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CATASTROPHIC ERUPTIONS OF THE DIRECTED-BLAST TYPE AT MOUNT ST. HELENS, BEZYMIANNY AND SHIVELUCH VOLCANOES

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ABSTRACT

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This paper describes catastrophic eruptions of Mount St. Helens (1980), Bezymianny (1955–56), and Shiveluch (1964) volcanoes. A detailed description of eruption stages and their products, as well as the quantitative characteristics of the eruptive process are given. The eruptions under study belong to the directed-blast type. This type is characterized by the catastrophic character of the climatic stage during which a directed blast, accompanied by edifice destruction, the profound ejection of juvenile pyroclastics and the formation of pyroclastic flows, occur. The climatic stage of all three eruptions has similar characteristics, such as duration, kinetic energy of blast (10^{17}–10^{18} J), the initial velocity of debris ejection, morphology and size of newly-formed craters. But there are also certain differences. At Mount St. Helens the directed blast was preceded by failure of the edifice and these events produced separable deposits, namely debris avalanche and directed blast deposits which are composed of different materials and have different volumes, thickness and distribution. At Bezymianny, failure did not precede the blast and the whole mass of debris of the old edifice was outburst only by blast. The resulting deposits, represented by the directed blast agglomerate and sand facies, have characteristics of both the debris avalanche and the blast deposit at Mount St. Helens. At Shiveluch directed-blast deposits are represented only by the directed-blast agglomerate; the directed-blast sand facies, or blast deposits proper, seen at Mount St. Helens is absent. During the period of Plinian activity, the total volumes of juvenile material erupted at Mount St. Helens and at Bezymianny were roughly comparable and exceeded the volume of juvenile material erupted at Shiveluch. However, the volume of pyroclastic-flow deposits erupted at Mount St. Helens was much less.

The heat energy of all three eruptions is comparable: 1.3×10^{18}, 3.8–4.8×10^{18} and 1×10^{17} J for Shiveluch, Bezymianny, and Mount St. Helens, respectively.

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INTRODUCTION

Catastrophic directed-blast eruptions of andesitic volcanoes are among the events most hazardous for humanity; they occur rather rarely and often have a duration of only moments. Directed-blast eruptions often result when viscous gas-rich magma is emplaced at shallow levels in a volcanic edifice. In many instances, the larger the catastrophe, the less frequently and more unexpectedly it occurs. For these reasons, direct observations and detailed studies of past catastrophic eruptions are very important. However, one rarely succeeds in studying such an event while it is in progress. During the last century, the largest eruptions of this type, such as Bandai-san in 1888, Bezymianny in 1956, and Shiveluch in 1964, occurred unexpectedly; the catastrophic explosions were not predicted and volcanologists were not successful in observing them directly. The most recent eruption of this type occurred in 1980 at Mount St. Helens, Washington, USA and, although it was not predicted by the U.S. Geological Survey, American volcanologists were successful in observing the eruptive process and in studying in detail the character of the eruption as well as its consequences.

This paper considers catastrophic directed-blast eruptions of the three volcanoes studied in greatest detail, Mount St. Helens, Bezymianny and Shiveluch, in order to show both similarities and differences between the eruptions at the three volcanoes.

1980 MOUNT ST. HELENS ERUPTION

Mount St. Helens, in the Cascade Range of the northwestern United States, had been dormant since 1857. Before the 1980 eruption, it was a smooth, steep-sided stratovolcano with an absolute altitude of 2975 m (relative altitude 1450 m). The summit crater was snow-filled and glaciers covered the flanks.

A study of the volcanic history of the Cascade Range for the last 4,500 yrs (Crandell and Mullineaux, 1978) has shown that Mount St. Helens was the most frequently active and explosive volcano during this period. Its activity included numerous eruptions of tephra and pyroclastic flows and andesitic and dacitic flows and domes. During the last 2,500 yrs, the volcano produced lava flows of andesite and erupted domes on the flanks and in the summit crater.

The last major eruptive cycle occurred 500–300 yrs ago and consisted of pyroclastic eruptions and lava flows, and the formation of an extrusive dome that plugged the crater; later, smaller eruptions occurred during the intervals 1802–04, 1844–47, and 1854–57 (Hoblitt *et al.*, 1980). The eruptive activities of Mount St. Helens in 1980 an be divided into three stages:

1. A preclimactic stage that consisted of intense seismic activity, deformations of the edifice, and phreatic eruptions.
2. A climactic stage that included formation of a large debris avalanche, a direct blast, and a plinian eruption.
3. A post-climatic stage characterized by growth of an extrusive dome in the crater.

Preclimactic stage

After a 123 yr dormant period ending in late March 1980, earthquakes began occuring under the volcano. Their number and intensity increased quickly for 7 days prior to the first eruption (Christiansen and Peterson, 1981). The eruption began on March 27 with a brief crater-forming event and periodic small explosions of resurgent ashes and pulverized old volcanic rocks. Steam-blast eruptions continued intermittently throughout most of April, and between May 7 and 14. In April, the summit crater reached dimensions of 300 × 500 m. During April and May, the seismic energy release decreased slightly.

During April and May, 1980, rapid and essential deformation, averaging about 2 m per day, occurred on the north flank of the volcano, evidence that magma had ascended in the conduit to form a cryptodome within the edifice (Lipman *et al.*, 1981). The bulging north flank, including the Goat Rock dome, was covered with fractures. Intense seismic activity produced frequent snow avalanches and small mudflows that moved down the flanks of the volcano.

Climactic stage

The paroxysmal eruption began on the morning of May 18. At 0832 PDT, with no known immediate precursors, a magnitude-5+ earthquake triggered a rapid series of events (Christiansen and Peterson, 1981). As seen by observers from a small aircraft directly above the summit crater, the earthquake caused avalanching from the walls of the crater and, only a few seconds later, the north flank began to slide away, within 26 s, was displaced about 700 m. The resulting, huge debris avalanche moved downslope with a velocity of 50–100 m/s. At a distance of 8 km, it displaced water from Spirit Lake and raised its level by 60 m, then it turned west and moved down the valley of the North Fork Toutle River as far as 23 km (Christiansen and Peterson, 1981). The avalanche represented a slightly heated ($T^\circ = 70^\circ$–$100^\circ C$) mixture of blocks and ash and volcanic debris, and contained blocks of glacier ice, snow, and water.

Within the avalanche deposits, seven different units have been recognized, corresponding to different parts of the destroyed volcanic edifice (Voight *et al.*, 1981). The avalanche deposits covered an area of 60 km^2 with debris, with an average thickness of about 45 m. The total volume of debris avalanche deposits was 2.8 km^3. Mudflows generated within the debris avalanche moved with a velocity of about 15–40 m/s beyond the avalanche for 120 km, and devastated bridges, highways, and logging areas in the valley.

Beginning about 26 s after the flank began to slide off the cone, a directed blast occurred. Removal of the flank of the volcano by failure of the north slope resulted in rapid decompression of a cryptodome that had formed within the volcanic edifice (Hoblitt *et al.*, 1981). Rapid expansion of the gas-charged debris produced a gigantic directed blast that erupted through the breached north flank of the volcano at speeds up to 200 m/s. As a result, no trees remained out to a distance of 10 km from the summit; from 10 km out to as far as 28 km, all standing trees were snapped off or blown to the ground. Near the outer margin of the blast, trees were left standing, but were thoroughly seared (Fig. 1).

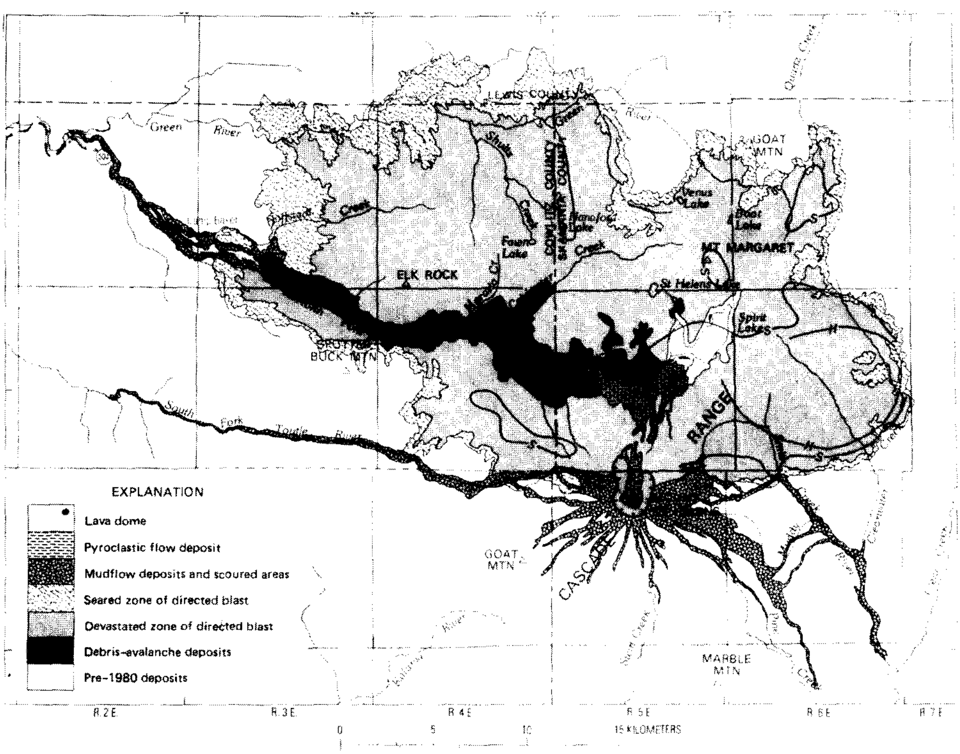

Fig. 1. Geological map of Mount St. Helens after the paroxymal explosion in 1980 (Wash., 1981).

A layer of blocks and ash, with a volume of 0.2 km^3, covered a devastated area of about 600 km^2 (Hoblitt *et al.*, 1981). The deposit consisted of about 50 percent juvenile gray dacite from the blasted cryptodome, mixed with rocks of the old edifice. The basal layer of blast deposits contained numerous wood and soil remains. The thickness of the deposit ranged from several meters near the volcano to 1 cm or less in the marginal parts, depending on the surface relief. The emplacement temperature of the blast deposits ranged from 70° to 277°C (Banks and Hoblitt, 1981).

A large horseshoe-shaped crater about 1.5 × 3 km across was formed as a result of the eruption. After the directed blast, a Plinian eruption of juvenile dacitic pumice occurred during a 9 hr period. The eruptive column reached 20 km high. Ash spread for 1500 km to the northeast of the volcano. The volume of friable airfall ash deposits amounted to about 1.1 km^3. Pumiceous pyroclastic flows were formed simultaneously with the Plinian column. The first flows appeared 4 hr after the eruption began and pyroclastic flows developed periodically during the following 5 hrs; their length reached about 8 km (Rowley *et al.*, 1981). The temperature of the deposits near the crater was 750–850°C (Banks and Hoblitt. 1981). Near the base of the volcano, pyroclastic flows formed fan-shaped deposits; the pyroclastic-flow tongues were composed of friable deposits of ash with blocks of pumice and dense dacite. The volume of the pyroclastic flow deposits was 0.12 km^3 (Rowley *et al.*, 1981). Phreatic-explosion pits, 5–25 m across, formed when hot pyroclastic flow and debris flows encountered streams, ponds, and springs; the water flashed to steam, and the upward-directed steam explosions reamed holes in the overlying deposits.

Postclimactic stage

Following another explosive eruption on June 12, a lava dome 300 m across grew in the crater. At first, the rate of vertical dome growth was 2–3 m/day; within 7 days, however, it ceased and the dome collapsed slightly (Moore *et al.*, 1981). Additional pyroclastic eruptions occurred periodically during the Fall of 1980. A lava dome continues to grow within the crater to the present time (SEAN Bull., 1981 through 1984). The periodical appearance of new lobes or plugs at the dome is accompanied by explosions, by increase in the seismic activity and by the formation of glowing avalanches occasionally descending to the northern foot of the volcano. Explosive eruptions connected with the intrusion of new magma portions into a composite lava dome occur episodically throughout the year and each increase in activity continues for several days. Continuous measurements of deformations of the crater floor and of the dome have demonstrated that each explosive episode resulted in displacements of individual blocks or a group of blocks. Deformations of the edifice of the volcano were not marked. The lavas were hypersthene-amphibole dacite with 61 to 64 percent SiO_2.

Thus, the main events of the Mount St. Helens eruption were (1) failure of the flank of the volcano, resulting in debris avalanche deposits with a volume of about 2.8 km^3 that extend down the North Fork Toutle River Valley as far as 23 km; (2) the catastrophic directed blast that destroyed an area of nearly 600 km^2 to the north of the volcano and formed the crater

TABLE

Characteristics of the 1980 Mount St. Helens

<table>
<tr><th>Stages of eruption</th><th colspan="2">Main events</th><th>Duration</th><th>Type of deposit</th><th>Character of occurrence</th></tr>
<tr><td>POST-CLIMAC-TIC</td><td colspan="2">The beginning of extrusive dome growth</td><td>1981–1984</td><td>Lavas of the extrusive dome</td><td>Intracrater extrusion</td></tr>
<tr><td rowspan="4">CLI-MAC-TIC</td><td rowspan="2">PLI-NIAN ACTI-VITY</td><td>Eruptive cloud (20 km high)</td><td>9 hrs</td><td>Tephra</td><td>Pyroclastic layer</td></tr>
<tr><td>Pyroclastic flow-eruption</td><td>Several hrs</td><td>Pyroclastic-flow</td><td>Flat and low-lying ground filled with pyroclastic material</td></tr>
<tr><td colspan="2">Directed blast. Formation of crater 1.5 × 3 km</td><td>Several minutes</td><td>Directed blast</td><td>Blanket of blocks, lapilli and ash</td></tr>
<tr><td colspan="2">Failure of north flank</td><td>26 s</td><td>Debris avalanche</td><td>Hummocky-surfaced topography</td></tr>
<tr><td>PRE-CLI-MAC-TIC</td><td colspan="2">Phreatic eruptive activity. Deformation of volcanic edifice. Seismic preparation.</td><td>2 mos</td><td>Tephra</td><td>Pyroclastic layer</td></tr>
</table>

about 1.5 × 3 km in size. The total volume of blast deposits is about 0.2 km^3. (3) A 9-hr-long Plinian eruption that generated ash deposits that covered a wide area up to about 1500 km to the east (volume = 1.1 km^3), and a series of pyroclastic flows up to 8 km long that were deposited beyond the base of the cone. The total volume of pyroclastic-flow deposits is about 0.1 km^3; and (4) the post-climactic activity of the volcano that consisted of intracrater extrusions and periodic explosive activity (Table I).

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eruption (Data are from Lipman and Mullineaux, 1981)

Character of deposits		T° at time of deposition (C°)	Thickness (m)	Area (km^2)	Volume (km^3)
Lithology	Composition				
Hornblende-pyroxene dacite		700–800	—	—	0.2
Coarse to fine ash	Juvenile material mixed with resurgent material in lowest layer	< 100	—	—	1.1
Agglomerate-sandy aleurite material with rounded pumiceous dacite debris	Juvenile material (hornblende-pyroxene dacite)	750–850	⩽ 10–20	—	0.12
Five stratigraphic units (basal, massive, pyroclastic surge, unstratified pyroclastic flow and accretionary-ash) are recognized in deposits composed of blocks and lapilli and ash. The units differ in degree of sorting. The content of juvenile component in debris is about 50 percent; in the matrix it ranges from 35 to 65 percent.		70–277	> 1.0–0.01	600	0.2
Coarse-rock agglomerate with sandy-aleurite matrix	Deposits divided into seven units composed of rocks of destroyed edifice	50–70	45	60	2.8
Fine and coarse ash	Resurgent ash-rocks of the old volcanic edifice	—	—	—	—

1955-56 BEZYMIANNY ERUPTION

In 1956, 25 yrs before the Mount St. Helens eruption, a catastrophic directed blast occurred at Bezymianny volcano in Kamchatka, USSR; the nature of the eruption and resulting deposits were surprisingly similar to events at Mount St. Helens in 1980.

Bezymianny volcano is one of the least conspicuous volcanoes in the Klyuchevskoy volcanic group (Fig. 2). For more than 1,000 yrs prior to 1956, the volcano was dormant and no historic eruptions were recorded (Braitseva and Kiryanov, 1982). The absolute altitude of Bezymianny before the 1956 eruption was 3085 m, the relative attitude was 700 m to the north and 1200 m to the south. A poorly developed crater containing a small

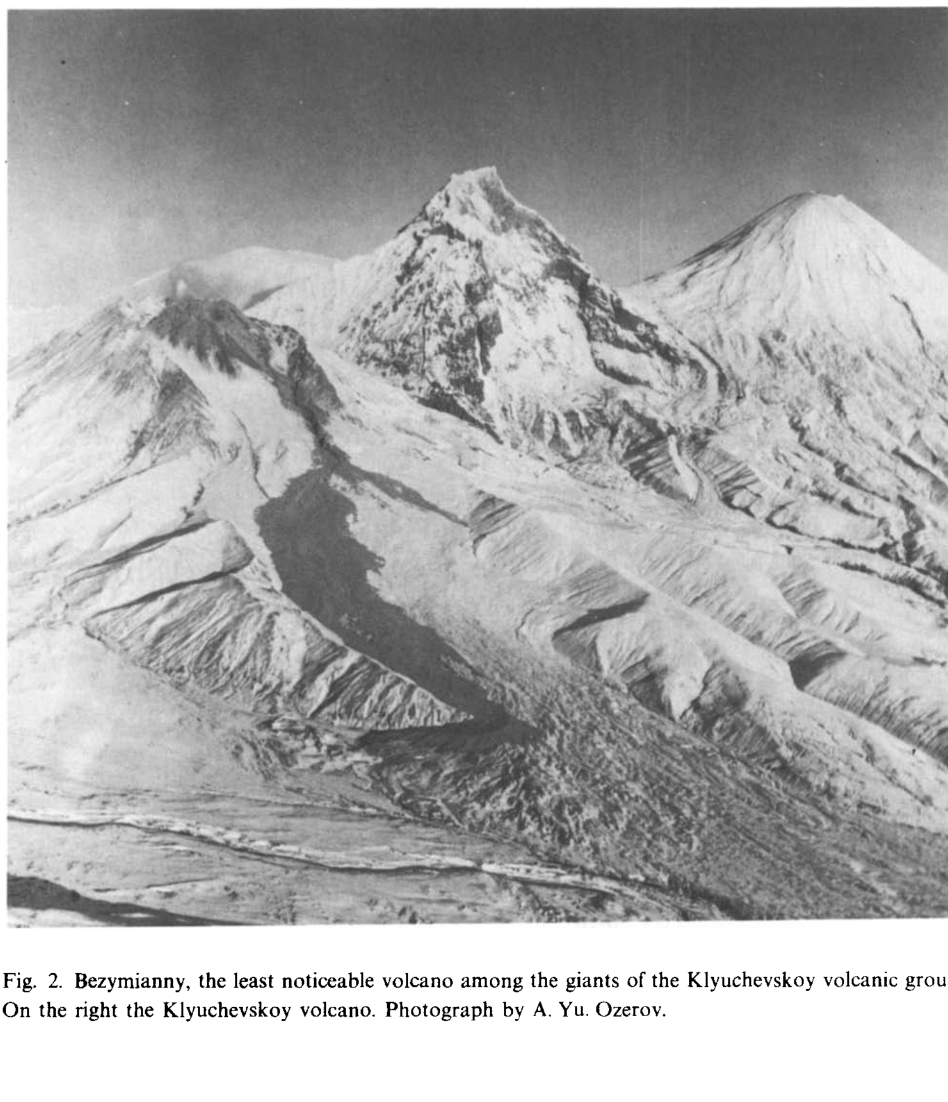

Fig. 2. Bezymianny, the least noticeable volcano among the giants of the Klyuchevskoy volcanic group. On the right the Klyuchevskoy volcano. Photograph by A. Yu. Ozerov.

inner cone was located at the top of the volcano (Gorshkov and Bogoyavlenskaya, 1965).

More than 10 extrusive domes of different ages are located on the south flank of the volcano and near its base. The base of the complex is composed of the deposits of pyroclastic flows from eruptions that occurred during the last 2,000 yrs. Young lava flows of the same age are also well exposed on the south flank of the volcano; older lava flows are exposed on the northern flank.

A new cycle of eruptive activity began with the 1955–56 catastrophic eruption and is continuing today. For this eruption, the following stages have been distinguished:

1. A preclimactic stage that consisted of intensive seismic activity, Vulcanian explosive activity, and deformation of the summit part of the volcano.
2. A climactic stage that included a directed blast that destroyed the summit, and Plinian activity that erupted a large volume of juvenile pyroclastics (tephra and pyroclastic flows).
3. A post-climactic stage characterized by growth of an extrusive dome in the crater of the volcano.

Preclimactic stage

On September 29, 1955, the first earthquake was recorded beneath Bezymianny volcano. In October, the frequency of earthquakes increased rapidly and earthquakes occurred at a rate of a few tens per day by October 9. From October 19 on, earthquakes occurred at a rate of hundreds per day. On October 11, the hypocenter of several earthquakes was deduced to be 50 km beneath Bezymianny volcano (Gorshkov, 1961).

The eruption commenced on October 22 with strong Vulcanian explosions from a new summit crater. The Vulcanian activity continued during November and the eruptions produced large quantities of ash. In December, 1955 and January and February, 1956, the explosive activity decreased, and consisted of occasional small vapour and ash outbursts. At this time, the summit crater was 500–600 m across. Tephra of the preclimactic stage consisted of gray coarse to fine ash with a total volume of about 0.4–0.5 km^3.

The eastern slope of the volcano began to expand simultaneously with the explosive activity. An old dome, part of the ancient volcano located on the east flank of the volcanic massif, was slowly pushed up by roughly 100 m. The duration of the preclimactic stage was 5 months.

Climactic stage

The directed-blast eruption on March 30, 1956 destroyed the summit of Bezymianny and its eastern slope. An enormous crater, about 1.5×2.8 km in size and 700 m deep, was formed in the place of the summit. The crater occupied not only the summit but the whole southeastern slope down to the base of the volcano. The height of the edifice decreased by more than 200 m (Fig. 3).

The area covered by the directed blast had an oval form and an area of about 500 km^2. Its boundary was rather well-defined and delineated not only by deposits from the blast, but also by a zone of damaged trees and vegetation (see Fig. 3) (Gorshkov, 1962; Gorshkov and Bogoyavlenskaya, 1968).

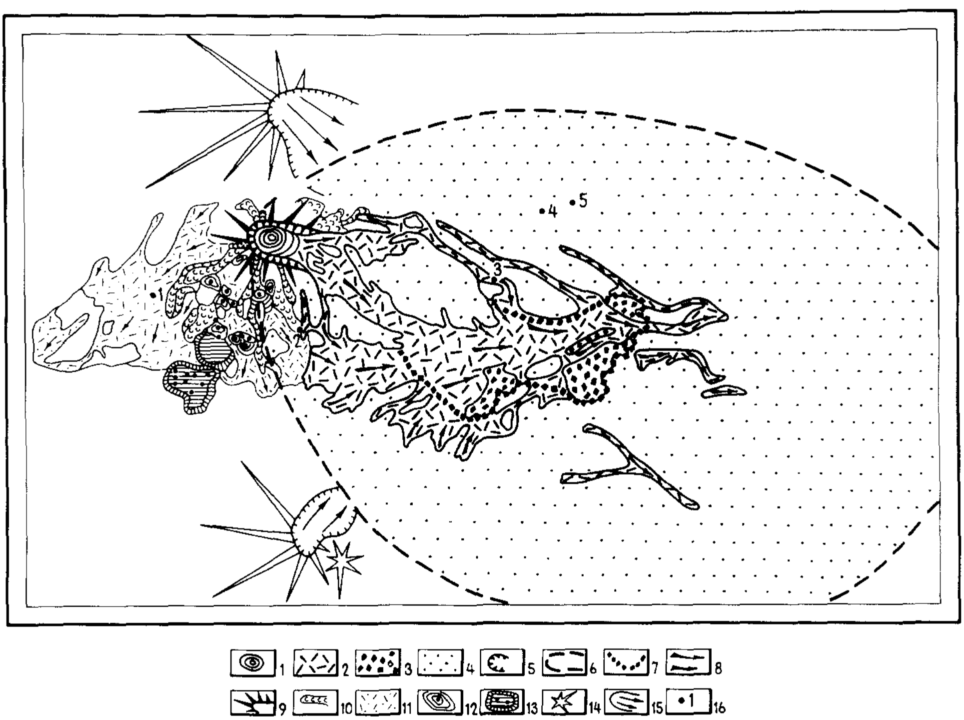

Fig. 3. Volcanic formations of the 1955–1956 Bezymianny volcano eruption. 1. intracrateral extrusion; 2. pyroclastic flows; 3. directed-blast agglomerate; 3,4 directed-blast sand; 5. the crater in 1956; 6. boundary of the directed-blast sand distribution; 7. boundary of the directed-blast coarse-debris deposit distribution; 8. direction of pyroclastic flow motion. Upper Pleistocene-Holocenic formations of Bezymianny volcano; 9. edifice of the volcano; 10. lava flows; 11. pyroclastic flows; 12. extrusive domes; 13. extrusions of Tyuya type; 14. edifices of stratovolcanoes; 15. failure cirques; 16. points of taking the sections in Fig. 5.

During the Bezymianny directed blast, material of the old edifice was erupted as a compact mass and deposited within a narrow sector covering more than 60 km^2 within about 15 km of the base of the volcano. The deposit forms a wide area (35–40 km^2) of irregular topography characterized by hummocks ranging from a few meters to 20 to 30 km high. The material covered low-lying ground and river valleys and also was deposited on uplands and steep slopes (Fig. 4). The deposit consists of poorly sorted, coarse-debris agglomerate such as sandy-aleurite, with large amounts of blocks and rock debris, the maximum size of which reached 10–15 m. The dominant lithology is lava debris from the old edifice of the volcano. The thickness of deposits was 10–30 m and the total volume was equal to about 0.8 km^3. This irregular deposit has been termed the directed-blast agglomerate and is comparable in character to the debris-avalanche deposit at Mount St. Helens.

The directed-blast agglomerate accumulated primarily near to the axis of the directed-blast. A much more extensive area enveloped by the directed-blast was covered by a thin layer of incandescent material (the blast deposit proper), the thickness of which amounted to 60–70 cm near the volcano and 1–2 cm near the margin. This facies of the blast deposits has been named (Gorshkov, 1962; 1963) "directed-blast sand" and is equivalent to the

Fig. 4. Irregularities of the directed-blast agglomerate material of Bezymianny volcano. Photograph by G. E. Bogoyavlenskaya.

"directed-blast deposit" of Hoblitt *et al.* (1981). The facies consisted of ash and aleurite material with dispersed lapilli and debris varying in size from 1 to 2 cm up to 20 cm (Fig. 5). Gray juvenile andesite was widespread in the directed-blast sand and amounted to 10 percent of the total volume of the deposit. The total volume of the directed-blast sand facies was 0.2 km^3.

The total volume of the directed-blast deposits, including the directed-

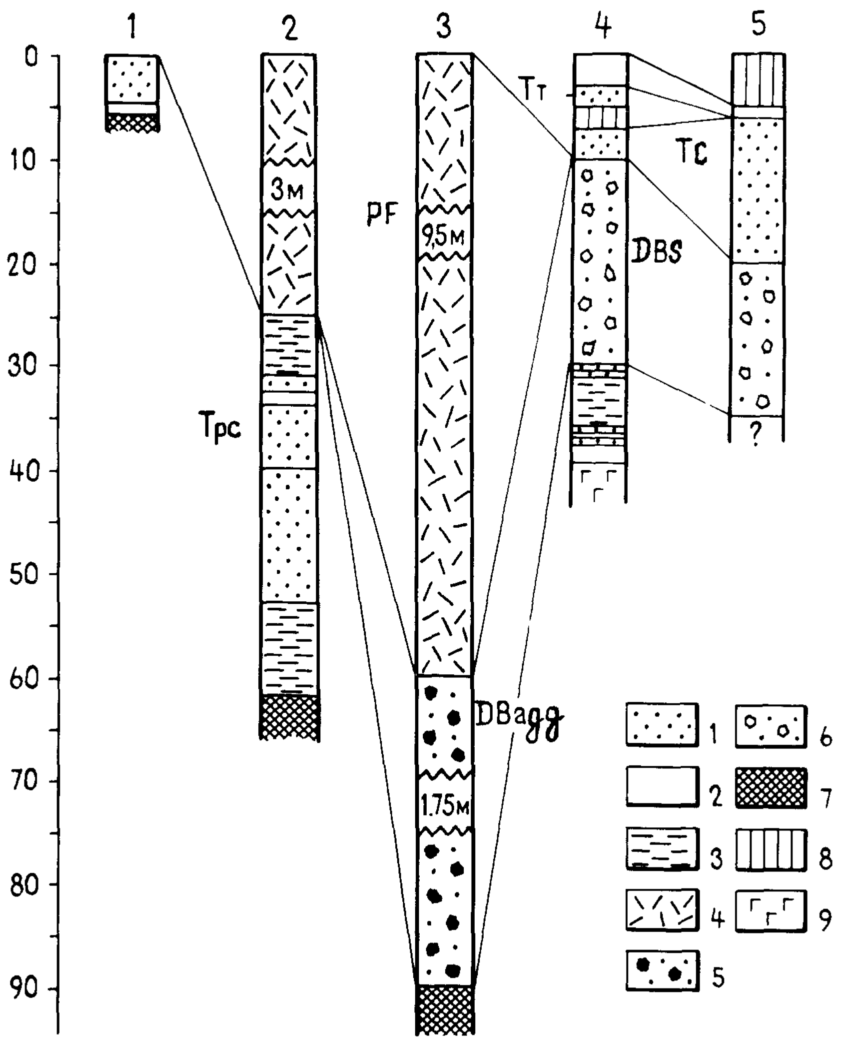

Fig. 5. Relations between the main types of the 1955–1956 eruption deposits. 1. coarse ash; 2. fine ash; 3. fine stratified ash; 4. pyroclastic-flow deposits; 5. agglomerate; 6. sand with small debris (5,6. the directed-blast deposits); 7. soil; 8. sandy loam; 9. basalt. PF-pyroclastic-flow deposits; DBagg-directed-blast agglomerate; DBS-directed-blast sand; Tc-tephra of climactic stage; Tpc-tephra of pre-climactic stage; TT-tephra of the 1975 Tolbachik eruption.

blast agglomerate facies and the directed-blast sand facies, amounted to about 1 km^3. Both resurgent material (the old rocks of the destroyed edifice) and the juvenile component (gray vesicular hornblende andesite) were present in the blast deposits. A study of the matrix of both facies revealed considerable similarity. Resurgent material is dominant in both facies (Fig. 6), and the fraction of juvenile material is only about 15 or 10 percent.

The kinetic energy of the directed-blast at Bezymianny amounted to 1.2×10^{17} J. The initial velocity of debris in the directed-blast was 360–500 m/s and the emplacement temperature of blast deposits was about 200°C.

Plinian activity began soon after the directed blast. An eruptive cloud rose above the crater to an altitude of 30–40 km, lasted for 4 hrs, and formed a tephra lobe about 50 km wide trending toward the northeast. At this time, a 2-cm-thick layer of ash was deposited on the settlement of Klyuchi, 40 km from the volcano. In the settlement of Ossora, 400 km distant, the ash thickness was 0.1 cm. The volume of ash deposits was approximately 0.4 km^3. The quantitative-mineral composition of the ash is given in Fig. 6.

Pyroclastic flows developed simultaneously with formation of the eruptive column, and flowed from the crater and filled the river valleys near the base of the volcano. The flows travelled for 18 km along the Sukhaya Khapitsa River valley.

The maximum exposed thickness of pyroclastic-flow deposits amounted

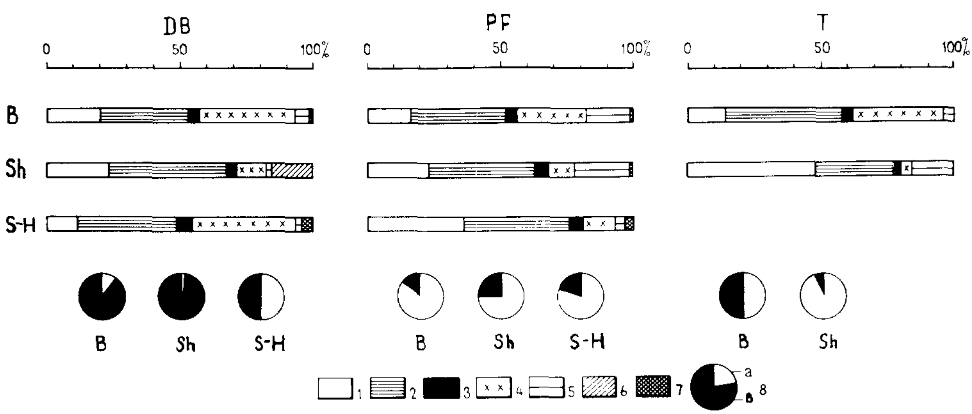

Fig. 6. Quantitative-mineral composition and relations of resurgent and juvenile material in the matrix of pyroclastic deposits of Bezymianny, Shiveluch and Mount St. Helens volcanoes. 1. volcanic glass; 2. plagioclase; 3. ore minerals; 4. rock debris; 5. green hornblende; 6. brown hornblende; 7. pyroxene; 8. relation of juvenile and pyroclastic material in the matrix (a. juvenile material, b. resurgent material; a size of fraction as small as 2 mm). B-Bezymianny, Sh-Shiveluch, S-H-St. Helens, DB-directed-blast, PF-pyroclastic flow, T-tephra.

to 35–40 m. The volume of pyroclastic-flow material was estimated in 1956 to be 1 km^3 (Gorshkov and Boyoyavlenskaya, 1965), later estimates suggest a volume of about 0.7–0.8 km^3 (Melekestsev, 1980; Melekestsev *et al.*, 1980); the difference may reflect consolidation of pyroclastic material with time.

The temperature of pyroclastic flow deposits at the time of eruption was probably at least 300–400°C, because wood debris in the flows was charred. Temperature determination on the flows in April 1956 showed that on the average they were about 100°C; one of the fumaroles had a temperature of about 250°C.

At the moment of their eruption, the pyroclastic flows were very mobile; they flowed easily down the slopes of the volcano and accumulated only where the angle of the slope did not exceed 2°–3°. On steep slopes, pyroclastic-flow deposits were completely absent; as a result, the pyroclastic flows deposited in some valleys had no visible connection with the crater of Bezymianny volcano.

The deposits of pyroclastic flows consist of sandy-aleurite material, light-gray in color with inclusions of vesicular debris of hornblende andesite, similar in color. The density of this material is 1.6–2.3 g/cm^3, while the dominant size of the debris normally is 0.2–0.3 to 0.5–0.6 m, and occasionally about 1.5 m. The deposits are nonsorted and nonstratified. The dominant lithology (nearly 80–90 percent) in the pyroclastic flows is fresh juvenile material. Rocks of the old edifice are subordinate; their presence increases only in the lower parts of some deposits.

Post-climactic stage

An extrusive dome began to form in the crater after the climactic explosion; its development was accompanied by small explosions, pyroclastic flows, and incandescent avalanches. By July 1956, the dome had growth to a height of 300 m.

Since 1956, activity of Bezymianny is limited to continued growth of the intracrater dome, which is the largest extrusion in recent history at Bezymianny (Bogoyavlenskaya *et al.*, 1971; Bogoyavlenskaya *et al.*, 1976; Bogoyavlenskaya and Kirsanov, 1981).

During the dome growth the character of magma extrusion changed periodically. During the first decade, individual rigid blocks of the dome and occasionally of the whole massif of extrusion squeezed out. Beginning from 1965, along with rigid blocks, there also occured an extrusion of plastic lava in the form of small dykes and lava bulges. In 1969 through 1975 rigid extrusion predominated. In 1976 the absolute altitude of the

Novy dome was 2869.1 m, the height of the dome itself was about 800 m and its volume was about 0.367 km^3 (Seleznev *et al.*, 1983).

The third stage of the life of the dome began in 1977 with a strong explosive eruption as a result of which a smaller crater formed at the summit of the dome. During the subsequent five years pyroclastic eruptions occurred from this crater and small lava flows poured out (Fig. 7). The chemical composition of rocks of the dome during the 29 yrs of its growth changed slightly from 59.9% SiO_2 in 1956 to 57–56% SiO_2 in 1978–1979. Variations in mineral composition were more considerable, i.e. from hornblende pyroxene andesites in 1956 to bipyroxene well-crystallized basic andesites in 1962–63 and in later years.

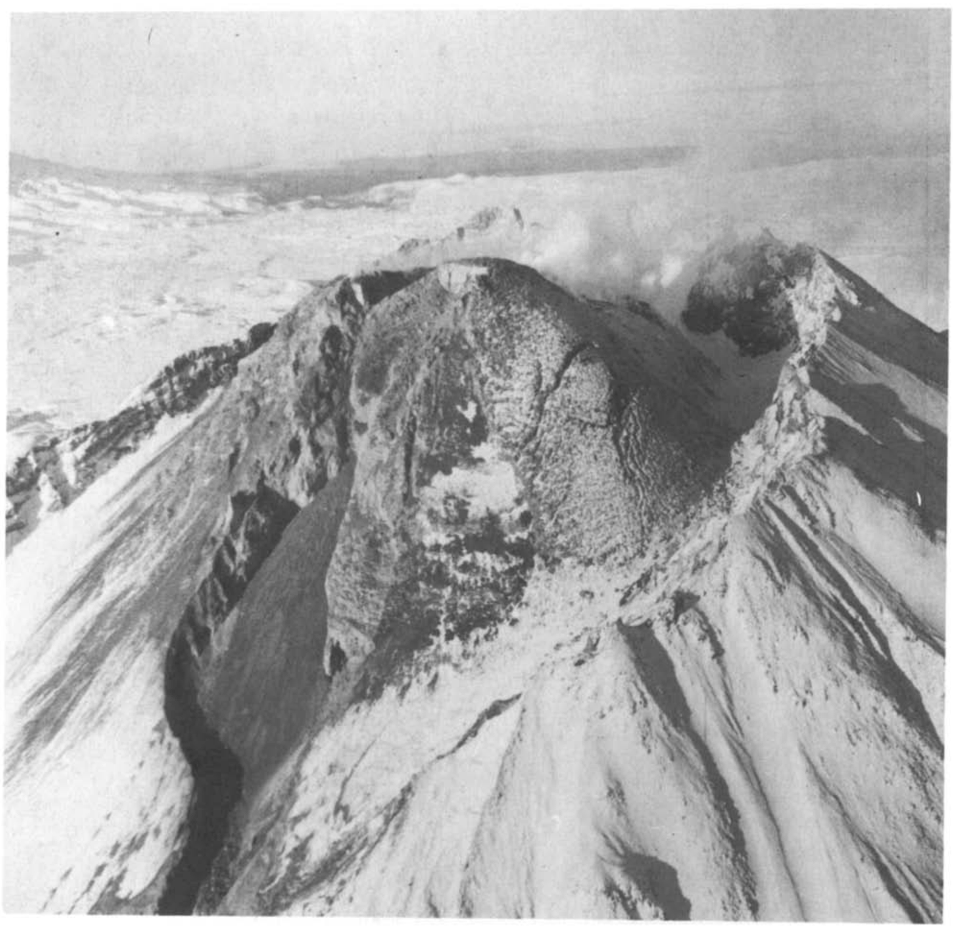

Fig. 7. The Novy dome in the crater of Bezymianny after the 13 October 1984 eruption. Photograph by A. Yu. Ozerov.

The details of the Bezymianny eruption are cited in Table II, which lists the main events of the preclimactic, climactic, and post-climactic stages of the eruption, the types of the deposits associated with them, and the characteristics of resulting deposits.

Figure 6 shows the results of studying the composition of matrix material for different types of deposits. To determine the quantitative-mineral composition, all of the < 0.5 mm fractions were studied with a microscope; the

TABLE

Characteristics of the 1955–56

<table>
<tr><th>Stages of eruption</th><th colspan="2">Main events</th><th>Duration</th><th>Type of deposit</th><th>Character of occurrence</th></tr>
<tr><td>POST-CLIMAC-TIC</td><td colspan="2">The growth of extrusive dome</td><td>1956–1984</td><td>Lavas of the extrusive dome</td><td>Intracrater extrusion</td></tr>
<tr><td rowspan="3">CLI-MAC-TIC</td><td rowspan="2">PLI-NIAN ACTI-VITY</td><td>Eruptive cloud about 35–40 km high</td><td>Several hrs</td><td>Tephra</td><td>Pyroclastic layer</td></tr>
<tr><td>Puroclastic-flow eruption</td><td>Several min.</td><td>Pyroclastic-flow deposits</td><td>Low-lying ground and valleys filled with pyroclastic-flow material</td></tr>
<tr><td colspan="2">Directed blast. Formation of crater about 1.5 × 2.8 km in size</td><td>Several sec.</td><td>Directed-blast sand</td><td>Blanket of sandy material</td></tr>
<tr><td rowspan="2">PRE-CLI-MAC-TIC</td><td colspan="2"></td><td></td><td>Directed-blast agglomerate</td><td>Hummocky-surfaced deposit covers area independent of to-pography</td></tr>
<tr><td colspan="2">Explosive activity, deformation of old volcanic edifice. Seismic preparation 28 days.</td><td>5 mos</td><td>Tephra</td><td>Pyroclastic layer</td></tr>
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