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Bezymyannyi Eruption on March 30, 1956 (Kamchatka): Sequence of Events and Debris-Avalanche Deposits

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A detailed reexamination of the deposits and comparison with the descriptions of the eruption revealed that on March 30, 1956, a collapse and a landslide 0.5 km^3 in volume took place on the eastern slope of Bezymyannyi (Central Kamchatka). After a series of explosions, an old dome was slowly uplifted by rising magma, and a cryptodome intruded the eastern flank prior to a cataclysmic explosion. A rockslide changed to a cold (< 100°C) debris avalanche which rushed down at a speed of more than 60 m/s and covered a distance of 10 km from the volcano. The avalanche split into three branches that flowed along the river valleys. The central flow covered the largest distance (22 km). The avalanche stripped and pushed the material at the volcano's foot (snow, soil, alluvium, and vegetation), which produced long mud flows. The landslide unroofed the cryptodome and triggering a devastating lateral blast followed by the eruption of pyroclastic flows.

INTRODUCTION

Bezymyannyi Volcano is a member of the Klyuchevskoi volcanic group situated in the central part of the Kamchatka Peninsula. Its eruption of March 30, 1956, was among the greatest explosive eruptions of the 20th century. Proceeding from its unusual effects, such as the devastation of the cone, the creation of a horseshoe-shaped crater 2 km across, the trees felled in one direction within a range of 25 km at the eastern foot, and a peculiar character of the deposits, G. S. Gorshkov and G. E. Bogoyavlenskaya [10] classified this eruption as a Bezymyannyi-type lateral blast. They also identified a specific type of blast-related deposits: (1) lateral-blast agglomerate and (2) lateral-blast sand. The agglomerate consisting of thick, coarse, resurgent, poorly sorted pyroclastic materials, hilly on the surface and spread along the axis of the devastated zone, were interpreted as the material of the old cone ejected by the explosion. The lateral-blast sand occurs as a thin, fine-grained juvenile pyroclastic material deposited around the agglomerate over the entire area of the felled forest. These deposits were believed to be comparable with the deposits of the nuee ardente that broke through the crater after the thrown out dome material.

Gorshkov and Bogoyavlenskaya [10], [26] classified the mechanism of the eruption as an "excavating explosion". They believed that the free liberation of volcanic gases had been prevented by the old dome which had plugged the vent and later thrown out ballistically by a lateral blast. They associated the lateral direction of the blast with the nonuniform strength of the cone slopes. This interpretation caused debates. For instance, Ryabinin and Rodionov [16] calculated that the huge crater produced at Bezymyannyi by the 1956 eruption had required a volume of steam that could not be contained in the volcano's edifice. Adushkin *el al.* [1] demonstrated that the airwaves recorded during the 1956 eruption could not be produced by the blast of that size. Gushchenko [11] proposed a few unconventional mechanisms for the eruption because of a problematic source of energy for an explosion as great as that. In spite of these contradictions, many volcanologists [4], [5], [14] supported the sequence of events, the mechanism of the eruption, and the genesis of the resulting deposits proposed by Gorshkov and Bogoyavlenskaya [10], [26]. Later a lateral-blast agglomerate was discovered among the products of the November 12, 1964, eruption at Shiveluch. This fact served a basis for classifying that eruption as a lateral blast [4], even though no lateral-blast sand was found among its deposits.

Interest in lateral blasts increased greatly after the catastrophic Mount St. Helens eruption of May 18, 1980 [27], which showed a great resemblance to the 1956 Bezymyannyi eruption [4]. Visual observations, as well as the video, photo, and motion picture filming of the Mount St. Helens eruption, indicated that it had begun with a large rockslide avalanche which was followed by a lateral blast. The landslide was transformed to a debris avalanche whose deposits turned out to be similar to the lateral-blast agglomerates of Bezymyannyi and Shiveluch. The Mount St. Helens lateral-blast deposits were similar to the lateral-blast sand of Bezymyannyi. The results of the study of the Mount St. Helens eruption and deposits suggested a new approach to the interpretation of the character and sequence of events of the 1956 Bezymyannyi and 1964 Shiveluch eruptions. Our reexamination of the materials deposited by the Shiveluch eruption confirmed the rockslide-avalanche genesis of its "agglomerate" and proved that no lateral blast had occurred there on November 12, 1964 [2], [19].

In this paper we present the results of our reexamination of the debris-avalanche material deposited by the 1956 eruption of Bezymyannyi and discuss its lateral-blast agglomerate and its relations with the other deposits of this eruption. The aim of this work was to reconstruct the sequence of events that took place during the March 30 cataclysmic explosion on the basis of the study of its deposits and of the data provided by the visual observations of the process.

ERUPTION OF 1955-1956

A cataclysmic lateral blast of March 30, 1956, was an episode of a long eruption, during which several types of eruptive activity changed one another. This eruption was described comprehensively in [8] and [10]. It was the first historical eruption (since 1697 in this area) and occurred, as indicated by tephrochronological studies, after a 1000-year period of dormancy [6], [7].

Prior to the eruption, the edifice of the volcano was a normal cone 3085 m high (Fig. 1). It was an andesitic stratovolcano with a summit and flank extrusive viscous lava domes.

The eruption began on October 22, 1955, after a 23-day swarm of earthquakes. Till March 30, 1956, the eruption had a vulcanian character (preclimactic phase). During that period a crater, 800 m across, was formed at the summit, through which ash was frequently ejected to heights of 2-7.5 km. By the end of November the height of ash ejections declined to 1-1.5 km, and a dome began to grow in the crater, which was first seen from an airplane on January 22 [8]. Simultaneously with the dome growth the SE slope of the cone was slowly uplifted by rising magma. The uplift was estimated from photographs to be as high as 100 m [10]. This deformation was probably related to the fact that some volume of magma was intruded into the edifice as a cryptodome. As a result of the explosive activity during the preclimactic phase, a >1-meter member of thin-bedded, fine- and medium-grained ash was deposited at the eastern foot (preclimactic ash).

A cataclysmic explosion occurred on March 30, 1956, unexpectedly during the general weakening of the volcanic eruption and seismic activity. A relatively large volcanic earthquake took place during the outbreak of the eruption at 17 h 11 min 05 s. Visual observations provided little information of the sequence of events during the paroxysm, because the observers were at a distance of >45 km and in the direction unfavorable for observation. The photographs taken at that instant from Ust-Kamchatsk City [8] allowed one to estimate merely the general height of the eruption cloud (34-36 km).

The eruption produced a horseshoe-shaped crater, ~1.8 km across, open to the east (Fig. 2). The bushes and trees were broken and felled away from the volcano over an area of ~500 km^2 at the eastern foot of the cone. This area was covered by pyroclastic deposits of a peculiar type. After the cataclysmic explosion a dome of viscous lava began to rise slowly in the explosion vent. Its growth was accompanied by a relatively weak explosive activity with the development of ash-and-block pyroclastic flows, and continues at the present time [3].

Figure 1 Bezymyannyi before the eruption of March 30, 1956; view from the east. Photo by B. I. Piip, 1950.

Figure 2 Bezymyannyi after the eruption of March 30, 1956; view from the east, 1988. A dome of viscous lava grew in the new crater that had been formed on March 30, 1956.

MATERIAL DEPOSITED ON MARCH 30. 1956

Gorshkov and Bogoyavlenskaya [10] identified lateral-blast agglomerate, lateral-blast sand, and pyroclastic-flow and tephra[a] deposits among the materials deposited by the March 30 cataclysmic explosion. A later study revealed that the lateral-blast agglomerate had a rockslide-avalanche genesis [22]. For this reason this material is called here a rockslide-debris avalanche deposit [25], [31]. Because the lateral-blast sand was proved to have been produced by a catastrophic lateral blast, it is called here a lateral-blast deposit.

During a fairly long period of time since the March 1956 eruption, its deposits were eroded in many localities as deep as their base. This made it possible to correlate them using quite a number of sections. It was found that the sequence of the deposits varied with the increasing distance from the volcano. This was possibly related to the fact that the ejections of the materials were separated by intervals of seconds or minutes, whereas their transportation and dispersal occurred at different speeds. In this context the depositional sequence near the volcano contains information of the succession of the eruptive events, and variations in the positions of pyroclastic units in the sequence with distance from the volcano provide evidence of the transportation speeds of the erupted material. The composite section of the deposits in the near zone of the foot (< 10 km), which records the sequence of eruptive events is displayed in Figs 3 and 4 and consists of (1) debris-avalanche deposits (previously reported as a lateral-blast agglomerate), (2) lateral-blast deposits (previously identified as a lateral-blast sand), and (3) pyroclastic-flow and tephra deposits. We failed to determine relations between the pyroclastic flows and tephra because of the different localities of their deposition and a too small tephra thickness.

DEBRIS AVALANCHE DEPOSITS

Geometry. These deposits occur as three branches (northern, central, and southern) emplaced in river valleys at the eastern foot of the volcano (Fig. 1, Table 1). They were not found at the crests that separate the valleys.

The northern branch rests in the narrow canyon of the Sukhaya Khapitsa River upper reaches. Where the canyon makes abrupt turns, the deposits produced short spatters on its sides. This branch is 11 km long and ~200 m wide. The maximum thickness of the deposits is 20-30 m (Fig. 4). The deposits cover an area of 2 km^2 and are 0.06 km^3 in volume.

The term "tephra" is used here to denote all pyroclastic materials, whatever their particle sizes, transported in the eruption cloud (lapilli and ash).

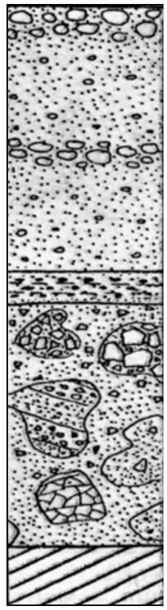

Figure 3 Composite stratigraphic section of the materials deposited on March 30, 1956.

The central branch is the largest of the three and is emplaced in a long system of river valleys. It starts in the broad valley of the left tributaries in the lower reaches of the Tundrovyi Klyuch River (known as "Gate"), passes to the lower reaches of the river, and ends in the valley of the Sukhaya Khapitsa middle course. Part of the deposits occur as a broad spatter on the northern offshoots of Mt. Zimina, which form the right side of the Tundrovyi Klyuch Valley. In this locality the valley makes an abrupt turn to the east. The relative height, to which the material was splashed, is as great as 200 m. This branch is 22 km long, 1-4 km wide, 1-15 m thick, 29.5 km^2 in area, and 0.4 km^3 in volume.

The southern branch is located at the upper reaches of the Tundrovyi Klyuch River and in the area of its left tributary. Its deposits could not be studied adequately because they are poorly exposed by erosion. Their rough estimates are a thickness of 3-10 km, a length of 8 km, an area of ~4.5 km^2, and a volume of 0.04 km^3.

The total volume of the debris-avalanche deposits is 0.5 km^3, or ~10% of the previous volume of the cone. This estimate is roughly comparable with the volume of the new horseshoe-shaped crater (0.74 km^3 [17]). The smaller volume of the deposits can be explained by the fact that part of the cone (>0.05 km^3) was destroyed during the preclimactic phase of the eruption, when the crater was formed, part (~0.03 km^3) constituted the lateral-blast deposits, where the proportion of the resurgent material averages 16%, and part was mixed with snow and produced the material of mudflows.

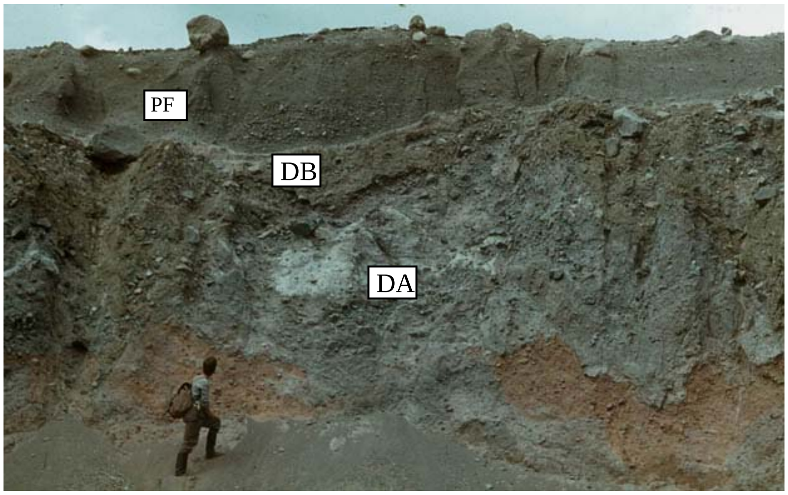

Figure 4 Section of the materials deposited by the March 30, 1956, eruption in the upper reaches ol the Sukhaya Khapitsa River. DA - debris-avalanche deposits. DB – directed blast deposits, PF - py roclastic flow deposits.

At distances <10 km from the volcano, the debris-avalanche deposits occur as the lower layer of the deposits erupted during the March 30 paroxysm. They rest on the alluvium, or (where they onlap the sides of the valleys) on the rocks of the Ambon sequence (rockslide deposits of Kamen Volcano with an age of ~1000 years [6], [7]), or on the soil-pyroclastic cover (soil intercalated with numerous ash layers). The contact with the underlying deposits is even and clearcut. The latter are usually undeformed except for some deformation imprints in the soil-pyroclastic cover, left by the lateral movement of the rockslide avalanche (lateral detachments, microthrusts, recumbent folds).

The debris-avalanche material is overlain by the lateral-blast deposits which in the valleys occur as a thick layer (max. 3 m) of gray, vesicular and dense, juvenile andesite fragments of gravel and block sizes.

A contact between the debris avalanche and the overlying lateral-blast deposits is fairly rugged. The top of the avalanche deposits has high protrusions and deep hollows of irregular shapes and differences in elevation as large as a few meters. The bulges on the surface of the avalanche might have originated from the deformation of the material in the course of its movement and also from the heterogeneity of its structure inherited from the heterogeneity of the old cone. Some of the bulges penetrate the overlying lateral-blast deposits and rise at the ground surface as isolated cone-shaped hills, the conical form being the result of the gradual bulge crumbling. Where the overlying deposits are thin (generally in spatters on the sides of the valleys where the lateral-blast deposits are thin, and pyroclastic flow deposits are missing), the surface of the debris avalanche has a well-

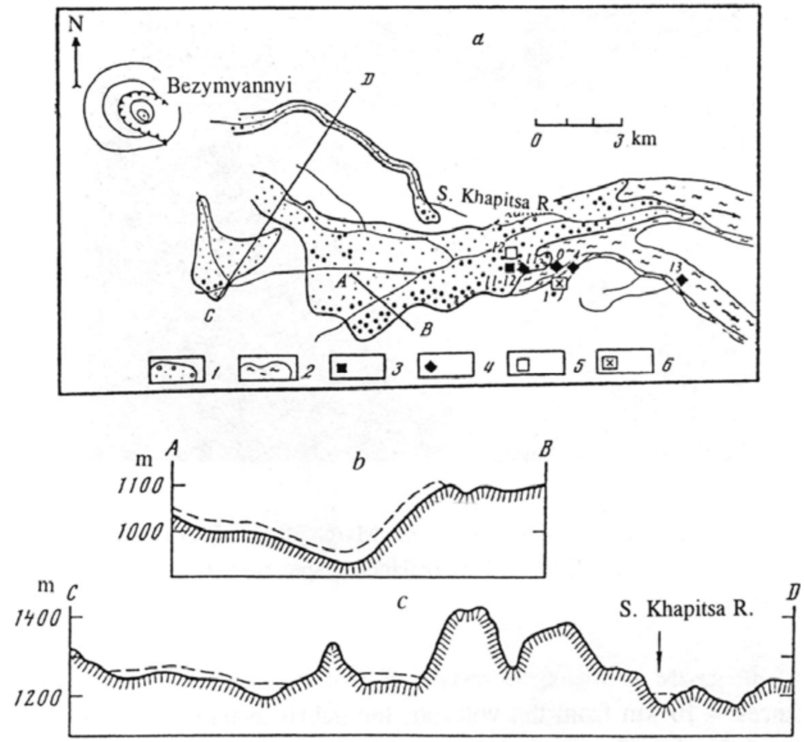

Figure 5 Schematic map *(a)* showing the distribution of the debris-avalanche deposits on March 30. 1956: *1* - debris-avalanche deposits; 2 - mudflow deposits; *3-6* - sites (and numbers) of the detailed study of the debris-avalanche block facies *(3),* of the debris-avalanche mixed facies *(4),* of lateral-blasi clastic dike in debris-avalanche deposits (5), and of isolated avalanche hills in die lateral-blast deposits. Profiles along lines *AB (b)* and *CD (c)* show relations between the debris-avaianche deposits (dashed line) and the topography.

defined hilly topography (Fig. 6). Most of the hills have a form close to conical with slopes of ~30^0. Some of the hills have the form of a truncated cone with a flat, almost horizontal top. There are occasional hills with tops as acute crests. The hills may be isolated or merged into groups. The bulk of the hill is usually covered by a waste material with a dense core of the undisturbed avalanche material in the top. The isolated hills or their groups are usually separated by relatively flat grounds covered by the lateral-blast and redeposited materials. The hills measured in the area where they are very high (Fig. 5, *a)* showed a maximum height of 16 m (Figs 6 and 7). The number of hills there is~700 per 1 km^2. In addition to the hills, there are elevations and depressions of a larger order. These usually repeat the ruggedness of the underlying topography and show lesser

Figure 6 Hilly surface of the debris-avalanche deposits. The hill in the foreground is 16 m high.

differences in elevation than the hills. In other words, the debris-avalanche deposits did not fill the hollows completely to smooth the topography in contrast to the pyroclastic-flow deposits which flooded the remaining depressed areas completely.

At a distance > 10 m from the volcano, the lateral-blast deposits start to be found both above and below the debris-avalanche deposits. This indicates that the materials of the avalanche and lateral blast were deposited simultaneously.

It was difficult to determine the character of the lateral boundaries of the debris-avalanche deposits because they are usually covered by the lateral-blast deposits and pyroclastic flows. A fairly distinct boundary was found only in a few localities where it occurs as a scarp a few meters high. A distinct frontal boundary was seen as a scarp ~4 m high only in the northern branch. The front of the central branch had been obliterated by erosion, and that of the southern branch is covered by pyroclastic-flow deposits.

In a few localities some isolated cone-shaped hills, made up of lateral-blast agglomerate, occur as far as a few kilometers from the limits of the major avalanche mass. The occurrence of these kicked-away hills was interpreted as having been thrown

Table 1 Morphological characteristics of the March 30, 1956, debris avalanche.

Branch	*Distance, km*	*Thickness, m*	*Area, km^2*	*Volume, km^3*
Northern	11	20-30	2.0	0.06
Central	22	1-15	29.5	0.4
Southern	8	3-10	4.5	0.04
Total			36.0	0.5

out by explosions along ballistic paths by some researchers (Yu. B. Slezin and I. V. Melekestsev, personal communication). Our study of some of these hills revealed that they were individual lenses (blocks) of the avalanche, whose rounded bases were submerged into a relatively homogeneous mixture of soil and avalanche material, structurally resembling a mudflow. In some localities this material frames the avalanche deposits of the central branch and occurs as independent long flows (a few kilometers) extending from its front and also where the avalanche experienced abrupt turns. Apparently, in the course of its movement the avalanched stripped, raked, and pushed, like a bulldozer, a rampart of various materials from the foot of the volcano: snow, soil, vegetation, alluvium, etc. Thanks to a great water content this material was more mobile and traveled a greater distance entrapping part of the avalanche material. We discovered two hills, ~ 1 m in size, half-sunk in the lateral-blast deposits and located at a distance of a few hundred meters from the debris-avalanche limits. We found them in an area where the lateral-blast cloud overtook the avalanche where the latter turned abruptly eastward as it collided with the spurs of Mt. Zimina (Site *1** in Fig. 5, *a).* It appears that small fragments of the avalanche material were picked up by the lateral-blast cloud there and transported for a small distance. According to our field observations, this process was of limited occurrence.

Composition. The debris-avalanche deposits contain materials of three types.

Type I: The resurgent material of volcanic origin that prior to March 30, 1956, composed the eastern part of the volcano, old pyroclastics, lava flows, domes, and dikes primarily of basaltic andesite and andesite composition. This material occurs in the avalanche in a highly fragmented but not mixed state. It can be classified as a breccia whose large angular fragments are cemented together in a matrix of the same material but fragmented to a silt and sand size. There are occasional areas, measuring a few tens of meters, composed of poorly fragmented (sometimes only fractured) rocks. Some outcrops of the debris avalanche showed lenses of irregular shape or severely deformed beds of different colors (crimson, yellow, green, black, gray, etc.) because of the different compositions and a varying degree of the oxidation and hydrothermal alteration of the initial rocks. The contacts between the lenses are uneven, wavy, and mostly clearcut. The lenses usually range in size between 1 and 100 m, though may be both larger and smaller.

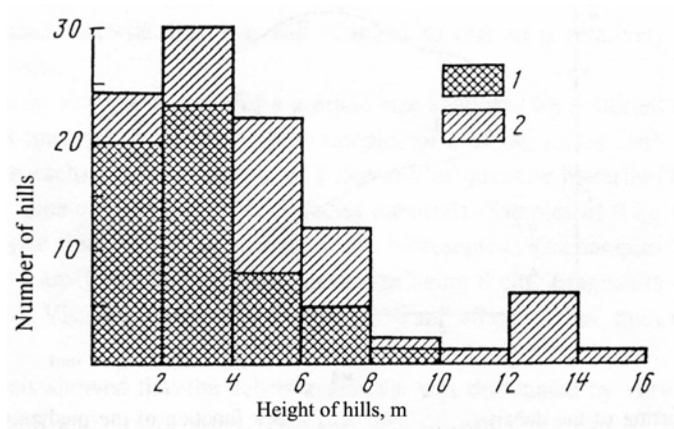

Figure 7 Histogram showing the height distribution of the debris-avalanche hills over an area of 0.14 km^2: 1 - isolated lulls, 2 - groups of hills. The total number of hills was 100.

The lenses of different sizes, shapes, and colors produce a mosaic pattern in outcrops, which can easily be identified: this mosaic pattern is typical of debris-avalanche deposits of volcanic origin [28], [29]. In foreign literature these lenses were called "blocks" or "megablocks" where they are larger than 100 m in size [29]. The avalanche material consisting of such blocks was termed a "block facies" [24], [25].

At a distance of > 10 km from the volcano, the material of the other two types begins to appear in growing amounts in the debris-avalanche deposits.

Type 2: A breccia of a dark, dirty-brown color consisting of a relatively homogeneous mixture of the cone material, soil, pebbles of underlying alluvium, and fragments of gray, juvenile lateral-blast andesite. This matrix encloses deformed soil lumps and round or highly elongated lenses of the old cone material (Type 1) ranging from centimeters to a few meters in size, as well as fragments of uncharred, shredded wood. In foreign literature this type of debris-avalanche deposits is known as a "mixed facies" [24]. This facies is found only in the deposits of the central avalanche branch. Its content increases away from the volcano.

Type 3: Gray, juvenile lateral-blast pyroclastics of gravel and block sizes, which fills pockets or occurs as lenses of irregular shapes and clastic dikes emplaced usually in a block or, less commonly, a mixed facies. This material is composilionally identical to the overlying lateral-blast deposits. In some localities we were able to follow these lenses and clastic dikes into the overlying deposits. Generally the content of the lateral-blast juvenile pyroclastics in the avalanche deposits is insignificant.

Geology. The geologic structure of the avalanche branches is different, mainly because their materials traveled for different distances. In this context the central branch can be regarded as more developed and has a more complex structure. The northern branch is

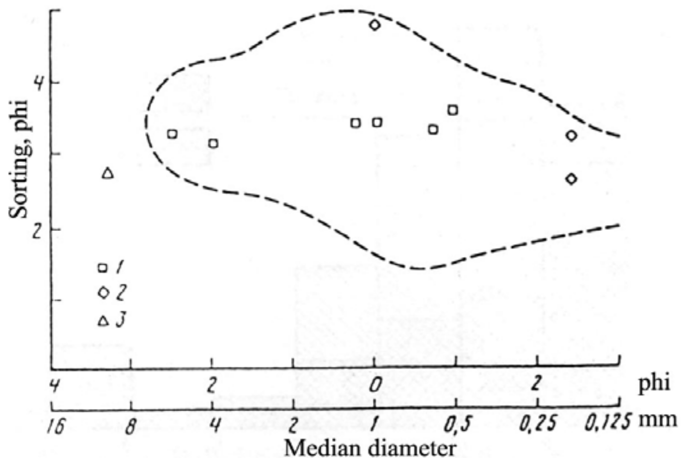

Figure 8 Sorting of the debris-avalanche deposits as a function of the median diameter (Inman coefficient): *1* - block fades. *2* - mixed facies. *3* - lateral-blast material enclosed in the avalanche deposits. The dashed line is the pyroclastic-flow area [32].

much simpler and can be used as an example of debris avalanches "conserved" at the early movement phase. It consists totally of the fragmented but not mixed material of the old cone (Type I or a block fades). The sizes of its individual lenses range between tens and hundreds of meters. They have distinct contacts without evidence of the material displacement. The northern branch does not contain a lateral-blast (Type 3) or a mixed-facies (Type 2) material. The southern branch is structurally similar to the northern. Because of its poor exposure, we could not study it in detail.

The sequence of deposits in the central branch varies regularly with an increasing distance from the volcano. Outcrops are rare within a range of 10 km because the avalanche deposits are covered there by block-and-ash pyroclastic flows that were erupted during the growth of a viscous lava dome in the crater. Still the outcrops available show that the structure of the central branch is similar here to that of the northern (almost 100% of the block facies). Further away the content of the mixed facies increases; this material occurs either as intermittent beds along the top and/or the bottom of the debris avalanche or as lenses enclosed in a Type 1 material. Simultaneously, there appear pockets, lenses, and clastic dikes of the lateral-blast juvenile pyroclastic material. The blocks of the Type 1 material become smaller with distance. These variations were caused with a progressively developing mixing process. At a distance of >22 km the debris-avalanche deposits of the central branch grade to mudflow deposits, 1-2 m thick, which contain occasional material. The largest of them emerge above the flat mudflow surface as rare isolated cone-shaped hills with a maximum height of 1.5 m. The transformation of the debris avalanche to a lahar occurred as a result of the mixing of the collapsed material of the old cone (initially dry enough) with a large amount of water from the snow that filled the valleys, along which the avalanche travelled. As a result, the initially heterogeneous lens (block) structure of the avalanche material was lost and changed to that of a relatively homogeneous mud flow deposits.

Particle size. For the purpose of a particle-size analysis, we collected six samples of a block-facies material (8 kg each), four samples of a mixed facies (one weighing 8 kg and three 1 kg each), and one sample of a lateral-blast juvenile material (1 kg, collected from a clastic dike emplaced in a block-facies material). Samples of 8 kg were collected so that large-size fractions could be statistically represented. The samples were analyzed using dry sieve analysis, the maximum sieve size being 8 cm. Fragments of larger sizes were discarded. Visually, these ranged between 10 and 40 cm across; their number varied widely.

The analysis showed that the debris avalanche was dominated by very poorly sorted material of sand and gravel sizes. The results of the analysis can be summarized as follows:

Median diameter, Md	-2.5-2.5(0.3) phi
Sorting coefficient,	2.7-4.6(0.3) phi
Gravel: >2 mm (%)	16.7-59.0 (37.2)
Sand: 0.063-2 mm (%)	37-2-62.6 (52.6)
Clay: <0.063 mm (%)	3.8-20.7(10.2)

The figures in the parentheses are average values.

Figure 8 shows relations between sorting and median diameter (Inman coefficients), where the Bezymyannyi debris-avalanche deposits occupy a region characteristic of volcaniclastic deposits that were not subjected to sorting: pyroclastic flows, lahars, and debris avalanche.

To make a particle-size analysis of the block facies, we collected samples of the material which prior to the rockslide had been hard rock (lava flows, viscous-lava extrusions, and dikes). No samples of ancient pyroclastic materials were collected because their particle size depended on the initial origin and was likely to be extremely diverse. Therefore the results of the analysis of the block facies characterize the fragmentation of the hard rocks of the cone which was caused by the intrusion of the cryptodome, rockslide, and debris-avalanche movement. The histograms of the particle-size distribution of the block facies showed roughly equal weights of the measured fractions (usually 5-10%). They do not have any well-defined peaks and generally display a polymodal distribution (Fig. 9, *a).* The block-facies material is distinguished by its poorest sorting compared to the other avalanche deposits. The histograms for the lateral-blast deposits from a clastic dike (Fig. 9, *b)* show an obvious predominance of large-size fractions which are characteristic of the lateral-blast deposits filling the valleys that begin at the eastern slopes of the volcano. The bimodal distribution of small- and large-size fractions of the mixed facies (Fig. 9, *b)* records its genesis. The content of fine material increased through the addition of soil and preclimactic ash, and that of the coarse fraction, through the admixture of lateral-blast material.

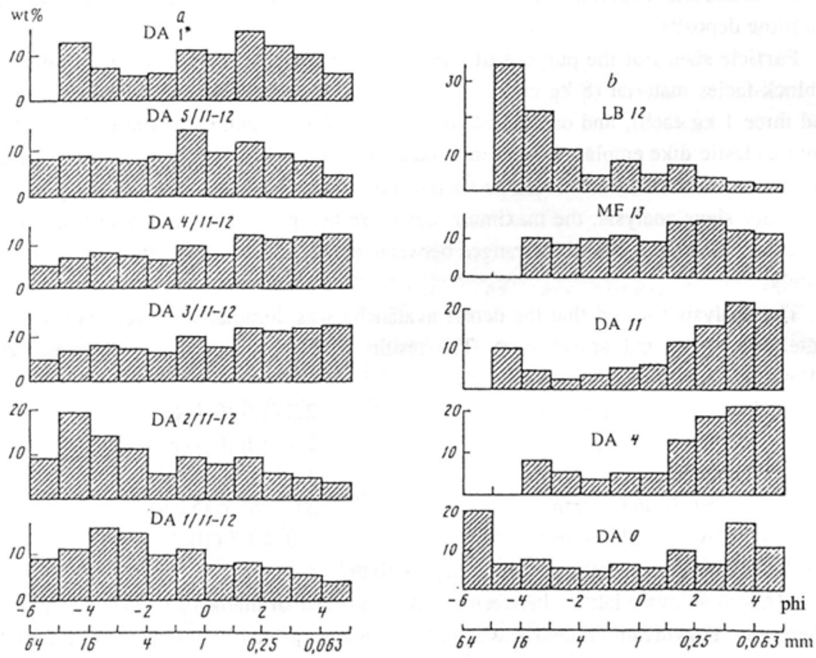

Figure 9 Histograms showing the panicle-size distribution in the debris-avalanche deposits: *a* -block facies, *b* - mixed facies (DAO, DA4, DA11, MF13) and a lateral-blast clastic dyke in the avalanche deposits (LB12). DA - debris avalanche. MF - mudflow, LB - lateral blast. The site numbers are as shown in Fig. 5. *a*.

Temperature, flow mechanism, speed and mobility of the avalanche. The uncharred wood fragments found in the deposits and the fumarol pipes showing no evidence of water boiling suggest that the temperature of the avalanche during its movement was not higher than I00°C. The structure of its deposits indicates that the avalanche was poorly fluidized, was comparatively dry, and moved in the manner of **a** laminar flow.

Using the measurements of the height of the avalanche material spattered on the spurs of Mount Zimina, where the avalanche made an abrupt turn, we attempted to evaluate its speed. We did it using the formula $v = (2gh)^{1/2}$ for a body thrown vertically upward, where v is velocity, *g* - gravitational acceleration, and *h* - spatter height (200 m). The result was 60 m/s at a distance of 10 km from the volcano. This estimate is a minimum value because friction was neglected. This value is comparable with the speed of the avalanche at Mount St. Helens (max. 80 m/s, average 30 m/s), which was evaluated by a direct and some indirect methods [31].

Debris-avalanche mobility is generally estimated as a ratio of a maximum fall height to a maximum path traveled by the fallen material. The fall heights for the northern, central, and southern branches were 2.2, 2.6, and 2 km, respectively and the maximum paths covered by these avalanches were 11, 22, and 8 km, the ratios between these values being 0.2, 0.12, and 0.25, the values close to the average estimates reported for the volcanic debris avalanches of equal volumes [28].

Sequence of events on March 30, 1956. We concluded that the material in question was not thrown out ballistically but flowed as a debris avalanche on the following bases: the material spatted on the sides of the valleys in places of their turns: the absence of the agglomerate on the ridges separating the avalanche branches; very poor sorting, uncharacteristic for air-transported material; the absence of impact deformations and the presence of displacements; the normal mixing of the material increasing away from the volcano, etc. The absolute identity of the lateral-blast agglomerate with the Mount St. Helens debris-avalanche deposits proved that both had been produced by a rockslide avalanche of some cone parts.

The occurrence of the debris avalanche at the very bottom of the sequence deposited on March 30 (at a distance of < 10 km) indicates that the rockslide was the first event of the paroxysmal phase. Prior to this phase the stability of the cone was violated by the intrusion as dome and a cryptodome. The rockslide was triggered by a volcanic earthquake that occurred ac 17 h 11 min 05 sec. The fallen part of the cone was dissected, in the course of its movement, into three flows by two ridges, the relatively large and steep spurs at the eastern foot of the cone. Each flow propagated as a separate branch. The northern and southern branch did not travel far, probably because of their smaller volumes. The more voluminous central flow moved much farther. As it moved, the avalanche stripped and pushed ahead the material of the cone's foot (snow, soil, alluvium, vegetation). Some of this material mixed with its debris forming a mixed facies; the remaining material traveled as independent long mudflows.

As the rockslide unroofed the cryptodome, a catastrophic lateral blast took place as a result of a sudden decompensation. The pattern of a contact between the debris-avalanche and lateral-blast deposits (twisted clastic dikes and apophyses) indicates that the lateral-blast material was deposited on the surface of the moving debris avalanche. The occurrence of this material under the avalanche at a distance of > 10 km suggests that the front of the lateral-blast cloud overtook the front of the avalanche. Considering that the speed of the avalanche was > 60 m/s, this event occurred less than 2.5 minutes after the origin of the rockslide. Because the speed of the lateral-blast pyroclastic surge is unknown, the time of 2.5 minutes can be taken as possible interval between the onset of the rockslide and the lateral blast. Assuming that the speed of the surge was equal to the speed of the lateral-blast cloud at Mount St. Helens (~ 100 m/s [27]), the interval between the rockslide and the lateral blast at Bezymyannyi was <1 minute.

The rockslide and the blast were immediately followed by the eruption of pyroclastic flows of pumice-like andesite. These flows were deposited in the valleys at the eastern foot of the volcano; they terminated the sequence of the deposits produced by the March 30 cataclysm.

Although we did not carry out a tephrochronological study of the March 30 deposits, the fine particle-size fraction and small thickness of the tephra suggest that the material was deposited by an ash cloud that had travelled above the lateral-blast and pyroclastic-flow materials rather than had been derived from the eruption column of the Plinian eruption. If this supposition is correct, there was no a distinct, long Plinian eruption phase during the March 30 paroxysm, as it happened during the May 18, 1980, eruption at Mount St. Helens.

For many years the Russian geologists had used the lateral-blast agglomerate of Bezymyannyi as a marker of lateral-blast deposits. The identification of these deposits at Shiveluch (30 000 years B. P. [14] and in 1964 [4], [14]), as well as at Kamen [13], Taunshits [18], Avacha [15], Kharimkotan [9], and some other volcanoes, had been used as evidence that lateral-blast eruptions had taken place in the eruptive histories of these volcanoes. Out study of the Bezymyannyi agglomerate revealed that this material had been deposited by a debris avalanche which had been produced by a huge rockslide on the old cone. The product of a lateral blast proper had been merely a lateral-blast sand, the material that had been found thus far only at one volcano. Mount St. Helens. The data reported from Shiveluch [2], [19], [20], Kharimkotan [21], and Avacha [231 indicated that huge collapses and rockslides, usually accompanied by large explosive eruptions, had in fact taken place at these volcanoes. Because an equivalent of lateral-blast sand was found at none of them, there are no grounds to classify these eruptions as lateral blasts.

The results of our study and data from literature [19], [20], [25], [28-31] show that collapses and rockslides at volcanoes may be caused by various factors. Usually, volcanic cones lose their stability because of the intrusion of viscous magma (by way of deformations, seismicity, or changes in ground water conditions) during the preparation of a new eruption, as it happened at Bezymyannyi in 1956, at Shiveluch in 1964, and at Mount St. Helens in 1980. Sometimes the cone loses its stability because of the slow decomposition of the rocks under the influence of fumarolic activity (as seems to have happened at Bandai-san Volcano in 1888) or as a result of a not uniform erosion (as might have occurred at the extinct Kamen volcano 1000 years ago). Very often, rockslides provoked by volcanic or tectonic earthquakes.

The events that follow a collapse (or a rockslide) depend on the factors that caused it. Where a rockslide occurred under the influence of intruding magma, the release of lithostatic pressure caused an explosive eruption of magmatic origin, the depth of the magma telling on the type of the eruption. Where magma stands at a considerable depth, usually a Plinian eruption takes place with the development of pyroclastic flows (Shiveluch in 1964). Where a hydrothermal system operates in the cone, its discharge provokes a phreatic explosion which precedes a Plinian eruption (Shiveluch in 1964). Where magma rises close to die surface as a dome and/or a cryptodome, the above scenario develops further as a catastrophic lateral blast that follows immediately after a rockslide (Bezymyannyi, 1956; Mount St. Helens, 1980). As follows from data reported in [19], [20], and [30], in most cases the cone loses its stability and rockslide occurs as magma is still deep enough. This is why lateral blasts are fairly rare. The scenarios considered above concern andesite and dacite magma eruptions. Apparently the character of eruptions after rockslides for magmas of other compositions (and, to be more exact, with other physico-mechanical properties) can be substantially different. Where volcanic cones lose their stability as a result of fumarolic activity, rockslides are followed merely by phreatic explosions without (he eruptions of juvenile material (Bandai-san). Rockslides at extinct volcanoes are not followed by any eruptive activity (Kamen). In spite of the fact that the effect of rockslides on the eruptive behavior has not been studied well enough, the above regularities give some key to the evaluation of volcanic hazards during rockslides.

CONCLUSIONS

1. The lateral-blast agglomerate produced by Bezymyannyi eruption on March 30, 1956, is a deposit of a rapid (60 m/s), cold (<100^0C), and relatively dry debris avalanche which took place as a result of a rockslide.

2. The rockslide was the first event of the March 30, 1956, paroxysmal eruption. It was followed, with an interval of < 2.5 minutes, by a lateral blast, after which pyroclastic flows were erupted.

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REFERENCES

1. V. D. Adushkin. Yu. A. Gustintsev. and P. P. Firstov, *Vulkanol- Seismol.* N5: 3-11 (1984).
2. A. B. Belousov and M. G. Belousova. *Volcanol. Seismol.* N4/5: 497-507 (1995).
3. A. B. Belousov, M. G. Belousova. and C. Yu. Zhdanova. *Vulkanol. Seismol.* N2: 25-33 (19S6).
4. G. E. Bogoyavlenskaya. O. A. Braitseva, I. V. Melekestsev, *el al. Vulkanol. Seismol.* N2:

3-26 (1985).
5. G. E. Bogoyavienskaya. 0. A. Braitseva. 1. V. Melekestsev, *et al.*, *Deistvuyushchie vulkany Kamchatki* (Active Volcanoes of Kamchatka)(Moscow: Nauka, 1991): 168-200.
6. O. A. Braitseva and V. D. Kiriyanov. *Vulkanol. Seismol.* N6: 44-55 (1982).
7. O. A. Braitseva, I. V. Melekestsev, G. E. Bogoyavlenskaya, and A. P. Maksimov. *Volcanol. Seismol.* 12. N2 (1990).
8. G. S. Gorshkov. *Bull. Vulkanol. Statsiy* N26: 19-72 (1957).
9. G. S. Gorshkov. *Vulkanizm Kurilskoi ostrovnoi dugi* (Volcanism of the Kuril Island Arc)(Moscow: Nauka, 1967).
10. G. S. Gorshkov and G. E. Bogoyavlenskaya, *Vulkan Bezymyannyi i osobennosti ego poslednego izverzheniya (1955-I963)* (Bezymiannyi volcano: Specific Behavior during Its Last Eruption. 1955-1963)(Moscow: Nauka. 1965).
11. I.I. Gushchenko. *Peply Severnoi Kamchatki i usloviya ikh obrazovaniya* (Northern Kamchatka Ashes and the Mechanisms of Their Formation)(Moscow: Nauka, 1965).
12. N. F. Dobrynin. *Volcanol. Seismol.* 13. N2 (1991).
13. V. A. Ermakov, in: *Vulkany i izverzheniya* (Volcanoes and Volcanic Eruptions) (Moscow: Nauka, 1969): 82-93.
14. I. V. Melekestsev. 0. A. Braitseva, E. N. Erlikh, and N. N. Kozhemyaka. in: *Kamchatka, Kurilskie i Komandorskie ostrova* (Kamchatka and the Kuril and Komandorskie Islands)(Moscow: Nauka, 1974): 162-234.
15. I. V. Melekestsev, S. N. Litasova, and L. D. Sulerzhitsky. *Volcanol. Seismol.* 13, N2 (1991).
16. Yu. N. Ryabinin and V. N. Rodionov, in: *Vulkanizm i gtubinnoe stroenie Zemli. Tr. Vsesoyuz. Vulkanol. Sovesh. T. 3* (Volcanism and the Deep Structure of the Earth. Proc. All-Union Volcanol. Conf. Vol. 3)(Moscow: Nauka. 1966): 56-60.
17. V. I. Seleznev. V. N. Dvigalo, and N. A. Gusev. *Vulkanol. Seismol.* N1: 52-65 (1983).
18. A. E. Shantser, *Bull. Vulkanol. Stantsiy* N49 (24-28X1983).
19. A. B. Belousov, *J. Volcanol. Geotherm. Res.* 66: 357-365 (1995).
20. A. B. Belousov and M. G. Belousova. in: *Proc. 7th Intern. Symp. on Landslides, Norway* (1996): 953-957.
21. M. G. Belousova and A. B. Belousov, *Periodico Mineralogia* LXIV: 99-101 (1995).
22. A. B. Belousov and G. E. Bogoyavlenskaya, in: *Proc. Kagoshima Intern. Conf. on Volcanoes, Japan* (1988): 460-462.
23. B. Castellana. G. P. Davidson. A. B. Belousov. and M. G. Belousova, *EOS. Trans. AGU 1995 Fall Meeting* 76, N46: 357.
24. H. Glicken, in: *Soc. Econ. Paleontol. Mineral. Spec. Publ.* 45: 99-106 (1991).
25. H. Glicken, in: *U.S. Geol. Survey Prof. Pap.* 1488 (1997).
26. G. S. Gorshkov, *Bull. Volcanol.* 26: 83-88 (1963).
27. P. V. Lipman and D. R. Mullineaux, eds., *The 1980 Eruptions of Mount St. Helens. U. S. Geol. Surv. Prof. Pap.* 1250 (1981).
28. L. Siebert, *J. Volcanol. Geotherm. Res.* 22: 163-197 (1984).
29. T. Ui, *Ibid.* 18: 135-150 (1983).
30. B. Voight, M. G. Belousova, and A. B. Belousov, *Abstr. Geol. Soc. Amer. Meeting, Seattle, USA* (1994).
31. B. Voight, H. Glicken, R. I. Janda, and P. M. Douglass, in: *U.S. Geol. Surv. Prof. Pap.*

1250: 347-378(1981).

32. G. P. L. Walker, *J. Geol.* 79: 696-714 (1971).