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THE DIRECTED BLAST PHASE OF THE ERUPTION OF BEZYMYANNYI VOLCANO IN 1985

M. A. ALIDIBIROV, A. B. BELOUSOV, AND N. M. KRAVCHENKO

Institute of Volcanology, Far East Scientific Center, USSR Academy of Sciences

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The article is devoted to the consequences of a directed blast during an eruption of Bezymyannyi Volcano in 1985. Information is given on the morphology and structure of the deposits of the directed blast. A map of the explosion deposits has been compiled, and the area covered by the deposits and their volume have been determined to be 7 km^2 and 0.001 km^3 respectively. The results of the study of the deposits are used to reconstruct eruptive events during the culminating stage of the eruption.

The most recent eruption of Bezymyannyi Volcano occurred between June 12 and December 14 1985. In the period before the culminating stage of the eruption growth of an extrusive dome was noted on the Novyi (New) dome; by June 30 it had risen to approximately 100 m above its base. During the explosive culminating stage of the eruption on June 30 - July 1, 1985 the extruded block and a part of the dome were destroyed and extensive deposits of an ash and block pyroclastic flow extending for 80 m were formed.

The trench formed by abrasion that existed in the eastern part of the dome before the last eruption has been appreciably deepened and broadened. The pyroclastic flows that poured out in the culminating stage reached a length of 13 km.

Specific pyroclastic deposits extending for a distance of several kilometers from the foot of the volcano were discovered in a preliminary examination of the area around Bezymyannyi; these deposits were morphologically different from the pyroclastic flow deposits. Two observation huts 3.5 km from the dome that had been used by volcanologists were destroyed and their remains were dispersed in a direction away from the volcano.

Further study of the consequences of the culminating explosive stage of the eruption led us to conclude that there had been a "directed blast" at this period on the volcano. Our tasks included study of the morphology and structure of the explosive deposits, determination of their volume and the area covered by them, and determination of the position of the phase of the directed blast in the course of the culminating stage of the eruption.

Morphology and structure of the deposits of the directed blast

In this paper we shall use the term "sand of the directed blast" to describe the pyroclastic material relating to the phase of the directed blast. This term was first brought into use by G. S. Gorshkov and G. E. Bogoyavlenskaya [3]. Foreign researchers use the term pyroclastic surge to describe similar or quite similar explosion deposits, but it is ambiguous and, in our view, less successful for description of the pyroclastic material of an entire class of volcanic eruptions.

In July-August 1985 the authors, together with N. E. Grushko, studied and mapped the sand deposits of the directed blast. The map of the deposits is reproduced as Fig. 1, the sand of the directed blast was deposited as gentle hills and relatively even sheets. This region, which is largely hills, is distinguished on Fig. 1 as zone I, while the region occupied by sheet deposits is

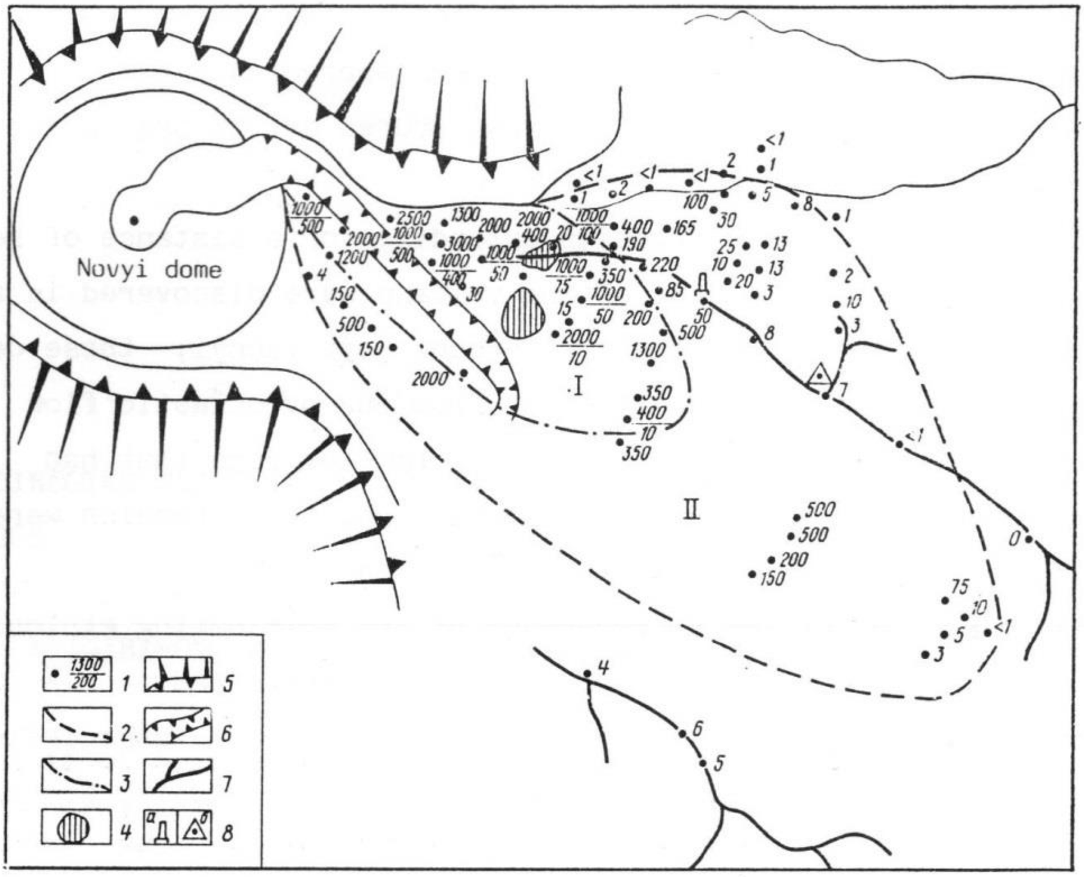

Fig. 1. Sketch may of sand deposits of the directed blast. 1 - thickness of sand, mm; 2 - outer limit of deposits; 3 - limit of zone I; 4 - elevations in the topography; 5 - walls of the 1956 caldera; 6 - canyon; 7 - ridges; 8 - a - observation hut, b - triangulation point.

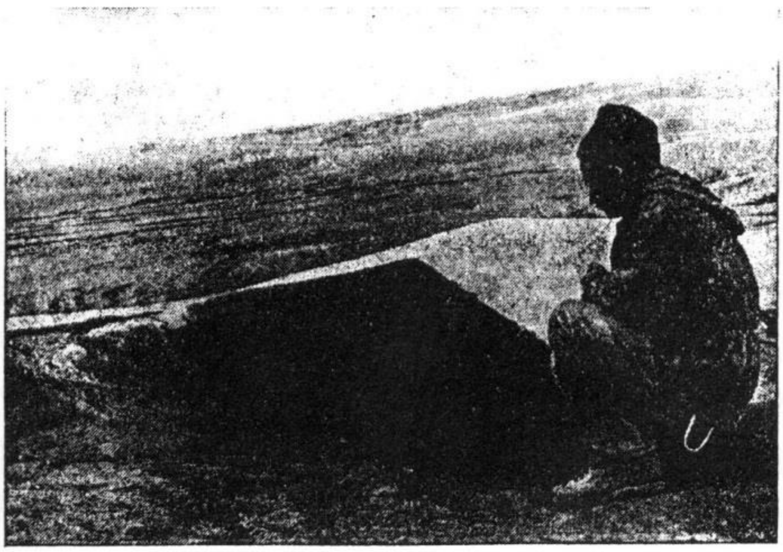

Fig. 2. Sand hill at the boundary of zones I and II. Photograph by A. B. Belousov.

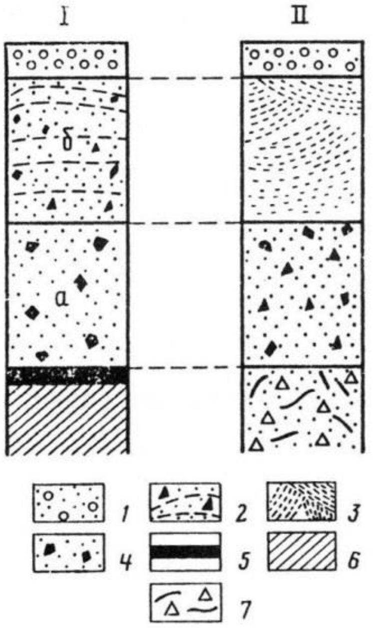

Fig. 3

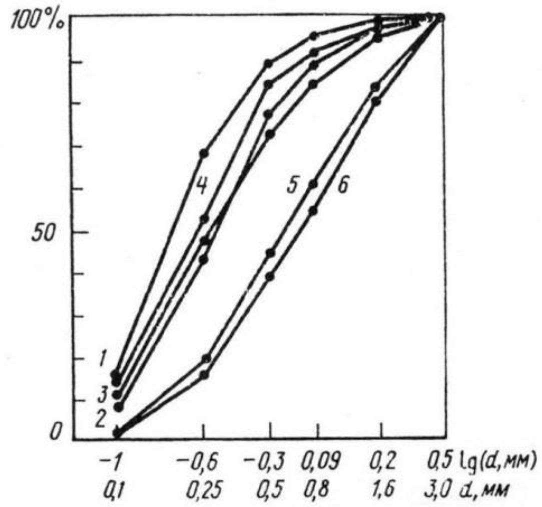

Fig. 4

Fig. 3. Sections of layered sand deposits of a directed blast. I - Bezymyannyi Volcano; II - Mount St. Helens; 1 - accretionary lapilli layers (Bezymyannyi Volcano) and accretionary lapilli unit (Mount St. Helens); 2 - layer b: layered medium-fine-grained sand containing andesite fragments; 3 - surge unit layer (Mount St. Helens); 4 - layer a: coarse-grained, poorly graded sand containing andesite fragments (Bezymyannyi Volcano) and massive bed (Mount St. Helens); 5 - ash of Bezymyannyi Volcano (initial stage of 1985 eruption); 6 - deposits of preceding eruptions of Bezymyannyi Volcano; 7 - basal unit layer (Mount St. Helens).

Fig. 4. Cumulative particle-size curves of samples of sand from a directed blast. The figures correspond to the numbers of the samples indicated in the text. See the text for clarification.

distinguished as zone II.

Size gradation of the hills was observed within zone I. At the foot of the Novyi dome for a distance of 1700 m from its summit the hills were greatly smoothed and about 1 m high. The highest hills were located at a distance of 1700-2600 m, where their height was on average about 2 m. In plane section the hills were elongated, extending away from the volcano, with mean linear dimensions of about 8 x 4 m. With distance from the volcano the size of the hills reduced to tens of centimeters and they gradually gave way to relatively level cover. On Fig. 1 fractions are given for a number of sections: the height of the hill is indicated in the numerator, the thickness of the sand between in the denominator.

When studying the sections of the hills near the boundary between zones I and II we distinguished two main types of deposits: arenaceous and layered. A typical sand hill is shown on Fig. 2, and a typical section of a layered hill on Fig. 3. The lower layer a (see Fig. 3) consists of coarse-grained, poorly graded sand containing a large quantity of andesite fragments measuring up to 2 cm. There is no fine layering. The thickness of layer a is between 10 and 50 cm. This layer usually has a fine ash layer about 1 cm thick beneath it. The upper layer b lies directly on the deposits of layer a and consists mainly of medium-grained sand, with fine-grained sand in the upper part; the sand, which is well graded, contains occasional fragments of andesite (0.5 - 1 cm) and is clearly layered. These fine interlayers are usually parallel to the surface of the hills and vary in thickness from between a few centimeters to millimeters. The thickness of the upper layer reaches 40 cm in some places.

The bulk of the pyroclastic material deposited within zone II consists of fine-grained layered light sand similar to the sand from the upper layer b of the hills near the boundary of zones I and II. However, the sand deposits of the directed blast in zone II are mainly sheet deposits varying in thickness from 10-15 cm to a few millimeters.

The sand of the directed blast deposited as large hills near the volcano in zone I looks quite like the sand from the lower layer of the hills at the boundary between zones I and II, while the sand from the sheet deposits in zone II is closer to the upper layer b from the "boundary" hills. The results of particle-size analysis of the sand from the directed blast are depicted on Fig. 4. Samples 1 and 4 are light, fine-grained sand from layer b, while samples 2 and 3 are dark, coarser-grained sand from layer a of the hills (see the section on Fig. 3). The coarse-grained sand of the warm hills near the volcano in zone I is represented by samples 5 and 6. We give below the mean-weighted particle diameters

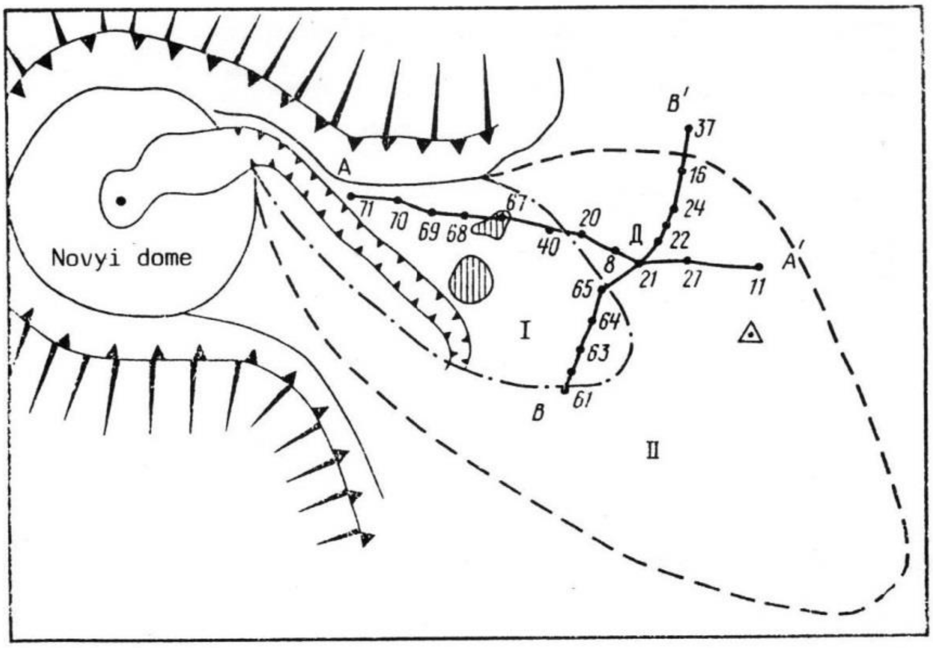

Fig. 5. Map of deposits from the directed blast. The figures on profiles AA' and BB' are the numbers of the sections. See Fig. 1 for a key.

of samples 1 - 6, determined as $d_{mn} = 1/\Sigma\frac{x_i}{d_i}$,

where x_i is the bulk proportion of particles of diameter d_i.

	n	1	2	3	4	5	6
d_{mn},	mm	0.15	0.21	0.19	0.17	0.38	0.41

Profile sections AA' and BB' in the axial and transverse directions depicted on Fig. 5 were worked in the region of deposits of sand from the directed blast. Sections along these directions are given in Fig. 6,a,b. The decline in the thickness of the deposits with distance from the volcano (along the profile AA') is apparent on Fig. 6,a. The relationship is illustrated on Fig. 7. One of the sections given on Fig. 6,a is considerably thinner than all the others. The explanation is that the point concerned was within what is known as the shadow zone. The profile depicted on Fig. 6,b indicates only a part of the sand deposits of the directed blast, since the southwestern sector of its deposits was covered in the course of this eruption by pyroclastic flow deposits and was not therefore distinguished by us.

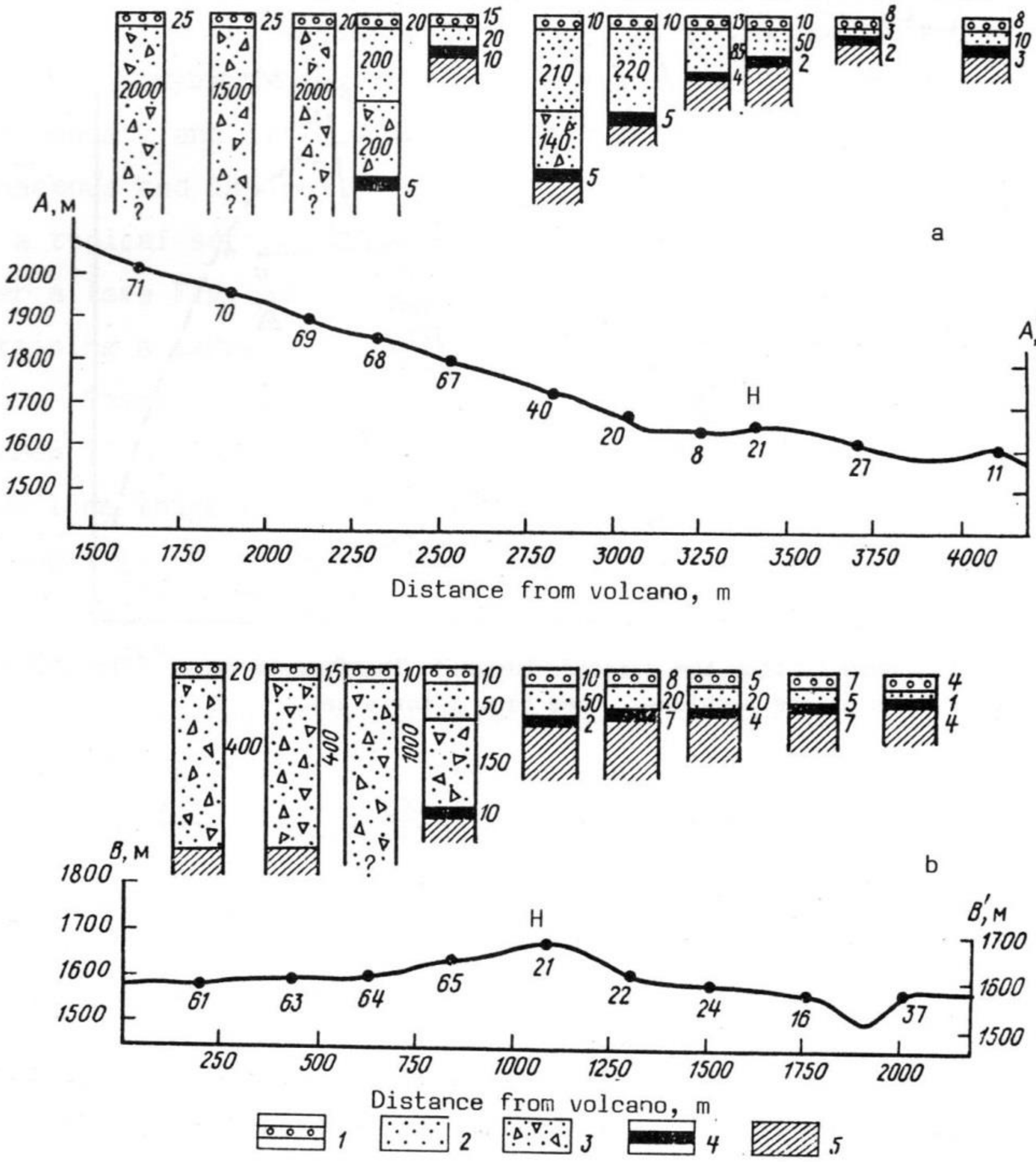

Fig. 6. Sections along the profiles AA' (a) and BB' (b). 1 - layers of ash and accretionary lapilli; 2 - fine-grained sand; 3 - coarse-grained sand; 4 - ash from initial stage of eruption; 5 - deposits of previous eruptions. A column is given for each section, to the right of which the thickness of the deposit (m) is stated. H - observation hut.

It is interesting to compare the deposits of directed blasts on Bezymyannyi Volcano in 1985 and Mount St. Helens in 1980. The structure of these deposits is depicted in Fig. 3. On comparison of two typical sections of the sand deposited in the course of the directed blast, it is evident that a basal unit was lacking in our case. In the opinion of the authors of [4] the lack of this unit is due to intensive erosion of the vegetation and soil by the gas-pyroclastic mixture. However, the sand deposits of the directed blast on Bezymyannyi Volcano are universally underlain by a layer of ash of the initial stage of the eruption. Sand layer a is similar in its lithologic characteristics to the "massive unit" layer, while layer b is similar to the "surge unit" in possessing thin parallel and oblique layering, and also in having well graded material. The uppermost layer in both cases consists of fine ash with accretionary lapilli.

Consequently, the main difference between the sections depicted in Fig. 3 is the absence of a basal layer for Bezymyannyi Volcano and the presence of ash of the initial stage of the eruption for it laying beneath the sand deposits of the directed blast. The general features of the deposits of both eruptions are a gradual reduction of thickness and a reduction of the grain size of the sand with distance from the volcano, as well as the existence of shadow zones and regions with hilly, "dune-like" topography.

The effect of the phase of the directed blast and reconstruction of the eruptive events

The area covered by the sand deposits of the directed blast is depicted in Figs. 1 and 5. Its outer limit corresponds to the points at which the thickness of the sand does not exceed 1 mm. This area is fairly asymmetric in shape, its maximum extent in the axial direction being about 6 km, and transversely about 4.5 km. The total area covered by the deposits of the directed blast is approximately 7 km^2.

In determining the volume of the sand of the directed blast use was also made of the map of the deposits given in Fig. 1. The area of the deposits was divided into squares with 200 m sides, for which mean thickness was determined. In so doing allowance was made for the hilly topography of the deposits in zone I. The total volume of deposits determined in this manner proved to be around 10^6 m^3 or 0.001 km^3.

Two huts used by volcanologists 3.5 km from the volcano were

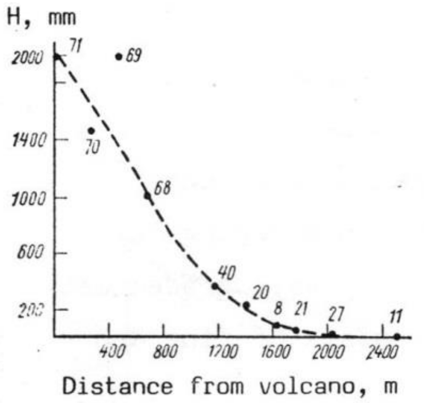

Fig. 7. Alteration in thickness of sand from the directed blast along the profile AA' with distance from the volcano.

completely destroyed, and fragments of them were transported for a distance of up to 1 km. The azimuth of the dispersion approximately evaluated from 100 fragments was 110°, which coincided with the direction to the volcano. The surviving corner planks of the hut partly shielded by the slope from the direct effect were bent and torn off in the same direction. On the benchmark located about 1 km from the destroyed huts there were traces of erosion on the side facing the volcano. Individual small stones and particles of sand had been driven into the wood to a depth of 2-3 mm. There were no other signs of destruction in the vicinity of the volcano since there had not been any vegetation there at the time of the eruption.

The indicated nature of the destruction and erosion is evidence of the velocity effect of the gas and pyroclastic mixture coming from the direction of the volcano. However, the limited nature of these data rules out the compilation of any detailed picture of the field of flow in the region covered by the directed blast. All that can be done is to make an approximate estimate of the rate of the gas and pyroclastic flow at the point of destruction of the huts. Such estimates show that a velocity of the two-phase mixture of about 50 m/s would have been quite adequate for the destruction.

The temperature of the gas and pyroclastic mixture at the time of the directed blast may be estimated as at least 150° C. One month after the blast the temperature of the sand in the hills was about 60° C. The estimate of the temperature of the gas and pyroclastic mixture is based on the presence of traces of melting of polytheylene objects found around the destroyed huts. These temperatures are far lower than the temperatures of the pyroclastic flows which, according to observations at the time of the eruption, reached 700° C.

Consequently, the existence of an area covered in specific pyroclastic deposits, and the velocity and temperature effect on the environment justify us in speaking of an extraordinary event during the culminating explosive stage of the 1985 eruption of Bezymyannyi Volcano. We classify that event as a directed volcanic blast. The most characteristic feature of explosions of that kind is the directed escape of a gas and pyroclastic mixture with an essentially horizontal component [2. 3. 5].

In contrast to large directed blasts like the blasts of Bezymyannyi in 1956, Shiveluch in 1964 and Mount St. Helens in 1980, the directed blast of Bezymyannyi in 1985 was on a far smaller scale and was not acompanied by any appreciable destruction of the volcanic structure. However, study of even such a small-scale event has led to information of importance for an understanding of the mechanism of an entire class of volcanic explosions.

Let us pause to consider the place of the directed blast phase in the course of the culminating stage of eruptions as it emerges from observations of the eruption and study of the deposits of the directed blast. An ash horizon lying beneath the sand of the directed blast is a characteristic feature of almost all sections of the deposits of a directed blast. This is clearly apparent in Figs. 3 and 6. Observations during the culminating stage of the eruption showed that ash deposits in the vicinity of the volcano were formed from the fallout of ash clouds rising above the pyroclastic flows. Eruption of a series of pyroclastic flows was observed at 20 h 30 min on June 30. In our view, it is the ash fallout from the clouds that accompanied the pyroclastic flows of this series that occurs beneath the sand deposits of the directed blast. The upper horizons of the ash with accretionary lapilli in sections of the deposits from the directed blast (see Fig. 6,a) is most probably connected with the formation of the final series of pyroclastic flows at 3 h 20 min on July. It was at that period of the eruption that fallout of accretionary lapilli from the ash cloud that had accompanied the pyroclastic flows was observed at the volcanologists' camp 8.5 km from the dome. It may be concluded from the facts as described that the phase of the directed blast occurred betwen two series of pyroclastic flows observed at 20 h 30 min on June 30 and 3 h 20 min on July 1, 1985. It is possible that the noise like a jet engine that was heard about 3 o'clock in the morning on July 1 accompanied a high velocity escape of a gas and pyroclastic mixture that preceded the last series of pyroclastic flows.

The sand of the directed blast, the volume of which is estimated by us at 10^6 m^3 resulted from explosive destruction of a congealed or practically congealed melt. In a rough approximation the volume of the gasified melt may be treated as equivalent to the volume of the sand of the directed blast. In that case the linear dimension of the volume of the gasified magma should be about 100 m. A knowledge of the porosity of the original material and the natural density of its composition would be needed for accurate estimates, but the place of this "charge" immediately before the directed blast is coming to be of interest.

Analysis of the asymmetric nature of the sand deposits of the directed blast, having regard to the effect of the "directivity" of the deposits, and comparison of the morphology of the Novyi dome before and after the culminating stage lead us to assume that part of the structure of the dome associated with the abrasion trench had been destroyed by explosion. It was precisely in the upper part of the trench that there was an extrusive obelisk destroyed during the culminating stage of the eruption. Following the culmination the area of the abrasion trench approximately on the level of the middle of the dome remained active for a long time. During the night of July 2-3 the glow of molten material was observed there; on July 30 a pyroclastic flow formed, and in September-October 1965 a block of the dome was extruded. The assumed site of the "charge" itself explains the direction assumed by the escape of the gas and pyroclastic mixture. In fact, the walls of the abrasion trench could in this case have directed the gas and pyroclastic flow in a definite direction. The wall of the explosion crater formed in 1956 could in that case have "screened" the flow, resulting in the asymmetric nature of the deposits after the directed blast in a northeasterly direction.

Consequently, analysis of the observations made at the time of the eruption and the data obtained as a result of study of the deposits of the directed blast shows that the directed blast occurred between the outpouring of series of pyroclastic flows and took place from an area of the dome associated with the abrasion trench.

The active crater was the site of the predominant outflow of pyroclastic flows, while the area of the dome below the crater was the "charge" of the directed blast. This also explains the place occupied by the directed blast phase in the course of the culminating stage.

Let us now consider the mechanism of directed blasts. There is not as yet a theory of these explosions, but in our view the approach briefly set out in [1] is extremely important for an understanding of the phenomenon of a directed blast. Essentially the approach is as follows. If we have a volume of a highly viscous or congealed magma melt containing gas-filled pores (having a pressure in excess of atmospheric pressure), fragmentation of that volume may occur on decompression. The rate of release of the energy of the compressed gas will be determined by the rate of advance of the fragmentation wave deep in the gasified congealed melt. However, the creation of an appropriate discharging pressure drop is an essential condition. A powerful rockfall process in the culminating stage of the eruption on Bezymyannyi Volcano in 1985 may evidently have been just such an initiating factor for the directed blast.

Conclusions

Let us single out some of the main results obtained in the study of explosion deposits and the analysis of observations made during the 1985 eruption of Bezymyannyi Volcano.

1. During the culminating explosive stage of the eruption between June 30 and July 1, 1985 there was a directed blast resulting from fragmentation of the inner gasified part of the Novyi dome uncovered as a result of a rockfall. A volume of gasified magma (with a characteristic linear dimension of about 100 m) in the area of an abrasion trench on the southeastern slope of the Novyi dome underwent explosive destruction.

2. Study of the sand deposits of the directed blast has led us to conclude that the directed blast phase occurred in the interval between the eruption of two series of pyroclastic flows. The layering of the sand deposits of the directed blast indicates comparatively lengthy and, possibly, repeated escape of gas and pyroclastic material.

3. The area covered by the sand deposits of the directed blast is about 7 km, and the volume of the deposits around 0.001 km^3. The limit of the deposits furthest removed in the axial direction is about 6 km from the Novyi dome. Study of the consequences of the destruction of the observation huts 3.5 km from the volcano has shown that the flow of the gas and pyroclastic mixture at that place was away from the volcano (along an azimuth of 110°), that the velocity was about 50 m/s and the temperature $\geq$ 150° C.

The results obtained enable us to regard the directed blast phase of this eruption as an interesting and extraordinary event for the volcano, similar in nature to the large directed blast on the same volcano in 1956, but differing in its appreciably smaller scale. The results set out above may be used subsequently for the construction of realistic models of directed volcanic blasts.

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