VI.—FURTHER NOTES UPON THE FORM OF VOLCANOS.¹

By JOHN MILNE, F.G.S.,

Professor of Geology and Mineralogy, Imperial College of Engineering, Yedo, Japan.

DURING the last summer I made a journey from Yedo as far north as the southern end of Kamschatka.² As when upon this trip I saw and visited many volcanos in Yezo and the Kuriles, I venture to offer a few remarks in addition to those which I have already expressed upon the form of this interesting class of mountains.

In the *GEOLOGICAL MAGAZINE*, August, 1878, I endeavoured to show that the sides of all regularly-formed volcanos are not straight slopes, but have a curvature which in form is logarithmic. This form, it was pointed out, was that which would be assumed by any heap of loose materials such as those out of which we may suppose a volcano to be built. From this it was inferred that these regular volcanos were natural forms, and not forms which had been produced by the wearing away of one part and the bolstering up of another, as we find spoken of in treatises on volcanos and physical geology. It was also pointed out that from the external form of a mountain it might be possible to calculate the dimension of any internal core.

To illustrate these views, I used several profiles traced from a series of photographs of two volcanos.

From the volcanos which I have subsequently seen in Yezo, the Kuriles and South Kamschatka, I see that my views were very poorly illustrated, and had I the means when there of obtaining other profiles, I feel that the case stated in the above-mentioned paper might be more satisfactorily demonstrated. In looking at the illustrations which I have given, it will be observed that some of my curves, although generally logarithmic in character, are by no means absolutely so. By comparing the curves of each profile it will be seen that the discrepancy in the fourth column is greatly due to not having had any true method of fixing an axis, and it would have been better to have taken the mean of each pair of ordinates and treated the two sides of a profile as a single curve.

Another point to be observed is, that if the logarithmic curve drawn for purposes of comparison had been placed on profile No. 4 rather than upon profile No. 2, it would have been seen to have a nearer coincidence with the curvature of the mountain.

Notwithstanding these misleading illustrations, the logarithmic character of the curvature is clearly to be recognized.

Similarity in curvature.—When in the Kuriles, I saw many beautifully formed volcanos, and these, almost one and all, showed a slope which, so far as I could judge, was similar to that upon the mountains which have been shown to have a logarithmic curvature. Unfortunately I was unable to take an outline of these mountains which, for purposes of geometrical measurement, would be of any value. All that I can say is that these contours appeared to have a general

¹ For my previous paper, "On the Form of Volcanos," see *GEOL. MAG.* 1878, Decade II. Vol. V. pp. 337—345, Plate IX.

² See *GEOL. MAG.* 1879, Decade II. Vol. VI. p. 337, Pl. IX.

character, and that this character was similar to what I have already described.

One confirmation of this identity I find by reference to my sketches. Another confirmation was obtained whilst taking the angular distance between several of these mountains by means of a sextant held horizontally. By this I was enabled to carry the reflected image of one mountain and place it in juxtaposition with the image of its neighbour, the latter being seen directly. Whenever this was done the similarity in the curvature of the two mountains was very striking. Experiments of this sort were made at several places. The first were made along the north-west shore of Paramushir, where there are a number of extremely well-formed mountains. The only one of these which bears a name is Mount Fuss. Another well-formed mountain is the Island of Alaid.

Curvature of hills, piles of debris, etc.—Curvatures which appear to be similar to those we see upon the sides of volcanos are to be seen upon the slopes of many hills. These are especially noticeable upon the surface of debris lying beneath steep scarps. These curves are, however, seldom to be observed. The reason is that it is only rarely we can obtain their profile view. In looking at a range of hills, we usually see them curving downwards towards the low ground, and if we ascend them we usually remark that the climbing becomes more difficult the higher we go up. When the slope of hills like these can be looked at from the end of the range instead of from the front, a peculiar curvature will be observed, and this is not unlike the logarithmic curvature of volcanos. Profile views of curvatures are strikingly exhibited upon the sides of Hakodate Head. This is a solitary mountain at the south end of Yezo, upon which the town of Hakodate is built. Its position and its shape make it very like Gibraltar. It consists of a mass of trachytic rock covered with alluvium. Near the top of the mountain, which is more than 1,100 feet in height, the alluvium is thin, but near the base it is many feet in thickness.

From its nature it is to a large extent evidently the result of the degradation of the rocks on which it rests. Materials from high levels have been constantly rolling to low levels, larger stones rolling farther than smaller ones, and the consequence has been that from the base to near the summit long curvatures have been formed. As the mountain is a solitary one, these curvatures can be seen in profile, and their form is remarkably like that exhibited by volcanos.

Experiments upon the form of heaps.—In order to determine the form which a heap of loose material assumes, I made several experiments by allowing a stream of sand and gravel to fall through a funnel upon a level floor. The heaps which were produced were as follows:—

1. *Fine sand.*—This fell from a height of about 3 feet until it formed a heap 27 inches high. The sides appeared to be straight, and they had a slope of $31^{\circ} 30'$.
2. *Fine gravel.*—This fell until it formed a heap 21 inches high. The sides of this were also straight, and the slope was $31^{\circ} 30'$.

3. *Fine gravel mixed with sand.*—This fell to form a heap 26 inches, high. Round the base a slight curvature was observed.

4. A mass of gravel mixed with sand was formed by throwing it against a board, on which a sheet of paper had been stretched. Here also a slight curvature was obtained, which was marked off upon the paper.

Taking these experiments as a whole, it will be observed that I did not obtain much evidence in favour of my views. In experiments number 3 and 4, where slight curvatures were obtained, it must be noticed that I was using a material the particles of which were of *different sizes*. Had the experiments been upon a larger scale, I think the results might have been more satisfactory. Also, if the sand and gravel, instead of falling in a column, had fallen as a rain upon the heap, and the heap had subsequently been left some months to settle, the curvatures would in all probability have been more decided.

By allowing water to fall for some time as a light shower over the heaps, I endeavoured to imitate the effects of denudation. Although many of the showers were infinitely greater in proportion to the size of my heaps than the showers of rain which fall upon a mountain are to the mountain and its materials, the dragging of materials to the base was not sufficient to produce any observable curvature. This would seem to show that it is not denudation of a kind like this to which we must turn in order to find an explanation for the curvatures of volcanos.

In looking at any large heap of materials, the component parts of which are of *different sizes*, a curvature will, I think, be always observed.

A short time ago I observed this upon a number of heaps of gravel, which, for purposes of measurement, had been piled in large rectangular cases. These cases had subsequently been removed, and the heaps left to themselves. First, the sides had fallen downwards and outwards, the larger stones rolling the farthest, and a curvature had been produced. Since the first general form had been assumed, a similar action had been slowly going on under the combined influence of gravity, and, to a slight extent, the weather.

These heaps were about 3 feet high. Their curvature was best observed by standing at a distance, and then stooping until you brought your eye on a level with the heap.

As the result of these experiments and observations, I would classify the principal causes which tend to affect the form of a volcano under the following three heads:—

1st. Causes tending to give a volcano its characteristic curvature.

a. The tendency of a self-supporting heap under the influence of its own weight to spread outwards at the base. This would tend to give a logarithmic curvature.

b. The tendency during the building up of a mountain of the larger particles to roll farther than the smaller ones. This will also depend on the specific gravity, the porosity, etc., of the particles thrown out during an eruption. We may regard this action as extremely rapid denudation carried on by gravity.

c. Denudation by weather and gravity. This tends to efface a mountain by digging away materials from the top and making its steepness less and less. At the bottom of the mountain, where denudation is also going on but at a slower rate than it takes place near the top, these materials are deposited and spread out.

It must here be noticed that on a volcano, and especially near its summit, material is seldom to be found lying at an angle which is *less* than its angle of repose. Of this fact I have convinced myself that it is the case upon the slopes of many volcanos; 1st, by observing that the materials on any particular slope were uniform in size; and, 2nd, that if upon such a slope I dropped a piece of material larger than those of which the slope was made, it commenced to roll towards a lower level.

If this be granted, then the levelling action of denudation cannot have played a very important part in giving the form to a volcano; otherwise we should expect to find materials lying at angles *less* than that which a heap of them would naturally exhibit. However, denudation must have had some effect, and as this effect will probably have been nearly the same on all sides of the mountain, it will not materially affect its regularity.

2nd. Causes principally affecting the regularity of a mountain.

About these I have written before. Briefly they are as follows:—

1. Position of the crater. If this is central, we should expect the mountain to be regular.

2. Lateral and parasitic craters will tend to destroy the regularity.

3. Direction of the wind during an eruption.

4. Nature of the eruptions. If these have been paroxysmal, and have blown away portions of a crater,—if lava has flowed on one side more than on another, etc., we have causes tending to destroy regularity.

3rd. Causes partially affecting the form of a volcano, but principally its height.

The movement of the strata upon which a volcano is built.

As has been pointed out by Mr. Mallet, the weight of a volcano may tend to crush the strata on which it rests so as to form a saucer-shaped depression. Round the bottom of the mountain the ground may be caused to rise.

Evisceration or honeycombing beneath a mountain may also cause a depression to take place.

I would also suggest that because it is probable that during the period of activity, which is a length of time to be measured by many years, the rocks beneath the protective covering which has been built above them must become extremely hot, and the mountain will have an augmented height due to the expansion of the beds upon which it rests. When the activity becomes less intense, contraction sets in, and a sinking may take place.

To form any accurate idea of the effect which may be produced by any action of this description is very difficult. If we think of the small amount of heat which passes through the bricks of a furnace, we might suppose that the conduction of heat from the heated nucleus of a volcano into the surrounding rocks would be too small to produce any appreciable effect, whilst if we think of the rapidity with which heat travels through a glass into which we pour hot water, we might arrive at opposite conclusions. The rate at which

heat flows through rocks is a subject of which we have little or no personal experience, and about which we cannot therefore form any *primâ facie* opinion.

To give some idea of what actually must take place, the case of an infinite mass of rock heated from a plane surface of constant temperature has been taken as the simplest case for which calculations can be made. The temperature of the plane is taken at 2000° Fahr.; and the time during which conduction has taken place at 2000 years, the object being to find the temperature at various distances from the hot plane in the surrounding rock. We might consider the hot surface to be spherical or a vertical cylinder, but the simple case of a plane surface kept constantly at a high temperature is easier to calculate, and at the same time sufficiently illustrates my idea.

If the isothermal surfaces are parallel planes, and x is measured at right angles to these planes, then an element of rock of unit area and thickness dx , if it is at a temperature v at the time t , receives heat when increasing in temperature dv ;—

$C.D. dv \cdot dx$ in the time dt , where $C.D.$ is the capacity for heat of the rock.

But through one face it receives heat by conduction in the time dt , and through the other face it loses by conduction, and the difference is—

$$K \cdot \frac{d^2v}{dx^2} dx \cdot dt.$$

K being the conductivity, and hence—

$$C.D. \frac{dv}{dt} dx = K \frac{d^2v}{dx^2} dx$$

$$\frac{dv}{dt} = \frac{K}{C.D.} \frac{d^2v}{dx^2}$$

The initial conditions are that where $x=0$, the temperature v is constant; when $t=0$, then $v=0$ everywhere except where $x=0$, and the above equation leads under these circumstances to the result—

$$-\frac{dv}{dx} = \frac{V_0}{\sqrt{\pi kt}} e^{-\frac{x^2}{4kt}}$$

This equation cannot be integrated in finite terms, but the following table of values for $-\frac{dv}{dx}$ has been calculated; t being 2000 years, K as equal to 400 in Foot, Year, Fahrenheit units,¹ and V_0 the temperature of the melted rocks which fill the plane fissure, being at least 2000° Fahr.

¹ For this value I am indebted to the experiments of Professors Perry and Ayrton, "On the Conductivity of Stone," Phil. Mag. 1878.

x in feet.	$-\frac{dv}{dx}$
0	1·2500·
500	1·1560·
700	1·0690·
1000	0·9140·
2000	0·3580·
3000	0·0751·
5000	0·0005·

A curve was drawn with these numbers as co-ordinates, and it is evident that the area of this curve up to any value of x is the difference between the temperature at that point and 2000° Fahr. In this way the following table showing the temperature at various distances from the hot surface was obtained.

Distance from Hot Surface in feet.	Rise of Temperature Produced in 2000 Years.
0	2000° Fahr.
600	1275° „
800	1062° „
1000	862° „
1200	667° „
1400	548° „
1600	423° „
1800	321° „
2000	244° „
2200	178° „
2400	129° „
2600	92° „
2800	64° „
3000	45° „

On looking at these results, it will be observed that they are far greater than might have been anticipated. Perhaps it may be objected that the conditions which have been taken as compared with those which occur in nature have been overrated. I think quite differently.

First, 2000 years is hardly an overestimate of the length of time during which a volcano may remain in activity. Vesuvius is recorded as having erupted in the year A.D. 79, and it still continues in activity. Before that time it was a recognized volcano, but how many thousands of years it may have been in existence we do not know. In Ischia and neighbouring places there were eruptions 400 years previously. All that we can say is that, as evidenced by the large amount of ejected matter which was in existence before the eruption of 79, it was even then a mountain of some antiquity.

Secondly, a temperature of 2000° Fahr. for molten matter, such as that about which we speak, is an estimate which is extremely low.

Sir William Thomson, in his calculations relative to the age of the earth, takes the temperature of molten rocks from 7000° to 10,000° Fahr., but these temperatures are purposely taken as large as possible. Bischof, in his "Geologie," p. 98, takes as the melting point of lava 2250 °Fahr.

When speaking of this temperature, it must be remembered that it is not supposed to exist in molten rocks near the surface, but in

rocks beneath the base of a volcano, which at their central parts are buried beneath a mass of material equal to the height of the volcano, which will usually be many thousands of feet. And just as the water at the bottom of an Icelandic geyser is hotter than that near the surface, so we may expect the rocks of which we speak to have an augmented temperature.

Another condition is that of the heated plane. From what is known of the internal structure of a volcano, a central column terminating in a crater above, and provided with many branches ramifying through the mass of the volcano, would be a truer representation of the actual conditions than those which have been taken. These ramifications would probably be continuous into the ground beneath, and deep down it is not at all unlikely that they converge towards a highly heated nucleus from which all the molten matter emanates. If these are anything like the conditions beneath a volcano, and I see no reasons why they should not be, then the plate of heated matter is but a very feeble representative of the heating surfaces which actually exist.

The only point about which I think any doubt can be expressed will be relative to the length of time during which such a heating surface may be imagined to retain a constant temperature. Whilst a volcano is in actual activity, the temperature deep down beneath the crater probably remains constant far above 2000° Fahr., and during the intervals which fall between the eruptions, whilst the volcano is only perhaps giving out wreaths of vapour, it does not seem at all improbable that, if it were possible to take the temperature some thousands of feet below the crater from which the steam is issuing, we should also find a temperature far above 2000° Fahr.

It must be also remembered that the heating effect which takes place is over and above any original temperature which the rocks may be supposed to have had before any volcanic eruption took place.

On the whole, therefore, I think the conditions of the given case have by no means been overestimated, but rather, were we able to take the conditions which actually exist, we should find temperatures far above 2000° Fahr., acting over periods longer than 2000 years, and, what is more important, instead of heat being given off from a single plane, it would be found to be given off from a multitude of surfaces, and the effect dependent on these temperatures enormously exaggerated.

Confining one's self to the example which has been taken, it now only remains for us to consider what these effects might be.

In vol. ii. p. 238, Lyell, in his "Principles of Geology," says, "It was ascertained that fine-grained granite expanded with 1° Fahr. at the rate of '000004825; white crystalline marble '000005668; and red sandstone '000009532, or about twice as much as granite. Now, according to this law of expansion, a mass of sandstone a mile in thickness, which should have its temperature raised 200° Fah., would lift a superimposed layer of rock to the height of ten feet above its former level. But suppose a part of the earth's crust fifty

miles in thickness, and equally expandible, to have its temperature raised 600° or 800°, this might produce an elevation of between 1,000 and 1,500 feet. The cooling of the same mass might afterwards cause the overlying rocks to sink down again and resume their original position."

In the case we have been considering, we see that temperatures are produced far greater than those spoken of by Lyell, and consequently the effect will be correspondingly augmented.

But the effect produced by simple expansion is not all. The rocks distant from the heating surface will offer resistance to the expanding mass which lies between them, and cause it to elevate itself towards the centre, the action being not unlike that which is exhibited by the iron arch of a bridge when expanding on a hot day. In the bridge the rise is only perhaps one or two inches. To us this is almost imperceptible. But if the same fact could be communicated to a creature no larger than a fly which lived upon the bridge, it would seem to be immense. Similarly if we could only learn the height to which a volcano is elevated by the heat developed during its period of activity, we might be equally astonished; for, when reckoned in feet, it is probably very great.

So far we have only considered the heat beneath a volcano as an agent producing expansion, and consequently elevation. If we imagine the heat to be much greater than that which I have taken, it is possible that in certain tracts it might produce fusion or at least plasticity, the result of which might be that the pressing downwards of the superincumbent weight would produce depression. However, if such conditions have any existence, I fancy that their extent is limited; and anyhow, outside the plastic area there will be expansion and consequent elevation.

Results of elevation or depression.—As elevation or depression beneath a volcano, such as those of which I have been speaking, will, in all probability, take place so slowly, the effect cannot be expected to materially alter the form of a volcano, degrading influence tending to produce a natural form compensating sufficiently rapidly to outweigh the influence of these motions. The effect which will be produced is rather a change in height.

We have here perhaps in part the means of explaining why the measurements of the heights of certain volcanos when made at long intervals apart should have given different results.¹

We may carry these ideas from a single volcano to a volcanic district. During periods of activity we should expect to find the heat gradients steeper than during periods of repose, and therefore during such periods of maximum temperature, elevation might be expected. Also the rate at which the steepness of a heat gradient in a district varies might indicate the approach or recession of volcanic agency, and perhaps may even yet give us a measure of the time by which such actions are removed.

¹ I think that these discrepancies have been noticed and written upon in the "Geographical Magazine," October, 1877, but I have not the means of making reference.

Conclusion.—In this, and a preceding paper already referred to, I have endeavoured to point out, firstly, what are the actual forms of certain volcanos, and secondly, the principal causes which produce and subsequently modify these forms.

Taken as a whole, these causes are very varied in their character. If we examine them singly, we can but barely form an idea as to the nature of their actions, and when we remember that, not only are they irregular in themselves, but that they act irregularly in their relations to each other, we see that the task of unravelling their complications becomes quite hopeless. In cases like this mathematical investigation helps us to obtain a clearer idea of an action, but it is seldom that it can be made to measure it. All that we can do is to fall back upon opinions, observations, and common-sense, the ordinary weapons which build up or destroy geological hypotheses.

NOTICES OF MEMOIRS.

I.—COAL AND IRON IN SOUTH AFRICA.¹

(From the "Friend of the Free State," etc., Bloemfontein, August, 7, 1879.)

THE following extracts from Mr. G. W. Stow's Geological Report on the Orange-River Free State show what immense supplies of coal and iron-ore await the arrival of the miner in that region:—

Taking the road to Rietvlei, before reaching the homestead of Fieldcornet Stoffel Bosman, the old partially metamorphosed sandstones² are again met with, cropping up above the surface. Here they are pinkish-white, fine-grained, and dip to the W.S.W. at an angle of 54° to 55°. The most important feature connected with their appearance at this spot is the great beds of iron-ore associated with them. These become distinctly visible immediately in the rear of Mr. Bosman's house. I was first struck in finding fragments of these ferruginous rocks employed in building portions of the fences round the land and kraals. Once upon their trail they are easily traced for miles. At one spot, about a couple of miles from the homestead, three beds are most clearly exposed. They are as follows:—On the top of a high bank the first bed is exposed on the surface for a breadth of about sixty feet, with a westerly dip of about 60°; about 450 feet from this a second bed makes its appearance, with a surface exposure of 45 feet, continuing towards a lower bank on the right about 750 feet distant; a third, but smaller, bed next crops out, with a surface exposure of about 25 feet. The dip of these last is similar to the first. These beds, therefore, run parallel one to another, and are regularly interstratified with the sandstones. The true thickness of the respective beds is: first bed, 50 feet; second bed, 40 feet; third bed, 20 feet; making a total thickness of 110 feet. A considerable quantity of magnetite, or magnetic iron-ore, is found in them, which quickly makes itself

¹ Kindly communicated by Prof. T. Rupert Jones, F.R.S.

² See Quart. Journ. Geol. Soc. vol. xxx. p. 624, etc.