

ACTIVITY OF NORTH KAMCHATKA VOLCANOES IN 1985

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In 1985 eruptive activity renewed at three of the North Kamchatka volcanoes. This paper presents the description of eruptions at Klyuchevskoi, Bezmyannyi, and Shiveluch. Data are provided of the seismic activity and ground deformation caused by the Klyuchevskoi eruptions. Estimates of eruption cloud thermal power are presented.

The North Kamchatka volcano group includes five active volcanoes: Klyuchevskoi, Bezmyannyi, Shiveluch, Ploskii Tolbachik, and Ushkovskii. Eruptive activity renewed at the first three volcanoes in 1985. The description of the eruptive activity of these volcanoes is given below in the order of their location from north to south.

Shiveluch is the "northernmost" volcano of the Kamchatka active volcanoes. Its eruptive activities are dominated by the growth of extrusive domes and their subsequent disintegration during violent explosive eruptions. The last eruption of this kind occurred on November 12, 1964 [2]. During the 1964-1980 period of time its activity was characterized by the emission of fumarolic gases. In 1980-1981 a domelike mass of andesitic lava began to form in the crater. Its growth was particularly active from late August into November, 1980, when the rate of lava discharge was approximately $0.15-0.2 \times 10^6$ cubic meters per day [6, 15]. By the end of 1981, the dome reached a maximum height of 180 m and a volume of 0.02 km^3 and ceased to rise. From 1981 to 1984 fumarolic activity was observed on the dome. Eruptive activity resumed in 1984, when occasional gas and ash explosions began to occur on and at the base of the dome [13].

In 1985, moderate to strong emissions of fumarolic gases continued and four gas-ash eruptions occurred on the dome and at its base; the maximum height of eruption columns was 4 km.

The first eruption took place at 10:00 a.m. on May 26. The eruption column was approximately 3 km high. On May 27 two high columns of white steam rose in the area where the eastern flank of the dome bordered the crater wall. At 11:00 a.m. on May 31 this activity changed and a gas-ash cloud rose to a height of 350 m. Ash was ejected from two round vents 7-8 m in diameter spaced 50 m apart. Ramparts of light gray, fine-grained andesitic ash were formed around both vents. Ash ejection ceased on June 1.

The second explosion occurred at 1:43 p.m. on August 8. An ash cloud rose to a height of 3 km. At 4:50 p.m. on September 19, the third explosion took place; a pyroclastic column reached a height of 4 km (Figure 1). The ejection of ash was accompanied by incessant volcanic tremor and lasted about 30 minutes.

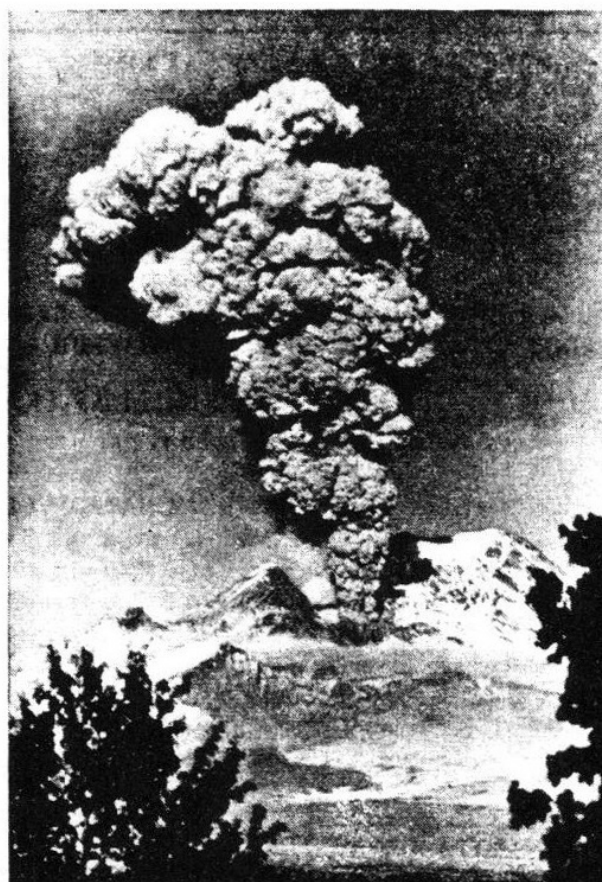


Fig. 1. Ash-filled gas cloud at Shiveluch, September 19, 1985. View from the east (from Klyuchi). Photo by A. Ozerov.

The last, fourth explosion in the series of the 1985 pyroclastic eruptions occurred on October 25. A pyroclastic column rose to a height of 1 km and deposited volcanic sand and ash produced by the disintegration of the crystallized lava dome.

As a result of this activity, several explosion craters were formed on and around the extrusive dome. They were surrounded by the ramparts of ejecta.

Klyuchevskoi is one of the most active basaltic volcanoes of the Kamchatka and world volcanoes. Its age is approximately 7 thousand years. The height of its cone changes from one eruptive event to another and averages 4750 m. Its activity is distinguished by lateral

(flank) eruptions with summit eruptions occurring averagely every five years. The summit crater has been active on a varying scale since 1983 [13, 14].

The summit eruption consisting of explosions and lava extrusion, which had continued since April 1984, ceased on January 28, 1985. It was described by Fedotov et al [13]. From that time to May 20, the volcano was in the state of mild, gradually attenuating fumarolic activity. A repose period lasted from May 21 to mid-August. On August 16 gas columns were seen above the summit crater from an airplane. Since then, the volcano was growing more and more active. A constant roar with no intermission, so it was impossible to distinguish between explosions, was heard since August 18. A barogram from the Apakhonchich seismic station (13 km from the summit crater) recorded 40 explosions per minute. At the same time, steam-and-gas ejections were less than 150 m in height. From August 23 ring-shaped gas ejections were observed. Activity of this kind lasted to September 13.

On September 13, observers from the Apakhonchich station saw red-hot bombs hurled to a height of 50 m; gas and steam columns rose to 200-300 m. An increase of explosive activity occurred on October 22. Gas columns were as high as 1.5-2 km. Bombs were hurled from two bocas to a height of some 100 m. That period of eruptive activity can be identified as Strombolian.

A change in activity occurred on November 5. A stream of lava flowed along the Kozyrevsk lava trench. It came to a halt when it was 700 m long. From November 10 lava flowed along the Krestovskii lava trench and from November 23 along the Apakhonchich trench. The lava flows descended to an elevation of 3000 m (Figure 2, *d*).

Lava extrusion was accompanied by intensive explosive activity. The ash column averaged 2.5-3 km in height and bombs were hurled to a height of about 250 m. A distinctive feature of that period was the occasional ejection of dense ash-filled columns rising to a height of 1 km. The maximum height of an ash-laden gas column was recorded on November 19 (3.5 km above the crater rim). Bombs were hurled to a maximum height of 500 m.

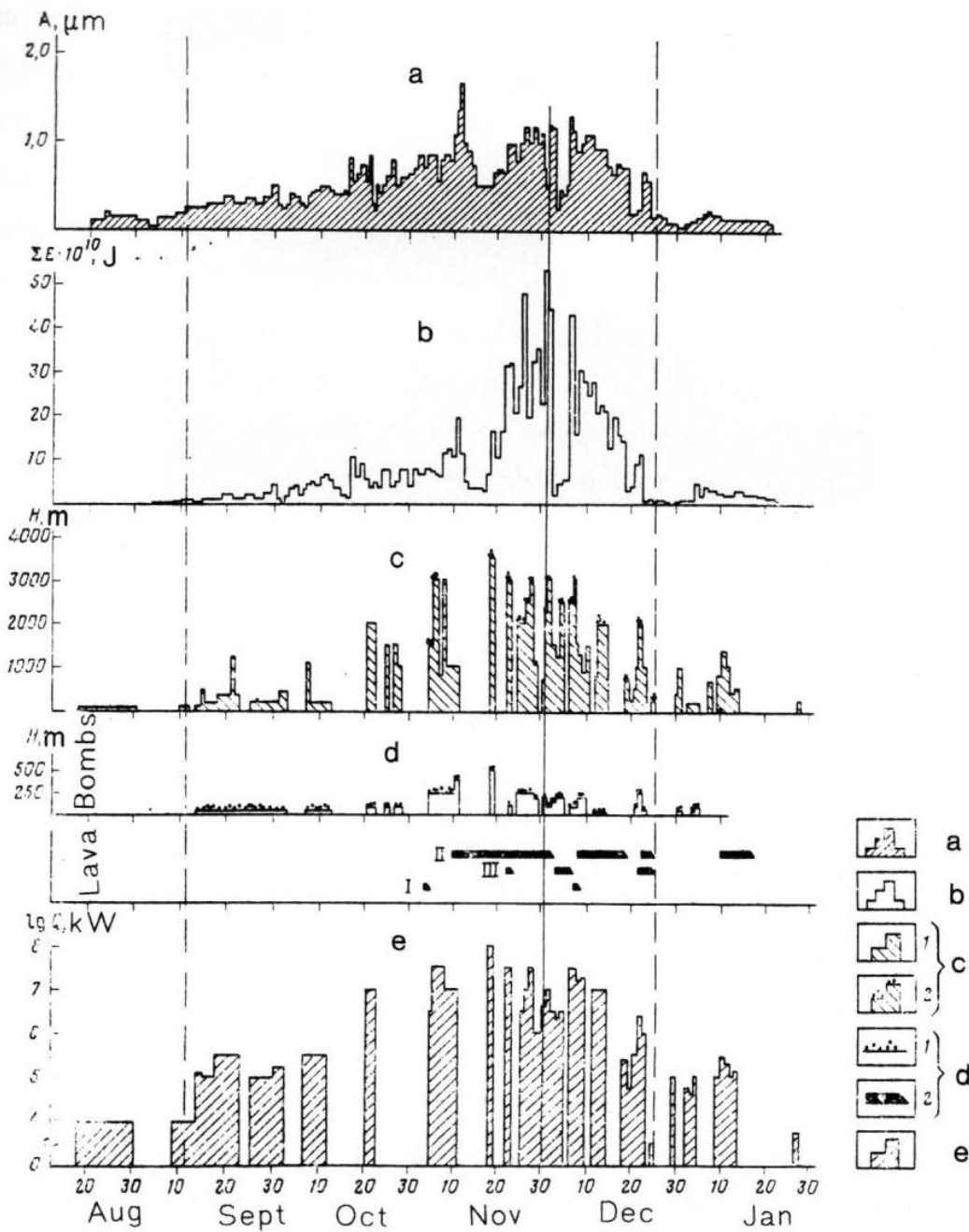


Fig. 2. Characteristics of the Klyuchevskoi summit eruption, August 18, 1985, to January 21, 1986. a - mean amplitude variation of tremor recorded at s/s Apakhonchich; b - tremor energy variation; c - height variation of steam-gas (1) and ash-gas (2) columns; d - height of bombs (1) and duration of lava flowing (2) along Kozyrevsk (I), Krestovskii (II) and Apakhonchich (III) lava trenches; e - thermal power of eruption columns.

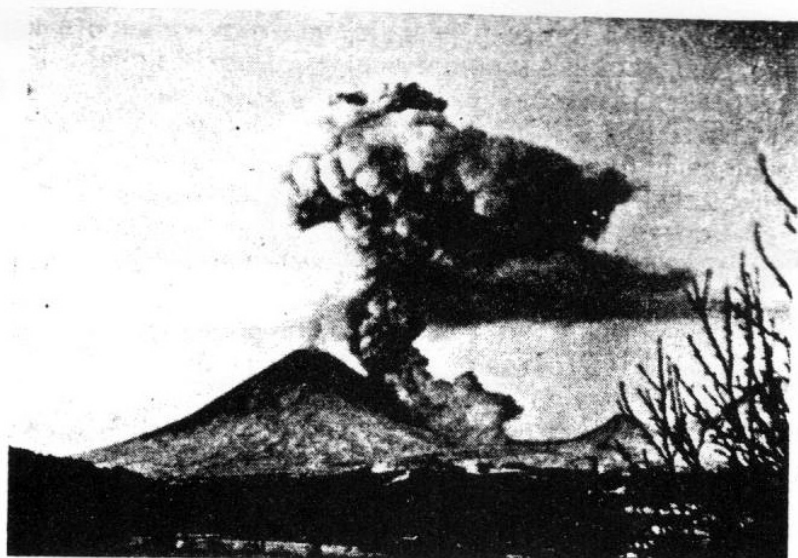


Fig. 3. Phreatic explosion in the Krestovskii trench of Klyuchevskoi, December 2, 1985. View from Klyuchi. Photo by A. Belousov.

On December 2, in the morning, a series of violent phreatic explosions occurred in the Krestovskii lava trench as lava came in contact with a glacier. Gas and steam were ejected from the summit crater with some outbursts having a height of about 2.5 km above the crater rim. Lava continued to flow along the Krestovskii trench. At 8:35 a.m. a white steam cloud appeared at a height of 3100 m above the lava flow front; then a series of explosions occurred which generated a high column of tephra and gases. It rapidly reached a height of 9.6 km and was drawn to form a line (Figure 3). The cloud produced by phreatic explosions was crossed by vertical lightning lines up to 3 km long. Six lightning discharges of this kind were recorded.

The propagation and size of the gas and ash cloud were measured by means of a meteorological radar from a zonal weather observatory. The cloud reached a maximum height of 9.6 km and two hours later had a size of 45 by 15 km. Figure 4 shows horizontal sections across the cloud at different altitudes (*b*) and the site of explosion located by means of radar (*a*). As the tropopause had a height of 7.8 km on

December 2, part of the erupted material reached into the stratosphere and the cloud began to spread rapidly in the horizontal direction. Most of it moved to the northwest. The remaining portion was drawn to the northeast and east by surface wind. The weight of the ash was 45 g/m^2 at the Apakhonchich seismic station and 20 g/m^2 at the Podkova station.

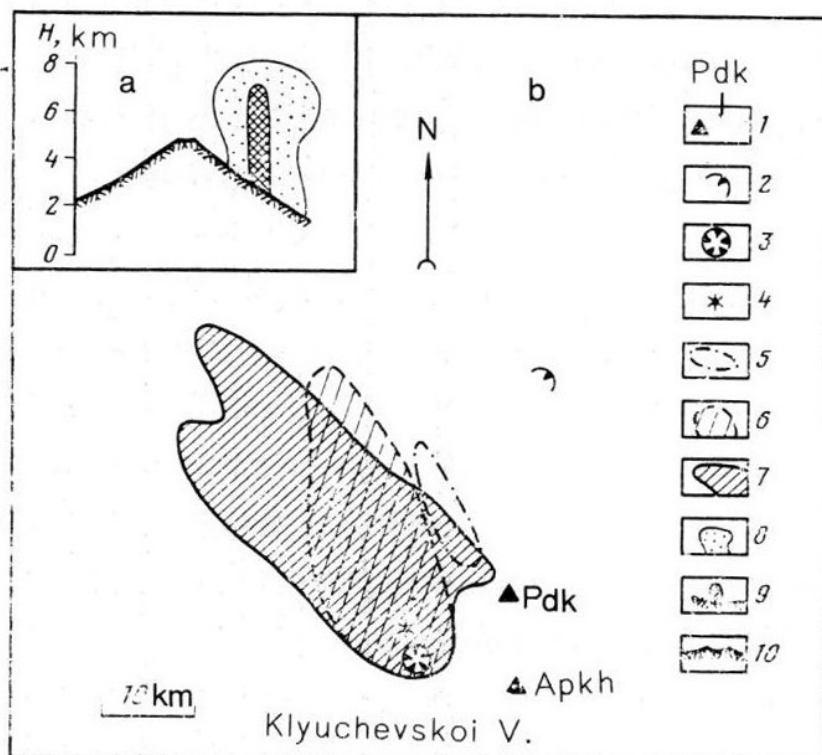


Fig. 4. Radar display of the eruption cloud produced by phreatic explosion in the Krestovskii trench of Klyuchevskoi, December 2, 1985. a - vertical section across the cloud; b - horizontal sections; 1 - seismic stations: Apkh - Apakhonchich, Pdk - Podkova; 2 - radar site; 3 - Klyuchevskoi summit; 4 - site of explosion; 5, 6, 7 - sections of the cloud obtained with radar antenna angles of 16.7° , 10° , and 6.5° , respectively; 8, 9 - outer and inner portions of the eruption cloud; 10 - Klyuchevskoi cone.

When explosions ceased, the observers did not see any significant changes in the lower portion of the Krestovskii lava trench, except

that a small debris cone was deposited there by a lahar. The lahar moved farther along the Erman Glacier and then along the channel of the Kruten'kaya River. It travelled over a distance of about 30 km and deposited an approximately one-meter layer of material consisting of unsorted debris of fresh and old basalt. The material contained many large blocks of ice mixed with pyroclastics.

After December 2, explosive activity at the summit crater began to subside. The eruption column was 1.5-2 km high. Extrusion of lava continued at the same rate with lava flowing along the Apakhonchich and Krestovskii trenches. Attenuation of the eruptive activity continued to December 20-21, when incandescent bombs were no longer ejected and extrusion of lava ceased; occasional outbursts produced dense ash-filled eruption clouds rising to a height of 600 m. On December 22 to 26, explosive activity intensified again and lava extrusion resumed. Outbursts of ash-filled eruption clouds increased in height to 2 km; incandescent ejecta were hurled to a height of 250 m. Lava flowed along the Apakhonchich and Krestovskii trenches and formed lava flows of 1 and 1.3 km, respectively.

On December 26, both explosive and extrusive activity began to subside rapidly till January 1, when explosions resumed: red-hot bombs were hurled to a height of 100 m above the crater rim. On January 11, the last lava flows descended along the Krestovskii trench to an elevation of 3100 m. Explosive activity during this last period of eruption was mild: the height of eruption clouds was 500-600 m and red-hot bombs did not rise to more than 50 m. On January 21 the eruption terminated.

Five eruptive periods can be distinguished (in terms of Vlodayets' classification [3]): I — steam-gas ejection (August 16 to September 13); II — explosions (September 14 to November 4); III — explosions and lava extrusion (November 5 to December 26); IV — explosions (January 1-10, 1986); V — lava extrusion (January 11-21, 1986). Changes from one eruptive period to another were marked by the

onset of regular ejections of incandescent bombs, or the appearance of lava flows, or by the predominance of lava extrusion over explosive activity.

The eruption was accompanied by seismic activity (see Figure 2, *a* and *b*). Volcanic tremor had a mean amplitude of 0.1–0.25 μm and $T = 0.4$ s during the first period and grew to 0.85 μm with $T = 0.5$ s during the second with a 2.4 μm outburst on November 2. The intensification of eruptive activity during the next period (III) was marked by a mean amplitude growth from 0.85 to 1.7 μm with $T_{\text{mean}} = 0.7$ s. The maximum amplitude of 3.6 μm was recorded on November 12 and December 2. As eruptive activity subsided by the close of period III, tremor diminished to 0.02 μm . The values of 0.1–0.2 μm with the mean period of 0.7 s were recorded during periods IV and V.

The height of the eruption column was measured whenever visibility was good enough. Using a technique proposed by Fedotov [11], the thermal power of the eruption was estimated; its variation is plotted in Figure 2, *e*. One can see that each eruptive period is characterized by a certain level of thermal power. The 1st period shows a power of 10^4 kW. As intensive explosions began during the 2nd period, the thermal power increased first to 10^5 and then to 10^6 – 10^8 kW. It was greatest during the 3rd period, 10^7 – 10^8 kW, and decreased to 10^5 kW at the close of the eruption. The thermal energy of the eruptive column was estimated for the whole period of eruption to be 1.5×10^{15} J. Correlation between the tremor and thermal power points to a relation between the tremor and explosive activity (Figure 2, *a*, *e*).

A cinder cone began to grow in the summit crater during the 1984 eruption. Since September 1984 the height of the cone above the crater rim was measured by trigonometric leveling from Klyuchi. The accuracy of measurements was within 2 m. Figure 5 shows differences in the form and height of the cinder cone indicated by three levelings. By May 16, 1986, the cone rose to a height of about 130 m (see Figure 5).

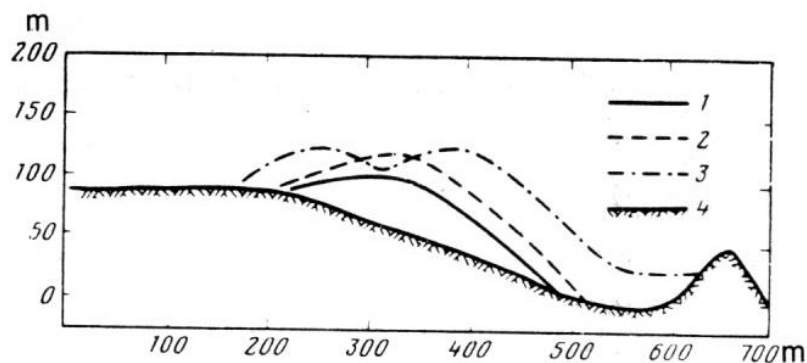


Fig. 5. E-W profile of the cinder cone and the Klyuchevskoi crater rim from trigonometric levelings of: 1 - February 5, 1984; 2 - March 18, 1985; and 3 - May 16, 1986; 4 - crater rim.

In 1979 precise leveling was undertaken along a radial line on the northern flank of the cone and line measurements were made on a radial network with the center situated 13 km from the crater [7]. It was found that the cone flank had risen before the summit and flank eruptions of 1983 and before the summit eruptions of 1984-1985 and subsided after the eruptions. The rise had a maximum value of 8 cm at a distance of 10 km from the crater as measured in 1985.

The line measurements showed a systematic compression along all lines and extension before and during the eruption. Maximum extension of 16 cm over a distance of 6.6 km was observed on the subradial lines for a period of September 1984 to April 1985.

The products of the 1985 summit eruption are calc-alkalic, Al-rich sub-aphyric basalts (Table I) with scarce phenocrysts of olivine, clinopyroxene, and orthopyroxene. The ash produced by that eruption is not different from the ash ejected during the other Klyuchevskoi summit eruptions [5, 9].

The volume of the erupted material will be estimated from the stereophotogrammetry of aerial photographs which is in progress.

Bezmyannyi. After the catastrophic eruption of 1956, an extrusive andesitic lava dome, called Novyi, began to grow in the newly formed crater 1.3 by 2.8 km in size [4].

TABLE I

Chemical Composition of Klyuchevskoi Lava, 1985 Eruption

Oxide	KL-85-86	Oxide	KL-85-86	Oxide	KL-85-86
SiO ₂	53.44	MnO	0.17	P ₂ O ₅	0.19
TiO ₂	1.14	MgO	5.07	H ₂ O ⁻	0.03
Al ₂ O ₃	18.15	CaO	8.16	H ₂ O ⁺	-
Fe ₂ O ₃	2.61	Na ₂ O	3.38		
FeO	5.96	K ₂ O	1.20	Σ	99.50

Analyst, A.I. Okrugina

The growth of the dome was accompanied by explosive eruptions resulting in the formation of pyroclastic flows. In 1977 viscous lava was extruded along with pyroclastic ejections.

This activity ceased by the close of 1984 and a repose period with mild fumarolic activity lasted for about half a year. In 1985 two eruptions took place, one in June-July and the other in October-December. The summer eruption (June 12-28) began with the squeezing out of a block in the eastern part of the Novyi lava dome which caused avalanches of lithic debris (Figure 6).

According to the observation of Seleznev et al [10], the process of squeezing and subsequent disintegration of lava blocks is a premonitory symptom of coming explosive activity. Explosions began on June 29 and lasted to July 2. They destroyed part of the Novyi lava dome and generated pyroclastic flows. The first pyroclastic flow was formed on June 29. It was approximately 5 km long. A day later several pyroclastic flows, the largest having a maximum length of 12.5 km, descended during the night of June 30; a strong roar (like that of a jet engine) was heard. In the morning this type of activity subsided and ended on July 2 when the last pyroclastic flow was observed.



Fig. 6. Extrusive dome Novyi in the Bezymyanni crater before explosion in June 1985. View from the east. Photo by A. Belousov.



Fig. 7. View of Bezymyanni after explosion, from the east. Photo by A. Belousov.

This eruption produced a crater at the summit. It was 400 m in diameter, had a maximum depth of 250 m, and was open to the east

(Figure 7). The pyroclastics deposited at the eastern base of the cone consisted of directed-blast sand and pyroclastic flow material. The deposits were identified and delineated on the basis of a topographically uncontrolled areal spread, a gradual decrease in thickness away from the cone (from 2 m to 1 mm), an outward decrease of grain size (from gravel to fine-grained sand), and the presence of parallel and cross bedding.

TABLE II

Distribution and Volume of Deposits Erupted by Explosions at Bezymyanyi in 1985

Type of deposit	Max outward extent, km	Area, km ²	Volume, km ³
Block and ash flow deposit including rock debris	7-8	4.0	0.012
Directed-blast sand	6	7.0	0.001
Pyroclastic flow deposit	12.5	10.5	0.025

The pyroclastic-flow deposits consist of unsorted andesite blocks 3 to 5 m across and fine-grained material. They range between 1 and 4 m in thickness.

Distinctive features of the pyroclastic flows were a high speed of motion and the burning of gas above the surface which was supposed to be related to a high gas content in the juvenile andesite and to the presence of juvenile hydrogen in the volcanic gases [8].

The accretionary lapilli were 4-6 mm grayish-pink, spheroidal, concentrically layered pellets composed of silt-size particles.

By the end of the period of explosive activity lava began to outpour on July 2 and continued to flow till July 14.

During the final period, from July 31 to September 8, there were no explosions and a viscous lava flow moved slowly into a volcanic trough on the eastern flank of the cone.

Incessant tremor was recorded during the periods of explosive activity as a superposition of seismic impulses with periods of 0.1–0.2 and 0.5–0.7 s. Occasionally, the period increased to 0.8 or 1 s against the background of continuous tremor having an amplitude of 0.1 μ and a period of 0.1–0.2 s. Changes in the intensity of eruptive activity were indicated by sudden changes in the amplitude and period of seismic impulses. The appearance of the first pyroclastic flow was marked by a seismic response of $A = 4.5 \mu\text{m}$ and $T = 1 \text{ s}$. Subsequent changes in tremor were recorded on June 30: $A = 1.45 \mu\text{m}$ and $T = 0.8 \text{ s}$ at 1:30 a.m., $A = 21.6 \mu\text{m}$ and $T = 0.9 \text{ s}$ at 8:08 p.m., and on July 1: $A = 12.4 \mu\text{m}$ and $T = 0.7 \text{ s}$ from 1:25 to 2:14 a.m. and $A = 18.2 \mu\text{m}$ and $T = 0.8 \text{ s}$ at 3:10 a.m. Occasional shocks with $S-P = 4.6 \text{ s}$ were recorded during the other time periods of the June 29 to July 1 explosive activity. The maximum power of tremor was $1.8 \times 10^8 \text{ W}$.

In October, the volcano became active again. On October 15, avalanches of lithic debris appeared and were as frequent as 1–2 per minute by November 5. Lava started to outpour on November 7 and flowed till December 14, 1985.

The products erupted by explosions (from June 29 to July 2) are two-pyroxene andesites with scarce inclusions of hornblende. The areal distribution and volume of erupted material are given in Table II.

CONCLUSIONS

Three volcanoes of the North Kamchatka volcano group, Shiveluch, Klyuchevskoi, and Bezymyanni, continued to be active in 1985.

1. Outbursts of ash-filled gas columns at Shiveluch were indicative of explosive activity at the extrusive dome which continued

since 1984.

2. The eruptive activity at Klyuchevskoi can be interpreted as an interparoxysmal event of moderate intensity on the basis of the eruptions that occurred from bocas on the crater floor, Strombolian-type explosive and extrusive activity, and other evidence.

3. The 1985 Bezymyanni eruption ranks among the major events that took place at the volcano after the catastrophic eruption of 1956.

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