Journal of Volcanology and Geothermal Research xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Overview of the precursors and dynamics of the 2012–13 basaltic fissure eruption of Tolbachik Volcano, Kamchatka, Russia

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ARTICLE INFO

Article history:
Received 14 January 2015
Accepted 22 April 2015
Available online xxxx

Keywords:
Kamchatka
2012–13 Tolbachik eruption
Basaltic volcanism
Eruption dynamics
Eruption monitoring
Eruption forecast

ABSTRACT

We present a broad overview of the 2012–13 flank fissure eruption of Plosky Tolbachik Volcano in the central Kamchatka Peninsula. The eruption lasted more than nine months and produced approximately 0.55 km^3 DRE (volume recalculated to a density of 2.8 g/cm^3) of basaltic trachyandesite magma. The 2012–13 eruption of Tolbachik is one of the most voluminous historical eruptions of mafic magma at subduction related volcanoes globally, and it is the second largest at Kamchatka. The eruption was preceded by five months of elevated seismicity and ground inflation, both of which peaked a day before the eruption commenced on 27 November 2012. The batch of high-Al magma ascended from depths of 5–10 km; its apical part contained 54–55 wt.% SiO_2, and the main body 52–53 wt.% SiO_2. The eruption started by the opening of a 6 km-long radial fissure on the southwestern slope of the volcano that fed multi-vent phreatomagmatic and magmatic explosive activity, as well as intensive effusion of lava with an initial discharge of >440 m^3/s. After 10 days the eruption continued only at the lower part of the fissure, where explosive and effusive activity of Hawaiian–Strombolian type occurred from a lava pond in the crater of the main growing scoria cone. The discharge rate for the nine month long, effusion-dominated eruption gradually declined from 140 to 18 m^3/s and formed a compound lava field with a total area of ~36 km^2; the effusive activity evolved from high-discharge channel-fed 'a'a lavas to dominantly low-discharge tube-fed pahoehoe lavas. On 23 August, the effusion of lava ceased and the intra-crater lava pond drained. Weak Strombolian-type explosions continued for several more days on the crater bottom until the end of the eruption around 5 September 2013. Based on a broad array of new data collected during this eruption, we develop a model for the magma storage and transport system of Plosky Tolbachik that links the storage zones of the two main genetically related magma types of the volcano (high-Al and high-Mg basalts) with the clusters of local seismicity. The model explains why precursory seismicity and dynamics of the 2012–13 eruption was drastically different from those of the previous eruption of the volcano in 1975–76.

1. Introduction

The 2012–13 flank fissure eruption of Plosky Tolbachik Volcano (Samoylenko et al., 2012; Edwards et al., 2013; Dvigalo et al., 2014) produced approximately 0.55 km^3 DRE (Dense Rock Equivalent) of basaltic trachyandesite magma (here and later the DRE is a volume recalculated to density of 2800 kg/m^3 for non-vesiculated magma taken from average lava densities of 2500 kg/m^3 and pyroclast densities of 1100 kg/m^3). It is the second largest historical eruption of mafic magma in Kamchatka (the largest was the 1975–76 fissure eruption at the same volcano). The 2012–13 eruption lasted more than nine months, and its different stages were studied by several teams of scientists focused on various aspects of the eruptive process. We present here our own observations of the eruption dynamics collected during six long-term field campaigns on the volcano, combined with the published observations made by the other teams. The goal of this paper is to present a general overview of the 2012–13 eruption precursors and dynamics as well as interpretations of the observed variations in eruption mechanisms.

1.1. General geology and volcanology of the Tolbachik volcanic complex

Tolbachik is comparatively well-studied volcanic complex in central Kamchatka. It was first mentioned in the works of the famous 18th century naturalists Krasheninnikov (1764) and Steller (1774, 2003). Piip (1946, 1956) described the general geological features of the volcano and its eruption in 1941. A large volume of geological, geochemical, and geophysical data was also collected during the 1975–76 eruption of the volcano which became known as 'The Great Tolbachik Fissure Eruption' (GTFE; Fedotov et al., 1980; Fedotov and Markhinin, 1983; Fedotov, 1984).

Tolbachik encompasses the southern part of the Klyuchevskaya Volcanic Group, which is located inside the Central Kamchatka Depression

DOI of original article: http://dx.doi.org/10.1016/j.jvolgeores.2015.04.009.
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http://dx.doi.org/10.1016/j.jvolgeores.2015.06.013
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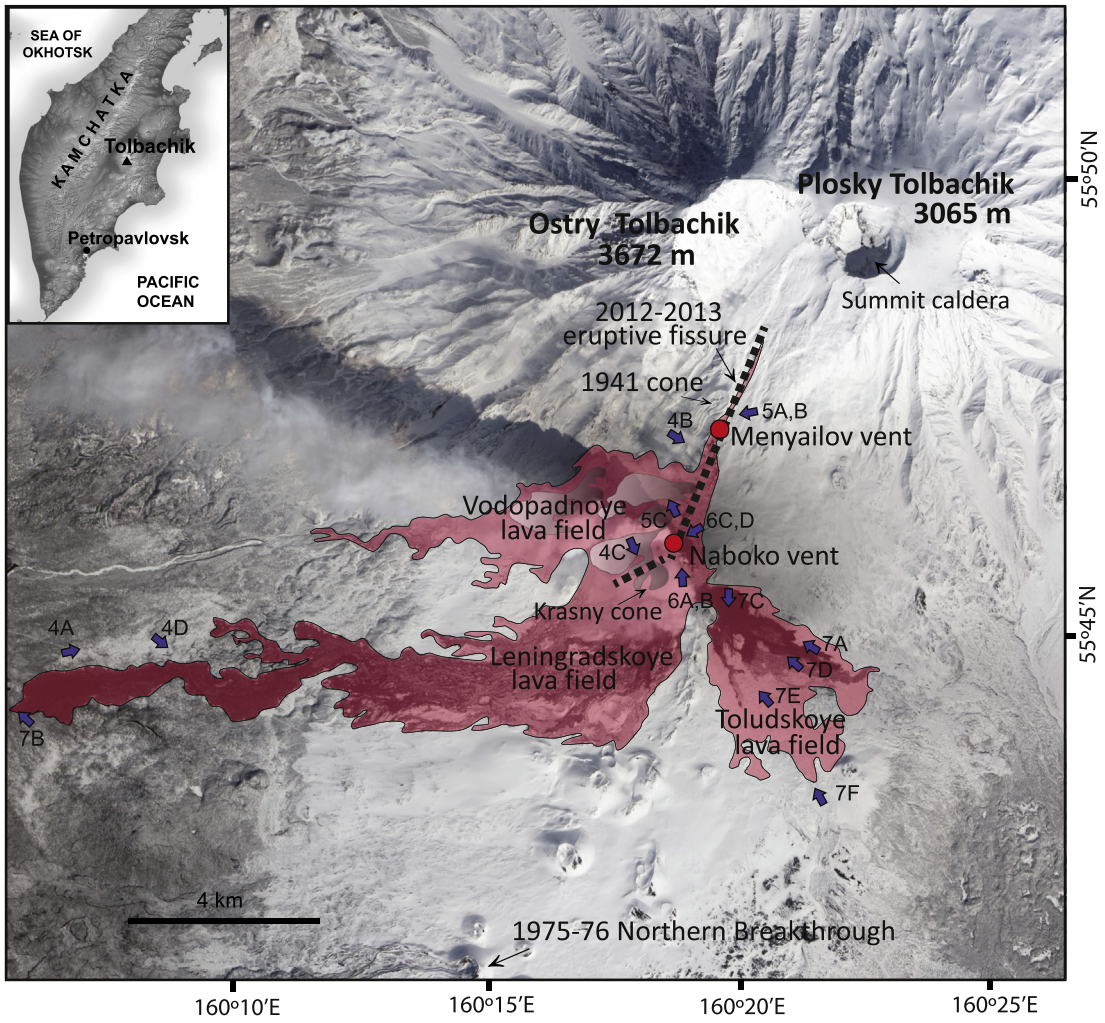

Fig. 1. Location of the eruptive fissure (dashed line) and generalized final areal distribution of the 2012–13 lava flow fields (in pink). Lava fields are shown superimposed over a NASA EO-1 ALI satellite image taken on 5 April 2013 (multiple small kipukas are not shown). Red circles — main eruption vents; blue arrows indicate approximate locations from which the photos illustrating the eruption were taken (the numbers correspond to the figure's numbers). The merged edifices of Ostry and Plosky Tolbachik volcanoes are in the upper right corner of the image. The inset shows the location of Tolbachik Volcano on the Kamchatka Peninsula. EO-1 image is courtesy of NASA's Earth Observing One (EO-1) satellite managed by the Goddard Space Flight Center (http://eo1.gsfc.nasa.gov).

(Fig. 1). The group is well-known as the most productive and diverse subduction-related volcanic area on Earth with compositions of the erupting magmas ranging from basalt to dacite (Piip, 1956; Portnyagin et al., 2007). The volcanism of the group is driven by the subduction of the Pacific Plate under the Okhotsk microplate with an average convergence rate of 9 cm/yr. The unusually high magma production rate is likely related to both the very fast subduction and the proximity of the corner of the Pacific Plate (Yogodzinski et al., 2001).

The first eruptions in the Klyuchevskaya Volcanic Group started in the Early Pleistocene with voluminous effusions of basaltic andesite rich in plagioclase megacrysts that built a broad lava plateau. Later, several high stratovolcanoes were constructed (Piip, 1956; Churikova et al., 2015). At present, some of these volcanoes (Krestovsky, Kamen, Zimina, Gorny Zub, Bol'shaya and Malaya Udina) are considered to be extinct and Ushkovsky is dormant, while Klyuchevskoy, Bezymianny, and Tolbachik are very active. Klyuchevskoy, the youngest and highest volcano (7000 years old; 4800 masl (meters above sea level)) has a basaltic to basaltic andesite composition and has erupted almost continuously throughout historical time (Piip, 1956; Guschenko, 1979; Ozerov, 2000; http://www.volcano.si.edu/volcano.cfm?vn=300260).

The edifice of Tolbachik has a basal diameter of 25 km and comprises two merged stratocones: Ostry (pointed summit) with an elevation of 3672 masl and Plosky (flat summit) with an elevation of 3065 masl. Both edifices grew simultaneously in the Pleistocene, but then Ostry Tolbachik ceased its activity, while Plosky Tolbachik continued to erupt throughout the Holocene (Braitseva et al., 1983). In the beginning of the Holocene, Plosky Tolbachik underwent an important transformation of eruption activity: two long rift-like radial structures were formed on its northeastern (azimuth 45°; length 11 km) and southwestern (azimuth 203°; length 35 km) slopes. Subsequent eruptions of basaltic magma along these zones formed numerous monogenetic scoria cones and lava flows. Approximately 80 km^3 of magma were erupted during the Holocene through the southwest rift that is locally referred to as "Tolbachinsky Dol" (Braitseva et al., 1984).

Lateral withdrawal of magma from a shallow magma chamber beneath Plosky Tolbachik associated with the rift eruptions led to repeated formation of subsidence calderas on the volcano's summit (Fedotov et al., 1980). Between the subsidence episodes, the summit eruptions partially refilled the calderas with horizontal layers of lava. Circular escarpments of three nested calderas are currently visible on the flat summit of the volcano. The oldest and largest is a 3 km-wide caldera that likely formed in the beginning of the Holocene, and the youngest is a 1.5 km-wide caldera that subsided during the 1975–76 fissure eruption in the southwest rift of the volcano (Fedotov et al., 1980; Dvigalo et al., 1991). In the Early Holocene, the southern slope of the twinned volcanic edifice experienced large-scale lateral collapse that affected

Please cite this article as: Belousov, A., et al., Overview of the precursors and dynamics of the 2012–13 basaltic fissure eruption of Tolbachik Volcano, Kamchatka, Russia, J. Volcanol. Geotherm. Res. (2015), http://dx.doi.org/10.1016/j.jvolgeores.2015.06.013