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## Geochronology of Quaternary Volcanism of the Krestovyi Pass Region, Kazbek Neovolcanic Area, Greater Caucasus

V. A. Lebedev<sup>a</sup>, Corresponding Member of the RAS I. V. Chernyshev<sup>a</sup>,  
A. V. Chugaev<sup>a</sup>, and G. T. Vashakidze<sup>b</sup>

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The Krestovyi Pass area (2379 m) is located within the Main Caucasus Range (Fig. 1) in the eastern part of the Keli volcanic highland, which represents a large Quaternary magmatic center of the Greater Caucasus [1–4]. This work is a continuation of our systematic isotopic–geochronological study of the neovolcanic rocks in this region. The first results were reported in [1].

The Krestovyi Pass environs are a highly rugged mountainous region with elevations within 1500–3700 m. The highest peaks are the West Khorisar (3736 m) and Didi-Nepiskalo (3694 m) volcanic buildups located near the crest of the Main Caucasus Range. They serve as sources of the main water artery (Belaya Aragvi River) in the study region. The northern part pertains to the Terek River basin and includes the northern slopes of the Main Caucasus Range (west of the Krestovyi Pass) with the adjacent section of Truso Canyon and Baidara Valley (Fig. 1).

The basement of the studied part of the Keli Highland is made up of Mesozoic sedimentary rocks, which are overlain in the majority of the study area by Quaternary volcanics. The thickness of lava flows is no more than 300 m, and the relative height of volcanic buildups is less than 600 m. The Didi-Nepiskalo and Patara-Nepiskalo volcanoes are the largest ones. Extrusive domes are predominant, and lava volcanoes are subordinate among ten volcanic buildups found in the area.

Previous K–Ar dating of many volcanoes and lava flows in the western part of the Keli volcanic center allowed us for the first time to establish the total duration (about 200 ka) of its activity and to identify its main phases: middle Neopleistocene (225–175 ka) and

late Neopleistocene (130–60 ka). Based on datings of the North Shadilkhokh Volcano, we assumed that volcanism could be more widespread at the Keli Highland up to the terminal Neopleistocene–Holocene [1].

On the basis of geological–geomorphological data, the sequence of the neovolcanic events in the Krestovyi Pass area appears to be as follows [2–4]. According to [2], rocks of Patara-Nepiskalo Volcano and related lava flows in the Belaya Aragvi River valley (Ganisi-Miket) and Baidara River valley, as well as Krestovyi Pass lavas are the oldest [2]. Based on geomorphological data, their age was confined to  $Q_{II}$ – $Q_{III}^1$  [3, 4]. The same age range was proposed for the small Kordieritovyi extrusive dome, which is the third peak of the Patara-Nepiskalo Ring. A younger age ( $Q_{III}^2$ ) was reported in [3, 4] for the Esikom, West Khorisar, and Levinson-Lessing extrusions of the Main Caucasus Range; Didi-Nepiskalo Volcano; and in [3] for the Ploskaya Vershina Volcano, the second peak of the Patara-Nepiskalo Ring. The youngest (Holocene) age was proposed for East Khorisar Volcano, whose extended lava flows form the Kasara gorge in the Terek River Valley, as well as for Ploskaya Vershina Volcano in [4].

As compared to effusives in the western Keli Highland [1], products of neovolcanism in the eastern Keli Highland show wider chemical variations and higher alkali contents (%):  $SiO_2$  57.9–71.9, ( $Na_2O + K_2O$ ) 5.8–8.4 ( $K_2O$  1.5–3.2). The rocks are dominated by dacites, with less abundant trachyandesites (Ploskaya Vershina Volcano), rhyodacites (Patara-Nepiskalo, West Khorisar, and Esikom volcanoes, as well as the oldest lavas of East Khorisar Volcano), and rhyolites (Didi-Nepiskalo Volcano). All volcanic rocks studied belong to the calc-alkaline series.

Isotopic–geochronological study of volcanic rocks of the Keli Highland was conducted with the K–Ar method version specially developed at the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry [5]. Groundmass separated from

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<sup>a</sup> Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences, Staromonetnyi per. 35, Moscow, 119017 Russia; e-mail: leb@igem.ru

<sup>b</sup> Alexander Djanelidze Geological Institute, Georgian Academy of Sciences, st. M. Aleksidze 1/9, Tbilisi, 0193 Georgia

phenocrysts was used for analysis. Dating results are shown in the table.

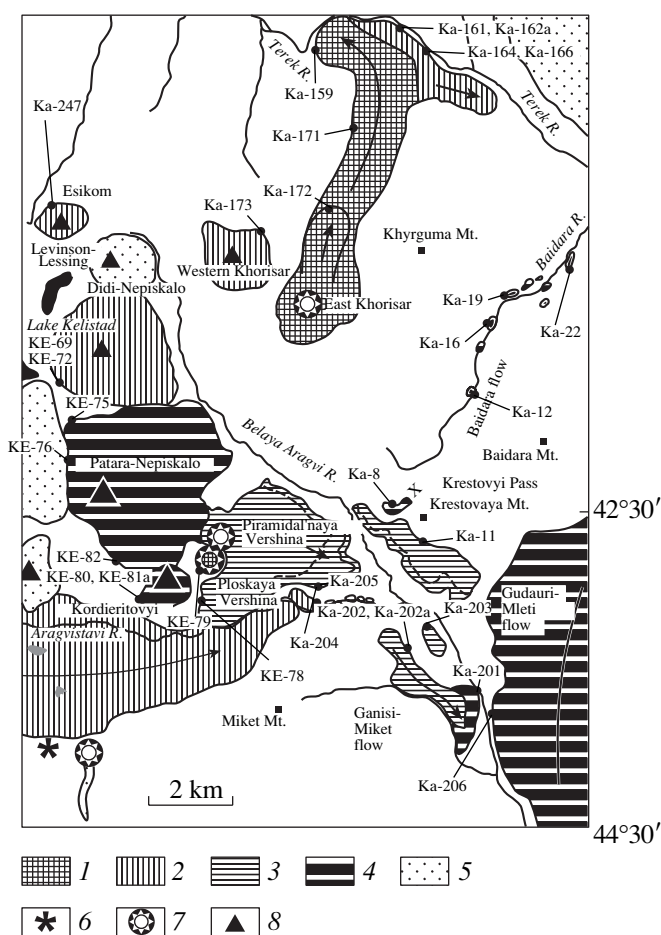
It is seen that all datings range from 200 to <30 ka. This is consistent with previous conclusions on the total duration of the neovolcanism in the Keli center [1]. In addition, the K–Ar dates are distinctly subdivided into three age groups (205–170, 130–70, and <30 ka), which coincide with ages of previously distinguished major volcanic phases of the considered region [1]. Thus, Quaternary volcanism in the western and eastern parts of the Keli Highland was concurrent but differed in eruptive styles. In the western part, the first (middle Neopleistocene) phase of volcanic activity was mainly marked by the formation of extrusive domes; the second (late Neopleistocene) phase, by the formation of lava volcanoes. Melts showed regular temporal evolution (increase in SiO<sub>2</sub> content and decrease in alkalinity). Volcanism in the Krestovyi Pass area (eastern part of the Keli Highland) was characterized by mixed character: extrusive domes and lava volcanoes formed in both middle and late Neopleistocene times without clear compositional variations with time.

The data obtained allowed us to reconstruct the temporal evolution of Quaternary volcanism in the Krestovyi Pass area (Fig. 2).

*Middle Neopleistocene (205–170 ka ago).* Patara-Nepiskalo Volcano, one of the oldest volcanic buildups in the Krestovyi Pass area, was formed at the termination of watershed between the Belaya Aragvi and Aragvistavi rivers. The volcano presumably represented a large extrusive dome without lava flows. At present, this buildup has been strongly destroyed by glacial activity. Its arcuate eastward-open remnant consists of several summits joined by a common base. According to some geologists [2], the cuplike shape of this volcano indicates that its evolution was terminated by the formation of small collapsed caldera [2]. The volcano is mainly composed of dark gray or pink aphyric rhyodacites with scarce ortho- and clinopyroxene phenocrysts.

The small extrusive Kordieritovyi dome was formed in the middle Neopleistocene immediately south of Patara-Nepiskalo Volcano on the left bank of the Aragvistavi River (Fig. 2). It consists of garnet–cordierite dacites, which are unique for the Keli Plateau and were described for the first time in [6]. These rocks are gray or pink, distinctly porphyritic, with phenocrysts of predominant plagioclase and orthopyroxene with minor cordierite, garnet, and clinopyroxene.

The Baidara flow of the same time is preserved as separate remnants on the lower terraces of the Baidara River and along Krestovyi Pass (upper lavas of Krestovyi Pass). The viewpoints on the possible location of eruptive centers of the Baidara flow are significantly different [2–4]. According to [2], it erupted from Patara-Nepiskalo Volcano. However, the obtained data support the assumption [7] that the eruptive center of the Baidara flow located in Krestovyi Pass is now completely destroyed and overlain by glacial deposits. In



**Fig. 1.** Geological map of Quaternary volcanic occurrences in the Krestovyi Pass area, Greater Caucasus. Compiled by V.A. Lebedev. (1) Volcanic rocks of phase III (late Neopleistocene–Holocene); (2) volcanic rocks of the termination of phase II (late Neopleistocene); (3) volcanic rocks of the beginning of phase II (late Neopleistocene); (4) volcanic rocks of phase I (middle Neopleistocene); (5) undated volcanic rocks; (6) scoria cones; (7) lava volcanoes; (8) extrusive domes.

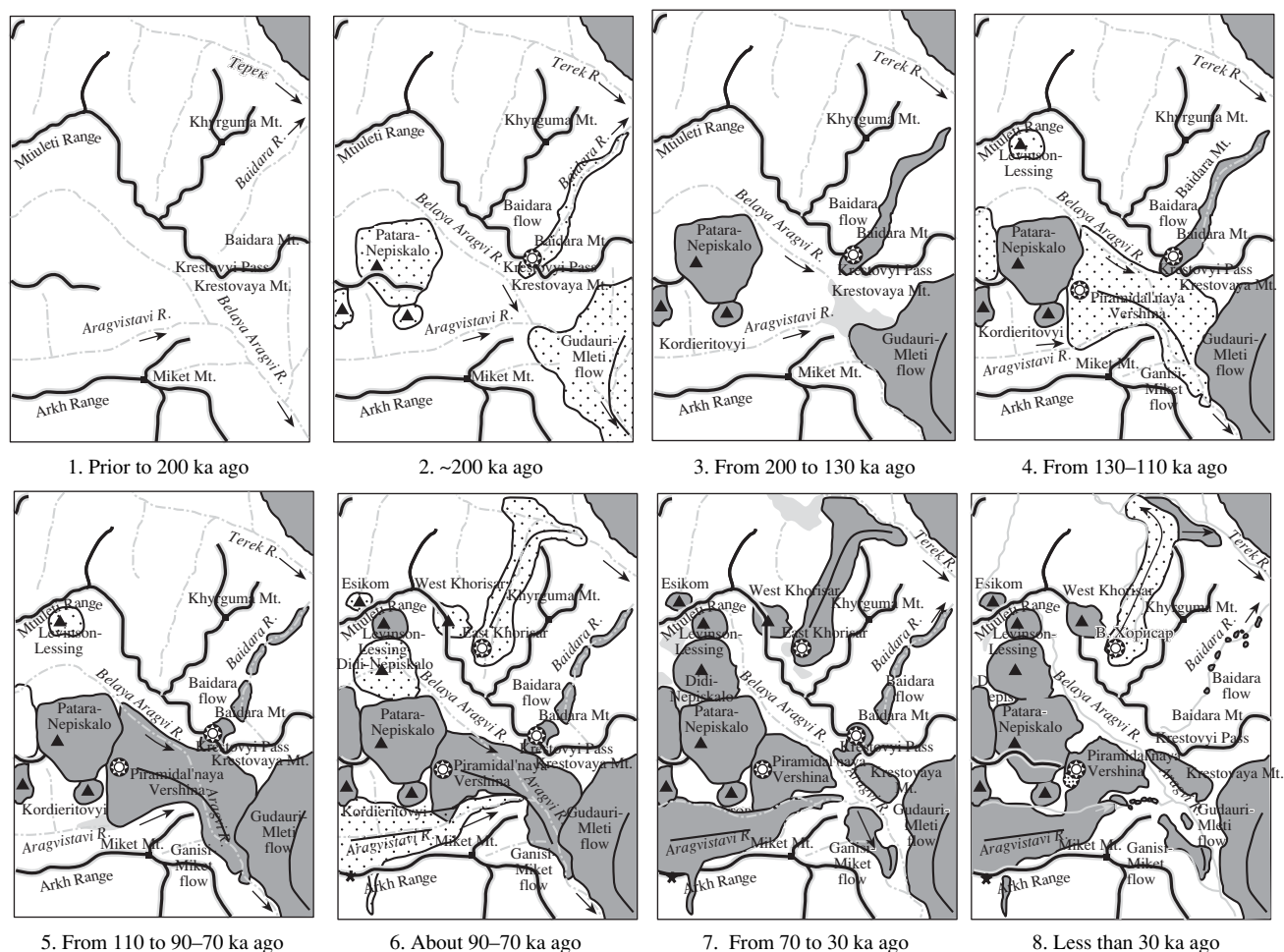
the Baidara River valley, the flow is composed of dark gray or red porphyritic amphibole–orthopyroxene–plagioclase dacites.

One more edifice operating in the middle Neopleistocene was Sakokhe Volcano located east of Krestovyi Pass in the Kabardzhin–Sakokhe volcanic center. This scoria cone produced a thick (up to 250 m) Gudauri-Mleti lava flow, which dammed the Belaya Aragvi River valley and reached the Settlement of Kvesheti (13–14 km of Sakokhe Volcano). The lava flow is typically composed of dark gray massive orthopyroxene–plagioclase andesites or trachyandesites with a weakly developed porphyritic or aphyric texture. Lava flow in the northern area of the dam produced a lake in the Belaya Aragvi Valley, and the river began to cut a new channel along the right bank of the lava flow along its contact with host rocks.

*Late Neopleistocene (130–70 ka ago).* The beginning of late Neopleistocene activity in the Krestovyi

## Results of the K–Ar isotope dating of groundmass from Quaternary lavas of the Krestovyi Pass area

| Sample no.  | Geological object                            | Potassium, % $\pm \sigma$ | $^{40}\text{Ar}_{\text{rad}}$ , ng/g $\pm \sigma$ | $^{40}\text{Ar}_{\text{air}}$ , % (sample) | Age, ka $\pm 2\sigma$ |
|---|--|---------------------------|---|--|-----------------------|
| Patara-Nepiskalo Volcano                            |  |                           |   |  |                       |
| KE-75   | Northern part                                | 1.47 $\pm$ 0.02           | 0.0189 $\pm$ 0.0019                               | 87.1                                       | 185 $\pm$ 40          |
| KE-76   | Western part                                 | 1.48 $\pm$ 0.02           | 0.0195 $\pm$ 0.0020                               | 90.6                                       | 190 $\pm$ 40          |
| KE-82   | Southern part                                | 1.50 $\pm$ 0.02           | 0.0200 $\pm$ 0.0020                               | 88.4                                       | 195 $\pm$ 40          |
| Kordieritovyi Volcano                               |  |                           |   |  |                       |
| KE-80   |  | 2.00 $\pm$ 0.02           | 0.022 $\pm$ 0.006                                 | 99.1                                       | 160 $\pm$ 80          |
| KE-81a  |  | 2.16 $\pm$ 0.03           | 0.0268 $\pm$ 0.0016                               | 91.3                                       | 180 $\pm$ 20          |
| Baidara lava flow                                   |  |                           |   |  |                       |
| Ka-8  | Upper lavas of the Krestovyi Pass            | 1.94 $\pm$ 0.02           | 0.0254 $\pm$ 0.0020                               | 83.6                                       | 190 $\pm$ 30          |
| Ka-12   | 1st remnant in the Baidara River valley      | 2.00 $\pm$ 0.02           | 0.023 $\pm$ 0.004                                 | 98.4                                       | 170 $\pm$ 50          |
| Ka-16   | 3rd remnant in the Baidara River valley      | 2.01 $\pm$ 0.02           | 0.0286 $\pm$ 0.0014                               | 82.7                                       | 205 $\pm$ 20          |
| Ka-19   | 4th remnant in the Baidara River valley      | 2.00 $\pm$ 0.02           | 0.0226 $\pm$ 0.0014                               | 85.1                                       | 170 $\pm$ 20          |
| Ka-22   | 6th remnant in the Baidara River valley      | 2.00 $\pm$ 0.02           | 0.0227 $\pm$ 0.0018                               | 84.1                                       | 170 $\pm$ 25          |
| Gudaury-Mleti lava flow of Sakokhe Volcano          |  |                           |   |  |                       |
| Ka-201  | Right bank of the Belaya Aragvi River        | 2.03 $\pm$ 0.02           | 0.0260 $\pm$ 0.0017                               | 80.7                                       | 185 $\pm$ 25          |
| Ka-206  | Left bank of the Belaya Aragvi River         | 1.53 $\pm$ 0.02           | 0.0182 $\pm$ 0.0029                               | 94.0                                       | 200 $\pm$ 60          |
| Piramidal'naya Vershina Volcano                     |  |                           |   |  |                       |
| Ka-205  | Lower plateau                                | 1.39 $\pm$ 0.02           | 0.0103 $\pm$ 0.0016                               | 93.9                                       | 110 $\pm$ 30          |
| KE-78   | Upper plateau                                | 1.48 $\pm$ 0.02           | 0.0085 $\pm$ 0.0035                               | 99.4                                       | 85 $\pm$ 65           |
| Ka-11   | Lower lavas of Krestovyi Pass                | 1.21 $\pm$ 0.02           | 0.0104 $\pm$ 0.0021                               | 96.6                                       | 125 $\pm$ 45          |
| Ka-202  | Ganisi-Miket lava flow                       | 1.38 $\pm$ 0.02           | 0.0112 $\pm$ 0.0024                               | 98.4                                       | 120 $\pm$ 50          |
| Ka-202a   | The same                                     | 1.38 $\pm$ 0.02           | 0.0120 $\pm$ 0.0019                               | 91.4                                       | 125 $\pm$ 35          |
| Ka-203  | Lava remnant near the Settlement of Dzuarkau | 1.34 $\pm$ 0.02           | 0.0123 $\pm$ 0.0016                               | 93.8                                       | 130 $\pm$ 30          |
| Lava at the eastern termination of the Keli Plateau |  |                           |   |  |                       |
| Ka-204  |  | 1.70 $\pm$ 0.02           | 0.0084 $\pm$ 0.0020                               | 94.0                                       | 70 $\pm$ 30           |
| Ploskaya Vershina Volcano                           |  |                           |   |  |                       |
| KE-79   | Hyalodacites of the volcanic peak            | 1.26 $\pm$ 0.02           | Not detected                                      | $\geq$ 99.9                                | $\leq$ 30             |
| Esikom Volcano                                      |  |                           |   |  |                       |
| Ka-247  |  | 1.37 $\pm$ 0.02           | 0.0080 $\pm$ 0.0010                               | 83.9                                       | 85 $\pm$ 20           |
| Didi-Nepiskalo Volcano                              |  |                           |   |  |                       |
| KE-69   |  | 2.80 $\pm$ 0.03           | 0.0129 $\pm$ 0.0013                               | 90.7                                       | 70 $\pm$ 15           |
| KE-72   |  | 2.75 $\pm$ 0.03           | 0.006 $\pm$ 0.006                                 | 99.9                                       | 35 $\pm$ 50           |
| West Khorisar Volcano                               |  |                           |   |  |                       |
| Ka-173  |  | 1.66 $\pm$ 0.02           | 0.004 $\pm$ 0.004                                 | 99.8                                       | 50 $\pm$ 50           |
| East Khorisar Volcano                               |  |                           |   |  |                       |
| Ka-161  | Lower tuffolavas                             | 1.75 $\pm$ 0.02           | 0.0092 $\pm$ 0.0018                               | 93.3                                       | 75 $\pm$ 25           |
| Ka-162  | 1st lava flow                                | 1.72 $\pm$ 0.02           | 0.0137 $\pm$ 0.0019                               | 93.4                                       | 115 $\pm$ 30          |
| Ka-164  | The same                                     | 1.60 $\pm$ 0.02           | 0.0114 $\pm$ 0.0019                               | 96.0                                       | 105 $\pm$ 35          |
| Ka-166  | "  | 1.76 $\pm$ 0.02           | 0.0083 $\pm$ 0.0016                               | 94.6                                       | 70 $\pm$ 25           |
| Ka-159  | 2nd lava flow                                | 1.57 $\pm$ 0.02           | Not detected                                      | $\geq$ 99.9                                | $\leq$ 30             |
| Ka-171  | The same                                     | 1.46 $\pm$ 0.02           | The same  | $\geq$ 99.9                                | $\leq$ 30             |
| Ka-172  | 3rd lava flow                                | 1.54 $\pm$ 0.02           | "   | $\geq$ 99.9                                | $\leq$ 30             |



**Fig. 2.** Paleoreconstruction of Quaternary volcanic events in the Krestovyi Pass area, Greater Caucasus.

Pass area was related to eruptions of Piramidal'naya Vershina Volcano, which is adjacent to the Patara-Nepiskalo Ring in the southeast and previously was not considered as an independent eruptive center. According to our observations, this volcano was the eruptive center for the Ganisi-Miket flow, which extends along the right bank of the present-day Belaya Aragvi River Valley, as well as for the lower lavas of the Krestovyi Pass, and lavas of the Lower and Upper plateaus near the confluence of the Belaya Aragvi and Aragvistavi rivers (Figs. 1, 2). After three eruptions, lava flows completely jammed the impounded lake area up to the Krestovyi Pass, while the excess lava (Ganisi-Miket flow) advanced to the new channel of the Belaya Aragvi River cut along the wall of the Gudauri-Mleti flow. Our observations suggest that lavas of the Ganisi-Miket flow rest on the older Gudauri-Mleti flow. Products of the eruption of Piramidal'naya Vershina Volcano are represented by gray or pink orthopyroxene-plagioclase dacites with a weakly developed porphyritic or oligophytic texture.

After the termination of eruptive activity of Piramidal'naya Vershina Volcano, the Belaya Aragvi River

began to cut a new channel at the new contact point of the Gudauri-Mleti and Ganisi-Miket flows. Lava sequences were destroyed completely in areas where they covered loose lacustrine deposits. One lava remnant, which possibly was separated from the main body of the Ganisi-Miket flow or was preserved when the Belaya River cut a new valley, is observed along the recent riverbed near the ruins of the Settlement of Dzuarikav.

Approximately 90–70 ka ago, late Neopleistocene volcanic activity in the Krestovyi Pass area was confined to the Main Caucasus Range (Esikom and West Khorisar extrusive domes, large Didi-Nepiskalo strato-volcano without lava flows, and East Khorisar lava volcano). Esikom Volcano is made up of gray and pink massive rhyodacites with a weakly developed porphyritic texture. Phenocrysts are represented by plagioclase, hornblende, and occasional ortho- and clinopyroxenes. Porphyritic rhyolites in Didi-Nepiskalo Volcano vary widely in color and texture of the groundmass. Phenocrysts are observed as biotite, plagioclase, and occasional hornblende. Products of West Khorisar Volcano are represented by gray and pink porphyritic rhyodacites with phenocrysts of plagioclase,

hornblende, and orthopyroxene. Neopleistocene activity of East Khorisar Volcano was related to the formation of an extended (up to 8 km) lava flow, which descended down to the Terek River valley, dammed it, and formed a small tongue (up to 2 km long) in the lower reaches of the river. This flow comprises massive porphyritic orthopyroxene–amphibole–plagioclase rhyodacites. Later, the Terek River cut the narrow canyonlike Kasara gorge along the contact with host rocks.

*Late Neopleistocene–Holocene (less than 30 ka ago).* The terminal phase of volcanic activity in the Krestovyi Pass area was associated with Ploskaya Vershina and Vostochnyi Khorisar volcanoes. The first volcano is located on the slope of the Patara-Nepiskalo Ring between the Kordieritovyi and Piramidal'naya Vershina volcanoes and, in our opinion, represents an extrusion of glassy aphyric trachyandesites. The lava flow of porphyritic plagioclase–orthopyroxene andesites, remnants of which are observed in the lower part of the Aragvistavi River Valley, was previously ascribed to Ploskaya Vershina Volcano [2, 4]. However, the lava flow has no relation with the latter volcano and represents a part of the lower terrace of the Keli Plateau composed of the lavas of South Narvan Khokh Volcano. East Khorisar Volcano erupted twice in the terminal Neopleistocene–Holocene. The first eruption was associated with formation of an extended lava flow, which descended along the bed of the Terek River over the older flow (70–90 ka). The lower part of the lava flow turned upstream along the valley due to the existence of the older lava dam (Fig. 2). The flow has distinct side-swells, and its surface is not altered by glacial impact. The last eruption of East Khorisar Volcano was related to the outburst of the northern wall of the crater and the formation of a lava tongue up to 2 km long. Lavas of the activity of East Khorisar Volcano in the late Neopleistocene–Holocene are represented by massive porphyritic gray and pink orthopyroxene–amphibole–plagioclase dacites. The compositional variations in products of the East Khorisar Volcano activity with time are consistent with the acid-to-basic evolution of the melts in the magma chamber.

Thus, K–Ar dating of the volcanic rocks from the eastern part of the Keli Highland confirmed our previous conclusions that magmatic activity in this region lasted for ~200 ka and was subdivided into three phases: middle Neopleistocene (225–170 ka ago), late Neopleistocene (130–60 ka ago), and late Neopleistocene–Holocene (<30 ka ago). The data obtained indicate that neovolcanism in the Keli Highland evolved almost concurrently with magmatic activity in another large volcanic center (Elbrus) in the Greater Caucasus [8].

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#### REFERENCES

1. V. A. Lebedev, I. V. Chernyshev, E. V. Arutyunyan, et al., *Dokl. Earth Sci.* **399**, 1227 (2004) [*Dokl. Akad. Nauk*, **399**, 378 (2004)].
2. N. N. Skhirtladze, *Post-Paleogene Effusive Volcanism in Georgia* (Akad. Nauk Gruz. SSR, Tbilisi, 1958) [in Russian].
3. E. E. Milanovskii and N. V. Koronovskii, *Orogenic Volcanism and Tectonics of the Alpine Belt of Eurasia* (Nedra, Moscow, 1973) [in Russian].
4. N. M. Dzotsenidze, *Geological Study of Lava Deposits in the Keli Area, Greater Caucasus: Report* (KIMS, Tbilisi, 1965) [in Russian].
5. I. V. Chernyshev, V. A. Lebedev, and M. M. Arakelyants, *Petrology* **14**, 62 (2006) [*Petrologiya* **14**, 69 (2006)].
6. F. Yu. Levinson-Lessing, *Volcanoes and Lavas of the Central Caucasus* (Politekhn. Inst., Moscow, 1913), Vol. 20 [in Russian].
7. A. L. Reingard, *Izv. Kavkaz. Otd. Ross. Geograf. O-va* **22** (1), 1913/1914.
8. V. A. Lebedev, I. V. Chernyshev, S. N. Bubnov, et al., *Dokl. Earth Sci.* **405**, 1321 (2005) [*Dokl. Akad. Nauk* **405**, 389 (2005)].