HOW WERE THE CONE-SHAPED HOLES ON BANDAISAN FORMED?

By E. Odlum.

[Read December 4th, 1888.]

Before saying anything about the different theories advanced to explain this question, it is right and proper to say that Professor Seikya and Mr. F. Kikuchi, Assistant Professor of Geology in the Imperial University, have ably pioneered the way for the true explanation. In fact they have done more. They have met several or all of the objections raised against what must finally be accepted as the only scientific explanation of many, if not of the large majority of the numerous cone-shaped holes to be found all the way from the broken crater edge, and the adjoining peaks, down to the valley below. The testimony of these gentlemen is of the greatest value, as they have made an extensive and scientific exploration of the entire region affected by the eruption. As their report was given in lecture form by Professor Seikya, there is no need of making any general observations concerning the outburst. It is the aim of this paper to deal only with the cone-shaped holes.

That there are vast numbers of such holes, probably hundreds of thousands, all admit. That most of them were formed during the eruption all are agreed. That they are found scattered irregularly in all directions from the peaks to the valleys below is known by those who have examined them. That many theories have been advanced to account for them is now a matter of history.

THE DIFFERENT THEORIES.

A. Solfataras—*i.e.* vents from which issue sulphureous gases.

B. Steam and other gaseous vents.

C. Seismic action operating on bodies of matter concealed in the mountain slopes.

D. Falling stones.

E. Human agency.

F. The uprooting of vast numbers of trees by the combined force of the earthquake shock and hurricane which prevailed at the time of the eruption.

Some of these theories may be dropped at once, as they are not accepted by any one who visited the scene of the outburst.

A. "Solfataras" as a theory is dropped, and never was held by more than one or two.

B and *C* may be passed over for the present as the former has no following now, and the latter is only a theory, which has not yet produced *one fact* to give it any lasting claim as a general explanation.

We shall now consider *F* for a moment.

Those who have travelled over the mountain slope know well that almost all the large trees have been blown out by the roots. This is true concerning the trees on at least one half, if not two-thirds of the mountain, from the peak downward. Large quantities of clay, sand and gravel adhered to the roots and thus many large holes were formed. In many cases the great force sent the trees a little distance from the place on which they stood, and in a few instances turned them completely over; but the large majority are lying with their roots close to the holes made by their falling, with their tops pointing down the mountain. This is enough to show that many holes were formed by trees blown out by the roots.

Let us now look at *E* for a moment. It certainly sounds strange to say that large numbers of the cone shaped holes

were formed by *human agency*. Nevertheless it is true, and easily proved.

While examining the holes carefully, with the object in view of seeing what were the facts, the men whom I had engaged to dig, concluded that there was no use of digging any further in one of the holes in which I was interested. In fact they were determined to stop, because they *knew* there was no stone in that particular hole.

To convince me, they pulled out some small *pine roots* and set them afire, and informed me that the people in the villages, dug out many such *pine roots* for the purpose of getting material for fire and for *light*.

This seemed very strange, but was worth considering. Towards evening a labourer came down from the heights above witn a large load of *pine roots* on his back. He gave the same information as the diggers. On returning to the village of Inawashiro the same facts were again substantiated.

Professor Seikya looked into the matter carefully, and in reply to a letter on the subject, sent by him to a friend in the Bandaisan region, received the following answer, which he has kindly translated for my use:—

"It is very natural for you to ask that question." (The writer of the letter was interrogated as to the use of the Pine Roots.) "Pine Roots are used for *lighting* purposes. They contain an abundance of resin—so much so that some of them are semi-transparent-light. Some of them give better light than oil or candles. In winter nights they also serve for heating rooms, and are mostly used among the peasantry. Call them *farmer's lamps* if you like. The price for one stump is below 10 *sen*. Sometimes owners of the forests allow people to dig them gratis, I suppose for their own convenience. One large root often requires two or three horses to carry it, but lasts six months for one household. Being so cheap, convenient and near at hand no wonder almost every farmer goes to the mountains for them—the reason why you find so many holes on the slopes of Bandai and Akahagi."

I wrote to Mr. Kinichiro Hasegawa, the chief of police at Inawashiro, a gentleman who did all he could to answer my questions carefully, and comprehensively; and he sent the following reply:—

"After careful examination I gained this information. Digging up pine roots is done not only by one or two villages but by nearly all the villages around the mountains. They use them for light when they are working at night. They are used chiefly by the poor."

From these two letters and the other facts already mentioned, we readily see that a large number of holes was formed in this manner. These holes are conical; and, as a large amount of earth is dug out to clear away the roots, there is also a rim of earth around them, much the same as around these formed by the falling stones. It is impossible to tell these two kinds of holes apart, without actual digging. When the ashes, or volcanic dust fell over the slopes of the mountain, it covered the *old pine stump holes* and also the *new holes made by falling stones* in such a manner as to make them look alike.

We now come to the chief topic, to the consideration of *D*. It must be examined into most carefully, as this particular phase of the question has been the chief "bone of contention."

Before a proper answer can be given to the question "Did falling stones make a large number of the holes on the slopes of Bandai-san?" we must decide that stones were projected into the air at the time of the eruption. If they fell they were projected, and vice versa.

1ST.—Did stones fall?

A. Many eye witnesses have testified to the fact that they fell in immense numbers. The newspaper correspondents, sightseers, amateur and matured scientists, have given overwhelming testimony proving that stones, countless in number, both large and small, fell with terrific violence all over the slopes of the mountains.

B. Many persons were wounded and two, *at least*, were killed by falling stones.

C. The ruins of villages, and broken trees of all sizes show that they were bombarded by stones both small and large. In fact all admit that *Yes* is the true answer to the question *did stones fall?*

2ND.—Where are these stones?

A. They must be *above* or *beneath* the surface of the earth. They fell in all directions, mostly to south-east, and in some cases to the distance of *five miles* from the crater. Most careful search reveals the fact that they are nowhere to be found, and therefore they are not above the surface.

B. If they are below the surface they must have penetrated, by the great force gained while falling thousands of feet through the air, *into the earth* several feet, leaving large holes to mark their present resting places.

C. It is inconceivable to suppose they buried themselves in the earth without making holes.

D. Are there holes? Yes, *tens* or *hundreds of thousands.*

E. In many of these holes are found fresh, angular, ash covered stones of different sizes.

F. Under all the stones dug out there were found grass, leaves, weeds, branches, and other kinds of vegetable matter, which had been carried down by their lower surface. These different plants were mostly bruised until little remained but the coarse tough woody fibre which has the appearance of having been passed between heavy iron rollers.

G. In one hole the large stone had struck on a boulder of the mountain mass, and ground or crushed the corner into powder. The stone had almost come to rest before it came in contact with the old imbedded rock or boulder, so that the corner of each, at the place of impingement, was pulverized to the extent of not more than four or five inches square, but it was quite fresh.

3RD.—Running down the mountain slopes from the tops to the valleys are many gorges, some of which are very deep, and at places along their bottom may be found comparatively level spots.

Such places were visited and many holes found in them. But the holes are just as numerous on the slopes of these gorges, and on the ridges between two adjoining gorges as in

their valleys. If seismic action operating on water were the cause of the holes, we would expect the holes to be in the gorges and along the water-ways, *but not all over the high and dry ridges hundreds of feet above*, as is undoubtedly the case.

4TH.—The solid, bare, native, mountain rock has on its upper surface marks and large scars which could have been made only by falling stones. In Fig. I., *A* and *B* represent two very important phases of this question. In *A*, *CC* is the native rock, *X* represents a coarse irregular scar made by the falling body; *Y* the dark spot in the centre is intended to show *what would have been the case* if the huge fracture were made by steam, gas, or water action from below. Undoubtedly there would be a hole corresponding to *Y*. *Such a hole does not exist.* But the scar is represented by the centre *t* in *B*.

5TH.—As said before, the trees show most conclusively that stones were hurled with great violence through the air. Fig. II. is a sketch of a tree about half a mile from the crater. In the shattered trunk, the stone is imprisoned in the splinters, as shown in the diagram at *S*.

6TH.—Fig. III. represents one of the holes found on a level spot in one of the gorges before mentioned. Its diameter is 31 feet, and depth about 10 feet. The crater is about *five miles* distant in the direction of *C*. The rim of earth is deeper and larger on the side marked *B*. This is most natural. If the stone fell perpendicularly, the rim of earth would be the same general size all around the the hole, but as the stones fell in a slanting direction, and *away from the crater*, the rim of earth is larger at *B*, *i.e.* on the side distant from the crater.

7TH.—On digging into these holes and examining the position of the stones, I found that they were not in the centre, but to one side, and always on the side *distant from the crater*.

In fig. IV. *C* is a large hole about 10 ft. in diameter; *AA* is a perpendicular erected at the centre of the hole; *BB* is a

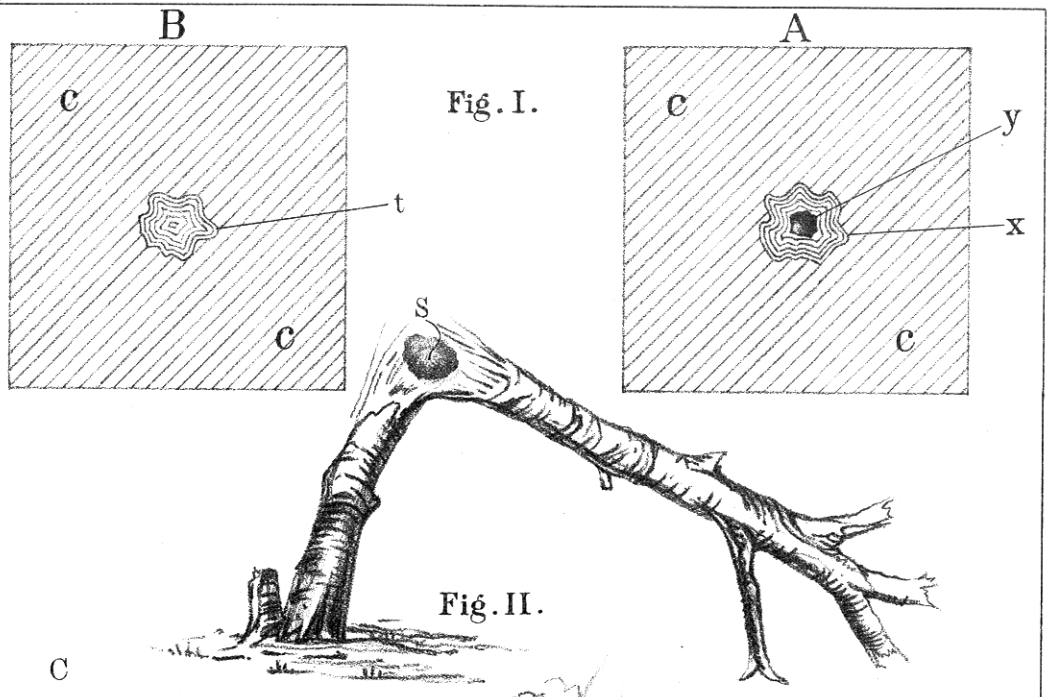


Fig. I.

Fig. II.

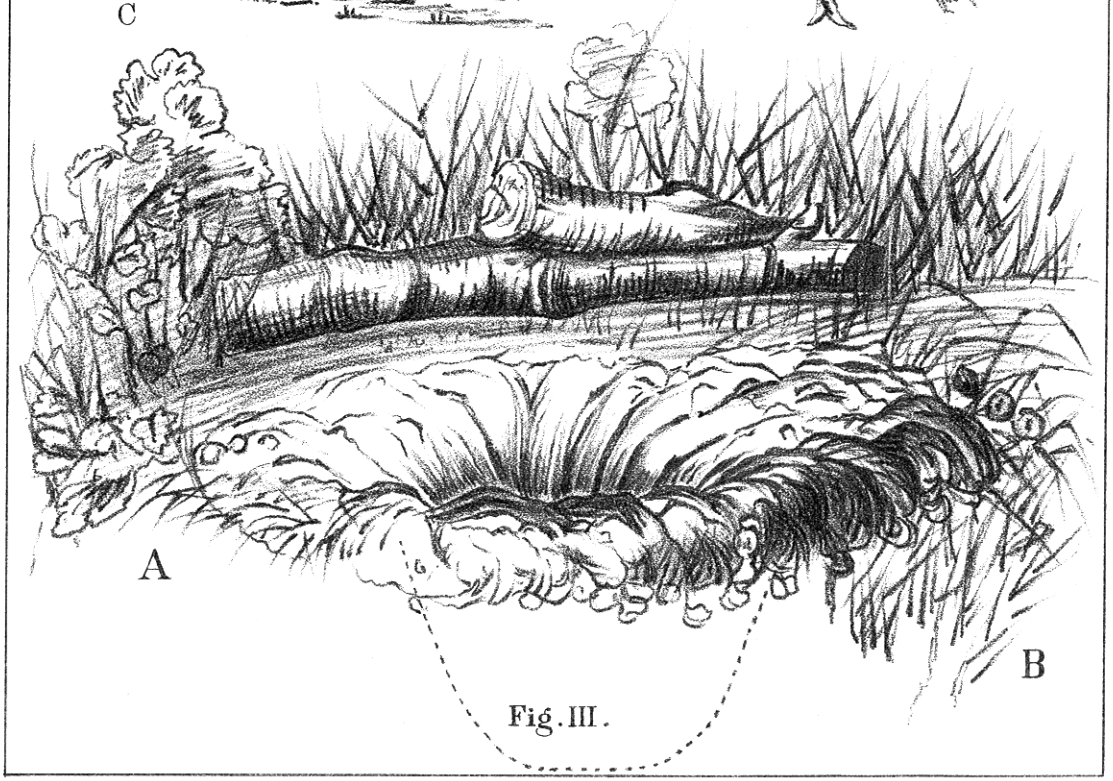


Fig. III.

perpendicular from the centre of the stone. The crater is fully four miles distant in the direction of *Y*. The distance from *AA* to *BB* is about 10 or 12 inches. This distance is varied according to the shape of the surface and the material on which the projectile fell.

8TH.—On many parts of the mountain the small trees and shrubbery are very dense. Among this thick growth some important facts were observed. In fig. IV. *D* is a large hole about 15 ft. in diameter. *Rt.* is the mountain slope. The crater is off in the direction of *X* between 3 and 5 miles. As the stone came crashing to the earth, it cut its way through the bushes, tall grass, and weeds, bending them in *the direction s c*; but as the earth was forced out on the lower side of the hole, the shrubs and small plants were bent *away from the centre toward the base* of the mountain.

9TH.—The weeds, leaves, branches, etc., found under these stones, correspond to those growing around the hole.

10TH.—Where the stones fell on the steep slopes of the mountain so steep as to make the angle *CDE* 45° or more, fig. *V*. *CD* being the inclined surface where the hole was made, the earth rim is found *on the lower side only* as at *n*; and the distance from the upper side of the break to the lower centre of the hole is much greater than that from the centre to the surface on the lower side, *in some cases twice as great.*

NOTE.—The mountain slopes are for the most part soft mud, sand and deteriorated volcanic scoriæ. This is true of nearly all the mountains of Northern Japan.

11TH.—The rim of earth thrown out is for the most part fairly regular in its shape, and confined within a distance of a few feet from the edge of the hole. Very seldom is it more than 10 feet from the edge of the hole to the outer edge of the rim. If the holes were made by steam, gas, or water action from below they would have around them very irregular rims of dirt, which would be scattered hundreds of feet from the centre. This is *not* the case.

12TH.—On reaching these stones, careful examination was made beneath them. We turned them over, and continued digging to see if the ground below was solid, or loose and crumbling. We found it *solid*; just like the well compacted earth generally found by digging to a distance of 6 to 12 feet. Had there been a "blow up" from below there would be some signs of such action. No such signs were found. The earth would have been loose, *but it was solid.*

13TH.—That stones are not found in all the holes may be readily explained by the fact, before mentioned, that many holes were made by people digging out pine-roots.

14TH.—Many of the holes were measured. They vary from a few feet in diameter to over thirty feet, and from 2 to 10 feet in depth.

The following table gives the measurements of a few of those most carefully examined.

1.— 7 feet diameter, 3 feet deep.
2.— 5 feet diameter, 1⅔ feet deep.
3.—15 feet diameter, 5 feet deep.
4.—10 feet diameter, 3½ feet deep.
5.—31 feet diameter, 10 feet deep.
6.—10 feet diameter, 2 feet deep.
7.—20 feet diameter, 6 feet deep.
8.—20 feet diameter, 5 feet deep.
9.—10 feet diameter, 5 feet deep.

15TH.—The ratios between the diameters and depths of the holes low down the mountain sides are different from the ratios between the diameters and depths of the holes near the summit. Above, *i.e.* near the peak, the diameter is greater than the depth in comparison with the same functions below.

This is natural. The stones which fell near the summit did not fall so far, and therefore their final velocity was less; while those reaching the ground far down the mountain had much farther to fall, in some cases between 3,000 and 4,000 feet. Hence the final velocity would be much greater and they would penetrate to a greater depth in proportion to the diameter.

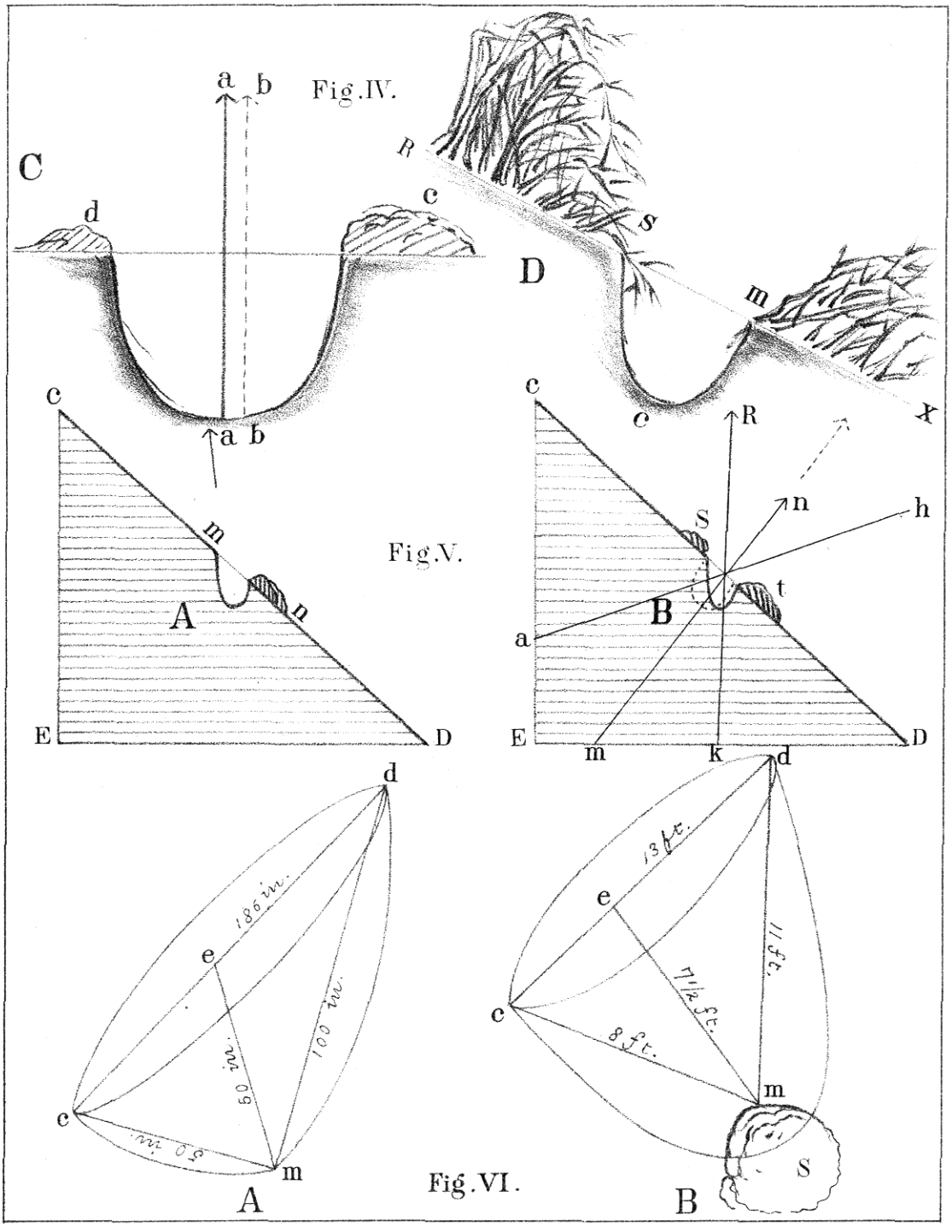


Fig.IV.
C
a b
d
c
a b
D
R
S
m
x
Fig.V.
c
m
n
A
E
D
c
R
n
h
S
t
B
a
E
m
k
d
Fig.VI.
d
e
180 in.
100 in.
50 in.
50 in.
c
m
A
e
13 ft.
11 ft.
7½ ft.
8 ft.
c
m
S
B

16TH.—Some think the holes are too large to be made by the stones found in them. But when we consider the height from which they fell, and their momentum, we can readily believe they made the holes in which they are found.

One excavated stone had the following measurements, as nearly as could be ascertained.

It measured 27 × 35 × 40 inches.

This gives 37,800 cubic inches.

Taking the specific gravity as 2.5, which is a little above the fact, as shown by the results arrived at by Professors Sekiya and Kikuchi, the total weight would be 3,975 lbs. Suppose the stone fell 7,744 feet, which is a very moderate height, the final velocity would be 704 feet per second.

This gives a momentum of 2,798,400 foot pounds and a working energy of 30,782,400 foot pounds.

This force, or capability for performing actual work, is simply inconceivable; even after due allowance is made for atmospheric resistance, which would be considerable.

17TH.—The average tendency of steam, gas, or water action in forming holes on the slopes of the mountains, would be to emerge at right angles to the surface, as indicated by *m n*, in fig. *V. B*, or *a h, but not K R, as is really the case in all the holes so situated.*

Again, if the holes were formed from below there would be considerable ejecta all around, *on the upper side,* as well as the lower, which is not the fact, as inspection shows in fig. V. *A*. There is no rim of mud at *m*, on the upper side, but much at *n*, below.

18TH.—In fig. VI., *A* is a hole from which a large boulder was taken; *c d* is 186 inches, *c m* 50, *d m* 100, *e m* 50. In *B*, *c d* is 13 feet, *c m* 8, *d m* 11 and *e m* 7½ to the top of the stone, *s*. X represents the direction of the crater from *A* and *B*.

NOTE I.—While these holes are generally spoken of as cone-shaped, quite a number are not of such a form, but vary considerably owing to many cir-

cumstances, such as position of surface and the heterogeneity of the material on and under the surface.

NOTE II.—Although the term *ashes* is used to indicate the pale blue *volcanic dust*, serious doubts are held concerning their true composition. I think they may be more correctly considered as fine dust resulting from the pulverizing of the soft stones and clay of which the mountain is mostly formed. Stone dust, or volcanic dust would, perhaps, be a better term.

19TH.—Besides the objections already made to the theory that the holes were formed by seismic force operating upon water and forcing it to perform the wonderful feat of blowing out tens of thousands of holes all over the mountains from their peaks to the valleys, not only in the lower parts, but along the dry tops of the ridges, another objection may be raised. It is as follows:—

The whole mountain looks as if it had a heavy attack of small-pox. Now, to suppose each hole, or every second, or third hole, was formed by water action is to suppose such a quantity of water in all parts of the mountain as would have turned the entire mass into muddy slush, which would have run down into all the adjoining valleys long before the eruption could have taken place. Such a mountain could not stand half an hour.

20TH.—The innumerable holes of all sizes on the inner slopes of the crater and on the peaks are most difficult to explain. Doubtless many of them were caused by falling stones, and perhaps a number of them by steam or gaseous action as indicated in the beginning of this paper.

In the marsh known by the name of Numanotaira, the explanation so ably advocated by Mr. J. Milne, Professor of Mining in the Imperial University, may be true for some of the holes. Here of course is a large quantity of water which must have under its lower surface many fissures filled with water. In such a spot there is reason for the hypothesis of seismic action. But this marsh is not the one thousandth of the area dotted with holes, and is close to the crater, comparatively speaking.

21ST.—Why are the holes more numerous towards the north east side of the mountain ?

A. The wind, which was blowing E.S.E at the time, would have a tendency to carry all the material projected into the air in the same direction. In 30 to 50 seconds this wind would certainly move the stones somewhat out of their course, and especially so, if the wind at a great elevation was very strong, as it was in all probability. This we may infer from the fact that large quantities of the volcanic dust were carried 60 miles distant with the wind.

B. Perhaps the fierce hurricane rushing down the sides of the mountain would aid in driving much of the ejecta, including the stones, towards the north-east. Looking over the different parts of the mountain, and excluding the north, in the direction of the great outburst, one is led to believe the hurricane force was stronger on the N.E. side than in any other direction.

C. But the chief cause may be understood by looking at Fig. VII.

There are four peaks:—*A.* Kushigamine, *B.* Akahagi, *C.* Ôbandai, and *X.* Kobandai, the peak that erupted northward towards *D.*

The dark, cone-shaped mass is intended to represent the peak in the act of lifting. The enormous steam or gas pressure that lifted the cone, having an altitude of between two and three thousand feet, with a volume of 158,700,000 cubic yards as shown by Prof. Sekiya, and hurled it many miles over a large area, found an immense vent at the north side. From this vent issued vast masses of stone ash, mud, and hundreds of thousands of stones. The high peak *C*, Ôbandai, in close proximity, and the other high summit *A*, Kushigamine, on the east, would to a very large extent turn the force of the northward explosion through the low and large opening between them, *i.e.* between *A* and *C*. This would cause the mass of projected matter to pass north-east over the lower peak *B*, Akahagi.

This, is perhaps, a reasonable explanation for the appearance of the great quantity of mud and boulders which came north-east to Mine, and does away with the necessity—according to some—of supposing there are two distinct craters.

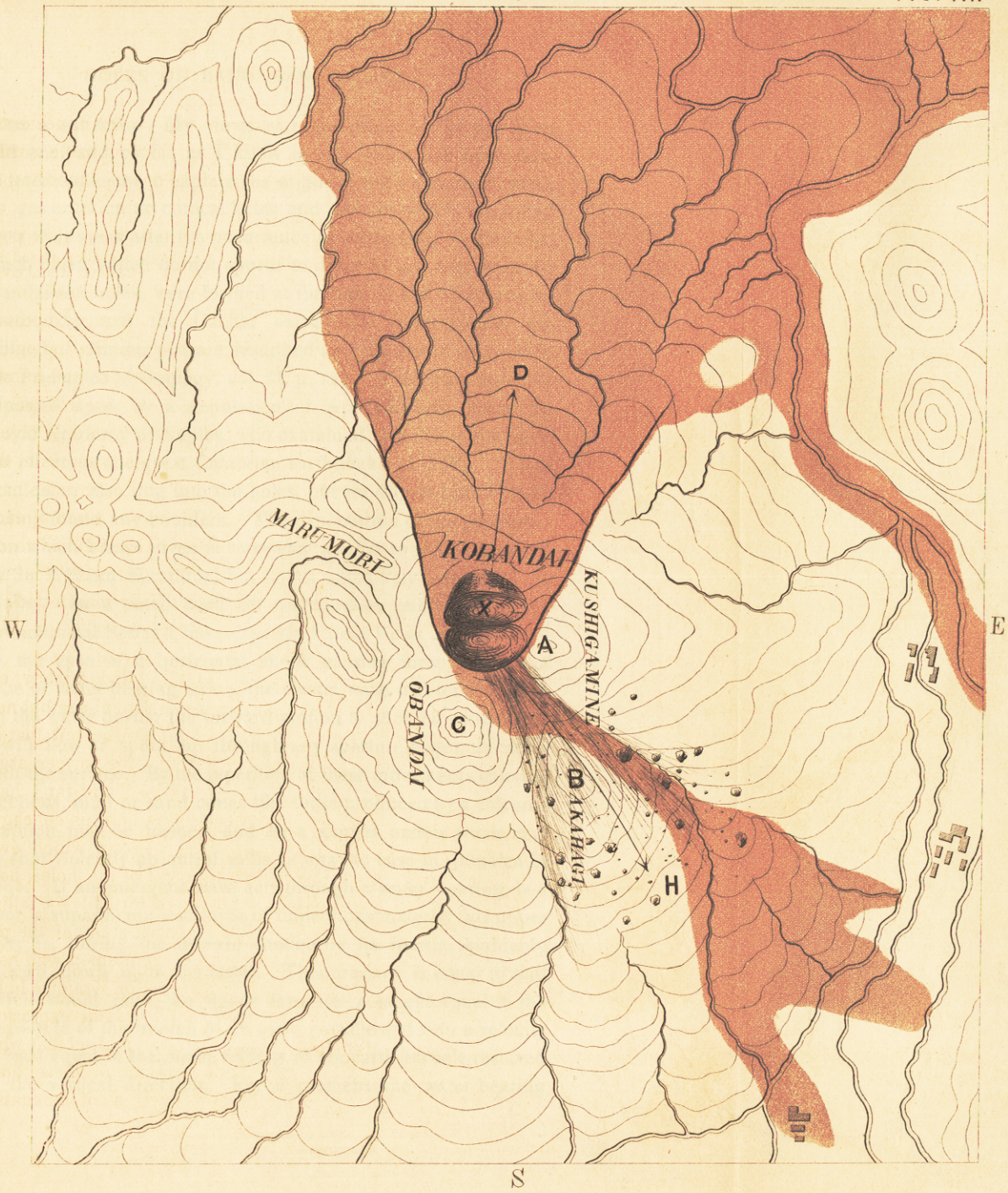
NOTE.—True there are many stones and boulders visible in and on the mud areas; but they came down the mountain gorge or valley mixed up with the mud, and did not fall from the crater on the mud after it had come to rest.

In presenting the above facts, I have felt encouraged because the gentlemen who have the management of the Seismological Society of Japan in hand, men whose labours are well known among scientists of other lands, who stand in the front ranks in their several departments of research, and whose only object is to patiently and faithfully glean the gems of truth from the broad and rugged fields of nature, are the gentlemen who have given me this opportunity to add my little to the much already harvested, and in whose hands, one, in his inability to do justice to the work undertaken, feels safe, knowing that not only fairness but even leniency will be cordially manifested.

DISCUSSION.

Professor Milne first remarked that he had already expressed his views about the conical holes at Bandai-san but now that the matter was receiving special attention he felt that he must reiterate and express more definitely his former arguments. Continuing, Professor Milne said:—Thus far I have been in a minority of one. Professor Sekiya and his colleague Professor Kikuchi after elaborate investigations which even extended to excavating and boring in some of the holes, have arrived at the conclusion that they were formed by falling stones. Mr. Odlum who has made a special study of the pits arrives at similar conclusions, and other gentlemen who have seen Bandai-san are of like opinion. Herr Von Kreitner holds the belief that the holes were produced by steam explosions from below, and in support of his views has told us that when he and his companions were approaching one of these holes they invariably noticed a sulphurous smell, as if emanating

FIG. VII.


N
W
E
S
D
KOBANDAI
MARUMORI
X
A
KUSHIGAMINE
OBANDAI
C
B
AKAHAGI
H

from a solfatara. My views as to the origin of the pits is an old one, and so far as I know is one which has been considered sufficient to explain the origin of the water, mud, sand, or gas eruption at conical holes and fissures which are found over wide areas after the occurrence of every large earthquake. Such holes, which do not appear to differ in any way from the Bandai-san holes, were formed at the time of the Charlestown earthquake and the Cachar earthquake (photographs exhibited). Similar pits are described and illustrated by Lyell in his Principles of Geology, vol. II. p. 127. They were specially reported upon by a deputation of Academicians, from the Royal Academy of Naples, who examined into and wrote upon the effects of the great Calabrian earthquake of 1783. These gentlemen also dug into the holes, but we do not hear of their having found any boulders. The explanation of the pit formation which I have given is somewhat similar to that suggested by Sir William Hamilton, but more accurately expressed by Mallet. In a small book on earthquakes published in the International Series I have expressed these views as follows :— In the case of a horizontal shock passing through a bed of ooze or water bearing strata, the elastic wave will tend to pack up the water during the forward motion to such an extent that it will flow or spout up through any aperture communicating with the surface. By the repetition of these movements causing ejections, mud or sand cones like those produced by a volcanic eruption may be formed, and by a similar action water may be shot violently up out of wells as was the case in Jamaica in 1692. If an emergent wave acts through a water bearing bed upon a superincumbent layer of impervious material this upper layer is, during the upward motion by its inertia, suddenly pressed down upon the latter. This pressure is equal to that which would raise the upper layer to a height equal to the amplitude of the motion of an earth particle and with a velocity at least equal to the mean velocity of the earth particle resolved in the vertical direction. For a moment the water bearing

strata receive an enormous squeeze, and the water or mud starts up through any crevice which may be formed leading to the surface. We therefore have three theories to discuss, and I will take them *seriatim*.

1ST.—The Volcano or Solfatara Theory.—Although Herr Von Kreitner and his friends detected a sulphurous smell at the holes, may not this have been due to the decomposition of organic matter? Although such occurences are not uncommon, I did not smell anything noticeable nor did any of my numerous acquantances who have explored Bandai-san. Therefore, I conclude that the observations of Herr Von Kreitner were exceptional and not general. As a sulphurous smell was therefore exceptional, and as all the water in the holes was cold, and as there was no steam, I am strongly of opinion that the holes were not of volcanic origin. Further, were they of volcanic origin I fail to see why they should be spread over so large an area and be practically of uniform size. Some I should have expected to have been of considerable size and others small. For a similar volcanic effort to have been made at practically similar depths, at thousands of points beneath an extended area, is not only improbable but outside the history of vulcanology.

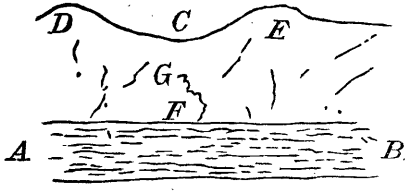
2ND.—The Falling Stone Theory.—The only experiment, of which I am aware, which supports the theory that the Bandai-san holes were formed by falling stones is that of throwing a bullet into dry sand, when the sand will splash outwards and a conical hole may be formed. The like effect, however, is not produced when a bullet is thrown into ordinary earth or clay, nor is it produced when fired through a piece of wood. In the latter case the effect is reversed and the apex of the cone is on the side where the bullet entered. A stronger objection to the theory is that the holes are tolerably uniform. When Bandai-san exploded, stones of all sizes were shot to different heights and therefore very different effects might have been

produced. Some boulders should be resting on the surface, some buried a few inches, some a foot, some two feet, and so on. The facts, however, are that it is only in a few holes that stones have been discovered just as they might have been discovered by digging anywhere in the side of a mountain; and further, they all, or nearly all seem to have had just sufficient velocity to penetrate the upper crust and then disappear in a softer layer beneath. Even supposing that the stones were shot to a height of 10,000 feet, which is double the height we can reasonably suppose them to have gone, as judged from pictures of the eruption, the velocity with which they struck the ground can not have been much over 700 feet per second. It does not seem likely that an ill shaped rock striking the ground with this velocity, which is only quarter that of a ball from a modern gun could have excavated a conical hole in moist earth 10 or 15 feet in diameter and then have buried itself in the hole it formed. The fact that perfect branches of bamboo have been found beneath one or two boulders is surely an argument that the hole was *not* formed by the falling of the boulders, which rather than carrying down with it leaves which are as perfect as if prepared for an herbarium, ought on the contrary to have crushed and broken them. Then again, amongst the thousands of volcanic eruptions, when materials have been thrown to a height of 20,000 feet, where have we an account of the falling stones producing pits? The boulders from the great eruption of Asama-yama still lie round its base, but they do not appear to have made pits. We read of huge boulders having been thrown a distance of 9 miles, but we do not read of pits having been produced by the boulders. Neither in the three treaties on volcanoes—one by Scrope, one by Daubeny, and the other by Judd, nor in many other works do I ever remember reading that pits have been produced by falling boulders. If pits have been produced at the time of a volcanic disturbance I think we shall find that such a disturbance was accompanied by an earthquake, and if the pits at

Bandai-san were formed by falling rocks it is a new and important observation in vulcanology. In the case of a meteorite we have a body passing through the atmosphere with a velocity sufficient to render itself red-hot, yet even in the case of heavy bodies such as these I do not think we read of conical holes being excavated. My own conclusion therefore is that the majority of the holes were not formed by falling stones. A few in the soft mud of the crater may have been formed in that manner, but it is more likely that the few holes in such position were made by the explosive action of steam.

3RD.—The Water Pressure Theory.—I am led to believe in this theory partly because there are so many objections to the other theories and partly because it is supported by many facts. At the time of the Bandai-san eruption there was a severe earthquake, and it is an extremely common event to have holes like those at Bandai-san formed at the time of large earthquakes. Why therefore should we seek for any other cause, when we remember that nearly all volcanoes have ejected large rocks, but it is seldom if ever that these have been known to excavate crater-like pits? It seems very improbable that the pits at Bandai-san were formed in this manner. If they were formed in this manner pits in all stages of formation should exist, the large ones being relatively few in number and each pit should contain its boulder, which in the majority of cases ought to show freshly fractured surfaces, and beneath no boulders ought we to discover branches and plants, so perfectly preserved and uncrushed as those which have been exhibited. The earthquake effort, which may be illustrated experimentally by coating a surface of water contained in a shallow vessel with alternate and irregular layers of paraffin and sand, and then tapping the surface or sides of the same, would round the immediate vicinity of Bandai-san be felt with approximately equal intensity. The effect of this upon water bearing strata at moderate depths, in bursting through the crust, we should anticipate would be tolerably uniform, and in the majority of

cases result in the formation of conical holes, rather than fissures.



Thus a disturbance passing along the water bearing strata *A B*, would tend to burst through the surface at *C*, rather than at *D* and *E*, where the resistance to rupture is comparatively great. Further, the ruptures would, for the following reasons, generally take place at some particular point or points along the depression *C*, which runs at right angles to *D C E* rather than from a fissure. (1) Assuming *A B* to be of a stream-like form running at right angles to the depression *C*, in this case it would only be where *A B* passed beneath *C* that fracture would take place. (2) Assuming *A B* to be of a stream-like form but running beneath and parallel to the length of the depression *C*, or even let A B be of sheet-like form, in this case, because in the earth beneath *C* there are fissures, cracks, or lines of weakness as *F G*, which when traced along their length vary in their dimensions, at some places rising to the surface more than they do at others, there are therefore points of comparative weakness, and at such places we might expect the superficial soil to be burst through rather than at others. In some instances however, especially with very severe shocks fissures may be formed. The holes which I inspected followed an irregular line along the length of a valley on the west side of O Bandai, along a line of drainage. The boulders which have been found in such holes, so far as I am aware, are in no way different and not more numerous than I should imagine them to be in the soil lying upon any portion of the mountain side. The shape of the holes is such as would result from an explosive effort

in soil, branches of shrubs and the grass forming a fringe round the edge of such holes being blown outwards. After an explosion, much of the material, not having been projected to any height, probably in no case more than 20 feet, would fall back to the cavity from which it had been ejected, while other materials might roll down its sides. In this way I should account for boulders, grass, leaves, and the like being found in the holes—in some cases the boulders resting on the vegetable matter. Regarded in this manner, the seismic theory may be made to account for all the observed phenomena, while the solfatara theory, or the theory of falling stones, leaves, as we have seen, much to be explained. For my part, with such observations as have been brought before us, I prefer to believe that the majority of the holes at Bandai-san were formed by a seismic effort packing up watery strata which here and there burst through the superincumbent strata at points of least resistance, rather than by any of the unusual methods which have been suggested.

Prof. Knott said there were difficulties which prevented him from accepting some of the theories advanced. The argument as to the mud being thrown up on the lower side of the hole would, he thought, apply equally to Prof. Milne's theory, as in any case the mud which was thrown up on the higher side must fall back into the hole while that on the lower side remained. He was inclined to Prof. Milne's belief that there should be a great many holes of different sizes corresponding to different sized boulders. How was it therefore that the the size of the holes was so limited? Those were some of the difficulties regarding the stone theory. Now he would bring forward a theory of his own which was caused by the mention of the pine stump holes. Possibly where stones were found in holes, such holes were made by the digging for pine roots, and the stones discovered might have rolled in during the eruption.

Mr. R. Whittington remarked that the stone theory might

apply to some of the holes, while the water theory might also account for others, but no definite evidence had been produced. Before the latter theory could be proved it would be necessary to discover whether the mud in the holes was similar to the watery stratum underneath.

Professor Sekiya complimented Mr. Odlum on his paper, and considered that he had advanced decisive evidence in support of his theory,

The Chairman did not consider any of the theories advanced sufficiently established by the facts. The presence of mud on the lower side was certainly not more against Professor Milne's theory than in favour of Mr. Odlum's. The question was still left an unsettled one.

Professor Knott enquired what was the ratio of the number of holes in which boulders were discovered to the number of holes investigated.

Mr. Odlum, in the course of his reply, referred to an experiment with paraffin and mercury which he said indicated that his conclusions as to the forms of the holes were correct. As to the argument that the plants taken from beneath the stones should be crushed and not perfect, he informed the meeting that the plants which were removed were immensely crushed, in fact there was nothing but fibre left as his specimens showed. The stones had the appearance of having been recently thrown in the holes, neither were the stones all of one size; there were many small ones, but the larger ones were better suited for investigation. He was delighted to see Professor Milne holding on with such vigour to his theory but he himself could hardly conceive Bandai-san being a sort of watery mountain. To suppose that the holes were made by water was to suppose that the mountain was one of water, and such a mountain could not stand. The holes were both large and small in size, they varied according to the size of the boulder, and those he examined evidenced the cor-

rectness of his theory. Dealing with the theory that the stones might have rolled into holes which were waiting to receive them, he remarked that he should have expected to find the stones on the surface of the hole and not buried several feet below as was the case.

The usual compliments to the lecturer and chairman concluded an interesting meeting.