Stages of Magmatic Activity in the Elbrus Volcanic Center (Greater Caucasus): Evidence from Isotope-Geochronological data

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Stages of Magmatic Activity in the Elbrus Volcanic Center (Greater Caucasus): Evidence from Isotope-Geochronological Data

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This work presents K–Ar and Rb–Sr isotope-geochronological datings that allowed us to establish temporal ranges of magmatic activity in the Elbrus volcanic center.

Mount Elbrus has a well-known reputation as a geographic object and tourist center. Recently, it has also been attracting the interest of researchers as a large Quaternary (presumably dormant) volcano. In the European part of Russia, Mount Elbrus is the most hazardous area in terms of the probability of volcanic activity resumption. This structure is referred to as an active volcano in catalogs of volcanic objects [1, 2]. The Elbrus volcano (altitude 5643 m), the highest peak in the Caucasus, is located in a densely populated area near large settlements, popular tourist centers, and mining enterprises in the Northern Caucasus.

Eruptions of volcanoes Saint Helens (Washington, United States) in 1980 and El Chichon (Mexico) in 1982 in the Cordilleras demonstrated the scale of possible ecological and economic consequences of the catastrophic activity of apparently dormant volcanoes. At the same time, they stimulated isotope geochronological and other detailed studies of similar structures in the world. In Russia, such works are carried out within the framework of the Federal Integral Scientific-Technical Program "Global Changes of Environment and Climate" (Academician of the RAS N.P. Laverov, supervisor) and other projects.

The isotopic age of recent volcanic eruptions is considered a major parameter indicating probable volcanic activity in future. In addition to prognostic implication, the geochronological study of recent (Quaternary) volcanoes has fundamental significance for determining the life period of volcanic structures, centers, and regions, as well as the duration of their activity cycles. The systematic reliable dating of products of Quaternary volcanic eruptions has become possible in the last few years thanks to progress in the K–Ar method, first of all the technique of measurement of very low ^{40}Ar concentrations [3, 4]. The K–Ar method is crucial for the reconstruction of Quaternary volcanic history, because it encompasses a major part of the Quaternary Period ranging from 2 Ma to 20–30 ka. The dating of younger (upper Pleistocene and Holocene) lavas is possible by radiocarbon, uranium–ionium, and other methods.

The Elbrus volcanic center (Fig. 1) is located on the northern slope of the Main Caucasian Range. It incorporates the Elbrus Volcano (watershed of Malka, Baksan, and Kuban rivers), several small edifices on the volcanic slope, and some separate vents of lavas and pyroclastic rocks at the eastern and northern margins of the volcano in basins of the Khudes, Kyrtyk, and Tyzyl rivers. The Elbrus Volcano has two cone-shaped peaks with distinct volcanic funnels. The volcanic basement is composed of Variscian metamorphic rocks that are exposed in areas up to 3.0–3.7 km high. Based on the latest reconstructions, recent volcanism in the Greater Caucasus, including the Elbrus volcanic center, was manifested during a continental collision [5, 6]. Researchers have also proposed more intricate geodynamic models, such as the juxtaposition of collisional and initial riftogenic settings [7] and the juxtaposition of intraplate "hot field" and continental collision [8].

Most researchers believe that tuffs and ignimbrites of the rhyolitic and rhyodacitic compositions are the oldest volcanic rocks in the Elbrus center. Crystalloclasts in these rocks consist of predominant quartz, biotite, and plagioclase along with the occasional hypersthene. Practically all crystalloclasts are strongly crushed, melted, and fractured. They are sometimes partially dissolved by the groundmass. The plagioclase composition varies from oligoclase to labrador, andesine being the predominant phase. The groundmass of ignimbrites is usually composed of quartz–feldspar aggregate or glass with a flow microtexture and fiamme-type segregations.

Within the Elbrus center, pyroclastic rocks are conformably overlain by thick lava sequences that compo-

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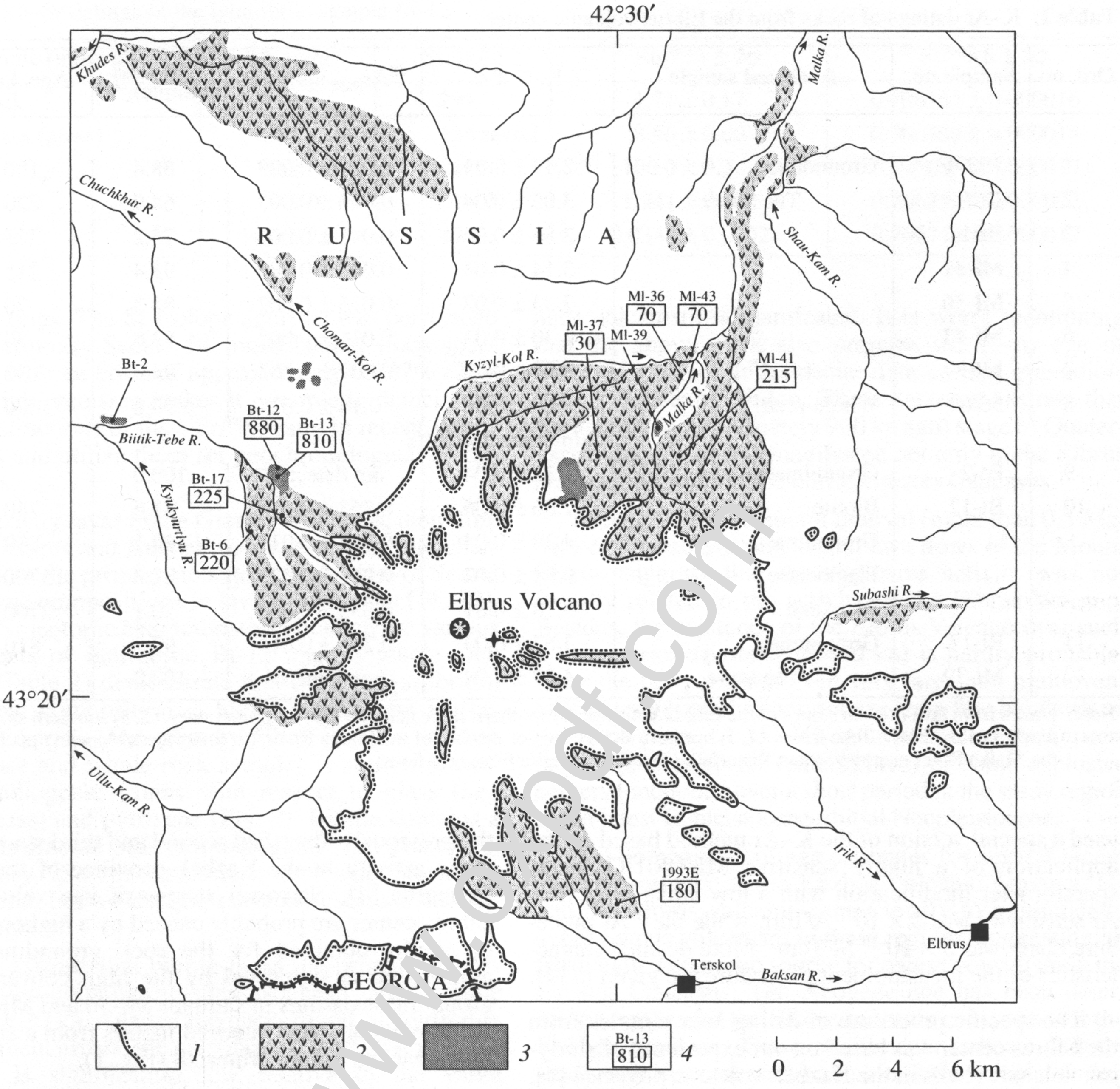

Fig. 1. Schematic geological map of the Elbrus volcanic center (based on large-scale geological maps of the region). (*1*) Glaciers; (*2*) lava flows; (*3*) ignimbrites and tuffs; (*4*) K–Ar datings.

sitionally range from andesidacites to rhyodacites. Phenocrysts in lavas always contain plagioclase (varying from andesine-labrador to oligoclase), orthopyroxene, and biotite. Amphibole and quartz are subordinate minerals. Some lava varieties contain quartz xenocrysts in the clinopyroxene rim. Phenocrysts of clinopyroxene (augite) are extremely rare. Generally, the rock groundmass has a flow microtexture and consists of partially or completely crystallized volcanic glass, which is locally transformed into spherulitic aggregates. Plagioclase, the most common mineral in the groundmass, is usually associated with bronzite, biotite, and the less common augite. Volcanic rocks of the Elbrus volcanic center (including pyroclasitic rocks) primarily belong to the calc-alkaline series with the following composition (%): SiO_2 63.7–71.8, $K_2O + Na_2O$ 5.6–7.6, and K_2O 2.5–4.4.

Previous concepts about the age of lavas in the Elbrus center were generally based on geomorphological and paleomagnetic data [9]. Like the paleomagnetic data, the available scanty and tentative K–Ar datings suggest a Quaternary age for volcanic eruptions in the Elbrus center. Recently obtained radiocarbon datings of coals and buried (humic) soil layers in this center [10] indicate the possibility of volcanism in the Holocene.

We carried out K–Ar dating of volcanic rocks from reference sections on the western and northern slopes of the Elbrus Volcano (basins of Biitik-Tebe and Malka rivers). The samples were taken during field works. We

Table 1. K–Ar datings of rocks from the Elbrus volcanic center

Ord. no.	Sample no.	Analyzed sample	K, % ± σ	$^{40}Ar_{rad}$, ng/g ± σ	$^{40}Ar_{nonrad}$ (sample), %	Age, ka ± 1.6σ
			Lavas			
1	1993E	Groundmass	2.99 ± 0.03	0.037 ± 0.003	88.4	180 ± 30
2	Bt-6	The same	3.05 ± 0.04	0.046 ± 0.003	64.9	220 ± 30
3	Bt-17	"	2.86 ± 0.04	0.045 ± 0.003	75.2	225 ± 30
4	Ml-41	"	3.14 ± 0.04	0.047 ± 0.003	93.4	215 ± 30
5	Ml-36	"	3.23 ± 0.03	0.015 ± 0.002	85.3	70 ± 20
6	Ml-43	"	3.30 ± 0.03	0.016 ± 0.002	83.8	70 ± 20
7	Ml-37	"	3.04 ± 0.03	0.007 ± 0.003	94.9	30 ± 25
8	56/64*	Whole-rock	2.66 ± 0.04	0.14 ± 0.02	93.8	800 ± 150*
			Ignimbrites and tuffs			
9	Bt-2	Groundmass	3.32 ± 0.04	not detected	100.0	–
10	Bt-12	Biotite	7.06 ± 0.06	0.363 ± 0.018	81.6	740 ± 60
		Groundmass	4.30 ± 0.04	0.263 ± 0.015	88.1	880 ± 70
		Plagioclase	0.84 ± 0.02	0.913 ± 0.035	82.3	15700 ± 1000
		Pyroxene	0.18 ± 0.01	0.033 ± 0.003	90.1	2700 ± 500
11	Bt-13	Groundmass	3.67 ± 0.04	0.206 ± 0.015	97.2	810 ± 90
12	Ml-39	The same	4.39 ± 0.04	not detected	100.0	–

Note: Dacite from lava flow on slopes of the Elbrus Volcano: (1) southern slope near the Terskol observatory, (2, 3) southern slope in upper reaches of the Biitik-Tebe River, (4, 7) northern slope in upper reaches of the Malka River, (5, 6) northern slope in upper reaches of the Malka River near the Sultan Waterfall; (8) trachyandesite from lava flow.

used a special version of the K–Ar method based on the application of a highly sensitive MI-1201IG mass-spectrometer modification with a low noise level. The Ar sensitivity was 5×10^{-3} A/Torr, while the ^{40}Ar procedure blank was 5×10^{-10} SPTcm^3. More detailed characteristics of the measurement procedure are given in [4].

The specific procedure of dating lava samples from the Elbrus center was based on our experience of studying volcanic rocks in the Kazbek volcanic province [4]. We used rock groundmass separated from phenocrysts as a geochronometer (i.e., primary object for analysis). We revealed that the phenocrysts contain an appreciable amount of excess radiogenic ^{40}Ar, which is presumably related to the contamination of primary magma by the material of older crystalline rocks.

Results of the dating of volcanic rocks from the Elbrus center are presented in Table 1. Let us first examine data on dacitic lava flows on the Elbrus Volcano. We can recognize at least two stages of magmatic activity: middle Neopleistocene stage (180–225 ka) and late Neopleistocene–Holocene stage (<70 ka). The first stage witnessed the effusion of lava flows exposed in basins of the Biitik-Tebe and Malka rivers and the accumulation of lava units below the Terskol summit (Baksan River basin). Products of eruptions during the second stage are observed as lava flows in the upper reaches of the Malka River (Fig. 1, Table 1). These stages of volcanic eruptions in the Elbrus center match the previously identified second and third stages of volcanic activity in the Kazbek province of the Greater Caucasus [4]. Narrower ranges of age values in the Elbrus center are probably caused by a higher accuracy of results obtained for the rock groundmass. This assumption is supported by the high convergence of groundmass datings in samples Ml-36 and Ml-43 taken at intervals of a few hundred meters from a single lava flow near the Sultan Waterfall (Fig. 1).

Among four tuff and ignimbrite samples taken from the Elbrus center, only two samples (Bt-12 and Bt-13) turned out to be suitable for K–Ar dating (Table 1). The radiogenic ^{40}Ar admixture could not be measured due to an extremely high concentration of atmospheric Ar in samples Bt-12 and Ml-39. We analyzed all major components (plagioclase, pyroxene, biotite, and glass matrix) in Sample Bt-12. Plagioclase and pyroxene yielded anomalously high and geologically senseless K–Ar dates (15.7 and 2.7 Ma, respectively). This is obviously caused by the presence of excess ^{40}Ar in the above-mentioned low-K minerals, although the K-based data suggest that the ^{40}Ar content, on the whole, is low. At the same time, high-K phases (biotite and glass) yielded rather similar dates (740 and 880 ka, respectively). A close K-Ar date (810 ka) was obtained for the groundmass in another ignimbrite sample (Bt-13).

Sample Bt-12 contains biotite characterized by a high Rb/Sr ratio. Therefore, we could obtain additional

Table 2. Rb–Sr datings of the ignimbrite sample Bt-12

Sample (mineral)	Rb, µg/g	Sr, µg/g	$^{87}Rb/^{86}Sr \pm 2\sigma$	$^{87}Sr/^{86}Rb \pm 2\sigma$
Whole-rock	174	299	1.71 ± 0.17	0.706453 ± 0.000016
Groundmass (glass)	388	134	8.46 ± 0.80	0.706489 ± 0.000014
Biotite	667	18.0	106.0 ± 0.3	0.708086 ± 0.000017
Pyroxene	9.0	14.7	1.741 ± 0.008	0.706350 ± 0.000022
Plagioclase	5.7	476	0.0344 ± 0.0002	0.706714 ± 0.000017

Rb–Sr datings. The Sr isotope analysis was performed on a Micromass Sector 54 multichannel mass-spectrometer with an error of approximately 0.002% (2σ). Such a high precision makes it possible to detect even minor distinctions of the $^{87}Sr/^{86}Sr$ ratio in recent volcanic rocks and utilize them for geochronological reconstructions.

Quaternary lavas in the Greater Caucasus, including both the Elbrus and Kazbek volcanic centers, are characterized by the primary nonequilibrium state of Sr and Nd isotopic compositions in lava components [11, 12]. The Rb–Sr isotopic characteristics obtained for various components of ignimbrite Bt-12 and its whole-rock sample (Table 2) demonstrate that the nonequilibrium Sr isotopic composition is highly contrasting in this pyroclastic rock. The primary $^{87}Sr/^{86}Sr$ ratio in both plagioclase and whole-rock samples is shifted toward higher radiogenic values with respect to glass (i.e., groundmass) and pyroxene (Fig. 2). Biotite contains a noticeable amount of *in situ* radiogenic ^{87}Sr. Therefore, the primary $^{87}Sr/^{86}Sr$ signature is somewhat blurred in this mineral, but we can still correctly estimate the ignimbrite age.

If we assume that biotite lacks the primary excess ^{87}Sr, the two-point biotite–glass isochron yields a value of 1150 ± 20 ka. Against the background of negligible measurement errors, the calculated $(^{87}Sr/^{86}Sr)_0$ value of 0.70635 is significantly low relative to the value obtained for plagioclase. The biotite–glass–pyroxene isochron yields practically similar values. On the other hand, if we suppose that the primary $^{7}Sr/^{86}Sr$ ratio is identical in both biotite and plagioclase, the Rb–Sr dating based on the biotite–plagioclase pair yields 910 ± 15 ka. Age estimates for two possible values of the primary $^{87}Sr/^{86}Sr$ ratio in biotite determine the lower age limit for ignimbrites (1150 ka). The second value (910 ka) is probably close to the upper age limit. If the primary $^{87}Sr/^{86}Sr$ ratio in biotite is really higher than in plagioclase, which is unlikely, the biotite age may turn out to be slightly younger than 910 ka.

The K–Ar and Rb–Sr data reported in this work suggest that explosive activity took place within the Elbrus volcanic center approximately 900 ka ago. Previously, one of the authors of this work obtained the K–Ar age of 800 ± 150 ka (Table 1) [13] for trachyandesite sample taken by A.M. Borsuk from the periphery of the Elbrus center in the Khudes River basin, where Quaternary volcanism is manifested. It is worth mentioning that the above work also presents the K–Ar age of 850 ± 250 ka for andesidacite dike cutting granodiorites of the Teplin Pluton. These data demonstrate that the ancient (approximately 900 ka ago) stage of Quaternary magmatism was manifested not only in the Elbrus area but also within the entire Greater Caucasus.

The significant temporal interval (more than 0.5 Ma) between pyroclastic rocks and lava flows of the Mount Elbrus suggests that the explosive activity was not directly related to the activity of the Elbrus Volcano. Besides, the existence of the Elbrus Volcano over such a long period (more than 800 ka) is hardly probable, since the life period of even very large and multievent volcanoes generally does not exceed a few hundreds of thousand years [14, 15]. It is quite possible that a Quaternary explosive center (paleoElbrus) or some explosive centers functioned over a short period in the study region in the latest Eopleistocene–initial Neopleistocene.

The comparison of age estimates for several recent volcanic centers of the Kazbek volcanic province [4] and the Elbrus volcanic center testify to a practically synchronous volcanism in these regions, suggesting, in particular, a common source for recent volcanism in the Greater Caucasus. The Neogene age has been determined neither for the Elbrus volcanic center nor for the Kazbek province. The available data indicate that the study region witnessed volcanic activity only during the Quaternary Period, and it was most active during the middle Neopleistocene and latest Neopleistocene. However, the Elbrus center and Kazbek province were probably somewhat different in terms of the scenario of volcanic activity. For example, we have not obtained datings of the order of 450 ka, which correspond to the first stage of the Kazbek Volcano activity [4], for lava flows in the Elbrus center. At the same time, isotope-geochronological data suggest that the Elbrus center witnessed explosive volcanic activity approximately 900 ka ago, which is not registered within the Kazbek province.

Thus, based on K–Ar datings of the groundmass of volcanic rocks, we have deciphered two major stages of magmatic activity in the Elbrus volcanic center with the following time intervals: 180–225 ka (middle Neopleistocene) and <70 ka (late Neopleistocene–Holocene). These stages were synchronous with major stages of magmatic activity in several other recent volcanic cen-

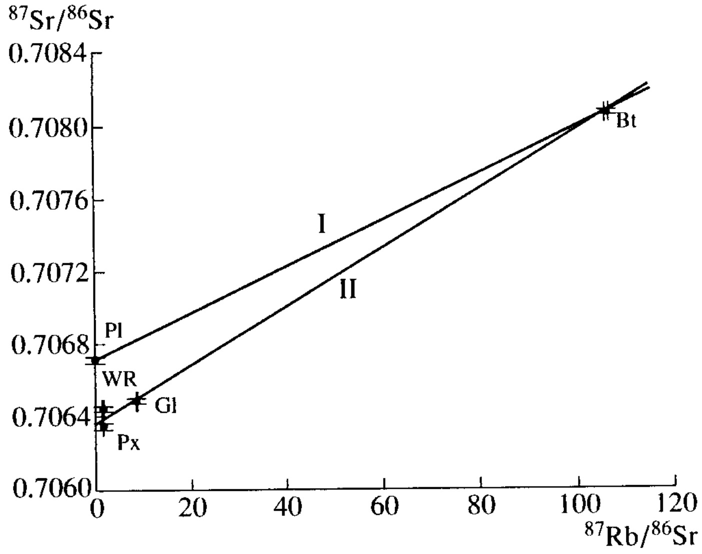

Fig. 2. Rb–Sr isotope diagram for components and whole-rock ignimbrite sample Bt-12. (I) Biotite–plagioclase, $t = 910 \pm 15$ ka, $(^{87}Sr/^{86}Sr)_0 = 0.7067 \pm 3$; (II) biotite–glass, $t = 1150 \pm 20$ ka, $(^{87}Sr/^{86}Sr)_0 = 0.70635 \pm 2$. (Bt) Biotite, (Pl) plagioclase, (Gl) glass, (Px) pyroxene, (WR) whole-rock.

ters of the Greater Caucasus (Kazbek, Keli, and others). The K–Ar data reported in this work (with allowance made for the cited errors) and earlier radiocarbon data [10] point to the possibility of modern activity in the Elbrus Volcano region and support its assignment to the category of hazardous volcanoes. The latest volcanic activity within the Elbrus volcanic center commenced approximately 900 ka ago (Eopleistocene–Neopleistocene boundary).

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