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GEOCHEMISTRY

Geochronology of Neogene–Quaternary Volcanism of the Geghama Highland (Lesser Caucasus, Armenia)

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This work continues the systemic isotopic–geochronological studies of Late Cenozoic volcanism in the Lesser Caucasus [1–5] undertaken to elaborate the general regional scale of magmatic activity in this region during the Neogene–Quaternary and to establish neovolcanic centers potentially hazardous in terms of possible catastrophic eruptions.

The young magmatism in the Caucasian segment of the Alpine belt that developed in the course of collision between the Eurasian and Arabian lithospheric plates is genetically related to the activity of the mantle "hot field" [6], which determined the prevalence of basic rocks among volcanics. The most intense pulses of volcanic activity during the Neogene–Quaternary are recorded in the Lesser Caucasus and eastern Anatolia, while young igneous rocks are distributed only in small areas of the Greater Caucasus.

The Lesser Caucasus volcanic province, which extends in the arcuate manner from Ajaria to Nagornyi Karabakh and includes abundant Neogene–Quaternary volcanics [7], is divided into six neovolcanic areas (from the northwest to southeast): Erusheti–Arsiani, Javakheti, Aragats, Geghama, Vardenis, and Syunik. Young volcanics of the Lesser Caucasus are highly variable in terms of their chemical composition with varieties of normal and elevated alkalinity being most abundant.

Our previous studies [1–5] provided ages for Neogene–Quaternary igneous rocks from several reference volcanic centers of the Aragats and Javakheti areas. These dates allowed us to define regional geochronological scales for young volcanism. In this work, we consider isotopic–geochronological data obtained for Neogene–Quaternary igneous rocks from the Geghama neovolcanic area located in the territory of the Republic of Armenia.

The Geghama neovolcanic area is localized within the synonymous highland in the central part of the Lesser Caucasus. The field of Neogene–Quaternary volcanics is bordered by Lake Sevan in the east, the Razdan River valley in the north and west, and the Eranos Ridge (Cretaceous–Paleogene volcanosedimentary rocks) and Argichi River valley in the south (figure).

The specific feature of the Geghama neovolcanic area is determined by Quaternary volcanism that is atypical for the entire Caucasian region. In contrast to other regions of the Greater and Lesser Caucasus, where the Quaternary stage of young volcanism is marked by the formation of large stratovolcanoes, such as El'brus, Aragats, and Kazbek, the Gegan Highland (approximately 200 km^2 in size) was characterized by the appearance of approximately 100 autonomous (largely monogenic) explosive volcanic centers that erupted mainly basaltic trachyandesites and trachyandesites at that time (figure).

According to recent views on the geological structure of the Geghama area [8], intermediate and acid rocks of the Kaputan Formation of the Late Miocene based on geological and previous K–Ar age estimates (7–5 Ma) [9] are considered to be oldest formations in the study area. In the Late Pliocene, flow units of olivine subalkaline basalts and basaltic trachyandesites formed in the Geghama area. Unlike other neovolcanic areas of the Lesser Caucasus, they are characterized by limited distribution in the Geghama Highland. In this area, the Quaternary was marked by the formation of volcanoes characterizing the Kotayk center (Atis, Gutansar, and others) in the Geghama Highland. Their products are largely represented by obsidian lavas and rhyolitic perlites. Subsequently, numerous cinder and volcanic cones appeared in the Geghama center (water-

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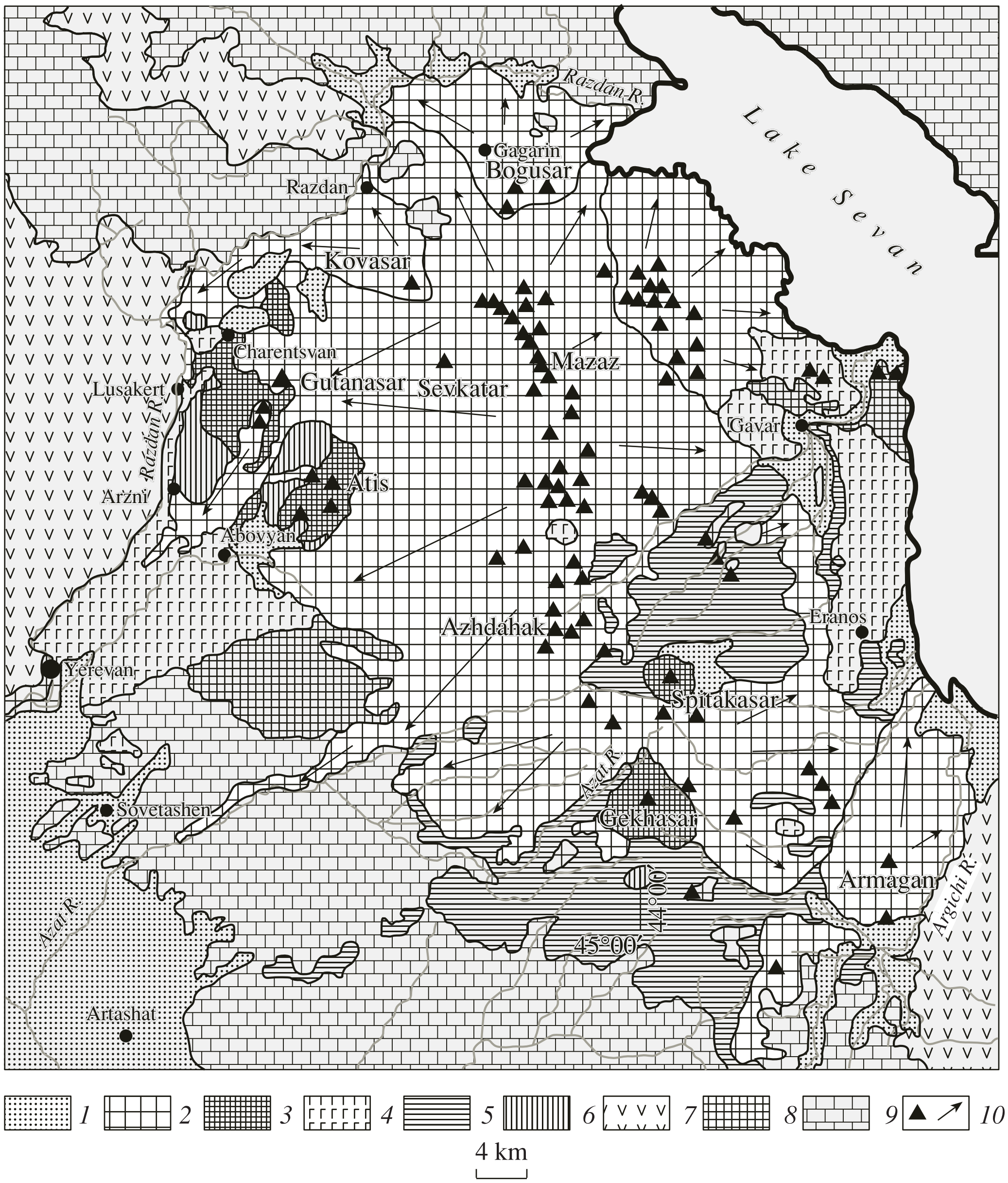

Schematic geological map of the Geghama volcanic highland. (*1*) Quaternary sediments; (*2*) Quaternary trachyandesite–basaltic andesite lavas of the Geghama Highland; (*3*) Quaternary rhyolite–obsidian volcanoes; (*4*) Late Pliocene plateau basalts and pyroclastic sediments; (*5*) andesite–dacite lavas and pyroclastic sediments of the Geghama Formation (Pliocene?); (*6*) trachyandesite–andesite lavas of the Kaputan Formation, rhyodacite dikes, and rhyolitic extrusions (Late Miocene); (*7*) Neogene–Quaternary volcanics of the Aragats and Vardenis neovolcanic areas; (*8*) Neogene sedimentary and volcanogenic–detrital sequences; (*9*) basement rocks; (*10*) Quaternary volcanoes and movement directions of lava flows.

shed ridge of the highland and eastern coast of Lake Sevan) and erupted largely basic lavas.

We carried out isotopic dating of rocks from the Geghama Highland that characterize different stages in the development of young volcanism (table). The applied modification of the K–Ar method was developed in the IGEM RAS especially for the study of young igneous rocks. It is described in detail in [10].

The data obtained made it possible to establish that lavas of the Kaputan Formation, the oldest among young volcanics of the area, erupted 5.7 to 4.6 Ma ago. It should be noted that both the flow unit and their subvolcanic bodies have been dated. Rocks constituting the main part of the Kaputan Formation in the Akunk, Kaputan, and Atis areas are largely represented by trachyandesites. Plagioclase (labradorite) and clinopyroxene (diopside) form typical paragenesis in phenocrysts. In some volcanic varieties, they are accompanied by biotite-bearing amphibole (kaersutite) or olivine. The rock groundmass is usually composed of plagioclase

K–Ar ages of Neogene–Quaternary igneous rocks from the Geghama neovolcanic area

Sample	K, % ± σ	$^{40}Ar_{rad}$, ng/g ± σ	$^{40}Ar_{rad}$, % (sample)	Age, Ma ± 2σ
Late Miocene volcanics				
10G	1.42 ± 0.02	0.465 ± 0.006	43.0	4.70 ± 0.17
11G	1.95 ± 0.02	0.710 ± 0.006	72.5	5.25 ± 0.14
12G	1.85 ± 0.02	0.730 ± 0.007	57.4	5.65 ± 0.16
20aG	3.44 ± 0.04	1.090 ± 0.003	2.4	4.55 ± 0.11
20bG	3.45 ± 0.04	1.160 ± 0.006	24.2	4.85 ± 0.12
22G	2.16 ± 0.03	0.700 ± 0.003	25.8	4.65 ± 0.14
27G	3.33 ± 0.04	1.160 ± 0.007	24.4	5.00 ± 0.13
Pliocene volcanics				
1G	1.79 ± 0.02	0.330 ± 0.003	76.0	2.62 ± 0.07
Quaternary volcanics				
2G	1.82 ± 0.02	0.009 ± 0.002	97.8	0.07 ± 0.04
9G	2.09 ± 0.03	0.012 ± 0.003	97.1	0.08 ± 0.04
8G	1.98 ± 0.02	0.022 ± 0.002	96.7	0.16 ± 0.03
32G	2.47 ± 0.03	0.027 ± 0.003	91.3	0.16 ± 0.03
30G	2.15 ± 0.03	0.027 ± 0.003	97.6	0.18 ± 0.04
26G	3.28 ± 0.04	0.110 ± 0.005	58.5	0.48 ± 0.04
33G	2.32 ± 0.03	0.085 ± 0.004	93.7	0.53 ± 0.05
17G	2.06 ± 0.03	0.080 ± 0.003	79.0	0.56 ± 0.05
13G	3.43 ± 0.04	0.156 ± 0.004	89.2	0.66 ± 0.04
24G	3.24 ± 0.04	0.157 ± 0.003	57.9	0.70 ± 0.03

Note: Groundmass was analyzed. Characteristic of examined samples. Late Miocene volcanics: (10G–12G) trachyandesite from the Kaputan Formation, (20aG, 20bG) rhyodacite from dike in the Kaputan Formation, (22G) trachyandesites from the Gtsain Ridge, (27G) rhyolite from the Gyumush extrusive dome; Pliocene volcanics: (1G) basaltic trachyandesite from the Lchain Volcano (Geghama Ridge); Quaternary volcanics: (2G) basaltic trachyandesite from the Aknotsasar Volcano (Geghama Ridge), (8G) trachyandesite from the Lodochnikov Volcano (Geghama Ridge), (9G) basaltic trachyandesite from the Sevkatar Volcano (Geghama Ridge), (13G) rhyolite from the lower member of the Atis Volcano (Kotayk volcanic center), (17G) basaltic trachyandesite from lava flow of the Tekblur Volcano at the slope of Mt. Atis (Kotayk volcanic center), (24G) rhyolite from the Atis Volcano (Kotayk volcanic center), (26G) obsidian from dike (Atis Volcano, Kotayk volcanic center), (30G) trachyandesite from the Noraduz Volcano on the western coast of Lake Sevan, (32G) trachyandesite from the lava flow of the Karapetyan Volcano (Eratumber group of volcanoes), (33G) trachyandesite from the lava flow of Razdan River canyon in Yerevan.

microlites submerged into slightly crystallized glass. Subvolcanic rocks from dikes and extrusions, which intrude trachyandesite sequences, are usually represented by rhyolites and rhyodacites. Plagioclase (labradorite) is a dominant mineral in phenocrysts. In some rocks, it is accompanied by subordinate orthopyroxene (hypersthene) or clinopyroxene (diopside or augite) and less common biotite. The groundmass consists usually of slightly devitrified volcanic glass with submerged plagioclase and biotite microlites, ore minerals, and rare quartz. The rocks of the Kaputan Formation are classed with the calc-alkaline and subalkaline petrochemical series. They contain 58.7–72.4% of SiO_2 and 5.9–9.0% of $K_2O + Na_2O$ with K_2O = 2.1–4.0%.

The K–Ar ages obtained for volcanics of the Kaputan Formation constrained the total duration of Neogene–Quaternary volcanism for the Geghama area (<6 Ma). Our geochronological data also allowed us to refine the viewpoint on the stratigraphic positions of some volcanogenic sequences. For example, lavas of the Gtsain Ridge adjacent to Mt. Atis in the north, which were previously considered as products of Quaternary fissure eruption [8], appear to have erupted during the Miocene–Pliocene transition period (table). In our opinion, these lavas belong to the Kaputan Formation, which outcrops in the immediate proximity. Flow units of clinopyroxene trachyandesites at the southern foothill of Mt. Atis (5.3–5.7 Ma), which were previously considered to represent Late Pliocene plateau basalts [8], also belong to the Kaputan Formation.

The Pliocene stage of volcanic activity (approximately 2.5 Ma ago) in the Geghama area was probably of limited scale. It is characterized by plateau basalts distributed in the Razdan River valley and Elar Gates area. We studied a basaltic trachyandesite sample from the Lchain Volcano near Lake Aknalich in the Geghama Highland (Sample 1G). Phenocrysts in the rock are represented by plagioclase, clinopyroxene, and olivine. The volcanic glass groundmass encloses plagioclase microlites and finely dispersed ore minerals. The basaltic trachyandesite belongs to the subalkaline series. It contains 51.2% of SiO_2 and 6.0% of K_2O+Na_2O with K_2O = 1.9%.

According to our data, the calm period lasted for 1 Ma. This period was followed by the resumption of volcanic activity in the Geghama Highland in the Quaternary (approximately 0.7 Ma ago). Our K–Ar data indicate four phases of volcanic activity: (I) approximately 700 ka ago, (II) 550–480 ka ago, (III) around 200 ka ago, and (IV) less than 100 ka ago. By the age and composition of the erupted rocks, phases I and II of volcanism in the Geghama Highland correlate well with defined phases II and III in activity of the Aragats volcanic center located west of the study area near the Aragats center [1].

Phase I, manifested locally in the Kotayk volcanic center in the western Geghama area, was marked by the formation of the Atis and Gutansar volcanoes. The composition of obsidian and aphyric lavas in these edifices corresponds to calc-alkaline rhyolites.

Phase II of neovolcanic activity commenced approximately 150–200 ka later. Similar to the previous phase, it is also manifested only in the Kotayk volcanic center. The volcanic activity during this phase acquired a regional character, and the composition of lavas changed simultaneously from rhyolite to subalkaline trachyandesites and basaltic trachyandesites. Eruption of basic lavas from fissure volcanoes located at slopes of the Atis and Gutansar volcanoes (Tekblur, Kharamblur, Tekh, Tsakhkot, and others) and the formation of the lava flow in the Razdan River valley near Yerevan occurred also during this phase (table). Plagioclase and olivine represent typical paragenesis in porphyric varieties of examined rocks. The groundmass of volcanics consists of partly crystallized glass with microlites of plagioclase and clinopyroxene. Trachyandesites and basaltic trachyandesites from the Kotayk center are classed with subalkaline series. They contain 54.3–56.9% of SiO_2 and 6.8–7.1% of K_2O+Na_2O with K_2O = 2.5–2.7%. The terminal pulse of phase II was marked by intrusion of small obsidian dikes (sample 26G) that crosscut acid volcanics produced by volcanoes of the Kotayk group.

The peak of volcanic activity likely corresponded to the period of approximately 200 ka ago (phase III). It is reflected in the formation of most volcanoes in the Geghama volcanic center of the eponymous highland, as well as volcanoes of the Eratumber group and western coast of Lake Sevan (table). Phase III is most productive with respect to erupted material and the formation of volcanic edifices. Its rocks are represented by trachyandesites and basaltic trachyandesites. In porphyric varieties, plagioclase (labradorite) and olivine are dominant minerals accompanied frequently by clinopyroxene. The groundmass is composed of crystallized glass with submerged plagioclase, rare clinopyroxene, and olivine microlites. All the examined rocks are subalkaline. They contain 54.5–57.9% of SiO_2 and 5.9–6.7% of K_2O + Na_2O with K_2O = 2.0–2.8%.

The terminal phase (IV) was marked by the activity of some volcanoes in the Geghama center (watershed ridge), the Aknotsasar and Sevkatar volcanoes included. In chemical composition, their lavas correspond to basaltic trachyandesites. Phenocrysts are represented by olivine, plagioclase (labradorite), and rare clinopyroxene. The groundmass is composed of volcanic glass with plagioclase microlites and grains of pyroxene and olivine. The rocks are classed with the subalkaline series and contain 54.5–55.2% of SiO_2 and 6.1–6.7% of K_2O + Na_2O with K_2O = 2.0–2.5%. The age of volcanics erupted during phase IV is estimated at <100 ka.

Thus, the performed studies made it possible to estimate the total duration of young volcanism in the Geghama Highland (<6 Ma) and outline stages of magmatic activity: 5.7–4.6 Ma, ~2.5 Ma, and 700–<100 ka ago. The fourth stage includes four main phases of volcanic activity, the last of which occurred in the Late Pleistocene and, probably, Holocene. Since the Geghama center hosts neovolcanic rocks younger than 100 ka, this area of the Lesser Caucasus should be considered as a potentially hazardous one with the possibility of resumption of volcanic activity.

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