hot springs on the Waipapa Stream to those on the Kaituna River near Taheke, Rotoiti, seems to indicate—by the presence of several hot springs, geysers, fumaroles, and mud-volcanoes—another fissure of about thirty-five miles in length. Along this line are some very celebrated springs, such as Whakarewarewa, Ohinemutu, &c., with

the hot-mud caldrons and boiling sulphurous waters of Tikitere a short distance off it to the east, and the Waimahana Springs on the Waikato River to the west, these latter being the most westerly or north-westerly ones of the Taupo Zone. And here again, as in the great fissure, we find this one following, (or being followed by,) a marked depression of the country, along which the main streams flow, and on which are situated the lakes Rotorua and Rotoiti. Somewhat to the north-west of the continuation of this line we find another hot spring near Maketu, close to the coast of the Bay of Plenty, and, equally with the middle fissure, its southern part seems also to indicate a fault running along the edge of the Horohoro Mountain and the Patetere Plateau; but it is here much more obscure and more sinuous than the opposite one of Paeroa.

East of the great fissure, no signs of thermal action are found until the volcanic district is left, and a point well within the old slate rocks forming the main range of the Island is reached. At Tarawera, on the Napier coach-road, a distance of about forty-four miles from Taupo, is a hot spring, and south of that again, at the foot of the Ahimanawa Mountain, are a few hot springs and a small hot stream, none of which, however, are of much importance, nor are they connected with volcanic rocks.

Whilst the number of places within the Taupo Zone at which hydro-thermal action is still in full force may be counted by the thousand, and in which every known variety of such action is exhibited, it is the prevalent opinion of both learned and unlearned that in former times the forces producing it were far more active, and in some respects on a grander scale, than at present. No one can traverse the district without seeing on all sides evidence of former hot springs, now extinct. Even within the memory of those living, geysers have ceased to play, temperatures have sunk, and the activity generally appears to have decreased. The traditions of the Maoris bear witness to the same facts; and amongst a people so observant of natural phenomena, and whose traditions have been handed down orally from father to son with such scrupulous care as to make them almost equal in value to documentary evidence, it is not likely that such changes would escape their attention. Making due allowance for possible exaggerations in these traditions, there is no doubt that they are correct in stating that the thermal activity has been decreasing. But it is to be observed that none of their traditions speaks of any such catastrophe as that which has lately occurred; indeed, it is impossible to believe that any such occurrence has been witnessed by the Maoris during the five or six hundred years of their occupancy of this

country, or the signs of it would still be visible to any one having a habit of observation.*

That the Maoris were very observant, however, of natural phenomena is well known, although the reasons they assign as the original causes of such phenomena or events appear to us often absurd, but at the same time frequently poetical. The well-known story of the origin they assign to the volcanic fires of the Taupo Zone shows this observant faculty, while, at the same time, exalting the powers of one of their great ancestors, Ngatoroirangi, who was the high priest of one of the original canoes—the “Arawa”—in which the first emigrants came to this country; and this legend, as pointed out by Hochstetter, truly indicated the line of greatest activity. It is abridged below, as taken from Mr. S. Locke's translation.†

To recapitulate briefly what has been stated with respect to the Taupo Zone: we find that the volcanic rocks extend immediately to the westward from, and are abutting against, the much older series of slate rocks of the backbone range, of Palæozoic age; that the rocks are acidic in character; that a definite axial line, running about north-east and south-west between the extreme points—each end marked by active volcanoes—indicates the line of greatest present activity, and that this is probably a fissure in which the molten lavas are everywhere near

* The eruption of the Waikite geyser, at Ohinemutu, which occurred eight generations ago, cannot be compared, of course, to that of Tarawera, although it caused the death of a number of persons, belonging—strange to say—to the same Tuhourangi Tribe who suffered so much lately. These people, it seems, were camped outside of the Ohinemutu village when the geyser exploded, throwing mud and stones all over that part of the ground, killing and scalding many; but the village itself is said to have escaped any damage.

† “This is an account of one of our renowned ancestors who visited the sea of Taupo, and the open country, the forests, and the plains around. He came to this island from Hawaiki in the ‘Arawa’ canoe, which landed first at Whangaparaoa (near the East Cape), then sailed on to Whakatane and Maketu. After Ngatoroirangi had resided on the coast for a time he travelled inland by way of Kanakaua, Ruawahia, and Te Punatahahi. After crossing the Kaingaroa Plains he reached Tauhara Mountain, which he ascended, and from thence looked down on the sea of Taupo and at the snow-capped Tongariro in the distance. Ngatoroirangi then descended to the shores of the lake, near Waipahihi, and performed incantations and erected a *tuahu*, naming it Taharepa. When he discovered there was no fish in the lake he scattered the threads of his mat on the waters and performed religious rites, and the lake at once contained fish—viz., the *inanga* and the *kokopu*. He then travelled along the shores of the lake and ascended Tongariro, and was there benumbed with the cold on that snowy mountain. His companion, Ngauruhoe, died here from cold. So Ngatoro commenced calling out to his sisters to bring him fire from Hawaiki; for they had been left behind there. His sisters heard him and came at once, bringing fire. Their canoe was a *taniwha*. The sisters landed at Whakaari (White Island), and here lit a fire (geyser), and then came on to the main land at Umakopkapoka (a geyser), and then travelled on by the Kaingaroa Plains. The sisters lit a fire (geyser) at Tarawera Lake, then ascended a hill and looked down on Rotorua Lake; one of them slipped down here, so they called the place Te Hemo, and lit a fire (geyser) there, and then proceeded on to Paeroa and Orakeikorako, where they lit another geyser, and shortly after arrived at Taupo. But Ngatoro had returned to Maketu, so the sisters determined to join him there,” &c. (Trans. N.Z. Inst., Vol. XV., page 435.)

the surface; that it is along this line the recent eruption has taken place, and further, that the volcanic rocks on either side of this line differ somewhat in character; and finally, that the volcanic forces have been gradually dying out, the present activity being hydrothermal rather than volcanic.

PREMONITORY SIGNS.

A sense of security had thus—owing to the decreasing action of the volcanic forces—been induced in the inhabitants of the district, and no fears or expectation of any violent outburst hindered the gradual settlement of the country in the neighbourhood of the springs. For ages past the Maoris had selected their villages in the immediate vicinity of the boiling waters, induced thereto by the facilities offered to culinary operations, the additional warmth to be gained in an atmosphere pervaded by hot vapours, or the pleasures of a plunge into the ever-warm baths. As European settlement extended, the neighbourhood of the most famous hot springs was fast becoming occupied. Hotels and other accompaniments of civilization were a frequent adjunct to the Maori village, built frequently in the midst of steaming solfataras and fumaroles; and but for the accident of difficulties in connection with the Maori titles, many more Europeans would ere this have occupied the district. The far-famed terraces of Rotomahana were year by year attracting larger crowds of visitors to view their wonders, and had not the eruption occurred a hotel would ere this have been erected in their neighbourhood on the very site of what is now a roaring crater. It is a matter of hearty thankfulness that the eruption occurred at the time of year when the visitors had nearly all left the district, or we might have had to add to the already long list of killed, the names of others from all parts of the world. And yet, notwithstanding the universal opinion as to the decadence of the volcanic forces, there were signs in the air shortly preceding the eruption, which, if properly understood, would have told that some changes of moment were taking place—which should have acted as a warning to those who now lie buried under the ashes at Te Arika, Rotomahana, and Wairoa. Some few of these premonitory signs may be mentioned.

Although quite unconnected with the late eruption, a change of a somewhat remarkable nature in Lake Rotokakahi is here recorded, as showing that the volcanic forces were active, though unnoticed except in the locality, for some time past. In April, 1881, there was a sudden and unaccountable rise in the waters of the lake; and again, in October, 1883, without any warning whatever, the water

suddenly rose for 4ft., causing a flood to rush down the Wairoa Stream into Lake Tarawera, whilst at the same time the olive-green colour of the lake was changed to a turbid, muddy appearance. The water fell the following day as suddenly as it rose. The cause of these phenomena is obscure; but, as they occurred at a time of year when little rain falls, and as no visible stream supplies Rotokakahi, they must have been subterranean, and evidently connected with volcanic action.

In March, 1880, the coasts of the Bay of Plenty, and indeed, far outside it, were strewn with millions of dead fish of all descriptions, and as these showed no signs of disease, it follows that probably they were poisoned. The line of the great fissure passes south-westerly from White Island under the sea towards the shore of the bay, and if, as is possible, an eruption of gases, even on a small scale, was to take place anywhere along this line, the result would doubtless be that fish in great quantities would be destroyed. We have no direct evidence as to whether this was the case; but it is a reasonable inference in the absence of any exact information as to other causes.

Very nearly a year previously to the eruption of Tarawera the crater-lake of White Island disappeared, leaving its bed quite dry, and it remains so to the present time. Changes, however, in the level of the lake were not uncommon, and have been noticed for many years past; but, as far as can be learnt, it has never been so completely dry before.

For some time previously to the eruption the hot springs in the neighbourhood of Mount Edgecumbe and Te Teko were noticed to be much more active than usual, and the water of a higher temperature.

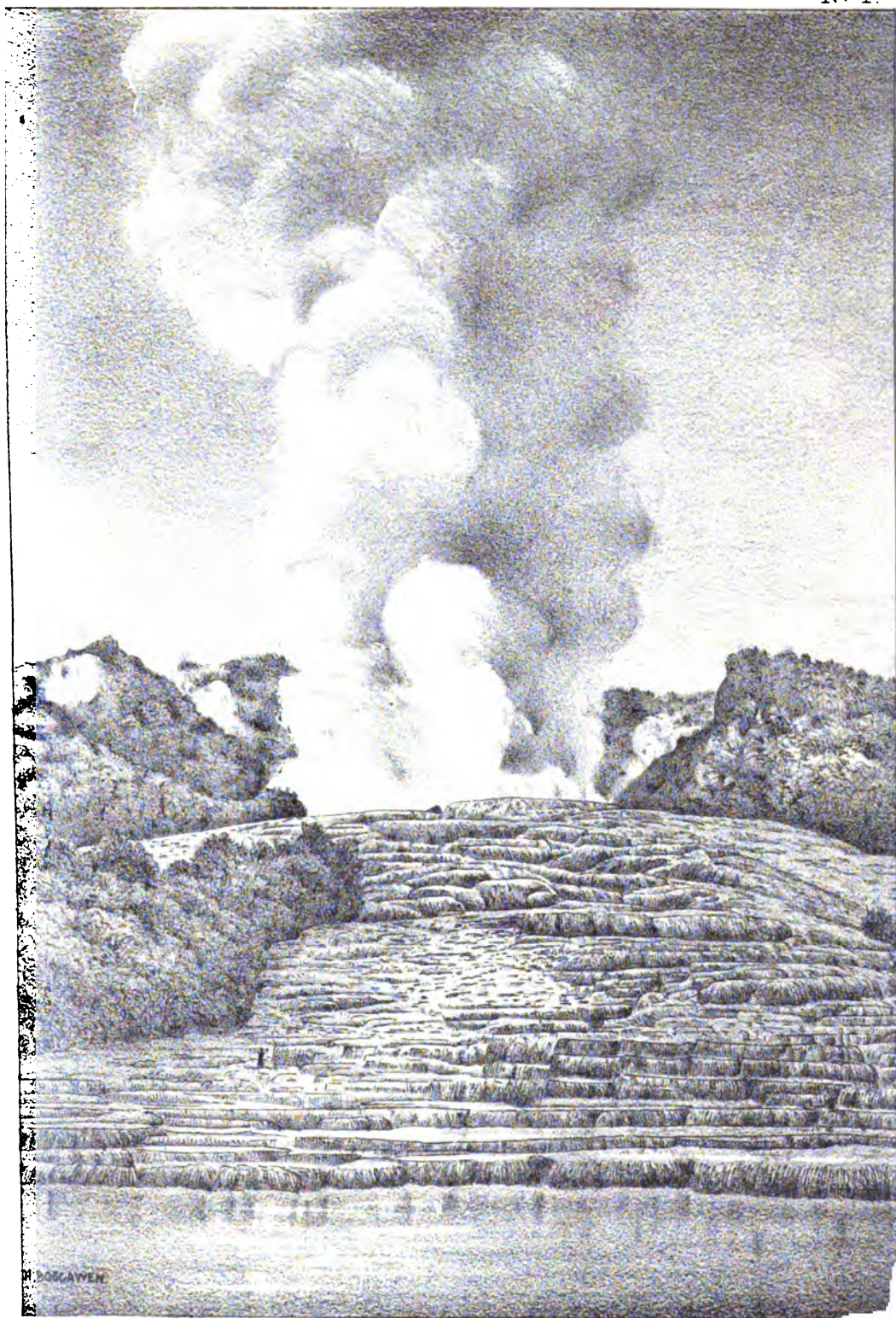
Next in order, and much nearer both in time and locality, was a change in the fountain which supplied the waters of the White Terrace of Rotomahana. It is a well-known fact that the water in the great caldron on top of the terraces was affected in a remarkable manner by the wind. This is so clearly described by Captain Gilbert Mair, F.L.S., in his paper, "Notes on the Influence of Atmospheric Changes on the Hot Springs and Geysers in the Rotorua District" (Trans. N.Z. Inst., Vol. IX., p. 27), that it may be transcribed here. He says: "Perhaps the most singular instance of atmospheric influence is in the case of Te Tarata, the White Terrace of Rotomahana. The great crater, which is about 90ft. in diameter, is usually full of deep-azure-blue-coloured water, occasionally boiling up 10ft. or 15ft.; but when the keen south wind, or *tonga*, blows, the water recedes, and you can descend 30ft. into the beautifully-

encrusted crater, which remains empty until the wind changes, when it commences to refill at the rate of 3ft. or 4ft. per hour, boiling and roaring like a mighty engine. When the crater is almost full, grand snow-white columns of boiling water, 20ft. in diameter, are hurled 60ft. into the air. Blue waves of boiling water surge over the shell-like lips of the crater, and fall in a thousand cascades over the alabaster terraces." This was not by any means an uncommon event; but Mr. Josiah Martin, F.G.S., who was staying at the terraces in the month of November, 1885, was lucky enough to witness an eruption of the waters on a far grander scale, a description of which he has been good enough to supply as follows: "From the 19th to the 21st November, 1885, the wind was from the west to south-west, with rain-squalls and a falling barometer. The water from the caldron was flowing down the terrace as usual. On the 22nd the wind changed to south, with clear, calm weather, and a rising barometer. The activity in the caldron ceased, and the waters began to recede within the basin. By 6 a.m. the basin was empty, the water having retired into the tube below. At 12 noon, the activity had again commenced, and the water was rising within the tube. At the same time it was noticed that the barometer was falling. At 1 p.m. the action of the water was feeble, but agitated, and rising slowly within the basin. By 4 p.m. the action had become vigorous, and dense clouds of steam were given off; and at 5 p.m. the basin was half full, the water violently agitated. Suddenly a deep boom was heard and felt on the upper terrace, like an underground explosion, and the water in the basin was instantly lifted into a huge dome, from out of which shot vertically with enormous velocity a glistening fountain, the top of which was lost to sight in the dense mass of accompanying vapour, the broken waters falling in heavy showers around. This was succeeded by another similar outburst; but the height attained was not so great. The Maoris, observing this eruption from the lake, were greatly surprised, and said it was the most violent they had ever seen. By 8 p.m. the activity had ceased, and the water had retired about 1ft. within the basin, the barometer rising at the same time. On the 23rd, a calm, clear morning, the basin was empty, but the tube full, with very slight ebullition, in which state it continued till evening, when the terraces were dry and the barometer falling. On the 24th, the early morning was calm and clear, with a rising barometer. Very suddenly, at 6 a.m., the water was violently active. Two explosions occurred, each throwing up the water more than 150ft., accompanied by a dense column of steam rising rapidly to a height of 800ft. or 1,000ft.,

followed by several smaller eruptions ejecting the waters to 100ft.. By 8 a.m. the eruption had ceased, and the basin was quiet but full, and the barometer rising. A slightly-increased activity, with constant overflow down the terraces, was noticed at 4 p.m. From the 24th to the 28th November the activity was normal, with a constant overflow and high barometer, the winds being light and variable, with bright, clear days, cold nights, and hot weather. During the first four days the overflow occurred with falling barometer and low readings, and ceased when the barometer was rising. During the subsequent period activity was renewed with rising barometer and continual higher readings; and from these and previous observations I consider north and north-east winds, with heavy weather, most favourable for excessive overflow, and that action has generally ceased, and the basin been emptied, with a south wind and bright, clear weather." It is to be regretted that Mr. Martin's beautiful mezzotint picture of this eruption, enlarged from an instantaneous photograph, cannot be reproduced here; but the drawing attached (Plate No. 1) gives some idea of what it was like. As respects the Tarawera eruption, this minor one is adduced as evidence of the increasing activity and changes taking place on the line of the great fissure. It is noticeable that the Maoris who have always lived near Rotomahana never saw (or presumably heard of) any occurrence on such a scale before.

On the 10th March, 1886, the writer was at Wairakei, near Taupo, a place celebrated for its geysers, hot springs, and boiling-mud pools, and where the hydro-thermal action is displayed in a variety of forms not often seen. On visiting one of the geysers called the Twins, it was found to be in great commotion, throwing up the water to a height of some 20ft., a thing it had not been known to do for a long time previously.

Reference has already been made to the fact that the grand mountain of Ruapehu, situated at the southern end of the Taupo Zone, and which bears on its shoulders a deep mantle of perpetual snow, had until quite recently been supposed to be a volcano whose fires had ages ago died out. But on the ascent of the southern peak, Pari-te-tai-tonga, by Mr. W. Cussen in 1884 the lake lying in the crater-like hollow near it exhibited some differences from ordinary basins of cold water which inclined Mr. Cussen to suggest the possibility of the water being warm, if not hot. It was impossible to descend the steep snow-bound walls to decide the question, and it therefore remained in abeyance until March of the present year, when Mr. L. Cussen, in the execution of his triangulation, again made the ascent on two occasions. All doubt was then set at rest by his find-



ERUPTION OF WHITE TERRACE - 22nd NOV^r 1885.
From a photograph by M. J. Martin, F.G.S.

Plate № 14



RUAPEHU FROM OHINEPANGO

ing the crater-lake to be steaming, and the waters showing that turmoil of surface common to hot-water lakes, whilst the snow had been melted for some way up around the margins, particularly so on the side where the prevalent westerly wind had blown the heated vapour on to it. Mr. Cussen states that it is impossible to get down to the level of the lake, on account of the steepness of the snow-covered sides, without the aid of appliances, which his other duties precluded his providing. There is no doubt, however, that the agitated waters and the steam rising from the surface prove that thermal action is still going on. On the 16th April and 23rd May last he observed from the lowlands to the west a column of steam rising up to a height of about 300ft. above the mountain-top, over the crater-lake, and at other times since then has seen more or less vapour at the same place when the surrounding atmosphere has been quite clear.

Mr. Dunnage, a young officer of the Survey Department, who performed the difficult feat of ascending the southern peak on the 8th June (almost in midwinter), reports: "The snow was in a favourable condition for climbing, but it was necessary to cut each footstep for the last thousand feet. The height given by the barometer, which was very low that day, was 10,200ft. [The true height is 8,878ft.] Large quantities of steam were issuing from the little lake in the centre of the crater, nearly 1,000ft. below us; but was all condensed before reaching the top. The cold was very severe."

Major Scannell, residing at the north end of Taupo, in answer to inquiries, says, "There can be no doubt about it. The steam was noticed from here, and I saw it myself rising from the mountain about three weeks previous to the eruption, but nothing whatever since."

The Maoris have no tradition of any activity, either volcanic or thermal, ever having been noticed on Ruapehu, nor have the European settlers ever seen or suspected anything of the kind previous to the twelve months before the eruption of Tarawera. The only prior indication of anything of the kind which might have led to a suspicion of the true character of the mountain was the fact that the waters of the Whangaehu River, flowing from a point high up in its side, were of a peculiar nature—strongly acid and flavoured with sulphur, of a milk-white colour, and extremely unpalatable either to man or beast; but no weight was attached to this as indicating that the mountain contained thermal springs on its top.

To anticipate somewhat the order of events, it may be stated that Mr. A. B. Wright, when crossing this river at the usual place on the 20th July, found that a change had taken place. The water was quite

The enumeration of the above-mentioned facts goes to prove that along the whole line of fissure, from White Island in the north to Ruapehu in the south, a more than usual degree of activity was displayed some time prior to the eruption; and if we had records of the various other springs, &c., along the line, possibly other evidence might be adduced. It is not the purpose of this account to deal with the Tarawera eruption as bearing on the volcanic activity as exhibited in various other parts of the world during the past few years, or to trace any connection between the local outburst and lines of volcanic force which several writers suppose to be connected with that of New Zealand; but it is significant that seismic and volcanic activity have marked the last few years as quite exceptional in that respect. We can only hope that the wave of activity has passed, and that New Zealand, having contributed its share, will now regain its usual state of quiescence.

THE ERUPTION.

Wednesday, the 9th June, was wet, with heavy showers and squalls from the south-west, which cleared up by nightfall. The evening was fine, allowing many to see the occultation of Mars by the moon, which occurred at 10.20 that night. There had been some rain during the previous week, but no great amount, and this was the first rain of winter after a long dry summer.*

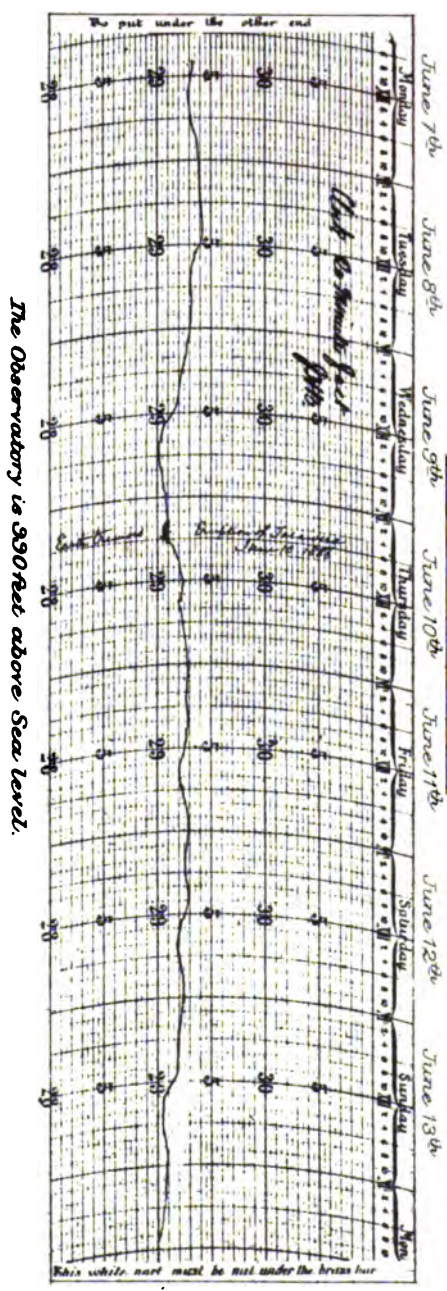
The readings of the self-registering barometer at Rotorua showed no sign of atmospheric disturbance, as will be seen by the following table, the readings being reduced to sea-level: 8th June, at noon, 30.2in.; at midnight, 30.08in.: 9th, at 6 a.m., 30.03in.; at 10 a.m., 29.97in.; at noon, 29.90in.; at 6 p.m., 29.80in.; at midnight, 30.01in.: 10th, at 2 a.m., 30.01in., (eruption); at 4 a.m., 30.20in.; at 6 a.m., 30.30in.; at noon, 30.30in.

The description of the phenomena observed at the actual eruption is taken by permission from a paper read before the Auckland Institute by Messrs. S. Percy Smith and J. A. Pond, on the 12th July, with some additions and alterations derived from subsequent inquiries by the writer.

The best account obtainable seems to place the first sign of anything extraordinary being at hand at about 1 a.m. on the morning of Thursday, the 10th June, 1886, when slight earthquake-shocks were felt by the people of the Wairoa, a village situated just eight miles from, and nearly due west of, Mount Tarawera; and also by those of

* The rainfall for June, as registered at Rotorua, was 4.74in. (Vide *New Zealand Gazette*, 1886, page 1296.)

BAROMETRIC RECORD AT ROTONDA - 1896.



The Observatory is 390 feet above Sea level.

Rotorua—accompanied at the latter place by rumbling noises—which appear to have been continued with varying degrees of intensity up to 2 a.m. or past. At 2.10 or 2.20 the rumbling noise had increased to a continuous and fearful roar, and at that time was accompanied by a heavy shock of earthquake. At this same time, or immediately afterwards, an enormous cloud of smoke and vapour was observed from the Wairoa rising over the hills which shut in that village from a clear view towards Tarawera, the outside edges and margins of the different masses of which were outlined by vivid flashes of electricity darting through the cloud, and colouring it most brilliantly and beautifully. This electric display was accompanied by repeated claps of loud thunder, and by a rustling or crackling noise which appears to have been distinctly heard above the deafening roar, and which is probably the same as that heard in electric discharges of an artificial kind, and also in auroral displays. This heavy shock of earthquake is, doubtless the same as that reported at Maketu at 2.30, Tauranga at 2, Whakarewarewa at 2.30, Opotiki at 2, and Oropi at 2.30 a.m., the differences of time being due to local inaccuracies of clocks. It was noted by two observers—Messrs. Blythe and Greenlees—that from 2.30 onwards severe shocks occurred at regular ten-minute intervals up to 3.30; and it was between these hours that the outburst at Rotomahana occurred, for Mr. Blythe noticed that the white cloud of steam arising therefrom was first seen about 2.30, that from Tarawera being black by contrast. It is proved by several witnesses that the eruption of Tarawera took place first; and Mr. McRae, of the Wairoa, who witnessed the scene, shortly after the first outburst, from the old mission-house, believes this to have been shortly before 2 o'clock. As seen by himself and others, this consisted of three columns of smoke and fire—or probably the glare reflected on the vapour from the heated lava below—shooting up into the air from the flat plateau-like summit of the mountain to an immense height, with flashes of electricity darting forth in all directions, accompanied by balls of fire, some of which fell at great distances, whilst others appeared to roll slowly down the steep sides of the hill towards the lake. Small stones now began to fall at the Wairoa and at Kaiteriria, as the great black cloud which had rapidly formed over the mountain worked its way towards the west, to be quickly followed by a downpour of mud and water and occasionally heavier stones, some of which were hot, which battered down some of the houses in the village, and in other cases lodged in the thatched roofs. The mud appears to have fallen in the form of an exceedingly heavy rain, with occasional large lumps; and

this continued up to 6 a.m. During this downpour, stones of various sizes continued to fall, endangering the lives of those who ventured out of the houses; and, as the stones prove to be of the same scoriaeous nature as those found on top of the mountain, they must have come from there, although the mud, doubtless came from Rotomahana and the fissure in which Rotomakariri Lake was formerly situated. All this time there appears to have been a more or less strong odour of sulphurous and other gases experienced by the people of Wairoa; and Mr. Blythe describes a hot suffocating blast which nearly choked himself, Mr. Lundins, and Miss Haszard, after their escape from the burning house, and which warmed them through—a welcome change from the bitter piercing cold which appears to have prevailed the whole time.

Soon after the commencement of the eruption, and before the fall of the first stones, a great wind rose, which rushed down the valley of the Wairoa towards the eruption, and which branched off by Tikitapu Lake, rushing up the funnel-shaped valley there, prostrating the beautiful forest, and utterly destroying it.

It is noticeable that the people who survived and were nearest to the seat of eruption—viz., those at the Wairoa—failed to hear the loud detonations which reached Auckland and other places: possibly the loud and continuous roar drowned the other reports by interference. These explosions were heard at Hamilton, Cambridge, Coromandel, Te Aroha, Taupo, Christchurch, Nelson, Blenheim, Auckland, New Plymouth, Helensville, Whangarei, Waiapu, and Wellington, and in a much less degree at places on the Bay of Plenty Coast.* They sounded like the reports of distant cannon, or, as has been described by a large number of people, like the noise caused by blows on an iron tank. A considerable disturbance of the atmosphere was noticed in Auckland in the form of vibrations of the air. After each report the windows of the houses rattled and shook as much as they would have done from a slight earthquake-shock. The flashes of the electric display also were distinctly seen there, a distance of 120 miles in a straight line from Tarawera. It must have been on the grandest scale. The vast cloud appears to have been highly charged with lightning, flashing and darting across and through it, sometimes shooting upwards in long curved streamers, at others following horizontal or downward directions, frequently ending in balls of fire which as often burst into thousands of rocket-like

* It is strange that the reports were not heard at Lichfield, only about forty miles to the west, whilst they were heard distinctly at Waotu, about six miles further off. Mr. Howard Jackson suggests that the waves of sound were deflected by the eastern side of the Patetere Plateau, and so carried over the heads of the people of Lichfield.

! "ball lightnings" 29 or "UF's" or "gig" stars

stars. Fireballs fell at the Wairoa and other places. Doubtless the streams of lava reported as having been seen coursing down the sides of Tarawera were some of these slowly rolling along the surface, or appearing to do so from the point of observation. Mr. Blythe describes some of them as moving horizontally along the edge of Lake Tarawera, just under the mountain, in such a manner as to give rise to the belief that they were lights in the boats from Te Ariki. Whilst sheltering in the verandah of Mr. Haszard's house he saw a large ball of fire fall on the roof and slowly roll over to the ground, and there disappear. In all probability Mr. Haszard's house was set on fire either by one of these, or by the lightning, as was also the forest on the north side of Lake Tarawera, which was burning a few days after the eruption in several places.

The immense cloud of ashes and dust which was shot high up into the air, driven first by the south-easterly wind in a westerly course, and then by the south-west wind in a northerly and easterly direction, quenched the bright moonlight and darkened the sky for hours after daylight should have appeared. The Cimmerian darkness was such as "could be felt." Charged with its burden of ash, dust, and sand, it gradually spread from the point of eruption, one edge of it taking a north-westerly direction, the other nearly east, until it passed out to sea, dropping as it went its load of matter all over an extent of country covering 5,700 square miles of land, the extreme western point of which was on the coast near Tairua, the extreme eastern being at Anauroa, a few miles north of Gisborne—points 160 miles apart. All over this area more or less fine ash, dust, sand, or scoria can be found, decreasing in quantity as the focus is left, the extreme edges being so lightly covered that the deposit disappeared with the first rain.

The height to which this dust-laden cloud and its accompanying brilliant electric discharges reached, was enormous. It was clearly seen from Auckland by several people, one of whom, Mr. R. Arthur, of Mount Eden, carefully noted the height of the topmost edge as seen against the profile of a neighbouring hill: the angle of elevation, afterwards measured by Mr. Vickerman, of the Survey Department, gives a height above sea-level of 44,700 feet, or a little over eight miles. Great as this height may appear, it is less than the observed height of the column of steam arising from Krakatoa, as measured by Professor Verbeek in 1883, which was 50,000ft. Archdeacon Williams, at Gisborne, who took some rough observations of the cloud, calculated the height to be six miles.

Mr. Eric C. Gold-Smith, District Surveyor, Tauranga, has collected

the following data from gentlemen living on the coast of the Bay of Plenty as to the times that the first fall of dust and other phenomena occurred. At Tauranga it began to fall about 6 a.m., first lightly, afterwards heavier, and then lightly again, till it ceased finally at noon on the 10th. Depth of deposit, about half an inch. The darkness was so great that no gleam of daylight appeared till 10.30 a.m.; the greatest darkness being from 9.30 to 10.30, from which time it gradually became lighter till 11 a.m., when the sun was first visible. The passage of the cloud was accompanied by a strong sulphurous smell.

At Te Puke, on the evening before the eruption, there was a light east wind, changing to the south about 4 a.m. on the 10th; and at 6 a.m., just at dawn, the first fall of light dry ash was noticed, which, as the south wind freshened to heavy squalls, with rain, turned to mud, with an increase of quantity. By 8 a.m. the dust was falling steadily, but dry, the rain-squalls having ceased. At 12.30 it finally ended. Depth of deposit, 3in. At 6.30 the darkness was intense, with thunder rolling overhead, accompanied by lightning seen at intervals through the dense cloud. It gradually cleared off, till at 1 p.m. the sun was just visible.

At Maketu, the dust began to fall at 4.30 a.m., and the air was full of it at 1.30 p.m. Depth of deposit, 1in. A slight appearance of daylight at 6.50 a.m., but total darkness from 6.55 till 9.45 a.m., and more or less dark till 1.30 p.m. when the sun was first seen. Strong electrical disturbance noticed on the 16th April and 3rd, 5th, 10th, and 14th June. On the 5th June very strong, and lasting from 9 a.m. until 12.10 p.m. The telegraphist, Mr. Benner, who kindly supplies the above, says, "I had never seen anything so continuous as the electrical disturbance on the 5th until the 10th June, when the wires became altogether unworkable from 5.50 a.m. until 9.50, and continued later but not so strongly."

At Whakatane the dust began to fall at 3.30, and at 8 a.m. it was wet like wet sand; the fall ceased about 9.30. Depth of deposit, 3in. The darkness came on (eclipsing the moonlight) at 4 a.m., and it was not light till 10.30. The dark cloud appeared to travel down the Whakatane Valley, its nearer edge flashing with lightning, accompanied by rolls of heavy thunder and a rumbling noise.

At Opotiki, it was pitch-dark till 10.20 a.m., from which time it gradually brightened till noon, when the sun became visible. The dust began to fall at 3.30 a.m., and continued steadily to do so till 10 a.m., and in a lesser degree from that time till noon, when it ceased. Depth of deposit, 1½in. The cloud as it approached was seen

to be illuminated with chain and forked lightning, and many balls of fire seemed to fly upwards from base to top. x

At Orete Point daylight broke as usual, but it became quite dark again at 8 a.m., and remained so till 11 a.m. Depth of deposit, 1 in.

At Waiapu, near the East Cape, Mr. White states that it was quite dark till 11 a.m., and that the dust fell to a depth of $1\frac{1}{2}$ in., most of which has since been washed away by the rains. It was so dark at 10 a.m. that a candle could not be seen at 10 ft. distance through the falling dust.

At Motiti Island, Mr. Douglas states that it was daylight as usual, but that shortly after 7 the black cloud came over and caused it to be pitch-dark till 11 a.m., the lightning flashing and the thunder rolling through it the whole time. Depth of deposit, $\frac{1}{2}$ in.

At Oropi, (just on the edge of the deposit,) the dust first fell at 8 a.m., softly at first, quickly at 9 a.m. and slightly moist, ceased at 10 a.m. Depth of deposit, $\frac{1}{2}$ in. At 9 darkness set in ; 9.15, total darkness ; 10 a.m., bright again. In addition to the ordinary thunder there seemed to be constant explosions within the cloud, with continuous zigzag lightning, and for three hours intense cold.

At Mayor and Alderman Islands the dust fell to a depth of $\frac{1}{2}$ in.

At Rotorua the dust began to fall at 4 a.m. It was quite dark at 7.30, and again at 9 a.m. Depth of deposit in the township, $\frac{1}{2}$ in.

The earthquakes accompanying the eruption are described as severe ; and, no doubt, to those who experienced them they appeared so, but, judging from the effects at Rotorua and other places, they cannot be properly so called—no light articles such as bottles or vases on shelves appear to have been thrown down, nor can these earthquakes be compared in point of severity with those experienced in the neighbourhood of Cook Strait in 1843 ; 16th, 17th, 19th October, 1848 ; or that of the 23rd January, 1855, which elevated the coast near Wellington and formed the great fissures at Wairau, in the Southern Island. They were evidently much more severe in the immediate neighbourhood of the eruption, and especially in the southerly continuation of the great fissure towards the Paeroa Mountain ; for here we find the ground cracked and fissured to a considerable extent, but in all cases these cracks follow the lines of former ones, or lines of subsidence (faults, in fact), as will be shown later on. Still, notwithstanding their lightness, they were felt over a considerable area of country, extending in several cases outside the zone of volcanic rocks, and were continued in many parts for six weeks after the eruption.

The following notes respecting them have been collected :—

Tauranga.—The first shock felt at 2 a.m. on the 10th, the

heaviest at 4.30 a.m., and constant light shocks and tremors were felt up to the 25th July.

Opotiki.—First shock at 2 a.m., subsequently frequent slight shocks.

Te Puke.—First shock felt at 1.30 a.m.; two severe shocks, one at 4.30, the other at 9 a.m., with continuous slight shocks and tremors for two days.

Oropi.—First shock at 2.30 a.m., continued motion every ten minutes up to 6 a.m. It is worthy of note that this part of the district seems to have been more subject to continued heavy shocks up to the end of July than any other part, excepting only the immediate vicinity of the eruption.

Whakatane.—First shock noticed at 3 a.m., with continuous subsequent shocks, the most severe being those at 3 a.m. and at 5 a.m.

Maketu.—First shock felt at 2.30 a.m., the most severe at 4.32 a.m., and the period during which the heaviest and most frequent shocks were felt was from 4.32 a.m. to 6.30 a.m., and a rather heavy one at 8 a.m.

Matata.—Shortly after midnight; continued and severe shocks subsequently continued up to the 19th June.

Rotorua.—Slight rumbling and shake at 1 a.m., heavy shock at 2.10 a.m. and at 4.30 a.m., and since that date continued up to the end of July, when they ceased.

The earthquakes were also felt at Te Aroha, Waiorongomai, Cambridge, Lichfield, Waiapu, Taupo, and, no doubt, at numerous other places; but those named seem roughly to mark the western limit of them. At Galatea they were continuous and heavy for some days, but eastwards of that we have no record except at Waiapu*, the country being inhabited solely by Maoris.

In the immediate vicinity of the eruption, at the survey camp, Pareheru, they were felt daily from the 25th July up to the 8th August, when they ceased, the cessation being accompanied by a decrease in the activity of the various points of eruption.

From early in the morning of the 10th, when the great cloud of dust and ashes descended, covering the country for miles round the seat of eruption, nothing was visible of the mountains until the morning of the 13th. Everywhere a great cloud of smoke and vapour, lying close to the surface, hid the face of the country from those anywhere in the neighbourhood to the west. Of the five or six

* The heaviest shock of earthquake ever felt by the European inhabitants of the district occurred in the first week in September (the 3rd), when also a heavy shock was felt in the neighbourhood of Cook Strait.

Europeans living at Galatea, some twenty-five miles to the east, two—Mrs. J. C. Blythe, and, subsequently, Mr. H. Burt—attempted on the 12th to get through to Rotorua by the usual track, but had to turn back, as they found the road cut off by deep deposits of ashes. Mr. Burt subsequently reached Rotorua on the night of the 12th by a long detour, and he brought the news that the eruption had extended some few miles south-west of Rotomahana. The first sight of Ruawahia and Tarawera Mountains, on the morning of the 13th, at once disclosed to those who were acquainted with their shapes that a great change had taken place. The nearly level plateau-like top had become higher, and was broken up into a series of little peaks, from near which columns of smoke and vapour arose into the air. But the eruption had evidently ceased as far as the ejection of solid matter was concerned. A vast column of vapour arose from Rotomahana for at least 15,000ft. in height, and the roar it made was to be heard continuously, with sharper detonations occasionally, for a distance of sixteen or eighteen miles.

Subsequent observations prove that nothing was ejected from Wahanga, Ruawahia, and Tarawera but black and red scoria; and, as none of this fell after 6 a.m. on the 10th, it follows that the eruption was practically all over in six hours, as far as those mountains are concerned. But with respect to Rotomahana it is not so clear. Evidently the mud which covers the country from Rotorua to that place came from there, and this ceased in places where observations could be made by 6 a.m.; but whether the sand and ashes around Rotomahana and the southern group of craters were all ejected within that short space is doubtful. Most probably the eruption was in that locality of longer continuance. It had, however, quite ceased on any scale by the morning of the 13th, though paroxysmal outbursts from a large number of vents continued for some time longer—indeed, up to the 6th August, when the Black crater was in eruption for a short time.

When we come to consider the changes that have taken place in the face of the country, and the depth and amount of solid matter removed by the action of water flashing into steam, it is marvellous that so much energy could have been compressed into so short a space of time. Obviously the magnitude of the eruption must not be gauged by the time it lasted. It has already been stated that more or less dust, sand, or lapilli is to be found over an area of 5,700 square miles; but the country affected, in so far as vegetation has been injured and farming or grazing operations interfered with, is of much less extent, amounting to about 1,500 square miles. Even in

this area, fortunately, the country brought under settlement is not very great. The farms along the coast-line of the Bay of Plenty, extending from Tauranga to Opotiki, have suffered considerably, and great loss has been entailed by the destruction of the grasses, necessitating in many instances the removal of the cattle to other districts. But, generally speaking, the country is by no means permanently affected. Already the grasses are forcing their way through the covering of dust, whilst a general opinion seems to prevail that it will eventually benefit the light soils of the district by becoming incorporated with it.

There are some very noticeable facts in connection with the distribution of the various kinds of ejecta, which can only be explained by the supposition that some of them reached higher strata of the air than others, and there met with currents differing in direction from the lower ones. The first outbreak, as has been said, consisted of molten scoria and lapilli derived from Wahanga, Ruawahia, and Tarawera. This seems to have been distributed with a fairly constant radius from a direction south-east from those mountains, round by the south-west and north; whilst from a direction east of north the lapilli seems to have been ejected with greater force, and so has reached a greater distance. From Galatea, nearly on the southern edge of the deposit, northwards to Te Teko and beyond it, down the Whakatane Valley, scarcely anything but fine black scoria is found, and as the mountains are approached the depth of the deposit and size of the fragments increase until on top of the mountains molten masses weighing several tons can be found. To the south, and far beyond the limit of the subsequent covering of sand and dust, the fine lapilli is found thinly scattered, whilst to the west the sand and mud have distanced the lapilli.

The mud (or, rather, wet sand), which lies westward from Rotomahana, and extends to Rotorua and thence northwards towards the coast, is not found far east of the Tarawera River. The source of this mud was undoubtedly Rotomahana; for, though Dr. Hector is probably correct in attributing it partly to the condensation of the steam-cloud charged with dust as it met the cold south-west wind, we have only to reflect on the vast amount of water and mud which occupied the former basin of Rotomahana, and the great area of loosely-formed rocks which have there been blown out, to see that this supply is about equal to the covering laid over the country where it is found. This mud commences within a mile of the former lake, and, as there is abundant evidence that subsequent to its ejection the crater threw out dry sand and dust, doubtless in the immediate vicinity

of the crater the mud has been covered over and obliterated. South and south-west of Rotomahana no mud is found, the deposit there consisting of dust and sand, and as the southern edge is approached this becomes an impalpable white powder, feeling and looking more like flour of a somewhat dirty colour than anything else. It has been ejected, without doubt, from the southern group of craters. Scattered all through the sands and dust, however, and at various levels, the fine lapilli can be seen, showing that the outburst of Tarawera and its neighbours continued on a diminished scale nearly, if not quite, as long as the other craters; but in mentioning this an exception must probably be made with respect to the flour-like dust on the southern edge—an exception which will be referred to later on. Reference to the other ejectamenta will find a more fitting place when describing the several craters and points of eruption in detail.

SYMPATHETIC ACTION IN NEIGHBOURING AREAS.

An attempt has been made in the foregoing pages to show that the recent eruption occurred on a line of one of the great fissures of the earth's crust: a necessary corollary of this is that the action was deep-seated, and not local and superficial; consequently some signs of sympathetic action—either of a positive or negative order—might be expected in other parts of the great fissure, if not in those parallel ones which have been described. The following notes of occurrences which took place simultaneously or shortly after the outburst tend to show that such sympathy of action does probably exist. It is true that a few of these symptoms may be due in some measure to fractures of the underlying but more superficial rock-masses induced by the frequent earthquakes, but not wholly so, or otherwise similar occurrences would have been noted at the times of former earthquakes which equalled in severity those at the time of eruption.

Although it was reported by a road-party encamped at Poutu, just under the foot of Tongariro Mountain, that they were aroused on the early morning of the 10th by hearing a loud rumbling noise in the mountain, accompanied by louder detonations like the reports of cannon, and that lightning was playing round the summit of the mountain all the time and up to daylight, and that every moment an eruption was expected; Major Scannell, residing at Taupo, neither saw nor heard anything of it. He says: "I was up during the severest part of the eruption, that is to say, from half-past 2 to 5 a.m. I thought on first waking that the sounds I heard came from Ngauruhoe, and went round to look at it. The moon had set behind our western chain of hills, but there was sufficient light left to dis-

cern the snow-capped summits of Ruapehu and Tongariro—they stood out plainly from the clear starlit sky behind : they were perfectly quiet, and there was no cloud, no lightning, nor any sign of disturbance, either volcanic or elemental. During the two and a half hours I was watching the eruption I saw the mountains at least twenty times, and there was no change whatever, nor any when viewed through the glass at 9 o'clock in the morning—nothing but the usual column of steam arising from the crater. . . . I took the temperature of some of the springs near here (Taupo) about three years ago, and kept the record by me ; and again last week, the first day I could spare since the eruption, I did so again. With the exception of two or three at the Ruahine group, round the Crow's Nest, they were all colder. Those at the Ruahine, especially that known as the ' Witches' Caldron,' were much hotter ; but, as I had taken them previously after heavy rain, I think the increase in temperature easily accounted for." Te Heuheu, living at Toka-anu, also reported the detonations which had been heard at Tongariro ; but probably both he and the road-party were deceived by the reverberation of the noises from Tarawera echoing among the mountains. This is negative evidence, but nevertheless valuable, as will be shown directly.

If we now pass to the northern end of the great fissure or volcanic belt, we find abundant evidence of great activity displayed in White Island, which has, indeed, continued for some months since the eruption.

Thursday, 10th June.—" White Island is apparently quiescent." " Te Puke settlers state that shortly after the outburst of Thursday morning a violent eruption took place at White Island. Masses of rock and volumes of steam were hurled into the air."

Friday, 11th.—" The ' Hinemoa,' which passed about midnight, reported no unusual activity." " The only alteration noticed by the ' Hinemoa ' was a fresh steam-jet playing violently at the landing-place, and that all the gannets had left the island." " Captain Fairchild [on the 16th] stated that the island was slightly more active."

Saturday, 12th.—" Mr. West, mate of the ' Argyle,' when on watch late on the Saturday night off Cape Colville, with others saw a great glare of fire in the direction of White Island, and shortly after a ball of fire arose and immediately burst into numerous stars."

Sunday, 13th.—" ' Te Anau ' passed. Saw no unusual sign except that the island was enveloped in dense cloud." (This would be at night.) " A great cloud of steam seen arising all day " (from Rotorua).

Monday, 14th.—" A great cloud of steam seen arising all day from the Township of Rotorua." *Tauranga* : " During the whole of

the day White Island could be seen discharging immense volumes of steam and smoke." "It is evident there is a violent outbreak at White Island to-day. From early morning there has been a vast cloud of steam and smoke arising and hanging over the island—almost as much as from Tarawera."

Tuesday, 15th.—*Tauranga*: "White Island continues in a very active state, and could be seen discharging volumes of steam this morning."

Ever since the eruption up to the time of writing, White Island has frequently been observed to be in a greater state of activity than usual, though not continuously so. On the 8th July it was reported "that during the last two days it has been unusually active, and large columns of steam have been rising from it." On the 15th July Mr. J. B. Jackson observed from Oreti Point "that the cloud was very dense, and, instead of rising as steam does, it lay along the water in a northerly direction, there being at the time a light wind off the land, for a distance of nearly twenty miles, the angle subtended between centre of island and edge of cloud being $39^{\circ} 22'$. I have frequently observed that the crater has been extremely active since the eruption, and on several occasions have seen what I believe to be smoke issuing instead of steam." On another occasion Mr. Jackson measured roughly the elevation of the top of the column of vapour, and made it to be about 4,200ft.

Mr. C. Alma Baker, who visited the island on the 16th September, has been good enough to furnish the following notes: "The island, with the exception of two large rents or openings—the largest of which was our landing-place—forms a perfect crater with walls about 300ft. high, from the centre of which rises a grand column of steam to a height of about 15,000ft. On landing, a roaring, deafening sound could be heard, caused by the steam issuing from the vents at the far side of the crater. Numerous jets of steam were issuing from amongst the boulders at the landing-place. Here, and for some hundred yards inland, there was very little fresh deposit—indeed, all the buildings, tram-rails, &c., formerly used by the sulphur-workers at this spot were entirely free from it, although on the face of the cliff to the eastward, and, indeed, over the whole of the interior of the crater, there was a considerable deposit of fine mud similar to that at the Wairoa. After traversing about 200 yards over greyish, slippery mud, with numerous steaming sulphur-holes on every side, we came upon the vent which produced the noise. At the bottom of a depression about 30ft. deep, with a diameter of 100ft., were several fumaroles, from which issued steam at very high pressure, with a most

deafening noise. The ground vibrated all around here for many yards. The deposit on the surface about this part was extremely curious, being composed of layers of various colours from white to black. At the west end of the depression, and close to its edge, it was very beautiful, an acre or more being covered with lovely white globules. To my surprise, I found that only a thin crust of about 6in. in depth formed the surface, whilst underneath a stick could be thrust down 4ft. or 5ft. into a whitish, soft, steaming mass something like the diatomaceous earth of Rotorua. This was in the bed of the former lake, which has entirely disappeared. Moving to the north-west for about 600 yards, and picking our way carefully along the side of the old lake-bed to avoid the many deep steaming fissures that rent the surface, we arrived at the edge of a depression about 100ft. deep, at the bottom of which lay a small lake of an indescribable milky-green hue, around which arose the forbidding black walls of the crater to a height of 300ft. From innumerable fissures in the walls large quantities of steam issued forth. At the north-east end of this lake, and raised about 3ft. above it, and immediately under the walls of the crater, was a very large steam-hole, from which issued with fearful uproar columns of reddish-brown and white steam, which rose to a height of many thousand feet. This red-coloured steam was mistaken for flame at some distance off. Strange to say, I found that the water of the lake was hardly warm, whereas from its proximity to the steam I had expected to find it nearly boiling. There evidently has been an eruption at no distant date, for mud can be seen in several places, even on top of the higher peaks of the hills outside the crater." Plate No. 2, drawn from a sketch by Mrs. Alma Baker, gives a good idea of the appearance of White Island as seen from the south-east.

Some of the "Hinemoa" people landed on the island on the 3rd September, and walked across the bed of the crater-lake, the water having disappeared. They found the principal scene of activity in the north-west portion, where steam-holes were fuming away at a great rate. The aspect of the island is changed to a considerable extent. It has been a matter of general notice by settlers living on the coast of the Bay of Plenty that the island has exhibited greater and more frequent signs of activity since the 10th June; but, evidently, from the statements quoted above, this activity has been of an intermittent character.

At Rotorua, the site of innumerable hot springs, situated on the most westerly of the three parallel fissures before referred to, a very great increase in action was noticed on the night of the eruption,

Plate N^o 2.



WHITE ISLAND
looking north-east—three miles distant.
From a sketch by Mrs. C. Alraa Baker.

which still continues. The changes, indeed, are so remarkable that it is a matter of surprise that they should have been doubted. In numbers of places in and around the Maori village of Ohinemutu, and the Government township and sanatorium, hot springs burst forth from the ground in positions where none had been known before. Near the Government Agent's house a fine spring of boiling water, 10ft. in diameter, bubbles up to a height of several inches, whilst close by are smaller ones, from which flows away northwards to the lake a fine stream of hot water. From this spot northward, following round the foot of the Pukeroa Hill—the site of many hot springs in former days, as shown by the immense mass of siliceous sinter there deposited—steam escapes from the ground in numbers of places; whilst at others little springs of very hot or boiling water come to the surface, the water from which runs away to the lake. In the pa itself several fresh hot springs appeared—some in the floor of the great meeting-house called Tamatekapua—and many of the pre-existing springs showed increased ebullition and temperature. Nearly all of these burst out on the night of the eruption.

The temperature of Rachel's bath at the sanatorium, whose normal heat is 170° Fahr., rose gradually during the twenty days following the eruption to 196° Fahr., at which it was recorded on the 1st July; whilst at the same time the volume of water was increased. In the beginning of August this spring was more active than the writer had ever seen it. At the same time the fine boiling spring from which the main supply for the swimming-bath is derived was exceedingly active, the water rising in great bubbles two or more feet above the surface. In several places over the plain on which the township stands steam escaped from vents long extinct, and at others it burst out in fresh localities.

Whakarewarewa, the Maori village situated about two miles south of Ohinemutu, has been known as the site of many active hot springs and geysers for as long as tradition goes back. Ever since the eruption these springs have been somewhat more active, but on the 25th June the boiling caldron in which the Maoris ordinarily cook their food—a place 20ft. in diameter, and to which no bottom can be seen through the clear waters—suddenly burst out into eruption, casting scalding water, stones, &c., around. This frightened the resident Maoris so much that they abandoned the village. About this time, also, the great geyser of Waikite, which had been entirely inactive for twelve years, suddenly came to life again and commenced playing, sending boiling water high into the air, accompanied by dense clouds of steam. At the end of July the Whakarewarewa geysers presented

a most beautiful sight. There were generally three or four out of the five playing at the same time, and Waikite frequently sent the water up to 60ft. and 70ft. above the orifice from which it spouted.

At the time of the eruption the level of Rotorua Lake was observed to oscillate considerably, as the following notes, obtained by Mr. Boscawen from the bath-keeper at the sanatorium, show. At 7 a.m. on the 10th it fell 1in., at 9 it rose 6in., at noon it fell 3in., on the night of the 11th it fell 5in., on the 12th it rose $\frac{1}{2}$ in., and continued oscillating for some days afterwards. Up to the end of July the waters had risen—permanently, apparently—to 19in. above their ordinary level. A good deal of speculation has been indulged in as to whether this rise is permanent, and also as to whether the lake-shore near Ohinemutu has not subsided. The lake is unquestionably higher than the Maoris ever knew it before. It would seem to be somewhat doubtful if there has been any general rise in the water: the evidence relied on appears to the writer to be insufficient, but at the same time little doubt can be felt as to the fact of a local subsidence between the Pukeroa Hill and the sanatorium. The marks carefully placed and watched by Mr. Malfroy, the Government engineer, evidently show that such a subsidence has taken place, but to no great extent. The old water-marks on the concrete sides of three of the baths at the sanatorium all indicate the same, and that the fall has been in an easterly direction. The greater height of the water in the lake is probably due to the fact that the rain-water since the eruption runs quickly over the mud-covered surface to the lake, whilst formerly the porous strata of pumice absorbed it, and only allowed of its gradual infiltration down to the lake-level. The coming summer months will soon, however, prove the matter one way or the other.

It will thus be seen that there is a sympathetic action between the forces which gave rise to the eruption in the immediate vicinity of the Tarawera fissure, and those which cause the activity in other parts of that and the adjacent fissures—a matter which will be referred to again at a later stage. Some of the phenomena observed at Rotorua and its neighbourhood may be explicable by the action of the earthquakes in fracturing the underlying rock-masses, and so allowing the escape of steam and heated water in greater quantities; but the increase of temperature and retarded outburst of the Whakarewarewa geysers until after the heaviest earthquakes had ceased, is not so clearly connected with the same cause.

DESCRIPTION OF TARAWERA AND ROTOMAHANA PRIOR TO THE ERUPTION.

In the preceding description of the Taupo Zone some reference has been made to Tarawera Mountain and Lake Rotomahana, but only incidentally so: in order to a clear understanding of the changes which have taken place in their immediate vicinity some further particulars are necessary.

Rotomahana (or Warm Lake) occupied nearly—but not quite—the lowest position on the central axis of the volcanic zone, between Wahanga and Ruapehu Mountains. Its height above sea-level was 1,080ft., and in area it covered 185 acres. The whole of this was warm water of varying temperature, in some places little more than tepid, in others approaching boiling-point. Around its margins the steam escaped from innumerable hot and boiling springs, fumaroles, and solfataras, more particularly so at the northern end, in the neighbourhood of the celebrated White Terraces (or Te Tarata), the most beautiful objects of the kind in the world. On the western shore, the Pink Terraces (or Otukapuarangi), almost equally beautiful, were surrounded by hot springs and fumaroles. The waters of the lake were of a somewhat dirty greenish hue, reflecting the sombre-coloured fern and tea-tree covered hills which surrounded it, whilst its sedgy margins afforded shelter to vast numbers of duck, teal, tereas, and other aquatic birds, which were attracted there by the warmth of the water and the strict preserve enforced by the Maori owners of the country. Several small streams of cold water found their way into the lake, bringing down the drainage of a watershed of thirty-six square miles. The outlet was from the northern end, where a strong stream of hot water formed the Kaiwaka River, which, after a course of a mile, and a descent of 40ft., fell into Tarawera Lake near the Maori Village called Te Ariki. A short distance from its mouth it was joined by the Awaporohe Stream, which drained Lake Rotomahariri.

It has often been a matter of discussion as to the source of the powerful stream which drained the lake, for it was very apparent that the few small streams running into it, added to the water flowing from the terraces and other hot springs, were quite inadequate to account for it. The eruption has, however, disclosed the fact that the supply was mainly subterranean. The watershed was bounded on the north by the Tarawera Mountain, on the east by the Kaingaroa Plain, on the south by the Maungakakamea Mountain (which stands on the water-parting of the North Island), and on the west by the

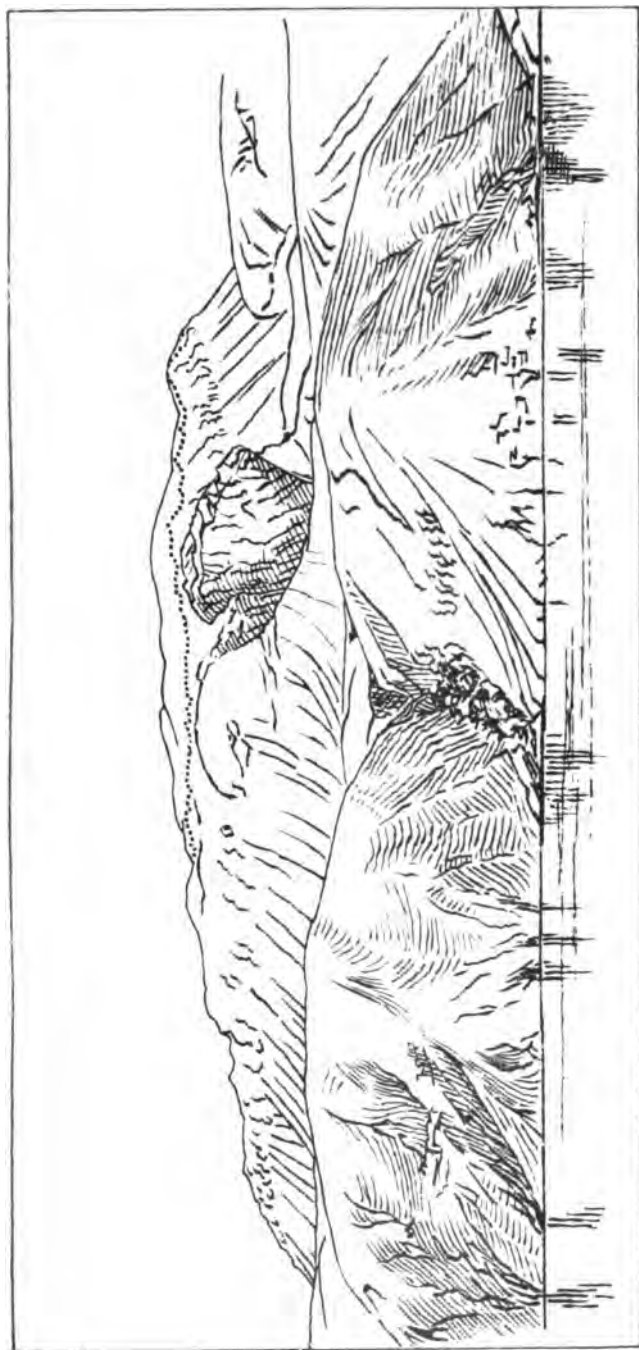
Pareheru Range. All over this area—which had a gentle slope to the lake—the surface was formed of a porous deposit of pumice and the accompanying rust-coloured loam before referred to; whilst here and there portions of the underlying trachytic or rhyolitic rocks protruded. The surface was a “graven” or “sculptured” one, due to the action of water, which had cut out numerous shallow gullies, all leading into the streams running into Rotomahana; but in very few of them could water be found. Indeed, it is one of the remarkable features of the whole of the volcanic zone that, whilst there are on every side the evident signs of a surface deeply scored by the action of water, the water itself, even after the heaviest rains, is rarely seen, and then only for an hour or so, standing in little pools or forming tiny runlets which have no power as excavating agents. Everywhere a thick growth of sombre bracken and tea-tree, or the yellow tussock-grass, covered the surface, relieved at long intervals by clumps of bush. That portion of the watershed which extends eastward from Rotomahana, and forms the gently-sloping plain at the foot of Tarawera Mountain, shows indications of having formed the bed of a former lake, in which deep deposits of the loamy earth lie with a nearly horizontal stratification, intercalated here and there with some fragmentary bands of lignite. In parts this plain was thickly strewn with rocks which had fallen from the rhyolitic cliffs of Tarawera.

Lying between Rotomahana and the base of Tarawera Mountain, and about a quarter of a mile from the White Terraces, was Rotomakariri, the cold-water lake, with an area of about twenty or twenty-five acres, between which and the mountain was a shallow valley called Waingongongongo, in which were two or three swampy ponds; but this valley was of no great depth below the bordering hills.

On the north-east water-parting of this basin is Rerewhakaiteu, a cold-water lake, without visible outlet, but the overflow of which, doubtless, percolated through the loose strata both to Rotomahana and eastward to the Rangitaiki River.

A noticeable feature in this part is the long straight line of escarpment forming the northern edge of the Kaingaroa Plain, the rocks forming which are tufaceous.

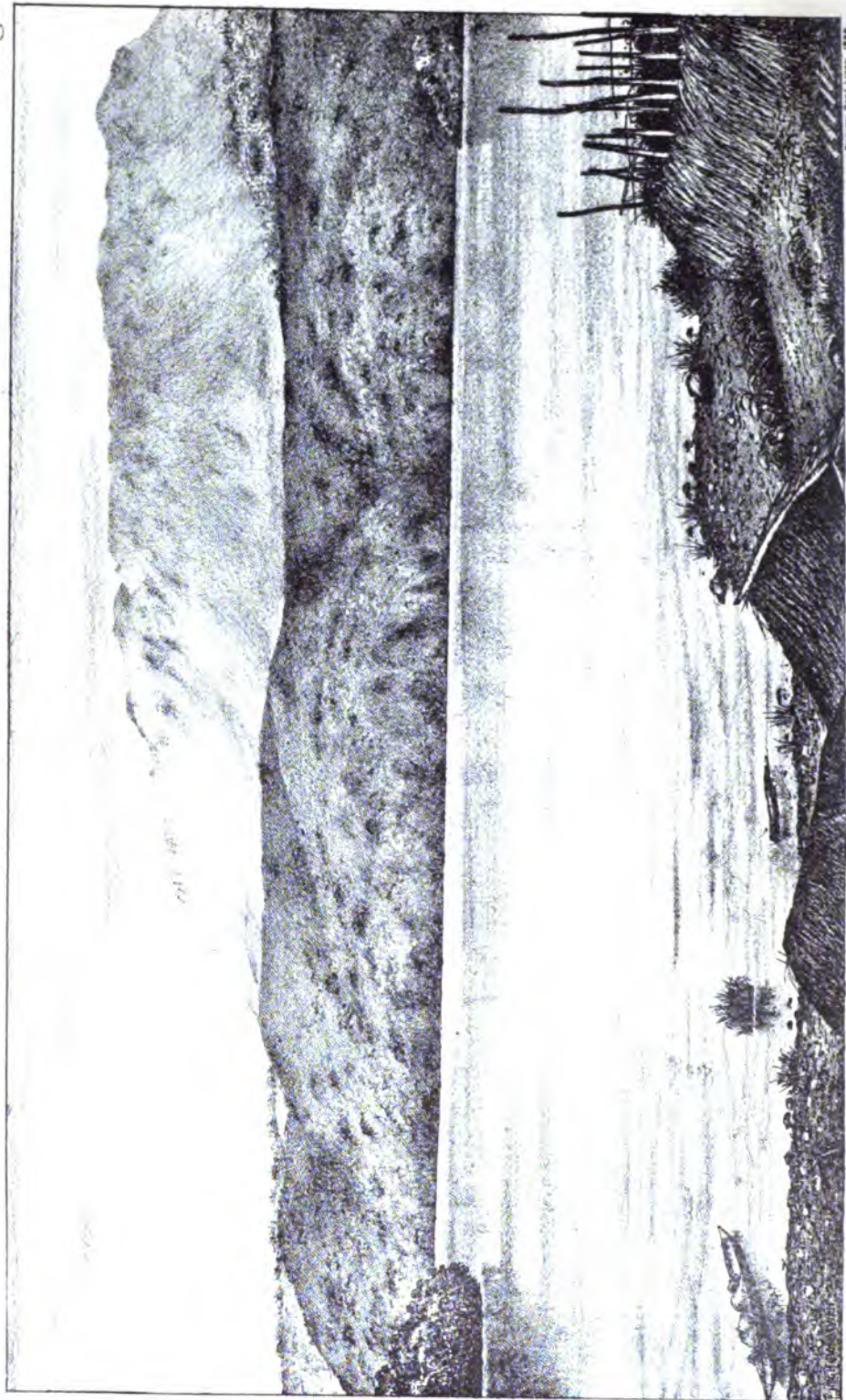
The name Tarawera will, no doubt, in future be applied as a general one to the plateau-like mountains which stand immediately to the east of the lake of the same name, though there are three separate and distinct ones given to it by the Maoris. The most northerly is Wahanga, the central and highest part is Ruawahia, and the southern end is Tarawera. The outlines given in Plate No. 3 and No. 3A, carefully traced from photographs, show the general shapes



Drawn from Photographs

MT. TARAWERA BEFORE AND AFTER THE ERUPTION.

The dotted line shews the former summit.



From a photograph by J. Maran, 1908

Tarawera, as seen from the South West.
Heiwa, the mountain.

of these hills, in one of which the alteration caused by the eruption is plainly seen. Map No. 2 also shows the ground-plan, and it will be noticed that they form together two plateaux of a mean height of about 3,500ft. above sea-level, or 2,500ft. above Lake Tarawera, and have an area on top of three square miles. Wahanga is divided from Ruawahia by a gap or defile about 500ft. lower than the plateau, and there is a smaller indentation in the cliffs which divide Ruawahia from Tarawera, though this is not continued across the plateau. The nearly perpendicular "mural crown" of rhyolitic and trachytic rocks which encircles the mountain is only to be scaled with difficulty in a few places, and from it a steep talus (inclination 33°) slopes down to the more undulating country below, on which several forests prior to the eruption were to be found. It has been stated that Tarawera is an ancient volcano on which was a well-defined crater; but this is not so. The writer made the ascent of the mountain three times in 1873, and spent several hours engaged in topographical work on the top, and consequently is able to state positively that no trace of such was to be seen.*

The surface was formed by a confused mass of rhyolitic rocks, broken and jagged, sometimes thrown up into hillocks, at others having the appearance of a lava stream, fractured as it cooled into innumerable large splinters, lying indiscriminately in all directions and positions, generally quite bare of vegetation, but here and there a little bracken or moss, or occasionally a weather-beaten shrub, relieved the sombre grey of the rocks. A central ridge, elevated somewhat above the general level, caused the surface to slope a little towards the cliff-formed edge of the plateau; but, excepting the gap between Wahanga and Ruawahia, it presented few deviations from a broken, rugged plain, over which it was very difficult to travel. The mountains have always been held by the Maoris to be very *tapu*, as here was situated one of their great tribal burial-grounds; and it was only with difficulty that Europeans obtained permission to ascend. The use of food or tobacco on top was considered especially wicked, and as likely to entail misfortune on the offender, the anger of the *atua* or guardian spirit being generally manifested by the sudden envelopment of the hill in mist and fog. Such was the fortune of the

* Mr. Charles Clayton, of Rotorua, who was surveying in the neighbourhood of the mountain in 1884, states that on one occasion he passed from Ruawahia over the top of Wahanga, and that he then saw a crater-like hollow about 200ft. deep, from the centre of which rose two or three small cones: he believes this to have been a crater. It is strange that, although the whole of the top of Wahanga is visible from Ruawahia, the writer saw nothing of the kind in 1873; and now, if any such crater exists, it is filled up by the late eruption and cannot be traced.

writer when attempting to take angles at the trig. station on two occasions; but whether the tobacco in his pocket had any connection therewith is left to the reader's discernment.

The origin of the mountains is undoubtedly volcanic, but the immediate process by which they have received their present form is somewhat obscure. The shape is remarkable, and like no other mountain in the district. The accompanying section (see Map No. 2) shows this quite clearly—the plateau-like summit, the steep “mural crown,” the sharply-inclined talus, and the beautiful easy slope below: and this is the section it presents with little variation on every side excepting the east, where a range of much less elevation joins it and thereby spoils its symmetry. The mountain is clearly built up of several lava-flows of probably distinct ages, which have a rude parallelism and a slight westerly dip. The lower one, which forms the cliff above the plain to the south, is composed of rhyolitic lava in very fine laminae, through which are scattered isolated portions of a similar rock, exceedingly hard and close-grained. This flow comes out on the shores of Tarawera Lake, and there forms the picturesque cliffs which, prior to the eruption, were clothed with beautiful pohutukawa. now, alas! all destroyed. A higher stream can be traced in the rounded hill lying immediately to the south of the mountain, whilst above it is the one which forms the “mural crown,” and whose surface occupies the higher parts of the mountain. It is difficult to say whether we have not here the remains of a series of great lava-streams whose former extension has disappeared by atmospheric denudation, or, on the other hand, the remains of one of those viscid flows of lava common to the acidic class of volcanic rocks, which never form craters, but, welling up from a fissure, spread out, as it were, in the shape of a great bubble, like many to be seen in the district of Puy de Dôme. Central France. The recent formation of the deep crater at the head of the chasm in the south-west of Tarawera should throw much light on the origin of the mountain when the poisonous fumes shall have subsided sufficiently to allow of an examination; whilst the vast number of rocks scattered all over the surface, brought up from great depths, will enable a mineralogist to tell its composition. The mountain as a whole is doubtless rhyolitic; but the varieties of that rock scattered about are very numerous, and sometimes beautiful, especially those containing red spherulites.

The Maori names of this mountain-group would appear to have a strange significance in view of the recent eruption, did we not know that each one has another meaning. Wahanga means the “bursting open,” Ruawahia, “the split or cloven hole or cave,” Tarawera, “the

MAP Nº 2

NORTH-
EAST

4000 feet
3000 "
2000 "
1000 "

MAHANA CRATER

Black Crater
Inferno Crater
Echo Lake Crater
Southern Crater

SOUTH-
WEST.

4000
3000
2000
1000

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burnt cliff or peaks." No weight can be attached to the meaning of these names as indicating that the Maoris ever saw any previous eruption or volcanic action displayed here. The very evident signs of great age, and denudation of the lavas, is against any such hypothesis, even if the size of some of the trees growing on them did not contradict it. Totara trees over 8ft. in diameter, growing in that stony soil, would scarcely reach such dimensions during the time—five or six hundred years—the Maoris have been in occupation of the country.

DESCRIPTION OF THE GREAT FISSURE.

Map No. 2, attached to this report, is based on the recent topographical survey, made specially to illustrate the changes in the country which have taken place since the eruption. It will be seen that the result of such eruption is the formation of a fissure in the earth's crust running nearly straight on a true bearing of 58° for a distance of eight miles and three-quarters, extending from the north end of Wahanga to near Okaro Lake. South-west of this it is continued by earthquake-cracks for some miles further. The fissure varies considerably in width and depth, being widest at Rotomahana, where it has a maximum breadth of a mile and a half, whilst its general or mean width where it crosses the mountain may be stated as an eighth of a mile. The depth is greatest near the northern end, just between Wahanga and Ruawahia, where it is about 900ft. below "the gap," or 1,400ft. below the top of Ruawahia; and the least is at the southern end, where it may be said approximately to have a depth of 300ft. It must not, however, be supposed that the fissure has the appearance of a continuous rent or split in the earth's surface for its whole length; on the contrary, it is bridged in several places by parts of the original surface remaining in position. It presents, indeed, more the character of a series of craters (not necessarily circular), arranged in a nearly straight line and at various elevations above sea-level.

As it will be necessary to use the word "crater" very frequently, it is as well to explain that it is intended to convey the idea of orifices of very different characters, but all of which have been actively engaged in the ejection of solid matter, either in the form of molten rock and scoria; or sand; earth, mud, and unfused rock, accompanied in the latter case usually by water. The first description of crater is confined to that part of the fissure extending from the north end of Wahanga to the base of Tarawera; the second description extends from the north end of Rotomakariri to the Southern Crater; whilst the Black Crater combines the characteristics of both.

Standing on the highest point of Ruawahia, 3,770ft. above sea-level, and looking north-east, the fissure is seen to have passed along the steep wall-like face of Wahanga, cutting part of it off, and terminating near the northern end of that hill in a deep oblong crater, the eastern side of which is very much lower than the western. Immediately to the north of Ruawahia is a long deep crater, with nearly perpendicular sides, which cuts off "the gap" completely, and the western side of which is also much higher than the eastern, reaching up, in fact, to the level of the Wahanga Plateau, whilst the opposite side is but little elevated above the lower plateau extending to Kanakana. The bottom of this fearful-looking chasm is about 1,400ft. below the top of Ruawahia. Its sides are so steep that a descent into it would be impossible. It is scorched and blackened by the heated matter from below, though here and there the rugged faces of the original lighter-coloured rock can be seen. The solid contents of it appear to have been blown clean out, and are scattered all over the country in fragments of various sizes, the larger and first-ejected portions being doubtless hidden by the black and reddish scoria which is now piled up on its edges. Some of this has fallen back again into the vent, and thus prevents a clear view of the more solid lava which is probably present at its bottom. It is separated from the most northern crater by a sharp ridge composed of loose scoria, which has fallen back from the air after being ejected, and which, no doubt, marks a point in the fissure where the molten matter met with some obstruction, or where activity first ceased. The lower walls of this crater are quite perpendicular, whilst the upper parts slope at a high angle to the surface. When the Survey party was there on the 28th July it was extinct, excepting that on the western side, near the Wahanga Plateau, steam escaped from a number of cracks, as it also did just outside the crater-edge on the eastern side. It is difficult to estimate the depth of newly-deposited scoria along the edges of these two craters; but it appears to be about 40ft. or 50ft., decreasing in depth as the crater is left.

The present height of the top of Ruawahia is 3,770ft. above the sea. The old station of the trigonometrical survey was 3,606ft. Its position was right in the centre of the fissure, and just to the east of the point lately determined, at a distance of about 250 yards. It follows from this that the depth of newly-deposited scoria is nearly 170ft. in that locality. From the position of the old station a line drawn on a true bearing of 62° for rather more than a mile will follow along the centre of the fissure in the direction of Tarawera. Along this portion, the width of which averages 250 yards, there



FROM A PHOTO BY C. SPRINGER

W. H. STEPHENS, ART. 312

THE GREAT FISSURE
ON TARAWERA AND RUAWAHIA MOUNTAINS.
Looking North-east.

4A



Seventy Six' Lyrus 1886

TARAWERA.
June 14th 1886.
From a sketch by S. Percy Smith.

5B



Reynolds, B. & L. 1968

GENERAL VIEW OF LOCALITY FROM OKARO TO TARAWERA TAKEN FROM RIDGE ON EDGE OF ASHFIELD

Lake Rotorua



Lake Taranaki

January 1907

are four distinct craters, whose depths vary from about 350ft. in the northern one to about 250ft. in the southern one, the central ones being the deeper—about 500ft. They are separated from one another by walls of loose scoria, which do not rise to the height of the east and west sides. As the violence of the first outbreak decreased, it would appear that the activity became more localized, and hence places were left where the escaping steam was insufficient to eject the scoria which fell on all sides from the more active parts of the vent, and thus allowed it to accumulate and build up the walls separating the several craters. Plate No. 4, which is taken from one of Mr. Spencer's photographs, shows the fissure as seen from the south-west, looking north-east. The separate craters will there be seen, with steam rising from the sides in several places. The day on which the picture was taken was beautifully fine and the atmosphere very clear, hence but little steam is visible, though in the early part of the day the steam completely obscured the view.

The margins of the fissure have several little peaks of scoria, rising as much as from 50ft. to 100ft. above the general level, and the outer slopes of these descend at a considerable inclination to the level of the parts of the plateau. (See Plate No. 4A.) Their structure is very evident to the eye, and illustrates exactly the ordinary formation of volcanic cones by the building-up of outwardly-inclined strata of fine scoria mixed with larger fragments of the unfused native rock. Inside the fissure the ejected scoria has fallen back so as to leave a deep talus sloping down to the bottom of the craters, though in many places the original rock can be seen protruding through it, sometimes partly fused and become scoriaceous, at others apparently unaffected by the passage of the heated matter.

Plate No. 5, looking along the fissure southerly, and across the deepest crater, shows very distinctly the surface of the older rocks, distinguished by their lighter colour; and here the deposit of new matter varies from 70ft. to 120ft. in depth. It will be seen also that this, the deepest crater, has much more perpendicular walls than the others. The margins of the fissures are cracked everywhere by minor fissures running generally parallel to the main one, though some are at right angles to it. In a few of the little peaks these cracks follow nearly horizontal lines round them, one above another, indicating the probability of a subsidence of the whole mass into the crater at no distant date. Nearly everywhere the regular stratification of the scoria along the margins can be traced, but it is particularly marked in the rounded southern end of this part of the fissure, as illustrated in Plate No. 6.

The surface of the slopes is everywhere composed of fine scoria of a black or reddish-brown colour, intimately mixed with fine pumiceous sand; and scattered over it in great profusion are blocks of trachytic and rhyolitic rock, of sizes varying from a few inches in cubic contents to blocks measuring as much as 250 to 300 cubic feet. Most of these show little or no sign of fusion; but there is one place on the south-east side of the fissure where enormous masses of fused or partly-fused rock (lava, in fact) are to be found. Two pieces of rounded form, containing about 250 cubic feet each, were found partly imbedded in the fine scoria, and these had evidently been ejected after the finer material on which they rested, for in their fall they had excavated dish-like hollows, and broken up other rocks on which they fell. Both were completely molten on the surface. Nor were these the only rocks which showed by their position the date of their ejection. Numbers of others, and many of large size, have certainly been thrown up since the outburst ceased in any force. Several minor outbursts of short duration were witnessed from Roturua and other places during the first and second weeks after the eruption, and these rocks were doubtless cast out at that time. The Survey party witnessed from below one of these paroxysmal outbursts on the 6th August. Without any warning or noise a vast mass of steam and smoke shot suddenly into the air with great velocity to a height of a thousand feet or more, and gradually rolled away before the wind. It was like the smoke from a gun, and was over directly.*

The south-eastern side and south-western end are where the native rocks lie in the greatest profusion—so much so that walking becomes difficult. Wherever they are found in the neighbourhood of the cracks which have been referred to they are coloured a bright yellow. These cracks, which may be numbered by the hundred, are of all sizes from a few inches to 20ft. in width, and are sometimes over 100yd. long. They all emit the disagreeable pungent vapour of muriatic acid, and are lined with a most beautiful yellow and green gelatinous matter, probably ferric chloride. One of them on the eastern side, over 100yd. long, 25ft. deep, and 10ft. wide, formed in the rich reddish-coloured scoria, was so thickly covered with this beautiful yellow and green matter, on which the ascending steam had condensed in little drops, as to form one of the most lovely sights possible. The crevice appeared to be lined with exquisite gems, reflecting the rays of the sun in prismatic colours. But this beauty

* As recently as the 30th October a considerable body of smoke was observed to rise from Wahanga.



Drawn by G. N. Sturtevant from a photo. by C. Spencer.

TARAWERA FISSURE,

*Shewing old surface of Mountain.
Looking South*

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From a photograph by G. Spenser

One of the craters in the Great Fissure on top of Ruawahia and Tarawera,
showing the stratified deposits of scoria and ejected stones, these latter are colored
a brilliant yellow by ferro-chloride.
(Looking South West)

is very fleeting: the fine yellow colour disappears within a few hours, leaving a rich brown tint on the stones, due, no doubt, to the oxidation of the iron contained in them. The prevailing tint of the scoria is owing to this cause.

When the first clear view of the mountain was obtained a few days after the eruption, the top and sides were seen to be coloured green and yellow, which gave rise to the report that sulphur in great quantities had been deposited there. This appearance was caused by the deposition of ferric chloride in large amount. The colour has since changed to reddish brown. A few minute crystals of sulphur were found in one locality, but only in one.

No sign of any lava-stream having issued from the fissure is to be seen anywhere. Solid lava may be, and probably is to be, found at the bottom of the craters, but at a considerable depth; but it certainly has not flowed out: and therefore those who saw the outburst on the 10th June are mistaken in supposing they saw lava pouring slowly down the mountain-side. The steam or vapour which rises from the craters and the cracks along their margins is that of muriatic acid—its pungent odour is unmistakable; but in some parts a strong smell of iodine was also noticed, and in others an offensive scent like that of burnt leather. As to what this may be, the writer hesitates to offer an opinion.

The escape of vapour, however, is not confined to the fissure or its immediate vicinity: places as far off as half a mile—some near the edge of the plateau—were also emitting steam in small quantities, which seems to indicate that the mountain has been shaken and fractured to its very base, thus allowing the heated vapour to escape by the crevasses formed. This opinion is also supported by the fact of finding the sands at the base of the mountain everywhere warm at 6in. under the surface, even after heavy rains. On the fifth day after the eruption the writer observed with the telescope that after each shock of earthquake—which then occurred hourly—cracks opened on the side and base of the mountain, and at considerable distances from the fissure, from which little jets of steam arose—to disappear, however, after the lapse of a few minutes. Generally the vapour is quite white in colour; but every now and then a jet of reddish-brown smoke-like steam is sent up from the craters, and in one or two places steam of a very light-bluish colour was noticed.

At the southern end of the fissure on Mount Tarawera one of the breaks or bridges occurs, where the escaping steam does not appear to have had sufficient power to force an outlet through the rocks of the mountain. The steep slope which this bridge occupies is covered

thickly with rocks of all sizes ejected from the fissure above, the space between being filled up with fine scoria and sand. The latter is, doubtless, derived from Rotomahana and that part of the fissure which lies on the north-east of it. This slope terminates on the perpendicular south-west face of Tarawera. In several places on it steam was escaping on the 28th July, showing that, although unequal to the exertion of opening a great fissure continuously, the eruption has cracked and shaken the underlying rocks sufficiently to allow the steam to reach the surface. The bridge is just a quarter of a mile in width. Its southern end marks the higher edge of the great crater forming the northern termination of the chasm which extends from top to bottom of the south-west side of Tarawera, the depth of which is between 800ft. and 900ft. This depth decreases as the lower end of the chasm is reached, until it finally runs out into the sloping plain lying at the base of the mountain. The western edge is very sharply defined—the rocks falling almost perpendicularly to the bottom—and is, like the fissure on the top of the mountain, a good deal cracked and shaken: the cracks run, however, more at right angles to the chasm than they do above. On the eastern side, nearly half-way down, another crater has been formed, which widens the fissure out somewhat, but its average breadth is about 80yd. Here, again, muriatic-acid fumes are escaping from the cracks, with the yellow ferric-chloride deposits lining them just as above. At the end of July but little activity was shown along this part of the fissure, though every now and then a column of reddish smoke was sent up into the air, but in no great volume. Plates Nos. 7 and 8, taken from below, show the appearance of the chasm.

At the bottom of the chasm another of the bridges occurs, about an eighth of a mile in width, where it is possible to cross the fissure; but immediately below it, and right at the foot of Tarawera, is a circular crater about 120yd. in diameter and 300ft. deep, which was at one time exceedingly active. In July it was quite extinct, and filled with dark-green water, from whence its name, Green Lake Crater. (See Plate No. 7.) It is separated from another crater of smaller size lying to the south-east of it by a sharp wall of rock. In the spot which this latter crater now occupies there formerly existed a rugged mass of rhyolitic rock, separated from the steep sides of Tarawera Mountain by part of the plain, and which from its general likeness to the mountain itself had received the name of "Little Tarawera." Most of this mass of rock has been blown away, leaving only small portions of jagged, riven pinnacles to denote its site. It now separates the crater from the new lake formed on its south-

Plate No 7.



Drawn by G. H. Sturtevant from a photo by C. Spenser.

“THE CHASM”

*in the south-west end of Turawera Mountain,--with Green Lake Crater.
Looking North-East.*



U. S. GEOLOGICAL SURVEY.

U. S. GEOLOGICAL SURVEY.

THE CHASM.

South West end of Tarawera.

western side. The immense power of the elastic gases is well shown in this little crater, for scattered around for a considerable distance are huge rocks of rhyolite which have been ejected from it. Many of the rock-fragments about here contain a good deal of obsidian, and some of them small reddish spherulites.

The steep slopes of Tarawera and Ruawahia Mountains, which lie directly under the "mural crown," are covered thickly with fine scoria, which, in many instances, has already become consolidated into a breccia which is difficult and even dangerous to travel over where the inclination is great. The cementing-matter appears to be the very fine sand or mud (or ash) whose origin is probably Rotomahana. The gently-sloping plain south of the foot of Tarawera is thickly covered with this scoria, as are the hills to the east, and where the water has already cut through it and spread it along the channels, it forms a hard stony bed just like the breccias seen in older volcanic formations, which are noted for their hardness and power of resisting atmospheric denudation.

As might naturally be expected from the description of the mountain given above, the nature of the ejecta on and around it are eminently stony. Scoria, black and reddish-brown in colour, generally in a complete state of fusion, forms the bulk; but spread all over and intermixed with it are fragments of the native unfused rock, rhyolitic, trachytic, and perhaps andesitic in character.* Some particularly interesting specimens of rock in a half-fused state have been preserved, in which the original structure, quite intact, is plainly to be seen; whilst in others the unfused masses are coated with the fused lava. On the top of Tarawera, volcanic bombs may be found, but of no great size; but globular masses as large as a walnut are very common—indeed, remarkably so—on the eastern side of the fissure. They look like grape-shot more than anything else. Newly-formed pumice has undoubtedly been ejected from some of the vents, but in very small quantities. It was only seen by the members of the Survey party on the extreme outskirts of the volcanic deposit, and the amount collected does not equal more than a handful. Most of the specimens are decidedly different in character from the common pumice of the district, in being heavier and more dense, and of a finer colour. Several specimens are interesting as having adhering to them little flakes of the black scoria of Tarawera, which have served to protect the softer pumice from the attrition to which it

* The writer makes no pretence to a knowledge of mineralogy, any more than such a rough one as may be gained by the comparison of specimens with the type-rock usually found in every museum.

must have been subjected when ejected. The character of these flakes of lava would seem to indicate that the pumice came from Tarawera. The presence of this newly-formed pumice, a product of the acidic class of volcanic rocks, in conjunction with the scoria, which, as far as the analysis at the command of the writer goes to prove, belongs to the more basic volcanic rocks—is particularly interesting, and is worthy of careful study by those having a knowledge of mineralogy.* The sands which are found on the mountain are precisely similar to those which surround Rotomahana crater and the other group of which it is the centre, and are doubtless derived from the same source. It has already been pointed out that Rotomahana was in eruption subsequently to Tarawera, and continued to be so for a more lengthened period, which accounts for the sand being found on top of Tarawera and on its slopes.

Mention has been made of the forests which once clothed the slopes of these mountains: they were of considerable extent, especially on the south-eastern flanks. The eruption has utterly destroyed them over an area of many square miles. They present the most melancholy and desolate aspect: not a green leaf is to be seen anywhere, but, instead, a mass of broken limbs and riven trunks, wrenched and torn to an extent that renders the wood utterly useless. Many of the trees have been burnt, and their charred remains alone are to be seen. The slope now occupied by the chasm on the south-west side of Tarawera was partly under forest formerly, and the trees which covered it suffered in the same manner as the rocks, and have been blown away far and wide over the country. On the southern side of Rotomahana large logs, some as much as 3ft. in diameter by 15ft. and 20ft. long, are found half-buried in the sands, battered and worn, and sodden with water; and these must have come from Tarawera, as there was no other forest in the line of eruption. They have been hurled through the air a distance of four miles. A very striking instance of the force of the wind which accompanied the eruption is exhibited by a totara tree, the stump of which is still standing near the chasm. It protrudes from the ground for about 15ft. or 18ft., and is evidently standing on the spot where it grew: at that height from the ground it is about 8ft. in diameter. The top has been twisted off, and has disappeared, leaving the jagged stump with the splinters all directed in the same way, showing it to have been subjected to a violent wrench. Many other trees (principally rimus) have suffered in a similar manner in the same locality.

* See Appendix, for note on recently-formed obsidian.



THE NEW LAKE - "ROTOMAKARIRI"
Within the Great Fissure - Looking South-west. (From a photo by C. Spencer.)

The craters and points of eruption which occupy the line of fissure from Wahanga to the base of Tarawera belong to that class which have been described above as characterized by the ejection of molten rock or scoria. But in continuing the description of the fissure towards the south-west we shall deal exclusively—the Black Crater excepted—with the other class, or that in which the ejection of unfused rock, mud, sand, and water predominated. The one class of crater is, strictly speaking, volcanic, the other hydro-thermal (if we give an extended meaning to this term), though undoubtedly the prime cause of action in both is the same. A glance at the map will show that the general character of the fissure changes immediately the base of Tarawera is left: it is no longer the narrow rock-bound rift like that on the mountain, but widens rapidly out into a large crater, or series of craters, through which, however, the narrower fissure can still be traced by the different craters marked on the map. This sudden change in its character is accompanied by a change in the nature of the rocks which have been blown out. The walls and sides of this large area are formed by soft earthy deposits which seem to be lacustrine in their origin, and the stratification of which is nearly horizontal, as may very plainly be seen in the steep cliff forming the eastern side. It naturally offered very much less resistance to the volcanic forces than that of the solid lava of the mountain, and consequently a very much greater amount of material has been removed.

The first point to which attention is drawn is the new lake, called after the smaller one which formerly occupied a position not far from it. This is an entirely new feature, directly due to the eruption. The lake is just one mile long, with an average width of nearly a quarter of a mile. Its eastern side is nearly perpendicular, but the western and higher one slopes much more gradually. In the beginning of August the waters showed signs of ebullition in several places, but very little steam arose therefrom. Its present height is 983ft. above sea-level, or 220ft. below the plain to the east. Plates Nos. 9 and 9A show the lake as seen from the northern end, and on the eastern or left-hand side can be observed some horizontal lines, the middle one of which denotes the former surface of the country; the recent deposit (there mostly sand) being piled up above it from 30ft. to 50ft. A little stream of water, draining through from the Green Lake Crater, is found at the northern end, whilst at the south-east side is another of considerable volume, which issues from the bottom of the cliff forming the side of the fissure. The water of the latter is warm, and of an astringent taste: where it leaves the cliff steam

issues in small jets, accompanied by a disagreeable smell as of sulphuretted hydrogen.

The muddy-coloured water of the lake prevents any estimate being formed of the depth, but it is probably not great, and must be decreasing rapidly as the incoherent material on its banks gets washed down by the rains. A few days after the eruption a vast quantity of steam was observed to arise from this locality, and at that time no doubt the fissure was dry; but on the seventh day the steam had entirely ceased, as far, at least, as could be seen from the hills near the Wairoa, and the new lake had probably begun to form in the fissure. It was not, however, until about the 20th July, when Professor Thomas and Mr. Lundius passed round it, that its existence was known. No change had taken place since then up to the date of survey. We can only suppose the origin of this lake to be due to a cessation of activity in this part of the fissure at an early date, which would allow of the falling-in of the sides, aided by the heavy rains early in July, until the lower part of the fissure became completely filled up, thus allowing the waters to accumulate. There is no doubt that a large portion of the drainage of the south and eastern slopes of Tarawera finds its way by subterranean watercourses into it. That large bodies of water have come down from the mountain since the eruption is proved by the width of the watercourses on the plain, and by the great depth (over 100ft.) that a channel leading into the lake has been excavated quite recently.

The nature of the ejecta around the lake is coarse sand and mud, evidently derived from the lake when in a state of activity; but as the steep slope of Tarawera is approached the scoria becomes more and more prevalent, and enormous blocks of stone are found. With a depth of from 30ft. to 40ft. on the shores, it decreases very soon as the lake is left, until at two miles to the east it cannot be more than 2ft. or 4ft. deep, as the stems of the tea-tree are everywhere seen sticking up through it. The surface is capital walking when dry. It is composed of coarse and very fine particles of grey sand, which have a strange power of retaining the water. The coarser particles appear to be loosely cemented together by the finer ones, and in this it differs materially from ordinary sand. After rain it becomes mud, but with no plasticity. It is difficult to say whether it should be called mud or sand: under different circumstances it may be either. As stated previously, the sands are warm 6in. to 10in. under the surface at the base of Tarawera even after heavy rains. This heat may be due partly to that retained ever since the matter was erupted, or partly to the heat of the underlying rocks. On top

Plate No 91



Drawn by G.N. Sturtevant

from a photo. by C. Spencer.

LOOKING SOUTH-WEST ALONG FISSURE
from Mt. Tarawera.

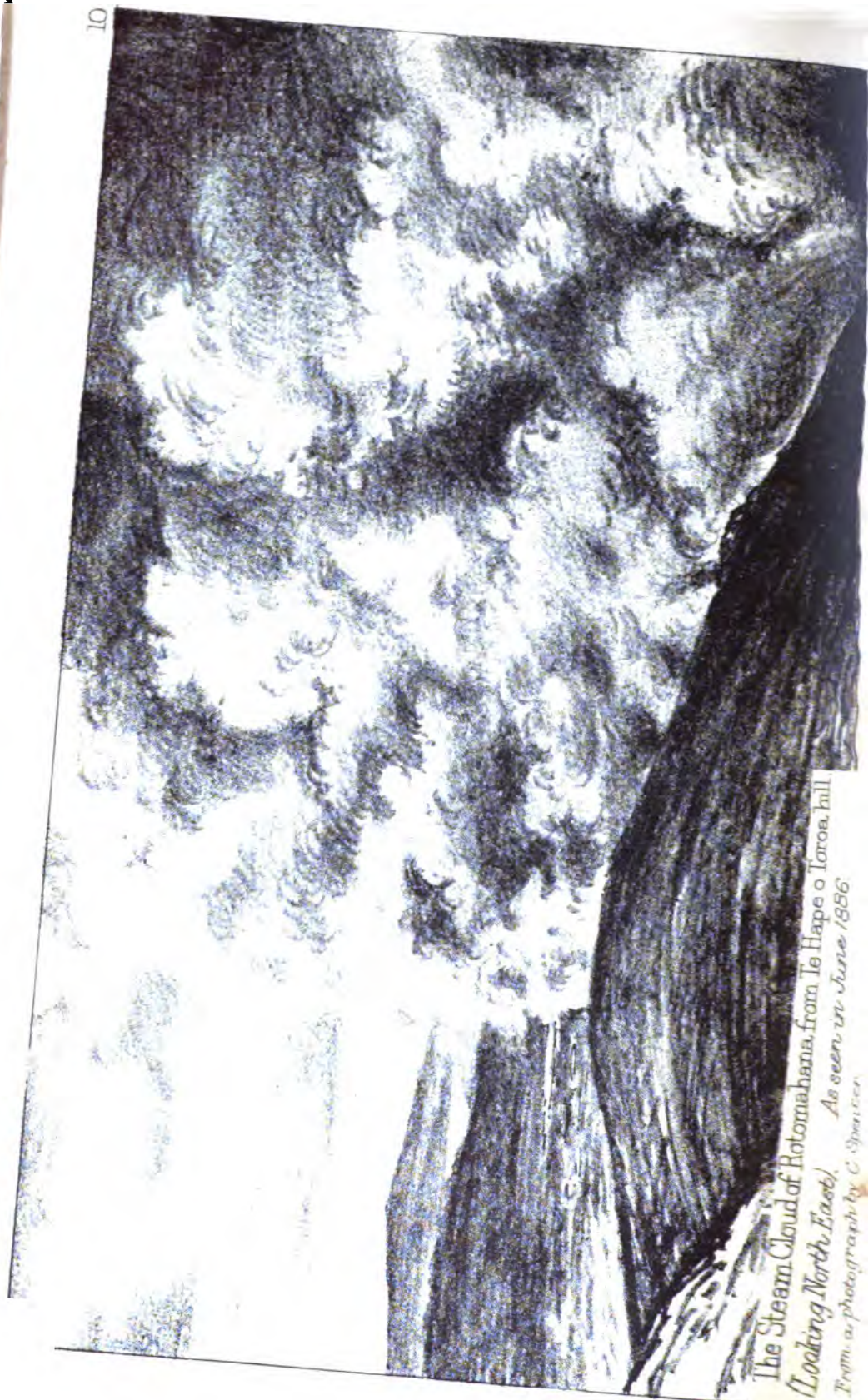
of the range of hills westward of the lake, steam in small jets still escapes from the ground in several places, even half a mile off the edge of the lake.

The fissure widens out somewhat suddenly at the south-west end of the lake into an undulating flat, covered with the usual grey sand and mud. The walls on the east are quite perpendicular and about 250ft. high, but a talus of mud is found along the foot everywhere, and from it oozes out in several places a little cold water, which drains away into a lake shown on the map. On the opposite or western side the bounding hills slope upwards at a very steep inclination. They are indented by three crater-form hollows, from which a large amount of steam arises. The steam issues from a number of funnel-shaped depressions varying in diameter from a few feet up to 30ft. or 40ft. The two little lakelets shown in the line of fissure are both very active along their margins, though the water of the larger one is cold. The western side of the latter is formed by perpendicular rocks, which are cracked and fissured from top to bottom, from out of which the steam issues with great violence, giving rise to a deafening noise, to be heard a long distance off. The crater directly to the west of Star Hill, although small, is very active indeed, and is filled with steam up to its rim—so much so that no sight of the bottom can be obtained. The ridge which extends from the Banded Hill directly towards Star Hill is composed of earthy stratified clays ending abruptly against masses of hard rhyolitic rocks, which form its northern end, just above the lakelet before mentioned. These rocks are also steaming, whilst immediately at their base are several extinct fumaroles, some filled with water, others dry, and near them a strong odour of petroleum is perceptible. This ridge seems to have formed a division in this part of the fissure separating the Rotomakariri series of craters from those of Rotomahana; but in the direct line of fissure it is blown out, and the lakelet occupies that part as a separate crater, now nearly extinct, but which has been exceedingly active, judging from the large amount of rock-fragments scattered about. All over the place just described there are several funnel-shaped depressions marking the sites of fumaroles of various sizes now extinct. The general level of the plain is 980ft. above sea-level, or just 100ft. below the former level of Rotomahana Lake.

If we take the Banded Hill as a natural division of the fissure, it forms the eastern side of the great crater of Rotomahana, which has an east-and-west diameter from there of just one and a half miles, and a north-and-south one of about the same. This gives an area of

slightly over two square miles as the size of the crater, which is surrounded by precipitous and in some places perpendicular walls, varying from 200ft. to 300ft. in depth. Below the walls the ground slopes by ridges and hollows to the central cavity, now filled by water. The height of this above sea-level is 565ft., or 515ft. below the former level of Rotomahana Lake. It will be seen from the map that the elongated lake or pool at the bottom of the crater occupies the line of the great fissure. The water is evidently hot, though none of the Survey party descended to it to ascertain the fact, the danger at that time being too great from the clouds of scalding steam which obscured a large portion of the crater. It is but a moderate estimate to assume that the depth of solid matter which has been removed from the crater by the eruption is 300ft.; but this will give a quantity equal to nearly 620 million cubic yards. In other words, it would cover two hundred square miles a yard in depth.

At the end of July and beginning of August the principal foci of activity within the crater were distributed along the line of fissure, and around the west, north, and eastern sides, though nearly everywhere, whenever the dense cloud of steam admitted of a sight, fumaroles and points of activity could be discerned in countless numbers covering other parts of the sloping bottom. The southern "bay" had ceased to be active, except in a few places where steam issued from the sides of the little river draining down into the central lake. This river was hot—indeed, almost boiling—where it issued from the ground, which it did with great noise and volume, its waters so strongly impregnated with iron as to colour the rocks with a bright-yellow ochreous deposit, though the water was quite clear. It is believed that this "boiling river" was one of the subterranean feeders of Rotomahana. It derives its waters from the drainage of the plain above and probably also from Rerewhakaite Lake and the slopes of Tarawera. The heat of the waters will arise from the same source as that which caused the excavation of the crater. The signs of recent great activity in the southern bay are exhibited in a striking manner. Huge rocks and masses of earth have been hurled and tumbled about in the most extraordinary manner, giving the place the appearance of having been the scene of sluicing operations on a most gigantic scale. Numbers of funnel-shaped depressions of all sizes up to 30ft. or 40ft. in diameter indicate the positions of the steam-vents which caused the havoc that has been wrought, though all are now extinct. No molten rock is to be seen anywhere—nothing but the native rock—that is, the earthy deposit which forms the basin of Rotomahana, and some of the harder trachytic or rhyolitic rocks, and these are half-buried in the grey-



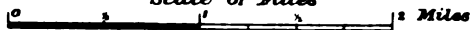
The Steam Cloud of Rotomahana, from Te Hape o Toroa, hill.
(Looking North-East). As seen in June 1886.
From a photograph by C. Spencer.

PLAN № 3



SHEWING CHANGES IN THE VICINITY OF LAKE ROTOMAHANA

Scale of Miles





INSIDE OF ROTOMAHANA CRATER SHOWING RITE OF PINK TERRACE

1900

coloured sands and mud which are prevalent everywhere. In other parts of the crater, pools and holes full of horrid-looking black mud are seething and boiling, with here and there little mud-volcanoes spurting out their contents around. It is difficult, however, to obtain a clear view of the crater, on account of the immense mass of steam arising from it. It is only on very fine dry days that a view can be obtained here and there over the interior. The steam-cloud, which is roughly a mile in diameter, rises to over 10,000ft., and frequently to 15,000ft., in height. Carried along by the wind, it forms great cumulus-like masses of vapour in the air (see Plate No. 16b), or spreads out over the country, condensing into fine rain, which, falling on the sand, converts it into deep and tenacious mud, the terror of all those who have once tried to wade through it. Immediately after sunset it is a sight never to be forgotten, the deep cool purples of the base passing into orange and carmine in the upper part, making a picture which is indescribably beautiful.

Seen every now and then through the clouds of steam, immediately to the north of the central lake, are some rugged pinnacles of black rock, rising to the height of the crater-rim. These have a special interest as marking the site of some of the hills which formerly stood close to the White Terraces. The exact position of the terraces cannot be identified, as the ground around where they formerly stood has been blown away; but they evidently were close to, and to the north-west of, the pinnacles. In all probability the very active vents in that locality still mark the old orifices of the terrace-basin and the solfataras near there, but cut down to a much lower level. Fragments of the white marble-like siliceous sinter of which the terraces were formed have been found scattered around the northern side of the crater. It was at a point due north from the centre of the lake that the Kaiwaka River flowed out of Rotomahana. The valley has been completely filled up with sand and mud to a depth of 80ft., forming, as it were, a great dam (see Plate No. 11), though within a quarter of a mile of the crater-rim the hollow, deepening into a valley now occupied by a watercourse, can still be seen and followed out to its junction with Lake Tarawera.

The site of the Pink Terraces cannot be identified with more certainty than that of the White Terraces. The ground in this locality has been blown out to at least a hundred feet below the former level. Map No. 3 will show the approximate position with respect to the present crater-walls, though, owing to the absence of any proper survey of Rotomahana, none of the features can be reproduced with exactitude.

Directly to the south-west of the crater is Te Hape o Toroa Hill, 1,940ft. above sea-level; and from a point on its side 1,800ft. above the sea the best view of Rotomahana is obtained. The following quotation from the writer's first report* describes the appearance of the crater on the fifth day after the eruption: "The Pink Terraces were in such a situation as to be at least a quarter of a mile within the margin of the present crater, and no eye can penetrate through the dense mass of steam to ascertain their fate. Occasional breaks in this dense veil allow of momentary glances into the crater, but for no great distance, and the sight disclosed is one of horror. A dim brownish twilight, making everything of a hideous hue, enables one to see a dreadful mass of boiling mud, black and brown in colour, with seething pools of steaming water or liquid mud, sometimes cast up into fumaroles ejecting steam, at others vomiting forth stones and mud with a noise like the roar of innumerable steam-engines. From time to time the more active vents along the margins, after a prolonged roar, or a sharper detonation like that of a cannon, shoot forth high into the air large bodies of stones, sand, and mud, which generally fall back again from whence they came; at other times they are scattered far and wide over the mud-covered hills around the margin, the stones leaving dish-like hollows where they disappear beneath the surface. The outer edge of the crater differs in height above the bottom according to position, and no general statement could be given as to an average height; but at the west side it is probably about 300ft., the upper part being formed of *débris* thrown out from the crater. To the margin of this ejected matter it is dangerous to approach: it is constantly falling in, and is full of cracks for many yards back. To the east of Te Hape o Toroa, along the valley which was formerly occupied by a stream running into Rotomahana, are several points of eruption (see Plate No. 10A, where a few of them are shown), some of them throwing up stones and mud at intervals, generally preceded by a loud detonation. The top of this hill, being about a quarter of a mile from the margin of the crater, affords an excellent view of the whole eruption; but, at the same time, the frequent earthquakes tend to engender a feeling of insecurity, and a wondering fear lest the whole steep hill-side should subside into the crater below." At that period the stones were frequently ejected from the

* Appendix to Journal, House of Representatives, H.-26, 1886. The writer is glad to have this opportunity of correcting the only serious mistake which later explorations prove to have occurred in that report. It was there stated that only some doubtful specimens of fused rock had been met with: the fact is, the molten matter was covered up by the later ejection of sand, mud, and ashes, and it was only after the first rains that it appeared everywhere. Tarawera at that time was unapproachable.





Drawn by G. H. Sturtevant from a Photo by C. Spencer

FORMER OUTLET TO ROTOMAHANA

now filled in with sand etc

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Bed of Gold A. J. A. J. A.
Showing rate of Blackberry Cuts

Photo by G. R. Hartman

several little craters which line the margin of the greater one to a height of from 300ft. to 400ft., whilst the finer sand was often carried to much greater heights—indeed, on several occasions it was seen to be falling outside the crater like a shower of rain from heights estimated at between 3,000ft. and 4,000ft.

On the 28th July the Survey party, in returning from the first ascent of Mount Tarawera, passed along the northern and western side of the crater, and there noticed a small pool of muddy shallow water, from the southern end of which a small jet of steam arose some 20ft. or 30ft. in the air. On the 31st, whilst in camp at Parcheru, and during very heavy rain, two heavy shocks of earthquake were felt at 1.5 p.m. and 8.10 p.m. On the 5th August, when carrying on the survey near the same place, a great change was noticed as having occurred where the little pool formerly was. A great cloud of steam rose into the air, nearly as high as that from Rotomahana, whilst stones and mud were cast up to great heights, showing that a fresh eruption had occurred. On nearing the place it was seen that a new crater had been formed about an eighth of a mile in diameter, but of what depth the impenetrable steam-cloud prevented our gaining a knowledge. Large quantities of water were thrown out together with the more solid material, whilst the roar of escaping steam was deafening, and to be heard several miles off. This crater received the name of Black Terrace Crater from the fact that it occupies approximately the position of a former solfatara, the sinter deposited by which was dark in colour. Up to the 15th August it continued to be one of the most active points in the district. Plate No. 12 shows the position of this newest crater.

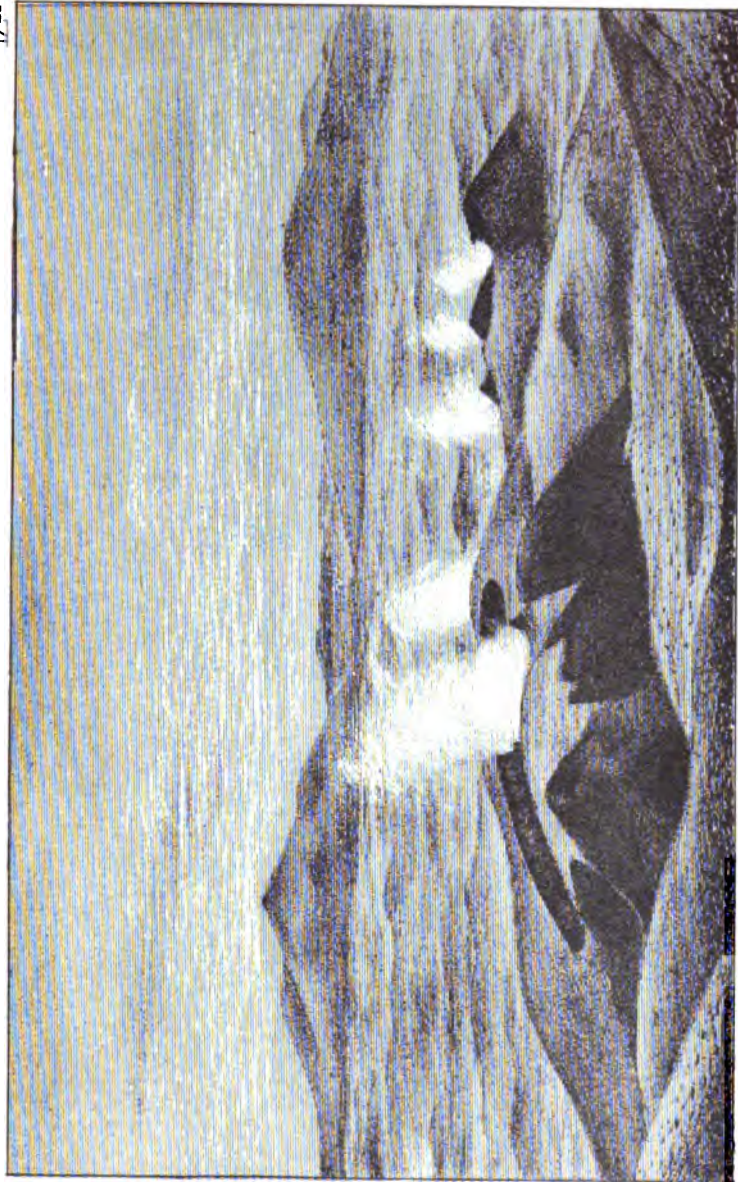
At the south-west end of Rotomahana Crater it will be noticed from the map that the great fissure is continued in its general direction, but greatly reduced in size to what it is in the large crater. This is believed to be caused by the more solid rock again appearing near the surface. It has several smaller craters within it, which have at one time been very active in the ejection of solid rock, for the hill-sides are thickly covered with the fragments in all sizes, up to four or five tons weight. The rocks are much the same as those found on Tarawera—rhyolitic, trachytic, and obsidian. On the hill-tops immediately to the east several logs, as before mentioned, are found half-buried in the sand, which must have come from the Tarawera chasm.

From this point to the Southern Crater, which marks its termination, the character of the fissure also changes: it is no longer continuous, but is bridged in several places, forming a line of seven separate

and distinct craters, all of which are blown through the solid rock, and are at the present time filled with hot water. The two northern ones of the group were nearly extinct in the beginning of August, but the others were intermittently active, especially so the Black Crater, a name derived from the colour of the ejecta. (See Plate 12A, and also 14B, which shows the interior of the crater as blown out from the solid rock.)

An attempt has been made in previous pages to show that the origin of the eruption is deep-seated; and some evidence of this is demonstrable from the position the fissure here occupies with respect to the original valleys and hills. It will be seen from the map that from the south end of the Echo Lake Crater a valley, varying from 300ft. to 400ft. deep, runs, parallel and quite close to the fissure, right down to Rotomahana Crater—for a distance of over a mile. Now, had the eruption been in any sense superficial, this valley, offering the least line of resistance, and quite close to the general direction of the fissure, would be the line which it would naturally be expected to take. But, instead of this, we find that spur after spur has been severed, and the straight line of fissure continued quite irrespective of the formation of the country. Plate No. 13 illustrates this well. The crater there shown is blown out of one of the steep spurs coming down from Te Hape o Toroa, whilst the deep valley on the left of the picture is left intact. Indeed, the explosive forces seem to have had, as it were, a preference for the spurs and hills rather than the lower intervening ground, for all of the five southern craters occupy the tops of the hills, excepting part of the Echo Lake Crater, which cuts right across a former valley.

The Black Crater, though small in size, has been, and still is, one of the most active along the whole line. When first seen, on the fifth day after the eruption, it presented a most beautiful sight: the vast column of steam that shot up into the air with great velocity, nearly as high as that from Rotomahana (15,400ft., as measured), was accompanied by constant paroxysmal discharges of rock and mud, which rose in a pyramidal form to a height of from 500ft. to 600ft. above the bottom of the crater. There appeared to be alternating ejections, first from one end, then from the other; and frequently the direction of the outburst deviated from the perpendicular, and the stones then shot out in a curve, falling on the exterior slopes of the hill with a noise like the rattle of musketry. The stones lay smoking on the surface for some time after their ejection. (See Plates Nos. 14, 14A, and 14c.) The activity has a good deal subsided now, but an eruption took place on the 4th August—only lasting a few moments, how-



From a photograph by J.C. Blythe.

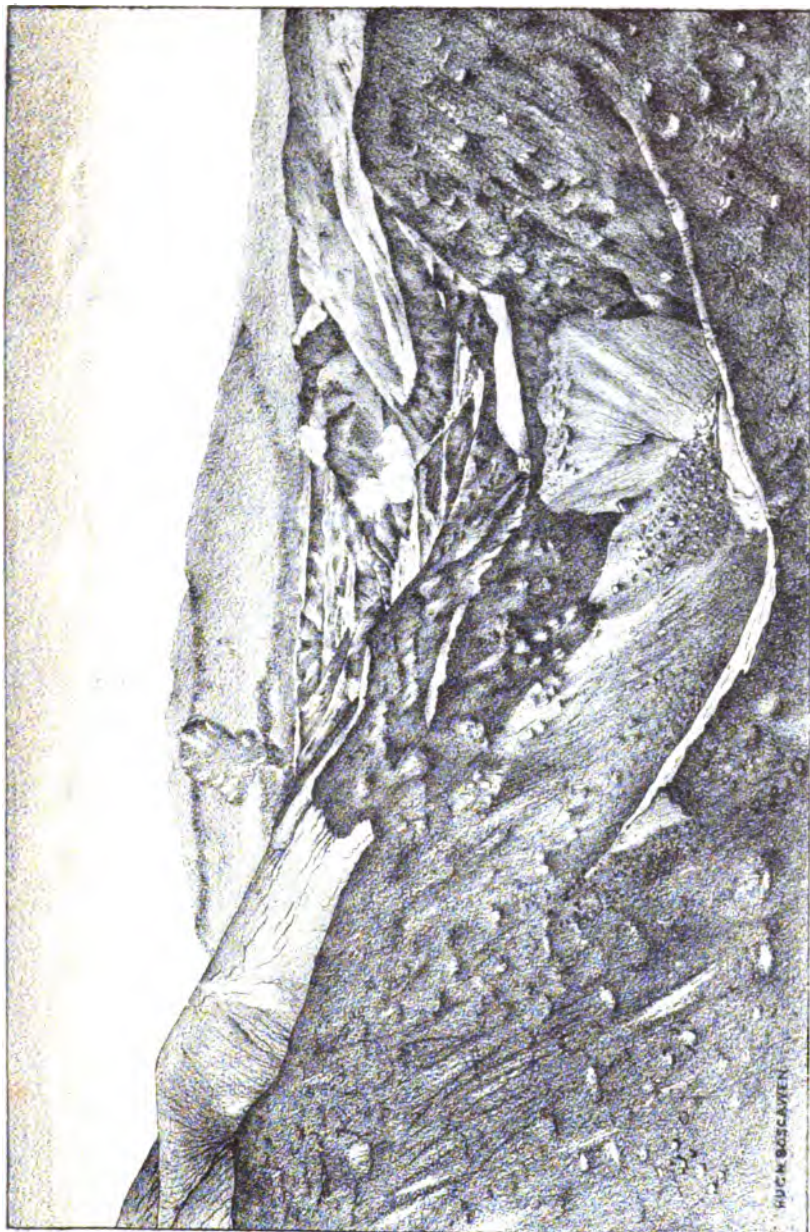
*From foot of Hape o toroa hill looking South to Kakaramea,
across "Black," "Echo," and Southern Craters.*

Plate No 13.



From the photograph for a photograph by E. S. S. S. S.

CRATER NORTH OF BLACK CRATER
showing how fissure has cut through the spurs of Hapeo-Torua Hill.

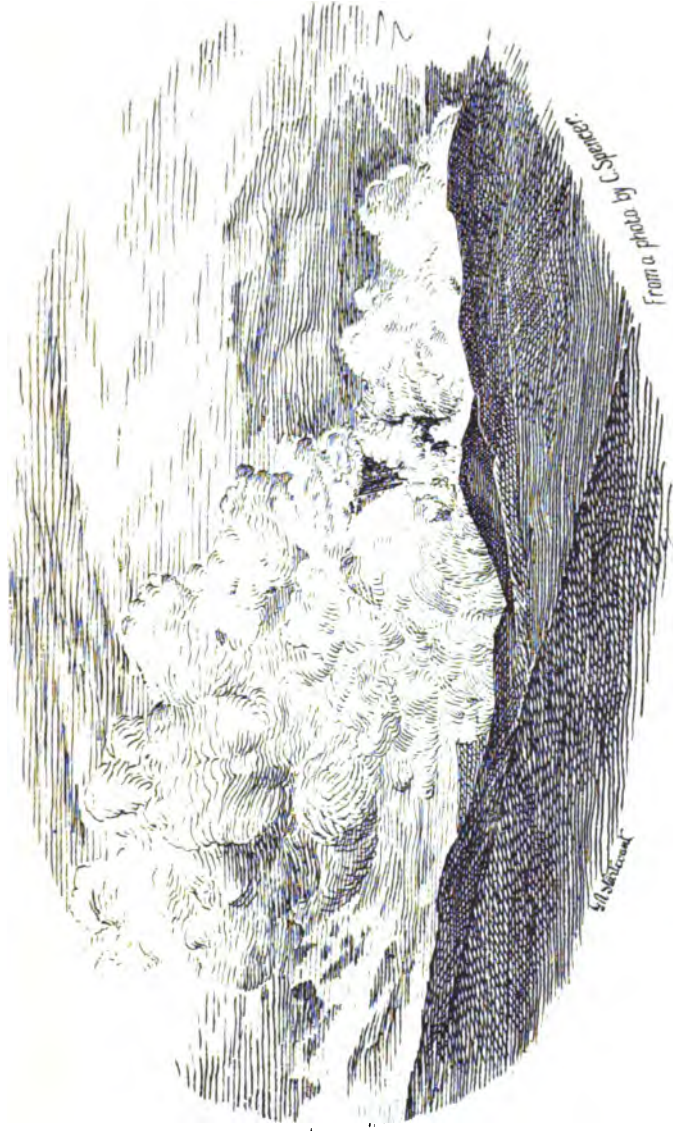


HUCK SCHCAWEN

G.D. VALENTINE PHOTO.

Sept 25th 1887

THE FISSURE FROM TOP OF BLACK CRATER,
LOOKING ACROSS ROTOMAHANA TO TARAREWA IN A NORTH-EAST DIRECTION.



THE BLACK CRATER IN ERUPTION



from a sketch by H. Boncompagni

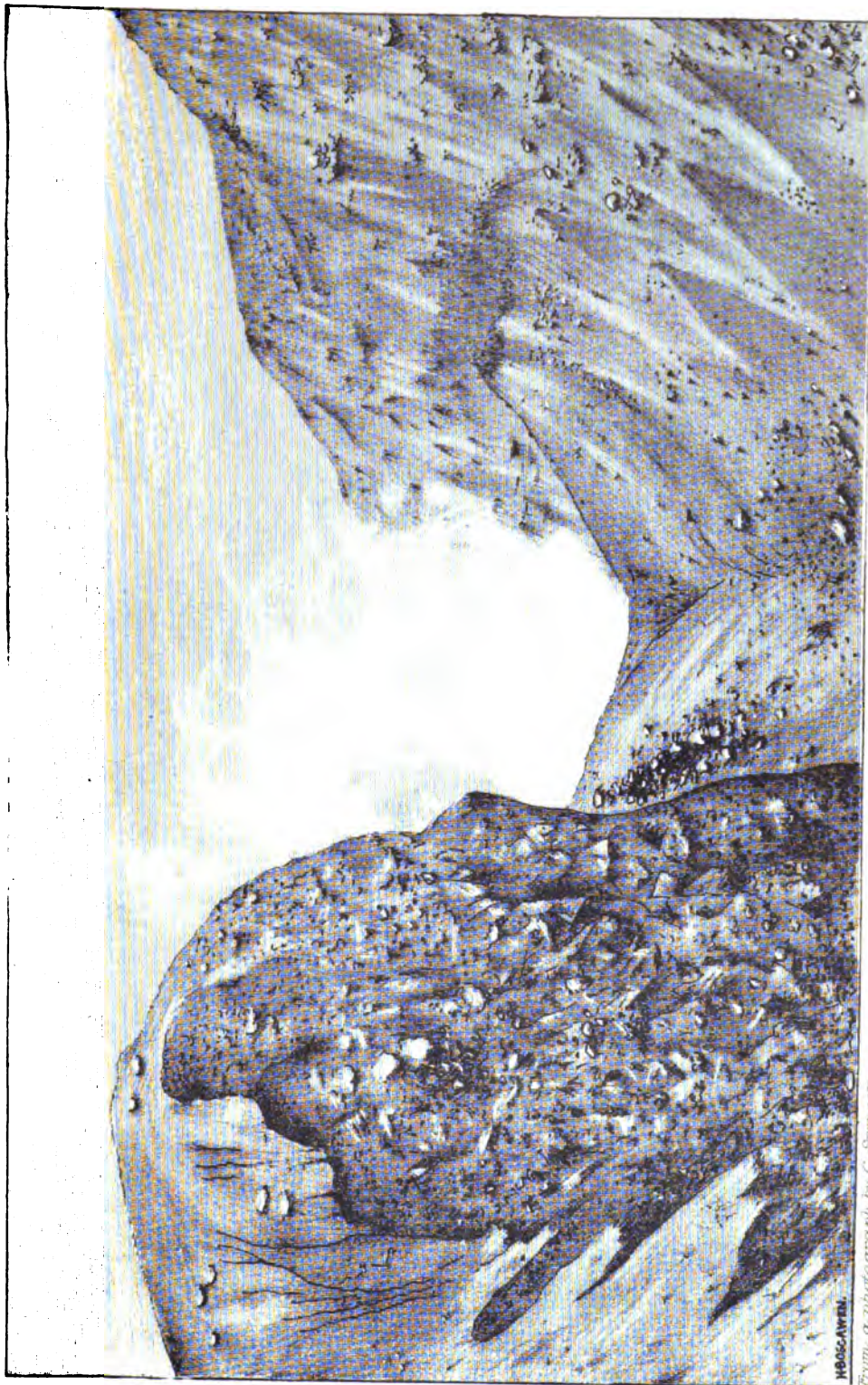
Source: The Library of Congress

View from Pareheru on June 19th 1886.
Black Crater in eruption.

1. The first part of the document is a list of references.

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HOOGSTRAAL

From a photograph by C. Spencer

Interior of part of the Black Crater.

HOOGSTRAAL



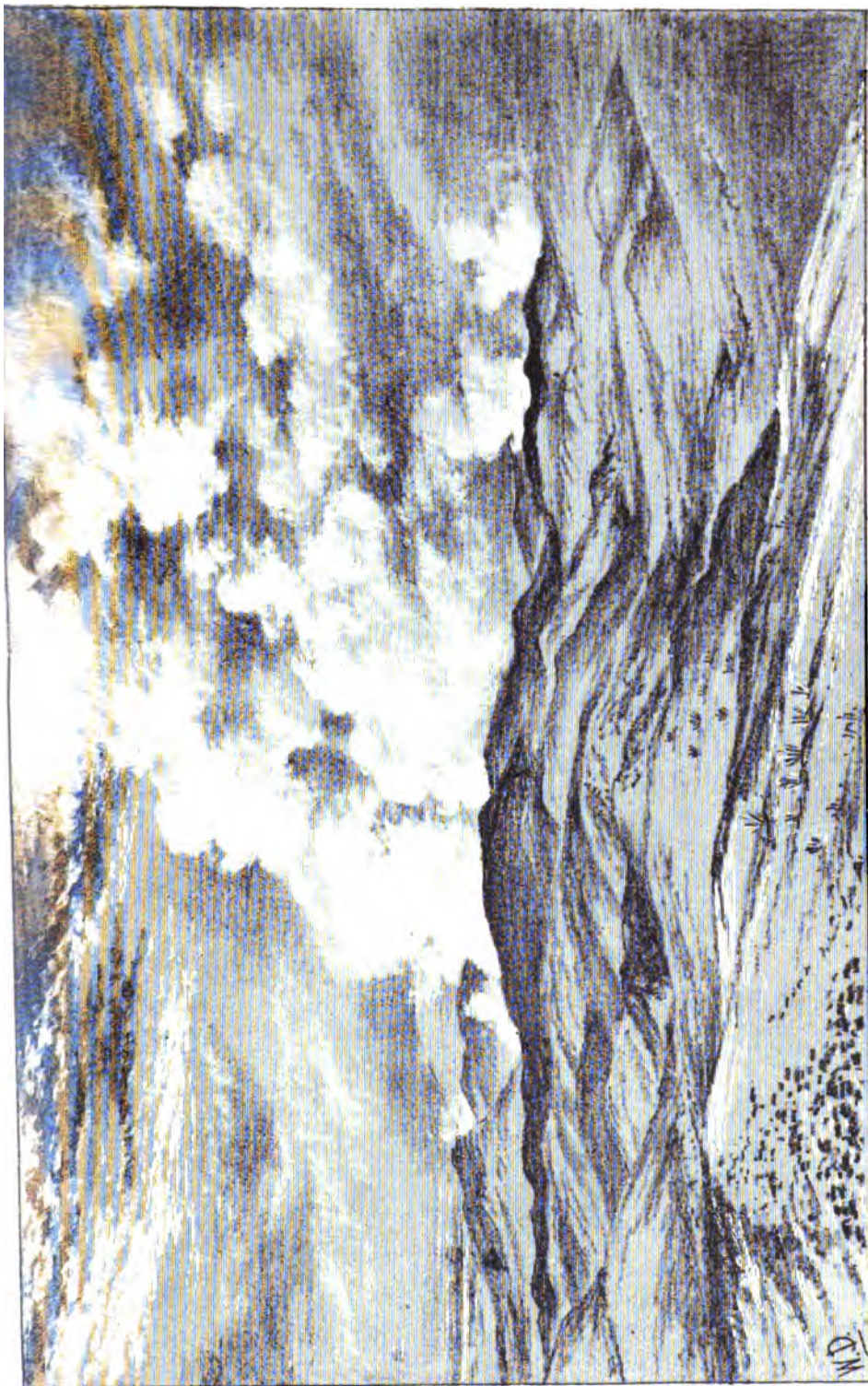
THE BLACK CRATER.

From the West.

Illustrates pit-marked appearance of the hills where stones have been ejected and sunk in.

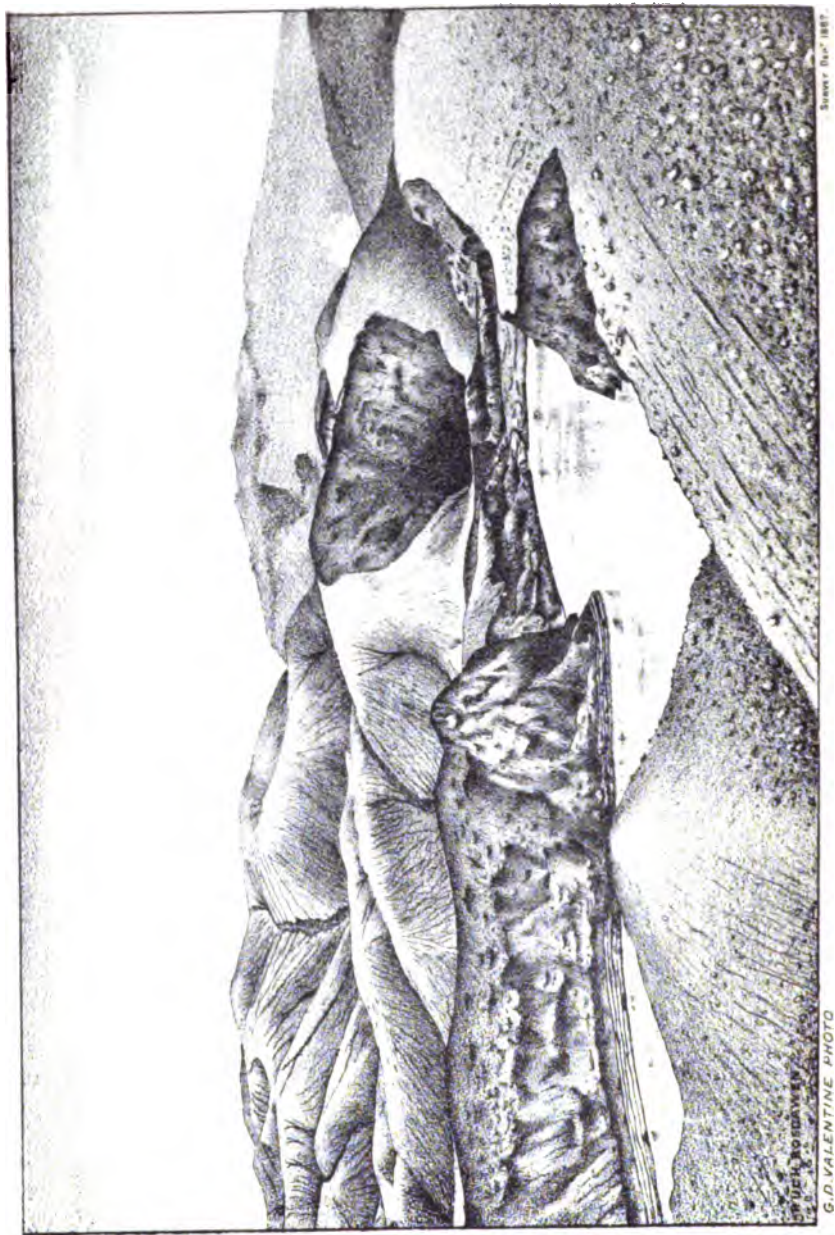
From a photograph by C. Spencer.

Survey No. 1, June 1896



Mount Doom, 1896

GENERAL VIEW OF CRATERS.
From a photograph by C. Spencer.



THE FISSURE.

LOOKING ACROSS ECHO LAKE AND INFERNO CRATERS IN A NORTH-EAST DIRECTION.



From a photograph by C. Spencer.

Echo Lake Crater looking North East.

Showing the large amount of ejected stone on the left; also the crater in the side of hill, called Gate of the Inferno.

ever—when stones and mud were thrown out. The next to the south is the Inferno Crater, which occupies the side of the hill sloping down from the Black Crater. It is in appearance like some enormous gateway leading to the nether regions. Little information can be gained, however, as to its features, for the dense mass of steam which arises from it obscures everything but part of the great boiling pool in the bottom and the black perpendicular rocks forming its sides.

Reference was made on page 45 to the exception which the Black Crater offered to the general character of the southern part of the fissure. This exception consists in the fact of it and the Inferno having ejected molten rock of the same composition as that from Tarawera. The walls of the Inferno present the same appearance as the fissure on Tarawera—that is, the rock appears to have been subject to heat sufficient to partly fuse it. Several small volcanic bombs and a large number of rudely spherical masses of molten rock have been picked up in this locality, though nowhere else except on the mountains. These fused globular masses vary in size from that of a walnut up to 4in. or 5in. in diameter; they are heavy and solid, and rarely scoriaceous.

The Echo Lake Crater, which lies immediately to the south of the Inferno, is divided from it by a low ridge about 50yd. wide. It is rather more than a quarter of a mile long, with an average width of 120yd. It has nearly perpendicular cliffs for most of its circumference, but at the north end these fall away to the level of the lake which now occupies the basin. In the beginning of August it had ceased to be very active, though the water was boiling here and there, and steam rose from the surface everywhere. Plates Nos. 15 and 16 give a good idea of its appearance as seen from the Southern Crater. The channel which leads away from the north-east end of this crater is now dry; but when Professor Thomas and Mr. Lundius passed along here in the middle of July, a large stream of very hot water was flowing from the crater-lake down towards Rotomahana. Where it leaves the crater the channel is about 20yd. wide, but it rapidly widens out to 120yd., and its bed is strewn with great rocks ejected from one of the adjacent craters. The rocks on the western side of the crater appear to be very solid below, and from fissures in them the steam still escapes. The mass of rock through which the crater has been blown out appears to be a hard, dense, banded sandstone of volcanic origin; in some specimens the bands or laminæ are highly coloured—green, red, and brown being the predominating tints. This crater (or craters, for there are probably two) has been

the scene of explosions on a large scale, if we may judge from the immense number of rocks scattered around it, some of which are very large—as much, indeed, as a thousand cubic feet in solid contents. The floor of the valley to the east of it is strewn with ejected rocks in a remarkable manner: they are piled up in such a way as to lead to the belief that a continuous and heavy discharge took place in this particular direction for a considerable time; and, as they are not covered with the lighter ash and sand, they must be the result of the latest effort of the crater. Nowhere along the whole fissure are such numbers and varieties of unfused rocks to be found. The mineralogist will here find, over the space of six or eight acres, a complete museum of volcanic rocks. Although the east side is that on which the greatest number of rocks is found, all the hills and gullies for a considerable distance round are thickly dotted with them, either lying on the surface or buried under the cup-shaped depressions which characterize the hills. One of these hollows measured 30ft. in diameter by 12ft. deep, denoting where a rock larger than usual had sunk out of sight. The sand and ash on the edges of the crater is about from 15ft. to 20ft. in thickness. Plate No. 15 shows the old and new surfaces plainly.

To the south of the Echo Lake, and separated from it by a valley, is the Southern Crater, the dimensions of which are 200yd. long by 100yd. wide, and with a depth of 350ft. below the crater-edge. On the fifth day after the eruption this was still very active, though filled with boiling water. An enormous column of steam arose from it high into the air, and obscured the surface of the water. The crater is blown out of a ridge, valleys dividing it, on the north from the Echo Lake Crater, and from the next ridge to the south. In neither of these valleys can the fissure be traced. It is somewhat remarkable that no sign of the fissure is to be observed south of the Southern Crater: not even a crack can be seen; but it is quite possible that the thick covering of ash hides any minor fissures or earthquake-cracks in this locality, whilst they are to be seen some distance south-westward. Plate No. 16c shows the nature of the country south-west of the Southern Crater, and in continuation of the line of fissure.

The nature of the deposit covering the country round the southernmost craters differs somewhat from that round Rotomahana: we no longer have the surface of sands and mud, which, acted on by the rain, forms deep furrows lying closely together (see Plate No. 17), but a fine impalpable powder of the consistency of flour, of the same colour and appearance as Portland cement. It does not cut up into

№154



HUGH BORMANN

STONES S.E. SIDE OF ECHO LAKE.
From a photograph by J.C. Blythe, Novr 1886.



HUGH BISCOE

G. D. VALENTINE, PHOTO.

SEVEN 1917

THE SOUTHERN CRATER.
Looking North-East along Fissure.



L. C. Blythe

THE INFERNO CRAITER.
From a photograph by Mr. J. C. Blythe, Nov. 1886.

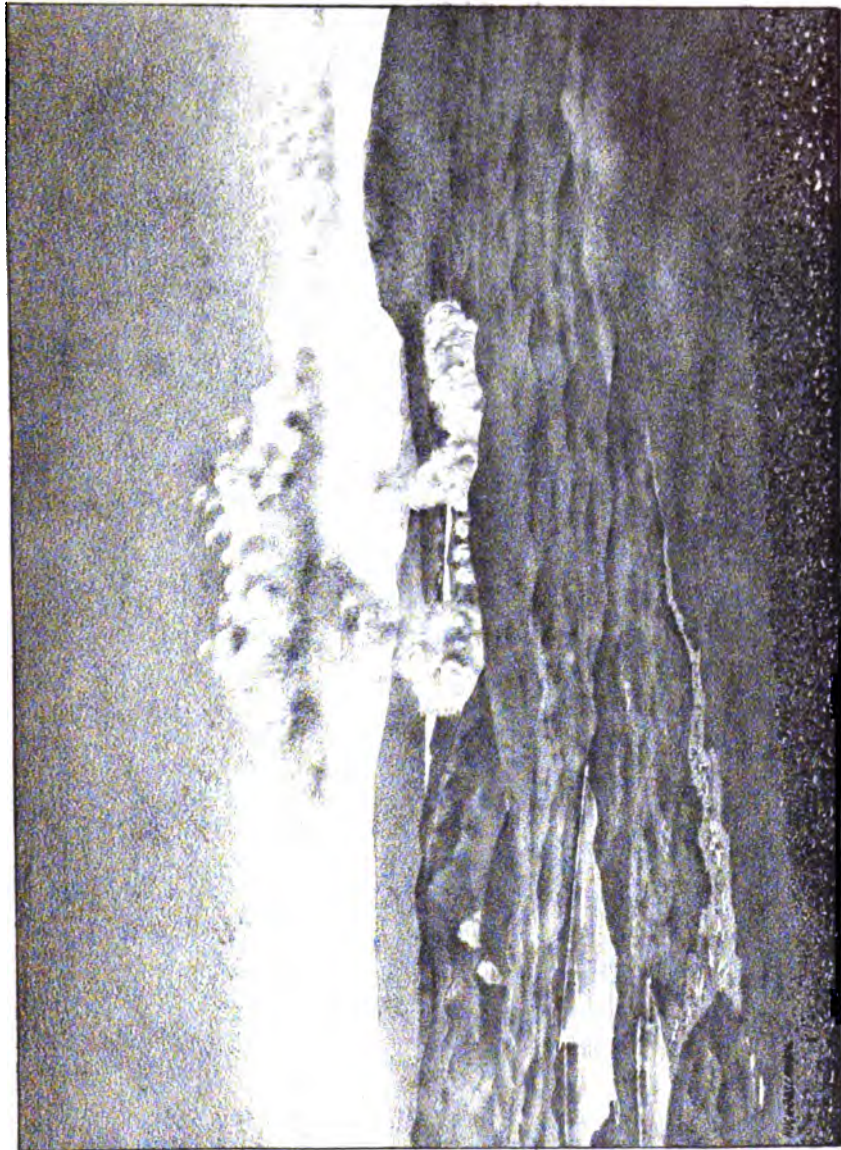


From a photograph by J. C. Blythe

Echo Lake from the Southern Crater.



From Kaitaramea Mt. (Imos. before eruption).



From Kakaramea M^t (looking north across line of eruption).



From a photograph by J. C. Blythe.

South West from Hape o Iorua.

Swamp Bay, Iorua. 1886

*Looking along country in the direction the great
Assure would extend, if produced.*



Looking South West,
From a photograph by
C. Spence.

Showing appearance of mud covered hills east of Rotorua, N.Z.,
and the deeply furrowed surface due to rain water

little channels as the sand and mud does, but still envelopes the hills much as it did when first ejected. Doubtless it owes its origin to the southern craters, and is probably of later date than the ejecta from Rotomahana. In some places where it could be observed in the beginning of August it was found to be quite dry at 3ft. under the surface, notwithstanding that very heavy rains had fallen since the date of the eruption. The base of the Hape-o-Toroa Hill is its northern termination, whilst it extends in a southerly direction to half-way up Maungakakamea Mountain, where when first seen it appeared to end quite suddenly, the lower part of the hill being quite white, as if covered with snow, whilst the upper showed the native vegetation of fern and tea-tree apparently uninjured. The western edge of the deposit at Pareheru Bush is almost equally well marked. Here it fell among the clumps of bush there growing, and has left them scorched and dying, showing that it fell quite hot: indeed, five days after the eruption it was quite warm 6in. under the surface. After heavy rain it forms a mud of the most tenacious and plastic character. Few who have travelled over it in that state will ever forget the fatigue it gave rise to. If moulded when in the wet state it dries quite hard, like cement. Scattered through it, but in no great quantity, is a little fine scoria, evidently derived from Tarawera; but this is only found a little way under the surface. Outside the bounds of this ash, (if ash it may be called, for the name seems somewhat of a misnomer) a little scoria or lapilli is found to extend for a mile or more, but in very small quantities.

On considering the character of the southern craters of the great fissure, together with the nature of the ejecta, we are forcibly reminded of Poulett Scrope's description of La Gour de Tazana, a lake in the volcanic district of Puy de Dôme.* He says:—

“Rather within a mile to the north-east of the Puy de Chalar is a circular lake called La Gour de Tazana, about half a mile in diameter and from 30ft. to 40ft. deep. Its margin for a fourth of the circumference is flat, and little elevated above the valley into which the lake discharges itself. Everywhere else it is environed by a crescent of steep granitic rocks, rising about 200ft. from the level of the water, and thickly speckled with small scoria and puzzolana lava. These fragments are all that indicate the volcanic origin of this gulf-like basin; but these are enough. No stream of lava, or even blocks of any size, are perceivable. The encircling rocks show marks of considerable disturbance. . . .

* “Extinct Volcanoes of Central France.” 1853. By G. Poulett Scrope, F.R.S., F.G.S.

"This curious and—in Auvergne—rather uncommon variety of crater is identical in character with some of the largest and most remarkable of volcanic *maare* in the Eiffel (particularly that of Meerfeld), with this only difference: that the former has been drilled, by the volcanic explosions through granite, the latter through superficial strata of grauwacke, slate, and secondary sandstone. . . .

"The peculiar character by which such craters are distinguished from the volcanic vents we have been describing—viz., their great widths, the total absence of all lava-currents, and the extremely small quantity of ejected scoria by which they are surrounded—are not easily accounted for. . . . The extremely regular circular figure which is characteristic of all such craters demonstratively proves that the explosion of one or more elastic bubbles was concerned in their production." (P. 81.)

"One remarkable and peculiar circumstance attends these cones of Montchal and Mont Seneire—viz., the existence of a deep, large, and nearly circular hollow immediately at the foot of each. The bottom is covered with water; and they bear the names of Lakes Pavin and Mont Seneire. Both are bordered with nearly perpendicular rocks of ancient basalt. Their position announces them to be contemporary with the eruptions of the neighbouring cones, and it seems probable that, like the Gour de Tazana already described, they owe their formation to some extremely rapid and violent explosion." (P. 143.)

"In this range also, as in Mont Dôme and Mont Dore, we meet with a few lakes, occupying wide, deep, and nearly circular basins, which bear every appearance of having resulted from some violent volcanic explosions, but differing from ordinary craters, not only in their larger dimensions, but in the nature, also, and disposition of their enclosures, which are usually of primary or, at all events, pre-existing rocks, merely sprinkled more or less copiously with scoria and puz-zolana, little, if at all, elevated above the surface of the enviroing country." (P. 185.)

No doubt Scrope is correct in assigning a sudden explosion as the cause of these and similar craters. After a few years, when the rains shall have washed the recent deposits off the hills, and the vegetation again appears near the southern craters, there will be little left to denote the origin of them but the blocks of unfused rocks which lie scattered around.

It seems very probable that Rotokawau, the beautiful little lake, encircled with perpendicular cliffs, which lies near Tikitere, close to the shores of Rotorua, is another of these craters due to a sudden explosive effort unaccompanied by the ejection of lava or scoria. It

Plate No 18.



Drawn by G. H. Sturtevant from a photo. by C. Spenser.

TARAWERA MOUNTAIN
From above Te Aniki. Shewing position of "The Chasm"

has been blown through a rhyolitic tuff or lava flow now covered with a growth of tall forest trees, and still has a small but active fumarole on its western edge.

EARTHQUAKE-CRACKS.

It has been before mentioned that the great fissure is continued in a south-westerly direction by earthquake-cracks. There are many features of interest connected with these as bearing on the recent eruption, and also on the proof they offer of the great disturbance of the crust of the earth in this locality in times long antecedent to the late eruption, when the earthquakes must have far exceeded in violence those recently experienced, and at the same time have extended over a much larger area than the near neighbourhood of the fissure. A glance at the map will show that there is a series of cracks which is directly in the line of fissure, whilst on both sides others exist which have a nearly parallel direction. No doubt, were the covering of ash removed from off the space between these cracks and the Southern Crater others connecting them with that crater would be found. The proof of it is this : The Survey party were in the habit of using one of the little valleys leading from Pareheru to the Black Crater as the road to their work each morning; but on one occasion after a heavy rain they found their way cut off by a crack which had appeared during the night, and this was so large and so deep as to be impassable. It extended across the valley from side to side, a distance of 60yd. by 20ft. wide, and had a varying depth of from 15ft. to 25ft. No sign of this had been seen before. Doubtless the heavy rain had worked its way down under the ash until it came to the crack, and had then excavated its sides till the covering fell in and disclosed its presence.

Now, it is remarkable that all the fresh cracks seen—and they were very numerous, only a few being shown on the map through want of time—followed the lines of old cracks, or subsidences, or perhaps it would be better to call them faults. In nearly every valley in this part of the country, a peculiar feature had been noticed by the writer for many years past, and many an hour had been occupied in endeavouring to assign a cause for it. These valleys are almost invariably dry, and, being generally of gradual easy ascent or descent, the ancient Maori pathways follow along them from one watershed to another. They thus formed the high roads of the country, and, being invariably grassed, whilst the hill-sides were covered with fern, formed excellent places for observing. Every here and there—sometimes within a few yards of one another, at others perhaps with

a mile or so intervening—were terraces or “steps” running athwart them, of various heights, from a foot or two up to 20ft., 30ft., or 50ft. A peculiarity about them is that they do not all face the same way—i.e., the descent is not always the same as that of the valley. It constantly occurs that a valley may have a gentle regular descent of 4° or 5° inclination for half a mile or so, then a nearly perpendicular step will have to be ascended, and then the regular descent is continued to the next step, which may be another ascent, or, on the other hand, it may be a descent. All of these valleys are, of course, due to the action of Nature’s most powerful graving-tool, running water; though rarely is running water now to be seen in them. What becomes of the water which after very heavy rain does come down them? The earthquakes attendant on the recent eruption have clearly explained this, as well as the nature of the steps. Every recent earthquake-crack follows along the face of these steps, generally about half-way up, sometimes on top, sometimes at the bottom, and more rarely a few yards off. Clearly the steps are old lines of earthquake-cracks, which have formed fissures—faults, in fact—in which the downthrow varies, sometimes in one direction, sometimes in the opposite. The running water coming down the valleys after rain, on meeting these fissures, naturally disappears into them. At the foot of the steps large holes or depressions are frequently seen, sometimes extending along them for considerable distances, marking where a subsidence of the surface has taken place. In the valley leading from Tutehu (see map) to Maungaongaonga (see Plate 18A for drawing of the mountain) the following notes of the cracks were taken: The three nearest the latter mountain have a downthrow to the north-west of amounts varying from 6ft. to 12ft.; the other one a downthrow to the south-east of about 15ft. In the valley leading from Maungakakarama towards Pareheru the three nearest the former mountain have a downthrow to the north-west of 10ft., 30ft., and 25ft.; the other three a downthrow to the south-east of 40ft., 50ft., and 15ft. The combined evidence of these two series tends to show that there has been a subsidence of the central area, which is north-west of the great fissure, of about 25ft. to 30ft. (See section in Plate No. 18B.) The long earthquake-crack shown near the Pareheru Bush was traced over hill and dale a distance of one and a half miles, the southern part of which has a parallel direction to the great fissure, but the northern portion tends more to the west. It has a downthrow to the south-east or towards the fissure varying from nothing to 60ft. or 80ft. In mentioning the downthrow, however, it must be understood that this is not due to the recent earthquakes, but to the more ancient

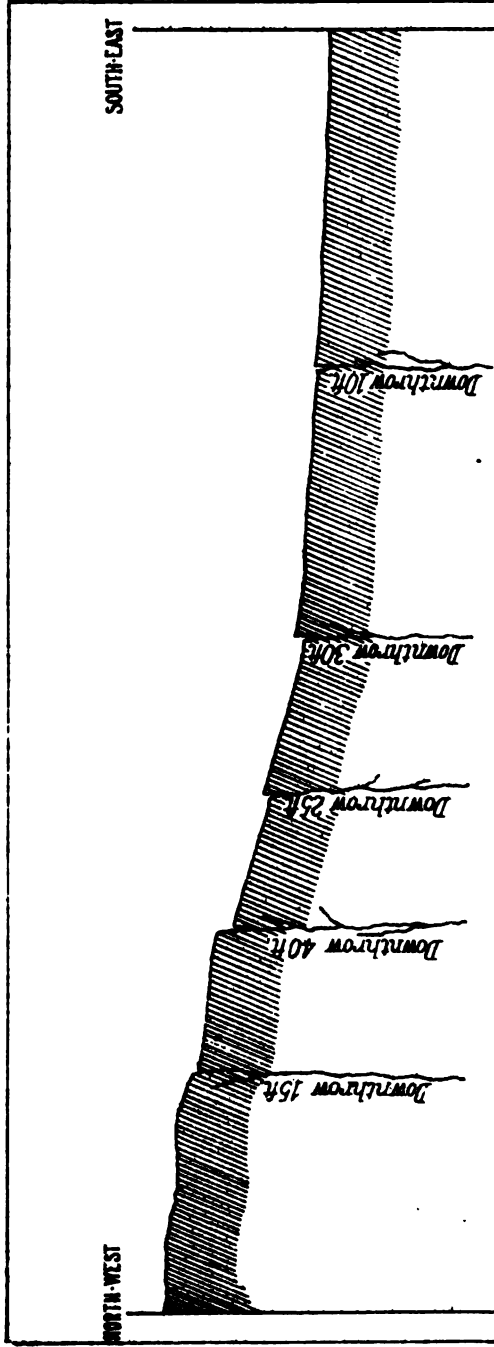


Mount Ma' Luma 1886

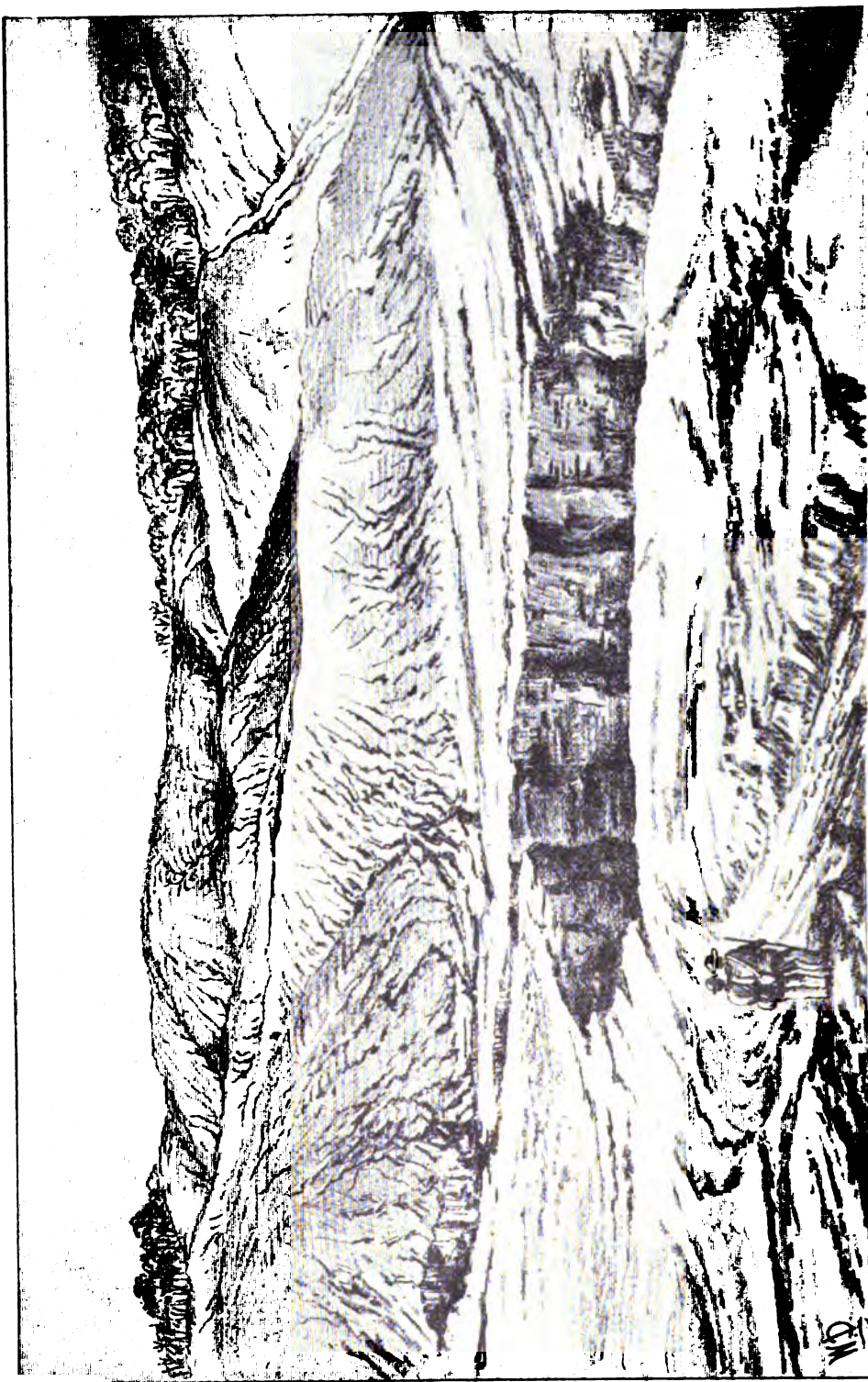
From a photograph by J. C. Blythe.

MAUNGAONGAONGA.

Plate 18B



SECTION ALONG VALLEY NEAR PAREHERU,
Shewing Earthquake Faults.



Survey Map, June 1898

RECENT SUBSIDENCE IN OLD EARTHQUAKE CRACK
 Also flattened appearance of the mud-covered hills.
 From a photograph by J. C. Blythe.

From a photograph by J. C. Blythe.



PLATE No 18



J.C. BLYTHE JULY 1885

SURVEY DECEMBER 1887

RECENT SUBSIDENCE ON OLD EARTHQUAKE CRACK

Front View
(Ninety feet deep)



RECENT SUBSIDENCE FOLLOWING OLD EARTHQUAKE CRACK.

Road Rotorua to Wairoa.

Looking South West

From a photograph by J. C. Blythe.

ones, which were of a much more serious nature; or perhaps the constant earthquakes for ages past may each have performed its part in causing a gradual subsidence.

Although these ancient lines of subsidence, or faults, are most plainly to be seen in the valleys, there is no difficulty in tracing them over the hills: in every case a depression will be seen where the subsidence has taken place. Plate No. 19 shows what is meant. This illustrates a recent subsidence along an old crack which occurs on the coach-road from Rotorua to the Wairoa. On the right of the picture the terrace or step which runs across the valley is seen, and by following it out with the eye it will be observed to cross the ridge in the background just under the little hillock. Similar depressions on the ridges can be seen in every other case noticed. The subsidence which has here taken place has, no doubt, been caused by the opening of the old crack by recent earthquakes in the first instance; and, as the covering of mud which there hides the face of the country no longer allows the rain-water to percolate slowly through the naturally porous surface, it has gathered in considerable volume near the crack, until its weight, charged with mud, has broken through into the old subterranean channel which had previously carried off the waters of the valley. This subsidence is, however, on a much larger scale than usual: the depth of the chasm formed is about 90ft.; it can be traced for a long distance over the hill to the north.*

In every case, in the neighbourhood of the great fissure, where these ancient lines of subsidence were seen, the recent earthquakes

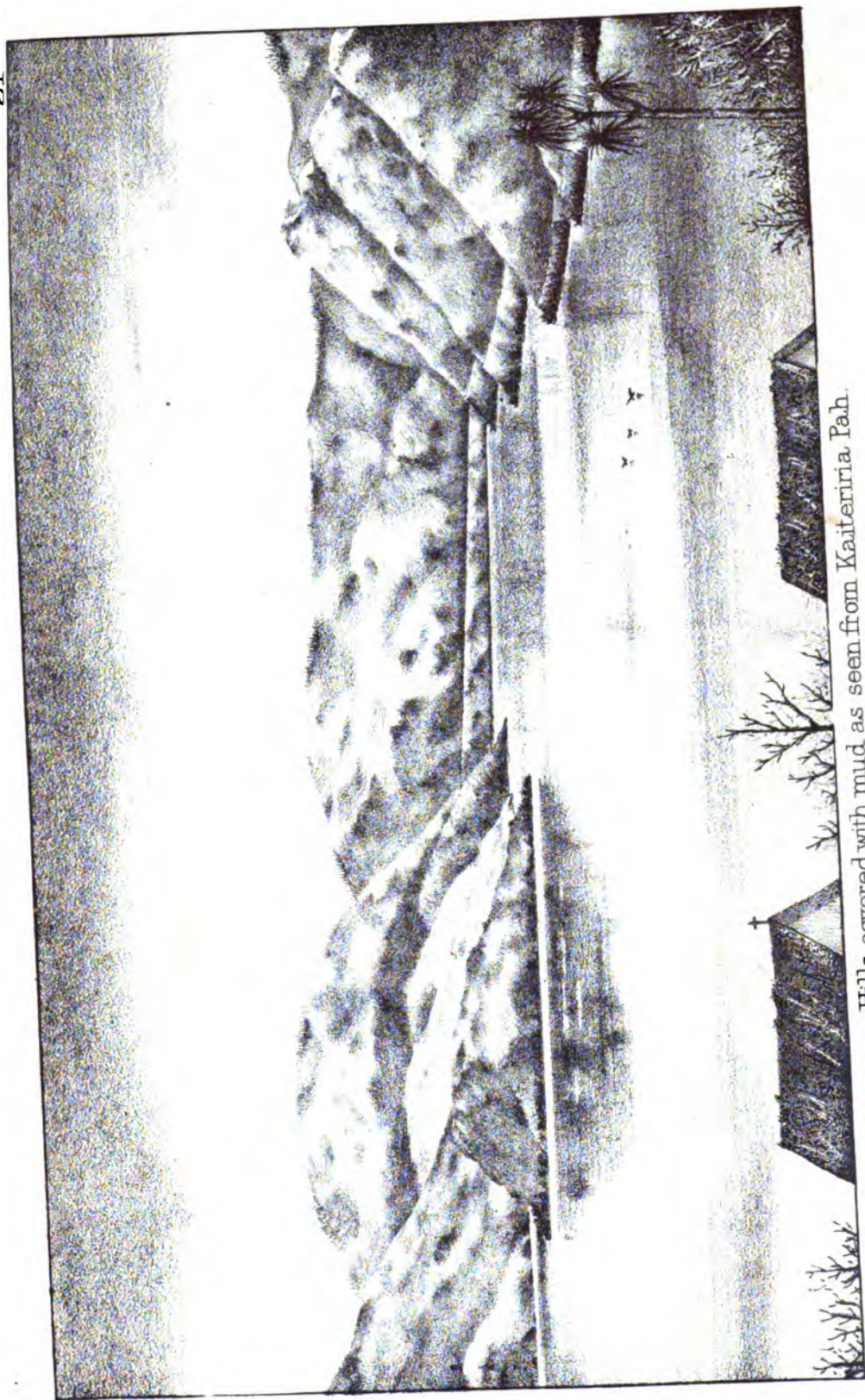
* The study of the mud- and ash-covered surface of the country around the seat of the eruption affords some very instructive examples of the power of running water acting on loosely-compacted materials. The views generally held as to the slowness with which meteoric agencies act in altering the form of surface are likely to be a good deal modified—at any rate, in a country of similar origin—after a visit to the district. It is quite astonishing the additional power that running water gains when charged with mud as an excavating agent. Many of the little streams draining the mud-covered hills, which were never known to flood to any appreciable extent, now come down as great torrents, carrying along an immense load of *débris*, to be spread over the lower levels, whilst the channels are cleared out and widened in a remarkable manner. In several instances watercourses were seen, which owe their origin to the eruption, that had been worn out to a depth of over 100ft., whilst on the hills the furrows were running down the sides every few feet, and often very deep. In parts the country exhibits an excellent example of the usual form of hill-shading on maps, the *hachures* being formed by the watercourses; and, as these, of course, run in the same perpendicular lines, the resemblance is complete. Plate No. 17 gives some idea of this appearance. The water when charged with mud and sand, is able to effect in an hour or two what under ordinary circumstances could only be accomplished by water alone in many ages. It is perhaps the action of water charged in this manner that has caused the excavation of the many gullies in this country down which no water ever runs now, and the origin of which is most difficult to arrive at. Possibly the "pluvialists" would quote this country as evidence of the truth of their theory of a former state of the earth in which a vastly greater amount of rain fell than at present; but we have only to observe what water can do when the conditions are favourable—as they are here—to account for almost any amount of denudation, and that, too, within a very short space of time.

have cracked the surface—and nowhere else. The cracks are not large—generally from a few inches to 4ft. or 5ft. wide—but they are sufficiently numerous in some parts to make it difficult to take a horse across country.

On the map will be seen a place called Waikorua, or Earthquake Flat. Here are to be seen several of the old lines of subsidence; and, as they are in this place closer together than usual, the intervening ground can plainly be seen to have subsided bodily for a few feet. The recent cracks follow the same lines, and have a general direction roughly parallel to the great fissure.* Some of them open out to a considerable width; one was noticed which appeared to have been in part occupied by hot springs or fumaroles formerly, for the sides were coloured as in many of the active fumaroles, and the rock had been in some cases decomposed by the action of the gases. The flat itself is a somewhat remarkable feature, having much the same appearance, though on a smaller scale, that Rotomahana Crater will have after the vegetation shall have covered its steep sides. It looks, in fact, just like one of the hydro-thermal craters which has possibly been occupied by a lake at a subsequent date, though the evidence of this is not very clear. Leading from it at each end is a long, dry, winding valley, with a gradual descent in both directions. The earthquake-cracks and faults in it are subsequent to its being occupied by a lake, if ever such lake existed.

Although the neighbourhood of the great fissure is that in which the greatest number of the steps or faults are found, they exist in considerable numbers in other parts, especially towards Rotorua, or between the fissures which have been described. They have a very general parallel direction, though some run nearly at right angles, and in one place they appear to radiate from Tikitapu Lake, as before referred to. It will be found that if the direction of the cracks south-west of the Southern Crater is continued for a few miles, it will lead, first, directly through a country in which are a large number of extinct hot springs and fumaroles, and then, at a short distance further, into the existing group of hot springs at Otamakokore and Waikite. These springs are situated immediately at the foot of the steep range of hills forming the northerly continuation of the Paeroa Mountains, which there is every reason to believe forms one side of a great fault or fissure.

* Major Mair states that after a heavy earthquake in 1865 he observed these same cracks to have been opened afresh.



Hills covered with mud as seen from Kaiteriria Pah.

CONCLUSION.

In concluding this report a few remarks on the general character of the eruption may prove of interest. It has been remarked by Judd that nearly every known volcano has originated in the formation of a fissure in the earth's crust, from which matter has been ejected in various forms, and for a longer or shorter period of time. The matter so ejected, if in the form of the acidic and more viscid lavas, has usually welled up from below and spread out from the vent in streams of great size, but extending to no great distance, and without forming a cone such as is usually associated with the term "volcanic mountain." These lavas tend rather to the formation of rounded dome-like masses, of which central France offers several examples. If, on the other hand, the ejected matter is more fragmentary, a true cone or series of cones is usually the result. It has also been observed in so great a number of cases as almost to have become a recognized law, that there is a regular sequence in the order in which lavas of different compositions have been ejected from vents. This generalization is due to the researches of Richthofen; and the order, in point of time and composition, which he laid down is as follows: (1) Propylites, (2) andesites, (3) trachytes, (4) rhyolites, (5) basalts.

Now, it is a matter of some interest to ascertain, if possible, to which of the above classes the recent eruption belongs, for on its determination (if the law holds good in this case) depends the question of the future history of Tarawera. It is evident that the solution of the problem depends primarily on the chemical analyses of the ejected matter; but these analyses have not yet been made public to any great extent. Such as are available tend to prove that the ejecta belong to the basic class of rocks, or to a transition from the acidic to the basic, and therefore are more basaltic than anything else—or, in other words, that the last phase in the history of the vulcanicity of this particular district has set in.*

Doubtless the report of the Professors who have already visited the district when it appears will clear up this important matter; but in the meantime there are certain points in connection with the subject which are so obvious, and bear such strong testimony to the great change in the character of the rocks ejected, from those forming the surrounding country, that it will be of interest to note them.

The matter ejected from Tarawera and Ruawahia in the greatest quantity is scoria, black and reddish-brown in colour, and highly

* *Vide* Appendix No. 1.

vesicular in texture. So much is it like in outward appearance to the basaltic scoria so common to the volcanic districts of Auckland and the Bay of Islands, that only a very close examination would detect any difference. Now, with the exception of a little around Ruapehu and Tongariro, no such thing as scoria is anywhere to be found all over the Taupo volcanic zone. Pumice there is in abundance; but pumice is to the acidic lavas what scoria is to the basaltic lavas—i.e., the froth or scum—and no pumice, except in such small quantities that a careful search by the Survey party only brought to light a quantity which may be held in the hollow of a hand—was ejected from Tarawera. It is true that the sands and mud which cover so large an area of country have the appearance of being formed largely of pumice in minute fragments; but these, it is believed, are not recent products, nor did they to any great extent emanate from Tarawera, but from the basin of Rotomahana and Rotomakariri: they are merely the comminuted fragments of pre-existing rocks of the acidic class.

No one who has carefully studied the nature of the molten ejecta can doubt for a moment that an entire change has taken place in the character of the volcanic rocks now brought to the surface, from those formerly to be found there. We know that those forming Tarawera are the most acidic of all—trachyte and rhyolite—and no one has ever shown that these lavas produce vesicular black scoria.

We are thus again brought face to face with evidence which tends to prove what has already been attempted from other lines of reasoning, that the late eruption was deep-seated. If Richthofen's law is in any sense true, the deductions from it are equally true. The prevailing belief of geologists is, that the heavier and more basic lavas occupy the lowest position in that fluid belt which Sir William Dawson so ably described in his presidential address to the British Association at its late meeting, and, as a consequence, are the latest to be brought to the surface, and come from the greatest depths.

Since in the recent eruption the ejecta on top of Tarawera have been of that fragmentary character which tends usually to build up a true volcanic cone, we may ask why they have not done so. Before an answer can be attempted to this question, some consideration must be given to circumstances connected with the eruption which have a wider range.

It has been shown in previous pages that there are strong reasons for believing that the volcanic forces in the Taupo Zone had been gradually dying out for ages past; but there were also reasons shown for thinking that latterly, and not very long before the eruption, an increase

in activity had taken place, although this increase was not altogether of such a character as to cause any alarm or apprehension of what was about to occur. We may suppose that during the period of decadence, and in the earlier stages of increasing activity, Ngauruhoe would act as the safety-valve at the southern end of the volcanic zone; and in its eruptions, which have been very minor ones, it would serve as the channel by which the superfluous energy of the elastic forces below would be carried off. But if, through any causes acting on the reservoirs of fluid matter below, a change in the locus of pressure were to occur, another vent would be sought. Whilst Ngauruhoe has remained unchanged in the degree of activity for many years past, the recently-proved activity of Ruapehu tends to show that such a change has occurred, and that the elastic forces endeavoured to find in the old channel of communication of that mountain a vent for their escape. But the effort was futile: possibly the elastic force of the gases was unequal to forcing solid matter to the surface at an elevation of over 9,000ft., and as a consequence another vent at a lower line would be sought. Recent events have shown that such a vent was found at Rotomahana and Tarawera, where the imprisoned forces seem to have gathered strength sufficient to overcome the resistance of the superincumbent rocks. It would appear as if a wave had passed along the fluid belt beneath the crust, first affecting Ruapehu, and passing thence northwards to Tarawera and on to White Island, and perhaps finally continuing its course to Niuafoou, in the Tonga Islands, where it burst out in eruption on the 30th August.

When we come to consider the circumstances attending on the recent eruption, one of the things which strikes us as almost inexplicable is this: Why should the outburst have occurred first in the solid mass of rock of which Tarawera is formed rather than in the basin of Rotomahana, where hydrothermal action has been displayed on a larger scale than in any part of the Taupo Zone, and that for ages past, and where it would appear as if a communication pre-existing was already established with the heated interior? To account for it by assuming an origin for the outburst of so great a depth below the crust that the difference in height between the top of Tarawera and the bottom of Rotomahana is, by comparison, so infinitesimal as to cause no difference in the amount of resistance to be overcome, does not remove the difficulty entirely. It is, perhaps, more reasonable to suppose that a communication existed within the mountain, forming the old channel by which the lavas of which it is formed first flowed up to the surface, and the rocks in which had not quite cooled down or consolidated, and that this was the immediate source of the heat which gave rise to the

record of in this country. The face of the ash-covered country will change too. Vegetation will soon appear and prepare it for the uses of man. But never, alas! can this compensate for the loss this colony—nay, the world—has suffered in the destruction of those masterpieces of Nature's handiwork, the Pink and White Terraces.

of rock and mud within the crater. It is nearly at boiling heat when it first appears, and evidently comes from underneath the cliffs forming the crater-walls. As it passes through only about 300yd. to 350yd. of ejected matter, it cannot derive its heat from that due to the outburst, but rather to subterranean sources.

It appears to the writer that all the evidence we have tends to prove the existence of a reservoir of molten heated matter within that part of the great fissure which underlies the mountains of Tarawera and Ruawahia, connected, of course, with the heated interior, and with other parts of the great fissure. What the immediate cause of the eruption was is a matter of pure speculation. Captain C. E. Dutton, of the United States Geological Survey, in his description of the Hawaiian volcanoes, says: "Volcanic action and regional uplifting are really associated phenomena, and the results of the same cause. When we come to inquire into the cause of elevatory movements of the earth's surface we only encounter a mystery. No solution has ever been given which does not go to pieces under criticism."

The Tarawera eruption appears to offer an example of the first stage in the formation of a volcanic mountain. It is, in fact, an incomplete effort to form a volcano. Whether the energy has exhausted itself in this effort, and matters will remain in a state of quiescence for long ages until it shall have again gathered strength to advance another stage, remains to be seen. As far as can be judged from the present state of affairs, the activity is fast dying out, and a return to the normal state appears imminent. Changes are for ever occurring in Nature, and these will be watched with great interest in this locality. The crater of Rotomahana cannot remain for long in its present state: as the activity decreases the equilibrium at present existing cannot continue; the drainage of the country which falls into the basin will no longer be carried off in steam, but begin to fill it with water and form a lake, probably of hot water. A time will come when this lake will increase to a much larger size than that which formerly occupied its site; but an end to that will come: after rising for some 80ft. above the former level, it will then force its way over the barrier now thrown across the outlet, and when that time arrives a very few hours will see the greater part of this barrier removed, and then the waters of Rotomahana must form a devastating torrent as they pour down into Lake Tarawera. Luckily that lake is of considerable extent, or otherwise the flood which would rise in the Tarawera River would prove more disastrous than any we have

ANALYSES OF TYPICAL VOLCANIC ROCKS, from CLARENCE KING'S "Geology of the Fortieth Parallel."

Name.	Locality.	Silica.	Alumina.	Iron Oxides	Manganese.	Lime.	Magnesia.	Soda.	Potassium.	Potash.	Chlorine.	Phosphoric Acid.	Sulphurous Acid.	Organic Matter.	Water.	Specific Gravity.
Propylite ..	..	60.90	16.90	5.50	Tr.	5.30	2.30	3.80	2.80	..	..	..	..	..	..	98.10
Quartz propylite ..	..	66.20	12.90	13.20	..	2.00	0.80	3.30	4.45	..	..	..	..	..	..	101.70
Andesite ..	..	62.40	16.10	12.40	..	5.10	1.90	2.80	2.70	..	..	..	..	..	..	103.5
Andesite, dacite ..	..	63.90	14.30	5.00	..	2.10	1.00	2.80	3.30	..	..	..	..	..	..	98.4
Trachyte ..	..	60.00	16.10	7.00	0.10	5.60	3.10	3.40	3.40	..	..	..	..	..	..	101.1
Rhyolite ..	..	73.60	12.90	1.90	0.10	1.20	0.50	3.00	5.60	..	..	..	..	..	..	98.7
Basalt ..	..	53.90	17.30	9.90	Tr.	7.50	5.70	3.40	1.60	..	..	..	..	..	..	99.5

From J. BETE JUK'S "Manual of Geology."

Basalt ..	..	48.00	13.80	13.80	..	10.20	6.50	3.00	1.50	..	..	..	..	..	..	100.0
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J. A. POND'S ANALYSES OF ROCKS, &c., from TARAWERA.

Ash*	..	Southern craters	66.85	17.95	6.05	..	3.85	0.20	0.33	..	0.16	0.05	0.09	0.39	1.30	0.85	97.07	..
Mud	..	Wairoa	70.10	15.95	5.15	..	2.60	0.30	0.97	..	0.19	0.07	0.09	0.82	1.30	0.90	97.34	..
Dust	..	Tauranga	64.00	18.16	7.20	..	5.42	1.90	0.58	..	0.18	0.03	0.14	0.48	0.90	0.75	99.74	..
Ash†	..	Whakatane	57.15	18.35	11.55	..	8.36	1.37	0.64	..	0.17	0.04	0.095	0.35	0.20	0.30	98.57	..
Ash	..	Opitiki	56.30	17.70	11.50	..	8.45	2.20	0.59	..	0.17	0.06	0.125	0.80	0.25	0.15	97.79	..
Lapilli‡	..	Wairoa	50.90	20.00	14.10	..	10.38	2.77	0.70	..	0.14	0.04	0.16	0.22	..	..	99.41	..
Lapilli	..	Pareheru	51.35	18.20	14.50	..	10.26	3.10	0.84	..	0.16	0.05	0.125	0.41	..	0.25	99.25	..
Lapilli	..	Rotoehu	52.60	16.30	12.70	..	11.05	4.65	0.67	..	0.09	..	0.06	..	..	..	100.12	..

Dr. HECTOR'S ANALYSES OF DUST from TARAWERA ERUPTION. (See Appendix, Journal House of Representatives, 1886, H.-25.)

Dust	..	Tauranga	60.74	16.09	11.53	Tr.	5.69	0.96	Alkalies, 2.68	..	Tr.	..	Tr.	2.26	100.0	..
Dust	..	East Cape	59.37	17.96	10.18	..	5.98	1.19	2.13	..	..	..	0.99	2.21	100.0	..

* The white impalpable powder.

† Mixed with fine lapilli.

‡ Lapilli from Tarawera Mountain.

ANALYSES of VOLCANIC ASH and LAPILLI from the Tarawera Eruption.—By J. A. POND, Colonial Analyst, Auckland.

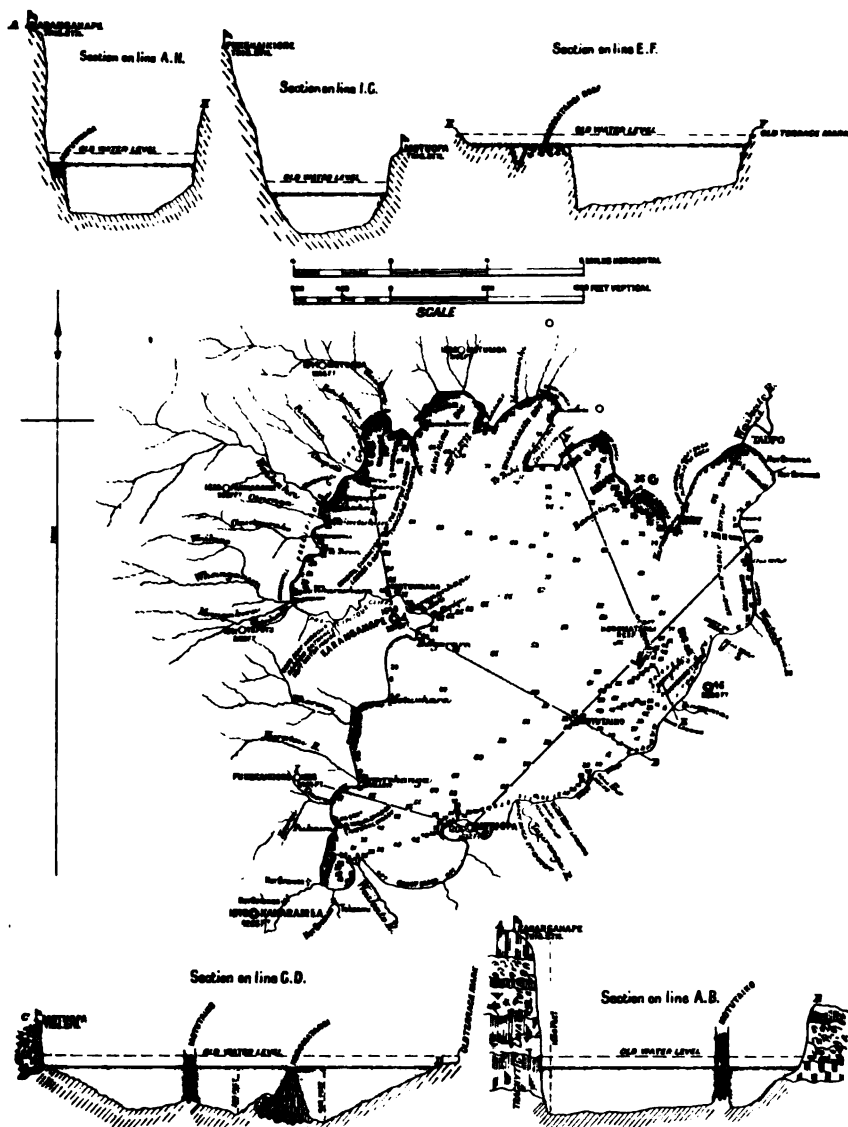
	Dust, Ash, or Mud.					Lapilli.		
	Oharo.	Wairoa.	Tauranga.	Whakatane.	Opotiki.	Wairoa.	Pareheru.	Rotoehu.
	1.	2.	3.	4.	5.	6.	7.	8.
Soluble on heating in hydrochloric acid and water, equal quantities—								
Silica	·85	·20	·85	·65	·60	·50	·70	·50
Iron oxides	2·05	2·50	3·00	2·90	3·20	3·90	3·85	3·50
Alumina	3·45	2·80	5·01	4·45	3·90	3·70	4·95	6·60
Lime	·95	·67	2·01	1·92	2·10	1·79	2·14	2·65
Magnesia	·20	·30	·30	·47	·80	·67	·45	·70
Soda	·33	·37	·58	·64	·59	·70	·84	·67
Potash	·16	·19	·18	·17	·17	·14	·16	·09
Chlorine	·05	·07	·03	·04	·06	·04	·05	..
Phosphoric acid	·09	·09	·14	·095	·125	·10	·125	·06
Sulphuric acid	·39	·32	·48	·35	·30	·22	·41	..
Carbonic oxide	Traces	Traces	Traces	Traces	Traces	Traces	Traces	Traces
Organic matter	1·30	1·30	·90	·20	·25	..	..	..
Water	·85	·90	·75	·30	·15	..	·25	..
Insoluble in acid—								
Silica	66·50	69·90	63·65	56·50	55·70	50·40	50·65	52·10
Iron oxides	4·00	2·65	4·20	8·65	8·30	10·20	10·65	9·20
Alumina	14·50	13·15	13·15	13·90	13·80	16·30	13·25	11·70
Lime	2·90	1·93	3·41	6·44	6·35	8·59	8·12	8·40
Magnesia	Traces	Traces	1·60	·90	1·40	2·10	2·65	3·95
	97·07	97·34	99·74	98·57	97·795	99·415	99·245	100·12

APPENDIX No. 2.

ASCENT OF RUAPEHU: EXTRACT FROM MR. L. CUSSEN'S REPORT,
DATED JUNE, 1886.

IN my monthly report for April I informed you that on ascending Ruapehu in the early part of that month we found a crateral hollow on its summit containing warm, or probably boiling, water: as this matter may be of interest at the present time, it may be well to give a few details and a short description of the mountain, so far as I can from the few notes which I was able to make in the limited time I could devote to the subject, my object, of course, being to complete the trigonometrical observations at the trig. stations in time to descend to our camp before night. We ascended the mountain from the western side, following a long and tolerably regular ridge which runs down from the top of the cone to its base. The ascent was not very difficult: we accomplished it in four and a half hours from our camping-ground, which was situated 5,000ft. above the sea-level; we had therefore 4,000ft. to ascend, nearly 3,000ft. of which was over frozen snow. As we ascended, on all sides of us were examples most various and instructive of volcanic phenomena, and the forms and shapes assumed by lava in cooling. The most remarkable feature of the mountain is the crater-lake on its summit. This lake is situated at the bottom of a funnel-shaped crater, its steep sides being mantled with snow and ice. I had no time for measurements to ascertain the correct dimensions of the lake, and its peculiar surroundings made it difficult to estimate them with any degree of accuracy. The water seemed to me to occupy a circular basin about 500ft. in diameter; it is situated inside the two peaks, Paritetaitonga and Ruapehu, which are about 60 chains apart on the southern portions of the mountain; the lake would be about 300ft. below the peaks, and quite inaccessible, except with the aid of a long rope, and even then the descent over the icy masses would be attended with danger and difficulty. On first reaching the top of the peak I noticed small clouds of steam floating over the surface of the lake; on watching it more closely the water appeared now and then to assume a rotatory movement; eddies and whirlpools seem to pass through it from the centre to the sides, steam or vapour flashing up from the eddies.

It was impossible to discover the exact form and construction of the summit of Ruapehu, the whole mountain-top being covered with a deep mantle of snow, which completely fills up and hides all the hollows between the peaks. Three prominent peaks are presented to



HYDROGRAPHIC SURVEY OF LAKE TAUPO

By L. Cussen Dist. Surveyor 1886
Soundings in Fathoms

C.P. del. Auckland July 7th 1886

SCALE OF MILES

S. Perry Smith Assistant Surveyor General

view : Paritetaitonga, on which our station stands, is on the south-western end of the mountain ; to the south-east of it, about 60 chains distant, is Ruapehu, which is the highest point of the mountain ; exactly a mile to the northward of Paritetaitonga is the third peak, called Te Heuheu, not quite so high as Paritetaitonga. All between these three points, with the exception of the crater lake, is a great undulating snow-field, intersected by irregular crevices of immense depth. From the vertical inward faces of the three peaks, their more gradual outside slopes, and the general configuration of the mountain on the western side, it would seem that the peaks formed part of a circular crater ring, the diameter of which would be about one mile, and the western portion of the lips of which have been destroyed. The crater in which the hot water now exists would probably have been formed, with others, on the floor of the old truncated cone. As stated in my monthly report for April, I noticed on several days after our ascent of Ruapehu a column of steam rising out of the crater and ascending high above the mountain-top. I drew the attention of Te Heuheu and several of the oldest Natives in the district to this fact, and they all agreed that it was quite a new thing—they had never heard of steam arising from Ruapehu before. I think it is more than probable, however, that a low state of volcanic heat prevailed in the crater throughout. Five years ago, when triangulating on the Kaimanawa ranges, I noticed a column of vapour arising from Ruapehu in the position of the crater ; but, not knowing of the existence of the lake, I thought it must be a cloud or fog arising out of one of the gorges of the mountain, although it seemed very like a column of steam.

When observing angles at Paritetaitonga, although the stones which formed the station-mound were frozen hard together, my instrument would not remain level ; the same thing occurred at Hauhungatahi station, eight miles to the westward of Ruapehu, which was likewise frozen hard when I was observing there. Three years ago, when taking angles on Ngauruhoe, I found the same difficulty in keeping my instrument level, although the ground on which it stood was formed of a solid conglomerate mass.*

* Mr. A. D. Wilson, writing on the 20th July, reports the same trouble. He says : " I experienced great difficulty in keeping my instrument level when observing at Hauhungatahi, even though the ground was ironbound with frost. I ascribe this less to present volcanic action than to the place where the trig. is being an old crater, which having been filled up with very loose materials never properly consolidated, the slightest weight upon the surface is sufficient to depress it. I am led to assume this from the character of the stuff taken out when digging the hole of the tube, which looked as if it had first been burnt and then put through a crushing-machine."

LAKE TAUPŌ.

In the month of January last I took a series of soundings of Taupo Lake, the details of which are shown on the map accompanying my report. The lake covers an area of 154,680 acres; its greatest length, from Tapuaeharuru to Waihi, is 24 miles 70 chains; its greatest width, from Waihaha Bay to the mouth of the Hinemaia River, is sixteen miles and a half. The result of the soundings shows that the lake has an almost level bed, the average depth being 65 fathoms, and the greatest depth, at a point nearly in the centre, being 89 fathoms. Only in one place was shallow water found at any considerable distance from the shore: this point is the reef about three miles to the north of the Motutaiko Island, where the rock is covered by only 7ft. of water.

Motutaiko Island is one of the most interesting features of Lake Taupo. It is formed of a column of rhyolitic lava, ascending perpendicularly from the bottom of the lake to a height of 600ft., half of it being below the water, and the upper half covered with stunted timber and scrub. Its construction points to the probability that it is the neck of lava which filled an old volcanic vent, and it was probably surrounded by a cone of loose ejecta, which have been worn away by denudation, and now cover the floor of the lake. To the north-east of Motutaiko Island, and extending northwards from near the mouth of the Hinemaia River along the shore for a distance of three miles, is a ledge running about two miles out into the lake; this ledge is covered by only from two to three fathoms of water, and at its edge the depth suddenly increases to over 30 fathoms. All along this ledge are lying large totara snags, many of them protruding above the water, and they seem to be in a good state of preservation. The Maoris have no knowledge as to how they came there, nor have they any tradition of a change taking place in the formation of the shore: it is more than probable that they were deposited by a slip occurring on the high land of the shore, at a time when the surface was covered with forest. A landslide on such a scale would scarcely have happened since the Natives have inhabited the district without their retaining some account of it, and it therefore seems probable that the timber has been lying there for four hundred years or more.

The evil spirit, or *taniwha*, of Taupo Lake, called Horomatangi, is said by the Natives to inhabit a cave in the reef which lies to the north-east of Motutaiko Island. They say that when a canoe approached the reef, Horomatangi lashed the water into foam, throwing up pumice and stones, and creating such a disturbance that the

canoes were frequently capsized. Another interesting legend in connection with the reef was told to me by Te Heuheu. He said that a totara log possessing great *mana* or power floated in the neighbourhood; sometimes it lay near Horomatangi reef, and sometimes it appeared with its end resting on the shore of the lake. It had worn for itself a passage through the snags from the shore to the reef; it would lie for days touching the shore, and then suddenly depart, and travel through the clear passage to Horomatangi, a distance of nearly two miles. An elderly Native assured me that, when a young man, in a journey from Tapuaeharuru to Motutere, he had sat on the log to rest as it lay on the shore of the lake; on returning in a day or two after he saw it floating far out on the lake on its way to Horomatangi. When the mission church was built at Motutere, the missionaries induced the Natives to use the log in the building of the church; the Native who dragged it out of the water died soon after, and all those who assisted in carrying it to the site of the church, or preparing it for the building, also died within a short time after. The movements of this log—which, no doubt, were considerably exaggerated—may be due to the current of the Hinemaia Stream, which passes slowly through the lake, being deflected in the direction of Horomatangi's reef by the ledge on which the submerged timber lies; the log would thus be carried out by the current, which extends to the reef, where it might remain till a westerly or a north-westerly wind drove it back against the light current of the river, until it again reached its former position on the shore.

At Karaka Point, a promontory four miles south of Tapuaeharuru, are some interesting caves. They were worn by the action of the water on the volcanic conglomerate in which they are formed. The caves are about 30ft. above the present level of the lake. Underneath the tufa of the caves, and along the shore of the lake, the rocks are rhyolitic lava. Three miles to the north-west of Karaka Point, on the shore of the lake, a large deposit of iron-pyrites appears in the rhyolite and tufa beds.

With the exception of the sandy bays of Whangamata, Waihora, Waihaha, and the several smaller bays shown on the map, the whole of the northern and western shores are formed of steep rugged cliffs of rhyolite, intermingled with which are masses of tufa and volcanic ashes. The heights of these cliffs vary from 100ft. to 800ft. above the lake, with generally deep water close alongside them—from 40 to 50 fathoms being found with our boat made fast against the rocks. The scenery all round the western arm is picturesque and beautiful: there are numerous interesting waterfalls and many secure

and picturesque boat-harbours, with a depth of water from 10 to 40 fathoms within them ; and safe anchorages can be reached, with good shelter from almost every wind.

The western shores of the lake are in many places wooded to the water's edge, the trees frequently seeming to grow on the almost bare rocks, which protrude here and there through the foliage. The Natives have their settlements inside the little sandy bays, and on the alluvial flats along the several rivers which empty into the lake.

Karangahape Point, with the little island-rock of Motuwhara, which lies a short distance off the point, would afford an interesting subject for the study of a geologist. The cliff is 1,500ft. in height from its base at the bottom of the lake to its summit. As will be seen from the section, it rises quite perpendicularly from the floor of the lake : a portion of it, 600ft. above the water, overhung our boat, whilst the lead-line, dropped close alongside the cliff, showed a depth of 400ft. The formation round the point is alternate beds of rhyolitic lava, scoreous tufa, and ashes. The little island of Motuwhara was probably a crater-plug : it is composed of rhyolite. At one time it was an important part of the Ngatituwharetoas, and a safe retreat from their enemies in time of war. At Karangahape Point are to be seen Tamatea's two dogs, which he left there to guard the point : they are represented by large masses of consolidated tufa, some 30ft. in height. It would be difficult to trace in their shapes any resemblance to the form of a dog. Many of the Natives to the present day retain a superstitious awe of these stone dogs, and I have seen them cover their faces in passing by them, as to see Tamatea's dogs would probably cause a storm and the wreck of their canoe.

It is unnecessary for me to enter upon any description of Tokaano, its thermal springs and other natural curiosities, which are all pretty well known. I may mention, however, that there are a number of hot springs and fumaroles on Kakaramea Mountain which I believe have not hitherto been known to Europeans. They are situated in the forest, at the head of the Waihi Stream, and about three-quarters of a mile north of the highest point of Kakaramea. They occupy a considerable area, extending for about 20 chains along the stream. The principal one is over 100ft. in length, and about 30ft. in width ; the water is muddy, of a greyish-cream colour. Fumaroles, steam-jets, and small mud-volcanoes abound. Several of the springs are of a boiling heat.

A distinctly-marked terrace extends right around Taupo Lake, 100ft. above the present water-level. This terrace plainly indicates that the water stood for a long period 100ft. higher than it now is :

the subsidence is probably due to the lowering of its only outlet, the Waikato River, where it probably broke through a barrier, about one mile from the point where it leaves the lake. Te Heuheu points out a flat rock at the edge of the lake at Waihi, which, he says, his ancestors used for a sacrificial altar shortly after their first arrival in Taupo. This would show that the lake has not altered its level within the last four hundred years, and from the appearance of the shores it is probably a much greater length of time since the subsidence took place.

It has been suggested that a great deal more water flowed into Taupo Lake from the many rivers which discharge into it than goes through its only outlet, the Waikato River, and that probably the volcanic foci in the district might be fed by the lake. To any one who has seen the volumes of the many rivers which flow into Taupo Lake it certainly would appear strange that the seemingly small outlet of the Waikato River would carry off as much water as is supplied by the infalling rivers. Whilst traversing the shores of the lake I took the opportunity to measure the volume of its rivers and streams. This was very carefully done, and under favourable circumstances, in fine weather, no rain having fallen during the operations. The Waikato River was measured where it leaves the lake at three different periods of the operations—namely, at the start; when half the rivers had been gauged; and at the end: the results showed that practically the same quantity of water was discharged as flowed into the lake: the actual quantities being: inflow, 16,455 gallons; outflow, 16,484 gallons per second.

I am indebted to Major Scannell for the following interesting narrative of the sudden rise and fall of the water at the north end of the lake on or about 28th August, 1888. On the day mentioned, a little schooner, which used to ply across the lake, was lying afloat at Tapuaeharuru. Some men working close by noticed that the schooner was suddenly left high and dry. They went to shove her afloat again, and in doing so they noticed that the river had fallen about 2ft. In the course of fifteen or twenty minutes it rose again to its previous level. This phenomenon was noticed by four or five people. It occurred at half-past twelve o'clock in the day. On that same afternoon, between one and two o'clock, Sergeant-Major Smith and Sergeant Miles, of the Armed Constabulary Force, were bathing in a warm spring called Waiariki, situated on the bank of the Waikato River, about a mile from the lake; the bath was fenced round with stones on the side next the river, and it stood about 2ft. above the level of the water. They found their bath become suddenly

cold, and were astonished to find that the river had risen to a level with it. It remained so for about five minutes, and then suddenly resumed its former condition. So far as I have been able to learn, this was the only occasion on which the phenomenon occurred.*

The origin of Taupo Lake is an interesting physiographical question, and one to be dealt with by an abler and more experienced observer than myself: sufficient evidence has probably not yet been collected to lead to any definite conclusion on the subject. The jagged appearance of the volcanic rocks forming the steep northern and western shores leads at once to the conclusion that they were separated from the masses of which they originally formed part by some violent agency, either of eruption or subsidence. The islands and reefs in the lake are more than probably plugs of volcanic vents and lava-flows; and it would seem reasonable to infer that the lake owes its origin, firstly, to eruption, which was followed by a subsidence, and that subsequently some of the vents within it continued active as subaqueous volcanoes, the ejecta from which now form the comparatively level floor of the lake, having been worn away from the cones by denudation. I brought down some specimens of the rhyolitic lava from Taupo, and I am indebted to Professor Thomas for the classification of it.

LAWRENCE CUSSEN,
DISTRICT SURVEYOR.

* The Surveyor-General, in his "Annual Report on the Surveys of New Zealand, 1885-86," says, "The sudden rise and fall of the waters of Lake Taupo on the 28th August, 1883, referred to by Mr. Cussen, as noted by Major Scannell, and also recorded by Dr. Hector in Vol. XVI., Proceedings of the N.Z. Institute, page 596, is a striking testimony to the terrible force of the volcanic eruption of Krakatoa, Straits of Sunda, which occurred on the 27th August, about twenty-two hours before the wave of pulsation reached Taupo, a distance of about 5,000 miles. It is recorded that in the great earthquake of Lisbon in 1755, the waters of Loch Lomond and other lochs in Scotland rose and fell similarly—the distance in this case being about 1,300 miles. The great lakes in America were similarly affected by the Lisbon earthquake."

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