VESUVIUS, THE TENGGER MOUNTAINS AND THE PROBLEM OF CALDERAS

BY

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(With the collaboration of Dr. PH. H. KUENEN for Chapter V).

With plates 5—22.

CONTENTS.

INTRODUCTION.

Until recently there was no good general map of the Tengger Mountains, so that in 1914 F. von Wolff (bibl. 1) in his work „Der Vulkanismus'', vol. I, p. 510—511, gives a reproduction of Fr. Junghuhn's map of 1844. For a volcanic district that has frequently been used as an example of a caldera and has been made familiar by the beautiful photographs from the firm of Kurkdjan in Soerabaya, this is an inadequate treatment, especially as Junghuhn's map is not accurate.

After I had gained a superficial knowledge of the Tengger Mountains in two excursions in 1918 and 1919, I conceived the plan of making a new general map after the topographical map $\frac{1}{20.000}$ of the Netherlands Indian Topographical Service. In 1922 I drew a wall-map $\frac{1}{20.000}$ with contour distance of *100 meters,* and coloured according to K. Peucker's method (Farbenplastik) (bibl. 2) the preparation of which occupied about a month. Plate 5 is a reduction of this map to $\frac{1}{100.000}$, made by the firm of Smulders in the Hague, to whom a word of praise is due for the excellent way in which they have carried it out 1)).

This map is based upon the old sheets of $\frac{1}{20.000}$ of the Topographical Service of the Netherlands East Indies, which were published in 1882 and 1885 (bibl. 1). Owing to the dense forest covering the district, these are of course not absolutely accurate.

In the meantime, in 1922, a map appeared of $\frac{1}{50.000}$ in two sheets: Tengger and Smeroe (bibl. M. 2), the latter of which, especially in the S. E. corner shows some slight differences with mine, but on the other hand it shows the morphology of the district somewhat less clearly.

In studying the history of the activity of the Tengger-group in Verbeek and Fennema's work (bibl. 8) it appeared to me that the structure of these mountains could not be explained in the way they propose. A visit to the Vesuvius in 1926, and the reading of Frank Perret's work on the eruption of the Vesuvius in 1906 and the changes which subsequently took place (bibl. 3), and of A. Malladra's works on the changes in the Vesuvius after 1906 (bibl. 4—7), suggested to me that Perret with his intermediate gas-phase had laid the

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1) There are a number of unfolded reproductions of Plates 5 and 6, which can be obtained on application at *f* 1,50 for the set, in cardboard case.

foundation of a new theory on the formation of calderas. This idea was supported by a comparison of the mechanism of the eruption of Vesuvius in 1906 with that of flowing oil-wells; and in connection with this I made some experiments.

Although I am not able to give an entirely satisfactory explanation of the origin of the Tengger Mountains I think I am right in publishing the following study in the hope that it may be a stimulant to a minute geological investigation of the Tengger, resulting in a monograph upon the subject.

I. HISTORY OF THE TENGGER MOUNTAINS ACCORDING TO R. D. M. VERBEEK AND R. FENNEMA.

The course of development of the Tengger Mountains is described by VERBEEK and FENNEMA in their work on Java, vol. I, pp. 132—133 and illustrated by Fig. 9 on pl. XIV in the atlas (bibl. 8) (see fig. 1). To get a clear idea of the history as conceived by them, I have worked up the data of their fig. 9 into a series of figures (fig. 2). The text follows below.

> „*Histoire du Tĕngguĕr.* L'histoire du Tĕngguĕr est donc, en résumé, ce qui suit: (voir Fig. 9),
>
> *1e période.* L'ancien Tĕngguĕr forme un volcan gémellaire, haut de 4000 mètres, à deux cratères, dont les centres se trouvent sur une ligne dirigée du S.W. au N.E. et à une distance de 3.4 kilomètres. Sur le versant se trouvaient au moins 2 petits cratères parasites, dont l'un est visible sur le dessin Fig. 9.
>
> *Catastrophe.* La lave monte dans les tuyaux du cratère et liquéfie une partie du manteau et du sommet. Grande éruption, combinée avec l'effondrement des sommets des deux grands points d'éruption situés près de la cime et l'effondrement partiel des sommets des deux petits. De la lave s'échappe au côté Est du cratère oriental, et cette lave exerce une pression sur les produits meubles du manteau du volcan, qui sont chassés au dehors sur une largeur de 3700 mètres et une épaisseur de 1000 mètres. Puis, la lave jaillissante se creuse dans le manteau une large vallée à bords escarpés; le fond de cette vallée se trouvait notablement plus bas que la vallée actuelle de Sapi kĕrĕp. Ecoulement de la lave dans deux espaces circulaires, dont les bords ont des rayons respectivement de 4.2 et 3.15 kilomètres, et forment ensemble avec les bords de 2 cratères plus petits un espace cratériforme irrégulièrement elliptique, long de 11 et large de 8 kilomètres, dans lequel se trouvent à la fin de la catastrophe deux lacs de lave, à un niveau de ± 1500 mètres d'altitude (niveau de l'écoulement de la lave de la chaudière orientale). Ces deux lacs sont séparés par une digue transversale droite, qui se trouvait *en-dessous* de la digue actuelle Tiĕmoro lawang, dont on ne peut voir que quelques couches de tuf au pied du Pĕnandiahan sous la coulée de lave de la digue, et dont la crête était alors aussi en grande partie au-dessous du niveau de 2100 mètres.
>
> *2e période.* L'activité cesse au cratère oriental après l'écoulement de la lave et celle-ci se solidifie. Au contraire, la lave reste

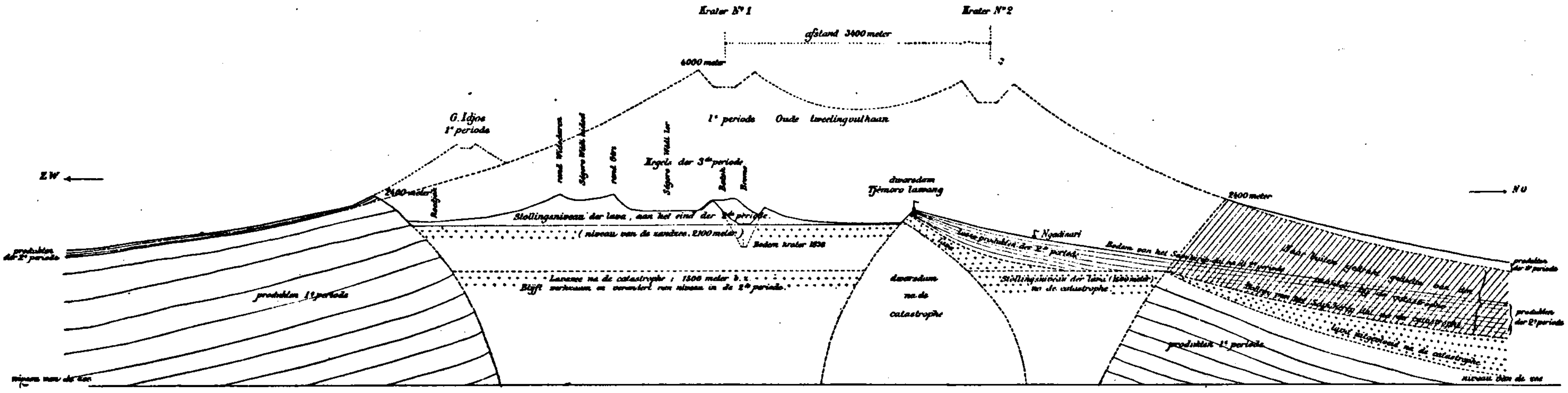

Fig. 9. Doorsnede van den top van den Tënggër. — Horizontale en vertikale schaal 1: 40,000

Fig. 1.

Cross section of the Tengger Mountains, according to VERBEEK and FENNEMA (bibl. 8, atlas supplement XIV, fig. 9).

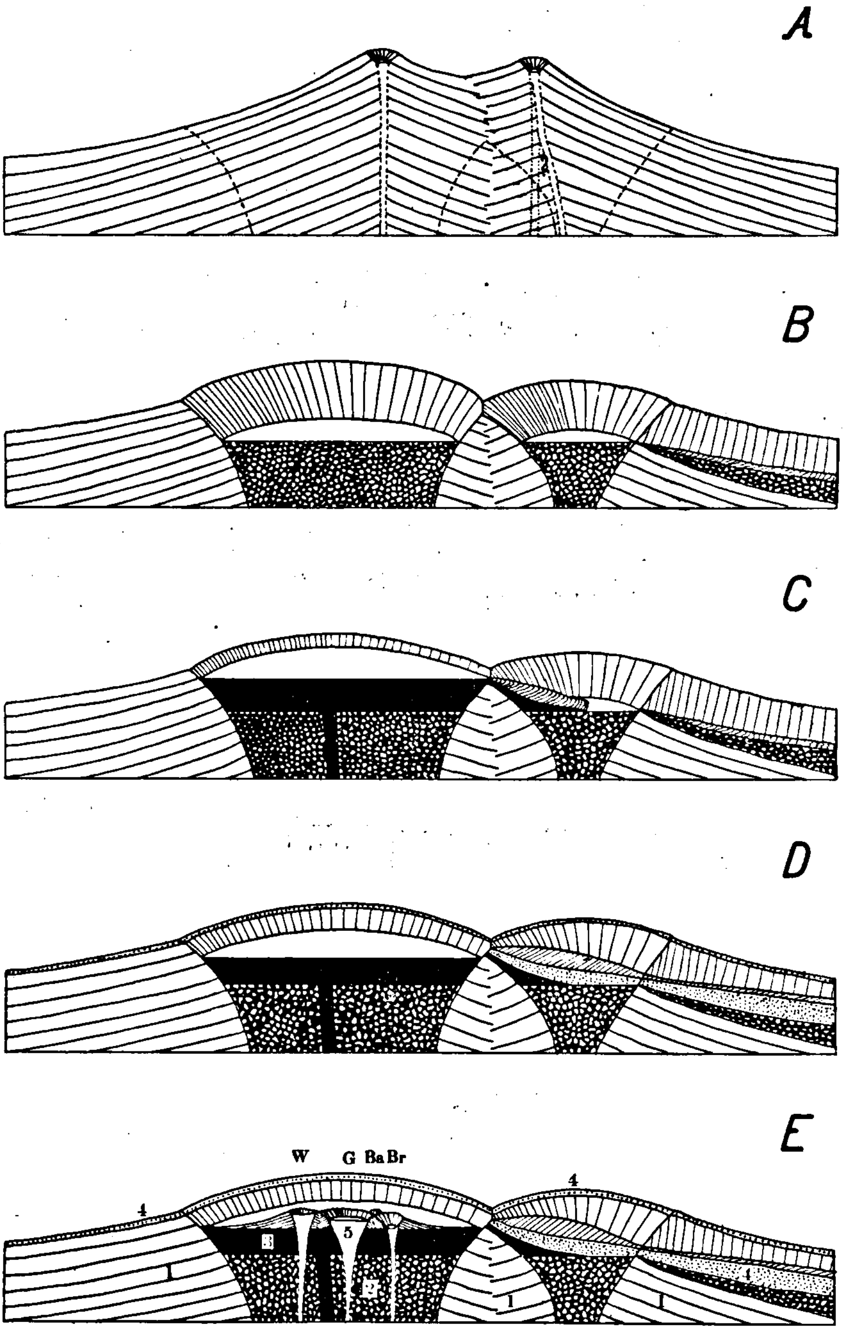

Fig. 2.

History of the Tengger Volcano according to VERBEEK & FENNEMA's theory, drawn by B. G. ESCHER.

Stage A: double volcano, shifting of the vent in eastern half.
B: two calderas, subsequently filled with lava, the valley of Sapikerep is formed by pressing out lava.
C: Lava overflows over the dam Tjemoro Lawang.
D: Lapilli and ash are deposited on the lava in the eastern caldera and in the valley of Sapikerep.
E: Present stage: 1 = old volcano; 2 = oldest lava filling; 3 = younger lava filling; 4 = ash, etc.; 5 = small new vents. W = Widodaren; G = Giri; Ba = Batok; Br = Bromo.

fluide dans la cuve occidentale, son niveau s'élève notablement et elle déborde même par-dessus la digue transversale. Il y eut ensuite de grandes éruptions de produits meubles, qui recouvrent maintenant la nouvelle lave de la digue et qui constituent les couches tuffeuses régulièrement inclinées de la vallée de Soukapoura. C'est ainsi qu'à la surface on ne peut plus rien voir de la lave qui a coulé dans la vallée. Le versant extérieur du Tĕngguĕr fut alors aussi probablement un peu exhaussé par les projections meubles du cratère qui retombaient plus loin. Plus tard la lave se solidifia aussi dans ce cratère, au niveau de 2100 mètres, et forma ainsi le fond de notre „mer de sable'' actuelle.

3e période. Sur cette croûte de lave, des éruptions répétées édifièrent successivement 5 cônes plus petits, le Widodaren, le Guiri, le Kĕmbang, le Batok et le Bromo, suffisamment connus par la description qu'en donne M. FENNEMA. On doit attribuer à l'action de ces petits cônes les cendres mobiles qui couvrent la lave solidifiée, dans la mer de sable. En certains points, des îlots de lave font saillie à la surface du sable et on peut alors remarquer çà et là que ces îlots inclinent vers l'extérieur autour d'un point central **a** (Fig. 10) et doivent apparemment leur origine à un mouvement faible de la lave déjà devenue visqueuse. L'activité du Bromo se continue encore; il projette de temps en temps des cendres et des pierres en même temps qu'il dégage beaucoup de vapeur d'eau. Mais pour le moment l'activité est faible, et l'érosion du versant extérieur du volcan et dans la vallée de Sapi kĕrĕp l'emporte de beaucoup sur le dépôt de nouveaux sédiments aériens.

Dans la Fig. 9 on voit représenté l'état du sommet du Tĕngguĕr a ses diverses périodes.''

In chap. VII I shall return to what I consider to be the errors attached to this conception.

II. HISTORY OF VESUVIUS FROM 1905 TILL 1927, ACCORDING TO THE WORKS OF FRANK A. PERRET AND OF A. MALLADRA.

There are very few volcanic eruptions of which an accurate account has been laid down in writing by a competent observer. Only FRANK PERRET's account of the eruption of the Vesuvius in 1906 can be placed beside A. LACROIX's monumental work "La Montagne Pelée". However valuable VERBEEK's "Krakatau" may be, in which the phenomena of the eruption are minutely described as they were observed from the far distance, the eruption itself was not observed by anyone from close by, and concerning the actual course of events we can only form conjectures.

FRANK PERRET followed the eruption of Vesuvius in 1906 from the Observatory on the mountain, and to him we owe an account of the mechanism of the eruption which is unique in volcanological literature for minuteness of observation coupled with penetration in the interpretation of the phenomena observed. After studying this work, it becomes very evident that for putting volcanological science upon a firmer basis more of such minute and accurate observations are needed. Undoubtedly the morphology of a volcano after an eruption yields data which may indicate the mechanism of the eruption; but it is necessary that a series of different eruption-mechanisms should be observed during their activity, before we can read the history of a volcano from its structure.

At the same time it seems to me that FRANK PERRET's work gives us so much deeper insight into the mechanism of an eruption and the morphology of the volcano following from it, that it is desirable to confirm this eruption, type Vesuvius 1906, in its mechanism and in its morphological consequences by experimental research and by comparison with the phenomena of other, non-volcanic, eruptions. FRANK PERRET's work would be morphologically incomplete if MALLADRA had not undertaken an accurate measurement of the changes in Vesuvius since 1906. It is by the combination of PERRET's and MALLADRA's work that we acquire the data for distinguishing a particular, closely definable type of eruption, presumably one out of many more existing types.

The numerous outpourings of lava which arose after the eruption of 1875 in the years 1881—83, 1885—86, 1891—94 (Colle Margherita) 1895—99 (Colle Umberto I) and 1903—04, took place too slowly to call forth a paroxysm.

In a volcano like Vesuvius we must therefore distinguish between a *solfatara stage (e. g. 1906—1913)*, a state of outpouring of *lava without any strong escape of gas* (e. g. 1875—1906 and 1913—today (1927)) and a *paroxysmal stage* with violent gas-escape.

The latest eruption began on April 4th 1906 and is divided into the following three phases by PERRET:

I. The luminous, liquid-lava phase (4—8 April 1906);
II. The intermediate, gas phase (8 April 1906);
III. The dark, ash phase (9—22 April 1906).

PERRET describes the cause of this eruption in the following words: "The great height of the lava column with the consequently strong pressure upon the walls of its conduit; the maintenance of the liquid at a high temperature by active gas conduction and reaction, with consequent fluxing power; the restriction of the vent to the tiny dimensions of the terminal craterlet, with resulting increase and accumulation of gas-tension in the lava-column — these factors could not fail, sooner or later (given continual intensification of the conditions) to bring about eruption, by the most natural means, in a volcano of this type — that is, perforation of its containing-walls and rapid drainage of the conduit, thus relieving the pressure upon the lower surcharged magma and initiating a paroxysmal gaseous outburst" (bibl. 3, p. 23).

Phase I is characterised by outpourings of lava which succeed eachother rapidly at a continually lower level. The first took place on April 4th from an opening in the volcanic cone at 1200 m. above sea-level. (The crater-rim before the eruption was about 1335 m. high).

During the night of April 4—5, an increased stream of lava issued at the height of 800 m. above sea-level.

Each of these streams of lava was followed by an increased activity of the crater.

On April 6th the lava burst through the cone of the volcano at 600 m. above sea-level; on April 7th another opening occurred also at 600 m. accompanied by increased eruption-clouds and the throwing up of bombs to a weight of 2 tons. The ejected material was about half old and half new (fresh pulverised lava and cinders). In the evening of April 7th the lava from the opening at 600 m. flowed towards Boscotrecase. In the meantime the lava rose up to the top of the crater, which became wider.

The IInd phase began in the night of April 8th at 3.30 o'clock and was marked by the enormous quantity of gas that greatly exceeded the amount of solid material ejected.

April 8th 3 o'clock p. m. maximum development of the paroxysmal stage.

The IIIrd phase, which lasted from 9—22 April was characterised by a constantly decreasing gas-pressure, while dark ash was thrown out.

It is plain that in the first phase the quantity of gas that escaped per time-unit was constanly increasing, which was rendered possible by the tapping off of lava at a lower and lower level. This caused the pressure of the lava-column to diminish, although till the end of the first phase it rose now and then to the top of the conduit; this can only be explained by assuming that the lava-column was constantly becoming lighter by increased mixing with gas-bubbles. The lava at the end of the first phase did not consist, as at the beginning, of lava, poor in gas, but of lava gas-froth. During the I^st^ phase, therefore, there was a constantly increasing frothing of the magma in the conduit, until the conduit was practically emptied and the II^nd^ phase commenced, in which the principle element was gas, escaped from the magma at a deep level, at first carrying *relatively* little magma with it (*actually* this will have been a large quantity) and having a strongly eroding, scouring effect upon the walls of the conduit. During this period, lasting for only about 24 hours, the vent was very greatly widened. In the II^nd^ phase, the intermediate gas-phase, an enormous amount of old material must have been ejected in the space of a few hours. PERRET speaks (bibl. 3, p. 43) of an "unfolding outwardly of the upper portions of the cone in all directions, like the falling of the petals of a flower". And of the gas-stream he says (p. 43—44): "This colossal column, with ever increasing acceleration, was actually coring out and constantly widening the bore of the volcanic chimney".

Thus there was no explosion here, and, therefore, no modelling of the volcanic chimney by explosive action, but *erosion by the scouring effect of a gas-stream*. This is the essentially new thing that PERRET has brought to light; a *new morphological agent:* the *gas-stream.*

The III^rd^ phase is characterised by a constantly decreasing gaseous pressure below the volcanic chimney and consequently continual decrease of velocity in the chimney, accompanied by a constant declining quantity of escaping gas per time-unit. In my opinion this can be explained by assuming that the gas from the magma in the immediate vicinity of the bottom of the chimney had already escaped, that the gas had therefore to travel a longer distance to reach the lower end of the chimney, in which a constantly increasing frictional resistance had to be overcome.

A state of rest was only reached when the pressure of the not yet escaped gas far from the bottom of the volcanic chimney was in equilibrium with the resistance in the gas-free magma lying between the chimney and the magma still containing gas.

As illustration of this theory of eruption-mechanism, founded upon PERRET, I will draw a comparison with phenomena that have been observed in oil gushers.

III. PHENOMENA OF A FLOWING OIL-WELL WHICH HAS PENETRATED AN OIL-BEARING STRATUM, CONTAINING GAS UNDER HIGH PRESSURE.

Casual references have been made now and then to the resemblance between a volcanic eruption and an oil gusher.

In my opinion this resemblance may be worked out and a parallel between the mechanism of these two gas-escapes through the outer crust of the earth, may be drawn down to the very details. This comparison will be made in chap. IV, while here the necessary particulars of oil-wells are given.

In some oil-fields the organic, natural gas is dissolved under high pressure and in large quantities in the oil. An example of this is Moreni in Roumenia, fields near Bakoe, others in Mexico; then the field of Panghalan Soesoe in NE. Sumatra, where a light gravity oil is obtained, which is rich in gasoline. Here the natural gasses are collected in compressors, where the heavier hydrocarbons they contain are condensed into gasoline. Another example is Tarakan, the oil-island near North-East-Borneo, where the oil is heavy and the natural gas contains no higher members of the gaseous hydrocarbons.

When drilling into a gas- and oil-sand under heavy pressure two things may occur. If sufficient precautions have not been taken, on drilling into a layer, an eruption of gas may take place which is sometimes so violent that the whole drilling rig is destroyed. On Tarakan, in March 1909, at well 14 in Concession I, the following occurrence took place. On bringing a well into the oil and gas containing stratum the velocity of the gas was so great, the pressure at the bottom of the boring so high, that the bit and drilling-stem with 4-in. drill-pipe were thrown out of the well. The well was then 356 m. deep. Presumably the casing became subsequently plugged, which would explain why first the casing of 8″ (331 m. long) was thrown out, and then the string of 10″ (185 m. long), and finally that of 12″ (145 m. long). After the well had thus become completely uncased, the natural gas could have a mechanically eroding action, on the walls of the well. There was finally formed at the surface a funnel-shaped well into which the whole drilling-installation collapsed. On March 27th the well became plugged and a crater-like basin had been formed, filled with water and oil. It was not possible to find the machinery. A piece of lignite of 1 m^3, however, was dug out that ~~must~~ have come from the first seam of lignite which was found at the depth of 32 m. The diameter of the upper rim of the crater was presumably a multiple of the channel widened by the gasstream.

A well known case is the crater-lake that arose from the gas eruption at the well Dos Bocas on the Tampico fields in Mexico. It was the first large oilwell that was opened in Mexico, on July 4th 1908, of a good 550 m. depth. According to BLUMER (bibl. 9, p. 279—80 and 389) shortly after sinking the well, the casing was thrown out; cracks formed round the well, from which gas and oil escaped. The gas caught fire and there arose a flame 300 m. high and 15 m. broad. After 58 days the flame expired and a crater was found of an area of some 120.000 m^2., filled with salt water and heavy oil, from which gas still bubbles up. The diameter of the rim of the crater would thus be about 350 m.; according to a communication from Prof. RUTTEN it must be at least 600 m.

Today uncontrollable outbursts of gas of this kind do not often occur, as the necessary precautions are known for drilling into an oil-layer rich in gas. The circular system is used, by which the pulverised material is not carried up by circulating water but by mud (a suspension of clay particles in water).

This mudwater may reach a specific gravity of 1.5 and higher, by which per 10 m. depth of well a pressure of about 1.5 atmospheres is attained. At the bottom of a well of 500 m. depth, therefore, there is a pressure of 75 atmospheres on the uncased walls. By this, the pores in the oil-containing rock (usually sand or sandstone) where they are not too large, are closed and the oil can only trickle out very slowly in drops and the gas only in a few small bubbles. The driller must attend very carefully to these small shows of oil, as otherwise there is a risk of drilling on beyond the oil-stratum.

To bring a well of this kind to production the circular system of mud is stopped and the mud gradually scooped out. This causes the oil-drops and the bubbles to increase. With the decreased pressure on the uncased walls at the bottom of the well, a larger quantity of oil and gas per time unit can escape.

This causes the mudwater to change into a heterogeneous system consisting of water with suspended clay-particles, drops of oil and gas-bubbles. And seeing that the gasbubbles continually increase as the mud-water is scooped out, the remaining column of mudwater becomes constantly of lower specific gravity and the pressure at the bottom of the well becomes less and less. The same phenomenon takes place, therefore, as in the tubing of an "air lift" system. Finally the column of mudwater begins to froth and the remainder is completely thrown out by the pressure of the gas dissolved in the oil. The well begins to gush, the gas carries the oil with it, just as the carbonic acid carries the water with it out of a syphonbottle where the gas is dissolved in the water under high pressure.

At first there is a great deal of gas with a large quantity of oil, gradually the amount of gas in proportion to the oil decreases. The proportion between the amount of oil and gas thrown up from the well changes constantly in favour of the oil, until there is not enough gas to eject the oil from the well. There may then arise an intermittent spouting or a frothy overflowing of gas and oil. Finally the natural production comes to an end and the oil must be further obtained artificially.

IV. COMPARISON OF THE MECHANISM OF A FLOWING OIL-WELL AND THE ERUPTION OF VESUVIUS IN 1906.

Oil-well.	**Vesuvius 1906.**	

A column of liquid in a more or less cylindrical pipe presses upon a liquid in which gas under pressure is dissolved.

Mud water. ↓ Oil + gas in solution.	Lava column poor in gas. ↓ Magma + gas in solution.	March 1906

Partial emptying of the conduit leads to decrease of pressure at the bottom, consequently gas begins to escape from the solution.

Emptying of the drill hole (scooping out the mud flush).	Flowing of lava at ever lower level, through the volcanic cone (accompanied by ejection of lava ash and cinders).	4—8 April 1906

An eruption begins, at first gently, but steadily gaining force. With decreasing pressure of the column of liquid, the liquid becomes more and more frothy and of lower specific gravity (air-lift principle).

Stage I

The remains of the mud flush are thrown out.	The remains of the magma in the crater conduit are thrown out.	April 8 1906

As soon as the conduit is empty, the resistance is removed and the gasses can escape freely, which happens forcibly. A great deal of gas, relatively less liquid, is carried along. The absolute amount of liquid shot up is, however, very great.

Eruption of the well with oil (if there is no casing an enlargement of the well takes place, by the scouring effect of the stream of gas).	FRANK PERRET's intermediate gas phase. The bare sides of the eruption conduit are scoured out by the stream of gas. (Besides powdered lava, a great deal of triturated material from the sides of the vent).	Stage II 8—9 April 1906

As soon as the liquid in the immediate vicinity of the bottom of the conduit has given up its gaseous contents the current of gas to the chimney becomes slower and slower, as the resistance which the gas encounters upon its lengthened journey through the liquid becomes greater.

The fluid, however, will be carried along with it, as long as the gas pressure at the bottom of the conduit is sufficient to raise the heterogeneous mixture of liquid and gas to the top of the vent. In this stage, also, the air-lift principle is present.

Gusher condition of the oil well, in which, unless there is plugging, the production gradually declines.	Dark ash phase of the volcano. The liquid is cooled by the expansion of the gas and solidifies to volcanic glas ash. No enlargement worth mentioning of the conduit.	Stage III 9—22 April 1906

The pressure of the gas in the solution far from the bottom of the conduit is in equilibrium with the sum of the pressure of the heterogeneous mixture of liquid and gas in the conduit and the frictional resistance which the gas encounters on its path through the gas-free liquid to the lower end of the conduit.

End of gushing stage. (The well is further worked artificially).	End of eruption. Solidifying and plugging of eruption channel. Dormant state of volcano.

V. EXPERIMENTS ON THE SHAPE OF CRATERS DEVELOPED BY THE EROSION OF A CURRENT OF GAS.

(With the collaboration of Dr. PH. H. KUENEN).

The experiments described in this chapter could hardly have been carried out without the friendly cooperation of the Directors of the Physics Laboratory Professors Dr. W. H. KEESOM and Dr. W. J. DE HAAS, as well as of the sub-director of the same Dr. C. A. CROMMELIN, who repeatedly supplied me with cylinders of compressed air and lent me such further apparatus as I needed. Besides these gentlemen my thanks are due to the engineer of the same laboratory Mr. L. OUWERKERK for his practical assistance.

All experiments were made in consultation with my assistant Dr. PH. H. KUENEN, who also built up most of the models.

The aim of the experiments was to ascertain what change in form took place in a cylindrical channel when a stream of gas was forced through it.

The current of gas was produced by compressed air in steel cylinders of about 24 litres at about 140 atmospheres.

The first experiments were made by introducing a regulation tap into the supply-tubes which consisted of copper tubes of 8 mm. external and 5 mm. internal diameter. Later on this was replaced by a reduction valve with manometer, which enabled us to allow gas up to 15 atm. to pass through the supply-tubes.

The model vents were made of dune-sand with an average grain of 0.22 mm., mixed with water, glycerine or plaster.

At first a "whole model" was used, a box with removeable front, where after the experiment the sand could be cut away until a section across the vent was laid bare. Afterwards we worked with a "half model" in which the front was of glass, placed about 1 centimeter in front of the opening of the supply (see fig. 3).

The copper tubing ended in a boring of 8 mm. diameter in a hardwood block. Before the model was built up, an iron rod of 8 mm. diameter was stuck into this hole and around this the model was built. Usually this rod was pulled out of the sand while air was slowly being forced up, to keep the vent free.

Some models were made with a horizontal upper surface, others with a cone-shaped surface (miniature volcanic cones). The size can be seen on the photographs. The case for the "half model" was 40 cm. long, 30 cm. wide and 40 cm. high.

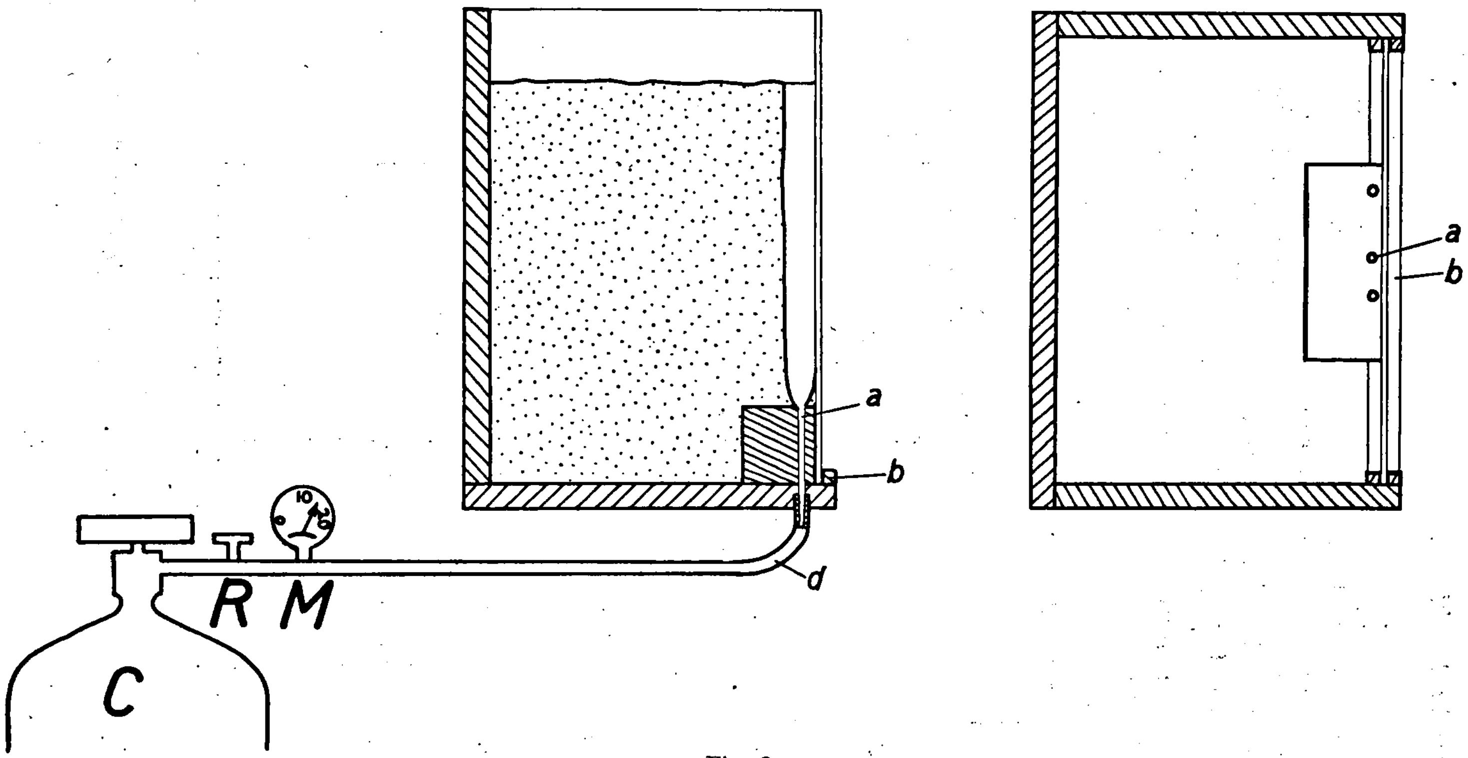

Fig. 3.

Illustration of the Experiments.

C = cylinder with compressed air.
R = reduction valve.
M = manometer.

d = copper tubing.
b = rib to hold pane of glass in place.
a = bore in wooden block.

I. *Experiments with wet sand.*

It soon became evident that the way in which the sand was packed, influenced the form of the vent. When the sand was packed with careful evenness the vent became cylindrical except for the lower extremity, which was always funnel-shaped, (inverted cone) leading to the narrow supply tube. (See photo experiment 6, plate 7). If the sand was not carefully and evenly stamped, the looser parts were hollowed out accompanied by gas eddies and irregularities in the vent. (See plate 8).

It was soon shown that the diameter of the cylindrical vent was a function of the pressure used, which was the reason for introducing the reduction-valve with manometer.

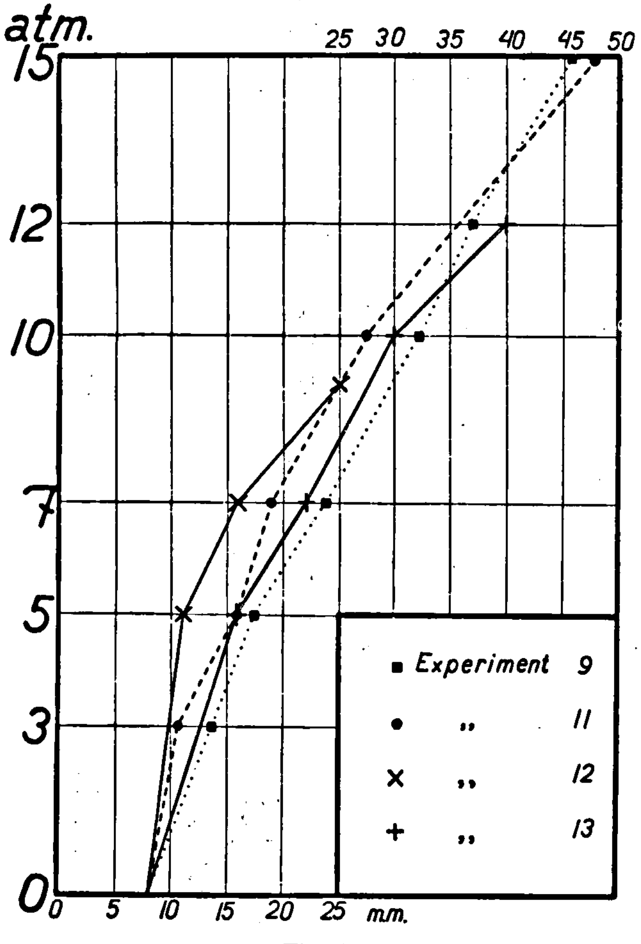

Fig. 4.

Graph representing the dependence of diameter of the cylindrical vent upon the pressure in the conduit during the blowing. Experiments 9, 11, 12 and 13.

We now made a series of experiments for the purpose of ascertaining the dependence of the diameter of the vent upon the gas-pressure. The results can be seen in the graph fig. 4. The function is almost a straight line. It must here be noted that the pressure was measured in the copper tubing of 5 mm. internal diameter, so that it in no way represents the pressure in the vent itself. All that can be said at present is that the velocity of the current of gas was dependant upon the pressure read, and that the diameter of the vent was directly dependant upon the velocity of the gas, indirectly, therefore, upon the pressure read. Velocity and pressure in the vent itself were not yet experimentally determined.

The cause of the clinging together of the sand-particles is cohesion, the force with which the grains are pressed together by the surface tension of the water. The sand was in a pendulary condition (bibl. 10). The widening of the vent rested in our experiments upon the plucking of sand-particles from the wall of the eruption-chimney by the velocity of the current of gas. Evaporation, in the pendulary condition of the water between the sand-particles, can not take place.

With the "half model" observations could be made through the glass front; at a sudden increase of pressure, from for instance 7 to 10 atm. an enlargement appeared first at the *bottom* of the vent, accompanied by eddies, these eddies subsequently working upwards, so that the vent was enlarged in a cylindrical form upwards until the surface was reached. When this was accomplished, no further change of shape took place at the same pressure (velocity). At a further increase of pressure the same thing occurred; an enlargement took place below, which spread upwards, forming thus a cylinder of larger diameter (see fig. 5).

The photograph of experiment 7 (plate 9) gives the result of an experiment on a layer of wet sand, which was covered by a layer of dry sand. Of course at the top, in the dry sand a crater-shaped widening took place, corresponding to the maximum incline of dry sand (fig. 6). The vent in the wet sand was here again beautifully cylindrical.

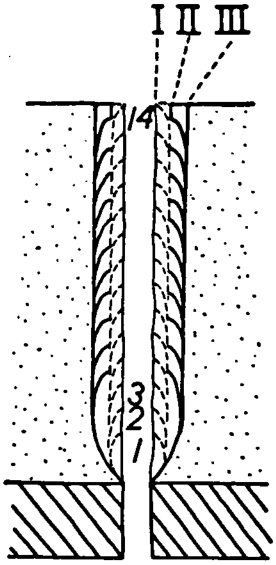

Fig. 5.

Schematic representation of formation of a cylindrical vent at a sudden increase of pressure. (II, 1 2 3...... 14) and expansion at sudden increases of pressure. (III).

II. *Experiments with sand and various binding agents.*

The purpose of the succeeding experiments was to ascertain if it was possible by causing differences in the cohesion of sand-particles in different layers to get a funnel-shaped (inverted cone) vent instead of a cylindrical one. For this we tried water, glycerine and plaster as binding-agent. Experiment 11 (plate 10) gave no results in this respect. What could be learned from it was that by tightly packing the layer of sand and glycerine by stamping it down, the upper part of it showed a much stronger state of cohesion than the lower part, and that therefore two funnels were formed, two bottoms of vents, which passed into cylinders above.

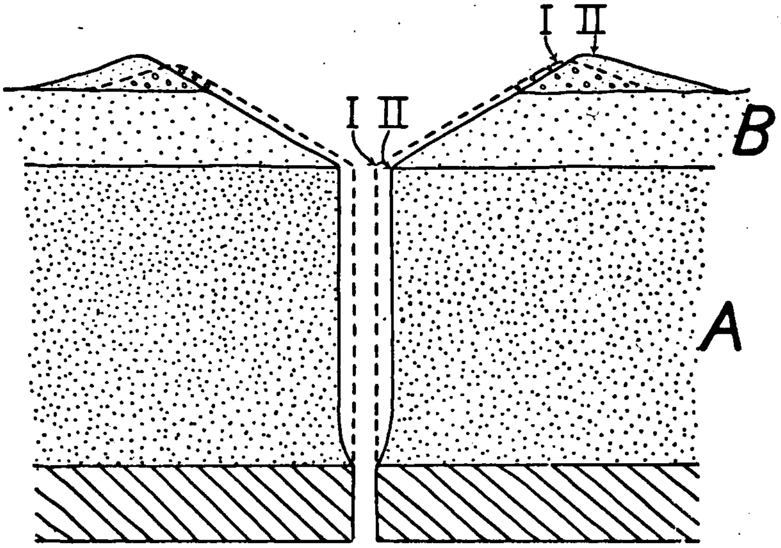

Fig. 6.

Schematic representation of Experiment 7 (see also Plate 9). Two stages in the development of the Vent.

A = wet sand. B = dry sand.

Experiment 13 (plate 11) also showed a coring out by eddies, which probably was caused by uneven packing, while the general funnel-shape that we were looking for was not obtained. The main shape of this chimney too was cylindrical.

In experiment 8 (plate 12) the model was constructed of sand, water and plaster, in various proportions. The plaster had not become hard. The result again was an irregular, more or less cylindrical vent.

A few experiments were made with cone-shaped superstructure to ascertain whether layers sloping away on all sides from the vent would have an influence upon the shape of the conduit.

Experiment 14 (plate 13) seems to show that in the uppermost part a small crater-shaped (= funnel-shaped) widening of the chimney was formed. This photograph shows very clearly how a softer layer (sand and water) is scoured out by eddies between two harder layers (hardened plaster of about 1 mm. thickness). It is possible that this is the cause of a small funnel-shaped expansion in the upper part of the gas vent, by the snapping off of the plaster layers thus undermined. The large expansion between 10 and 17 cm. was presumably caused by insufficient stamping of the sand.

Dr. Kuenen invented the following technique for building up the models in these experiments with their layers of plaster. The sand was poured round the iron rod quite dry, so that it took its natural incline. Then fine brass gauze was laid over the model and through this water was sprinkled upon the dry sand through the rose of a watering-can. Then a thin layer of powdered plaster was strewn over the now moist sand and sprinkled with water in the same way, upon which a new layer of sand followed and so on.

From experiment 15 (pl. 14) it may be seen that the vent in a model of this kind, built like a miniature volcano, is again in main shape cylindrical, that in homogeneous material, i.e. here in the upper part of the evenly packed moist sand, an almost purely cylindrical vent arose, and that in unhomogeneous material, here alternate layers of moist sand and plaster, the vent shows expansions and constrictions. Here too at the upper end an indication of a funnel-shaped enlargement may be seen.

Finally in experiment 16 (plate 15) an attempt was made to get gradual change of cohesion in the material, by different degrees of closeness in the packing of the material. Here at last a more or less *funnel-shaped-vent* was attained. Through the pane of glass its formation could be watched and was seen to be due to sliding in of the uppermost, loose layers and a forcing out of the collapsed material. In fig. 7 Dr. Kuenen has given a schematic representation of this process.

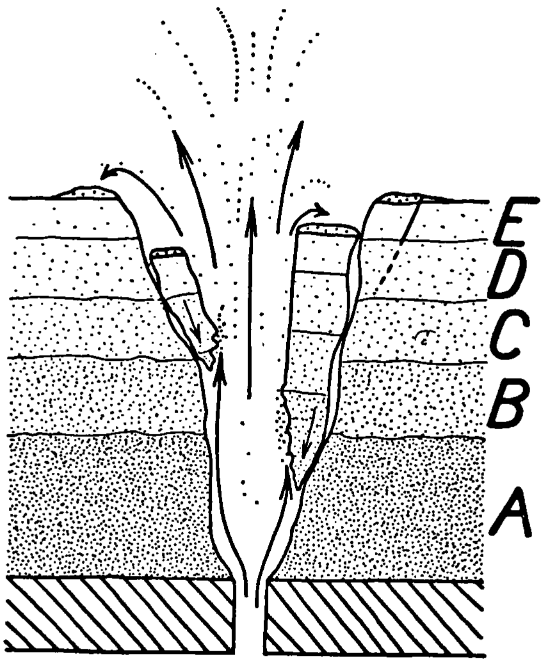

Fig. 7.

Schematic representation of the formation of a funnel-shaped widening of an originally cylindrical vent, in experiment 16, by slipping down of the walls.

A = stamped down firmly.
B = stamped down.
C = pressed down gently.
D = smoothed off.
E = strewn through brass gauze in damp condition.

The results of these experiments may be summarised thus:

1. By the erosive influence of a vertically directed stream of gas there arises, in general, a cylindrical chimney, of which only the bottom-end is funnel-shaped.
2. The diameter of the cylindrical vent is more or less a straight lineal function of the gas pressure in the supply tube.
3. At a sudden increase of pressure a cylindrical widening extends from below upwards.
4. Unhomogeneous material makes the vent irregular. Softer layers with less cohesion of the sand-particles are hollowed out by eddies, in harder layers the vent is narrower.
5. If the sand-particles in the top layer have very little cohesion a funnel-shaped opening arises from their precipitation into the chimney.

It seems to me that the results obtained may be applied to the much greater proportions of nature. We know of the scouring effect of the gas stream on a very large scale from the Vesuvius eruption in 1906, notified by FRANK PERRET and A. MALLADRA, we know of the same effect on a smaller scale in eruptions of oil wells. In the experiments described above, the shape of a vent, as it is scoured out by a stream of gas is shown on a much smaller scale. The scouring effect in nature is probably increased by the liquid carried along (oil or magma respectively). In a volcanic eruption of the type of Vesuvius 1906, the gas-stream will have created an approximately cylindrical chimney. This is in contrast to a chimney that is caused by explosion, which is always funnel-shaped at least at the upper end. (The war of 1914—18 gave sufficient proof of this in the bursting of mines, etc.). I consider that my experiments have proved that we must reckon with a new geomorphological agent in volcanology: the *gas-current, which blows out a cylindrical vent.*

Primarily, therefore, a cylindrical vent with perpendicular walls is formed.

Secondarily the upper part of this vent is changed into a steep funnel by internal avalanches which take place in the upper part of the volcanic body because of the declivity exceeding the maximum that could endure. This phenomenon is known in the Vesuvius eruption of 1906 and minutely described and illustrated by FRANK PERRET. The pseudo-eruptions arose from internal crumblings. It may be assumed that landslides of this kind had already taken place before MATTEUCI was able to measure the depth of the crater in 1906 (bibl. 6, section across the crater). Presumably these slides began in the III^rd^ phase of the eruption. They have now pretty well come to an end, because almost the whole crater of Vesuvius is filled up with lava. With very loose material at the top of a cylindrical vent a funnel-shaped opening will be formed even during the operation of the gas-stream, experiments 7 and 16 point to this (pl. 9 and 15). Further I think I am justified in drawing the conclusion from the experiments that in nature too, irregular expansions and constrictions will occur in the volcanic vent.

It is by no means certain that in its next eruption Vesuvius will pursue the same mechanism as in 1906. This, however, is certain, that FRANK PERRET has made us acquainted with a very important mechanical volcanic action which had never been previously distinctly defined. PERRET's *intermediate gas-phase* causes important geomorphological consequences.

As PERRET has described the great significance of the II^nd stage so distinctly, I should like to call the eruption type of Vesuvius 1906 the *Perret-type.*

VI. THE PROBLEM OF CALDERAS.

It is not my intention here to follow the Caldera problem in its historical development. There is not even unanimity as to the meaning to be attached to the word Caldera. The problem can be best discussed if we use the word in connection with a definite form without implying any particular genesis. Not until the form, that a volcanic depression must have to be considered as a caldera, has been generally accepted, can the discussion of its genesis begin.

WING EASTON (bibl. 11) typifies a caldera as a crater with a crater-floor, that is much too large in proportion to the supposed diameter of the conduit, while the crater walls are very steep. In this he joins issue with R. A. DALY (bibl. 12, p. 147) who says: "If the actually exposed "necks" of the world indicate the maximum size of central conduits, the vents beneath calderas must have cross-sections much smaller in area than the floor of the corresponding great depression. The writer is, in fact, inclined to make this the criterion for explosion craters from calderas. In each of the latter the area of the floor is many times greater than the cross-section of the magmatic column exposed to the air by the explosion."

In the present paper, by *caldera* I mean: *a very large, steep depression with a flat floor in the top of a volcano, the diameter of the upper rim of the depression being much larger than that of "necks".*

As on Las Palmas (Canary Isles) the caldera is accompanied by a barranco, some writers regard the barranco, a deeply cut radial valley, as an essential part of a caldera. In this paper the formation of the barranco is regarded as a separate problem, to which I return in Chap. VII.

There are a sufficient number of calderas without a barranco to be able to treat the caldera problem by itself, which is complicated enough when taken alone.

Some typical, entirely enclosed calderas, to take a few examples on Java and Bali, are:

Idjen-caldera, diam. about 16 km.
Batoer-caldera (Bali) 10 × 14 km.
Tengger-caldera (Sand Sea) diam. about 8 km.
Roeang-caldera, diam. about 2 km.

The Somma has also been called a caldera remains; its diam. is about 3 km.

The most important older hypotheses concerning the formation of calderas are the *collapse hypothesis* and the *explosion hypothesis.*

In my opinion WING EASTON is right to reject the hypotheses which try to explain the formation of calderas by explosion (bibl. 11, p. 70); neither can he accept the melting- and collapsing theory of VON HOCHSTETTER, which R. D. M. VERBEEK makes use of (bibl. 13 and 14). WING EASTON raises a new hypothesis, which he calls *cell theory* (bibl. 11, p. 73 ff.). This ranges with the collapse hypothesis, but gives a new explanation for the origin of the collapse. His opinion is that after a great eruptive period of a volcano has come to an end, the magmatic gasses through the plugging of the crater chimney, are forced to penetrate to the volcanic body at the sides, where their melting action honeycombs the body of the volcano, while the melted material finds its way into the supposed magmatic chamber under the volcano. In this way a cylindrical cellular skeleton is formed. Now the upper part of the volcano will collapse, either because the riddled portion cannot bear sufficient weight, or because, at a fresh eruption the magmatic gasses force a way out, upon which a collapse will follow. I will not here enter into the merits or defects of this modified collapse theory. It certainly belongs to the conceivable possibilities, but it is not supported by any single observation. Before throwing myself into the field of battle, I wish to premise that, if I venture to propose a new theory on the formation of calderas, I by no means wish to claim that this theory is the only possible explanation for their formation. We know by this time that in geology, also, different causes may still lead to the same morphological result.

Formation of Calderas by the scouring effect of the gas-phase in an an eruption of the Perret-type.

Let us first consider the morphological changes which have taken place in Vesuvius since 1905. We can do this with the three crater-maps $\frac{1}{10.000}$ (bibl. M. 5, A, B, and C) from the years 1900, 1906 and 1920 and the very important publications of the present Director of the Observatory on Vesuvius, A. MALLADRA, who also furnished the material for the 1920 map (bibl. 4, 5, 6, 7). The series of block-diagrams (pl. 16) is made with the help of these data and of photographs. I wish to point out specially that the section lines in the block-diagrams are correct and are drawn from the section $\frac{1}{5.000}$ made by MALLADRA (bibl. 6). The condition in April 1926 only is not constructed from measured data.

The following words will be sufficient to explain the block-diagrams.

1. Before the eruption in 1906 a small crater (diameter about 175 m., depth about 75 m., declivity of the inner walls about 35°).
2. After the eruption in 1906 a large deep crater (diameter about 700 m., depth about 500 m., declivity of the inner walls about 75° at the bottom, at the top about 65°).

3. Juli 1913. From April 1906 to July 1913 the volcano was in a state of rest. The steep walls crumbled off, giving rise to pseudo eruption clouds, by this the crater-floor was raised about 250 m. In July 1913 lava began to rise from a funnel-shaped vent in the crater-floor.
4. August 1917. In consequence of flows of lava over the crater-floor the latter was raised. A more or less centrally placed eruption-cone of lava-cinders from which magmatic gasses escape, was thrown up.
5. April 1926. The continual lava flows have raised the crater-floor, a principal eruption cone, some smaller ones and some lava-domes are found.

To this may be added that during the last increased activity of Vesuvius (in Nov. 1926) the lava flowed over the lowest rim of the crater in the direction of Valle del Inferno.

If the crater of Vesuvius is examined now, it will be seen that the proportion of the diameter of the conduit by which the eruption column is formed to the diameter of the crater floor, is very remarkable.

If Vesuvius continues in the same quiet way to build itself up, in a few years it will have acquired a form corresponding to that of 1906. If the constant changes had not been regularly registered by MALLADRA, it would be difficult for us to believe that a volcano, such as Vesuvius was before 1906, could possess a conduit such as it had immediately after the last great eruption.

What, now, is the difference between the present state of Vesuvius and a Caldera such as Raoeng, Tengger and Idjen possess? Morphologically they correspond to eachother almost completely, it is only that the dimensions are smaller with Vesuvius.

If we call to mind how the condition of Vesuvius in 1906 arose, we see that the important element for the diameter of the present crater was PERRET's phase II. When the gas-phase ceased, an end was made to the further primary expansion of the crater, but there followed a period of secondary expansion due to crumbling away of the walls. It is, however, evident that if phase II had been stronger the steep conduit would have become wider. The Vesuvius eruption of 1906 was certainly violent, but we may assume without hesitation that in the older Quarternary and Tertiary periods the activity of the volcanoes was sometimes much greater. We also know that even in the present time volcanic outbursts here and there occur of considerably greater violence. Is there any reason to assume that the gas-phase could never be strong enough to scour out a cylindrical conduit, which could be subsequently enlarged into a funnel-shape by the crumbling of the sides, to a diameter of 10 or even 16 kilometres? I do not believe so.

It seems to me very probable that at an earlier period the gas-phase may have been so much stronger, in other words, so much more magmatic gasses under high pressure escaped, that wide cylindrical vents were cored out, which later, by crumbling away of the crater-walls, became funnel-shaped and by lava-flows in the crater and by the formation of secondary eruption points inside the crater, gained the appearance of calderas like Tengger and Idjen.

I do not by any means wish to assert that this is the only possible way in which calderas could arise, for this there are not sufficient data in detailed descriptions of great eruptions. The Mount Pelée, through LACROIX, made us familiar with the phenomenon of the heat cloud, Vesuvius taught us through MALLADRA and PERRET, the scouring out of the conduit, the Valley of ten thousand smokes is a still unexplained phenomenon, as nobody witnessed the eruption by which it arose. These things happened between 1902 and 1912, in only 10 years time. Volcanology is indeed in a very immature stage. Without detailed observation of volcanoes and especially of great eruptions, hypotheses may be suggested, but no theories can be built up.

The hypothesis here developed of the *formation of calderas by the coring out effect of a gas-stream* is distinguished from other hypotheses by the fact that its mechanism is known, the working of this mechanism has been actually observed. This new hypothesis is therefore the extrapolation of a known phenomenon, the only assumption that is made in it is that a phenomenon with which we are now familiar on a small scale through experiments, in oil wells and the eruption of Vesuvius in 1906 is supposed to have taken place formerly on a considerably larger scale.

VII. THE TENGGER VOLCANO.

In my first chapter I have given Verbeek and Fennema's idea about the origin of the present form of the Tengger Mountains. Here I wish to discuss the Tengger question in the light of the results gained in chapters II—VI. I start, therefore, from the hypothesis that the two Tengger calderas are formed by the gas-phase of an eruption of the Perret type. I will add, moreover, that even if my hypothesis concerning the formation of the two calderas is not accepted, I still retain my objections to the history of their development, as laid down by Verbeek and Fennema.

In the problem of the Tengger there are two points, which I wish to consider more particularly: A. *the formation of the straight dam Tjemoro Lawang* and B. *the formation of the valley of Sapikerep.*

Besides the two maps (pl. 5 and pl. 6) block-diagram plate 17 should be consulted for this.

A. The dam of Tjemoro Lawang. (See plate 22).

Verbeek and Fennema assume in their history of the Tengger (see fig. 1 and 2) that there was a period at which there were two immensely deep funnels with steep sides bordering upon one another, inter-

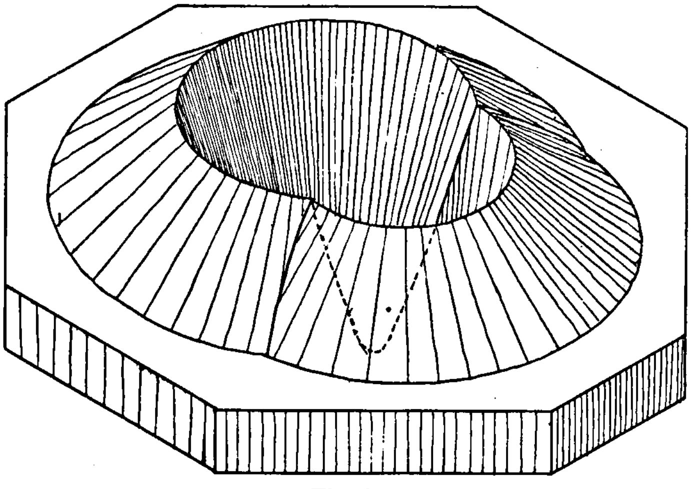

Fig. 8.

Intersection of two funnels with $R_1 = 4.2$ km, $R_2 = 3.15$ km,
Distance of the axes 3.4 km and declivity of 70°,
in isometric axonometry.

secting one another. It is peculiar that the conduits of these funnels should not correspond to the original conduits of the two volcanoes. Evidently VERBEEK and FENNEMA had to assume this shifting of the conduits, of which they do not say a word, in order to get the Tjemoro Lawang at the right place and high enough up.

To form a correct idea of the intersection of two funnel-shaped depressions, it is necessary to solve the problem by descriptive geometry.

In plate 18 this construction is made for two funnels of which the diameters and the distances of the axes are borrowed from VERBEEK ($R_1 = 4.2$ km., $R_2 = 3.15$ km. distance of the axes 3.4 km.) and in which the incline of the two funnels is taken as 70°. It then appears that the section of the two funnels is a concave line. Professor W. VAN DER WOUDE was so kind as to tell me that the section of two circle cones with the same apex angle and parallel axes is either a hyperbola or an ellipse, in this case a hyperbola. In fig. 8 this intersection of two funnels with an apex angle of 40° in isometric projection is given. The steeper the funnels are, the steeper the hyperbola is, the flatter the funnel is, the slighter the curve becomes (see plate 21). If we assume with VERBEEK and FENNEMA, that a catastrophic collapse occurred, which caused primarily funnels, then the concave section between these two funnels also arose primarily, a sort of "col". But then the section given by VERBEEK and FENNEMA is erroneous (see fig. 1) as the nucleus of the Tjemoro Lawang in the middle between the two funnels never could have reached up to the level at which they draw it, but would have been much lower. With funnels with an incline of 70° (an apex angle of 40° therefore) the lowest point of the "col", which lowest point VERBEEK

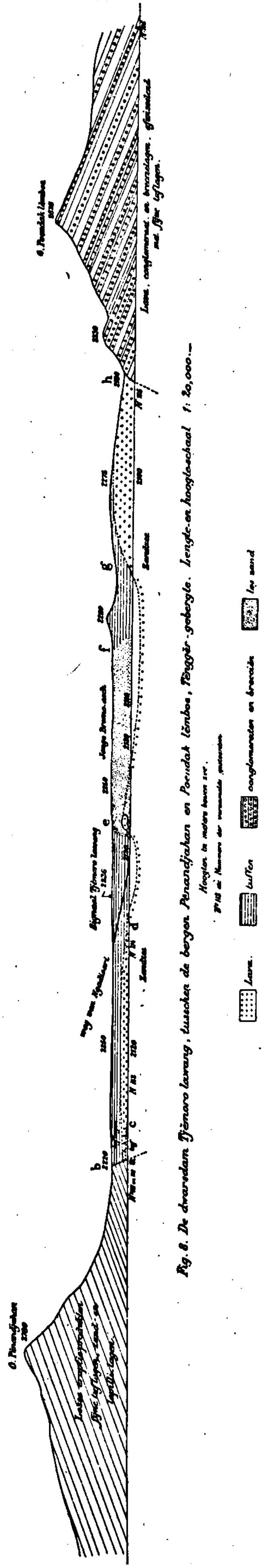

Fig. 9.

Longitudinal section of the Tjemoro Lawang, taken by FENNEMA (bibl. 8, fig. 8, Plate XIV).

and **Fennema**'s section cuts, would lie about 5500 m. below the rim of the calderas. If we assume, with **Verbeek** and **Fennema**, that the upper rim is 2400 m. above sea-level, then the deepest place in the "col" after the catastrophe would lie at — 3100 m., instead of at + 2100 m., as these writers give it.

That in reality a sector of this kind between two steep funnels did exist at a certain stage of Tengger follows from the longitudinal section of the Tjemoro Lawang taken by **Fennema** (bibl. 8, fig. 8, plate XIV) see fig. 9. Line *b a* on that section as well as the line at *h* are clearly the upper ends of the intersection curve. They are, moreover continued with a dotted line to below the level of the sandsea. I should not be surprised if **Fennema** had had a suspicion of the true significance of these two lines, but that in the complication of the large work on Java this detail had escaped the notice of the authors.

Since I made the experiments described in Chap. V, I have formed a different conception of the formation of the two funnels, namely that they are secondary, caused by falling in, after primarily two more or less cylindrical vents had been formed. But it must also not be forgotten that if the funnel-rims now have a diameter of about 10 km. it by no means proves that the cylindrical vents were as wide as this. On the contrary, it is certain that the primary diameter, that of the cylinder, therefore, was much smaller. The two cylindrical vents probably did not intersect eachother, nor touch eachother.

This, however, is far from solving all the difficulties of the Tjemoro Lawang, they only now appear in their true form, which had been obscured by the cross section given by **Verbeek** and **Fennema** (fig. 1).

The straight course of the Tjemoro Lawang presents two problems and challenges an answer to the questions: 1°. why is the projection on a horizontal plain a straight line? (see plate 5) and 2°. why is the projection upon a vertical plain an almost horizontal line? (see plate 22).

1. *The straight course of the Tjemoro Lawang on the map.*

In principle there is a possibility that first only one of the calderas was formed, which was filled by internal avalanches and rising lava, and that after this the second caldera was blown out. But this would have given a form similar to that in fig. 10; i. e. the projection of the boundary line between the two calderas on a horizontal plain would then have a *curved (circular) course.* The solution, of the problem, therefore, must not be sought in the direction of one of the funnels being filled with lava before the other was formed.

2. *The horizontal course of the Tjemoro Lawang.*

If we study **Fennema**'s longitudinal section (see fig. 9) we shall see that the uppermost layer consists of tuffs and loose sand, which is underlain by an irregular layer of lava. The lava surface lies to the north at the max. 50 m. above the level of the sand-sea, in the middle below it and in the South a good 100 m. above it. Taken as a whole, therefore, the lava layer is more or less horizontal, although higher at the sides than in the middle.

How did this surface arise?

The shape of the "col" may be compared to that of a Thomson weir, a V-shaped opening, as it is used in hydrology to measure the volume of running water. If we imagine a very viscous fluid, for instance pitch, flowing over this, out of a reservoir and then solidifying, the liquid will reach to the *same* level right acrose the section. In our case lava was the viscous fluid and it may be assumed that not one but many overflows of lava occurred, by which the surface did not become flat, but uneven. Gradually, by repeated flows of lava from the one funnel into the other the sudden bend in the longitudinal section of the stream straight above the overflow was moved upwards, but still remained suspended as a cord between two equally high points of the hyperbolical constriction between the two funnels.

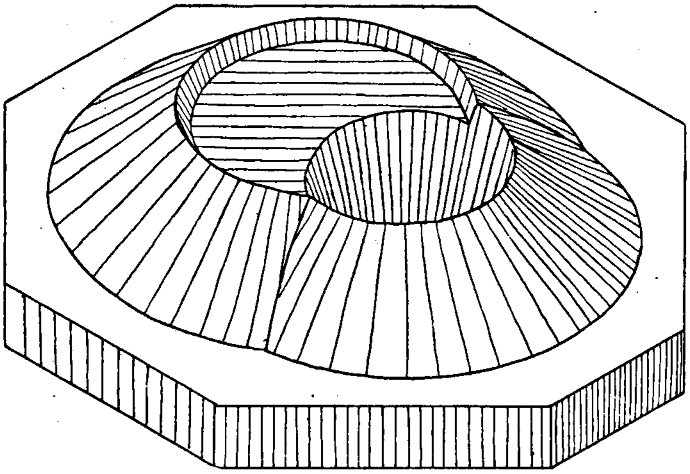

Fig. 10.

Course which would be shown by boundary line if one of the two funnels had first been filled up by lava, the other being formed subsequently.
In isometric axonometry.

This would furnish an explanation of the straight course of Tjemoro Lawang on the map. The liquid which flowed over a very wide weir, broadly speaking, would have had a flat surface. On one side, in the westerly funnel, the lava surface taken as a whole lais horizontal, the overflowing lava made a more or less flat inclined surface, which formed a slope over which the following lava flowed. The bend between the horizontal and the inclined surface always formed a straight line between two equally high points on the hyperbolic section curve.

B. The formation of the valley of Sapikerep.

Verbeek and Fennema imagined that this valley must have arisen by the forcing out of lava from the eastern caldera. Although they did not find any lava exposed in the valley, they think that it would have been buried by later clasmatic products from the western crater. Here it should be noted that lately lava-flows have in fact been exposed in the Valley of Sapikerep (Plate 20). Upstream from Sapikerep alternate layers of lava, ash and lapilli are to be seen in the beds of streams. But it is impossible to make out, without further research, whether these lava-flows have come down into the valley or are lava flows from an earlier external declivity of the volcano, which have been exposed later through erosion.

How did VERBEEK and FENNEMA come to think of the formation of valleys on the slopes of a volcano by forcing out of lava?

In April 1885 Smeroe had an eruption which is described by FENNEMA (bibl. 15). From above in the shallow crater a flow of lava made its way through the top of the cone, forming a small valley in which lais for a length of 2 km. a lava-flow. Below this came a stone avalanche, which was about 10 km. long. The course of this valley was quite straight. VERBEEK and FENNEMA (bibl. 8, I, p. 130) think that in a similar way, but on a larger scale, the valley of Sapikerep was formed by the forcing out of lava, accompanied by a stone avalanche.

There are two facts which make me consider VERBEEK and FENNEMA's view improbable. These are: the curved course of the Sapikerep valley on the map and the absence of landslide material at the lower end of the valley. In this periodical (bibl. 16) I have discussed the hilly district of Tasikmalaja and pointed out that it must have been formed by a land slide, caused by the collapse of the S. E.-section of the volcanic cone of the Galoenggoeng, after this side had been considerably weakened by erosion.

A priori, a valley, that arises from forcing out of lava will descend straight along a generating line of the cone, as gravity is the only force that influences such a great mass when descending. Local difference in the hardness along its course would have no effect worth considering when so great a $\frac{m\,v^2}{2}$ is developed as in this case.

It is true that most erosion-valleys will also run in a radial direction on the inclines of the volcano. As these valleys are deepened by backward carving erosion, which works much more slowly and in which the amount of eroding liquid per time-unit is so much smaller, a local difference in the resistance of the subsoil will be of great influence. It is quite possible that an ancient lavaflow may cause a backward working stream to deviate from its consequent course, as a lava-flow only occupies a sector of a few degrees on the cone and beside the lava much softer layers of ash and lapilli may occur.

Thus it is possible for a river to acquire a curved course upon the conical surface of a volcano.

This is the first reason for believing that the valley of Sapikerep did not arise from a pressing out of lava, but from the remounting erosion.

A second reason for doubting the truth of VERBEEK and FENNEMA's explanation is the absence of a region of land slide material after the termination of the valley. It is hardly possible that there should have been such a deposit and that it should now have been cleared away by erosion. Here, where the level is so much lower and therefore the gradient of the rivers so much less, the erosion is in the nature of things slower than higher up on the slope of the volcano.

Just as the Topographical Survey map on its detail-sheets shows nothing that can be regarded as the repository of a landslide, on shore, so by sea there is no special shallow place in the Straits of Madoera which could be brought into connection with a land-slide from the eastern crater. The distance of the eastern crater to the coast is about 48 km., which is fully long for a land-slide; that of Flims in Switzerland is 13.5 km., of Tasikmalaja about 16 km.

It appears to me, therefore, for two reasons, more probable that the valley of Sapikerep was formed by backward working erosion, and that this was also the principal cause of its deepening. It is only by a slowly working process of this kind, that the material eaten away, can be deposited elsewhere, topographically irretrievable.

C. History of the Tengger Mountains.

Nowhere in geology can such fruitful use be made of the familiar constructions of descriptive geometry, as in the study of the geomorphology of volcanoes; as these yield the most regular geometrical forms which geological forces produce. For a proper application it is of course necessary to know the way in which the columns, cylinders and funnels have arisen, and for a correct construction it is necessary to borrow the dimensions and the degree of declivity from nature. With the exception of plate 18, which is constructed according to the method of three projections at right angles, I have made the numerous other constructions in isometric projection (isometric axonometry). To these belong for instance fig. 8 and fig. 10 and the suit of block-diagrams, plate 19. These constructions were necessary to get a general view of various possibilities of stages of development in three dimensions. Here only those, which lead to useful results are reproduced. The cylindrical first stage of the two calderas is not drawn, as the collapse of these must have afterwards led to steep funnels. As declivity of these funnels in the construction, 70° is taken, from analogy with certain stages in the process of development of Vesuvius (see pl. 16).

In the absence of detailed research, the simplest reconstructions were made as being the most probable.

The results of the various endeavours to arrive at a reconstrutcion of the history of the Tengger Mountains is laid down in the series of block-diagrams on pl. 19.

The following may serve as elucidation.

In stage A there was a twin volcano, the tops of which, according to Verbeek and Fennema were about 4000 m. in height. Besides normal radial erosion valleys there appeared on the eastern volcano a more strongly developed valley with a curved shape in horizontal projection.

This valley (of Sapikerep) was considerably enlarged, principally by normal backward working erosion (stage B). Only after the valley of Sapikerep had become deep and wide, there arose from a gas-phase of the eastern crater, a scoured out cylinder which, through crumbling, formed a steep, funnel-shaped vent (stage C). Before stage D was reached a great deal might occur which cannot now be reconstructed. Subsequently there arose a scoured out cylinder in the western crater and from that, a large collapse-funnel (stage D); at the same time this gave rise to the hyperbolic "col" between the two funnels. Now in the western funnel lava rose up which flowed over the "col" into the eastern funnel and later also into the valley of Sapikerep (stage E). The highest level that was reached by the lava was the present level of about 2200 m. in the Tjemoro Lawang.

After this a period of rest began in the eastern crater, during which the erosion in the valley of Sapikerep continued to work (stage F) and the lava-sea in the eastern crater sank some 100 meters and finally solidified at the level of 2100 m.

Subsequently another, less violent state of activity commenced, which was manifested in the building up of Widodaren, Giri, Kembang, Batok and Bromo, of which now only the last is active (see present condition pl. 17).

From the history of Vesuvius between 1913 and 1927 we now know that secondary volcanic cones may be formed even during the process of filling up the large funnel.

I am well aware that weak points can be found in this new conception of the development of the Tengger Mountains. A monographic treatment of this beautiful volcanic group after careful field examination may lead to its history being reconstructed in a way which will approach the truth more nearly than I have been able to do.

Let us hope that this may soon be undertaken!

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TOPOGRAPHIC MAPS.

I. Tengger Mountains:

Bibl. M. 1 Detailsheets of the Topographic Survey of the Netherlands East Indies $\frac{1}{20.000}$

Pasoeroean: N 8, N 9, N 10, N 11, N 12,
O 8, O 9, O 10, O 11, O 12,
P 8, P 9, P 10.

Probolingo: C 8, C 9, C 10,
D 6, D 7, D 8, D 9, D 10,
E 5, E 6, E 7, E 8, E 9, E 10.

Bibl. M. 2 Topographic Survey of the Netherlands East Indies, Batavia. Residentie Pasoeroean, spoeddruk $\frac{1}{50.000}$. 1922.

Sheet Bråmå
Sheet S˘meroe.

II. Vesuvius:

Istituto geografico militare, Firenze:

Bibl. M. 3 Il Vesuvio 1 : 25.000, Stampa del 1908 (in colour print).

Bibl. M. 4 Carta Topografica del Monte Vesuvio 1 : 10.000, Stampa del 1908 (6 sheets).

Bibl. M. 5 A. Cono Vesuviano 1 : 10.000. Levata nel 1900.
B. Cono Vesuviano 1 : 10.000. Dopo l'eruzione dell' Aprile 1906.
C. Cono Vesuviano 1 : 10.000. Aggiornato per il cratere, con documenti del 1920 (Prof.re MALLADRA).

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The vent has become funnel shaped by slides from the walls which were originally cylindrical (see fig. 7).

Plate 16. Series of block diagrams. The history of Vesuvious from 1906 to 1926.

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Plate 22. The straight horizontal dam Tjemoro Lawang that devides the sand sea in the foreground from the valley of Sapikerep at the other side. Taken from the slope of the Bromo. Photograph by Prof. Dr. J. JESWIET.

I here wish to express my sincere gratitude to Prof. Dr. J. JESWIET of Wageningen for allowing me to reproduce the three valuable photographs op plates 20—22, which he took in the Tengger Mountains.

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In isometric axonometry.

PLATE 5.

MAP OF THE TENGGER AND SMEROE VOLCANOES (JAVA)

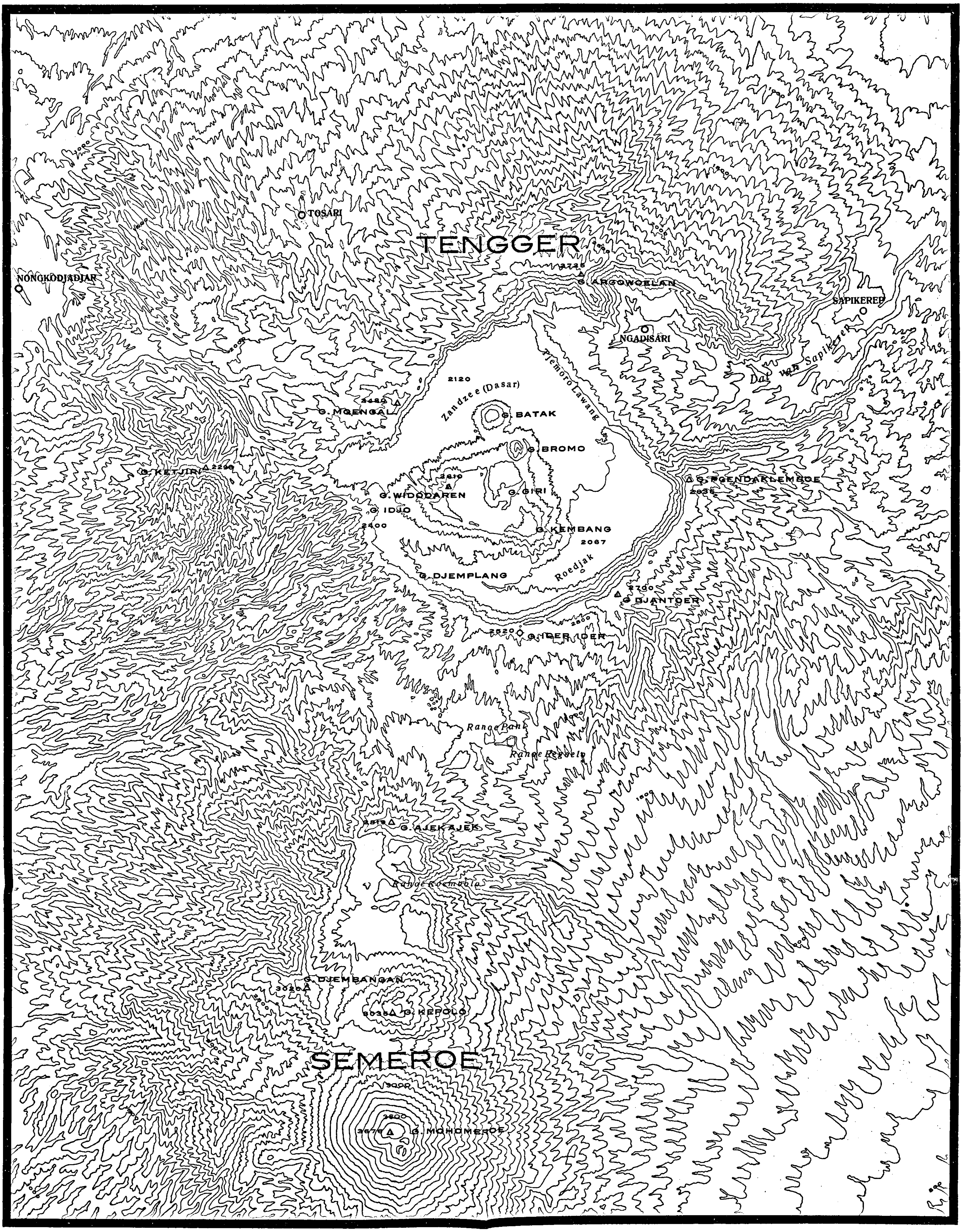
DRAWN BY B. G. ESCHER, AFTER THE SHEETS 1 : 20.000 OF THE TOPOGRAPHIC SURVEY
OF THE NETHERLANDS EAST INDIES.

SCALE 1 : 100.000
CONTOUR INTERVAL 100 M.

LITH. N.V. J. SMULDERS & Co., THE HAGUE

MAP OF THE TENGGER AND SMEROE VOLCANOES (JAVA)

DRAWN BY B. G. ESCHER, AFTER THE SHEETS 1 : 20.000 OF THE TOPOGRAPHIC SURVEY
OF THE NETHERLANDS EAST INDIES.



SCALE 1 : 100.000
CONTOUR INTERVAL 100 M.

LITH. N.V. J. SMULDERS & Co., THE HAGUE

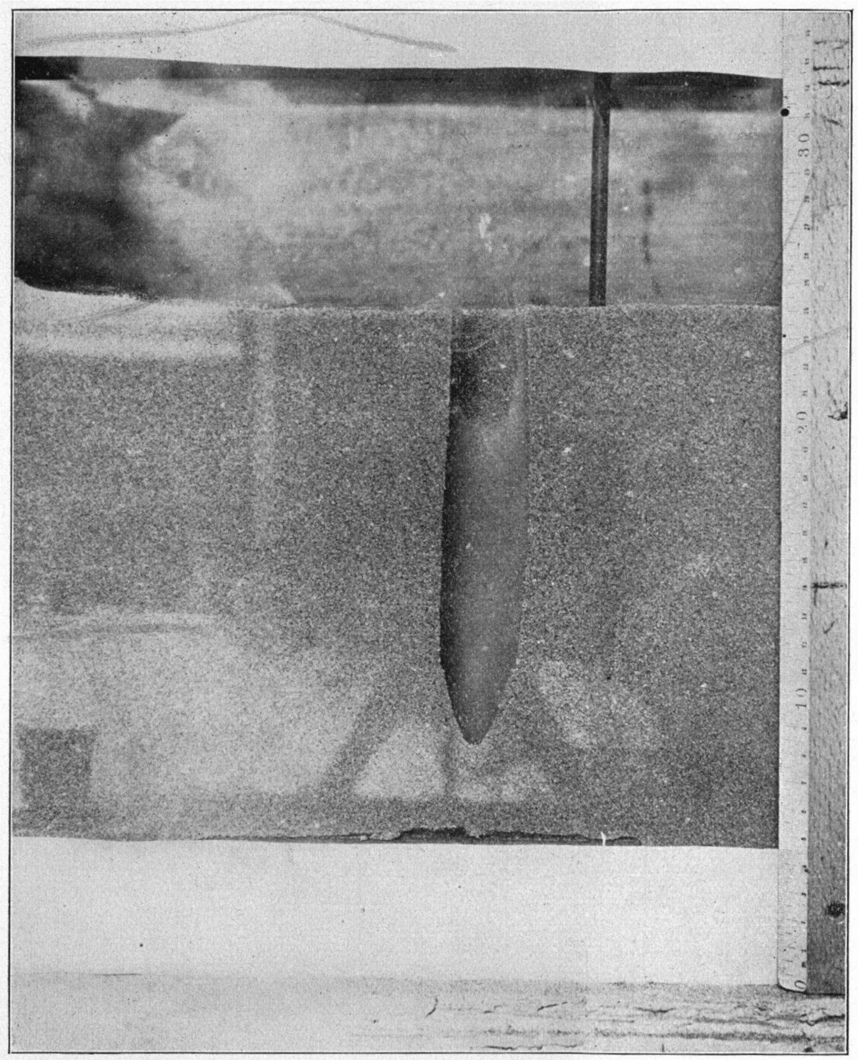


Plate 7.

Experiment 6. Cylindrical vent blown out in homogeneously pressed wet sand. (Photographed through the glass).

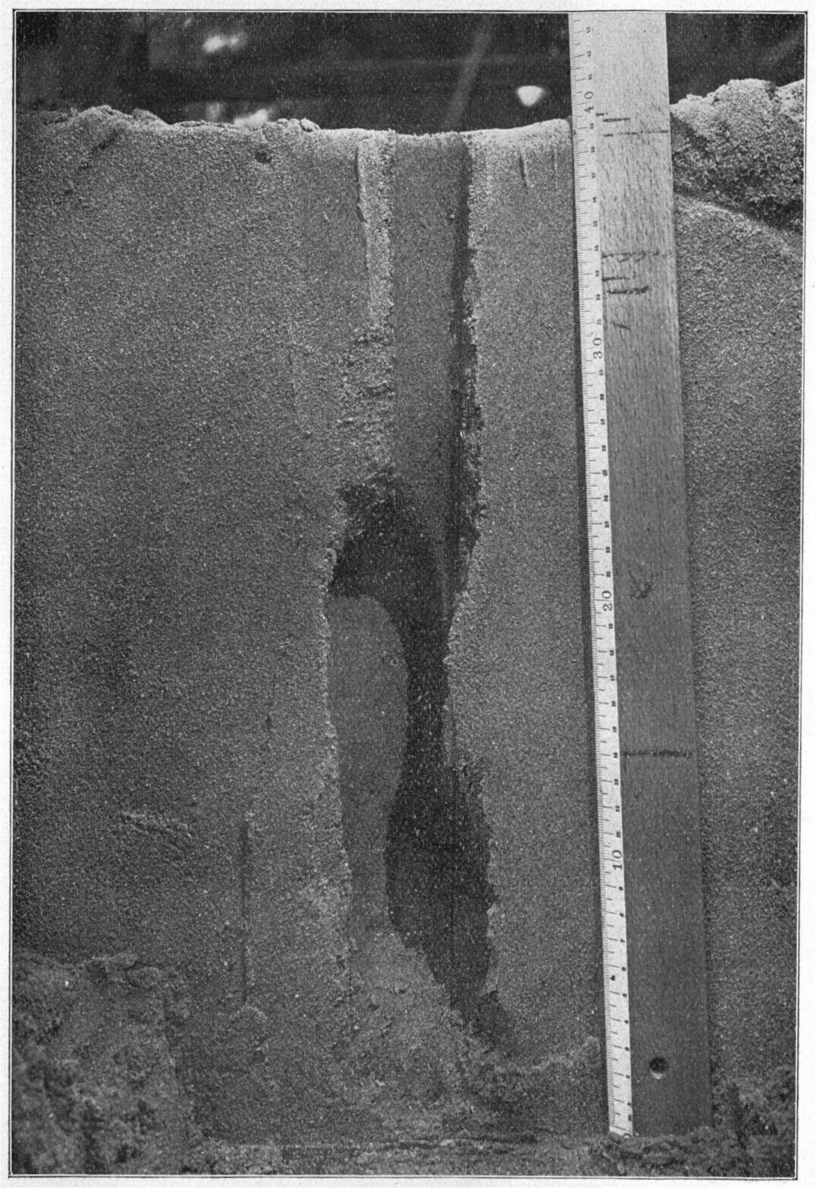
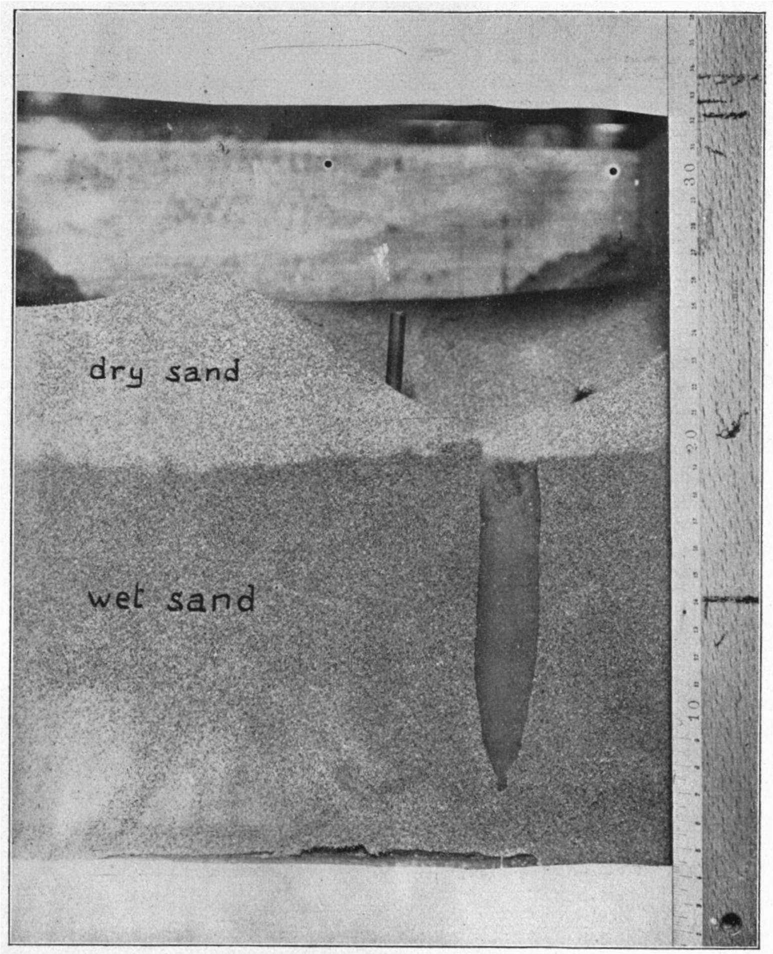


Plate 8.

Experiment 1. Irregular vent through not carefully pressed wet sand.



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Experiment 7. Vent in a layer of wet sand covered by a layer of dry sand. In the wet sand a cylindrical vent was formed, in the dry sand a funnel shaped vent, the declivity of which corresponds to the maximum declivity of dry sand (see fig. 6).
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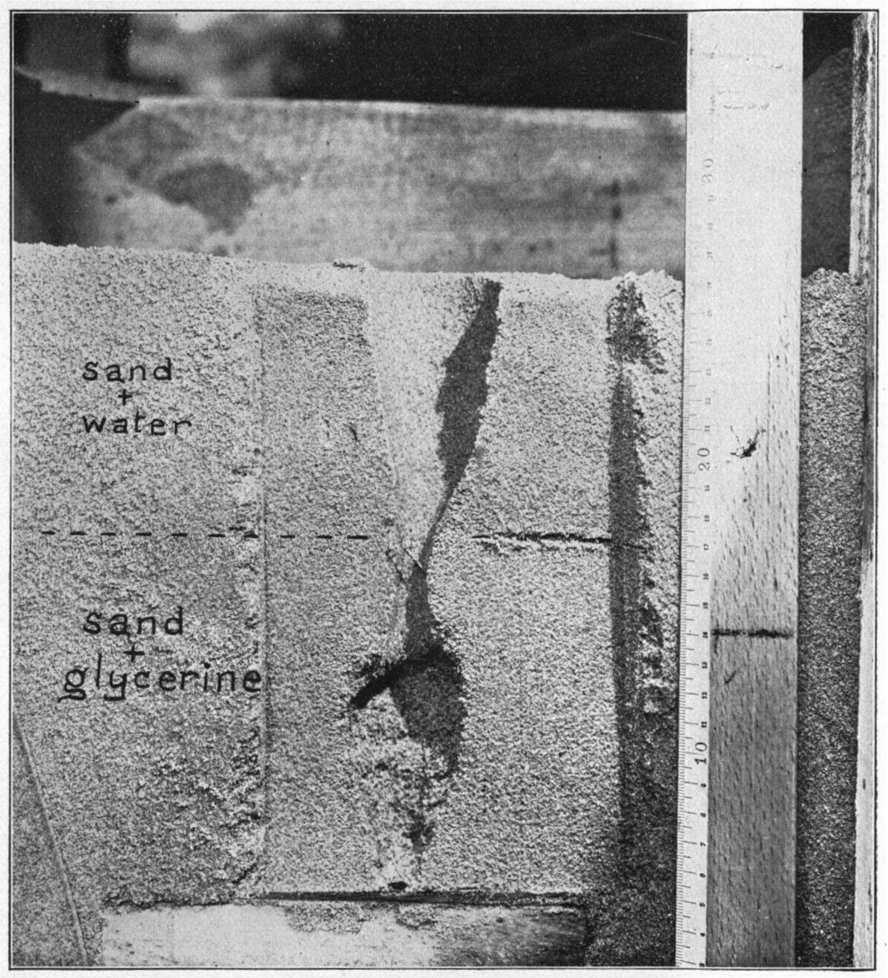

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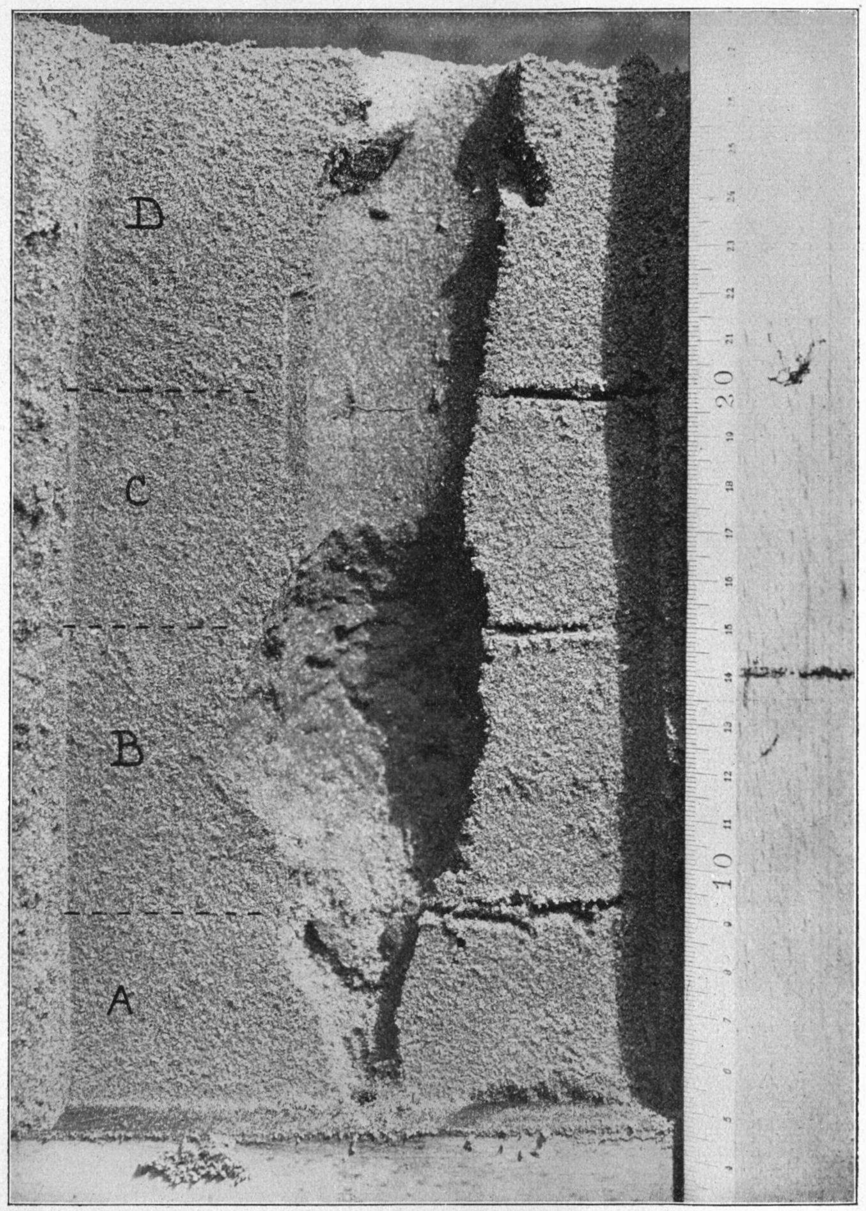
By firmly pressing the lowest layer a constriction has arisen in the highest part of this layer.



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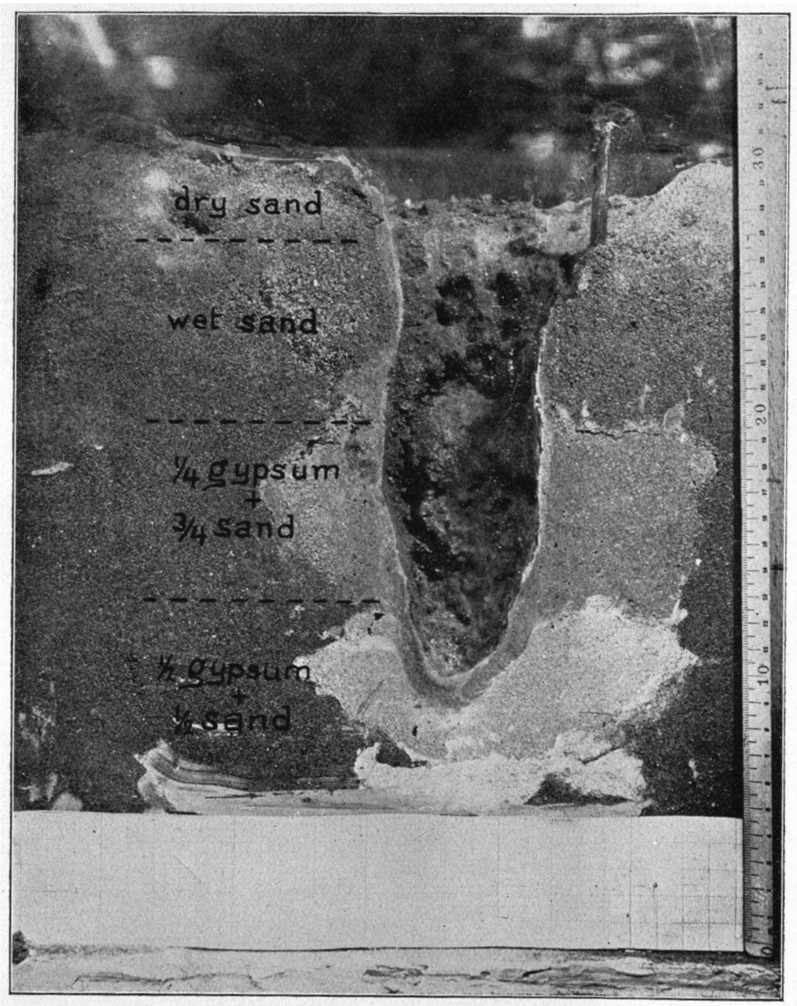
Experiment 13. Vent in four layers of sand with different matrix, water and glycerine in various proportions.

Irregularities, presumably due to uneven stamping down of the layers.

A = sand with glycerine.
B = sand with $^{3}/_{4}$ water on $^{1}/_{4}$ glycerine.
C = sand with $^{9}/_{10}$ water on $^{1}/_{10}$ glycerine.
D = sand with water.



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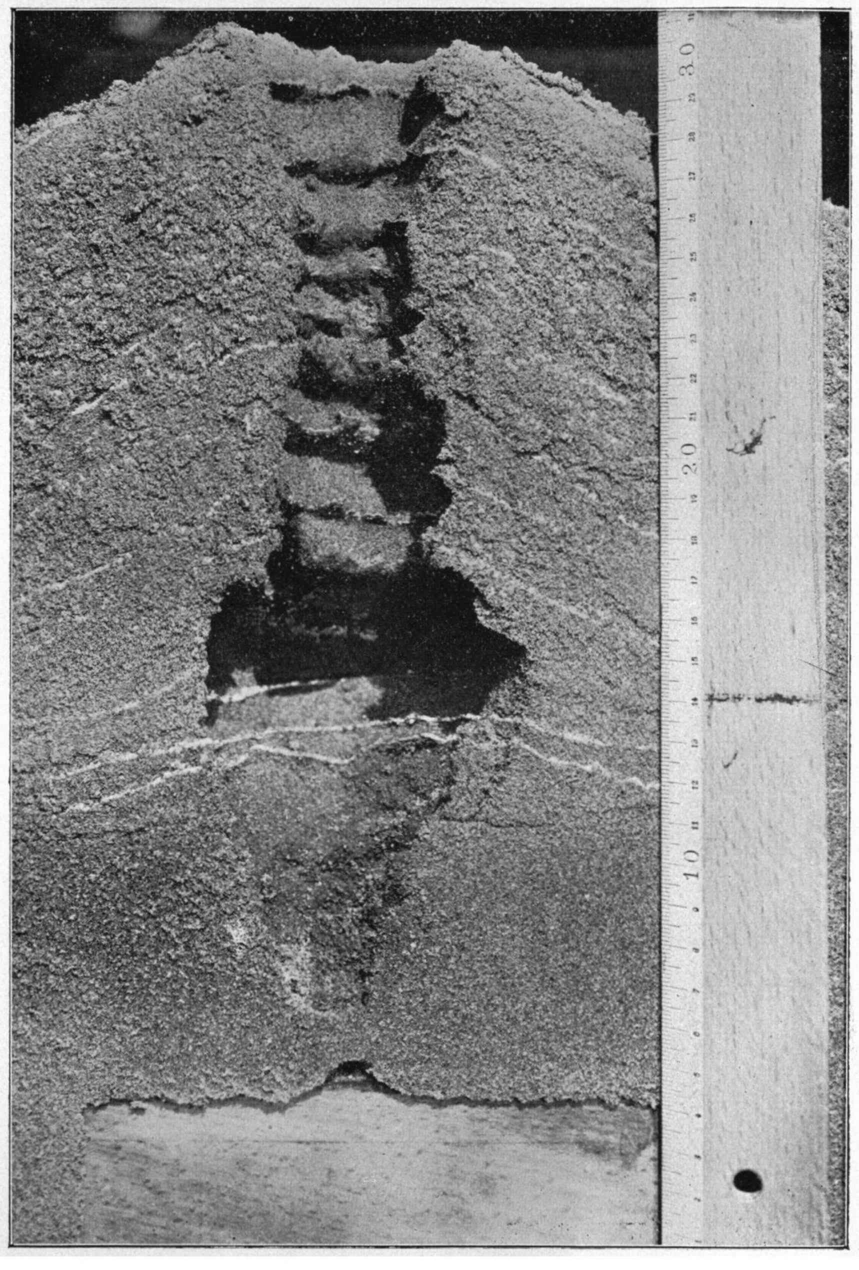

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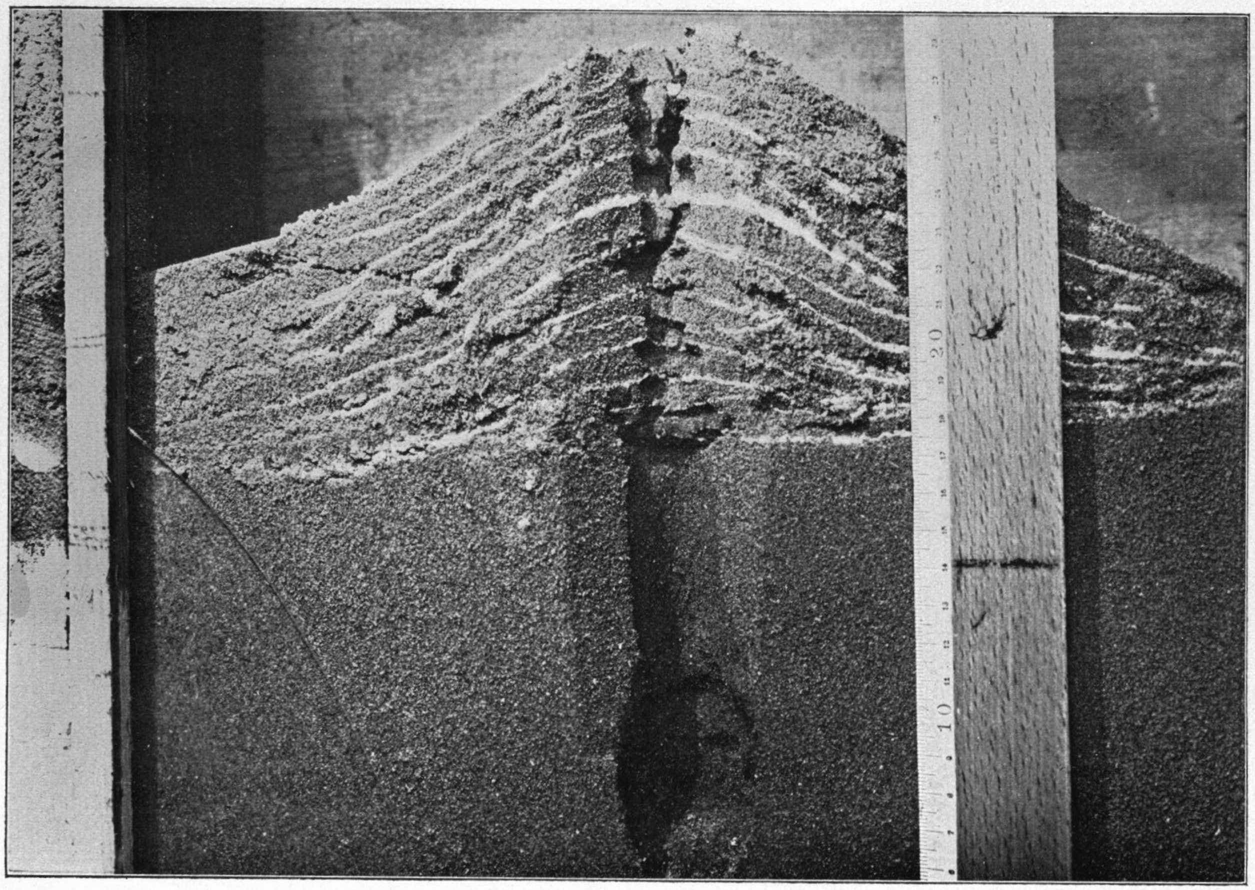

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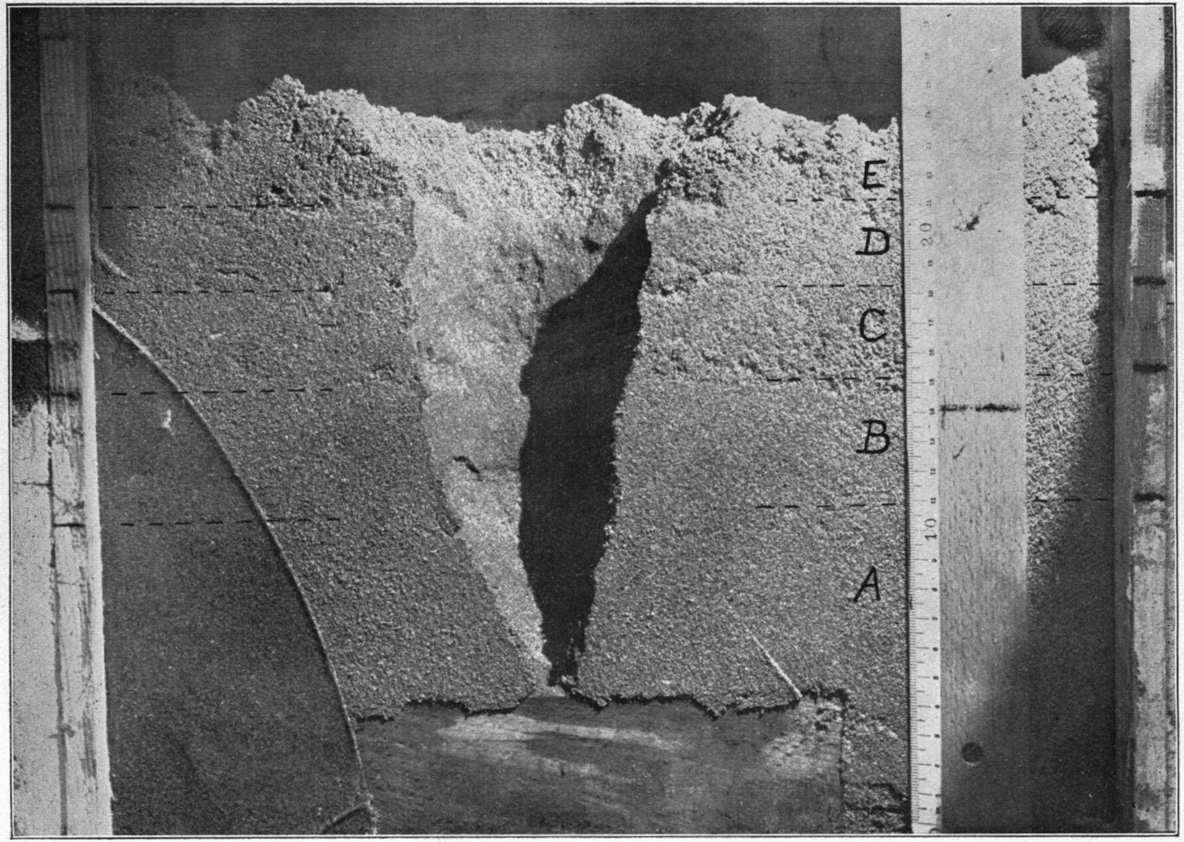

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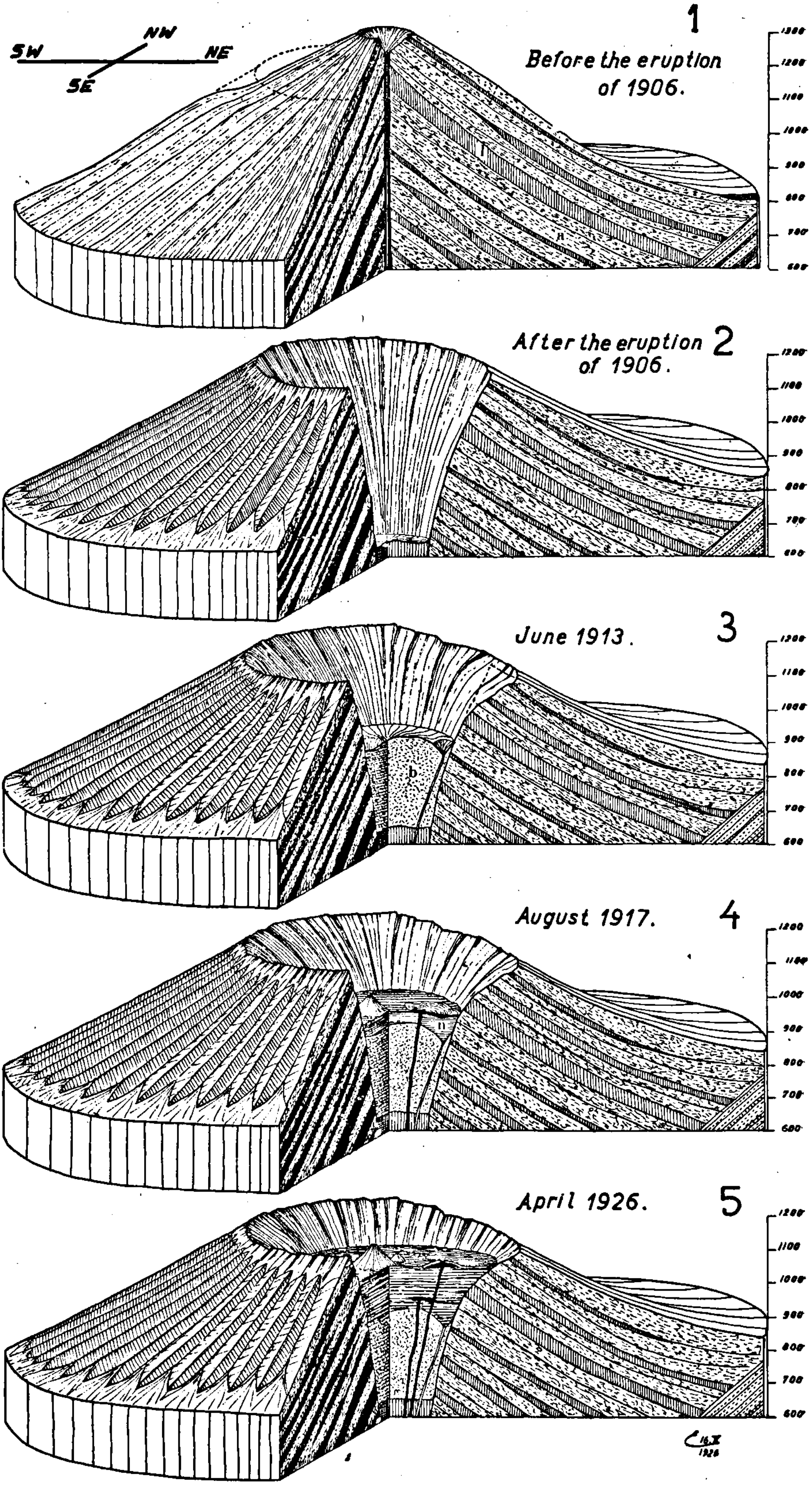
Experiment 16. Five layers of wet sand, from below upwards less and less firmly pressed. The vent has become funnel shaped by slides from the walls which were originally cylindrical (see fig. 7).

A = stamped down firmly.
B = stamped down.
C = pressed down gently.
D = smoothed off.
E = strewn through brass gauze in damp condition.



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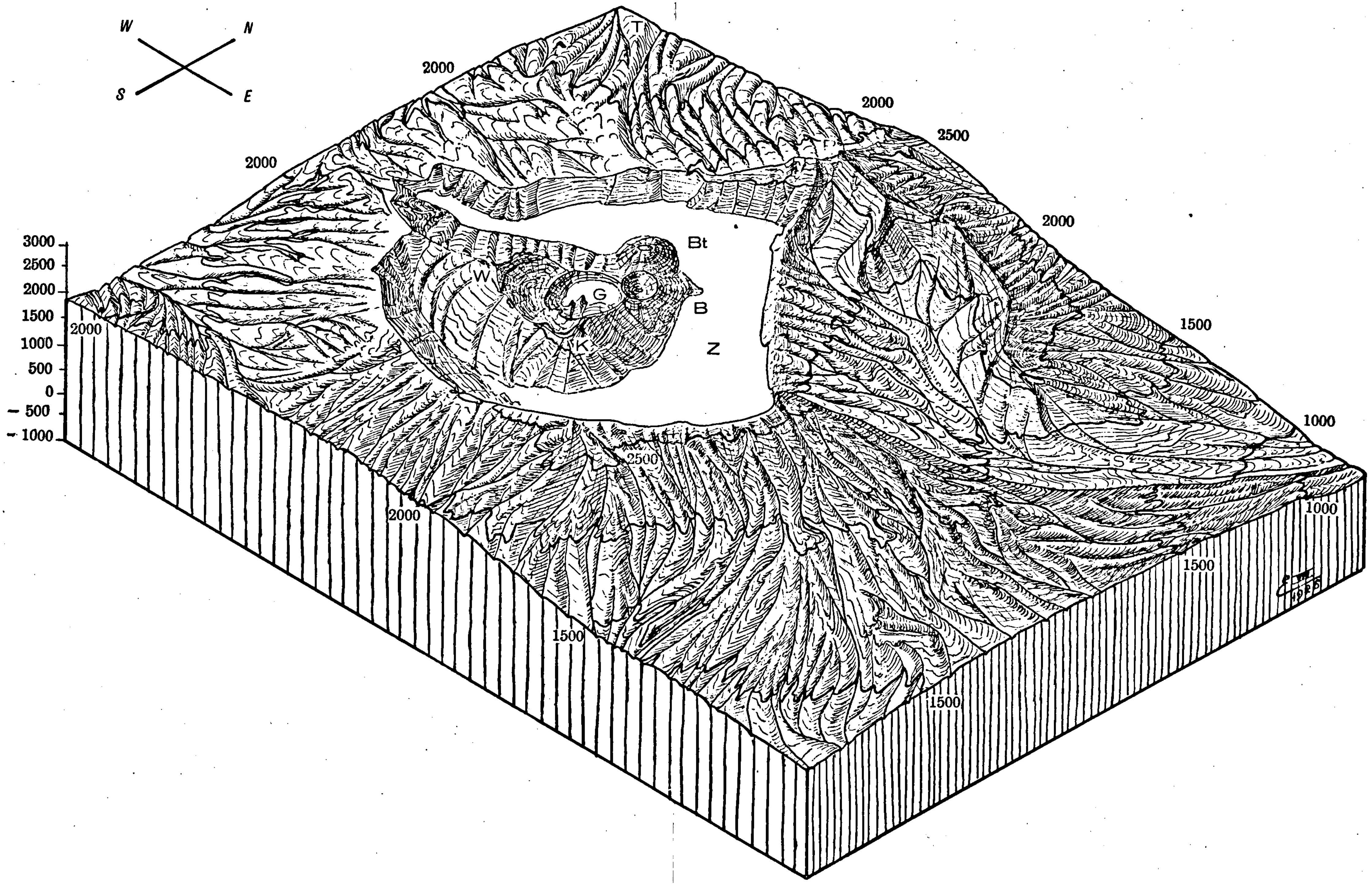
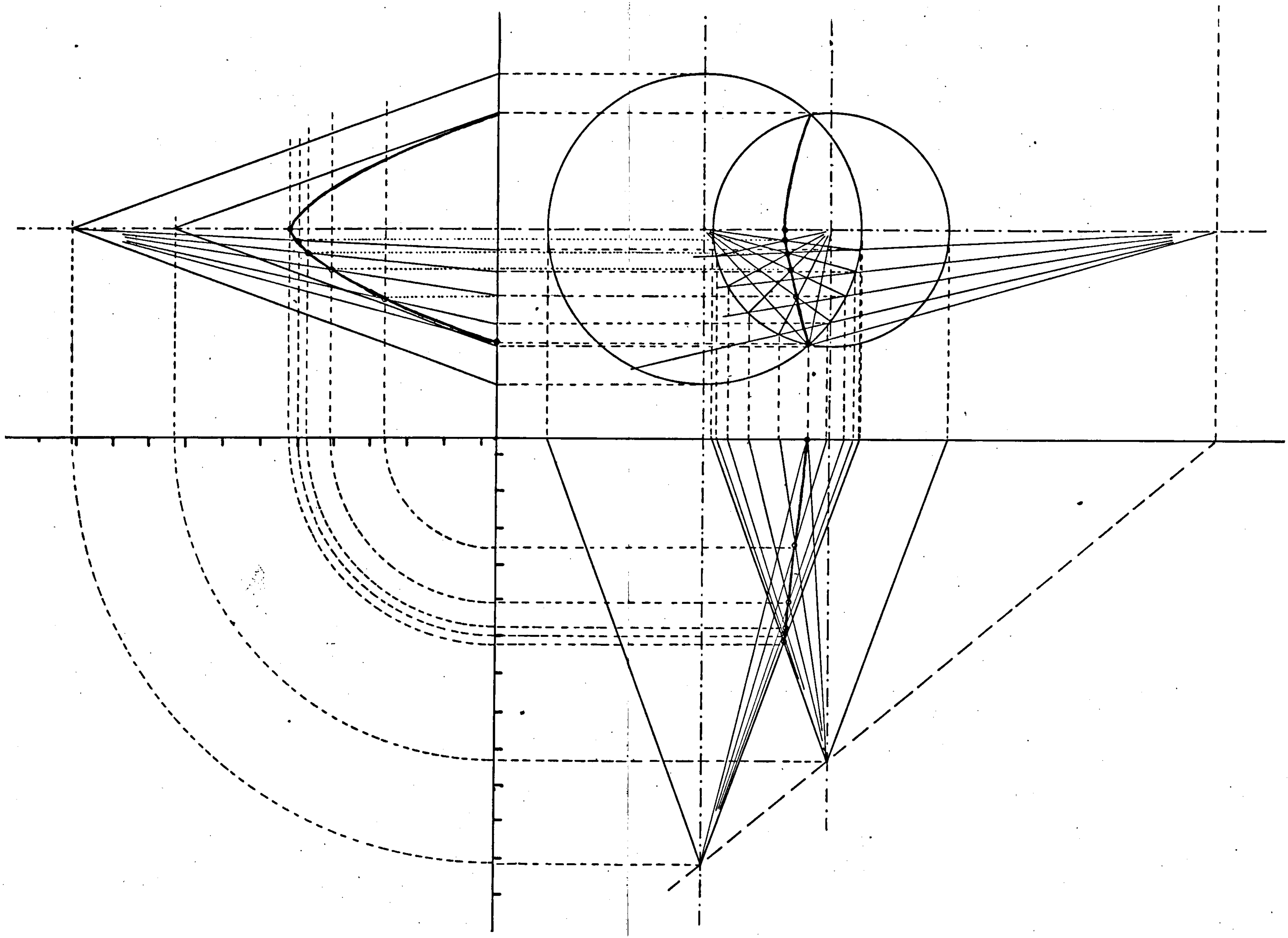


Plate 17.

Block diagram of the Tengger Mountains in isometric axonometry. Coutour lines at 1000, 1500, 2000 and 2500 m.

B = Bromo.
BT = Batok.
G = Giri.
W = Widodaren.
Z = Sandsea.
S = village of Sapikerep.



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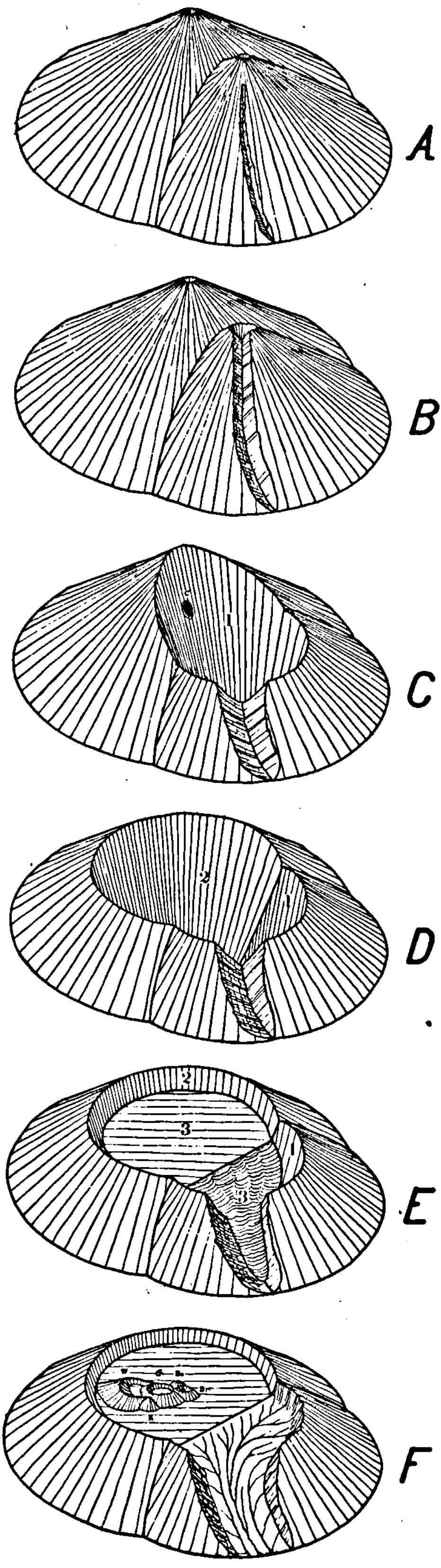
Construction of the intersection of two circle cones with radius of 4.2 and 3.15 km. Distance of axes 3.4 km. and apex angles of 40°.



A. Twin volcano.

B. The valley of Sapikerep is deepenend.

C. First funnel-shaped vent (1) (eastern volcano) formed by crumbling down of steep walls of cylindrical vent blown out by the gas phase.

D. Second funnel-shaped vent (2) (western volcano) formed in the like manner.

E. The lava has risen in the western funnel (3) and has flowed through the eastern vent into the valley of Sapikerep.

F. Present stage. Erosion in the valley of Sapikerep and formation of secondary craters in the western vent. W = Widodaren, G = Giri, K = Kembang, Bt = Batok and B = Bromo the only now active vent.

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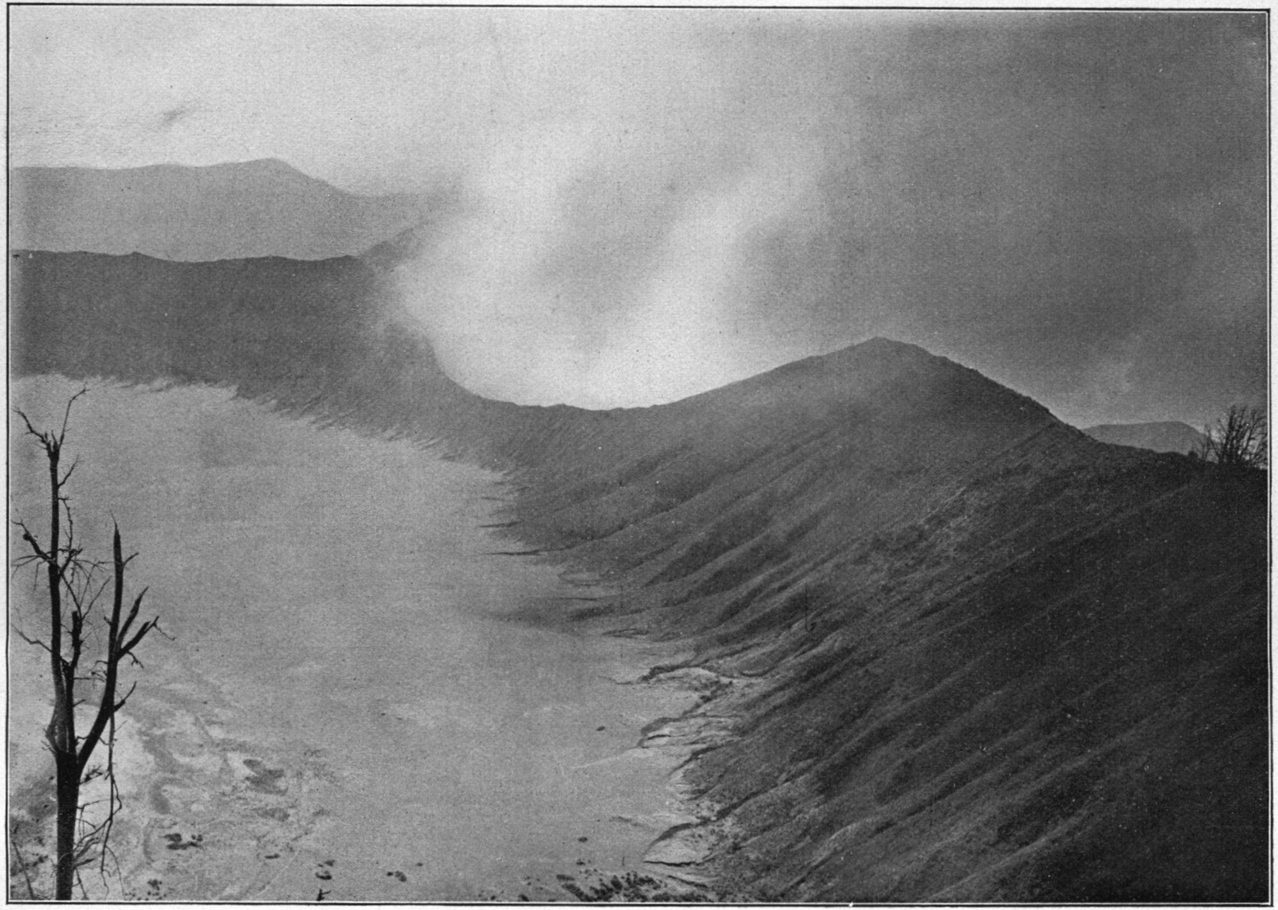
Lava in the stream Prahoe near the native village Poetoes in the valley of Sapikerep.
Photograph by Prof. Dr. J. JESWIET.



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Hyperbolic curve at intersection of two funnels, namely of the volcano **Giri**, with a flat crater floor named **Segoro wedi lor**, in the foreground, and of the **Bromo** out of which exhalation clouds are being ejected. Photograph by Prof. Dr. J. JESWIET.

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