NOTES ON BANDAI-SAN.

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On the 23rd and 24th of May 1889, we paid a visit to Bandai-san with the intention simply of viewing the scene of the great eruption of last year. We had the privilege before starting of reading some of the early proof-sheets of Professors Sekiya and Kikuchi's memoir on the eruption; * and were to a certain extent prepared for what we were to witness. On comparing our experiences with the records of the earlier observers, we found much of particular interest to the geologist, and were also enabled to arrive at certain definite conclusions which seem to have escaped the notice of our predecessors in the field.

Our notes are conveniently grouped under three headings, as follow :—

I.—The effects of erosion.

II.—The character of the outburst that produced the so-called Miné stream.

III.—The much disputed question of the origin of the holes in the vicinity of the mountain.

These we shall take up in order.

I.—THE EFFECTS OF EROSION.

One of the chief features of interest to a visitor to Bandai-san

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at present is the wonderful way in which the action of flowing water in hill sculpture is illustrated. The whole area of the recent deposits has been cut and carved till it shows on a fairly large scale the way in which hills may be moulded into the most fantastic shapes by the continued action by even very small streams. Without a carefully contoured map of the parts covered by the deposits it is impossible in many cases to determine with accuracy the amount of erosion. In others, however, where the streams have cut out narrow gorges and left the banks at each side of nearly the original height, it is easy to get an approximate measurement.

The part which we chiefly studied was the mud-field above Miné. As shown in some of the photographs taken very soon after the eruption the surface of this field was fairly uniform; at least there were no marked channels in it. Now, on the other hand, it is cut up by three deep channels and a number of smaller ones, down which streams of water are flowing. Plate I, enlarged from a photograph, shows some of the chief features of this erosion. The stream, which is only a small one, is flowing in a deep cutting with the sides sloping almost at the angle of repose of the material. Just below the part shown the stream turns through nearly a right angle, while at the upper part is a large block of stone under which the water has cut a tunnel. A little above this there is a very fine cutting which we measured. Its depth was found to be 80 feet and the width at the top almost the same, so that the sides are sloping at an angle of above 63°. Higher up the cuttings were even deeper, and we estimated some of them at from 120 ft. to 130 ft; one may have been as much as 150 ft. Plate II., also enlarged from a photograph, shows one of the best sections, taken a little higher up the stream. It should be mentioned that these photographs were taken on a very misty day, so that the definition is not so clear as might be desired.

At first sight it seemed very difficult to believe that such deep cuttings could have been excavated by comparatively small streams, in so short a time, especially since we found that the water in the lower part of the stream was beautifully clear and apparently almost free from suspended matter. Higher up, however, the water was muddy, and an examination of the ground showed that several causes had been at work to hasten the erosion. The most important of these was probably the damming up of the water of the streams by the falling earth, and the consequent accumulation of water behind the barriers. It is evident that there have been several such accumulations of water, and that in some cases the escape first began by channels other than those through which the final rush came. That such a rush of water as must have resulted from the opening of one of these dams would cause very rapid erosion is well recognized. It is very likely, from the nature of the soil, that the escape would not have been so rapid as to cause the water to spread over a wide area, but rather that as the channel through the barrier became deeper and deeper the volume of water would be kept at flood level for a considerable length of time. Another cause of the rapidity of the erosion is to be found in the way in which many parts of the deposit are saturated with water from springs or from small streams on the hill sides. In many places the ground is so soft that one has to pick his foot-steps with great care in crossing it. The large amount of snow which was still to be found on the mountain when we visited it probably indicates that the snowfall last winter was very heavy. Though the covering of snow no doubt helped to protect a large part of the ground from erosion the flood caused by the melting of the snow would be effective agents in deepening the water channels. It was evident that the steepness of the slope of the banks of the stream was so great that in some cases the snow had slid down from them as from the roof of house. This had, doubtless, caused considerable damming up at times, for even now in more than one case the water escapes by a tunnel cut under a mass of snow. The upper surface of the snow is in many cases so thickly coated with fallen earth that one would never suspect that it was snow if it were not for the whiteness of the lower ends where pieces have been broken off. While the erosion is now taking place mainly along certain definite lines which apparently coincide approximately with the former water courses, this has not by any means been always the case, and the result is that in some places very narrow ridges of earth have been left separating a now dry channel from the present bed of the stream, both slopes being at almost the angle of repose. Wind and rain will soon wear down these ridges, and before long the general appearance will be greatly changed. An interesting feature which illustrates very prettily the formation of waterfalls on rivers, is the effect of boulders in stopping the erosion above while the action still goes on below. Thus a small waterfall is formed. If the boulder is a large one so that it reaches to some distance beyond the channel on each side the fall may become a pretty high one: but if it be a small boulder it soon gets undermined and falls down leaving the upper part unprotected. High up the valley the slopes are at a very steep angle (as much as 35° in some cases), but the covering of earth is not very thick, and what there is, is protected to a certain extent by roots, stumps, and branches of fallen trees, so that there is much less marked erosion. It is worth noting that even in the deepest cuttings the old river bed has not yet been reached. In the crater itself there are some admirable examples of weathering of another kind. The photographs taken immediately after the explosion show some very fine tors and piles of rocks and *débris*. These are now very much reduced and smoothed by weathering, and are evidently rapidly falling (compare Plate III. with Sekiya and Kikuchi's Plate V.). The weathering of some of the rock masses is very interesting. In particular there is a kind of stone, probably basaltic, which has been apparently ejected from the interior of the mountain. This rock becomes perfectly white by exposure to the air, and scales off in layers more or less spheroidal. These layers are almost pure silica, and are very friable and soon crumble down into dust.

In the contoured map of the crater shown by Sekiya and

Kikuchi (see Plate IX. of their paper), two fairly large ponds are shown, the one towards the south side and the other a little further to the north-west. The latter has now distinctly diminished in size; and the former has quite disappeared, its site being taken by a large sandy flat, large enough to serve as a good cricket pitch. Immediately to the south of it the lower slopes of the crater wall begin to rise, while to the north is a series of rugged stony knolls, confusedly arranged, and in many cases covered with a thick layer of papillæ. Another smaller sandy flat lies close to the north-west of the "cricket pitch," and it also marks the site of a former pool of water.

The view to the north of the crater was bleak and bare in the extreme. Instead of several good sized lakes as in the days immediately succeeding the eruption, there was one very large expanse of water and a few smaller patches. This large lake reached as far as Hibara, and was some 5 or 6 miles long and fully a mile broad at the broadest part.

Generally speaking, the appearances in the crater had during the ten months since the eruption altered chiefly in three particulars. There was the direct action of erosion in smoothing down the rugged and fantastic piles and tors that were at first so characteristic a feature. There was the secondary effects of a rapid erosion in the silting up of ponds and their conversion into level sandy stretches. And finally there was the marked diminution in the intensity of the fumaroles, which existed in all states, from energetic bubbling and snorting to a gentle intermittent hissing at the bottom of a conical cavity; and so by a gradual transition to an extinct condition, in which perhaps the bottom of the cavity was still warm to the touch.

What seems specially worthy of note is the amazing rapidity of the erosion everywhere displayed, a result of the loosely compacted nature of the new surface soil. Even with this consideration present to the mind, it is difficult to credit running water with such rapidly erosive powers. There seems little doubt that in the Bandai-san catastrophe and the subsequent action of ordinary geological agents we have an example of what has been in Japan a frequent mode in which the surface configuration has been effected.

II.—The Character of the Outburst towards the South-East.

The small plateau of Numanotaira lies now between three conspicuous peaks, namely Ōbandai, Akahani-yama, and Kushigamine. The eastern crags of Ōbandai look due east across Numanotaira out between Kushigamine on the north and Akahani on the south. Akahani extends a broad shoulder northwards towards the southern aspect of Kushigamine. In a gorge between them the main stream of the Biwasawa has its source. The broad ridge connecting Kushigamine and Akahani may be regarded as the eastern limit of Numanotaira. A deep hollow with a marshy pool at the bottom lies just in the centre of this ridge. All over this region a thick forest originally spread, extending itself right and left over the slopes of Akahani and Kushigamine. The damage done to this forest varies greatly according to place. In some places the devastation is complete—ghostly trunks stand shorn of leaves, branches, and bark—while in others the bared branches still remain with some show of vitality.

Generally speaking, the damage done to the trees on the lower slopes where none of the mud stream has accumulated is distinctly less than that done over the higher slopes of Akahani and Kushigamine and over the broad ridge that connects them. We are unable to determine the exact character of the damage done to the trees which originally occupied tracts now covered with the mud stream. Probably, however, these trees were overwhelmed and prostrated before the earth torrent, except perhaps in its lower reaches. As we passed up the hill on the right bank of the Biwa, we found ourselves on a steep spur whose surface was covered with the material that had been shot from Kobandai. To what depth this covering lies it was impossible to judge; but there was abundant evidence that, as we ascended, the depth of the deposit thinned off. We were at this time far above the bed of the Biwa, where probably the mud-stream originally lay thickest.

The first sign of the deposit thinning off was the appearance of trees and shrubs tremendously shattered but still left rooted *in situ*. Shortly after these remnants of a wrecked forest were first encountered, the ascent became easier, until at length we found ourselves on the broad ridge between Kushigamine and Akahani. Just then the mist fortunately cleared and we had a fine view of the craggy flank of Ōbandai, the plateau of Numanotaira, and the sharp edge of the new crater. In wandering over this region, we were struck by many appearances which do not seem to have received from the earlier visitors the attention they deserved. This we think is a misfortune; for our observations, made ten months after the eruption took place, were necessarily incomplete.

It was abundantly evident, for example, that the forests to the east and south-east of Ōbandai-san had been subjected, not merely to a hurricane of wind, but also to a fierce cannonading of stones of all sizes from the tiniest grains to huge blocks. It may be safely said that the chief damage was due to this "hail-storm" of rocks and rubbish rather than to the wind, however strong that may have been. When the crest of Kobandai burst there were three main directions in which the fragments were hurled, namely northward, upward, and south-eastward. The south-eastward stream poured like a nearly horizontal hail-storm across Numanotoira, over the bounding ridge, and down the Biwa-sawa. The trees on the ridge and the neighbouring slopes of Akahani and Kushigamine were shattered, uprooted, felled, by this awful cannonading; but the cloud of stones, largely unchecked in their on-rush, shot over the ridge and down the steep slopes till the smaller gradients and their own accumulation brought them to a stand. Thus it is not surprising that no very thick deposit of new material is found at the higher levels. Much of the dust and many of the smaller fragments, retarded by the viscosity of the air, would no doubt settle; but the vast majority of the larger fragments would continue their headlong rush down to lower levels. The great accumulations of rocks and earth at these lower levels do not necessarily imply the the horizontal hail-storm we have been picturing. The matter might have been launched *over* the ridge at a considerable elevation. But that much of it was really launched horizontally so as to graze the surfaces of the ridge and high level slopes is demonstrated by the nature of the damage done to the trees. As already mentioned, many of the shattered stumps are left still rooted to the ground. These are all barked on the side facing the crater, and scarred and cut and torn in a way that mere wind could never explain. It is not possible, of course, to separate the mere wind effect from that due to the solid driven matter; but we think it necessary to emphasise the latter much more strongly than appears to have been done in any of the earlier descriptions of the catastrophe. To get some idea as to the heaviness of this bombardment, we counted the separate cuts and bruises on the quarter of a square foot of the surface of a battered tree. The tree was chosen as a fairly representative one. A first rough reckoning gave 50 distinct hacks; and a second more careful count gave 75. That is, a square foot of this tree was, *after the bark had been peeled off*, subjected to a bombardment of at last 300 missiles to the square foot. This number must evidently be less than the total number in the shower and we may, without making any extravagant demands assume that across every square foot of vertical area between Kushigamine and Akahagi 500 good sized fragments swept, probably with a speed comparable to the muzzle velocity of a rifle ball. Small wonder that after such a storm had passed it should have left such devastation in its track! The horizontal projection of a cloud of solid particles of the kind pictured was no doubt accompanied by a fierce gust of wind; but there really seems to have occurred nothing indicative of anything very extraordinary in this gust. By far the greater damage must be attributed to the horizontal hailstorm of rocks, stones, and solid fragments of all sizes from huge blocks to sand. The havoc was most complete on the eastern ridge of Numanotaira.* This is quite what we should expect. For the great velocity of projection of the rocky fragments would very quickly be cut down by the resistance of the air, even if no other impediments existed. The smaller particles would be retarded more quickly and would then act as a brake on the larger ones; so that in all probability the original energy of projection would have been almost entirely spent before the cloud of rubbish had reached the lower slopes. Just above Miné, the fragments were still able to indent the bark, but not to pull it off. In its descent, either through the air or down the steep slopes of the hills, the projected matter was of course aided by gravity.

To sum up the evidence, we see, from the character of the damage done to the trees on the upper ridges, that the shattered eastern flank of Kobandai was projected to a large extent horizontally, grazing the higher flats of Numanotaira, and mowing down the forests that grew there. The high speed of projection carried nearly all the fragments and dust quite over these regions into the ravines and valleys far below. As the *débris* descended it swept avalanche-like down the higher slopes which were too steep to give it a resting place, clearing them also of much of their vegetation.

In emphasising the effect of this horizontal rush of rocky fragments, we do not in any way mean to discredit the effects of matter projected at higher inclinations. There is no reason, however, to suppose that the vertical projection was denser than the horizontal; and there are good reasons for supposing that the horizontal was the greater. Or, to put it more accurately, the amount of matter projected at lower

* We leave out of consideration the regions now hid from view by the accumulated new material.

inclinations than 45° to the horizontal far exceeded the amount projected at higher inclinations. The particular manner in which the shattered mountain has re-distributed itself goes far to prove this. Thus there are certain regions in the vicinity of the new crater which have completely escaped any damage whatever; and there are other regions in which the damage done is comparatively slight. These lie to the north-east in the direction of Kushigamine, to the south in the direction of Obandai, and to the west. Of these, the first-named is perhaps the most remarkable, since it is wedged in between the great northern outburst towards Hibara and the south-eastern outburst towards Miné. Now in all these cases it is quite clear that the summits of Kushigamine, Akahani, Ōbandai, and the north-west ridge of the last, simply stopped the material from going in these directions. But very moderate upward inclinations combined with sufficient velocities of projection would have carried large blocks over these peaks and landed them on the further slopes. But no such blocks have been seen. In some parts *holes* have been found which have generally been regarded as having been made by falling stones. But in the regions we have specified these holes are not very numerous; and none have been found beyond Kushigamine or immediately to the south of Obandai. Assuming then that these holes were really caused by falling stones, originally projected at high inclinations from Kobandai, we must conclude that such stones were comparatively few in number. That no stones were hurled over Kushigamine shows that either the inclinations were insufficient or the velocities were insufficient, or that the eruption was singularly partial as to the directions of its out-burst. As an explanation of this apparent partiality, some have suggested the drifting action of the wind. Excepting, however, the local displacements of air which necessarily accompanied the avalanches of rock and rubbish, and which therefore cannot for a moment be regarded as giving direction to its own cause, the general drift of wind was from W.N.W. as proved by the well marked track of the fine dust and ashes. If such a wind had any sifting effect upon the heavier particles, it could not in any imaginable way cause the stones projected nearly eastwards towards Kushigamine to deviate appreciably from their original course.

In fact, the more the features of the eruption are considered, the more is one impressed with the fact that as, regards the larger fragments, the outburst was mainly a horizontal one, or (more accurately) confined to inclinations less than 30° to the horizontal. No doubt along with the ascending cloud of dust, smoke, and steam, fairly sized blocks of stone were projected at higher inclinations; but they must have been comparatively few in number, and their speeds of projection by no means great. Only in that way can we give a really plausible explanation of the immunity from damage of the very near region lying just beyond Kushigamine, and the part to the south of Ōbandai.

Although the great outburst took place to the north, very little can be gathered from it as to the details of the explosion. All we see there is a great spread of *débris* quite covering up whatever particular damage may have been done to the former surface.

With regard to the smaller outburst to the south-east along and down the Biwasawa, it is otherwise. There we can trace the course of the great blast of shattered rock and disintegrated soil right across the flats of Numanotaira. Trees have been fiercely battered by the irresistible cannonading; have been bent to the blast, twisted, stripped bare, barked on the "wind ward" side, broken, felled, uprooted, hurled along, and many no doubt swept down the steep slopes and buried fathoms deep below the rubbish. To this day all possible kinds of devastation can be studied in the shattered remnant of the blasted forest. All over the region of the once dense forest, a vast number of holes are still to be seen, very much as they were seen by the earlier observers. No doubt rains have had their usual denuding effects; but again the winter snows on the upper flats must have tended to preserve the original contour. These holes we believe to be mainly, if not entirely, the result of the uprooting of trees; the smaller holes being due to the uprooting of single trees, the larger ones possibly to the simultaneous uprooting of a clump of trees whose roots were more or less interlaced. That this is a sufficient explanation of many holes is admitted by Mr. Odlum in his paper, "How were the Cone-shaped Holes on Bandai-san formed?"—a paper, however, which was written avowedly with the object of proving that the conical holes were formed by falling stones. From what has been said above regarding the character of the outburst towards Miné, it will probably be readily recognised that many of these uprooted trees are to be sought for, not in the vicinity of the holes, but far below, buried deep in the accumulated *débris*.

As the very widely accepted theory of the formation of the conical holes through the agency of falling stones ejected from the crater has not been as yet critically examined in print, we propose here to consider it as fully as opportunity may permit. As Mr. Odlum's observations are the most complete on the subject, and as his paper has been already published in these Transactions, many of our remarks will naturally be suggested by his statements.

III.—The Conical Holes at Bandai-san.

It must be noticed at the very outset that the holes are not all of one class; and it appears to us, writing ten months after date, that the earlier observers did not pay sufficient attention to this. Leaving one of account the beautiful conical holes formed in the crater by the action of fumaroles, we are able to distinguish three kinds of holes in the vicinity of Bandai. These are sufficiently differentiated by the names conical, cylindrical, and flat basin-shaped. The conical holes abound in the devastated region to the east and south-east of Ōbandai. The other kinds are not by any means so numerous, and are chiefly to be found to the W.N.W. of Ōbandai in the neighbourhood of Kaminoyu. These last are what have been observed by the great majority of visitors to the mountain, since they lie near the path which leads from Inawashiro to the great crater.

That falling stones can make holes in the ground is no doubt a fact of experience. But when we are asked to believe ‡ that stones can make holes of 30 feet diameter and 10 feet depth, or even 10 feet diameter and 3 feet depth, and bury themselves to a further depth of at least 3 feet below the apparent bottom of the hole, we are compelled to demand at the hands of the supporters of such a view the most complete proofs. We shall consider later the so-called proofs which have been advanced in support of the falling-stone theory. We shall first, however, discuss the problem of the falling body generally, to see what kind of effect we may reasonably expect to obtain when a large stone falls to earth with a reasonable speed. The problem, we believe, has never been discussed even approximately, that is, taking into account all the conditions. It is no mere question of a uniform acceleration with which we have to deal. When once we obtain speeds of several hundred feet per second, we bring into play an atmospheric resistance of a magnitude quite comparable to the weight of the falling body. Indeed, we shall see that for any reasonable case, it is really impossible for a falling body to attain a velocity of 1,000 feet per second. The reason simply is that if a body were descending near the earth's surface with such a speed, the retardation due to atmospheric resistance would exceed the acceleration due to gravity, and the speed would tend to diminish.

Even at moderate speeds the retarding effects of atmospheric resistance on falling bodies are quite appreciable. Thus if a cannon ball and a roughly cubical stone are dropped simultaneously from a height of 50 feet, the ball is dis-

‡ See Mr. Odlum's paper in this volume (p. 28); also Professors Sekiya and Kikuchi's paper in the same (p. 169).

tinctly observed to gain upon the stone and reach the ground ahead of it. Suppose the gain is half a foot; and suppose further that because of its form and relative mass the stone experiences an atmospherie resistance twice that experienced by the ball; then a simple calculation gives for the average acceleration due to the viscosity of the air the value 3 (ft. sec.$^{-2}$). We shall see immediately that this is a fair approximation to the value, as inferred from experiments on the flight of projectiles. It is, indeed, only from the very elaborate experiments in gunnery that we can obtain any definite ideas as to the magnitude of the atmosphere's resistance. Scientific Artillerymen have prepared valuable tables embodying the results of their experiments; and we shall base all our calculations on one of these tables. The full table will be found in the article *Gunnery* in the *Ency-*

TABLE I.

Speed in Feet per Seconds.	Space in Feet.	Time in Seconds.
400	5,000	5·000
500	8,701	13·306
600	11,702	18·796
700	14,280	22·781
800	16,513	25·769
900	18,362	27·954
1,000	19,843	29·521
1,100	20,898	30·531
1,200	21,592	31·137
1,300	22,179	31·607
1,400	22,693	31·988
1,500	23,162	32·312
1,600	23,607	32·599
1,700	24,033	32·858
1,800	24,441	33·091
1,900	24,832	33·303
2,000	25,207	33·496
2,100	25,556	33·666
2,200	25,876	33·816
2,300	26,174	33·948
2,400	26,446	34·064
2,500	26,696	34·166

clopaedia Britannica (ninth edition); it is sufficient for our present purpose to use it in a condensed form. In Table I.

there are three columns headed speed, space, and time; and these are so related that if any two sets be taken, the difference of the time numbers represents the interval during which the speed of a particular kind of projectile will be reduced from the higher to the lower value, and the difference of the space numbers represents the space described. Thus, as an example, the projectile moving horizontally in air with a speed of 2,000 feet per second will have its speed reduced to 1,000 in 3·995 seconds, during which interval it will have travelled 5,364 feet. The particular projectile for which this table is constructed is an ogival headed projectile, whose mass in pounds is equal to the square of its diameter in inches. Now for similarly shaped projectiles, the resistance of the air varies directly as the square of the diameter and inversely as the mass. Hence, if d is the diameter and w the mass in pounds of any other ogival projectile, the number d^2/w will give the ratio of the average resistance experienced by this projectile to that experienced by the former in reducing the speeds of each from one given value to any other given value. If d^2/w is less than unity, the projectile will travel proportionately further between two given limiting values of speed.

Besides the relation between the size and mass of a projectile, another very important point is the shape. Thus according to Bashforth's tables the resistance experienced by a spherical shot varies, according as the speed is high or low, from 1.5 to 2 times the resistance experienced by an ogival headed projectile of equal weight and diameter. Then experiments have also proved that at tolerably high speeds, a flat-headed cylinder experiences a resistance about $2\frac{1}{2}$ times that experienced by the ogival headed cylinder. For lower speeds, say under 1,000 feet per second, the resistance experienced by the flat headed cylinder will in all probability be proportionally greater, as in the case of the sphere. Now a rough shapeless stone cannot possibly be less resisted than a smooth flat-headed cylinder, especially if, as is almost certain to be the case, the stone is also rotating. We are probably well within the mark if we consider the resistance experienced by a rough shaped stone to be three times that experienced by an ogival projectile of the same weight and of cross-section equal to the mean cross-section of the stone.

Again it should be pointed out that, in applying to the case of a large stone numbers that have been obtained by experiments on comparatively small projectiles, we are making the assumption that the resistance is directly proportional to the surface, other things being equal. But this law, true though experiment shows it to be for a limited range of dimensions, can hardly be expected to hold accurately when we compare say a 7 inch sphere with a 3 feet or 36 inch spherical shell of the same mass. When the nature of the dynamical process by which such a mass pushes its way through air is considered, it will probably be granted that the resistance increases somewhat more rapidly than the surface when the surface becomes very large. Taking all the conditions of the case into account, we are convinced that, in the calculations now to be presented, we are really underestimating the resistance experienced by a rough shaped stone as it travels through the air.

To fix our ideas, we shall calculate in detail various problems in connection with a stone of the size and weight of one of those described by Mr. Odlum. He gives 27 by 35 by 40 inches as the dimensions of a stone excavated by him out of one of the so-called conical holes. We may take as comparable with this a projectile of area equal to 36^2 square inches; and we shall certainly be underestimating the effects of atmospheric resistance if we regard this projectile, assumed cylindrical, as experiencing a resistance three times as great as that experienced by an ogival projectile of the same diameter and mass. The diameter corresponding to the above area is $\sqrt{1648}$; and the mass, as estimated by Mr. Odlum, is 3,975lbs. Hence the number d^2/w is 0.46; and multiplying by 3, we find 1.38 as the factor to be used in deducing from the numbers given in Table I. the numbers which may be supposed to be applicable to the case in point.

The simplest way to do this is to form a second table (Table II.), in which are entered the average accelerations corresponding to given speed limits. The operation consists simply in taking the first differences of the columns of Table I. and in dividing the change of speed or total acceleration by the corresponding interval of time. In Table II. the first column gives the limiting speeds; the second, the interval of time during which the resistance of the air reduces the speed from the higher to the lower limit; the third, the average acceleration produced by this resistance in the case of the ogival projectile for which $d^2=w$; the fourth, the same for the stone under discussion. The values for speeds less than 400 are estimated by a rough interpolation:—

TABLE II.

Limiting speeds in hundreds of feet.	Interval of time in seconds.	Average acceleration (ft. sec²) Ogival.	Irregular.
25-24	0·102	—980	—1352
24-23	0·116	—862	—1190
23-22	0·132	—758	—1046
22-21	0·150	—667	— 920
21-20	0·170	—588	— 811
20-19	0·193	—518	— 715
19-18	0·212	—472	— 651
18-17	0·233	—429	— 592
17-16	0·259	—386	— 537
16-15	0·287	—348	— 480
15-14	0·324	—309	— 426
14-13	0·381	—262	— 362
13-12	0·470	—213	— 294
12-11	0·606	—165	— 228
11-10	1·010	— 99·6	— 137
10-9	1·567	— 64·0	— 88·3
9-8	2·185	— 45·8	— 63·2
8-7	2·988	— 33·4	— 46·1
7-6	3·985	— 25·1	— 34·6
6-5	5·490	— 18·2	— 25
5-4	8·306	— 12·0	— 16·6
4-3	——	— 8	— 11
3-2	——	— 5	— 6·9
2-1	——	— 3	— 4·2
1-0	——	— 1	— 1·4

The numbers in the third column are obtained from those in the second by dividing 100 by each of the latter; and the numbers in the fourth column are obtained from those in the third by multiplying by 1·38.

In applying these numbers to any problem involving vertical motion, we must calculate at each step the combined effects of gravitation and atmospheric resistance. When the body is ascending, the resistance due to the air acts with gravity; whereas when the body is descending, the resistance due to the air acts against gravity.

Consider first an ascending body whose speed is reduced in time t from v to $(v-100)$. By gravity, the total acceleration in this time is $-g\,t$; and by resistance due to the air the total acceleration is $-a\,t$, where a is the number in Table II. corresponding to the limiting speeds v and $(v-100)$. Hence the total acceleration due to both combined is $-(g+a)t$, and this must be equal to -100. Thus we find for the interval of time during which v is reduced to $(v-100)$, the expression

$$t = \frac{100}{g+a}$$

From this we find for the space described the approximate value

$$s = t\,(v-50)$$

being the time multiplied by the average speed.

If the body is descending we must change the sign of a in the expression of t, or

$$t = \frac{100}{g-a}$$

In applying this formula we must confine ourselves to cases for which a is numerically less than g. Thus we see at a glance that it is impossible for an ogival shaped projectile to attain *by merely falling* a higher speed than 800 feet per second, or for an irregularly shaped mass to attain similarly a higher speed than 700 feet per second, however far each is allowed to fall.

The numbers given in Tables I. and II. hold only for the motion of projectiles in air at the ordinary pressure at the sea-level. Obviously at great heights the pressure and density of the air will be so diminished as to give rise to a resistance distinctly smaller than that experienced at low elevations. Exactly how the resistance to high speeds varies with the density of the air is not known; but we may here assume for the purposes of calculation that it varies in direct ratio. Thus at a height of 10,600 feet, the retardation due to atmospheric resistance experienced by our irregular body moving with a speed by 1,050 feet per second will be, not 137 as given in Table II. but 91—these two numbers being in the ratio of the pressures at the sea-level and at the height named. This correction for decrease of atmospheric resistance due to increase in height must be applied to every particular case.

Let us then take this problem as one directly comparable with what may have occurred at the Bandai-san eruption. A rough flat headed body 36^2 square inches in area and 3,975 lb. in mass is projected upwards from a height of 8,000 feet with an vertical speed of 2,500 feet per second. To what height will it ascend, and with what speed will it come to earth at any named elevation?

The first part of the problem is completely solved in Table III., and the second part in Table IV. Both of these tables are constructed on the same principle by means of the numbers given in the last column of Table II. The first column contains the limiting speeds in hundreds of feet; the second, the interval during which, at the assumed height, the particular change of speed takes place; the third, the space described during the interval in question; and the fourth, the total space described from the beginning to the end of the said interval:—

Table III.

Limiting speeds in hundreds of feet.	Interval in seconds.	Space described in interval.	Space described from the beginning.
25-24	·099	242	242
24-23	·113	265	507
23-22	·128	288	795
22-21	·147	312	1,107
21-20	·166	341	1,448
20-19	·191	372	1,820
19-18	·211	391	2,211
18-17	·234	410	2,621
17-16	·259	428	3,049
16-15	·291	452	3,501
15-14	·331	480	3,981
14-13	·386	522	4,503
13-12	·472	590	5,093
12-11	·588	675	5,768
11-10	·893	940	6,708
10-9	1·220	1,160	7,868
9-8	1·515	1,280	9,148
8-7	1·79	1,330	10,478
7-6	2·04	1,320	11,798
6-5	2·33	1,220	13,018
5-4	2·56	1,150	14,168
4-3	2·78	275	15,143
3-2	2·94	740	15,883
2-1	3·00	450	16,333
1-0	3·07	150	16,483

Table IV.

Limiting speeds in hundreds of feet.	Interval in seconds.	Space described in interval.	Space described from the beginning.
0-1	3·17	160	160
1-2	3·28	492	652
2-3	3·37	843	1,495
3-4	3·66	1,280	2,775
4-5	4·08	1,841	4,616
5-6	5·03	2,766	7,382
6-7	8·55	5,558	12,940
7-7·1	2·08	1,470	14,410
7·1-7·2	3·85	2,750	17,160

The mode in which these tables have been constructed will be made clear by working out a particular case in each.

Thus, to find the interval during which the ascending stone has its speed reduced from 1,100 to 1,000 feet per second, take from the last column of Table II. the number 137 corresponding to the said limiting speeds. This measures the negative acceleration due to the resistance of the air at ordinary sea-level pressure. But we know from the previous part of Table III. that the stone has ascended 5,768 feet, so that its mean height during the next interval will be about 14,000 feet (8,000 + 6,000) above sea-level. Hence the density of the air will be less than the density at sea-level in the ratio of approximately 17·51 to 30. Reduce 137 in this ratio, add 32 (or g) to it, and the result, 112 namely, will be the measure of negative acceleration acting on the stone. Divide 100, the total change of speed, by this number, and the quotient ·893 is the corresponding interval as given in the second column of Table II. This interval, multiplied by 1,050, the average speed, gives 940 as the corresponding space described; and this, added to 5,768, gives 6,701, the total space described from the beginning of the motion. In this way, step by step, the final column of Table III. has been deduced.

Then, again, to find the interval during which the stone in its descent has its speed increased from 600 to 700 feet per second; take from the last column of Table II. the number 34·6. But already the stone has descended 7,382 feet, and is therefore at a height of 17,101 feet. Before the speed can attain to 700 feet per second, the body will have to fall some 6,000 feet further. Hence we may apply to the number 34·6 the correction due to the density of the air at a height of 14,000 (16,000—3,000) feet. That is, we multiply 34·6 by the factor 17·6/30 and obtain 20·3. Thence we deduce 11·7 as the downward acceleration acting on the body, and 8·55 seconds as the interval during which the speed is increased by 100 feet per second. The space described in the interval is at once found by multiplying the time by the average speed, and this added to 7,382 gives 12,840 feet as the total space described since the beginning. After this condition is reached, the speed is accelerated more and more slowly as the body falls to lower levels. The two last rows of numbers in Table IV. are calculated for total accelerations of 10 feet per second at a time—the factors being obtained from Table III. by rough interpolation. We thus see that the mass, originally projected with a velocity of 2,500 feet per second, returns to the assumed level of its point of projection with a speed of barely 720 feet per second; and further, a consideration of the numbers in Table III. will show that, in descending to lower levels, even to the sea-level, the mass will suffer no appreciable increase of speed.

Thus a fair-sized block of 4,000 lb., projected from a height of 8,000 feet above the sea level with a vertical speed of 2,500 feet per second, will reach a height of 24,500 feet above the sea-level. It will return to earth from that height with a speed of 720 feet per second; and it will have nearly attained this speed after it has fallen about half that height.

The amount of energy lost during the ascent is 324 million foot-pounds, and the energy lost in the descent to the level from which the body was projected is nearly 63 million foot-pounds. This gives a total loss of 387 million foot-pounds of energy out of an original 390 million foot-pounds. Much the same loss of energy will occur in the case of a body projected with a high speed horizontally at low elevations. A large part of this loss of energy will appear as heat in the stone itself. If we suppose one-third of it to be so transformed, and assume the specific heat of the stone to be 0·2, the temperature of the 4,000 lb. block will be raised by fully 200° Fahrenheit. The hot particles felt by some of the sufferers are thus fully accounted for.

Although it has no particular bearing on the subject under discussion, an interesting calculation may be made as to the speed with which the same stone would reach the earth if projected from a height of 24,000 feet with an initial downward speed of 2,500 feet per second. By the time it had fallen half way, its speed would be diminished to 1,000 feet per second;

and it would come to earth with a speed of about 800 feet per second. This sufficiently explains the comparatively low speeds with which meteors reach the earth. Also since any initial horizontal or (more accurately), tangential speed will be cut down by the atmospheric resistance without being at all sustained by any other force, we see that such a meteoric stone will come to earth in a direction not much inclined to the vertical.

The foregoing calculations then lead to the conclusion that 700 feet per second is as much speed as an irregular cube-shaped stone 4,000 pounds weight, and one square yard in section, can be expected to attain by merely falling from any height, up to the practical limits of the earth's atmosphere at any rate. The next question to discuss is, what penetrating power can this stone, reaching the earth with such a velocity, be reasonably expected to have? From observation we know that a good sized meteoric stone can do little more than bury itself; and, in the absence of unquestionable evidence to the contrary we have no right to endow a stone projected from a volcano with any very superior powers. Here again, however, we shall appeal to the experiments of artillerymen.

In Chapter VI. of Bashforth's Motion of Projectiles (1873), Didion's constants for the calculation of the penetration of spherical shot into various kinds of woods, earths, and masonry, are given in English measures, together with the formula that gives the depth penetrated in terms of the striking velocity. From these data the following table has been calculated, giving for different velocities the penetrations in feet of a spherical shot, whose weight in pounds is equal to the square of its diameter in inches.

The first column contains the name of the substance penetrated, the other three columns contain the depths in feet to which the shot penetrates, and at the head of each of these three columns is the corresponding striking velocity in feet per second:—

Substance penetrated.	Depths penetrated for Striking Velocities of 1,000.	750.	500.
Oak, Birch, and Ash	3·76	2·57	1·36
Elm	4·89	3·33	1·77
Fir and Birch	7·04	4·80	2·55
Poplar	7·19	4·90	2·61
Sand, mixed with gravel	5·12	4·19	2·97
Earth, mixed with sand and gravel	3·72	3·05	2·17
Clayey soil	5·87	4·22	2·43
Old Parapet Earth	6·70	5·05	3·10
Damp clay	15·00	11·55	7·38
Moistened clay	43·52	33·52	21·4
Good masonry	1·51	1·05	0·54
Medium masonry	1·97	1·31	0·68
Brickwork	2·75	1·83	0·95

The object of the experiments on which these numbers are based was of course a very practical one, being nothing else than the investigation of the resisting power to bombardment of different kinds of defensive structures. The earths were therefore all "prepared" and cannot possibly have been more resisting than natural solid earth full of stones of all sizes and knit together by grass and tree roots. We are therefore quite warranted in regarding 4 feet as a superior limit to the penetration in natural earth of such a shot falling with an impact speed of 750 feet per second.

Hence a smooth spherical ball of the same weight and the same cross-section as Mr. Odlum's stone above described would penetrate (4/0·46=) 9 feet nearly. In penetrating power, an ogival headed projectile is distinctly superior to a sphere of equal diameter and weight, in a ratio not smaller than 3 to 2. We may reasonably suppose a cube or flat headed cylinder to have still less penetrating power in earth, as we have shown them to have in air. With the fair enough assumption, then, that a rough cuboid block experiences 3 times the resistance which an ogival headed projectile experiences, we find 4½ feet as the superior limit of depth to which a rough hewn stone of the size and mass described will penetrate.

In this discussion, the one step of any doubt is the last. It will certainly be admitted, however, by any capable of giving the matter scientific consideration that a rough cuboid will have distinctly less penetrating power than a smooth sphere. We have unfortunately no experiments to guide us to a definite understanding of the matter. Experiment would be difficult, indeed; for even were stones dropped from the top of an Eiffel Tower, they would reach the ground with a comparating low speed of some 200 feet per second. Still in such experiments, the results would be valuable as establishing comparative penetrating powers of masses of different shapes and sizes. Experiments with stones dropped from ordinary heights are worthless, as we found ourselves by trial. The stones were in many cases only half or even quarter buried, and it was not possible to estimate even approximately what might be called the average section.

Guided by the discussion just given and by a general consideration of the character of holes made by projectiles, we may safely sum up our conclusions thus:—

1. If a stone falls with sufficient speed to make it really bury itself beneath the original surface of the ground, it will form a cylindrical hole of a diameter a little greater than its own. A "conical" appearance may then be given to the hole either by the falling in of small ashes and dust following in the wake of the stone. The latter is highly probable in the case of an eruption like that which happened at Bandai-san; the former is very unlikely to take place in old vegetable-bearing soil. Now, in the Nakanoyu region to the west of Bandai-san, such cylindrical holes of comparatively small diameter were seen both by the earlier observers and by ourselves. The diagram shown in Professors Sekiya and Kikuchi's paper (p. 167 of this volume) evidently represents such a possible hole. It is believed by them to have been made by a cuboidal stone half a metre each way. Assuming this stone to be of the same density as Mr. Odlum's stone for which we have made detailed calculations, we readily see

that its penetrating power for a given speed will be a little more than half as much. Thus, even if we grant to it all the penetrating power of a smooth sphere of equal weight and cross section, we should not get it to penetrate deeper than 5 feet. In this conclusion we are in fair accord with Sekiya and Kikuchi's own rather vague calculation. They say, "The velocity needed for penetrating a soft loamy soil to a depth of 2.5 metres would be between 300 metres and 600 metres per second, according to the value of coefficients we take." Here we are left in complete darkness as to what will penetrate that depth with that speed—is it an ogival headed projectile, or a cannon ball? Still, taking the mean of these two speeds, namely, 450 metres or 1,480 feet per second, and calculating from Bashforth's formula and table for clayey soil, we find that a ball whose weight in pounds is equal to the square of its diameter in inches will penetrate 9 feet or 2.73 metres. But we absolutely deny that a stone falling in air can ever attain such a speed as 1,480 feet per second, even though it should fall from infinity; so that, in this particular case, we cannot follow Professors Sekiya and Kikuchi in believing that the hole as figured in their drawing was altogether formed by the stone that is shown resting at the bottom. But, although we are compelled to regard this as, to say the least, a doubtful case, we are quite prepared to admit that the comparatively small cylindrical holes that are pretty plentiful to the West of the mountain and which, be it noted, *were those chiefly seen by visitors*, were formed by falling stones. The holes described by Mr. Odlum can hardly, however, be included in this category, as we shall see further on.

2. If a stone falls with a moderate speed so as to be incapable of burying itself completely, it will probably produce a splash out of earth; and if, as is highly probable, it should be broken by the concussion, a shallow basin-shaped scar will be formed. Effects of this character were also observed in the Nakanoyu region. But it is difficult to regard the large coni-

cal holes described by Mr. Odlum as having been formed in this way. For according to his description (p. 28 of this volume) some of these holes are so large as to have required a very large boulder indeed to have produced them. But no such large boulder is described; and if it had broken into fragments, there would be fragments not only in the hole but all round it. But (p. 25 of this volume) there is nothing on which Mr. Odlum is more emphatic than the fact that in the region he is considering there are no stones to be found on the surface.

3. We believe that many of the holes described by Mr. Odlum cannot be sufficiently explained on the falling stone hypothesis. As Professors Sekiya and Kikuchi regard Mr. Odlum's researches as having settled the question of the origin of the comical holes, it will not be out of place here to consider the facts and proofs brought forward by him in support of his view. Mr. Odlum certainly deserves high commendation for the energetic way in which he carried out his labours. His facts, such of them as he gives, must be accepted as incontrovertible. It is unfortunate, however, that he has given such an incomplete statement of all that he must have observed. In the discussion which followed the delivery of his paper before the Seismological Society of Japan, one of us asked for distinct information on these points: (1) how many holes did he dig into, (2) how many of these contained new stones, (3) was there any relation between the size of the hole and the size of the stones found in it? No answer was given to these questions at the time; and it is with feelings of great disappointment that we search in vain through his paper for information on these important points.

Another important question suggested by our own visit there is, what was the former character of the region in which a given hole was found? Was it wooded, or was it grassy? In Mr. Odlum's paper there is no distinct statement even as to where he made his investigations. From his map we infer that it was to the South East of the mountain, including the region we have described above in discussing the character of the outburst towards Miné. This particular region was, we believe, not visited by Professors Sekiya and Kikuchi; and it is very questionable whether arguments based on the appearances in one region are applicable to the somewhat different appearances seen in another region. One gentleman, who made a very complete survey of the Numanotaira plateau, formed the theory that the large holes there were produced by small local tornadoes. We mention this simply as an illustration of the difficulty some have had in crediting falling stones with such tremendous hole-producing powers. The simple fact seems to be that the vast majority of visitors contented themselves with visiting the crater by way of Nakanoyu and that very few indeed took the trouble of ascending to the higher slopes of Ōbandai, Akahani, and Kushigamine. They thus saw only the moderately-sized holes formed to the west and north-west of the crater; and, as these could easily be formed by falling stones, they hastily concluded that all the other reported holes were formed by the same agency. Mr. Odlum, however, seems to have confined his investigations solely to the region to the south-east of the crater; for here only are the large conical holes of 20 or 30 feet in diameter to be found.

Let us now take up Mr. Odlum's proofs in order. To his 1st Question, did stones fall? no one can of course hesitate to answer yes. Under his 2nd Question, where are these stones? there are some some statements calling for remark. Statement *A*. proves indirectly that Mr. Odlum is dealing with the region to the south-east; for here only do we find holes and no stones on the surface; but that "stones fell in all directions" is a remark that is hardly borne out by the evidence. No holes are found to the south over Ōbandai, and no holes are found to the east over Kushigamine. These facts are difficult to reconcile with a heavy vertical projection of the kind that must be imagined if "tens or hundreds of thousands of holes" (see *D.*) are to explained as produced by falling stones. Kushigamine at any rate was a lower height than Kobandai; and it is difficult to believe that a heavy vertical outburst, which alone can give sufficient speeds for penetrating purposes, should have been so partial in its final distribution. In paragraph 21 (page 31) the author invokes the wind, which was blowing towards the E.S.E. at the time. But a "moderate northwesterly breeze," as it is characterized by Professors Sekiya and Kikuchi, could have very little drifting effect upon large masses; and besides Kushigamine lies in the very direction in which this wind was blowing. Mr. Odlum's assumption that the "wind at a great elevation was very strong," (p. 31, *A.*) is altogether gratuitous. His further suggestion* under heading *B* is an extraordinary example of making one of two co-existent effects the cause of the other. Under heading *C* on the same page, however, there is a very clear description of what in all probability actually took place. It quite falls in with our view of the largely horizontal character of the outburst towards Miné. Returning again to paragraph 2, we meet at once with another difficulty of distribution. It is distinctly laid down that no stones were found except in holes. Now it seems to us to be a great demand upon our credulity to be asked to believe that, granted a heavy vertical outburst, all the falling stones should have gone up so far as to have come down with speeds sufficient to enable them to penetrate considerable depths. Surely in such a case, in the region to the east of Numanotaira, stones of all sizes and shapes would be found strewn about. According to our view of the case, however, this lack of stones is easily explained. The outburst, occurring mainly at comparatively low elevations, carried nearly all the heavier fragments over the plateau and precipitated them down the slopes beyond. The whole forest

* In this page these are some obvious misprints of "north" for "south" and "N." for "S."

was devastated, and large numbers of trees carried bodily out of the ground. Into the holes formed by the uprooting of these trees, it is quite to be expected that some of the stones should fall and be more or less covered over with débris and loose soil. Mr. Odlum did not find stones in all the holes (see *E.*, page 25), which he explains in paragraph 13 (p. 28) on the hypothesis that these holes were holes made by people digging out pine-roots. Unfortunately, as already noticed, we get no information as to what proportion of the holes dug into were found to contain stones. The facts described under *F.* and *G.* are not inconsistent with what we have described as a probable explanation of the presence of stones in many of the holes; and the incidental information we get regarding the character of the soil, full of old roots and boulders, simply diminishes the likelihood of deep penetration. Paragraph 3 (p. 25) is much too vague in statement to lead to any certain conclusion; paragraph 4 proves nothing except that a stone hit a rock; while if paragraph 5 means anything, it means that the stone shown in Fig. II. was travelling horizontally and with a speed not by any means excessive.

In regard to the discussion of the forms and sizes of the holes, paragraphs 6 to 15, we may remark that the eccentric position of the stone in the hole proves only that the stone came into it obliquely and does not necessarily mean that the stone made the hole; that some of the arguments brought forward have no bearing on the question how were the holes formed (*e.g.*, 9, 10, 11); and that the discussion of what ought to be if Professor's Milne's theory were true is singularly pointless. On the other hand, in paragraph 8, Mr. Odlum brings forward a fact, which under certain conditions would be very difficult to explain on any other hypothesis than that of the falling stones. Under paragraph 14, more complete details regarding the admixture, so to speak, of large and small holes, would have been very desirable. In paragraph 15, Mr.

Odlum seems to say, that relatively to their diameters, the holes were shallower higher up the mountain than lower down; and this he explains by a difference of velocity. But, if stones went high enough so as to come to their original level again wlth sufficient speed to form large holes, we have seen that there will be very little acceleration as they fall an extra 4,000 feet. The relative shallowness of the higher holes seems to be sufficiently explained as due to greater density of ashes and dust that fell at the higher levels.

In paragraphs 16 and 18 we have some measurements given us, but strangely incomplete. Thus we are told the size and weight of one stone; but can gather nothing as to the size of the hole whence it was dug. Then we are given careful measurements of the dimensions of two holes; but not a hint as to the size of the stones found therein.

We have entered into a detailed criticism of Mr. Odlum's paper, since it has been made so much of by the supporters of the falling stone theory, and since he alone of all the many observers in the days immediately succeeding the eruption took the trouble to get at the facts. For such enthusiastic labour he deserves warm praise. But we doubt if he can be regarded as having established his case, that hundreds of thousands of holes to the South-east of Bandai-san were formed by falling stones. He seems to have been a little doubtful in his own mind as to the universal applicability of the theory he is striving to establish (see paragraph 20). In the early part of the paper he admits that many holes were formed by the uprooting of trees; but seems to expect that the uprooted tree would always be found lying near its hole. On the site of the devastated forest above the slopes of the Biwa-sawa we saw root stumps turned right up on end, often absolutely trunkless. Immediately after the eruption many of these torn up roots would be covered with fallen débris, and might easily escape the notice of investigators intent on the investigation of the holes. Our own impression is that sufficient attention has not been given to the formation of holes by the uprooting of trees; and that, when this cause is taken into account and the effect of earthquake shocks in producing landslips is given its full weight, the holes left to be explained by the action of falling stones will by no means bulk so largely as a reader of the papers already published would be led to infer.

We do not claim to have brought forward an hypothesis that can apply to every reported case of a hole; we do not think that to be possible. Our object has been to criticize, in a scientific manner, the widely accepted theory that all the holes were formed by one agency, namely falling stones. Not a few scientific men, at the first statement of this theory, felt there were grave difficulties in the way of accepting it. By our discussion of the effect of atmosphere resistance in retarding a falling stone, and of the probable penetrating powers of such stones in ordinary soil, we have pointed out exactly what these difficulties are; and the more one considers the whole subject, the more is one impressed with the insurmountable character of these difficulties, and the less is one disposed to accept the unqualified conclusion of Professors Sekiya and Kikuchi.

The following communication on tbe origin of the Bandai-san notes was received from Dr. G. Wagener on January 12th, 1890:—

I visited Bandai-san for the first time on the 25th of August, 1889, in company with Mr. Janson, Professor at the Agricultural College of Komaba. Following the well known road from Inawashiro to Nakano-yu, and coming near this last place, we noticed some of the holes in question, 4 to 6 feet in diameter and 2 to 3 feet in depth. Mr. Janson's immediate impression was that these holes were exactly like those which could be seen by the thousand, all around Paris, during the siege in the Franco-German war. These latter holes, of the above diameter and deep enough to hide a man squatting down, were well-known to have been made by the big shells thrown from the French forts against the German positions. These shells being mostly provided with time-fuzes, did not burst in the moment of striking the ground, and frequently did not burst at all. After having ricochetted perhaps several times, they had fallen flat upon the ground, as any spent cannon ball will do. There they were found, not at all inside of the holes, nor in their neighbourhood, but at places more or less distant from these holes. Such shells which had not burst, were laying about in such numbers, towards directions specially favoured by the French artillerists, that detachments of soldiers were sent out regularly to look for these shells and to bury them. This was done to prevent accidents in case cavalry or artillery advanced to meet a sortie, and should move over such ground strewn with shells. The holes made by the bursting of shells were entirely different in appearance from those made by ricochetting shells.

Dr. Kellner, Professor in Komaba, who also has been at the siege of Paris, not only confirms the above statement, but, having visited Bandai-san shortly after the explosion, is perfectly certain that the edge of the holes turned towards the crater, was much more sharply defined than the opposite side where by a ricochetting stone some sputtering must have occurred.

The similarity in the aspect of the holes around Paris and those on Bandai-san is so striking that both Prof. Kellner as well as Prof. Janson are of opinion that, if the gentlemen who are opponents to the hypothesis of falling stones had seen both kinds of holes they would not hesitate a moment to admit this explanation.

In the presence of the above facts and the absence of all evidence referring to the very act of originating the holes, it seems to be beyond doubt that there is no reason to reject altogether the theory of the falling stones. On the contrary, it is most probable that at least a number of the holes have been formed in this way. Whether all the holes, even the large ones of 20 and 30 feet in diameter, with depths proportional, have been made by falling stones or not, I do not venture to decide, and perhaps would not venture even if I had seen them, which is not the case. But if there are holes quite different in size, in appearance, in locality, etc., from others, there is no necessity to maintain that the origin of all of them is due to one and the same cause.

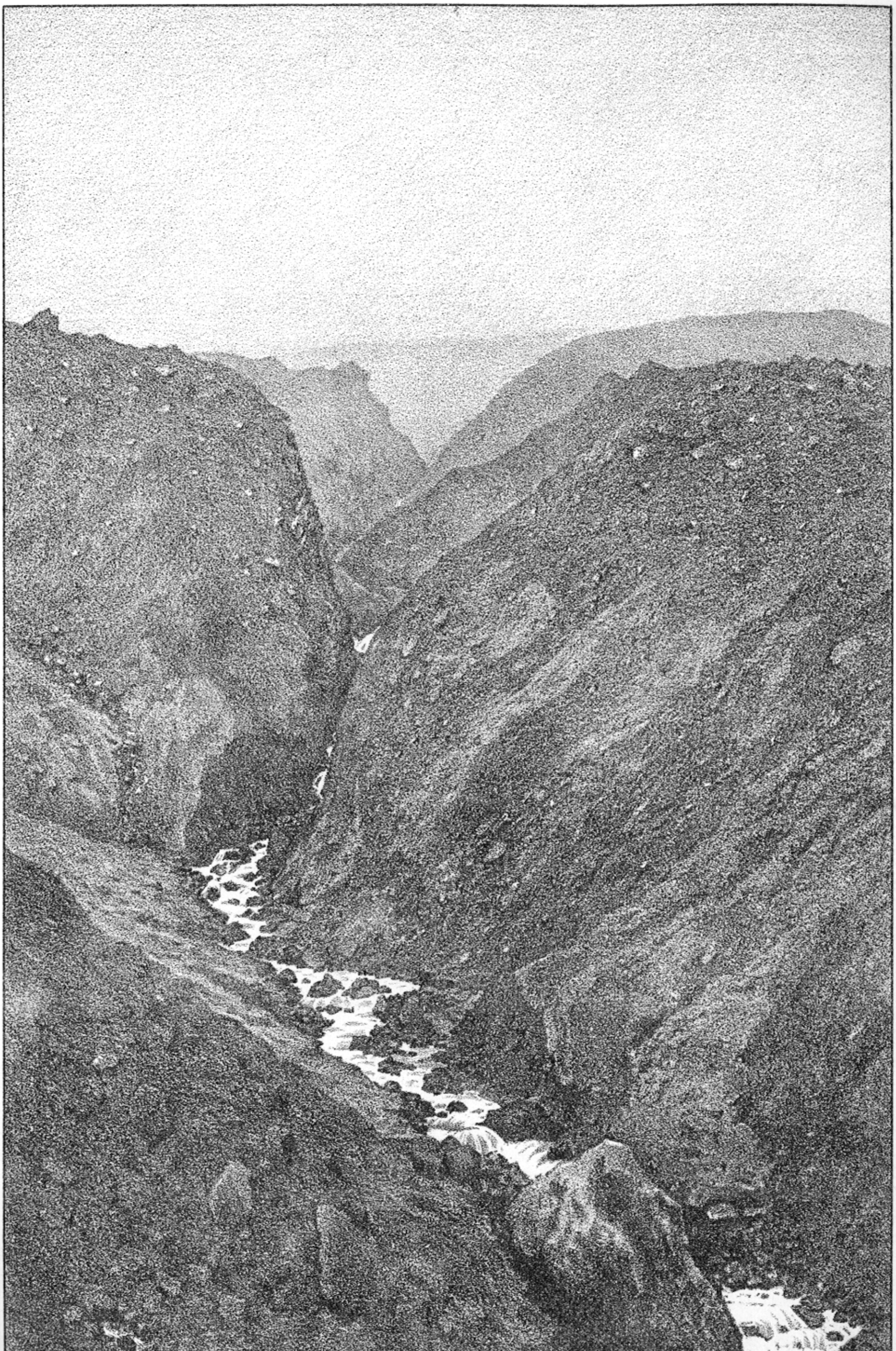
Perhaps some opponent to the theory of the falling stones will make the objection that the circumstances of the fall of the Paris shells and of the Bandai-stones are not the same, in so far as both struck the ground under very different angles. The distance at which the Paris shells were throw, was five English miles and even beyond 6 miles. For such distances, the elevation of the fixing guns must have been very considerable. I have no tables to refer to, but I think, an elevation of 30° to 35° is a low estimation. It is well known that the second half of a trajectory, chiefly of such a long one covering a horizontal distance of 5 to 6 English miles, is considerably steeper than the first half or than the elevation of the gun; and we may well admit that the Paris shells struck the horizontal ground under an angle, say of 50°, or even more. In the case of the Bandai-san, the holes are mostly found on the slope of the mountain. If not, and if of quite a peculiar nature, they may, as I said before, have been formed by some other cause than falling stones. Suppose a stone having been thrown out of the crater, and coming down at a very steep angle, say 70° to 75°; if it falls upon the slope of the mountain at a place where the incline is 20° to 25°, it will, just like the shells, strike the ground under an angle of 50°, make a hole and ricochet once or twice or more as the case may be. I do not think that my figures have been chosen thus as to make me incur the reproach of having forced my argument. At all events, any objection not based upon positive ballistic facts and experiments referring to similar circumstances of trajectories and ground as on Bandai-san, would be insufficient to outweigh the matter of fact statements made in the beginning of this letter.

There is a way, very simple—I do not say easy and comfortable—of ascertaining whether the foregoing explanations are to be point or not, that is to look for stones or boulders not inside, but outside of the holes, at places much lower down. Anyone who has amused himself in his youth to roll big stones down the slope of a hill, knows what tremendous bounds they make, carrying obstacles like small brushwood easily before them and stopping only at far away distances even if the gradient is gentle. Isolated stones or boulders may be found on Bandai-san down the slope below the holes, and their nature will show whether they have come from the crater or from somewhere else. That boulders have been thrown far away, there can be no doubt. Any visitor to Naka-no-yu can see evidences of a big boulder having been thrown against the slope of Masu-yama. It laid bare the rocky ground, and broke into several pieces, which slid down to the bottom of the slope where they are now lying.

[Note added April 28th, 1890.—Dr. Wagener's interesting communication suggests ricochetting stones as a sufficient cause of the smaller sized holes. He expressly guards himself, however, against extending such an explanation to the very large sized holes. His views therefore can hardly be regarded as antagonistic to those expressed in the foregoing paper. It will suffice to point out that, even with the modification suggested by Dr. Wagener, the chief difficulties still remain as regards the numerous holes to the south-east of Kobandai. Thus their very number is a difficulty; for if they were all formed by ricochetting stones that then hurled themselves down the slopes, these stones must have been so numerous that it is difficult to imagine many of them not getting stranded in the higher flats.—C. G. K.]

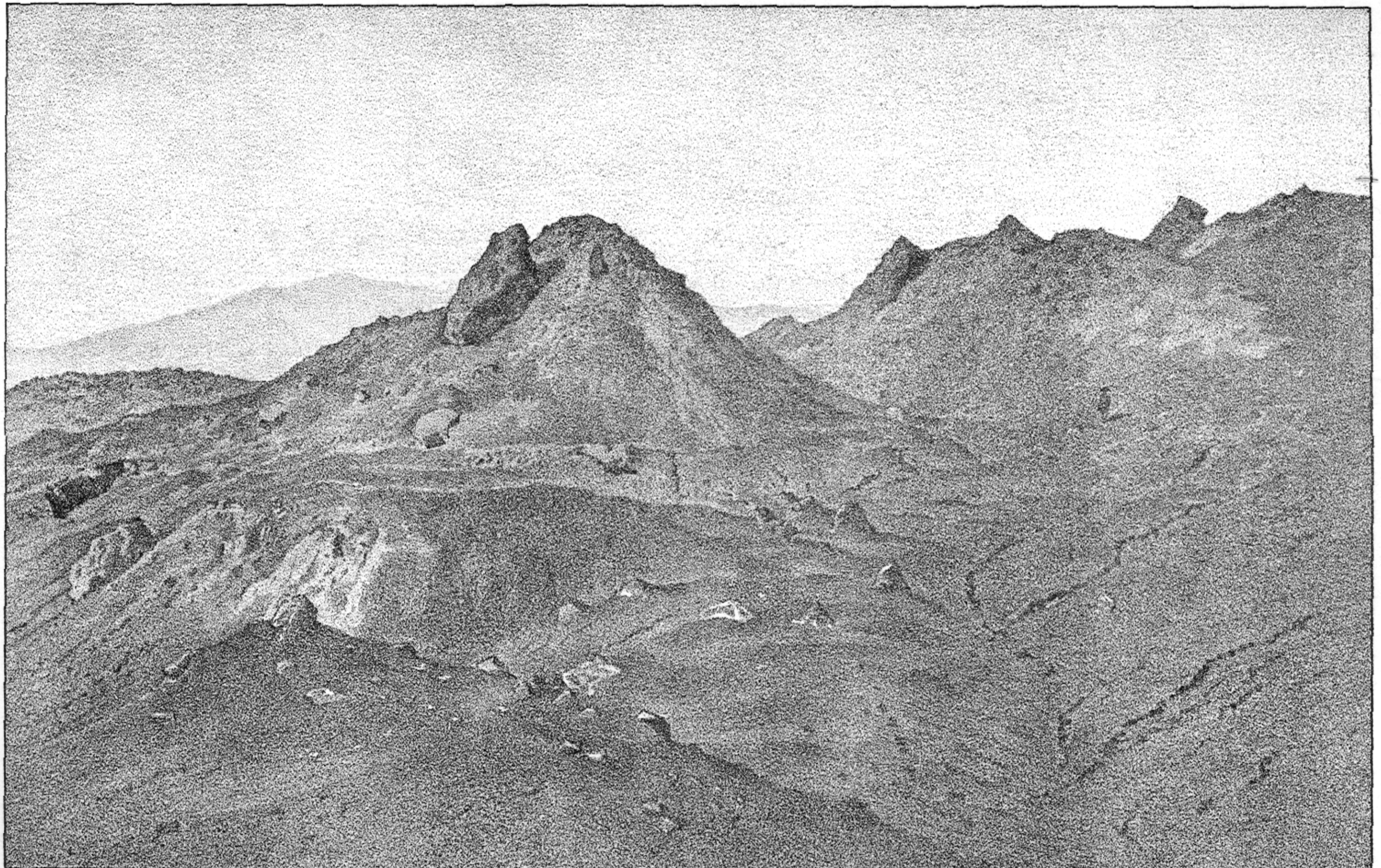
Erosion at Bandaisan *Plate I.*

LITHO PRINTING AT "SEISHI-BUNSHA."



LITHO PRINTING AT "SEISHI-BUNSHA."

Erosion at Bandaisan Plate III.



LITHO PRINTING AT "SEISHI-BUNSHA."