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Recent eruptions at Bezymianny volcano—A seismological comparison

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ABSTRACT

For the past few decades, Bezymianny volcano has erupted once to twice per year. Here, I examine eight eruptive events between 2006 and 2010. This is the first time period for which proximal or broadband seismic data have been recorded at Bezymianny. Several recurring patterns are demonstrated in advance of eruptions. Eruptions are generally preceded by 12–36 h of tremor energy elevated by 2 to 3 orders of magnitude. Locatable earthquake activity is quite erratic in the days before eruptions. For eruptions of juvenile magma, however, the cumulative moment magnitude increases with the repose time since the previous eruption. Though tenuous, this relationship is statistically significant and could improve forecasts of Bezymianny eruptions. The most energetic eruptions demonstrate increasing multiplet activity in the run-up, followed by a rapid cessation at the time of eruption. When present, this behavior marks increasing pressure in the conduit system as degassing eclipses the capacity for venting. Very long period seismicity (>20 s periods) accompanies some eruptions. These tend to be the same short-lived high-energy eruptions that exhibit multiplet precursors. Four eruptions are examined in detail to illustrate the variety in eruption mechanisms. Lava dome collapses, sustained eruptions, singular paroxysmal explosions and post-explosion lava flows occur in different combinations demonstrating that more than one eruption trigger is regulating Bezymianny. Compared to Bezymianny's fifty-year modern history, recent eruptions have been shorter-lived and separated by longer repose times. Some evidence suggests that these eruptions may be increasingly explosive—a speculation that carries significant hazard implications. If true, however, this threat is tempered by solid evidence that the most explosive eruptions are preceded by the clearest precursors, suggesting an ability to improve the already excellent eruption forecasts available for Bezymianny.

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1. Introduction

In the decade from 2000 to 2010, Bezymianny volcano had approximately 17 independent eruptions that were large enough to generate pyroclastic flows stretching several kilometers and put ash thousands of meters into the atmosphere (Senyukov et al., 2004; Girina, 2013). These eruptions were significant enough to warrant public safety notifications. The location of Bezymianny, on Russia's Kamchatka peninsula, poses significant hazards to trans-Pacific aircraft routes (Neal et al., 2009). Prevailing weather patterns sweep atmospheric ash eastward over the north Pacific (Schneider et al., 2000; Ramsey and Dehn, 2004). Eruptions in the past decade have regularly resulted in air traffic restrictions (e.g., Neal et al., 2009; McGimsey et al., 2011; Neal et al., 2011). Most of these were short-lived singular eruptions that, broadly speaking, appear similar to one another.

There is no single standard for measuring the size of a volcanic eruption. However, the majority of Bezymianny eruptions during this decade were assigned a volcanic explosivity index (VEI) (Newhall and Self, 1982) of 2 or 3 by the Smithsonian Global Volcanism Program (Venzke et al., 2012). Senyukov et al. (2004) have documented a common set of seismic and ground temperature observations that precede most of these eruptions. The repeatability of the precursory pattern has allowed many of the eruptions to be accurately forecast on the scale of days to hours, often with increasingly precise time windows (Senyukov, 2006). The author is unaware of a series of comparably sized eruptions with an equivalent forecasting success.

Bezymianny has been erupting intermittently since its initial historic eruption in 1956. During the VEI 5 eruption, the southeast flank collapsed concurrent with a massive lateral blast that erupted a combined volume of more than 3 km^3 of material and left a 700 m deep crater (Bogoyavlenskaya et al., 1985). The resulting horseshoe-shaped crater was 1.5 by 2.8 km in diameter. Subsequent eruptions have built a dome that now fills in much of this crater. For an overview of the 1956 eruption and ensuing activity see Gorshkov (1959), Bogoyavlenskaya et al. (1991) and Girina (2013). This eruption preceded the strikingly similar 1980 eruption of Mt. St. Helens by 24 years and is frequently considered the type example of sector collapse and lateral blast volcanism (Voight et al., 1981; Belousov et al., 2007). Though Bezymianny was only lightly instrumented during its first 50 years of recovery, the eruption record has been well documented through field observations, photographs and petrologic sampling. Because Bezymianny has rebuilt much of its edifice in just 50 years, it is an ideal place to examine how volcanoes respond, long-term, to massive sector collapse events.

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The first two decades following the 1956 eruption were characterized by magma extrusion accompanied occasionally by modest explosions. At times, spines of solid magma were extruded. At other times, the extruded products were more plastic. By 1976, the dome had reached a height of more than 800 m (Bogoyavlenskaya et al., 1985 and references therein). Beginning in 1977, the number of explosive eruptions began to increase. The duration of individual eruptions, on average, decreased as well. These eruptions have often been preceded and or followed by lava extrusion. There is evidence of solid magma spines being extruded prior to some eruptions (Malyshev, 2000). And several eruptions have been followed by viscous lava flows emplaced over the course of days (Carter et al., 2007). However, the extrusive periods have generally been short lived. If the first twenty years of eruption can be described as continuous effusive eruption with occasional lulls and explosions, the post-1977 era should be described as quiescence punctuated by discrete eruptions.

This activity is represented schematically in Fig. 1. Based on the growth of the dome, the rate of magma production was clearly very high in initial years and remained elevated during the first two decades. Once the dome was large, a significant portion of the eruption products began spilling out of the crater making it challenging to quantify magma production with existing data. As well, the volume of magma deposited as tephra remains largely unquantified. As a result, this model is purely qualitative. Even without constraints on the actual magma production rate, several features are likely robust: the high rate of magma production in the initial years; the dominantly extrusive phase; the transition to dominantly explosive phase; and the variability in recent eruption/extrusion sequences. When the top of the volcano was removed in 1956, the conduit system was effectively shortened by a kilometer when more than a cubic kilometer of overburden was removed. Any equilibrium that might have existed in the magmatic system was destroyed. The ensuing years of dome growth and punctuated extrusion are compatible with this model. Though several mechanisms might ultimately be driving eruption (e.g., second boiling, crustal relaxation, new magma from the deep crust), all of these eruption sources could be accelerated and sustained by unloading. Likewise, the slowed growth in recent decades is plausibly due to the fact that Bezymianny is closing in on its pre-1956 topography. Regardless of mechanism, the eruption behavior of Bezymianny has evolved steadily over the past half century.

Several lines of evidence suggest that the dome is a significant factor in regulating eruptions. Increases in surface temperature in the days to weeks prior to eruption are large enough to be observed with satellite remote sensing (Ramsey and Dehn, 2004). The rate of rockfalls on the dome increases similarly on a scale of days to weeks (Senyukov et al., 2004). The observations of magma spines extruded prior to eruption are anecdotal, but appear to have occurred on several occasions (Girina, 2013). Significant ground deformations have not been reported concurrent with eruptions other than the 1956 one, though it should be noted that deformation data has only recently become available. The fact that recent explosive eruptions typically last minutes, and not hours, suggests that the eruption source is shallow and quickly exhausted. Together these observations imply that the dome acts as a cap on the volcanic system and plays an essential role in regulating eruptions.

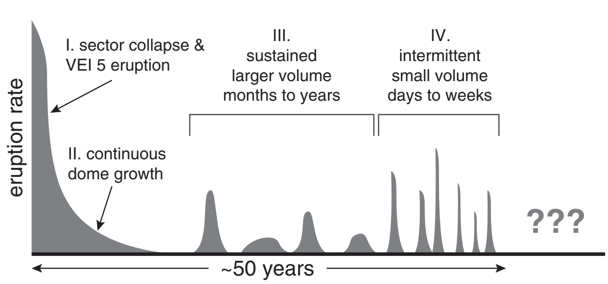

Fig. 1. Conceptual timeline of eruption activity at Bezymianny in the 50 years following the 1956 eruption.

Other evidence suggests a strong role for a crustal magma reservoir kilometers below the surface. Whole rock chemistry has evolved gradually but consistently since 1956. Linear compositional trends through time (including SiO_2, Al_2O_3, K_2O, Na_2O) suggest a homogenizing reservoir that provides a consistent source of magma. Geophysical evidence for crustal magma storage is scant. But a modest curtain of seismicity does suggest the possibility of magma storage at about 3 km below sea level. Seismic evidence from multiplet earthquakes suggests that at least one recent eruption sourced material from deep enough to disrupt the conduit system beneath the edifice (Thelen et al., 2010a). Lastly, the regularity of eruptions is striking. It is hard to conceptualize this regularity without invoking some type of steady inexorable driving process from below.

The goal of this study is to identify the features of the Bezymianny system that have regulated recent eruptions. There are many common features that suggest a repeatable eruption mechanism. Closer inspection however demonstrates a range of eruption triggers. By identifying the triggers for recent eruptions, and particularly the role of the dome, it becomes feasible to speculate about future activity in light of the model in Fig. 1. Significant geophysical instrumentation at Bezymianny, paired with repeated field observations and sampling, makes these objectives reasonable. In this paper, I focus on eruptions for which seismic data is available within 15 km of the volcano. Such data exists for 2006 and beyond.

2. Data

2.1. The PIRE project

Bezymianny volcano has been the centerpiece of a several-year multi-disciplinary project led by a collaboration of U.S. and Russian scientists. The project was focused on comparisons between recent sector collapse volcanoes with an emphasis on Bezymianny and Mt. St. Helens. Though Bezymianny has been known internationally for decades, political realities limited the involvement of foreign scientists until the 1990s. Even today, the logistical consequences of this history are felt by most researchers working in Kamchatka. The PIRE project (funded under the National Science Foundation's Partnership for International Research and Education program) sought to build an international research focus on Bezymianny while equipping young scientists with the skills to work in Kamchatka and similar environments.

Despite political isolation, one organization has had an ongoing presence at Bezymianny throughout its 20th century history. The Institute of Volcanology and Seismology (IVS), part of the eastern branch of the Russian Academy of Sciences, has coordinated research and monitoring at Bezymianny from its first signs of unrest in 1955 through today (e.g., Gorshkov, 1959; Bogoyavlenskaya et al., 1991). Beginning in 1999, the Klyuchevskoy group of volcanoes, of which Bezymianny is part, was installed with a seismic network and real time telemetry to IVS in Petropavlovsk-Kamchatsky. Since this time, the Kamchatka Branch of Geophysical Services (KBGS) has carried out real time seismic monitoring and routine earthquake location in the larger vicinity of Bezymianny. In 2005, KBGS was operating six short-period analog seismic stations within 50 km of Bezymianny. The closest stations to Bezymianny, 14 km distant, allowed the most prominent seismic events to be detected, though seismicity at neighboring volcanoes often masked activity. As part of the PIRE project, KBGS and U.S. collaborators undertook an effort to provide seismic coverage specific to Bezymianny. This network would provide greater sensitivity to Bezymianny seismicity, depth control on earthquake locations, broadband coverage to characterize the full spectrum of activity and high dynamic range digital recording to avoid issues with clipped data that are common to analog volcano networks.

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