Doklady Earth Sciences, Vol. 393A, No. 9, 2003, pp. 1323–1328. Translated from Doklady Akademii Nauk, Vol. 393, No. 6, 2003, pp. 802–808.

GEOCHEMISTRY

The Samsari Volcanic Center as an Example of Recent Volcanism in the Lesser Caucasus: K–Ar Geochronological and Sr–Nd Isotopic Data

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Received July 11, 2003

New possibilities provided by the isotopic geochronology, particularly the K–Ar method, open up fresh opportunities for deciphering the history of both individual Quaternary volcanoes and large neovolcanic zones from their early (several million to hundreds of thousands of years) to recent (<50 ka) development stages. The use of the K–Ar method for reconstructing Quaternary volcanism is of importance because it allows probable volcanic reactivation to be predicted for particular areas. One of the main aspects of this problem is the identification of volcanic centers where eruptions occurred in the last several thousand years and the highest potential volcanic danger is still present.

This paper is devoted to K–Ar dates and results of the study of Sr–Nd isotopic systematics, which allowed us to qualify the Samsari volcanic center, one of the known centers in the Lesser Caucasus localized within the synonymous ridge, as a center of recent volcanism and date stages of its magmatic activity.

According to present-day geodynamic reconstructions, Neogene–Quaternary magmatism of the Lesser Caucasus occurred at the stage of "rigid" collision between the Eurasian and Arabian lithospheric plates [1]. The activity of the Samsari volcanic center is related to the activity of the synonymous deep fault confined to the central part of the Transcaucasian transverse uplift.

The Samsari Ridge (Fig. 1) is located in the central part of the Dzhavakheti Highland in southern Georgia. It extends almost in the N–S direction from the southern slopes of the Trialeti Ridge in the north to the Paravani River valley, enveloping the Samsari Ridge as a semicircle in the south. Volcanic edifices merging at the bases form a virtually continuous mountain chain 35–40 km long. The total number of volcanoes in the Samsari Ridge exceeds 20. The largest of them are the following (from north to south): Tavkvetili, Beberiklde (Egoisar), Shavnabada, Samsari Caldera (approximately 10 km across), Kerogly, Godorebi, Didi-Abuli, Patara-Abuli, and Eshtia. Many volcanoes are complicated by lateral fissure eruptions. The average height of summits on the watershed ranges from 2500 to 3000 m. The highest of them are Mounts Didi-Abuli (3300 m) and Samsari (3284 m). The lower western ridge is separated from the main ridge by an intermontane depression and characterized by a relatively gentle topography. The basement of the Samsari Ridge is composed of Cretaceous–Paleogene volcanosedimentary rocks locally exposed in erosion windows. In the northern area, these rocks make up the Trialeti Ridge marked by the approximately latitudinal (general Caucasian) strike.

Up to recently, following Skhirtladze [2], almost all volcanics of the Samsari Ridge were attributed to the upper Miocene Goderdzi Formation, which is widely exposed in the neighboring Erushet–Arsian Highland [3]. Exceptions were the Tavkvetili and Godoberi volcanoes and several fissure lava flows on slopes of the Samsari Ridge, which were united into the so-called Quaternary Kechut Formation based on their geomorphological features.

In our recent paper [4], we presented first reliable K–Ar data on dacitic volcanics of the Dzhavakheti Highland, which should help in solving some problems of the stratigraphic subdivision of volcanic sections in this region.

In terms of composition, virtually all examined volcanics of the Samsari Ridge correspond to dacites. According to their petrographic properties, dacites of the Samsari Ridge can be subdivided into several groups. Rocks of the Didi-Abuli volcanic edifice, ring ridge encircling the Samsari Caldera, and the Shavnabada Volcano base universally contain phenocrysts of plagioclase (usually andesine) and basaltic hornblende. Phenocrysts in andesite-dacite lava flows on slopes of these volcanoes are mainly represented by orthopyroxenes and quartz xenocrysts. Mount Babakhngo (western branch of the Samsari Ridge) is composed of

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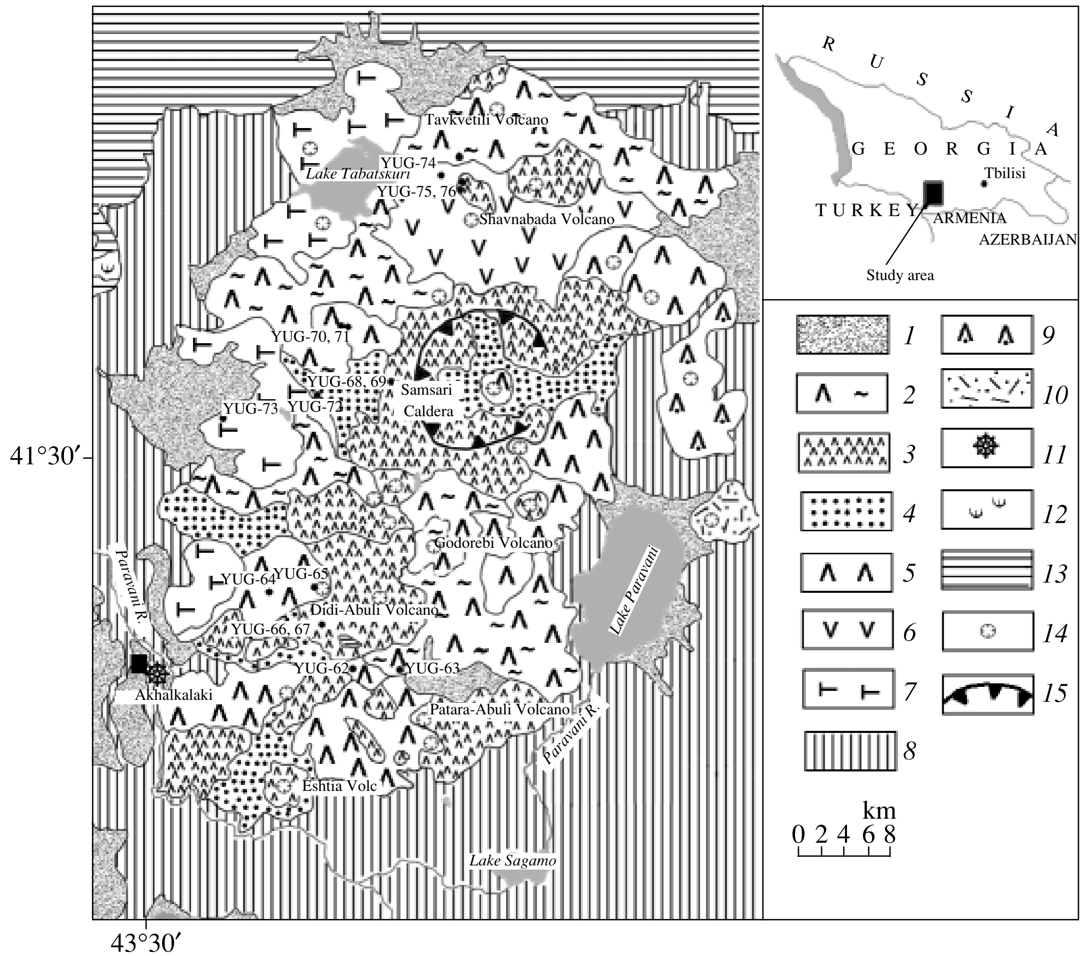

Fig. 1. Schematic geological map of the Samsari volcanic center (based on geochronological data obtained and available geological maps of the area). (*1*) Quaternary sediments; (*2*) volcanics of phase IV in the Samsari center (hyalodacites from the Tavkvetili, Godoberi, and other volcanoes); volcanics of phases II and III in the Samsari center: (*3*) amphibole–plagioclase dacites of volcanoes in of the Samsari Ridge, (*4*) pyroclastic rocks of volcanoes in the Samsari Ridge, (*5*) pyroxene–plagioclase dacite lava flows of volcanoes in the Samsari Ridge, (*6*) pyroxene–plagioclase andesite lava flows of volcanoes in the Samsari Ridge; (*7*) volcanics of phase I in the Samsari center: two-pyroxene–amphibole–plagioclase dacites of the western branch of the Samsari Ridge; (*8*) basalts, basaltic andesites, and andesites of the Akhalkalaki Formation (N_2); (*9*) dacites of the Dzhavakheti Ridge (N_2); (*10*) rhyolites, obsidians, and perlites of the Chikiani Volcano (N_2); (*11*) dacites of the Amiranisgora extrusion (N_2); (*12*) volcanics of the Goderdzi Formation ((N_1^3)); (*13*) Cretaceous–Paleogene volcanosedimentary rocks; (*14*) volcanic craters; (*15*) caldera.

the two-pyroxene–amphibole–plagioclase variety of dacites. The groundmass of these rocks is characterized by a fluidal, less commonly hyalopilitic or pilotaxitic texture. It consists of partly or completely crystallized volcanic glass. The most common minerals in the groundmass are plagioclase and magnetite, sometimes accompanied by hornblende or pyroxenes. All examined rocks belong to the calc-alkaline series. More detailed petrogeochemical characteristics of volcanics from the Samsari Ridge are given in [2, 4].

The applied modification of the K–Ar method was elaborated at the Institute of Geology of Ore Deposits, Petrogrophy, Mineralogy, and Geochemistry (IGEM RAS) specially for the study of recent volcanics and was previously used for dating young lavas from the Kazbek area and several other large Quaternary volcanic centers of the Caucasus and Transbaikal regions [5–7]. The K–Ar dating of volcanics and measurement of $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ values were performed using only the rock groundmass separated from phenocrysts. The isotopic analysis of Sr and Nd was carried out using a Micromass Sector-54 multicollector mass spectrometer. The error of $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ measurements did not exceed 0.003 and 0.002%, respectively.

Table 1 presents the K–Ar data obtained for the rocks from Samsari Ridge. Let us consider the data on individual volcanoes.

The Didi-Abuli Volcano. The oldest rocks of the Didi-Abuli Volcano (approximately 400 ka) are observed as dacitic lava flows with platy jointing on a small lava range in the Mount Chukhurnir area north of

Table 1. Results of the K–Ar dating of rocks from the Samsari volcanic center

Sample no.	K, % (±σ)	$^{40}Ar_{rad}$, ng/g (±σ)	$^{40}Ar_{air}$, % in sample	Age, ka (±1.6σ)
Didi-Abuli Volcano				
YUG-62	2.06 ± 0.02	0.041 ± 0.003	92.4	290 ± 30
YUG-64	1.92 ± 0.02	0.054 ± 0.002	79.1	410 ± 30
YUG-65	2.15 ± 0.02	0.048 ± 0.002	83.0	320 ± 30
YUG-66	1.90 ± 0.02	0.037 ± 0.004	97.5	280 ± 60
YUG-67	1.71 ± 0.02	0.029 ± 0.004	98.4	240 ± 60
Samsari Caldera				
YUG-68	1.68 ± 0.02	0.021 ± 0.004	99.0	180 ± 70
YUG-69	1.74 ± 0.02	0.029 ± 0.005	99.0	240 ± 70
YUG-70	1.71 ± 0.02	0.024 ± 0.002	89.7	200 ± 40
YUG-71	1.70 ± 0.02	0.025 ± 0.001	83.7	210 ± 20
YUG-72	1.70 ± 0.02	0.023 ± 0.005	95.8	200 ± 40
Shavnabada Volcano				
YUG-74	1.76 ± 0.02	0.021 ± 0.003	97.2	170 ± 50
YUG-75	1.92 ± 0.02	0.039 ± 0.001	97.1	290 ± 60
YUG-76	1.66 ± 0.02	0.037 ± 0.004	98.1	320 ± 70
Godorebi Volcano				
YUG-63	1.89 ± 0.02	0.003 ± 0.003	99.7	30 ± 30
Tavkvetili Volcano				
YUG-77	1.63 ± 0.02	n.a.	100.0	<30
Babakhngo Volcano				
YUG-73	1.68 ± 0.02	0.089 ± 0.009	91.4	760 ± 80

Note: (YUG-62) Pyroxene–plagioclase dacite from the lava flow of the Didi-Abuli Volcano; (YUG-63) hyalodacite from the lava flow of the Godorebi Volcano; (YUG-64) pyroxene–plagioclase dacite from the southern lava flow of the Didi-Abuli Volcano (Buzaveti Settlement area); (YUG-65) pyroxene–plagioclase dacite from the Pungartepe parasitic volcanic center on the western slope of the Didi-Abuli Volcano; (YUG-66, YUG-67) amphibole–plagioclase dacite from the Didi-Abuli Volcano; (YUG-68, YUG-69) amphibole–plagioclase dacite from the ring ridge of the Samsari Caldera (Pampule Ridge); (YUG-70, YUG-71) postcaldera pyroxene–plagioclase dacite from the Samsari Volcano; (YUG-72) dacite from pyroclastic sequence of the Samsari Volcano; (YUG-73) two-pyroxene–amphibole–plagioclase dacite from Mount Babakhngo (western branch of the Samsari Ridge); (YUG-74) pyroxene andesite from lava flow of the Shavnabada Volcano; (YUG-75, YUG-76) amphibole–plagioclase dacite from the base of the Shavnabada Volcano; (YUG-77) hyalodacite from the Tavkvetili Volcano.

Buzaveti (sample YUG-64). The Didi-Abuli volcanic edifice, as well as lava flows on its southern slopes and the parasitic Pungartepe volcanic center, formed at a later stage approximately 320–250 ka ago (samples YUG-62, YUG-65–YUG-67). No younger data were obtained. Thus, the total duration of the active period for the Didi-Abuli Volcano together with its lateral craters did not exceed 150 ka.

The Samsari Caldera. The K–Ar age of the Samsari Caldera is approximately 200 ka (samples YUG-68, YUG-69). The caldera undoubtedly formed at the site of a former large volcanic edifice similar to the Didi-Abuli Volcano, although precaldera rocks have not been found so far. Pyroclastic sequences exposed near Samsari in the Megreki River valley (sample YUG-72), which are synchronous to rocks of the caldera ring ridge (200 ka), accumulated probably at the caldera stage. Lava flows of the Pampule Ridge (samples YUG-70, YUG-71), which are attributed to postcaldera rocks and also dated at 200 ka, probably erupted immediately after the formation of the caldera. The Kyzyldag Volcano located in the central part of the caldera and several subsidiary volcanic craters (Karakuzei and others) on slopes of its ring ridge can likely be attributed to the postcaldera stage of Samsari Volcano development as well.

The Shavnabada Volcano. Based on two available dates (samples YUG-75, YUG-76), rocks of the base of the Shavnabada Volcano exposed in some erosion windows on its northern slopes are approximately 300 ka old. Younger andesitic lava flows are dated back to 170 ka (YUG-74). Thus, two stages are outlined in the Shavnabada Volcano development. The first stage (approximately 300 ka) was marked by the activity of the old volcano, which was subsequently eroded. The second stage started after an interval of more than 100 ka with

Table 2. The Sr–Nd isotopic characteristics of rocks from the Samsari volcanic center

Sample no.	Rb, ppm	Sr, ppm	$^{87}Sr/^{86}Sr \pm 2\sigma$	Nd, ppm	$^{143}Nd/^{144}Nd \pm 2\sigma$	$\varepsilon_{(Nd)_0}$
YUG-62	41	525	0.704168 ± 16	28	0.512831 ± 10	3.8
YUG-63	41	609	0.704124 ± 17	26	0.512770 ± 13	2.6
YUG-64	60	513	0.704274 ± 15	22	0.512783 ± 16	2.8
YUG-65	64	499	0.704297 ± 16	20	0.512848 ± 9	4.1
YUG-66	52	559	0.704117 ± 17	17	0.512874 ± 10	4.6
YUG-67	48	578	0.704434 ± 17	20	0.512811 ± 12	3.4
YUG-68	45	610	0.704053 ± 15	17	0.512874 ± 13	4.6
YUG-69	43	647	0.704076 ± 14	17	0.51283 ± 6	3.7
YUG-70	51	630	0.704050 ± 15	16	0.512725 ± 27	1.7
YUG-71	51	646	0.704054 ± 14	16	0.512752 ± 20	2.2
YUG-72	51	590	0.704060 ± 15	17	0.51269 ± 9	1.0
YUG-73	38	561	0.704161 ± 15	18	0.512786 ± 10	2.9
YUG-74	42	580	0.704046 ± 14	23	0.51278 ± 4	2.8
YUG-75	54	613	0.704089 ± 13	16	0.512711 ± 26	1.4
YUG-76	32	611	0.704041 ± 14	20	0.51286 ± 9	4.3
YUG-77	50	546	0.704116 ± 15	20	0.51272 ± 6	1.6

Note: Sampling sites and sample characteristics are given in notes to Table 1. The Rb and Sr contents are determined by the X-ray fluorescence method at IGEM RAS using a Philips PW 2400 spectrometer; the Nd content, by the method of isotopic dilution using a Micromass Sector-54 mass spectrometer. The rock groundmass was analyzed.

the activity of a newly formed crater, which erupted lavas of a more basic composition as compared with the older volcano.

The Tavkvetili Volcano. Hyalodacitic lava flows on volcano slopes are characterized by a fresh surface unaltered by glaciers. The volcano summit represents a well-preserved crater. A very young age of the Tavkvetili Volcano, which is evident from these geomorphologic features, is confirmed by our date of <30 ka obtained for sample YUG-77. The volcano and its flows probably appeared during the Late Neopleistocene or even in the Holocene.

The Godorebi lava flow. The K–Ar age value virtually similar to that of the Tavkvetili Volcano (30 ± 30 ka) was obtained for lava flows on the slopes of the Godorebi Volcano (sample YUG-63). These volcanoes were probably formed during the last magmatic episode in the Samsari Ridge.

The Babakhngo Volcano. The K–Ar date obtained for the Babakhngo Volcano (sample YUG-73) located in the western branch of the Samsari Ridge points to its formation in the Early Neopleistocene (800–700 ka). The western volcanic branch presumably formed at the first stage of the Quaternary magmatic activity in the Samsari center during the Late Neopleistocene.

Summing up the K–Ar ages obtained for the Samsari volcanic center, one can draw some conclusions concerning its Quaternary history. The data suggest four phases of volcanic activity separated by prolonged passive periods: (I) Early Neopleistocene (approximately 800–700 ka ago); (II) Early–Middle Neopleistocene (approximately 400 ka ago); (III) Middle Neopleistocene (320–170 ka ago); and (IV) Late Neopleistocene–Holocene (less than 50 ka ago). The first phase was marked by the formation of volcanoes in the western branch of the Samsari Ridge. Old flows of the Didi-Abuli Volcano formed during the second phase. The commencement of phase III (320–250 ka) is related to the activity of the Didi-Abuli Volcano and its parasitic craters, the old Shavnabada Volcano and, probably, the extinct Samsari Volcano, and several other craters in the Samsari Ridge. The formation of the Samsari Caldera and young Shavnabada Volcano was accompanied and the eruption of postcaldera lavas took place approximately 200 ka ago. Phase IV of the volcanic activity was less manifested in the Samsari center and resulted in the formation of the Tavkvetili, Godorebi, and, probably, some others volcanoes. It is highly probable, however, that the last phase has not terminated and volcanic activity may be recommenced in the study region. Therefore, the Samsari Ridge should be considered a region potentially hazardous with respect to volcanic activity. No correlation between the chemical composition of rocks and their age is observed, suggesting a constant generation of magmatic melts in deep-seated chamber during the last hundreds of thousands of years.

Comparison of the aforementioned geochronological data with previous dates obtained for several volcanic areas of the Caucasus [5, 6] shows that phases II, III, and IV of magmatic activity in the Samsari center were

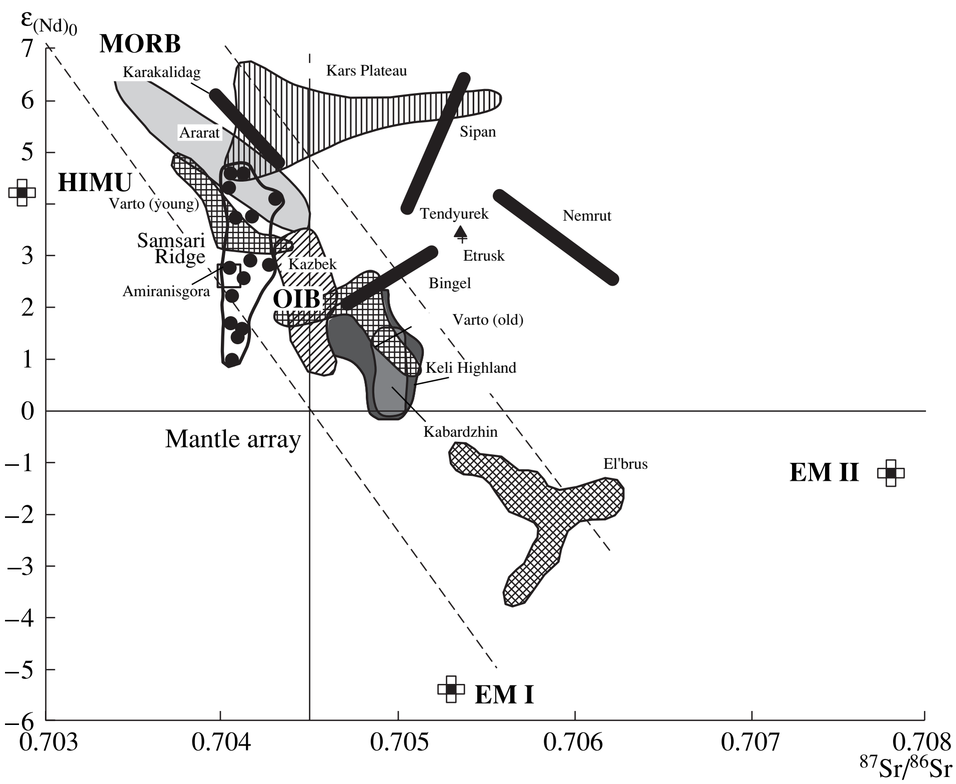

Fig. 2. Isotopic correlation diagram ($^{87}Sr/^{86}Sr)_0$–$\varepsilon_{(Nd)_0}$ for Quaternary volcanics of the Samsari Ridge and some young volcanic centers of the Greater Caucasus and eastern Anatolia. Data on volcanics of the Greater Caucasus and eastern Anatolia are adopted from [10] and [8, 9], respectively.

virtually synchronous with phases I, II, and III in the Kazbek neovolcanic area and Elbrus center. However, no volcanic manifestations younger than 500 ka are registered for the Aragats area located south of the Dzhavakheti Highland. Phase III (approximately 700 ka), when the Aragats Volcano formed, is synchronous with phase I in the activity of the Samsari center [7].

The study of the Sr–Nd isotopic–geochemical systematics in volcanics of the Samsari Ridge demonstrated that all examined rocks are characterized by elevated Sr contents (approximately 500–600 ppm) relative to clarke values. The Rb and Nd concentrations are typical of dacites (Table 2). The $^{87}Sr/^{86}Sr$ value varies from 0.70404 to 0.70443 and the range is even narrower for 13 of 16 samples (0.70404–0.70417). In contrast, the isotopic Nd composition in examined volcanics is substantially different. The $\varepsilon_{(Nd)_0}$ value varies from +1.0 to +4.6. No correlation between changes in Rb and Sr concentrations, as well as $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios, on the one hand, and the age of samples and the SiO_2 content in them, on the other hand, is observed. There is also no correlation between isotopic parameters $^{87}Sr/^{86}Sr$ and $\varepsilon_{(Nd)_0}$. In the Sr–Nd isotopic correlation diagram (Fig. 2), the distribution of data points of volcanics from the Samsari center implies the decisive role of mantle matter in the genesis of these rocks with an insignificant share of the crustal component. The substantial heterogeneity of the Nd isotopic composition in examined rocks can be explained by the contamination of mantle melts by sialic material with different petrochemical characteristics and ages. Most likely, these rocks could be represented by Cretaceous–Paleogene volcanics and Paleozoic granitoids exposed in the eastern part of the Dzhavakheti Highland (Khrami and Loki massifs). Contamination of melts by crustal material did not result in a substantial transformation of the Sr isotopic composition and its variations in dacite lavas, probably because of the high Sr content in parental magma. However, one can suggest with a high degree of confidence that interaction with crustal rocks, which were characterized by similar or, probably, higher Nd contents relative to parental magma of the Samsari volcanic center, could be responsible for the heterogeneity of the Nd isotopic composition in examined volcanics.

Comparison of isotopic parameters in examined volcanics with published data on other volcanic zones of the Caucasian region shows that volcanics of the Samsari center are characterized by average Nd isotopic values, while the Sr isotopic composition in them is less radiogenic (Fig. 2) [8–10]. Similar Sr and Nd isotopic characteristics were previously obtained for the

Pliocene Amiranisgora extrusion located west of the Samsari Ridge [4].

Thus, the isotopic–geochronological data obtained reveal a large center of Late Quaternary volcanism in southern Georgia–Samsari volcanic center), with its main development phases corresponding to phases of magmatic activity previously defined for other areas of neovolcanic activity in the Caucasus region. According to these data, the youngest volcanic events occurred in the terminal Neopleistocene–Holocene, which makes this region potentially hazardous with respect to future volcanic activity.

ACKNOWLEDGMENTS

This work was supported by the Russian Science Support Foundation, the Russian Foundation for Basic Research (project nos. 02-05-64082 and 03-05-06197), the Ministry of Industry, Science, and Technology of the Russian Federation (contract no. 43.043.11.1603), and Presidium of the Russian Academy of Sciences (Program 13 of Fundamental Research, Theme 2).

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