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PYROCLASTIC DEPOSITS OF THE 1984-1989 ERUPTIONS OF BEZYMYANNYI VOLCANO

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The volumes of the pyroclastics deposited by the Bezymyannyi eruptions in 1984-1989 were estimated at 0.75×10^{-3} to 0.05 km^3. The general properties of all types of pyroclastic deposits are approximately identical and reflect the present-day explosive-extrusive phase (with viscous and liquid lavas) of the Bezymyannyi activity. The composition and density variations of the pyroclastic deposits were caused by the layering differentiation of the material as it moved down the slopes of the cone during the culmination periods of the eruptions.

INTRODUCTION

The Bezymyannyi Volcano belongs to the Klyuchevskaya group of Kamchatka volcanoes. It has been a unique object of investigation since its rejuvenation in October 1955, due to the uninterrupted activity of this typically andesitic volcano till the present day. Numerous investigators have described culmination stages of its eruptions in much detail; its Holocene evolution has been reconstructed according to tephrochronological data, as well as the processes of individual eruptions, etc. [1], [2], [3], [5], [6], [8], [9], [13], etc. In the current eruptive cycle of the volcano (since 1956), two stages are recognized: extrusive-explosive with viscous lavas and (since the end of 1970s) extrusive-explosive with viscous and liquid lavas [1], [3]. Since the 1985 eruption [1] the attention of Soviet volcanologists was focused at pyroclastic products of this volcano, especially as the investigations of andesitic volcano pyroclastics dramatically expanded all over the world after the catastrophic eruption of the St. Helens Volcano (Cascade Mountains, USA) in 1980, aiming at modelling and prediction of eruption processes. Numerous descriptive, theoretical and experimental works resulted in the creation of genetic classifications of pyroclastic products of andesitic volcanoes, where all pyroclastic deposits were grouped into the following major types related to: 1 - directional explosions; 2 - pyroclastic flows; 3 - pyroclastic surges; 4 - ash

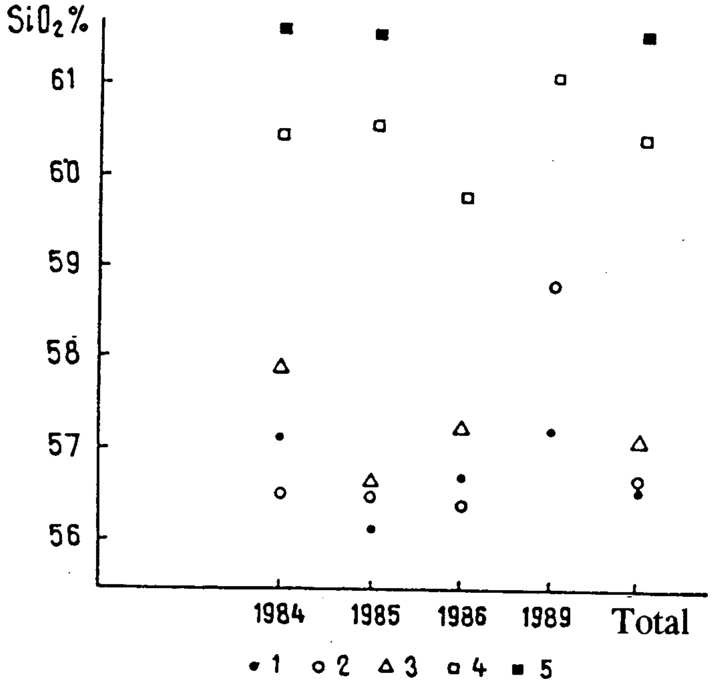

Figure 1 Variations of SiO_2 content in the products of the Bezymyannyi 1984-1989 eruptions: 1 - andesites of lava and pyroclastic flows; 2, 3 - filling material of pyroclastic flows (2) and surges (3); 4 - flow ash clouds; 5 - tephra.

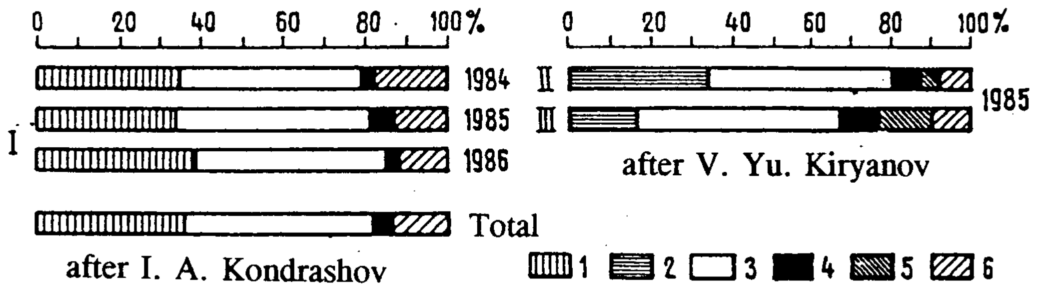

Figure 2 Mineral compositions of the products of the Bezymyannyi 1984-1989 eruptions: I - andesites of pyroclastic and lava (1986) flows (after I. A. Kondrashov); II, III - filling material of pyroclastic flows (II) and surges (III), grade 0.1-0.063 mm (after V. Yu. Kiryanov, Institute of Volcanology, Kamchatka): 1 - matrix; 2 - volcanic glass; 3 - plagioclase; 4 - ore minerals; 5 - rock fragments; 6 - pyroxene.

clouds of pyroclastic flows; 5 - tephra [2], [16].

This article deals with general results of investigation of pyroclastic products of the Bezymyannyi eruptions in October 1984, June-July 1985, June 1986 and August 1989 [1], [6], [8], [15] and classification of pyroclastics by type and eruption. Investigation of pyroclastics was undertaken 2-12 days after the culmination, and this enabled to identify deposit types more precisely. The 1984-1989 eruptions were not catastrophic, the volume of erupted pyroclastics ranging from 0.75×10^{-3} km^3 (1986) to 0.05 km^3 (1985). Eruptions are classified as catast-

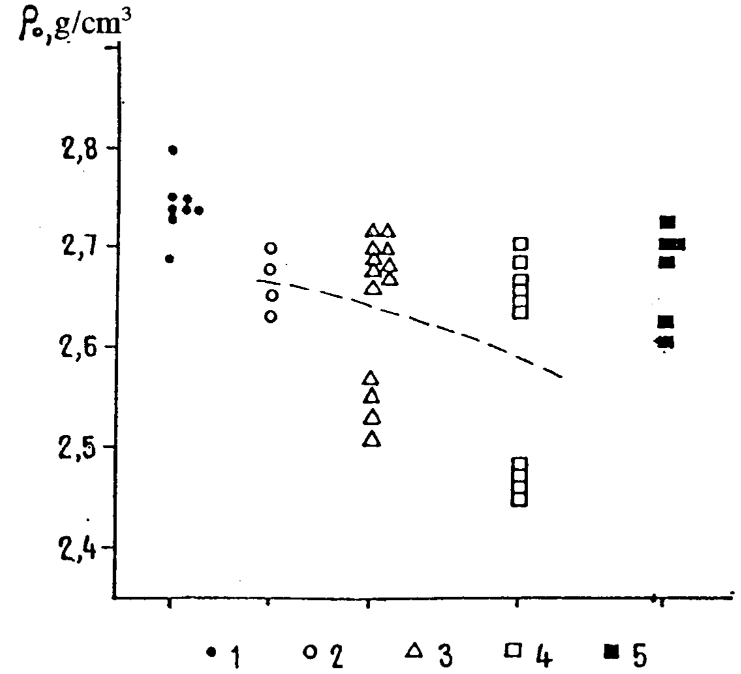

Figure 3 Density variations of the Bezymyannyi: 1 - fragments of andesitic lavas of the 1979 eruption (after V. M. Ladygin, Moscow State University); 2-5 - filling material of pyroclastic flows (2), surges (3), flow ash clouds (4) and tephra (5) of the 1984-1989 eruptions.

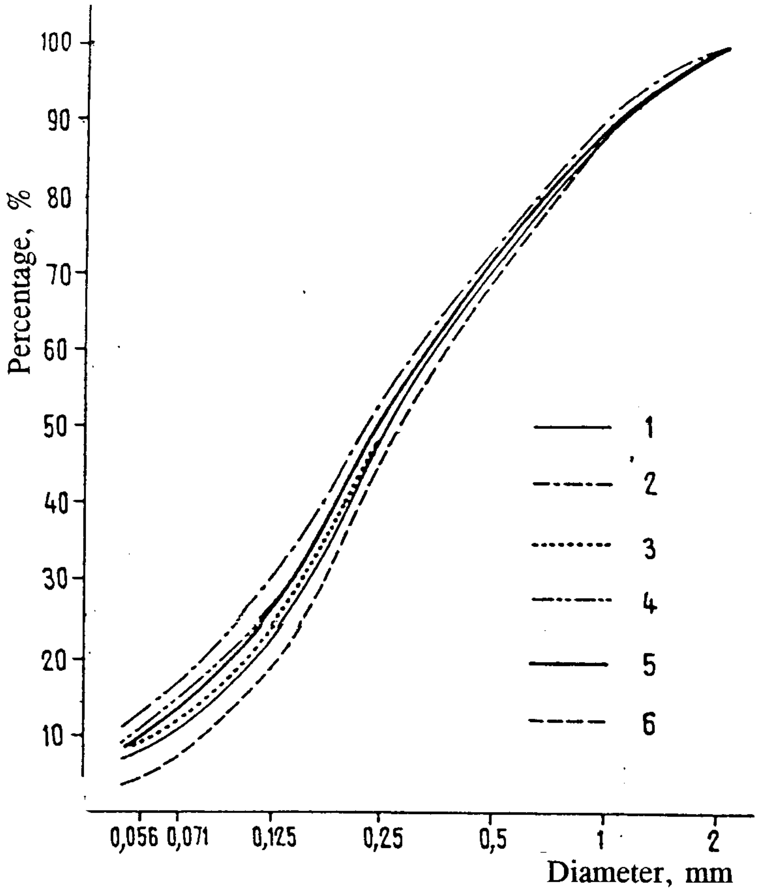

Figure 4 Cumulative curves of particle-size distribution of pyroclastic flow deposits of the Bezymyannyi 1984-1989 eruptions. Deposits of ash-block flows: 1 - 1984, 2 - 1985, 3 - 1986; 4 - 1989; 5 - generalized curve for 1984-1989; 6 - deposits of porous juvenile pyroclastic flows (1985-1986).

rophic if the volume of erupted material is equal to or exceeds 1 km^3 [14]. For instance, the catastrophe at Bezymyannyi in 1956 resulted in the eruption of ~3 km^3 [3]. This article is based on the analysis of 250 pyroclastic samples from the Bezymyannyi.

Table 1 Grain size characteristics of the pyroclastic products of the Bezymyannyi 1984-1989 eruptions.

Deposit types	*Median*	*Median diameter*	*Sigma*	*Skewness*	*Excess*	*Sorting coefficient*
Ash cloud	0,05 0,01–0,07	0,07 0,05–0,10	0,07 0,05–0,11	0,68 0,51–0,87	1,81 1,15–3,04	0,05 0,01–0,08
Ash cloud surge	0,12 0,0–0,15	0,16 0,12–0,23	0,17 0,11–0,26	0,58 0,49–0,67	1,59 1,31–1,88	0,14 0,09–0,22
Ground surge	0,17 0,12–0,21	0,22 0,13–0,27	0,19 0,10–0,26	0,51 0,24–0,65	1,52 0,81–3,44	0,16 0,07–0,23
Ash-block flow	0,26 0,21–0,37	0,38 0,32–0,50	0,35 0,26–0,43	0,60 0,52–0,65	1,22 0,91–1,53	0,33 0,24–0,41
Juvenile flow	0,25 0,19–0,32	0,38 0,30–0,47	0,37 0,31–0,42	0,60 0,54–0,65	1,20 1,04–1,32	0,35 0,28–0,42

Genetic types of deposition. Among the pyroclastic products of the studied eruptions, the following genetic types are recognized: deposits of pyroclastic flows and surges, flow ash clouds and tephra.

Pyroclastic flow deposits. Pyroclastic flows of 1984-1989 eruptions with the lengths ranging from 4 (1986) to 12.5 km (1986), emplaced in Dolina Potokov (the Valley of Flows) on the N-NE slope of the cone, were classified as the ash-block flow type. Besides, juvenile pyroclastic flows of porous andesites were distinguished in 1985 and 1986 [1], [6], [8], [15]. Flows of the first type are related to cupola collapse due to pressing out of its blocks, and collapses of the frontal parts of lava flows. Flows of the second type are characteristic of explosive processes, exhibiting a high content of juvenile material [2], [8], [9], [10], [16]. Besides, these flow types differ in relative amounts of andesitic lava fragments and ashy-sandy filling material, gas saturation, temperature and the resulting length. These two flow types were clearly distinguished during the 1985 eruption [1]. Ash-block pyroclastic flow loaded with large (up to 7-10 m) blocks and numerous andesite fragments of assorted sizes (up to 50-60% of the flow mass) in the sandy-ashy filling moves along the valley lows - canyons, brook streams, following all their curves and bends. For instance, ash-block flow of 1984 bent around the foot of the Kamen Volcano, failing to surpass an elevated landform [6]. Besides chaotic distribution of clasts characteristic of all pyroclastic flows, such flows feature pre-

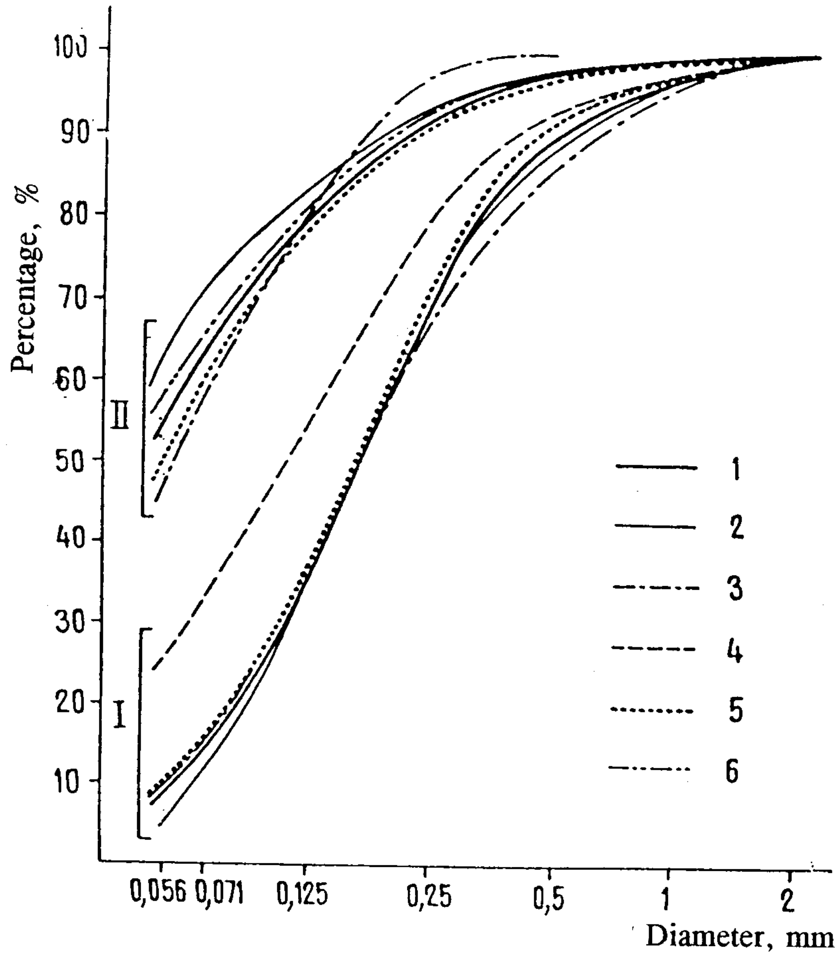

Figure 5 Cumulative curves of particle-size distribution of pyroclastic products of the Bezymyannyi 1984-1989 eruptions. II -pyroclastic surges; II - pyroclastic flow ash clouds. 1 - generalized curves of pyroclastics particle-size distribution; 2-6 - 1984 (2); 1985 (3,4); 1986 (5); 1989 (6).

sense of numerous streams, steep lateral and frontal ramparts [1], [2], [16]. Unlike ash-block flows, juvenile flows contain lesser amounts of large blocks and greater amount of small andesite fragments and ashy-sandy filling (60-70%), more gas-saturated, featuring subdued surface relief and rectilinear distribution through the valley. A case in point is the juvenile flow of porous andesites of 1986 ("southern tongue" of the flow, [15]), the pathway of which traversed from the source is more rectilinear than that of ash-block flow. Having overflown the canyon shoulder at a steep band forming a so-called overflow structure, the juvenile flow went on over the body of ash-block flow, forming a peculiar "outsplash" of thin to absent deposits composed of small andesite fragments a few centimeters in size and sandy-ashy filling in the end. The flow was obviously formed momentarily, as if it was "splashed out" (splashed out, indeed, like a splashed out pailful of water with the water leaving a narrow trace with drops at the end). The "drops" of this pyroclastic flow were composed of fine clasts and filling at the front of the flow.

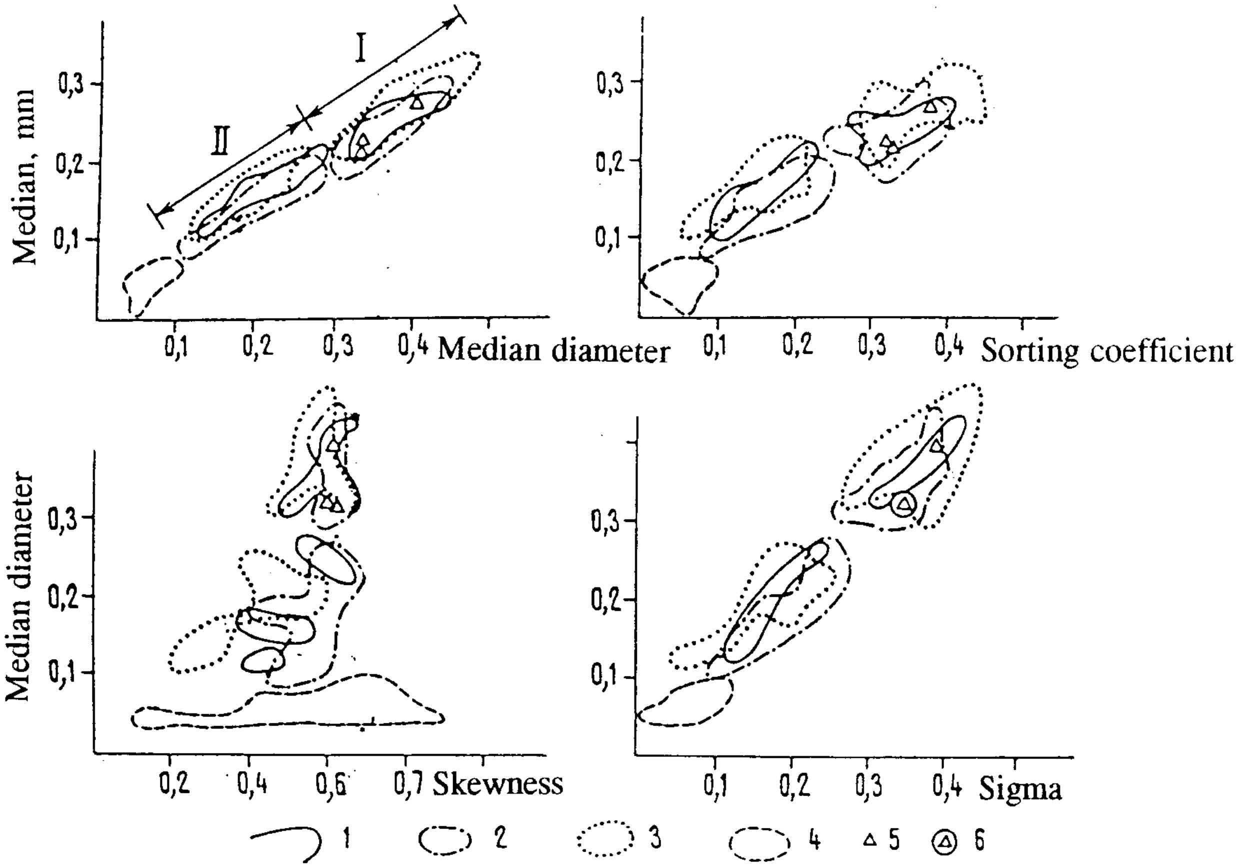

Figure 6 Correlation of the Bezymyannyi 1984-1989 eruption products grain size characteristics. I - pyroclastic flows; II - pyroclastic surges: 1-3 - 1984 (1), 1985 (2), 1986 (3); 4 - pyroclastic flow ash clouds and tephra; 5 - deposits of 1989; 6 - coincident values for the 1989 deposits.

Besides the study of general flow characteristics, diverse methods were applied for detailed analysis of the fillings. Although ash-block and juvenile flows differ in a number of features, their ashy-sandy fillings have much in common. Therefore the pyroclastic flow fillings shall be observed below by eruption, without reference to either ash-block or juvenile flows. Table 1 shows the data on 1984-1989, enabling to compare the two different flow types.

Pyroclastic surge deposits of the 1984-1989 eruptions of the Bezymyannyi underlay or surrounded pyroclastic flows, constituting well sorted sandy intercalations ranging from a few to 10 cm (ground surge). They also lay on the surface of pyroclastic flows or beside them, constituting isolated dunes or dune relief, knolls, peculiar minor flows up to a few meters thick. Pyroclastic surge types were most clearly distinguished for the 1985 eruption and identified for the 1984 and 1986 eruptions [1], [6], [15]. Pyroclastic surge deposits are homogeneous, composed of sorted medium to fine-grained sands with a distinct predominance of one grade (mostly 0.125-0.25 mm). The deposits sometimes include lenses of coarse-grained sands, scarce rock fragments up to several centimeters in size, and are stratified in places.

Pyroclastic flow ash cloud deposits are composed of aleuritic pelite with the thickness ranging from a few millimetres to 5 cm. The 1985 eruption deposits proved to be a reliable marker, enabling, for instance, to clearly distinguish the products of the 1986 eruption [15].

Tephra is composed of aleuritic pelite up to a few centimeters thick. The best studied is the tephra of the 1984 eruption [6].

Eruption products. All studied eruption products of this volcano are cenotypal, hypocrystalline, with porous structure and porphyritic texture. Porosity of compact rock varieties (according to I. A. Kondrashov[a]) is 10-15 wt.%, amounting to 40-50 wt.% for "foamy" andesites, the crystallization of which in pyroclastic flows was completed with gas phase separation. Porphyritic insets account for 30 to 70 vol.% of the rock, being represented by plagioclase, pyroxene, ore minerals, scarcely hornblende.

The rocks extracted to the surface by volcanic eruption constitute pyroclastic and lava flows. Besides juvenile material, pyroclastic flows also contain lithic debris of the collapsed Novyi Cupola. According to relative amount of juvenile and resurgent material (Novyi Cupola lithic debris), pyroclastic flows are subdivided into collapse and explosive flows [8], [9], [10].

It was repeatedly mentioned in numerous works on andesitic volcano eruptions, that pyroclastic flows moving down volcano slopes are accompanied by rising ash clouds, later denominated as "pyroclastic flow ash clouds" [2], [4], [7], [11], [13], [15], [16], etc. The author of [7] characterized this vertical differentiation of pyroclastics as layering differentiation. It should be reminded that layering differentiation means separation of pyroclastic mass moving down the volcano slope into heavy "body" of pyroclastic flow moving on the ground, the superjacent ash cloud surge and the topmost ash clouds of pyroclastic flows, amounting to several kilometres in thickness.

As is known, the chemical composition of pyroclastic flow filling material corresponds to average composition of the clasts [6]. Figure 1 shows average silica content variations for each type of pyroclastics of known eruptions. The greatest amount of samples was studied for the 1985 eruption (lava - 19, flow - 7, surge - 5), so pyroclastic type acidity distribution here seems more trustworthy. Generalized column shows a similar distribution. In terms of SiO_2 content, most basic in pyroclastic succession are lava fragments (56.72 wt.% - 33 samples) and filling material of pyroclastic flows (57.18 wt.% - 10 samples), followed by filling

[a] I. A. Kondrashov, *Petrologiya andezitov sovremennogo eruptivnogo tsykla vulkana Bezymyannyi* (Petrology of andesites of the current eruptive cycle of the Bezymyannyi Volcano)(Moscow State University: Diploma thesis, 1987).

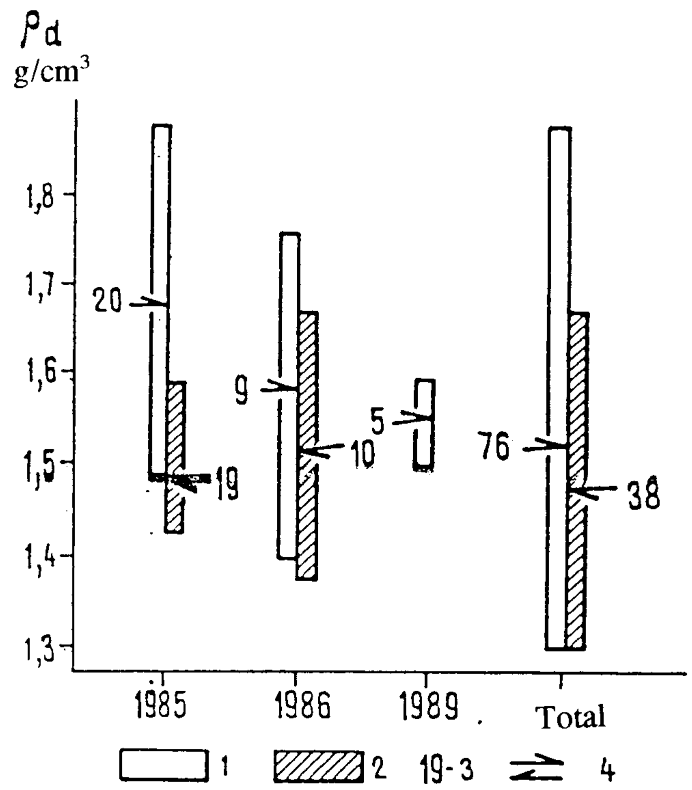

Figure 7 Density variations of the Bezymyannyi unlithified deposits: 1, 2 - pyroclastic waves (1) and surges (2); 3 - number of tests; 4 - average densities of the rocks.

material of pyroclastic surge (57.18 wt.% - 10 samples). Most acid are ashes of flow ash clouds (60.61 wt.% - 8) and tephra (61.72 wt.% - 7), which was mentioned before [1], [6], [7], etc. It is noteworthy that in all products of known eruptions surge deposits feature higher, even if only a little, acidity than lavas and flow filling material (see Figure 1). The same tendency of higher silica content in surge deposits as compared with flow filling material was shown in [17] with reference to the eruption of the St. Helens Volcano in 1980. The highest acidity is exhibited by tephra, because its clouds rise higher above the volcanic crater than flow ash clouds, and besides that tephra is afterwards subject to eolian differentiation. Hence the silica content variation by type of the Bezymyannyi pyroclastic deposits clearly reflects layering differentiation of its pyroclastic products.

Layering differentiation of pyroclastic material is also reflected in mineral composition of eruption products. Filling materials of pyroclastic flows and surges, ashes of flow ash clouds and tephra are composed of crystal fragments, intergrowths, volcanic glass and andesite fragments (Figure 2). General mineral composition of lavas is similar to the composition of pyroclastic flow of the 1985 eruption (see Figure 2), while the composition of pyroclastic surge deposits of 1985 is clearly different from the composition of flow filling material of the same eruption. Analyzing the data shown in Figure 2, it should be noted as follows: (1) flow filling material composition corresponds to average composition of eruption products [6]; (2) differences in mineral compositions of pyroclastic flow and surge deposits result from layering differentiation and enable to clearly distinguish these two types of pyroclastics.

Petrochemically, all eruption products are classified as normal alkali rocks of calc-alkaline series, being typical of the Bezymyannyi eruptions.

Solid phase density. Density of the solid phase of deposits is known to depend only on mineral composition, increasing with the amount of heavy minerals [12]. Figure 3 shows the Bezymyannyi pyroclastics solid phase density variations without their subdivision by eruption. The lower section of the plot reflects layering differentiation of the 1984 eruption [6]. Although types of pyroclastics of other eruptions feature similar values of density in general, taking into account 1984, still average specific gravities of various deposit types also reflect layering differentiation of pyroclastic material as it moves down the volcano slope (dotted line in Figure 3).

Grain size. Most of pyroclastic flow filling material is classified as medium-grained, minor part - as fine-grained sands. Filling material of ash-block and juvenile pyroclastic flows slightly differ in fine grade content (grain size <0.056 mm). Weight percentage of these grades and their relative amounts in the said two flow types are very similar, as is even more clearly evidenced by average particle-size distribution characteristics of the deposits (Figure 4, Table 1). Generalized cumulative curves of ash-block flows filling material grain size distribution for four eruptions lie within a relatively narrow band (see Figure 4), enabling to calculate a general curve of particle-size distribution.

Filling material of pyroclastic surges is composed of medium- and fine-grained sands; ashes of flow ash clouds and tephra - of fine-grained sands. Cumulative curves of particle-size distribution in these types of deposits for four eruptions of the volcano are closely spaced, also enabling to compile generalized curves (Figure 5). Therefore the generalized particle-size distribution curves for various types of pyroclastic products of four eruptions are generally characteristic of all pyroclastic products of the recent stage of the Bezymyannyi activity.

Noteworthy are some other features of particle-size distribution in the Bezymyannyi pyroclastics. Figure 5 shows the curves of particle-size distribution in the ground surge, ash cloud surge and ash cloud ashes of the 1985 eruption. These curves feature similar slope angles, i.e., similar particle-size distribution in these deposits. On the other hand, they clearly reflect pyroclastics layering differentiation: coarser deposits refer to ground surge, less coarse - ash cloud surge and fine - to ash cloud, this differentiation being also evidenced by grain size characteristics (Figure 6, Table 1). Presence of a steep-sloped curve of flow cloud ash particle-size distribution (1985) results from the high extent of this eruption as compared with the other three.

To compare particle-size distribution in the products of the Bezymyannyi 1984-1989 eruptions with that of the 1956 catastrophic eruption, one may apply to Figure 8 in [2]. The catastrophic nature, i.e., the great extent of the eruption of 1956, is evidenced by the fact that even at 15-20 km from the volcano (the banks of the Sukhaya Khapitsa River) the filling material of pyroclastic products of this eruption is coarser than that of the 1984-1989 eruptions at 3-10 km from the volcano.

Density of unlithified deposits. Figure 7 shows densities of unlithified products of various eruptions of the Bezymyannyi. Although the range of pyroclastic flows and surges filling material density variation is wide, their average values are similar. The data both on rock density and the density of unlithified deposits are used for the calculation of volcano models. These characteristics of the Bezymyannyi products, first determined immediately after the eruption, can be applied for compilation and improvement of andesitic volcano models.

Thus the studies of the Bezymyannyi pyroclastic products of 1984-1989 eruptions resulted in obtaining some values of their type characteristics. It was found out that in spite of the variable extent of the eruptions, deposit type characteristics are similar for various eruptions. For instance, average chemical compositions of pyroclastic flow filling material for all studied eruptions are almost constant, cumulative curves of particle-size distribution in deposit types of various eruptions fall into narrow bands, grain size characteristics of various types of pyroclastics are practically similar, etc., i.e., the general characteristics of various types of deposits produced by the 1984-1989 eruptions are similar, reflecting general characteristics of all pyroclastic products of the current stage of the Bezymyannyi activity. It is highly probable that the properties of the Bezymyannyi eruption in March 1990 will also prove to be similar to the average for the studied four eruptions.

Each of the major types of pyroclastic deposits of the current stage of the Bezymyannyi activity features its own peculiar characteristics. Types of pyroclastics differ in chemical and mineral composition, particle-size distribution and solid phase density (see Figures 1-6 and Table 1). The said properties may be considered as criteria for identification of pyroclastic rock types in recent and ancient deposits.

Variations of chemical and mineral composition, particle-size distribution and rock type densities of the Bezymyannyi pyroclastic products (filling material of pyroclastic flows - filling material of pyroclastic surges - ashes of flow clouds) are caused by layering differentiation of pyroclastics in the course of its moving down the volcano slope during the culmination stages of the eruptions.

CONCLUSION

1. All eruptions of the Bezymyannyi during 1984-1989 with volumes of pyroclastic products of 0.75×10^{-3} to 0.05 km^3, except the eruption in 1989, feature presence of all major types of pyroclastics, i.e., pyroclastic flows, pyroclastic surges, flow ash clouds, tephra.

2. Variation of composition and density of the types of pyroclastic deposits of the Bezymyannyi are caused by pyroclastic layering differentiation in the course of its movement down the volcano slope at culmination stages of the eruptions.

3. The general characteristics of each type of pyroclastic products of the 1984-1989 eruptions are largely similar, reflecting the present status of the Bezymyannyi - the extrusive-explosive stage of activity with viscous and liquid lava production.

4. The values of solid phase density of the rocks and the density of unlithified deposits first obtained immediately after the eruptions can be used for the compilation and improvement of the models of andesitic volcanoes.

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