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**GEOPHYSICS**

# The Tolbachik Fissure Eruption of 2012–2013: Preliminary Results

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At 17 h 15 min local time (5 h 15 min UTC) on November 27, 2012, lava started erupting from the submeridional fault formed south of Tolbachik Volcano. The fault zone extended for approximately 6 km between altitudes of 2200 and 1500 m. On November 28, lava flowing from two centers was accompanied by ash ejections with its distribution in the NNE direction for a distance of approximately 100 km. A strong sound were heard in settlements located 40–50 km away from the volcano. The period of November 29–30 was marked by moderate explosions, lava eruption from the upper eruptive center, intense lava flowing, and rapid movement of lava flows in the lower part of the fault. On December 1, activity in the upper center ceased. The length and area of the lava flow that erupted from the upper center amounted to 9 km and 5.6 km$^2$, respectively. From the beginning of December, the eruption became localized in the lower part of the fracture accompanied by an outflow of liquid Hawaiian-type lava from the fissure approximately 1 km long at altitudes of 1500–1600 m.

The lava flows of the Hawaiian pahoehoe type are 1–2 to 3–5 m thick near the fissure and in their frontal parts, respectively. The lavas form variably shaped corded pahoehoe and pillow structures to form a system of lava channels. The maximal measured temperature of the melt was approximately 1100°C. The lava density was calculated from its chemical composition and measured immediately in the field. The calculated density of lavas with temperatures of 1100°C and water contents ranging from 0 to 1 wt % that erupted on the first day of the event varied from 2.65 to 2.58 g/cm$^3$. Lavas with the same parameters from the lower part of the fissure were characterized by densities of 2.7 to 2.63 g/cm$^3$. The immediate density measurements yielded values of 2.0–2.2 g/cm$^3$. The lower measured density values are explained by the presence of residual gas inclusions. The effective viscosity was $10^4$ and 1.5–3.0 × $10^2$ Pa s at the beginning of eruption and in January 2013, respectively.

The eruption occurred within the Tolbachik regional zone of cinder cones approximately 900 km$^2$ in size and 70 km long. In its southern part, the zone extends in the NNE direction and then continues in the northeastern direction to cross the Ploskii Tolbachik Volcano. The southern part of the zone is called Tolbachik Dale. The narrow (3–4 km wide) axial part of Tolbachik Dale hosts up to 80% of all eruptive centers in the form of abundant fissures and chains of cinder cones, which were formed during the last 10 ka. In the historical period, eruptions in this zone occurred in 1740, 1941, and 1975–1976. The youngest eruption of 1975–1976, which is known as the Great Tolbachik fissure eruption (GTFE), was the strongest documented basalt eruption in the Kurile–Kamchatka volcanic belt. It was thoroughly studied, and the results of these investigations were published in many articles [1, 2, 4] and a monograph [5]. This eruption started on July 6, 1975, and ceased on December 10, 1976, consisting of two stages that were marked by eruptions either from the Northern (July 6–September 15, 1975) or Southern (September 16, 1975–December 10, 1976) centers. The integral volume of erupted material and the size of lava fields were as large as 2.17 km$^3$ and 44.73 km$^2$, respectively. The centers of the present-day eruption are located to the north and closer to Ploskii Tolbachik Volcano as compared with the centers of the Great Tolbachik Fissure eruption (Fig. 1).

According to seismic data, the formation of fissures started at 17 h 15 min local time on November 27, 2012. Lava flowing and effusion started at 20 h. The eruption was preceded by a swarm of low-magnitude earthquakes (maximal M = 2.25) that occurred at shallow depths (approximately 5 km) 15 hours prior to eruption. Unlike to the latter, the intense earthquake swarm that preceded the Great Tolbachik fissure eruption was documented 10 days earlier, which allowed its time and location to be predicted [3].

The main products of the youngest eruption are represented by lavas. Its initial stage is characterized by the intense outflow of moderately viscous lavas,

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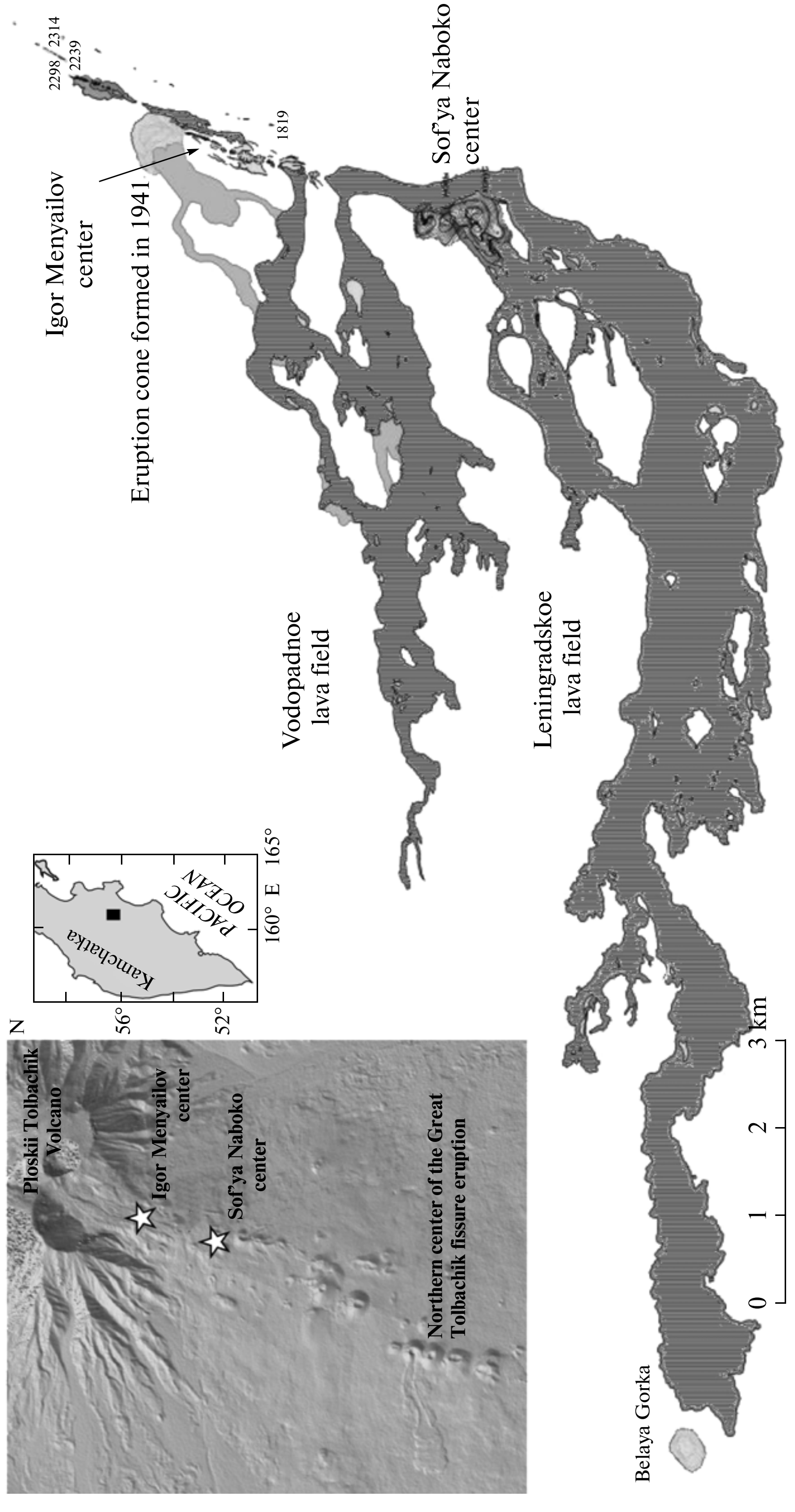


**Fig. 1.** Schematic location of the latest eruption and centers and map of lava flows for December 13, 2012.

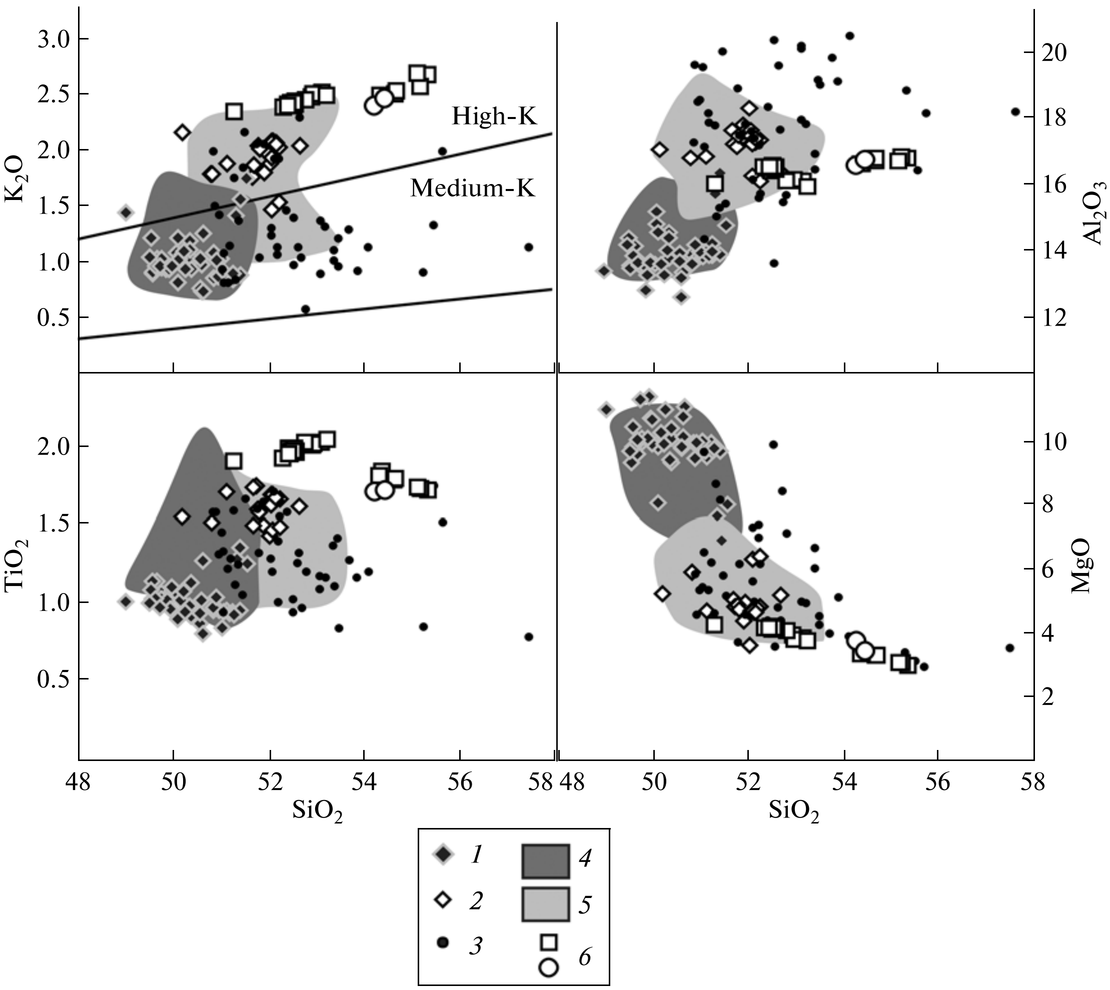


**Fig. 2.** Variations in $K_2O$, $TiO_2$, $Al_2O_3$, and MgO contents (wt %) relative to $SiO_2$ concentrations (wt %) in rocks of the Tolbachik fissure eruption of the 50th IVS Anniversary, Ploskii and Ostryi Tolbachik stratovolcanoes, Great Tolbachik fissure eruption, and regional zone. Discrimination lines at the $K_2O$–$SiO_2$ diagram after [6]. (*1*) Northern GTFE center; (*2*) southern GTFE center; (*3*) Ploskii and Ostryi Tolbachik volcanoes; (*4*) magnesian basalts of the areal zone; (*5*) aluminous basalts of the areal zone; (*6*) Tolbachik fissure eruption of the 50th IVS Anniversary: (squares) lavas and cinders, (circles) ashes.

which formed two spacious fields named Vodopadnoe and Leningradskoe (Fig. 1). The table presents the data on these fields.

The eruption was accompanied by the formation of cinder cones near both centers, with an integral volume of 0.008 $km^3$ estimated for December 13, 2012.

A peculiar feature of the latest eruption is its effusive mode with the volumetric coefficient of explosiveness (ratio between ash and lava volumes) being equal only to approximately 3%. Ash ejections were observed at the initial stage of the eruption, when the upper center was in action. They accompanied extension of fissures and lava intrusion into dead ice and permafrost on the southern slope of the Ploskii Tolbachik Volcano. In addition, the eruption was followed a month later by short-term ash ejections in response to the formation of additional eruptive centers near the lower fracture segment. Ash was documented approximately 100 km away from the eruption center being distributed in the north-northwesterly and easterly directions. The rate of ash deposition amounted to 500 $g/m^2$.

Parameters of lava flows according to aerosurveying data of December 13, 2012

| Parameter | Vodopadnoe | Leningradskoe |
|---|---|---|
| Area, $km^2$ | 5.654 | 17.035 |
| Volume, $km^3$ | 0.027 | 0.208 |
| Average thickness, m | 4.8 | 12.2 |

The eruption started with the outflow of high-K aluminous trachybasaltic andesites. The lavas of the initial stage differ slightly from the varieties that previously erupted in the Tolbachik regional zone primarily in the high silica content (Fig. 2). In addition, their composition differs also from that characteristic of

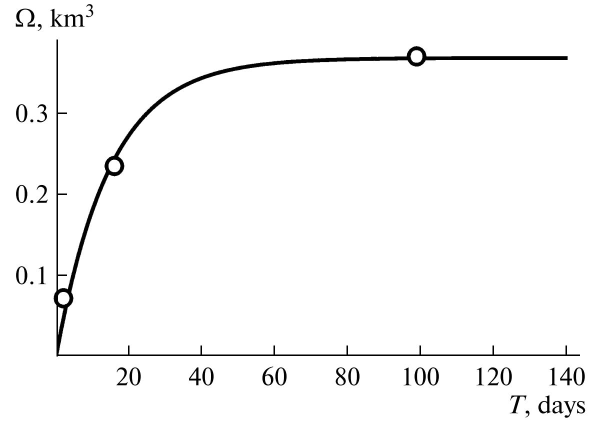


**Fig. 3.** Increase in the volume of erupted rocks with time. Dots correspond to aerosurveying and satellite image data; the curve illustrates the approximation using formula (1).

rocks constituting the volcano proper, which demonstrate higher alumina contents. Later, at the beginning of December, the erupted products became more basic. The $SiO_2$ content decreased by 2%. The concentrations of MgO, FeO, and $TiO_2$ increased slightly. The $Na_2O$ content became slightly lower, and that of $K_2O$ remained practically unchanged, although variations in its concentration and composition are noted precisely in rocks corresponding to the initial eruption stage. Eruption of such rocks was in progress during the entire subsequent period until the end of January. Lavas that erupted since mid-December exhibit larger plagioclase phenocrysts, some of which are up to 1 cm across and 1–2 mm thick, and the occurrence of olivine crystals (approximately 1 mm across) is also larger as compared with their counterparts in older lavas; the total abundance of phenocrysts increased as well.

The discharge of the magmatic reservoir during large fissure eruptions is described by the following formula [5, 7]:

$$\Omega(t) = \Delta B(1 - e^{-W_0 t/\Delta B}), \quad (1)$$

where $\Omega$ is the volume of magma that erupted by the moment $t$, $\Delta B$ is the volume of magma that provided excessive pressure in the reservoir prior to the eruption, and $W_0$ is the initial magma discharge. This model implies the exponential dependence of the erupted material discharge on time and allows its maximal discharge, integral volume, and duration of eruption to be estimated based on the eruption rate.

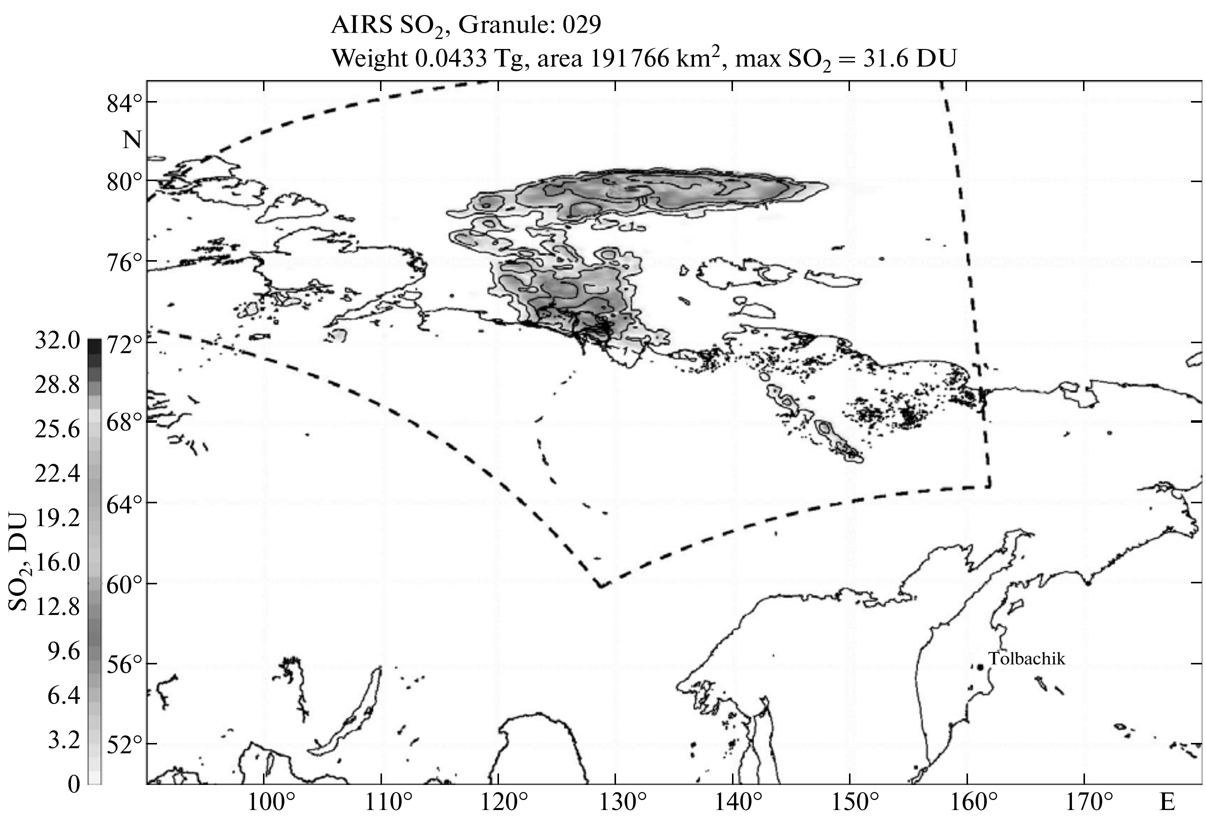


**Fig. 4.** Location of the cloud with sulfur dioxide that originated from the Tolbachik eruption according to satellite AIRS data for November 29, 2013, 02 h 53 min UTC. The concentration is given in Dobson units (DU) equal to 0.01 mm of the thickness of the compressed ozone layer under 0°C or $2.69 \times 10^{20}$ ozone molecules/$m^2$. The dashed line shows boundaries of the satellite image.

Figure 3 illustrates approximation of the theoretical dependence (1) based on the volumes of lava fields estimated for November 29, 2012, and December 13, 2012, from aerophotographs and satellite images obtained on March 6, 2013 (data of the EO-1 NASA satellite). This approximation yields the following values: the maximal volume of erupted material $B = 0.38$ km$^3$, the maximal discharge at the initial stage of the eruption $W = 250$ m$^3$/s, and duration of the eruption 140 days. The real magma discharge at the beginning of eruption (according to aerosurveying on November 29, 2012) exceeds 400 m$^3$/s. Such a significant difference between the calculated and real discharge values is explained by eruption at the initial stage along the entire fissure 4–5 km long, whereas formula (1) is valid for the channel with a constant section. The eruption along the entire fissure is usually followed during the first several hours by localization of lava outflow to give way to eruptions from several centers [5].

According to the preliminary analysis of satellite AIRS data using the known algorithm in [8], the emission of sulfur dioxide ($SO_2$) during the first days of eruption (November 27–28) was $5 \times 10^4$ t. The cloud containing this gas moved in the northwesterly direction under the influence of meteorological factors (Fig. 4). On November 28, it was located above the southern coast of the East Siberian Sea being 190 000 km$^2$ in size. During the next several days, it migrated in the westerly direction to reach the Kola Peninsula.

In satellite images, it is seen that the area of lava flows and their volume on March 6, 2013 (EO-1 NASA satellite), were as large as 28.7 km$^2$ and 0.37 km$^3$, respectively. The eruption is still in progress.

The Scientific Council of the Institute of Volcanology and Seismology (Far East Branch, Russian Academy of Sciences) came to a decision to name the eruption under consideration the Tolbachik fissure eruption of the 50th Anniversary of IVS (TFE-50); the upper and lower eruption centers are named in honor of Igor Menyailov and Sof'ya Naboko, respectively.

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