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Gigantic eruption of the Volcano Bezymianny

(With 39 plates)

Introduction

On October 22, 1955, after a three week swarm of earthquakes, for the first time in history a lengthy eruption of Bezymianny volcano had started. This volcano is located in the very centre of the famous Kliuchevskaia group of volcanoes in Kamchatka. Its absolute height before the eruption was 3085 m, relative height over the base level - from 700 m in the North up to 1200 m in the South. Geographical position of the crater: 55°58' North; 160°35' East. North of Bezymianny rises a ruined cone of volcano Kamen (4585 m), behind it - Kliuchevskaia sopka (4750 m); to the South of Bezymianny a mass of Zimina sopkas (3081 m) is found (fig. 1).

Until recently Bezymianny volcano was not much studied. According to preliminary data it consists of a complex mass, the southeastern part of which consists of a large extrusive dome, and its western part - of a younger strato volcano. Before the eruption we are describing, there was an ill-defined crater on the summit about 500 m in diameter, which has been practically completely filled by an internal cone with a sealed crater of approximately 200 m in diameter. From the western rim of the outer crater a deep gorge was descending; a second gorge was coming down eastwardly and gave birth to one of the heads of the river Sukhaia (Dry) Hapitsa (fig. 2).
Judging by the shape of the volcano its history must have been rather complicated: during the first phase of volcanism a big dome was formed, which could have grown in the crater of an old strato volcano. As turning point served the formation of the young strato volcano. This moment was preceded, apparently, by a lengthy period of repose. As the original vent proved to be plugged by a lava plug of the dome, the new eruptive centre shifted somewhat to the West and the strato volcano was formed in the marginal part of the dome, which was partly overlain by young lavas. The strato volcano displayed a mixed type of activity; a complicating feature was the formation of a number of smaller lateral domes. The final stage in the life of the volcano was marked by the formation of a small internal cone in the crater. After that a lengthy period of dormancy began. The second turning point was the eruption of 1955-1956, the description of which we will give below.

**Course of the eruption**

To make the description easier the process of eruption could be divided into the following five stages:

1. Pre-eruptive stage, which includes the period from the first volcanic earthquake until the day preceding the first gas outburst of the volcano, namely from September 29 up to October 21, 1955.

2. Stage of strong ash eruptions of Vulcanian type - beginning with October 22nd until the end of November, 1955.


5. Growth and development of an extrusive dome in the newly formed crater - beginning with April and up to late in the autumn of 1956.

The total length of the eruption is slightly over a year. The eruption took place in the eastern part of the volcano, unseen from the neighbouring villages. Observations of the process of eruption had to be carried out from an
uninhabited region in the upper reaches of the river Sukhaia Hapitsa. All the main volcanic phenomena took place during the winter of 1955-56. Severe winter conditions were made even harder by a frequent and lengthy recurrence of bad weather; of additional difficulty were ashfalls, which greatly hampered the use of dog-driven sledges - the only possible kind of transport in snowy Kamchatka winter conditions. In spring the road was blocked for our expeditions by extremely violent torrents streaming down from the mountains; *) in summer we were suffering from lack of potable water and our horses from the lack of grass buried under a thick layer of ash. In such difficult and sometimes even dangerous conditions constant observations were impossible and we did not succeed always to see everything we wanted with sufficient completeness.

1) Pre-eruptive stage

The eruption was preceded by a swarm of numerous earthquakes. Their total number before the beginning of the eruption was 1285.

The first shock of this swarm was registered on September 29, 1955, the displacement came to 11 μ. One shock every day was registered beginning with October 2nd until October 5th, there have been four of them on October 6th, five on the 7th; on October 8th the number of earthquakes exceeded ten; beginning with October 9, earthquakes were counted by dozens a day and beginning with October 12, - already 100-200 a day. On October 11th the displacement of the ground in Kliuchi exceeded 100μ, the epicentre was determined for the first time (volcano Bezymianny region) and its depth (about 50 km). Beginning with October 18, there have been shocks with an amplitude of 1000μ and more. However, owing to a considerable period of the maximum phase, shocks in Kliuchi, where registration was taking place, were not felt and were only recorded by seismographs.

*) Under a layer of ash the melting of glaciers in spring of 1956 was especially intense.
The character of this swarm of earthquakes permitted us with a considerable degree of certitude to expect the eruption at an early date. Epicentres of the earthquakes were falling on the area of Bezymianny volcano, which was regarded as extinct. This left a shade of doubt that the eruption will take place from this volcano. It could sooner be suggested that a new lateral crater will burst out near the southern base of Kliucheysky volcano. And yet this time seismic data gave an absolutely exact forecast of the point of eruption.

2) Stage of strong ash eruptions

The eruption began about 6.30 in the morning of October 22nd. At this time white puffs of an eruptive cloud appeared beyond the eastern flank of Kliuchevskaia sopka and could be seen from Kliuchi. Immediately after the first gas outburst emission of ashes began.

During the first days the eruption was of a moderate character; the height of the ash-gas cloud did not exceed 1-2 km above the crater. However, its intensity grew day after day. Beginning with October 26th ashfalls of growing intensity were taking place in a radius of 40-60 km from the volcano. For instance on November 1-3 all works in the streets of village Kozyrevsk (45 km West of the volcano) had to be stopped because of the ashfall. Weak ashfalls were taking place at a distance up to 120-130 km from Bezymianny (village Esso in Sredinny (Midle) mountain range - 120 km West of the volcano, village Ust-Kamchatsk on the coast of Pacific ocean at the same distance ENE of the volcano). In the village Kliuchi — 45 km NNE from Bezymianny — by November 9th a layer of ashes had fallen 6 mm thick or 3.5 kg/m². In the region of our expeditionary camps 1 and 2 the layer of ashes on the snow at this time reached 3-4 cm.

The column of ashes was bursting out of the new crater, which was formed somewhat below the summit of the volcanic mass, on the boundary between the old dome and the young strato volcano. Apparently the vent of the strato volcano also got plugged up completely, so that the zone of
least resistance proved to be the boundary between the two old vents and here a new channel had passed. (The question stands, naturally, only about the upper part of the channels) (figs. 3 and 4).

Judging by the thickness of the ash jet, the diameter of the new crater did not exceed 250 m. The first 160 m were passed by the ash cloud in 3 seconds, i.e. with an average velocity of 50 m/sec. At the very crater the puffs of ashes were literally boiling.

On November 7th the eruption obviously intensified. In camp No 2, 12 km from the volcano, deafening roars of explosions were heard, the rumbling spreading also on the ground. In the morning of November 7th a layer of ashes had fallen 10 mm thick. From the roof of the tent ashes had to be shovelled off (fig. 5).

On November 13th the height of the ash cloud over the crater reached 5 km. All night enormous bright lightnings were flashing through the eruptive cloud; sometimes they were globe lightnings, but mostly linear. Lightnings were flashing mainly aside from the crater and mostly on the lower margin of the eruptive cloud (fig. 6). The ash cloud was drifting eastwards, the ashfall was reaching the coast of the Pacific ocean and departing further into the open sea. On November 14th the height of the ash column reached 7.5 km over the crater (10.5 km above sea level) and on November 16-20 heavy ashfalls took place in Kliuchy. On November 17th it was dusk all day through, light was burning in the houses and on the streets, automobiles had their headlights switched on. All work in the street had to be stopped. Sometimes the ashfall was so heavy that lighted windows and street lanterns could not be seen at a distance of 150-200 m. During the period from November 16 up to November 21 a layer of ashes in Kliuchy came to 16.6 mm, which is 10.9 kg/m². 70% of this amount fell during twenty four hours of November 16th and 17th. From the beginning of the eruption to the end of November the total sum of the ashes in Kliuchy amounted to 25 mm, which is about 16 kg/m². During these
days ashes fell in a wide stretch going North from the volcano to a distance up to 250 km (fig. 7).

In November explosions considerably enlarged the crater. Now it had a diameter of 700-800 m and, being slightly elongated in the latitudinal direction, was embracing part of the summit of the old dome and the internal cone of the strato volcano.

3) Stage of moderate activity

Beginning with the end of November, 1955 the intensity of the eruption began to fall and by the end of December the volcano started on its phase of moderate activity, which lasted until March 29, 1956.

During this period ash eruptions became rarer and much weaker: the height of the ash and gas cloud, as a rule, did not exceed 1-1.5 km over the crater. From time to time in a radius up to 50-60 km ashes would fall, but now ashfalls got much weaker than before. So in Kliuchi, for instance, ashes were falling at a quantity of 10-20 g/m², instead of kilograms as in the preceding period. More often dense snow-white puffs of fumarolic gases would rise from the crater to a height of 1-2 km, but they would not contain any admixture of ashes.

On January 25, 1956 it became possible to observe the crater of the volcano more detailedly from an airplane (fig. 8). Against our expectations, the depth of the crater proved to be not great. The bottom of the crater looked like a sloping, convex shield and was covered by pyroclastic material, from underneath of which sharp spurs of dark lava were protruding in two or three places. Apparently, following the explosions of November, 1956, which widened the crater, there began to grow a dome. Its surface was littered by ejectamenta of weak explosions which took place from time to time on the margins of the dome at a boundary between the dome and the vent. Two eruptive bocca could be distinguished, from which thick wreathes of steam and gases were exhaled. Weaker fumarolic jets were rising in many places along the
periphery of crater. There have been, however, no fumaroles in the middle part of the crater (fig. 9).

The growth of the intercrateral dome was accompanied by shoves on the southeastern flank of the volcano and now the old dome was standing out quite clearly and its boundary with the strato volcano became very distinct (figs. 10-11). Especially noticeable were movements on the very boundary, where a cliff was protruded, speckled with hundreds of powerful fumaroles and covered with multicoloured sublimates.

Early in February the volcano could have been observed from our camps 1 and 2. In the southern part of the crater often, though weak, explosions were taking place which gave birth to minor incandescent avalanches. Sometimes stronger explosions happened, raising columns of ashes to a height of 2-3 km above the crater and accompanied by more powerful avalanches (fig. 12). One of these avalanches on February 9th reached the foot of the volcano in 50 seconds, the velocity of this glowing stream being about 50-60 m/sec or about 200 km/h on a grade of 35°.

Upon comparison of photographs taken at this time (fig. 13) with earlier pictures one could see that in the SE part of the volcano not only local shifts were taking place but that a general uplift of the old dome, which composed this part of the volcanic mass, also occurred. The magnitude of the uplift was determined as approximating 100 m. The new line of the flank perceptibly shifted to the SE and the volcano as if was widened. Fig. 14 gives new outlines on the background of old ones; we can see that the striking widening of the summit was determined not only by an increase of the crater, but to a considerable degree (by 230 m) also by the growth of the old dome.

The steepness of this part of the flank obviously increased - from 30 to 35°. The upper 300 m were built of the massive body of the dome and the lower part by a loose agglomerate, the formation of new portions of which was accompanying the shift of the old dome. Fresh «breccia
crust »*) completely covered up a considerable part of the eastern gorge.

The resumption of the growth of the old dome after a period of repose during several hundreds of years, and maybe even longer, was an exceptional fact and was an evidence of an exceptionally high magmatic pressure which could not find an outlet in the squeezing out of one intercratal plug alone.

4) Paroxysmal explosion of March 30, 1956

On March 30, 1956 a turning stage occurred in the process of eruption. On that day a tremendous explosion took place which destroyed the top of the volcano and completely changed not only its shape but even the relief of the surrounding terrain.

The day was very clear and the eruption could be observed, in that or other form, from all surrounding villages. At the moment of the eruption a rather strong volcanic earthquake took place, the time at the focus of which — 17 h. 11 m. 05 sec. — corresponds, apparently, to the beginning of the explosion. This time is well in accord with the time determined by the velocity of propagation of the blast, registered by barographs of many meteorological stations.

Line fitter V. P. Sorokin from the village Kamaki (65 km NE from the volcano) was the first who noticed the eruption. Being at home he felt a « pressure in his ears », i.e. a sharp change in the atmospheric pressure and immediately understood that something happened at the volcano. Running out of the house, he saw above Bezymianny volcano an obliquely directed eruptive column (about 30° to the horizon and in an eastward direction), which was impregnated by sparks and looked like one consisting of fire **) (judging by the velocity of propagation of the blast, it must have been 3-4 minutes after the beginning of the eruption). Above this « fiery spout », also in an oblique way, about 45° towards the

*) Brèches d’écroulement.
**) Apparently all light effects were connected with the sunset.
horizon, puffs of «smoke» were rapidly growing and in 1-2 minutes hid the tops of all the volcanoes. 4-5 minutes later light vapours began to rise along the valley of the river Sukhaia (Dry) Hapitsa and at the southeastern foot of Kliuchevskaia sopka. In Hapitsa valley they seemed to be rolling in waves and were accompanied by «sparks» (these were agglomerate streams). Soon a dense, black eruptive cloud with a powerful ashfall, moving towards the observer, hid the following course of events. It is interesting to point out that the sharp change in pressure resulting in an unpleasant feeling in the ears was noticed by many villagers in Kamaki; unfortunately there is no meteorological station here and the magnitude of the baric wave remained undetermined.

The most favorable conditions for observations were in Kozyrevsk: the sun was setting and illuminating the entire picture of the eruption and a SW wind in the higher layers of the atmosphere was drifting the ashcloud away from Kozyrevsk leaving the volcano open. The eruptive cloud quickly expanded in fan-like shape sidewise and upwards. The lower edge of the gigantic «fan» was at a height of 6-8 km, while the upper - at about 35 km. The giants of Kliuchevskaia group of volcanoes seemed insignificant in comparison with this formidable and awe inspiring volcanic cloud (fig. 15). At the moment of the eruption all sopkas were clear, but then rapidly got enveloped by thick «caps» of atmospheric clouds. The vertical velocity of the cloud’s movement was not measured, but all eyewitnesses unanimously noted its swiftness and impetuosity. Fig. 16 shows one of the early moments of the eruption; along with the general majestic picture several important facts should be indicated: 1) explosions did not ruin the western part of the top of the volcano, 2) the explosions were not directed straight upwards, but had a rather strong incline towards the East, 3) at the base of the volcano ashclouds were rising from descending agglomerate streams, one of which was descending into the head of river Studenaia, while the second — a more powerful one — into the valley of Sukhaia (Dry) Hapitsa. The thick ash wall of the latter could be seen also from Kliuchi.
From Ust-Kamchatsk the cloud of the main explosion was well seen, covering the entire western part of the horizon. The cloud itself was impenetrably black, but its light margins, illuminated by the rays of the setting sun, formed a bright golden rim. In 15-20 minutes after the main explosion a narrow gas wedge of one more explosion which could be seen only from here. The end of the eruption was hidden from Ust-Kamchatsk by a curtain of ashfall over Kumroch mountain range.

On negatives of pictures taken from Ust-Kamchatsk the height of the ashcloud could be determined with the greatest precision; the top of the ashcloud reached a height of 34-36 km, and the «wedge» of the following explosion grew for another 8-10 km, i.e. up to about 45 km.

In Kliuchi conditions for observation of the eruption itself were the most unfavourable, but that was the direction in which the ashcloud of the main explosion drifted and here were well seen all the phenomena occurring in the cloud, which rapidly advanced from the South. It was not wide, in the East and West clear sky could be seen. The cloud was curling intensely and quickly changed its outlines, advancing towards the North-East. It seemed to be very thick and almost tangibly heavy. Together with the cloud came also and was growing a rumble of loud thunder accompanying incessantly flashing lightnings. About 5.40 p.m., when the cloud already passed the zenith, ashfall began; the dirty surface of a slightly melted snow was quickly covered by a light-gray coating. At first only separate large particles were falling (up to 3 mm), which rattled against window glass like hail. By 5.40 p.m. the ashfall intensified and by 6.20 p.m. it got so impenetrably dark that one could not see his own hand, even if brought up to the very face. People returning from work were wandering about the village in search of their homes... Peals of thunder were crashing with deafening loudness without any interruption. The air was saturated with electricity, telephones were ringing spontaneously, loudspeakers of the radionet were burning out, sparks were bursting out.
of antennae inlets of radiosets... There was a strong smell of sulphurous gas. By 9.00 p.m. the ashfall thinned out and patches of starlit sky appeared. During three and a half hours in Kliuchi a layer of ash 20 mm thick had fallen (24.5 kg/m²).

The ashfall embraced a rather narrow zone in the northeastern direction. In the district of Sheveluch volcano (80 km from Bezymianny), where at that time a group of employees from the Volcanological station was working, the ashfall was just as intense as in Kliuchi. At the moment of eruption people have been in the valley of a mountain river and the ashfall caught them during their ascent to an expeditional cabin. Despite the increasing ashfall the group continued to ascend, but by 6.50 p.m. it got so inky dark, that a tent had to be put up in 300 m from the cabin. This happened in a forest, but the tent had to be stretched on skis, because it was impossible to leave the sledges even for a couple of paces. Just as in Kliuchy, thunder was rumbling incessantly. By 3 a.m. on March 31st the darkness dispersed; a coat of ashes 2 cm thick (22.3 kg/m²) was covering the snow.

A strong ashfall took place also in the mouth region of river Ozernaia (about 200 km from Bezymianny); in the village Uka (225 km from the volcano) 3 mm of ashes had fallen, and in the environs of village Ossora (400 km NNE from Bezymianny) the ash cover was about 1 mm. The two last points were, apparently, not in the axial part of the ashfall, which, probably, was in the Bering Sea, East of the island Karaginsky. Thus the ashfall occupied a comparatively narrow but long stretch, the width of which hardly reached 100-150 km and length exceeded 400 km (fig. 17). The total volume of ashes fallen on this area (40,000 km²) according to the most modest estimates comes to 0.4-0.5 km³.

To the West and South of the volcano no ashfall was observed, but there was a strong mist and a noticeable smell of sulphurous gas was felt (at a distance over 100 m from the volcano).

*) Thin ashes were caught at height by jet streams, passed over the North Pole and on April 3-4, 1956, a thin cloud of volcanic dust was seen in stratosphere over western Britain (8).
The picture of this explosion was stupendous and greatly exceeded everything ever seen by even oldtimers of Kamchatka and yet the entire might of this eruption could be grasped only after having visited the volcano and studied the consequences of the explosion.

As a result of the explosion the Bezymianny volcano had changed beyond recognition: instead of a regular, slightly truncated cone it became a semi-ring caldera-volcano. The dome in the SE part was fully destroyed and a new tremendous crater was occupying not only the summit, but also the entire SE flank up to its very base. The new crater acquired the shape of a semi-ring 1.5 by 2 km in size, somewhat elongated in a latitudinal direction. The uneven, breached rim of the crater is obliquely truncated towards the SE and has the greatest height in the West, descending in the East to the very basement of the volcano. The highest point of the volcano has decreased by 150-180 m and its absolute height now is about 2900 m instead of 3085 before the eruption. The western gorge on the flank remained, while the eastern got completely included into the new crater (fig. 18).

The valley of the river Sukhaia (Dry) Hapitsa, which begins on the eastern flank of the volcano, was completely littered at a distance of 18 km by a powerful agglomerate flow consisting of a chaotic mixture of ashes, sand and lava blocks. Many thousands of secondary fumaroles were rising from the surface of the flow.

The territory surrounding the volcano from the East at a distance of 10-13 km was covered by a coat of sand up to 0.5 m thick. Further eastwards at a distance up to 27-29 km the thickness of sand and cinder rapidly decreased up to several centimeters. Ashes were not falling quietly from above, but were breaking out of the crater with a colossal force like a jet of some gigantic sandblast apparatus. Our cabin, located in 12 km from the volcano, was literally «blown off», not a single board remained. At a distance of 25-30 km from the crater trunks of trees and bushes on the side facing the volcano were stripped bare; on the
opposite side the bark was fully preserved (fig. 19). At a
distance up to 25 km big trees up to 25-30 cm in diameter
were broken and felled by the force of the explosion (figs. 19,
20). Our main expedition camp (camp No. 1), separated from
Bezymianny by a distance of 16 km, several deep valleys and
barriers of lava flows and thought safe by us, proved to be
within the zone of destruction. Fortunately at the time of
explosion there was nobody there and in general, despite its
strength, the eruption did not result in loss of any human
lives.

Ashes of the directed explosion after falling on the
ground still kept some amount of gases and were very mobile,
«flowing». They were rolling down from the elevated parts
and filled all valleys of the rivers adjoining the volcano. Some
sand streams were several meters thick.

At the moment of explosion the ashes were so hot that
were scorching the bark of trees and bushes at a distance
up to 27-29 km, and some trunks, belonging apparently to
dry dead wood, were burning practically completely. The
snow cover, which reaches here by the end of the winter
1-2 m, melted under the coat of incandescent ashes completely
in the axial part of the explosion, and remained only partly
in more remote points. Glowing material was deposited on an
area of about 500 km² and the melting of snow was very
violent. Torrential mud flows (lahars) were formed in the
valley of Sukhaia Hapitsa and on the flanks of Kliuchevskaia
and Zimina sокkas. These torrents rushed down carrying big
stones and devastating everything they met on their way.

The largest mud flow began from the end of the agglu-
terate stream on Sukhaia Hapitsa; in the bed of the river
mud accumulations, up to 20 m thick, remained at a distance
of about 15 km. In the lower part of this mud flow glacial
boulders are lying weighing up to hundreds of tons and
having dozens of cubic meters in size. They have been
brought here by the lahar (fig. 21). The mud here was hotter
and its higher temperature in the upper section was preserved
throughout the winter of 1956-1957.
Powerful mud flows descended also the flanks of Zimina sopka and the SE basement of Kliuchevskai sopka, but here lahars were cold.

In the axial parts of the mud flows, dense and hardly passable forests were literally erased and the trunks carried away; sometimes only low, split stumps remained. Nearer to the borders of the flows trees and bushes were left standing and in some points impassable barricades were formed (figs. 22 a, 22 b).

Having reached the river Bolshaia Hapitsa in their movement to the East, the mud flows have turned along the valley to the North. In the vicinity of camp No 3 all lahars merged into one; an hour after the beginning of the eruption a mud flow destroyed here several dozens telegraph poles. Not only the poles but also trees were moved down like grass (fig. 23). The yourta, in which our camp No 3 was located, got completely flooded by mud (in other words the level of mud exceeded the level of the river at least by 15 m).

Further North the mud flow deviated from the bed of river Bolshaia (Big) Hapitsa. In the region of stream Chistaia (Clear) and lake Urukulon, at a distance of 80-85 km from the volcano, the lahar fell into the valley of the river Kamchatka. The lakes Katlynych and Bochkarevo were completely piled by debris transported by the mud flow. At the end of the lahar a sort of peculiar moraine was formed consisting of a chaotic mixture of dirt, trunks and branches of trees (figs. 24-25).

A ramified drainage system of channels and lakes safeguarded Kamchatka river from a catastrophic rise of water, but the masses of dirt contaminated the water so much that it became impotable in Ust-Kamchatsk for a whole week and could not even be used for technical purposes. Dirt also caused a mass mortality of fish in the river.

In the "Cheeks" of Kamchatka river (where the river cuts the Kumroch mountain range and all streams converge into one channel) the rise of water began during the night of March 30 to 31st; by the morning of March 31st the water
had risen 11 cm, and by that evening - 33 cm. In the morning of April 2nd the rise reached its maximum (35 cm) and the normal level was attained only by the evening of April 5th. Judging by the speed of the current (0.42 m/sec) and the width of the river at that point (314 m), the additional volume of water, which fell into Kamchatka river is estimated at $1.5 \times 10^7$ m$^3$.

As a whole the scheme of eruption on March 30th is presented as follows: the gigantic explosion embraced not only the summit crater, but also the squeezing out old dome on the SE flank of the volcano. The first explosion was directed to the SE at an angle of 30-40° to the horizon; in this direction a fan-like jet of incandescent ashes was bursting out with a tremendous force. The strength of this jet is proven by broken trees and peeled off trunks of bushes at a distance up to 25-30 km from the volcano. As a result of the explosion a large crater open to the East was formed. Its size was $1.5 \times 2$ km. Through a breach extremely powerful streams of glowing agglomerate and sand material rushed down into the valley of Sukhaia Hapitsa. Clouds of ashes over the crater and the agglomerate stream rose to a height over 40 km. NNE of the volcano an ashfall on an area of exceeding 400 km length took place. The tremendous mass of glowing material caused a quick melting of snow, which resulted in the formation of torrential lahars, which, in their turn, having passed about 90 km and destroying everything on their way, fell into the river Kamchatka.

At the moment of eruption on March 30th the summit crater of Bezymianny undoubtedly increased, but mainly from the SE side at the expense of ruining the dome; however, from the North and West the top of the volcano did not change its outlines (fig. 16). After the end of the eruption the walls of the crater collapsed and the crater greatly widened and the volcano got lower on its western side. Thus the picture here reminded the formation of calderas.
5) Stage of growth of the extrusive dome and end of eruption

Following the explosion of March 30th a squeezing out of an extrusive (endogene) dome began in the new crater. The growth of the dome, as usually, was accompanied by explosions of a weak and moderate force. Very rarely stronger explosions took place, like, for instance, the rise of an ash-cloud for 8 km over the crater on June 21, 1956. Quite often incandescent avalanches were forming, which rolled down the flanks of the dome and sometimes through the breach in the crater got outside the limits of the volcano for 1-2 km.

By early July the formation of the dome was mostly completed. By this time it reached a height of about 300 m above the floor of the crater.

In August 1956 (fig. 26), the height of the dome was determined to be 320 m. The upper 140 m were the massive body of the dome, while the lower 180 m were hidden by brèches d'écroulement. The diameter of the dome was 340 m, its top had a diameter of 230 m and the basement of the brèches d'écroulement - 620 m. During this period often but very weak explosions were taking place in the dome exposing incandescent, glowing lava. Judging by a dull red glow the temperature of the lava did not exceed 700°. At the moments of explosions small incandescent avalanches were rolling down the slopes of the dome (fig. 27).

On August 27, 1956 the author with a group of employees made an ascent into the crater Bezymianny and, in order to collect samples of fresh lava, approached the base of the dome. In the SW part of the crater at the foot of the dome there was a crater-like bocca, from which dense puffs of gases were emanating. Unfortunately, the danger of a lengthy stay in the crater of an erupting volcano did not permit us to study the structure of the crater with more details (fig. 28).

Late in October we studied the volcano from an airplane (fig. 29). Analyses of pictures taken from the air had shown that in the place where we observed the SW bocca one more dome began to grow. Later measurements, after the end of
the eruption, established that the second dome grew to a height of 260 m. This dome closely adjoined the first one; the common basement of the paired dome was 750 m wide and the summit was 320 m wide.

Late in the autumn of 1956 the eruption was completely over and by December of the same year the domes cooled so much that, with the exception of the top itself, were covered by snow entirely. During the following months the volcano displayed only an intense fumarolic activity (fig. 30).

«Valley of Ten Thousand Smokes of Kamchatka».

The most outstanding event in the eruption of Bezymianny volcano was the gigantic explosion of March 30, 1956 with all the phenomena which accompanied it and especially - the formation in the valley of Sukhaia Hapitsa of a big agglomerate stream with thousands of secondary fumaroles. This picture so vividly reminded the description of the Katmai flow, that we immediately christened this valley as «Valley of Ten Thousand Smokes of Kamchatka» (fig. 31).

We saw the agglomerate flow for the first time three weeks after the eruption from the neighbourhood of our camp No 1. Endless steam jets were merging in the height into one dense cloud, completely hiding the volcanoes Bezymianny and Zimina. Approaching the flow, we discovered that the fumaroles were associated mostly with the southern part of the valley and were grouped along a rather narrow line. Apparently, the fumarole smokes reflected the buried river channels. It should be said that previously this region had a dissected morainic topography, but now it presented a flat plain slightly inclined towards the East. All the ruggedness was buried under a cover of loose agglomerates many meters thick. At this time, in April, the flow was not yet dissected by river erosion and its surface was quite loose (fig. 32).

In details the agglomerate flow was investigated in summer of 1956. By this time its northern edge was cut.
by a deep bed of the river Sukhaia Hapitsa with plumb walls, the surface of the flow was also cut by a whole system of shallow beds of intermittent streams; the surface of the flow also bore evidences of a passage of channelless surface waters and was rather solidly cemented. Under a 2-3 meter solid crust the agglomerate remained loose.

In many points of the agglomerate flow and especially in its upper part, small explosion funnels were scattered. Explosions were taking place already when the flow stopped in its movement and, judging by all signs, were determined by a contact of incandescent material with underlying masses of ice or snow in places of their especially thick accumulations.

The agglomerate flow has rather complex outlines. At the moment of eruption the agglomerate, impregnated by gases, possessed a great fluidity and could not stay on steep flanks of the volcano. That is why there are practically no deposits of agglomerates on the flanks of the volcano and the flow begins seemingly not from the crater, but from the base of the volcano. In the narrow, long pan, which goes from the crater SE with a grade of 4-5°, the agglomerate is partly preserved but the thickness of the flow here is much less than in sections more removed from the crater and this part, contrary to the rest of the flow, cooled rapidly and in autumn of 1956 was partly covered with snow. Hills adjoining the volcano from the E divided the flow into three streams. Two of them (central and southern) merged at a distance of 5 km from the crater and here the flow is the widest - 4 km. The northern branch of the flow divided into two parts, one of which ended 15 km from the volcano near our camp No 4, and the second - followed the bed of Sukhaia Hapitsa and joined the main flow at a distance 10 km from the crater. Further down the valley the width of the flow gradually diminishes and the flow ends 18 km from the crater. At the end of the flow a characteristic swell is located, consisting of roughly rounded boulders of fresh lava. This swell reminds an end moraine line. Similar swells we observed also at the
end of the route covered by incandescent avalanches of Sheveluch volcano (1).

The area occupied by the agglomerate flow is 55-60 km$^2$. The thickness of the flow in the marginal northern part amounts to 20-25 m, in the central part it is, undoubtedly, higher and comes, probably, to 50 m. If we take an average thickness of the flow as 30 m, the volume of the agglomerate flow will come to 1.8 km$^3$. It is difficult to imagine the scale of incandescent avalanches which stormed here under the cover of the impenetrable ashfall.

By summer, fumarolic activity considerably weakened, however, thousands of steam jets still rose from the flow. On a clear, dry day they could hardly be discernible from a distance, but with a rise in the humidity of the air the apparent condensation of the vapours increased, creating the impression of fumarolic activity. The maximum temperature of fumarolic gases was 200°, predominant was the temperature of 100°.

The overwhelming majority of fumaroles was associated with the walls and beds of perennial and intermittent streams. The dependence of the location of secondary fumaroles on the filtration of water was quite obvious.

On clear and hot days mountain glaciers were melting more and water was rapidly increasing in the bed of Sukhaia Hapitsa. The banks consisting of hot agglomerate material were rapidly washed away, creeping down and collapsing into the water. Each such collapse caused a steam explosion — a peculiar "secondary eruption" (fig. 33) during which ashclouds were thrown up to a height of 200-300 m. Especially strong were explosion phenomena on those days when showers of rain were pouring in the mountains and torrents of water were rushing down not only along Sukhaia Hapitsa but also along the beds of intermittent streams and all over the surface of the agglomerate flow, cutting into it and making new channels. On the surface of the agglomerate flow hundreds and thousands of centres of secondary explosions were originating. Sometimes up went fountains of liquid mud (fig. 34), but more
often clouds of ashes and tiny stones. Ashclouds rose to a height of 0.5 km and drifted 2-3 km to a side, sowing ashes. Quite often pisolites were dropping out of ashclouds. On such days our camp No 4 happened to be surrounded sometimes by many dozens of secondary explosion centres. The picture was really bewitching.

The water of Sukhaia Hapitsa was overfilled with loose material forming a thick but very mobile mud, in which big stones were swimming like trees quite easily. Especially strange was it to see how in oxbows after waterfalls the stones were swimming slowly and whirling in the streams of countercurrents. The mass of solid material was 90-95% and a pail of such mud gave by the morning only several centimeters of water. The tremendous amount of hot material collapsing into the water produced a considerable rise in the temperature of cold glacial waters; the temperature of the glacial river Sukhaia Hapitsa rose to 35-45°.

Throughout the winter of 1956-1957 the agglomerate flow remained warm on the surface and was not covered by snow. Fumarolic activity as compared with the summer of 1956 got by May, 1957 much weaker.

As will be shown later, reserves of heat in the agglomerate mass of the flow is still sufficiently great and there is reason to hope that fumarolic and explosions phenomena in the valley of Sukhaia Hapitsa will last for a long time.

**Products of eruption**

During the first period of eruption - during the phase of strong volcanic explosions - the volcano was ejecting a considerable amount of ashes. In all cases under a microscope fragments of glass were discovered in the ashes, hypersthene, plagioclase and small inclusions of magnetite. The glass and minerals had the appearance of sharp-edged little fragments, i.e., the ashes were representing hypersthene andesite crushed in a solid state. The ashes could be a product of crushing action in the old dome or maybe rocks of the strato volcano, or even mixed ashes. The average ashes had a chemical com-
position of a typical andesite. Table 1 gives under No 2 analysis of ash, collected after the ashfall of November 7, 1955 in camp No 2, 12 km from the volcano; for comparison No 1 gives analysis of lava from the strato volcano.

Lavas of the eruption of March 30th by their mineralogical composition differ from the ashes of the Vulcanian stage. - they are more acid hornblende andesites. In lavas of the agglomerate flow the microscope reveals in a hyalopilitic groundmass phenocrysts of plagioclase No 50-55, hornblende and, in smaller quantities, hypersthene. A mixture of magnetite is also encountered. Andesite of the dome differs from the lavas of the agglomerate flow only by the colour of the hornblende: in the agglomerate flow it is predominantly green, while in the dome - brown. In both cases crystals of hornblende are surrounded by an opacite rim.

Ashes which fell from the explosion cloud of March 30th in Kliuchi by their mineralogical and chemical composition were like to lavas of the dome or of the agglomerate flow.

Sand of the directed explosion, taken in the zone of destruction, is a mixture of hornblende and hypersthene andesite, as well as fragments of more basic rocks, apparently from the Kamen volcano - from the basement of Bezmyianny. Fragments of all these rocks are easily distinguishable in larger fractions of sand.

It should be noted that the fraction of smaller clastic material of the agglomerate flow considerably differs by its chemical composition from the blocks of fresh lava. Study of fragments under the microscope, as well as inspection of stones 1-3 cm in size, permitted to establish that the finer clastic part of the agglomerate flow consists of a mixture of the most varied rocks, including basalts of Kamen volcano.

Table 1 gives chemical analyses of rocks connected with the eruption of Bezmyiannaia sopka. Analyses have been done in the chemical-analytical laboratory of the Kamchatka Volcanological station of USSR Academy of Sciences, by I. I. Tovarova.
### Chemical composition of lavas

<table>
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<tr>
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<td>0.77</td>
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<td>100.00</td>
<td>100.26</td>
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</table>

1 - Hypersthene andesite of stratovolcano.
2 - Ashes of the first phase of the eruption. Near the base of the volcano.
3 - Ashes of the eruption on March 30, 1956 (in Kluuchi).
4 - Hornblende - andesite of the first portion of the agglomerate flow.
5 - Hornblende - andesite. Lava of the agglomerate flow.
6 - Fine fraction of the agglomerate flow.
7 - Hornblende-andesite of the new dome.

**Gases.** Some idea of the composition of eruptive gases is given by the analyses of water extractions from fresh ashes. In the anion part of the extractions sulphate-ion prevails (up to 0.5% to the weight of the rock), then follows chlorine (up to 0.2%), always present are carbon dioxide, fluorine and boron.

During heavy ashfalls a smell of sulphurous gas was usually felt; analyses of the air in Kluuchi at the moment of the ashfall on March 30th established the presence of 2.2 mg/1 CO₂ (0.11%), 0.295 mg/1 SO₂ (0.01%) and 0.106 mg/1
HCl (0.006 %). This shows that even at a distance of 45 km from the volcano at the moment of the ashfall considerable quantities of volcanic gases were contained in the air. There is no doubt that in the eruptive cloud at the crater concentration of gases was much higher. It is not surprising that the ashes absorbed a certain amount of gases and, possibly, of volatile sublimates.

In water extractions from the ashes and in the air hydrogen sulphide was not discovered, but during the ascent to the crater and in the flights over the volcano a sharp and definite smell of hydrogen sulphide was felt quite distinctly. This smell is pervading everywhere on the agglomerate flow as well.

Secondary fumaroles of the agglomerate flow are steam jets with a mixture of air and acid gases. So, one of the fumaroles, which deposited sulphur, in September, 1956 had the following composition: (under a temperature of about 100°): 74.3 % of water vapour, 9.9 % of carbon dioxide, 0.3 % of hydrogen sulphide and 15.5 % of air; in addition about 0.01 % of methane was present (analyst L. A. Basharin). The air is poor in oxygen, the ratio of oxygen to nitrogen was 1/48 instead of 1/4 in the atmospheric air. Apparently, intense oxidizing processes are proceeding in the depth of the agglomerate flow, which can partly be connected with the carbonization of plants, buried under the mass of agglomerates. Sometimes a mixture of sulphur dioxide was determined in the fumaroles. In condensates of fumarolic gas also the presence of certain amounts of hydrogen chloride was observed.

Gas, collected after the eruption (in April, 1957) in the crater of Bezymianny at the base of the new dome, consisted of (with the exception of water vapours): 27.2 % of acid gases and 72.2 % of air. The air had a normal ratio of oxygen and nitrogen.

**Sublimates.** Around fumaroles of the agglomerate flow and the dome sublimates were deposited in abundance consisting of a mixture of chlorides and sulphates; some fumaroles were also depositing sulphur.
Earthquakes associated with the eruption

The eruption of Bezymianny was preceded and accompanied by numerous earthquakes. Their registration took place in Kliuchi, 45 km from the volcano with the help of Kirnos seismographs with uniform acceleration 500 in the interval from 0.2 to 10 sec, and Kharin seismographs with a «peak» characteristic (10,000 acceleration on a period of 0.2 sec.). In both cases the registration was galvanometric on photographic paper.

The total number of shocks in Kliuchy during nine months (beginning with October, 1955 up to June, 1956) was 33150; in other words, every 12 minutes there was an earthquake. This vast material is not completely studied yet and we will speak only about the main features of these earthquakes.

The number of earthquakes and their energy are presented in the form of a graph on fig. 35. The lower curve shows the total number of earthquakes for each ten days by months, the upper curve logarithm of seismic energy in ergs for the same periods of time. As the graph shows, the number of earthquakes and their energy do not coincide. The number of earthquakes in the process of eruption was sharply changing, while their energy remained approximately on the same level during a lengthy period of time.

The character of seismicity during the first, preeruptive phase of the eruption was described at the beginning of the preceding chapter. Without repeating the data presented there, we will just point out that during the preeruptive period the number of earthquakes and their energy were rapidly growing and the growth of the energy was surpassing the growth of the number of shocks and by the end of this period the energy of the earthquakes reached its constant value of about $10^{20}$ ergs for ten days, while the number of earthquakes did not reach the maximum yet and was by the end of the period 200-220 shock per day.

At the beginning of the eruptive stage of the eruption
the number of earthquakes rapidly reached maximum values of 350-450 per day (up to 3750 shock per ten days). The absolute maximum of earthquakes for a day took place on November 10 (470 shocks) (fig. 36).

The sharp rise in the number of earthquakes during this period of eruption occurred mainly at the expense of very feeble shocks, which were virtually not reflected in the energy balance. Corresponding estimates show that from the district of Bezymianny volcano our seismic station could confidently register shocks the energy of which was reaching values of about $10^{13}$ ergs, which corresponds to explosions of about $10^{16}$-$10^{17}$ ergs force, i.e. rather moderate volcanic explosions. There is no doubt that a sharp increase in the number of earthquakes was determined by a growth in the intensity of explosions. By the end of the stage of powerful ash eruptions, along with the weakening of explosions began just as sharp a drop in the number of shocks. On November 24th still 303 shocks were registered, while next day their number dropped to 100 for a day. In future such high figures for the number of earthquakes, as in the middle of November, were not observed any more.

Despite the fact that in December, 1955 and January, 1956 the number of earthquakes considerably decreased and the apparent manifestations of volcanic activity considerably diminished, the energy of earthquakes was preserved on the same level and we expected a further development of the eruption.

In February, 1956 a certain increase in the number of shocks was noticeable, which, apparently, was connected with shifts of the old dome and explosions, producing hot avalanches.

Beginning with the end of February a steady drop in the energy of earthquakes was observed. It seemed that the eruption had exhausted its strength and was coming to an end. But just at that time, on the decline of seismic energy, the gigantic culmination explosion of March 30th took place, which was reflected on the curve of the energy as a sharp
«peak». Following this peak seismic energy resumed its steady drop and by the end of June, 1956 the energy of earthquakes dropped to values of $10^{13}$ ergs for one day. Later lower values of energy we did not calculate.

Despite a general drop in the seismic energy during the phase of growth of the dome, the number of shocks in April and May, 1956 was obviously growing and during some days in April reached practically 300 per day. This increase in the number of shocks was, apparently, connected with the processes of growth of the new dome. By the end of June the number of earthquakes dropped to 1 a day. By this time the dome was mostly formed completely.

An extremely weak seismic activity continued, gradually dying down, until the end of 1956.

All earthquakes, associated with the eruption of Bezymianny, sharply differ from usual local tectonic and volcanotectonic earthquakes by their large period (2.5-3 seconds, instead of 0.2 sec) and a peculiar maximum phase after the arrival of S wave. All larger earthquakes with the minutest details repeated each other and had the same source and cause; they had a greater depth (about 50 km) and originated, apparently, within the magmatic reservoir or in the lower part of the volcanic channel. A peculiar form of recording of these earthquakes could have been explained, maybe, by the propagation of elastic waves through the liquid magmatic reservoir.

The number of earthquakes and partly their energy were in direct association with the process of eruption, but, as stated above, the curve of the number of earthquakes and of their energy did not coincide. The reason of this noncoincidence lies in the fact that in computing the number of shocks all oscillations were taken into consideration, including even the very feeble ones, associated with volcanic explosions and other surface phenomena. The energy characteristic depended mainly upon the stronger shocks, all of which, without exception, had a greater depth and were a consequence of deeper volcanic processes, which determined the *general course* of the eruption.
Some phenomena, associated with the explosion of March 30

The explosion of March 30th was followed by a strong earthquake, the records of which sharply differ from the records of thousands of preceding shocks. All preceding shocks were damped in 5-10 minutes, while this earthquake was recorded, gradually damping during 50 minutes. Judging by the first arrival, the earthquake had a hypocentre at a depth of about 50 km and should have been over rapidly; its lengthy duration, is due, apparently, to a recording of a surface explosion superimposed upon the record of the first earthquake.

During two days preceding the explosion 2-4 weak earthquakes were taking place every hour. During the 15 hours which followed the explosion the number of shocks even dropped, and then, beginning with 10 a.m. of March 31st a practically uninterrupted recording began, reminding spasmodic volcanic tremor with $T = 1$ sec. and $A = 1 \mu$. Beginning with early April 1st the record became uninterrupted, the period increased up to 1.2 sec. and the amplitude up to 1.5-1.8 $\mu$. Since 8 a.m. the vibration got weaker and since 4 p.m. the vibrations acquired a discontinuous character and began to disappear. As a whole the record reminded a spasmodic volcanic tremor; it could also have been a conjoint recording of incessant weak earthquakes, which reflected the establishment of the depth equilibrium disturbed by the catastrophic explosion.

It is interesting to point out that the explosion of March 30th was not heard neither near by nor at a distance; some observers mentioned only a feeble muffled rumble. At the same time all meteorological stations within a radius of at least 1000 km registered on their barograms a distinct blast \(^{\circ}\) (fig. 37). The rotation speed of the cylinder on usual station barographs is small, which makes the precision in determining

\(^{\circ}\) Microbarographs recorded the blast on all the world. The blast air wave went round the world one and a half time.
the time on barograms not very accurate. Consequently it was not possible to determine the velocity of propagation of the blast in the neighbourhood of the volcano with a sufficient accuracy. In the first approximation this velocity for different directions proved to be not uniform. In the western direction it was somewhat less than the sound velocity; in the eastern - somewhat higher (for a distance of 120 km). Such a difference is undoubtedly determined by the eastward direction of the explosion.

Comparison of the blast amplitude on different stations stresses the influence of the directed explosion even more definitely. So, for instance, in Kliuchi and Kozyrevsk, at the same distance from the volcano (45 km) the amplitude was 23.5 and 11.0 millibars correspondingly; for Ust-Kamchatsk and Esso (120 km from the volcano) it was 7.5 and 5.0 millibars (it should be remembered that these points are located in two opposite directions from the volcano). The amplitude of the blast is inversely proportional to the distance from the volcano; If the distance to the points is determined where the amplitude of the wave is 1 millibar, it will then correspond to 900-1000 km to the East, and only 500-600 km to the West. Actual data coincide with the expected.

A side effect of the explosion was the formation of seiches in the mouth of the river Kamchatka. During the explosion the tide was at its maximum and conditions of a closed water reservoir were created in the mouth of Kamchatka river. The blast resulted in the formation of standing waves - seiches. Their double amplitude came to 10-12 cm, and the period to 18.5 min. (fig. 38). At 10.30 a.m. on March 31st a full ebb was in action and conditions of a closed basin were discontinued and seiches disappeared.

It should also be noted that during the ashfall on March 30th a sharp increase in air humidity was observed in Kliuchi (fig. 39), though the ashes were falling dry. At the moment of eruption the humidity was about 50%; with the beginning of the ashfall it began to rise and at 7 p. m. reached 63%.
after which a rapid increase in humidity up to 93% occurred and beginning with 7.20 and up to 9 p.m. a drop to 67% took place. It should be remembered that by 9 p.m. the ashfall was coming to an end and patches of clear sky began to show. In such a way during the ashfall in addition to volcanic gases there was also an increase in the atmosphere of water vapours, which was, it seems, directly connected with the eruption.

Let us try to estimate the energy of the blast on March 30th; we have several ways for this. *)

1. Having calculated the energy of the earthquake, connected with the explosion and considering that during the explosion about 0.1% of the total energy is discharged as seismic energy, it is possible to evaluate the force of the explosion. The energy of the earthquake was determined by surface waves with the help of a nomographic chart, suggested by N. V. Shebalin (3). The average value of the energy according to data from five seismic stations of the Far East (Petropavlovsk, Magadan, Yuzhno-Sakhalinsk, Kurilsk and Vladivostok) amounts to \( E = 10^{20} \) ergs. From this the total energy of the blast is \( 10^{23} \) ergs.

2. The energy of the blast can be evaluated according to the air wave of the blast. For the energy of an air wave Taylor offers a formula (6):

\[
E = \frac{2 \pi R H \sin \varphi}{\varrho_0 V} \int P_0^2 \, dt \quad [1]
\]

Where \( R \) - radius of the earth, \( H \) - height of a uniform layer of the atmosphere (13000 m), \( V \) - sound velocity, \( \varrho_0 \) - density of the air at the ground, \( \varphi \) - distance from the source of explosion in degrees.

Replacing in formula [1] numerical values of the symbols we get:

\[
E = 1.25 \times 10^{14} \sin \varphi \int P_0^2 \, dt \quad [2]
\]

*) Preliminary data (2,9) have been somewhat changed and made more precise in this report as a result of later computations.
Replacing in [2] \( P = A \sin \omega t \) we have:

\[
E = 1.25 \times 10^{20} \sin \varphi \Sigma \frac{A^2 t}{2} \tag{3}
\]

Here \( A \) - amplitude of the wave in meteorological millibars, \( t \) - in seconds and \( E \) - in ergs.

For Kliuchi the energy is estimated to be \( 6.4 \times 10^{22} \) ergs; by data of other meteorological stations the energy of the air wave was somewhat less. The average value for the energy of the air wave according to records of eight meteorological stations, situated at a distance from 45 (Kliuchi, Kozyrevsk) up to 760 km (Kamenskoe in the mouth of the river Penzhina), is \( 3 \times 10^{22} \) ergs. This twenty times exceeds the energy of the air wave from the explosion of the largest hydrogen bomb (\( 1.4 \times 10^{21} \) ergs, according to Yamamoto (7)). But this does not mean that the energy of the explosion of Bezymianny 20 times exceeds the force of the explosion of a hydrogen bomb (\( 4 \times 10^{23} \) ergs). In a hydrogen bomb not more than 0.3% of the entire energy goes over into the air wave. During volcanic eruptions into an air wave is, apparently, transferred about 10% of the entire energy, i.e. the total energy of the explosion at Bezymianny, according to these data, is approximately \( 3 \times 10^{23} \) ergs.

The determination of the energy of an air wave is a rather simple problem and a comparison of energy of various volcanic explosions would be convenient by the energy of the air waves formed. With this purpose all volcanological stations should be equipped with microbarographs, in order to be able to register large volcanic explosions of any volcano on the Earth and weaker explosions in the vicinity of the station.

3. The energy of the explosion could be determined by the mass and velocity of ejected material, according to the formula:

\[
E = \frac{mV^2}{2} \tag{4}
\]
The mass of ejected material can be roughly appraised by the volume of the crater formed. At an average diameter of 1000 m and depth of crater of 600 m, its volume is determined as 0.5 cubic kilometers and the mass of ejected material at a density of 2.4 as $1.2 \times 10^9$ t.

The original velocity of the explosion can be determined by the distance to which the material has been ejected, considering the angle of ejection. A maximum distance of a body ejected obliquely is achieved at an angle of ejection of 45°, which approximates the explosion angle at Bezymianny. By the explosion of March 30th eruptive material has been transferred to a distance up to 25 km and at the same distance trees have been broken by the force of the explosion. Let us accept the range of « shot » as 25 km. Then according to formula

$$V_0 = \sqrt{rg}$$  \[5\]

the original velocity will be 500 m/sec. Actually this velocity was, apparently, even higher, because we did not consider air resistance. The original velocity approached, probably, 600 m/sec. i.e., it exceeded the sound velocity practically twice. It becomes clear why for near by meteorological stations, located in the direction of the blast the speed of the blast exceeded sound velocity.

The maximum velocity of the blast, apparently, should not be used for the determination of the energy, because the average velocity was somewhat lower. A mass drop of eruptive material was observed at a distance up to 13 km from the volcano, which corresponds to the initial velocity of 360 m/sec. This velocity we are going to use.

Putting in the established values of mass and velocity into formula \([4]\) we will find kinetic energy of the blast amounting to $8 \times 10^{23}$ ergs.

As we see, the blast energy determined by three independent methods, despite all the approximation in computations, generally speaking coincides, keeping the value of $n \times 10^{23}$ ergs. The average value of the explosion of March 30th amounts to $4 \times 10^{23}$ ergs.
It is possible also to evaluate the original pressure at the moment of explosion. Matuzawa thinks (4) that at the moment of explosion the Bernoulli law remains actually valid for pressure and velocity of the ejected material, i.e.

$$P = \frac{\rho V_0^2}{2} \quad [6]$$

where $P$ - is pressure, $\rho$ - density of the material, $V_0$ - initial velocity. From this for a velocity of 500 m/sec a pressure of 3000 atm. is obtained, and for a velocity of 360 m/sec - 1500 atm.

Judging by the volume ($1.8 \text{ km}^3$) and mass $3.3 \times 10^8 \text{ t}$ of the agglomerate flow, the thermal capacity of the rocks ($1.1 \times 10^9 \text{ ergs}$) and the temperature of the explosion (about 600°), the heat energy of the eruption is determined at $2.2 \times 10^{25} \text{ ergs}$. In such a way the energy of the explosion is only about 2% of the total heat energy of the eruption. This result is most remarkable from the point of view of the role of heat and energy of gases in the process of eruption. As we see the energy share of gases is more than modest. From this point of view the old premises that «gas is the active agent and the magma is a vehicle» (5) should be critically reconsidered. Apparently, the main active agent of the eruption is the heat energy of the magma, and gas only serves to transform this energy into an explosive one and the efficiency of a volcano as a heat engine is very low.

**Conclusion**

Summarizing some numerical values for the eruption of Bezymianny we get the following results: total energy of the eruption - $2.2 \times 10^{25} \text{ ergs}$, explosion energy on March 30th - $4 \times 10^{23} \text{ ergs}$, volume of material ejected by the explosion - about 1.0 km³, its weight $2.4 \times 10^9 \text{ t}$. Volume of agglomerate flow - about 1.8 km³, its weight - $4.3 \times 10^9 \text{ t}$. Initial velocity of the explosion up to 500-600 m/sec. Initial pressure up to 3000 atm. All these figures characterize the eruption of Bezymianny as really gigantic.
The Bezymianny eruption, by its force, stands in one row with the eruptions of Krakatau, Katmai and Mt. Pelée. By its character, it is very close to Katmai eruption.

A comparison of the eruptions of Bezymianny and Katmai permits, it seem to us, to establish some errors in conclusions regarding the formation of the Katmai agglomerate flow and the eruption of Katmai in general. Owing to lack of space and time I am not going to discuss this in detail here; in the near future I hope to make a special report devoted to this subject.

BIBLIOGRAPHY


Fig. 1 - Areal map of the location of Bezymianny volcano among other volcanoes of Northern Kamchatka. ▲—volcanoes, ■—settlements.

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(Photograph by the author).
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