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PYROCLASTIC DEPOSITS OF THE BEZYMYANNYI ERUPTION IN OCTOBER 1984

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The pyroclastic material of the last Bezymyannyi eruptions has been studied in detail. Four types of pyroclastic deposits have been distinguished among the material discharged during the 1984 eruption and the eruptive process of that event has been reconstructed.

INTRODUCTION

In the last two decades, Bezymyannyi ranked second in activity after Klyuchevskoi among the Kamchatkan volcanoes. After a long period of dormancy it reawakened in 1955 with an outbreak of intensive explosive activity. A cataclysmic explosion occurred on 30 March 1956. Explosive activity was followed by the growth of lava domes. Explosive and extrusive activity continued until the late seventies when lava began to flow.

Like all previous events, the October 1984 eruption was preceded by the extrusion of andesite lava blocks on the Novyi dome [10]. The climactic event occurred on October 13–14 and consisted in vertical explosions and low-angle blasts which deposited ash in a range of about 100 km and produced two pyroclastic flows. A viscous lava flow issued from a vent on the dome [7], [9], [10], [11]. On October 17 we collected samples of pyroclastic material and analyzed them in 1985. During the summer of 1985 another powerful eruption took place. We managed to collect samples of ash right after it was discharged. A detailed ash study resulted in distinguishing the principal types of pyroclastic deposits typical of andesitic volcanoes [1], [2], [3], [12]. The experience gained from the study of the products deposited by the 1985 eruption and those produced by a smaller event of 1986 encouraged us to reexamine the pyroclastics of the eruption which occurred in October 1984. This work resulted in the separation of four units: tephra, ash falling from clouds above the pyroclastic flows, block and ash flow, and pyroclastic surge. Another outcome of the study is a partial reconstruction of the sequence of the 1984 eruptive events.

The modern classifications of pyroclastic rocks [2], [12] subdivide the pyroclastics of andesitic volcanoes into: (1) pyroclastic flows consisting of a moving material arranged in laminae (laminar flow) characterized by a high value of the solid-gas ratio and (2) pyroclastic surges, turbulent flows of a low solid-gas ratio. Fisher and

Schmincke [12] indicated that during many events pyroclastic flows and pyroclastic surges arise from one flow of moving material which separates into two flows according to the relative gravities of its constituents. Generally, as the primary pyroclastic material moves down the slope, it separates into three layers of unequal volumes: the lower layer, a pyroclastic flow body abounding in large fragments and blocks; the middle layer, a pyroclastic surge of dust-sand material with small fragments; and the upper layer consisting of ash falling from clouds above a pyroclastic flow [1], [2], [6], [12] (Figure 1).

In contrast to pyroclastic flows, pyroclastic surges produce thin deposits of fine, well-sorted material. The movement of a pyroclastic surge down the slope is not controlled by the topography. As the pyroclastic surge travels at a greater speed than the pyroclastic flow, it separates from the latter. This is why surge deposits can be encountered both at the base and on the top of pyroclastic flows [2], [12]. A distinctive feature of pyroclastic surges is a great destructive force. For example, during the Bezymyannyi eruption of 1985 the surge of an inclined blast (directed blast sand) demolished all cabins in the volcanologists' camp situated 3.5 km from the volcano [1].

The magmatic material thrown out of the volcano during an eruption is of uniform chemical and mineralogic composition. Differences in the depositional mechanisms of various pyroclastic materials involve compositional variations. Pyroclastic flows which account for the larger part of the erupted material consist of lithic debris resulting from the fragmentation of the conduit walls and the top of the dome by explosions. As the material moves down the slope, it mixes and the chemical composition of the matrix of the pyroclastic flow becames similar to the average composition of the lava fragments. The chemical composition of the matrix thus represents the average composition of the eruption products.

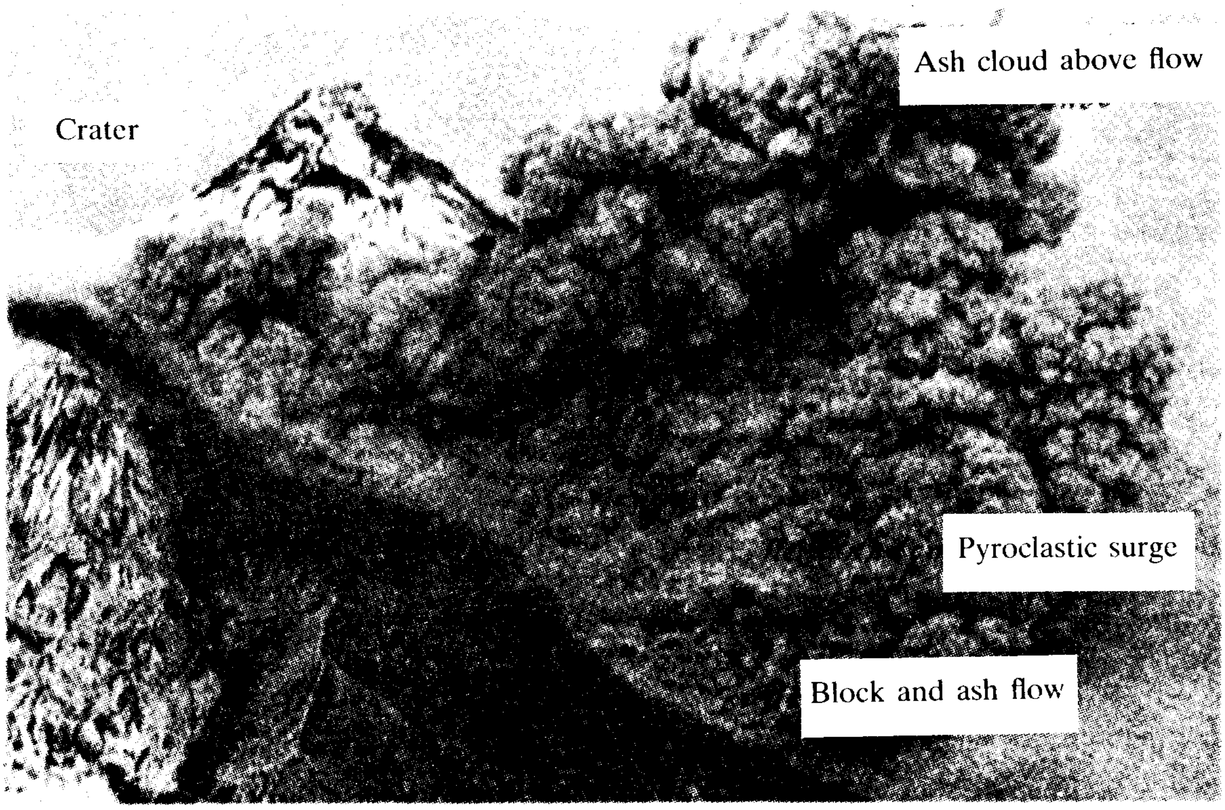

Figure 1 The separation of pyroclastic material into different types as it moves down the slope (in andesitic volcanoes). Photo by V.N. Nechaev

The Bezymyannyi eruption in 1984 deposited two pyroclastic flows on the flank of the dome and covered the surrounding area with ash (Figures 2 and 3).

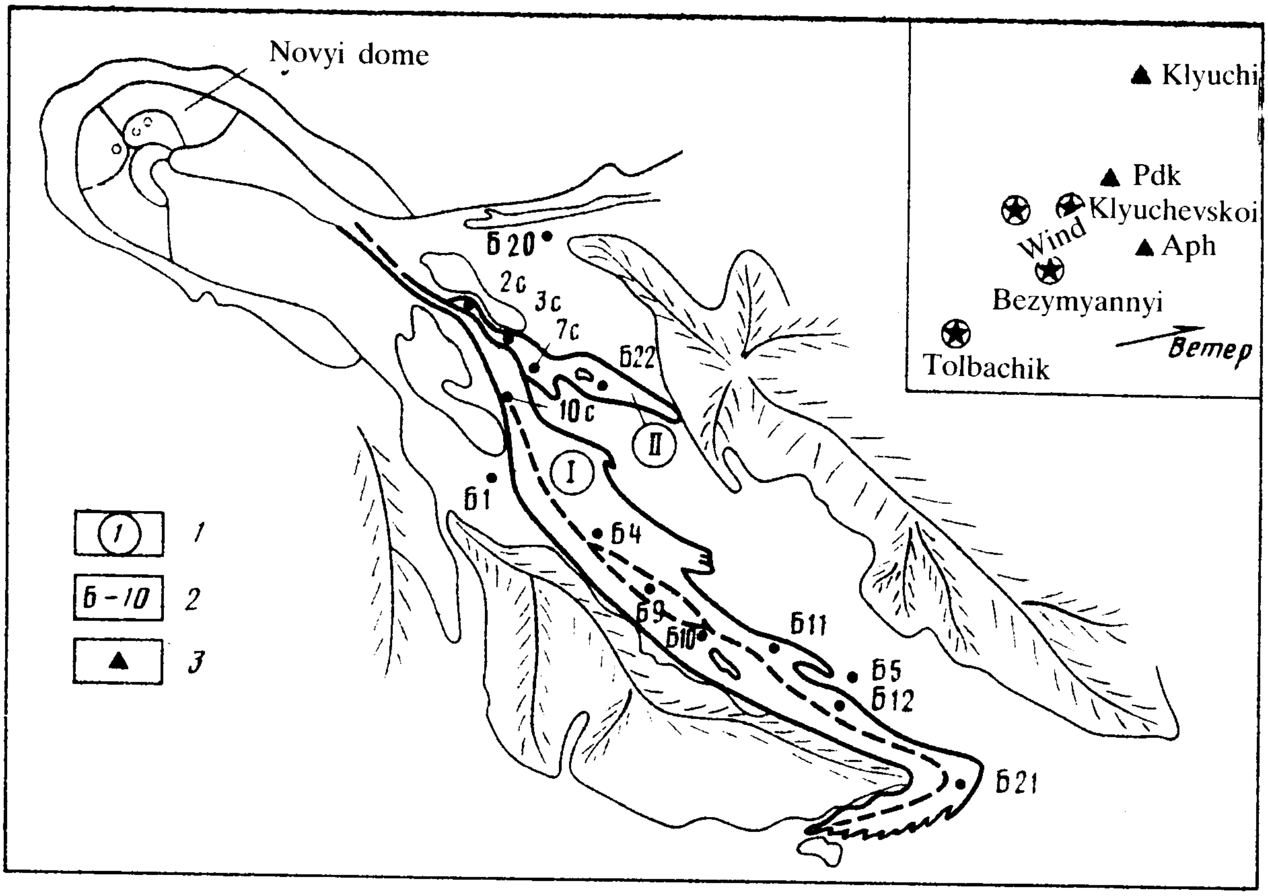

Figure 2 Sketch map showing distribution of pyroclastic flows during the Bezymyannyi eruption in October 1984. 1 — pyroclastic flows I and II; 2 — sampling sites; 3 — seismic stations. The inset shows location of the Klyuchevskoi volcanic group. Pdk-s/s Podkova, Aph-s/s Apakhonchich

Figure 3 Pyroclastic flow I deposited at Bezymyannyi during the October 1984 eruption. Photo by A.Yu. Ozerov

Table I Chemical Composition of the Material Erupted at Bezymyannyi in October 1984

Oxide	*Andesite lava fragments, flow I*		*Matrix, flow I*		*Sand, flow I*		*Matrix, flow II*			*Ash from clouds above flows*		*Tephra*	
	B97	*B99*	*B10*	*B12*	*B21*	*B4*	*B22*	*2C*	*7C*	*B5*	*B20*	*B24*	*B19*
SiO_2	56.62	57.54	56.20	56.48	57.0	56.68	57.32	58.60	57.86	59.84	62.20	60.62	60.46
TiO_2	0.62	0.75	0.72	0.63	0.65	0.65	0.77	0.76	0.78	0.65	0.48	0.57	0.57
Al_2O_3	18.61	18.27	18.45	18.74	18.39	19.10	18.54	18.18	18.42	17.28	18.02	17.77	16.77
Fe_2O_3	2.36	3.38	2.54	3.24	2.98	3.26	3.94	3.95	4.10	4.01	2.97	3.45	3.30
FeO	4.42	3.96	4.22	3.73	3.82	3.88	3.85	3.10	3.01	2.59	2.24	2.61	2.87
MnO	0.15	0.17	0.17	0.15	0.19	0.19	0.19	0.13	0.12	0.08	0.12	0.13	0.15
MgO	4.57	4.06	4.95	4.29	4.07	4.25	4.35	4.26	4.26	2.87	2.24	2.51	3.25
CaO	7.41	7.18	7.63	7.63	7.76	7.67	6.59	6.14	6.27	7.00	6.16	6.83	6.05
Na_2O	3.21	3.25	3.15	3.21	3.02	3.15	3.15	3.11	2.90	3.62	3.46	3.46	3.66
K_2O	1.29	1.38	1.24	1.24	1.19	1.19	1.29	1.33	1.25	1.52	1.73	1.58	1.76
P_2O_5	0.25	0.23	0.06	0.08	0.10	0.12	0.07	0.24	0.26	0.16	0.33	0.47	0.20
H_2O^-	0.07	0.06	0.25	H/$_{O\sigma H}$·	0.11	H/$_{O\sigma H}$·	0.05	0.05	0.23	H/$_{O\sigma H}$·	H/$_{O\sigma H}$·	H/$_{O\sigma H}$·	0.27
H_2O^+	0.07	0.00	0.27	0.26	0.19	0.20	0.19	0.16	0.15	0.20	0.19	0.21	0.25
Σ	99.65	100.29	99.85	99.68	99.57	100.34	100.30	100.01	99.61	99.82	100.14	100.21	99.56

Note. B97 to B19 are sample numbers. Analyses were made at the Chemical Laboratory, Institute of Volcanology. Analysts, N. Gusakova, samples 1 to 7 and 13; T. Osetrova, samples 8 and 9; L. Kartasheva, sample 10; T. Alekseeva, samples 11 and 12

The erupted products were of two-pyroxene andesite with scarce inclusions of hornblende. The average chemical composition of the matrix and lava fragments of the flows was uniform and the SiO_2 content was 57.16 wt.% (nine determinations) (Table I). The chemical composition of the ashes (both of the tephra and of the ash falling from the clouds above the pyroclastic flows) was considerably different from that of the flow matrix, their SiO_2 content averaging 60.78 wt.% (four determinations) (see Table I). The more acid composition of the ashes and their higher Mg content can be explained by eolian differentiation in the case of the tephra and by laminar differentiation in the ash falling from the clouds above the pyroclastic flows.

As tephra are ejected from the crater itself, their chemical and mineralogic compositions are identical to the average composition of the erupted products. The grain size, mineralogy, and chemistry of tephra changes with distance from the vent due to the effect of eolian differentiation. Convincing evidence in favor of this statement has been provided by Gushchenko [5], Dubik and Menyailov [6], Kir'yanov [8], and other investigators.

Primary pyroclastic becomes stratified as it moves down the slope by way of gravitational separation. This results in the accumulation of compositionally different types of pyroclastic deposits (see Figure 1 and Tables I, II, III). That the resulting rocks are different types is proved by variations in their solid phase densities. The matrix of the pyroclastic flows showed 2.69 g/cm^3, that of the

Table II Grain Size Distribution in Pyroclastic Deposits of Bezymyannyi Eruption in October 1984, %

Sample number		*Particle size, mm*						
		0.056	*0.056–−0.071*	*0.071 −0.125*	*0.125 −0.25*	*0.25– −0.5*	*0.5– −0.1*	*1.0– −2.0*
1	B9	6	3	12	25	22	20	12
2	B10	10	5	13	24	20	18	10
3	B11	5	3	11	29	27	18	7
4	B12	7	3	11	26	23	19	11
5	8c	8	3	16	30	18	16	9
6	10c	3	3	12	28	21	20	13
7	B21	9	4	12	27	20	17	11
	Mean	8	3	12	27	22	18	10
8	2c	7	9	26	34	16	7	1
9	3c	3	4	20	31	25	14	3
10	7c	1	4	26	37	18	10	4
11	B22	13	5	19	37	19	6	1
	Mean	6	6	23	35	19	9	2
12	B4	2	2	7	29	33	22	5
13	B1	43	11	23	16	3	2	2
14	B24	52	8	13	17	9	1	–
15	B19	57	15	25	3	–	–	–
16	B17	56	33	10	1	–	–	–
17	B5	55	11	16	13	4	1	–
18	B20	73	4	7	9	4	2	1

Note. 1 to 7 – matrix of flow I; 8 to 11 – matrix of flow II; 12 – material of flow I similar to flow II; 13 to 16 – tephra: 13 – 2.5 km from the vent, 14 – at s/s Apakhonchich site, 15 – at s/s Podkova site, 16 – in Klyuchi town; 17, 18 – ash deposited from clouds above pyroclastic flows: 17 – 7 km from the vent, 18 – northern valley side. Samples by courtesy of Yu. Slezin (5, 6, 8, 9, 10), I. Kirsanov (7), A. Malyshev (11, 14, 18), and V. Khanzutin (15).

Table III Physical Properties of Pyroclastic Rocks Produced by Bezymyannyi Eruption in October 1984

Sample	*Solid phase density, g/cm³*	*Whole rock density, g/cm³*		*Porosity factor, E*		*Porosity n, %*		*Compactability factor F*
		State						
		Loose	*Consolidated*	*Loose*	*Consolidated*	*Loose*	*Consolidated*	
B9	2.64 (2)	1.33 (10) 1.30–1.37	1.49 (9) 1.47–1.58	0.98 (10) 0.93–1.03	0.77 (9) 0.67–0.79	50 (10) 48–51	43 (9) 40–44	0.54
B11	2.64 (2)	1.24 (10) 1.20–1.28	1.51 (8) 1.45–1.54	1.13 (10) 1.06–1.20	0.75 (8) 0.71–0.82	53 (10) 51–54	43 (8) 42–45	0.69
B21	2.69 (2)	1.32 (10) 1.30–1.34	1.59 (9) 1.57–1.61	1.04 (10) 1.01–1.07	0.69 (9) 0.67–0.71	51 (10) 50–52	41 (9) 40–42	0.60
B22	2.56 (2)	1.20 (10) 1.16–1.25	1.52 (10) 1.49–1.54	1.13 (10) 1.05–1.21	0.68 (10) 0.66–0.72	53 (10) 51–55	41 (10) 40–42	0.83
B4	2.52 (2)	1.20 (10) 1.19–1.23	1.40 (7) 1.36–1.43	1.10 (10) 1.05–1.12	0.80 (7) 0.76–0.85	52 (10) 51–53	44 (10) 43–46	0.47
B1	2.70 (2)	1.06 (10) 1.03–1.10	1.47 (10) 1.43–1.51	1.55 (10) 1.45–1.62	0.84 (10) 0.79–0.89	61 (10) 59–62	45 (10) 44–47	1.05
B24	2.72 (2)	0.90 (10) 0.87–0.95	1.32 (10) 1.24–1.37	2.02 (10) 1.86–2.13	1.06 (10) 0.98–1.19	67 (10) 65–68	51 (10) 50–54	1.17
B19	2.62 (2)	—	—	—	—	—	—	
B5	2.47 (2)	—	—	—	—	—	—	
B20	2.46 (2)	0.86 (10) 0.84–0.88	1.31 (10) 1.27–1.34	1.86 (10) 1.79–1.93	0.88 (10) 0.83–0.94	65 (10) 64–66	47 (10) 45–48	1.32

Note. Top — mean value and number of samples in parentheses, bottom — a min. to max. range pyroclastic surges 2.56 g/cm^3, and the ash deposited from the clouds above the pyroclastic flows 2.47 g/cm^3. The density of the solid particles of rocks is known to be dependent solely upon their mineralogy; it grows with an increasing amount of heavy minerals [4]. Differentiation is particularly pronounced in the case of the ashes deposited from the clouds that traveled above the pyroclastic flows. They bear some resemblance in composition and density to the tephra, and not to the primary ones but to those that have undergone eolian differentiation (see Tables I, II, III).

As the predominant direction of the wind during the eruption was ENE, toward the seismograph station Apakhonchich, the larger part of ash was deposited in that direction. Figure 4 shows that ash sample B20 collected on the northern side of the Bezymyannyi valley 3.5 km from the vent and sample 24 taken at s/s Apakhonchich 16 km from the vent are markedly different in grain size from the other samples taken along the ash-fall axis. Although tephra and ash falling from clouds above the pyroclastic flows are classified as dust-like sand [4], it is important to note that the ash from s/s Apakhonchich is slightly coarser than the ash deposited on the northern side of the Bezymyannyi valley. The solid phase of these ashes showed density of 2.72 g/cm^3 and 2.46 g/cm^3, respectively. Ash sample B1 collected at a distance of 2.5 km from the vent in the SE direction yielded 2.7 g/cm^3 and sample B5 collected at a distance of 7 km from it along the same SE-trending ash fall, 2.47 g/cm^3. As will be demonstrated below, the density of the matrix solid phase of pyroclastic flow I, which represents the composition of the material erupted in 1984, is 2.64 to 2.69 g/cm^3 (see Table III).

Proceeding from the above data and the high explosivity of the volcano (25×10^8 to 5×10^9 kW [11]), it can be concluded that the bulk of the tephra ejected by vigorous explosions was transported by the dominant ENE wind over the northern side of the Bezymyannyi valley and propagated further ENE to be deposited far from the vent. This conclusion is corroborated by the fact that almost undifferentiated ash (density 2.72 g/cm^3) was deposited at the site of s/s Apakhonchich and that is was subject to eolian differentiation at 30 km from the vent (s/s Podkova): it lost heavy minerals and its density decreased to 2.62 g/cm^3. A small amount of tephra deposited near the dome can be explained by the ballistic pattern of the ejections. The ash that traveled in the clouds above the pyroclastic flows seems to have been deposited on the northern side of the Bezymyannyi valley and at a distance of 7 km from the vent. It has a distinct mineralogic composition and density of 2.47 g/cm^3. The air-fall deposition on the northern side of the Bezymyannyi valley was promoted by the wind that blowed largely in that direction and by the detachment of ash clouds from the pyroclastic flows as early as they began to roll down a trench on the Novyi dome.

The newly erupted pyroclastic material was very loose right after it was discharged. Later, as it was acted upon by various exogenic processes and gave off gases, the material was gradually lithified. Usually, the capacity of newly deposited pyroclastics to become compact is estimated using a compactibility factor based on the density and porosity of rocks in the loose and consolidated state [4]. The pyroclastics concerned showed a wide variation range of this factor, 0.47 to 1.32. Variation was largely a function of the size of the constituent particles. For instance, the ash from the northern side of the valley was more liable to compaction than the ashes from the other localities because it contained a larger amount of fine particles. At the same time although the tephra from the Apakhonchich site show approximately the same grain-size distribution, they are less compact because they contain less finely pulverized particles. As seen from Tables II and III, the grain size of a material is a factor responsible for its packing density and porosity and hence for its ability to become compact. The larger the quantity of fine particles in pyroclastic deposits, the more liable they are to be firmly indurated by compaction.

The larger pyroclastic flow, I, traveled for a distance of 7 or 8 km from the vent and had a maximum width of 500 m and an average thickness of 2.5 m. It followed numerous, well-defined channels with marginal ridges which marked the supply of new batches of volcanic material and had a 5 or 6 m high, steep frontal part where it swang southward round the end of the southern side of the valley (see Figures 2 and 3). The flow spread over an area of 2.7 km^2 and had a volume of 0.012 km^3 [7]. Being controlled by the valley floor topography, the flow had a maximum thickness of 6 m at the southern side and was below 0.3 m at the northern. The deposits consist of numerous fragments, 2–3 cm to 2–4 m across, of grey dense and vesicular andesitic lava of the Novyi dome and a medium sand-size matrix with the solid phase density of 2.64–2.69 g/cm^3. The material of the northern margin of the flow consists of 60 to 70% ash; patches of this kind were encountered in the middle of the flow (see Table II, sample B4). Flow I can be classified as a block and ash flow proceeding from a closeness of the solid phase density values of the flow matrix and the tephra near the dome, which are believed to represent the density of the primary pyroclastics, and from a similarity of the grain-size distribution in the flow I matrix and in the matrix of the block and ash flow discharged in 1985. The other evidence in support of this conclusion are the accumulation of the deposits in depressed areas, the presence of channels and marginal ridges, and the abundance of coarse material (see Tables II and III and Figures 4 and 5) [2], [3], [12].

The smaller pyroclastic flow, II, traveled 4 km, had a maximum width of 50 m, and averaged 1 to 1.5 m in thickness. It was markedly different from flow I. According to the private communication by Yu.B. Slezin, right after it was discharged, the surface of the flow consisted of fine-grained sand without lava fragments or lithic debris. Fragments measuring not more than a few tens of centimeters were encountered at a depth of about 1 m in the middle of the flow and at 10–15 cm at the margins. The flow covered an area of 0.075 km^2 and was 0.0002 km^3 in volume. The deposits are of smaller grain size and better sorted than those of flow I. They consist of fine-grained sand with the solid phase density of 2.56 g/cm^3. The cumulative grain-size distribution curves of the flow II material are similar in shape to those of the 1985 pyroclastic surge deposits (see Figure 4). The plots of the relations between various grain-size parameters show that their data points concentrate in one group separated from the points characterizing the matrix of the block and ash flows (see Figure 5). Proceeding from the known features by pyroclastic surges in general and of flow II in particular, it can be concluded with certainty that the deposits of this flow were produced by a pyroclastic surge.

It follows that the differentiation of the 1984 pyroclastics began as early as it started to roll down an abrasion trench on the Novyi dome. As a consequence of high explosive activity and strong wind, the bulk of the tephra was transported far away from the vent and the ash falling from the clouds above the pyroclastic flows was deposited near the dome. The distribution of the block and ash flow was

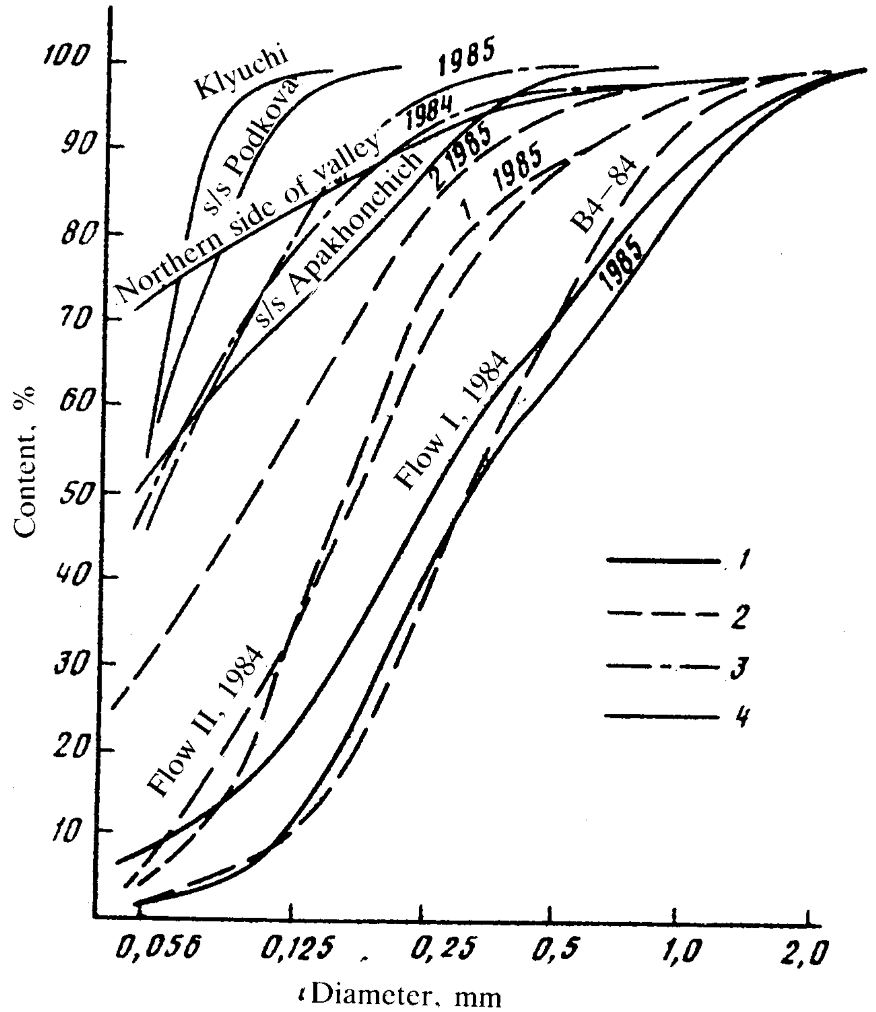

Figure 4 Cumulative curves of grain-size distribution in pyroclastic deposits produced by Bezymyannyi eruptions in 1984 and 1985. 1 — block and ash flow; 2 — pyroclastic surge; 3 — ash falling from clouds above the pyroclastic flows; 4 — tephra of 1984.

controlled by the topography: the flow followed all the turns of the trench on the dome and of the canyon on the slope of the volcano. The bulk of the more mobile gas-rich pulverized surge material which separated from the flow continued to move straightforwardly, where the main flow turned southward following the trench, and was deposited as flow II. Patches of pyroclastic surge deposits have been encountered on flow I. For instance, sample B4 bears resemblance in grain size and density to the pyroclastic surge material (see Figures 4 and 5 Tables II and III). The flow and the surge were derived from the same pyroclastic mix. The indirect evidence in support of this conclusion are the close values of their packing densities and porosities in the loose and consolidated state (see Table III).

CONCLUSIONS

1. Four types of pyroclastic products discharged during the Bezymyannyi eruption of 1984 were distinguished during this study: tephra, ash falling from clouds above the pyroclastic flows, block and ash flow, and pyroclastic surge.
2. The processes of eolian differentiation and laminar sorting were responsible for a more acid composition and a lower Mg content of the ash. The chemical

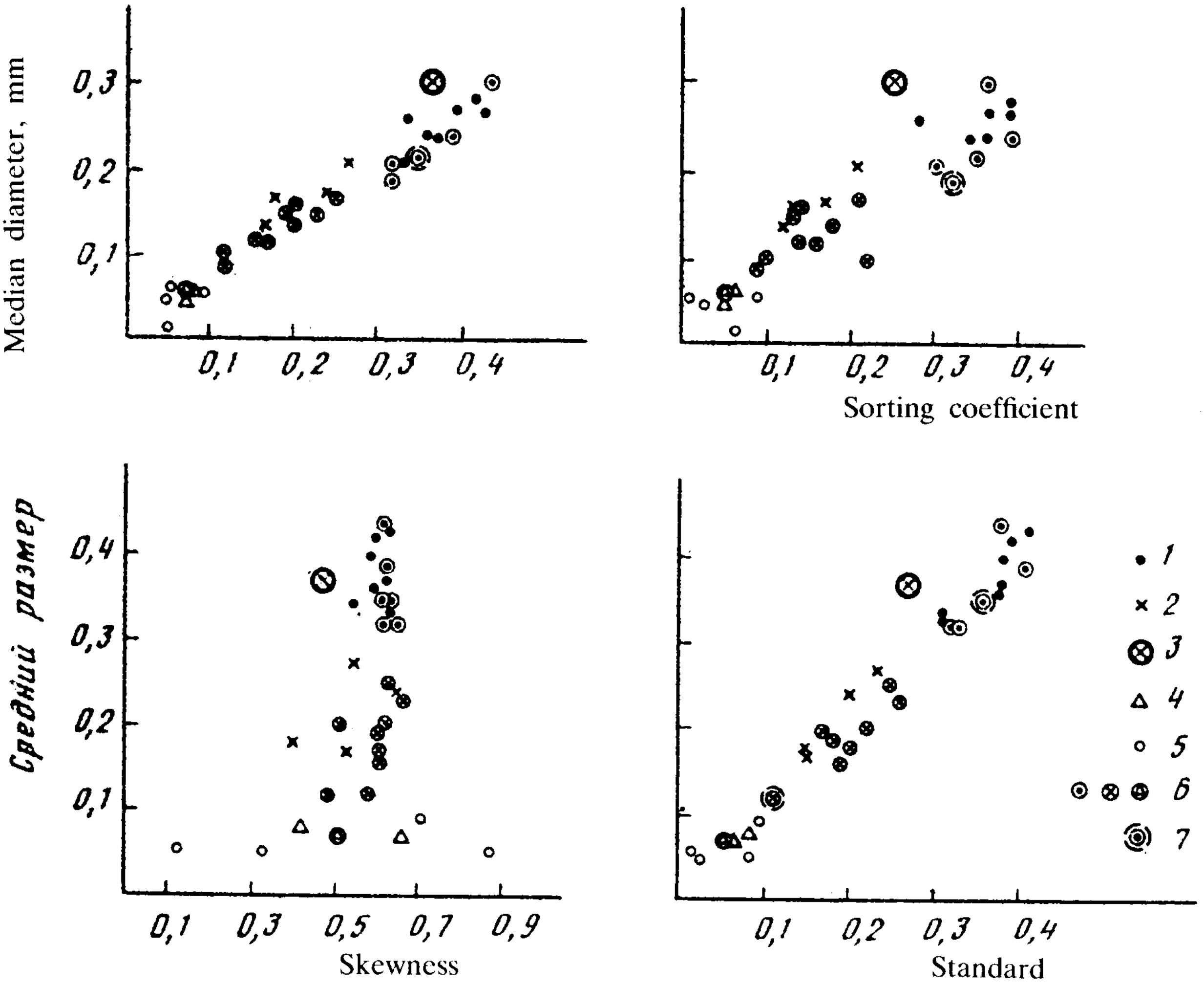

Figure 5 Plots showing relations between various grain-size parameters of the pyroclastic deposits produced at Bezymyannyi during eruptions in 1984 and 1985. Deposits of the 1984 eruptions: 1 — matrix of a block and ash flow; 2 — matrix of pyroclastic surge deposits; 3 — flow I; 4 — ash from clouds above the pyroclastic flows; 5 — tephra. Deposits of the 1985 eruption: 6 — same as 1, 2 and 4; 7 — value identical for the deposits of 1984 and 1985

composition of the matrix of the block and ash flow corresponds to the average composition of its andesitic lava fragments.

3. The "differential stratification" of the pyroclastic material which occurred as it moved down the slope manifested itself in the progressive upward mineralogic variation of the deposits: the matrix of the pyroclastic flow, the matrix of the pyroclastic surge, and the ash falling from the clouds above the pyroclastic flows. The solid phase density values of these deposits reflecting their mineralogic compositions were 2.69 g/cm^3, 2.56 g/cm^3, and 2.47 g/cm^3, respectively.

4. The study of the pyroclastic products of the last Bezymyannyi eruptions resulted in a partial reconstruction of the 1984 eruption sequence.

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