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# The Bezymyannyi, Shiveluch, and St. Helens Volcanoes: A Comparative Revision of their Catastrophic Eruptions during the 20th Century

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**Abstract**—Bezymyannyi Volcano, which is the first in the series that is considered here, supplied (with the help of G.S. Gorshkov) the name for this type of eruption, while the last of the three volcanoes that are considered here, St. Helens, furnished data for the most detailed study of the type. The comparison and study of the differences between the 1956, 1964, and 1980 eruptions of the above volcanoes have occupied the attention of many workers, who came to different conclusions. This paper is an attempt to provide another description of the differences that arose during these eruptions and to analyze the causes of the differences, to determine whether they are actually radical, and to decide whether they still allow one to classify all three eruptions as a common type. The main conclusion of this study is that yes, they do allow one to classify all of these three eruptions as a common type.

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## INTRODUCTION

The first of the three eruptions was the eruption of Bezymyannyi, which began in October 1955, culminated on March 30, 1956, and is still in progress. G.S. Gorshkov studied the eruption to identify and characterize a new type of eruption, which was first termed "directional explosion" (DE) after its culminating phase, but a more careful study of the entire sequence of events had the result that the name was changed to just "Bezymyannyi" (Gorshkov and Bogoyavlenskaya, 1965). This type was thought to include the two subsequent eruptions, viz., that of 1964 on Shiveluch Volcano, Kamchatka and then that of 1980 on Mount St. Helens, Washington, U.S.

Unfortunately, the Bezymyannyi eruption has not been observed and studied in detail because the volcano is far from population centers and is hardly accessible, especially in the winter, when it occurred. As well, the main, catastrophic phase in the Shiveluch eruption has not been studied by direct observation, because it was very short lived and took place in the nighttime. Only the Mount St. Helens eruption has been observed completely, from beginning to end, using all of the techniques that were available at the time, including space-born instruments which had recently appeared; thus, all of the information about it that could be obtained is now available for examination. For this reason this eruption has become a kind of standard for the verification and interpretation of indirect evidence that was obtained for the preceding eruptions.

It has become clear that certain inferences of the earlier investigators require revision, and the result was that significant (or only seemingly so) differences have been found among the three eruptions (Bogoyavlenskaya et al., 1985). This supplied fuel for discussions concerning some individual events. Nevertheless, it can at present be asserted with confidence that the differences as observed and frequently painstakingly examined by partial investigators are not significant in principle; they only affect quantitative relationships among individual phases of eruptions that occurred in the same sequence in all the three cases. This conclusion can be drawn from an examination of the available facts. We wish to note at the outset that much of the divergence in the opinions about the differences has been caused by uncertainties that are inherent in the terms themselves, starting with the first one, "eruption." Another important issue to remember when attempting to classify an eruption is the leading principle of the approach we take, the goal of classification. It may be that classification is based on a sequence of physical processes that take place as deeper material travels to the ground surface (this is treated in the present paper), while in other cases classification may be based on the degree and impact of the eruption on the environment and on the hazards it is likely to pose to humans. More will be said in the Conclusions about this issue.

The main phases of eruptions are as follows: (1) moderate explosive and intrusive (effusive) activity accompanied by failure of the volcanic edifice; (2) asymmetrical

The comparative characteristics of events for the eruptions of the three volcanoes

| Characteristic (scale) of event | St. Helens | Bezymyannyi | Shiveluch |
|---|---|---|---|
| The size of the collapse explosion crater | $1.5 \times 3$ km$^2$ | $1.5 \times 2.8$ km$^2$ | $1.5 \times 3$ km$^2$ |
| Remote volume of the edifice | 2.62 km$^3$ | 0.738 km$^3$ | ? |
| The volume increment after cryptodome emplacement | 0.11 km$^3$ | ? | ? |
| The volume of the rock avalanche (DE agglomerate) | 2.8 km$^3$ | 0.8 km$^3$ | 1.5 km$^3$ |
| The volume of the DE deposits (DE sand) | 0.2 km$^3$ | 0.2 km$^3$ | - |
| The tephra volume (the duration of the Plinian phase) | 1.1 km$^3$ (9 h) | 0.4–0.5 km$^3$ (1–2 h) | 0.3 km$^3$ (1 h) |
| The volume of PF | 0.12 km$^3$ | 0.8 km$^3$ | 0.3–0.5 km$^3$ |

? means “no data”; a dash means “no deposits of this type are observed”.

collapse of the volcanic edifice and an oblique explosion; (3) the Plinian phase, which is an intensive gas-charged pyroclastic eruption in the form of a vertical jet, with the products being transported both as an ash plume and as pyroclastic flows (PFs); (4) extrusive domes that are being squeezed upward in the crater that was formed after the collapse and the explosion.

These phases were present in the eruptions of all the three volcanoes, but the respective quantitative contributions and details of the timing were substantially different. This is especially relevant to the second phase: the Bezymyannyi eruption was at first found to consist of only an explosion (Gorshkov and Bogoyavlenskaya, 1965), the eruption on Mount St. Helens consisted of two consecutive phases, a collapse and an explosion (Lipman and Millineaux, 1981); a collapse with a very weak explosion or with no explosion at all was identified for Shiveluch, which can be gathered from the earlier study of the deposits by Gorshkov and Dubik (1969), although these authors persisted in using the term “directional explosion,” notwithstanding the facts that they themselves adduced, merely remarking that the direction was at a very low angle with the horizontal plane. A.B. Belousov and M.G. Belousova (1995) noted that no indications that would allow one to deduce that an explosion accompanied the collapse on Shiveluch in 1964 were known. The first of the above eruption phases differed widely among the eruptions, especially as concerns Shiveluch, where almost all investigators noted a complete absence of this phase.

Several quantitative characteristics of the respective events for the three volcanoes are summarized (see the table). It should be noted that this table lists volumes of pyroclastic deposits as measured merely geometrically, without taking density differences into account, while these differences may be very large. Comparison should be applied to masses rather than to volumes; however, mean density values are unfortunately far from being available in all cases, and when they are available, are not invariably to be relied upon. The densities of tephra deposits when measured immediately during an explosion and after the lapse of a few weeks, months, or years may differ by several times. Densities appear as large variations at different distances from the source as well. Nevertheless, the density of tephra deposits is nearly always half as much as that for the deposits that are due to the PFs of an eruption. This should be borne in mind when comparing the characteristics of an eruption.

## MAIN DIFFERENCES AND THEIR CAUSES

### 1. Collapse vs. an Explosion Relationship

The *Bezymyannyi and St. Helens volcanoes.* The first volcanologist who classified the Bezymyannyi eruption as a separate type was G.S. Gorshkov. He called it a “directional explosion” on the basis of an eyewitness who saw the eruption at a great distance and felt that its most characteristic phase wassimilar to an industrial explosion of the “excavation” type (Gorshkov and Bogoyavlenskaya, 1965). Gorshkov coined the term “directional explosion agglomerate” to describe the associated rudaceous deposits. The process by which the deposits were formed during the Bezymyannyi eruption has not been directly observed. On Mount St. Helens, the process that produced rudaceous deposits that are similar to the Bezymyannyi type was observed during the event itself as a collapse of the slope; this was termed a “debris avalanche.” Belousov and Belousova (1998) were among the most recent investigators who studied the 1956 Bezymyannyi deposits; they saw a complete identity between these deposits and the debris avalanche on St. Helens, thus they thought them to be produced only by a collapse. I.V. Melekestsev (2004) thought that the Belousovs lacked sufficient evidence for this inference and he proceeded to prove their explosion origin in a similar way to the original work of Gorshkov (Gorshkov and Bogoyavlenskaya, 1965).

It now seems obvious that no definitive selection of either mechanism, collapse or explosion, exists. Both of these processes took part in the production of the rudaceous deposits of the two eruptions; the deposits should be termed "collapse–explosive" ones. The only difference consists in the fact that the explosion made a considerable contribution to the transport of the destroyed edifice in the case of Bezymyannyi (although the bulk of the material was still transported by a collapse avalanche rather than along ballistic trajectories), while the respective contribution at St. Helens was extremely small (but not zero either, as can be seen looking at photographs that were made by Gary Rosenquist (Lipman and Millineaux, 1981) where the explosion is seen to begin shortly before the landslide stopped).

The directional explosion in both of these cases was triggered by destruction of the volcanic edifice due to a shallow intrusion that was emplaced within it. This consisted of a hot, gas-charged material, a kind of "cryptodome." The emplacement occurred somewhat "aside" during the terminal phase, along the boundary between the extrusive dome that had been formed in the crater after the catastrophic phase of the preceding eruption on the one hand and the older material of the edifice, toward the weaker slope of it, on the other; this resulted in the oblique directivity of the explosion. This follows from direct observation of the pre-failure deformation of the edifice. The slope experienced progressive deformation and finally began to fail, producing a debris avalanche and exposing the gas-charged cryptodome, which in turn was destroyed by the explosion, discharging "fine," mostly juvenile, pyroclastics, or "directional explosion sand" (DE sand, Gorshkov and Bogoyavlenskaya, 1965).

The difference between the respective explosions as they evolved on Bezymyannyi Volcano and on Mount St. Helens seems to be due to different modes of destruction acting on the material of the edifice that overlay (the "roof" or top) the emplaced cryptodome. On Bezymyannyi the top was strongly cracked at the very beginning of the landslide, and the explosive destruction of the cryptodome began nearly simultaneously with the beginning of the avalanche-like collapse, such that flows of explosion products ("DE sand") also entrapped some of the larger blocks of the sliding top. In this process, the flows of DE sand were naturally moving faster than the entrapped large blocks of the top and the deposits must contain DE sand in front of the agglomerate and *under* the DE agglomerate. This author made a special search in 1984 and found (with the help of O.A. Braitseva and I.V. Melekestsev, who are the most experienced specialists in the identification of pyroclastic deposits) this sequence of deposits. The same sequence in a sufficiently far zone on Bezymyannyi was noted later by Belousov and Belousova (1998).

The beginning of the collapse on the already unstable slope on Mount St. Helens was much sharper: the slope began to move as a solid sliding mass that was broken into separate blocks, when it accelerated to reach a high velocity and almost completely exposed the intrusion. This inference was drawn by the American volcanologists Voight et al. (1983) after a careful analysis of the observations and some laboratory modeling. This type of sliding was due to the greater relative volume of water and ice at definite horizons of the St. Helens edifice, as well as to the much greater volume and mass of the sliding material (2.8 km$^3$ on St. Helens against 0.8 km$^3$ on Bezymyannyi with approximately equal amounts of DE sand, see table). The great mass and poor stratification of the sliding block during the initial period of its sliding prevented its material from being largely involved in the explosion.

*Shiveluch Volcano.* No directional explosion like that on Bezymyannyi took place on Shiveluch, although the overall course of the eruption was similar. The cause for this lies in the absence of a cryptodome. Fresh material was travelling from depths as at the two other volcanoes, but it merely activated these domes, which were still fresh, instead of being emplaced to the side under the cooled, consolidated extrusions that were produced during the previous phases, with the result that the domes resumed their growth. The activated extrusive complex lost equilibrium and collapsed, producing a debris avalanche. The process undoubtedly also involved explosive destruction of inner portions in the collapsing domes (this is frequently referred to as "autoexplosivity"). However, because the material in these inner portions was under a comparatively low pressure and had been substantially degassed owing to fumarole activity and moderate vertical explosions that accompanied the dome growth, the explosion merely accelerated the beginning and movement of the landslide to a certain extent, leaving the surroundings practically unaffected. This follows from a detailed survey of "explosive" deposits on Shiveluch after the 1964 eruption (Gorshkov and Dubik, 1969). These authors recorded a very sharp boundary at the front of the "explosive" large-block deposits, with an absolutely uncontaminated, live forest at a distance of a meter from the front. A similar forest in the shape of long narrow strips was also found by these authors far from the front of the deposits in the "shadow" of some small obstacles (knolls 10–20 m high) that stood in the path of the discharge. The authors of this publication explained this by the very low-angle (below 30 degrees) directivity of the oblique explosion combined with the agglomerate being somewhat displaced along the ground after the deposition. However, in our opinion, all these observations and, which is the main issue, the fact that the forest was intact, as well as the absence of directional explosion sand behind the front of the "explosive" agglomerate is more likely to provide evidence of the insignificant role of the explosion and the vastly predominant role of the landslide in the production of the large-block deposits. Belousov and Belousova (1995) made a special and more careful study of the deposits that were left by the Shiveluch eruption of 1964 to come to the conclusion that they were exclusively of a landslide origin.

The reason that the domes in the crater resumed their growth instead of a situation where shallow intrusion was emplaced under them can be understood by recalling that Shiveluch has a much higher mean output (a greater mean discharge of material) compared with Bezymyannyi (approximately by an order of magnitude). The repose periods between major eruptions on Shiveluch have been shorter by an order of magnitude, activity during these periods was not totally extinct, a moderate extrusive process was occurring, and new portions of incoming magma found it easier to push the still warm domes rather than circumventing them.

The high mean output of Shiveluch is obviously also responsible for the near absence of the first phase in its eruption with a well-pronounced moderate explosive activity that precedes paroxysms. The moderate activity simply did not quite vanish between paroxysmal eruptions.

## 2. The Relationship between the Volumes of Tephra and of Pyroclastic-Flow (PF) Material and the Intensity of the Plinian Phase

When the quantities that are indicated in the heading are considered, we find that Mount St. Helens is sharply different from the two others, seeing that its volume and mass of discharged tephra considerably exceeds the PF mass, while both the Bezymyannyi and the Shiveluch eruptions have the reverse relationship. Mount St. Helens also shows a much lower intensity of the Plinian phase compared with the two other volcanoes (by factors of 3 to 5), although the total volume of discharged pyroclastics is about the same for all the three volcanoes, both for tephra and PFs.

Both of these quantities (the PF intensity and relative volume) should be considered in conjunction, as they are intimately interrelated: both tephra that is transported through the air and PFs that roll down a volcano's slopes are produced by the same process, viz., the discharge of a gas-charged pyroclastic suspension in the form of a vertical jet. Whether it will propagate subsequently through the air or along the ground surface depends on several factors (Wilson et al., 1980): the output of material, vent width, flow velocity, and the mass and volumetric fraction of gas in the flow.

The concentration of volatiles that are dissolved in the parental magma is approximately the same for all of the three volcanoes (about 5 wt %); thus, the volume fraction of gas in the flow must also be about the same, while the output of the gas-charged pyroclastic suspension is about four times smaller than for the other volcanoes.

Plinian eruption involves a high velocity of the gas-charged pyroclastic suspension at the vent mouth (a few hundreds of meters per second); it frequently exceeds the velocity of sound as determined in the jet and has a mean density that exceeds that of the surrounding atmosphere. The loss of energy to overcome gravity and friction leads to a rapidly decreasing jet velocity after its exit from the vent; however, simultaneously atmospheric air mixes itself in the turbulent jet and the larger pyroclastic particles are partially lost. The air that is mixed is heated; this combines with some loss of pyroclastics to reduce the jet density. If the jet density becomes lower than that of the surrounding air before the initial impulse has been spent, the jet velocity again begins to increase due to floating in denser air, then stabilizes, and finally decays to zero, as the jet cools and reaches less dense layers of the atmosphere. If, on the other hand, the initial impulse has been exhausted before the jet density is below the atmospheric density, the jet collapses and its material rolls down the slopes of the volcano in the form of PFs that are driven by the force of gravitation.

The discharge of material in a jet is proportional (apart from velocity and density) to its cross-sectional area (diameter squared) and the discharge of air that is mixed is proportional to the perimeter of this cross section (to the diameter). For this reason, the greater the jet diameter is, the smaller the relative contribution of the air admixture is and the density decreases. The differences in jet discharge, which reach several times between these volcanoes, are largely related to different vent diameters (the critical conditions in the conduit, which limit the velocity, do not allow it to vary widely from volcano to volcano). It is because of this issue that the volcanoes with high discharges (Bezymyannyi and Shiveluch) were dominated by PFs and these began to propagate and be deposited almost at the very beginning of the Plinian phase. On the other hand, the contribution of an air admixture with a discharge that was four times smaller, was relatively high compared with Bezymyannyi and Shiveluch. For this reason PFs were less important compared with air-transported tephra, and appeared as late as 4 or more hours after the discharge of tephra, when the initial jet velocity had appreciably diminished.

## 3. The Delayed Extrusive Phase

The extrusion began to be squeezed out on Mount St. Helens after a lapse of 3 weeks after the Plinian phase had stopped (Lipman and Millineaux, 1981). On Bezymyannyi it took 3 months for an extrusive phase to become detectable (Gorshkov and Bogoyavlenskaya, 1965). By that time the dome had reached impressive dimensions, and it was thought that this phase began a few days, and not later, after the Plinian phase stopped. On Shiveluch the dome began to grow as late as 16 years after the Plinian phase stopped.

The repose interval before the last and extrusive phase is a natural result of the partial emptying of the peripheral magma chamber or of the upper part of the conduit and degassed magma foam settling (Slezin, 1987). As magma continues to be supplied from the interior of the plumbing system, it must take some time before it can fill the empty volume and then rise to the surface. If the chamber is small and shallow and in a rigid crust it will retain its shape after partial emptying; it is only supply from below that can completely compensate for the loss that is sustained during the Plinian phase. If the chamber is deeper, in a plastic medium and under a high lithostatic pressure, the loss is largely compensated by both the elastic and inelastic response of the medium.

The 16-year repose interval before Shiveluch began its extrusive phase can be explained in a natural way as the time it would take magma to fill the shallow (about 5 km) peripheral chamber, which had been emptied by the eruption. Magma was travelling from depths at a rate that was little above the mean for the last 110 years (Slezin, 2005). The short repose period before the extrusive phase began on Mount St. Helens, and especially that for Bezymyannyi, seems to be caused by deformation of the host rocks that compensates for the loss of material for larger and deeper peripheral chambers of these volcanoes. Kadik et al. (1988) used crystallization conditions for phenocrysts to find that the Bezymyannyi magma chamber lies in the 10–20 km depth range. The chamber depth for Mount St. Helens has been estimated as approximately 10 km (Lipman and Millineaux, 1981).

## CONCLUSIONS

We wish to emphasize our leading inference: all of the three eruptions that are under study here can be classified as belonging to a common type, let us call it the "Bezymyannyi" type, since the differences in eruption behavior and deposited ejecta are not essential and are merely quantitative. The sequence of events can be satisfactorily explained using the widely accepted geometric scheme for a volcano in eruption, which is well supported by geological and geophysical evidence, viz., the "chamber–conduit" system, while all of the differences can be explained by quantitative differences in elements of the scheme, as well as by the properties of magma and by peculiarities in the structure of a volcano. The differences of opinion as to how to characterize individual phases of an eruption in order to find its type take their origin, in my opinion, from ambiguities that are inherent in the basic concepts and terms that investigators use.

Let us begin by discussing the most fundamental term, viz., "the eruption of a volcano." One geological dictionary defines this as follows: "the output of incandescent or hot, solid, liquid, and gaseous volcanic products onto the surface of the planet" (*Geologicheskii slovar'...,* 1978). However, nearly all investigators understand the concept as including, in addition to "output," the movement of products in the upper parts of the volcanic plumbing system before these products reach the surface, as well as along the ground surface and in the atmosphere after the output itself. Geologists are not unanimous as to which movements "before" and "after" should be incorporated into the concept of an "eruption." In addition, the definition of an eruption as an "event" that is separated from another similar event by a repose period is also widely used. Here too, it is not clear what the minimum physically grounded length of this period is that identifies it as exactly an interval between two different eruptions rather than a pause within an event that is in progress. As well, the concept of an "explosion" is not invariably understood in the same way by all investigators and one cannot clearly distinguish between juvenile and resurgent materials for every volcano that is in eruption.

On the whole, all of these issues properly belong to the geological nomenclature of terms, where debate has been going on for hundreds of years. It would be improper to attempt to discuss this in the present article, but several concrete comments are in order for the present case. The first and moderate phase in the Shiveluch eruption should include the growth of Suelich Dome, which had reached a volume of 0.25–0.3 km$^3$ by 1949 and which was accompanied by violent fumarole activity and explosions. This same Suelich Dome played a role that is similar to that played by cryptodomes on Bezymyannyi and Mount St. Helens: the resumption of magma movement at depth pushed the new dome; when small earthquakes that occurred due to this movement are taken into account, they led to its collapse. The hot interior of the dome that was then exposed also generated a directional explosion on a small scale. The interior consisted of juvenile material, as in the case of the material that composed the cryptodomes on Bezymyannyi and Mount St. Helens. These occurrences when combined triggered a mass collapse of the entire set of domes that had arisen in the Young Shiveluch crater after the 1854 eruption, which was accompanied by "autoexplosivity." It thus appears from this line of reasoning that the rudaceous deposits that are due to Shiveluch Volcano should also be called collapse–explosion deposits, although the contribution of explosions was small in this case.

## REFERENCES

Belousov, A.B. and Belousova, M.G., The 1964 eruption on Shiveluch Volcano, Kamchatka: A Plinian eruption accompanied by a large-scale collapse of the edifice, *Vulkanol. Seismol.*, 1995, nos. 4/5, pp. 116–126.

Belousov, A.B. and Belousova, M.G., The deposits and the sequence of events during the eruption of March 30, 1956 on Bezymyannyi Volcano, Kamchatka, *Vulkanol. Seismol.*, 1998, no. 1, pp. 25–40.

Bogoyavlenskaya, G.E., Braitseva, O.A., Melekestsev, I.V., et al., Catastrophic eruptions of the directional explosion type on Mount St. Helens, Bezymyannyi and Shiveluch Volcanoes, *Vulkanol. Seismol.*, 1985, no. 2, pp. 3–22.

Gorshkov, G.S. and Bogoyavlenskaya, G.E., *Vulkan Bezymyannyi i osobennosti ego poslednego izverzheniya 1955-*

*1963 gg.* (Bezymyannyi Volcano and Its Last Eruption in 1955–1963), Moscow: Nauka, 1965.

*Geologicheskii slovar'* (Geological Glossary), vol. 1, Moscow: Nedra, 1978.

Gorshkov, G.S. and Dubik, Yu.M., A directional explosion on Shiveluch Volcano, in *Vulkany i izverzheniya* (Volcanoes and Explosions), Moscow: Nauka, 1969, pp. 3–37.

Kadik, A.A., Maksimov, A.P., and Ivanov, B.V., *Fiziko-khimicheskie usloviya kristallizatsii i genezis andezitov (na primere Klyuchevskoi gruppy vulkanov)* (Physico-Chemical Conditions of Crystallization and the Origin of Andesites: The Klyuchevskoi Group of Volcanoes), Moscow: Nauka, 1986.

Lipman, P.W. and Mullineaux, D.R., *The 1980 eruptions of Mount St. Helens*, Washington. Geol. Survey, Prof. paper 1250, Washington D.C., 1981.

Melekestsev, I.V., On an explosive origin of the debris avalanche due to the paroxysmal phase of the catastrophic eruption of March 30, 1956 on Bezymyannyi Volcano, Kamchatka, *Vulkanol. Seismol.*, 2004, no. 2, pp. 9–23.

Slezin, Yu.B., The mechanism operating to empty a magma chamber during caldera generation, *Vulkanol. Seismol.*, 1987, no. 5, pp. 3–15.

Slezin, Yu.B., Characteristics of the magmatic plumbing system beneath Shiveluch Volcano, *Vulkanol. Seismol.*, 2005, no. 2, pp. 3–7.

Voight, B., Janda, R.J., Glicken, H., and Douglass, P.M., Nature and mechanics of the Mount St. Helens rockslide-avalanche of 18 May 1980, *Geotechnique*, 1983, vol. 33, no. 3, pp. 243–273.

Wilson, L., Sparks, R.S.J., and Walker, G.P.J., Explosive volcanic eruptions-IV. The control of magma properties and conduit geometry on eruption behavior, *Geophys. G. R. Astr. Soc.*, 1980, vol. 63, pp. 117–148.

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