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Krasheninnikov Caldera (Eastern Kamchatka): Age and Magnitude of Eruption

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Abstract—New data on the composition of the pyroclastic deposits of the Krasheninnikov caldera allowed us to correlate it to the previously studied tephra horizon Geys30, which until recently was erroneously attributed to an eruption within the Geysernaya caldera. Deposits of pyroclastic density currents from the eruption that led to the formation of the Krasheninnikov caldera were found on the caldera's rim and along the southern shore of Kronotsky Lake. Its distal tephra was found in the sediments of the Central Kamchatka Depression (CKD) at a distance of up to 200 km from the source. The age of this tephra was previously estimated at ~30 ka, which now allows us to accept this estimate for the Krasheninnikov caldera. The identification of tephra of the caldera-forming eruption in distal sites allows for a minimum estimate of the erupted pyroclastic volume of ~13 km^3 and the eruption magnitude at 6.1.

Keywords: Kamchatka, explosive eruption, tephra, Krasheninnikov caldera

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INTRODUCTION

In the course of a regional study on the compositions of volcanic glasses in the pyroclastic products of Kamchatka's largest explosive eruptions, we examined pumice lapilli collected by N.A. Kim in 2016 on the southern shore of Lake Kronotskoye (Portnyagin et al., 2020). The chemical composition of the volcanic glass in this pumice (particularly its low potassium content) indicated that the pumice source was located in the frontal part of the Eastern Volcanic Belt, closest to the Kuril-Kamchatka trench (Volynets, 1994). The nearest center of explosive activity that could be linked to this pumice was the Krasheninnikov caldera (Fig. 1). However, at the time of the regional study, it was believed that the pyroclastics from the Krasheninnikov caldera were characterized by a higher potassium content in volcanic glass than the pumice from the shore of Lake Kronotskoye (Portnyagin et al., 2020). Consequently, the Geysernaya caldera was suggested as the source of this pumice. Further studies of Late Pleistocene deposits within the Central Kamchatka Depression (CKD) revealed a regionally distributed tephra with a glass composition identical to the pumice from the southern shore of Lake Kronotskoye. This tephra was also attributed to the Geysernaya caldera and labeled as "Geys30". Using radiocarbon dating of the sediments enclosing the tephra, its age was estimated at approximately 30 ka (Ponomareva et al., 2021).

In 2020–2022, we collected samples of pyroclastic deposits on the rim of the Krasheninnikov caldera and carried out a detailed study of pyroclastic deposits on the southern shore of Lake Kronotskoye (Figs. 2a–2c). These studies confirmed that the Krasheninnikov caldera is the source of the Geys30 tephra. Additionally, studies of CKD deposits allowed us to identify the Geys30 tephra in multiple sections, from the village of Milkovo to the slopes of Kliuchevskoi volcano (Fig. 1a). Here, we present new data that support the interpretation of the Geys30 tephra as a product of the catastrophic eruption that led to the formation of the Krasheninnikov caldera, along with an assessment of the parameters of this eruption.

MATERIALS AND METHODS

We sampled pumice tuffs at the northwestern rim of the Krasheninnikov caldera and in the southwestern part of the Lake Kronotskoye shoreline (Figs. 1, 2). The visible thickness of the tuffs on the caldera rim is at least 30 m, with their base not exposed. On the southern shore of Lake Kronotskoye (Ovalny Cape), pyroclastics are represented by 2.5–3 m thick pyroclastic density current deposits, while on the western

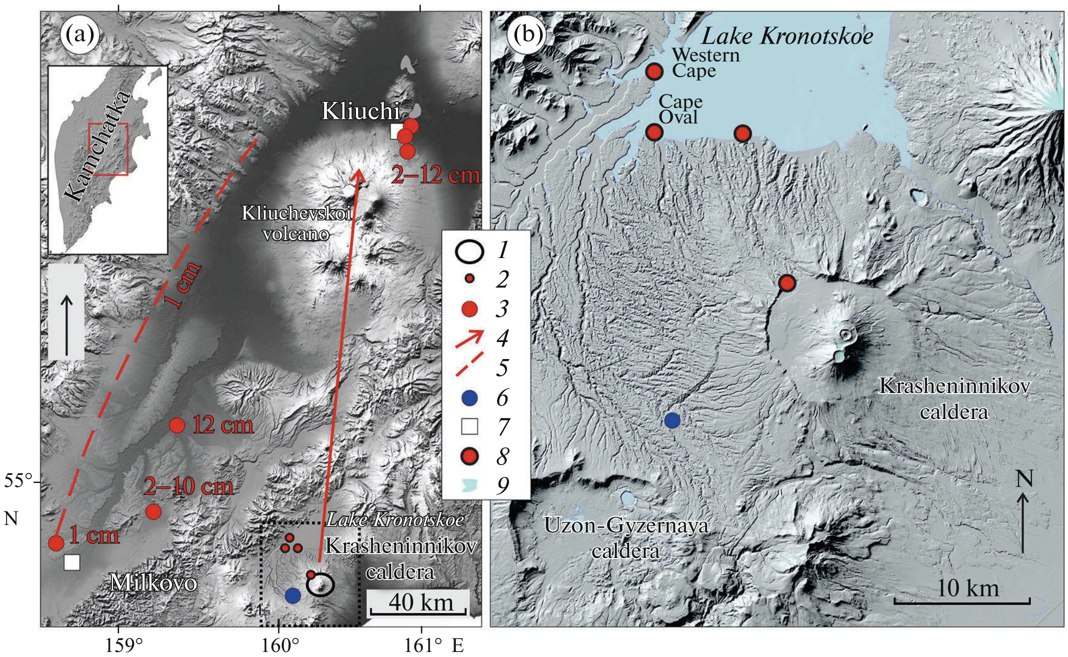

Fig. 1. A map showing the location of sections where the pyroclastic deposits associated with the Krasheninnikov caldera were identified (a) and its enlarged fragment (b): *1*—Krasheninnikov caldera; *2–3*—position of examined sections of the caldera-forming eruptive deposits: *2*—pumice tuff, *3*—distal tephra; *4*—presumed ashfall axis; *5*—approximate position of the 1 cm isopach for the Krsh airfall; *6*—location of pumice tuff sample, previously erroneously attributed to the Krasheninnikov caldera (Portnyagin et al., 2020); *7*—villages; *8*—position of examined sections of pumice tuff; *9*—glaciers.

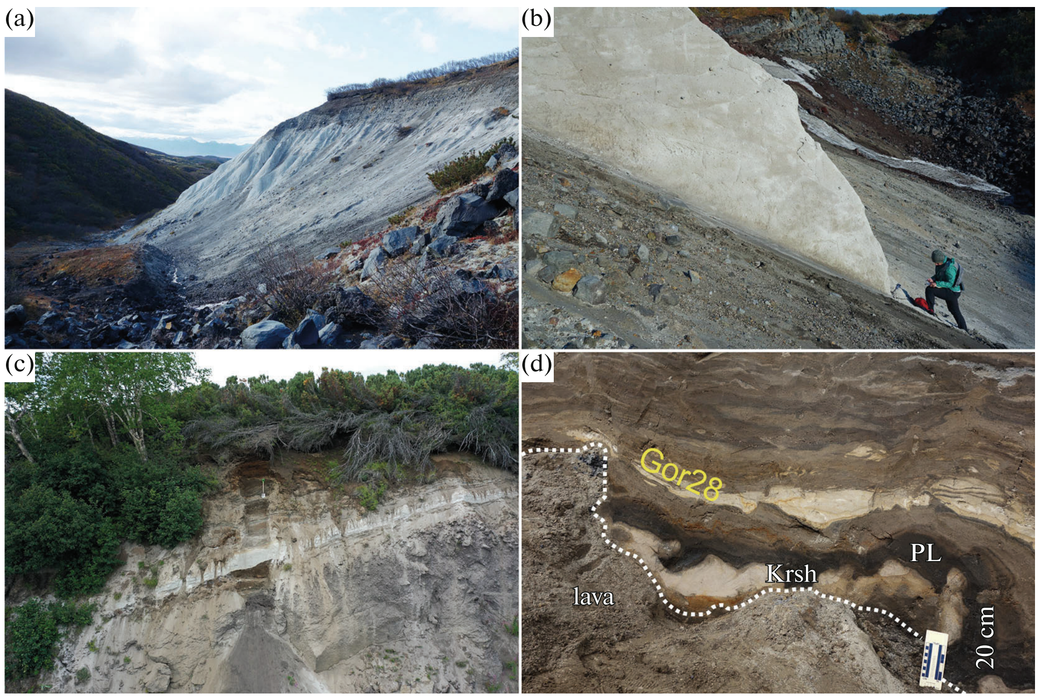

Fig. 2. Pyroclastic deposits associated with the Krasheninnikov caldera. (a–c) Ppyroclastic flow deposits near the northwestern caldera rim (a, b) and in the western part of the southern shore of Kronotsky Lake (Cape Ovalny) (c) where dark gray ignimbrites of the Uzon caldera are exposed in the lower part of the section. Sediment section in the Klyuchi village (d). Gor28—tephra layer from the Gorely volcanic center; PL—cinder from the regional fissure zone superimposed on the Plosky volcanic massif; Krsh—Krasheninnikov caldera tephra (former label Geys30).

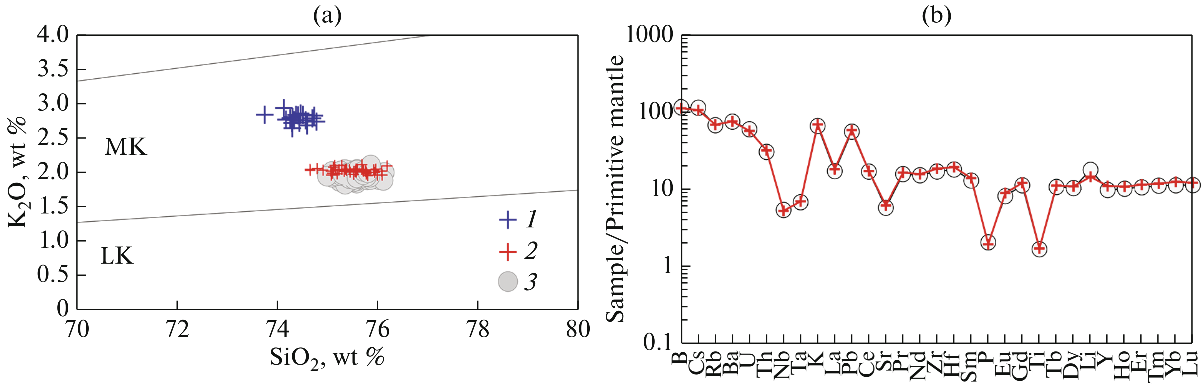

Fig. 3. Chemical composition of glasses from pumices sampled between Krasheninnikov and Uzon calderas (*1*), from pumice tuff sampled near the Krasheninnikov caldera (*2*), and from Krsh tephra from distal sections (*3*). (a) SiO_2–K_2O diagram; (b) trace element contents (ppm) in the products of the caldera–forming eruption normalized to the composition of primitive mantle according to (McDonough and Sun, 1995). Boundaries of low–potassium (LK) and medium–potassium (MK) rocks according to (Igneous..., 2002).

shore (Zapadny Cape), they occur as isolated pumice bombs. The stratigraphic position of the pyroclastics suggests deposition in a water environment. The studied pyroclastics overlie ignimbrites from the Uzon caldera (Florensky, 1984). The distal tephra from this eruption, in addition to previously described locations on the Kitilgina River and in the village of Kliuchi, has now been identified in sections along the Kirganik River and at the slopes of Kliuchevskoi volcano (near the terminal parts of lava flows from the 1932 Kirgurch and Biokos cone eruptions).

The geochemical characteristics of the pyroclastics were obtained by analyzing the major and trace elements composition of volcanic glass. Major elements, as well as F, S, and Cl, were analyzed using a JEOL JXA 8200 microprobe at the GEOMAR Helmholtz Centre for Ocean Research Kiel. Analyses were conducted using a 5-micron electron beam. The concentrations of 40 major and trace elements were determined at the Institute of Geosciences, Kiel University using a modified GeoLas Pro HD 193 nm laser ablation system, integrated with an Olympus microscope and an Agilent 8900 triple quadrupole ICP mass spectrometer. Glass shards were analyzed in a static ablation mode using a 24-micron laser beam. Analytical conditions and data processing procedures are described in detail in Portnyagin et al. (2020).

RESULTS AND DISCUSSION

Analytical data indicate that the compositions of volcanic glass from the proximal pyroclastic deposits of the Krasheninnikov caldera and the distal Geys30 tephra are identical and correspond to rhyolites with K_2O ~ 2 wt %. These compositions plot near the boundary between medium- and low-K fields on the SiO_2–K_2O diagram (Fig. 3). Such K_2O content and the low Nb/Y (0.079) and La/Y (0.256) ratios indicate that the source volcano was located in the frontal part of the volcanic belt (Portnyagin et al., 2020). These glass compositions differ from those of pumice samples collected by V.L. Leonov (http://www.kscnet.ru/ivs/memory/leonov/) between the Krasheninnikov and Uzon calderas, which were previously thought to be products of the Krasheninnikov caldera (Portnyagin et al., 2020).

Thus, the Geys30 tephra appears to be associated with the caldera-forming eruption that led to the formation of the Krasheninnikov caldera. We propose using the label “Krsh” for this tephra. Its previously estimated age of ~30 ka (Ponomareva et al., 2021) now provides a reference for the timing of the eruption that formed the Krasheninnikov caldera. Based on tephra thickness distribution, which allows for a rough estimation of the 1 cm isopach position, the axis of ashfall was directed northward (Fig. 1). At ~200 km from the caldera, in the Kliuchi area, the tephra thickness reaches 12 cm. The Krsh tephra is an important marker for the northern part of the Kliuchevskoi volcanic group, as it allows dating of voluminous lava eruptions in the regional fissure zone cross-cutting the Plosky massif (Flerov et al., 2017; Ponomareva et al., 2021).

Eruption volume calculations using the Legros (2000) method estimate the minimum volume of Krsh tephra at 9 km^3. Considering the volume of pyroclastic density current deposits (~4 km^3), the total volume of pyroclastics from the caldera-forming eruption is at least 13 km^3, with an eruption magnitude (logarithm of erupted mass in kg minus seven, Pyle, 1995) of at least 6.1. These estimates place the event among the largest volcanic eruptions in Kamchatka, comparable to the Holocene caldera-forming eruptions KS1 and KS2 at Ksudach eruptive center (Braitseva et al., 1995).

Previously, the age of the Krasheninnikov caldera was estimated at about 35–38 ka (Braitseva et al., 1995). This estimate was made on the basis of a single radiocarbon date of 39600 ± 1000 years BP obtained on the southern shore of Kronotsky Lake under the ignimbrites of the Uzon caldera (Fig. 2c), i.e., significantly lower in the section (Florensky, 1984). Our new data allow us to estimate the age of the Krasheninnikov caldera at 30 ka.

The pumice tuffs distributed southwest of the Krasheninnikov caldera and closer to the Uzon-Geizernaya caldera, which were previously suggested to be associated with the Krasheninnikov caldera, appear to be products of eruptions within the Uzon-Geizernaya caldera. Reconstruction of these eruptions requires further research.

CONCLUSIONS

Our new data suggest that the catastrophic eruption that formed the Krasheninnikov caldera occurred approximately 30 ka ago. The tephra from this eruption has regional distribution, extending over 200 km north of the caldera. The volume of pyroclastic deposits and the magnitude of the caldera-forming eruption are Studies of Late Pleistocene sediments of the CKD were supported by RSF grant No. 21-77-10102, https://rscf.ru/en/project/21-77-10102/, studies of Pleistocene pyroclastic sediments in the Kronotsky Lake area were supported by RSF grant No. 22-17-00074, https://rscf.ru/en/project/22-17-00074/. The authors are sincerely grateful to Ruslan Talgatovich Akbirov and Natalia Sergeevna Akbirova, inspectors of the Kronotsky Nature Reserve, for their invaluable assistance in conducting sampling on the shore cliffs of Kronotsky Lake, as well as to the anonymous reviewers whose comments made it possible to improve the text of this report.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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