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GEOLOGY

The Beginning of Volcanic Activity within Sredinny Metamorphic Massif (Sredinny Range, Kamchatka)[1]

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Abstract—For the first time, the age of the beginning of the volcanic activity within Sredinny metamorphic Massif is determined (7–6 Ma). We suppose that this event was caused by the collision of Kamchatka with the Kronotsk arc that started about 7 Ma from accretion of Shipunsky peninsula. We demonstrate that at least two types of rocks were erupted within Sredinny Range of Kamchatka in late Miocene times: typical island-arc rocks were produced in the central and northern parts of the Range, and hybrid type rocks—in its southernmost part.

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The Sredinny Range (SR) of Kamchatka is a largest volcano-tectonic structure of the peninsula. It consists of two parts: Sredinny Metamorphic Massif (SMM) and a volcanic zone (Fig. 1, inset). SMM (200 × 50 km) is located in the southern part of SR. According to A. V. Soloviev [8], the peak of metamorphic events and subsequent lifting of the metamorphic rocks to the surface took place in the early Eocene (~52–50 Ma). Volcanic zone occupies the central and northern parts of SR. Volcanic rocks are found along 600-km–long profile (from SMM in the south to the Kamchatka isthmus in the north); in its widest part, the volcanic zone exceeds 100 km. Sredinno-Kamchatskaya volcanic arc was formed at the end of the Oligocene–the early Miocene [1, 11]. Late Miocene–Pliocene volcanic rocks of the central and northern parts of SR are represented by typical island-arc rocks, similar to the rocks of the frontal parts of the contemporary arc [14]. Pliocene–Quaternary rocks have a hybrid geochemical signature, combining both island-arc and intraplate affinities [14].

Volcanic rocks, overlapping SMM, are located in its northern part (Khangar caldera) and on the eastern flanks, upstream of the Luntos, Yurtinaya and Levaya Kamchatka rivers (Fig. 1).

This research was aimed at determination of the age of the initiation of volcanic activity within SMM. During the fieldwork in the southern part of Khangar caldera and at the watershed of the Yurtinaya and Levaya Kamchatka rivers (Yurtinaya Mountain), we gathered a representative collection of early volcanic rocks of the area (Fig. 1). The results of K–Ar isotopic dating are presented in the table.

Khangar is located in the northern part of SMM. It is a complex caldera (12 × 6 km), with an active [2] volcano of the same name within it and numerous monogenetic edifices of Middle–Late Pleistocene age.

The effusives of Yurtinaya Mountain (1428.6 m) break through and overlap Cretaceous rocks on the eastern flank of SMM. Morphologically, they are represented by a large remnant of a plateau, composed of a series of megaplagiophyric basaltic andesites lava flows.

The earliest manifestation of the volcanic activity within Khangar caldera is represented by substantially destroyed andesitic lava flows, which overlap Miocene hypabissal granodiorite intrusions, located in the southern parts of the caldera. Early Khangar volcanic rocks differ from the later products of this volcano and from all previously studied SR rocks by the elevated magnesium number, lower concentrations of TiO_2, Al_2O_3, CaO, and P_2O_5 and high Sr/Y ratio (Fig. 2a). The concentrations of major elements in Yurtinaya

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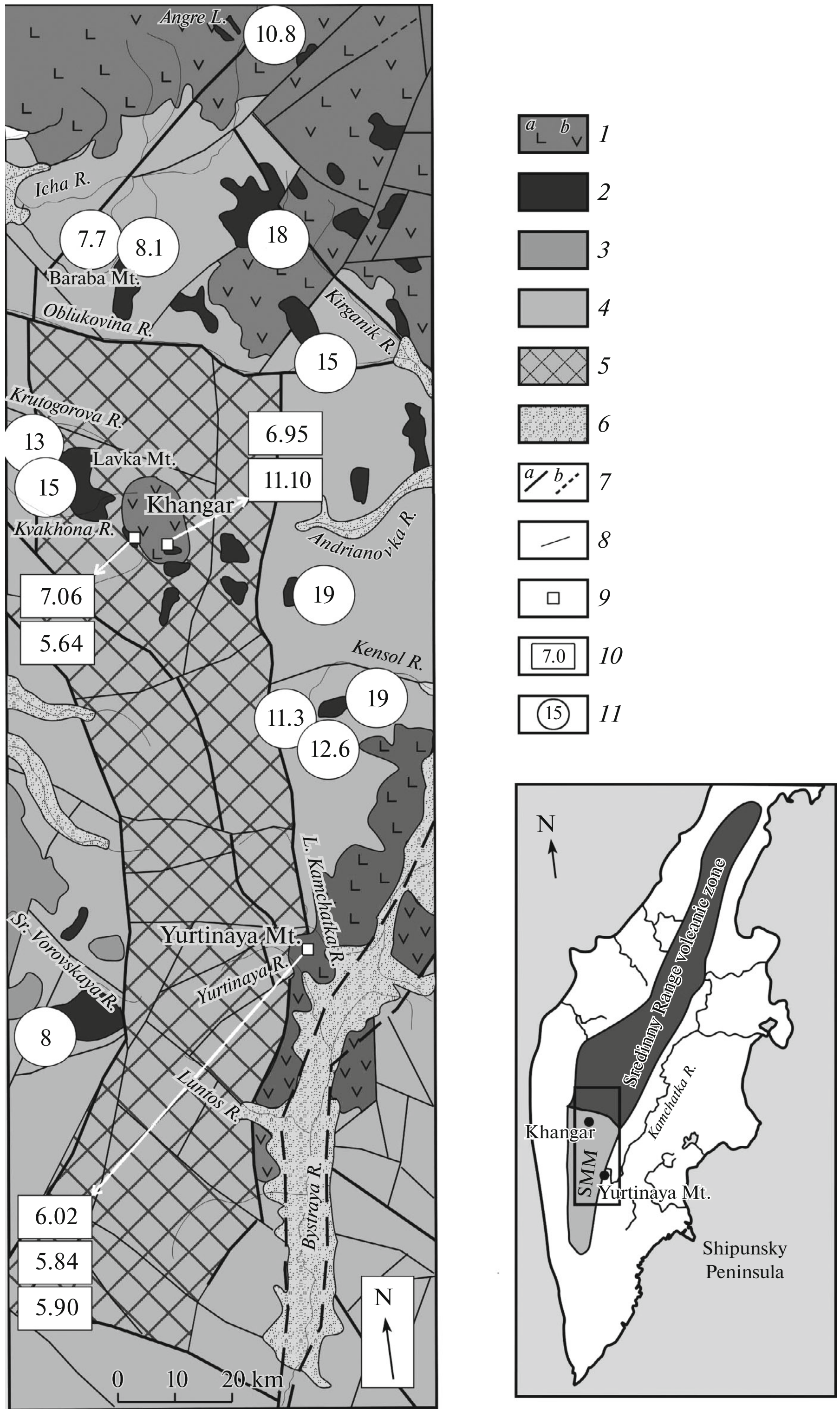

Fig. 1. Geological scheme of the fragment of the southern part of Sredinny Range of Kamchatka, based on [5, 8]. Location of the Sredinny Metamorphic Massif (SMM) and volcanic zone of Sredinny Range on the map of Kamchatka is shown in the inset. *1*, Miocene–Quaternary volcanic rocks: *a*, basic; *b*, acid; *2*, Miocene intrusions; *3*, Paleogene rocks; *4–5*, Cretaceous rocks, *4*, nonmetamorphic, *5*, metamorphic; *6*, Quaternary river deposits; *7–8*, faults: *7*, main structure-forming: *a*, exposed; *b*, hidden beneath the overlaying formations; *8*, secondary; *9*, location of the objects of this study; *10–11*, rounded isotopic (K–Ar) age: *10*, of lavas and intrusions, author's data (see table), *11*, of the intrusions after [3, 4, 6].

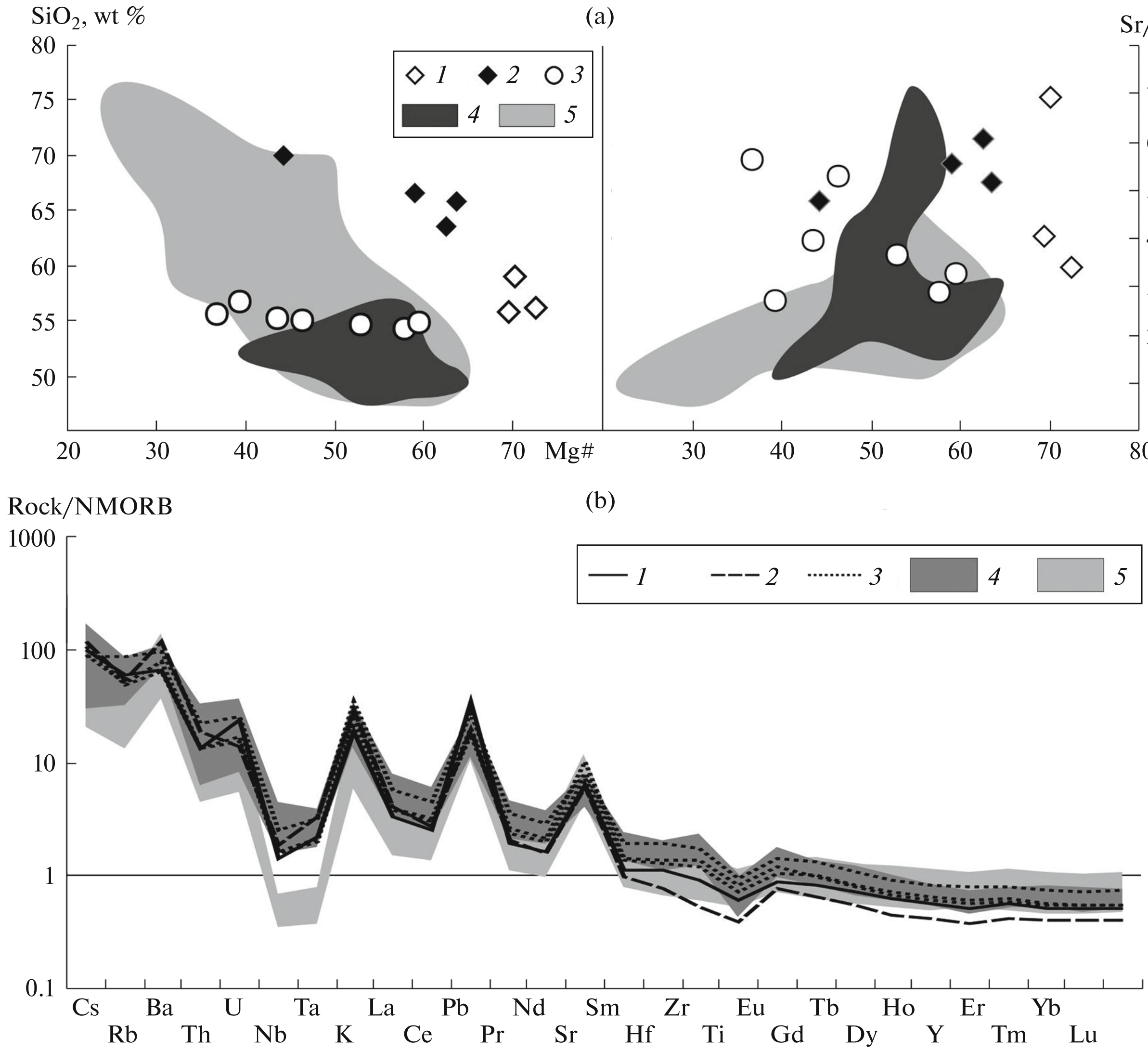

Fig. 2. Distribution of (a) major and (b) microelements in the Miocene rocks of Khangar caldera and Yurtinaya Mountain compared to the previously studied volcanic rocks of the Sredinny Range of Kamchatka. Legend: (a) *1–2*, Khangar caldera rocks: *1*, lavas; *2*, intrusions; *3*, Yurtinaya Mountain rocks; *4–5*, rocks of the northern part of Sredinny Range after [14]: *4*, typical island-arc Neogene rocks; *5*, hybrid type Quaternary rocks and volcanic rocks of Khangar caldera (unpublished data of the authors). Mg# = MgO/(MgO + FeO_{tot}). (b) *1*, sample HNG-12-02, lava; *2*, sample HNG-12-04, intrusion; *3*, Yurtinaya Mountain rocks; *4*, IAB-type rocks of Ichinsky volcano after [10]; *5*, Neogene plateau-effusive rocks of the northern part of Sredinny Range, after [14]. Concentrations of microelements are normalized to N-MORB, after [13].

Mountain rocks vary within the range of compositions of the hybrid type rocks of the northern SR and Khangar volcano (Fig. 2a). The Nb and Ta concentrations are also increased in the studied rocks, similarly to SR hybrid-type volcanites (Fig. 2b). Plateau-effusives of Yurtinaya Mountain are geochemically similar to the hybrid-type rocks of Ichinsky volcanic massif with up to 10% of the enriched component in the source, which were identified as IAB-type rocks in [10]. Rocks of the initial stage of volcanic activity of Khangar volcano, at similar Nb and Ta concentrations, have lower HREEs, Zr, Hf, and Ti, but can also be classified as hybrid [Fig. 2b].

The K–Ar age was determined for two lava/intrusion pairs from Khangar caldera (table). All the rocks studied here appeared to have a Miocene age (11–6 Ma). One of the intrusions has an earlier age (5.6 ± 0.2 Ma) than the overlapping lava flow (7.1 ± 0.3 Ma). This is, most likely, caused by a breach of the K–Ar system closure due to secondary alteration processes, observed in the HNG-12-04 sample. The age received for the second intrusion (11.1 ± 0.4 Ma) does not contradict the geological situation and may characterize the real time of its formation.

The series of dates received for Yurtinaya Mountain lavas allows determination of the age of these effusive

Table 1. Results of K–Ar dating of lavas and intrusions from the northern and eastern parts of the Sredinny Metamorphic Massif, Kamchatka

Sample number	Sample description	Age, Ma ± 2σ
	Yurtinaya Mountain	
OZK-11-07	Px andesite, top horizon	6.02 ± 0.18
OZK-11-05	Px–Pl basaltic andesite, middle part of the cross section	5.84 ± 0.17
OZK-11-01	Columnar megaplagiophiric basaltic andesite, visible base of the cross section	5.90 ± 0.19
	Khangar caldera	
HNG-12-05	Bi–Hb–Px–Fs andesite. Lava overlaying granodiorites, sample HNG-12-04	7.06 ± 0.25
HNG-12-04	Px–Hb–Bt granodiorite. Intrusion	5.64 ± 0.21
HNG-12-13	Bi–Hb–Px–Fs andesite. Dyke 1.5 m thick, intruded in granodiorites, sample HNG-12-12	6.95 ± 0.19
HNG-12-12	Px–Hb–Bt granodiorite. Intrusion	11.1 ± 0.4

Radiogenic argon was determined in the Laboratory of Isotope Geochemistry, Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences, using a MI-1201 IG mass spectrometer with the method of isotopic dilution with ^{38}Ar as a tracer; K was determined with the method of flame spectrophotometry [7]. Constants used in the age calculation: $\lambda_e = 0.581 \times 10^{-10}$ year^{-1}; $\lambda_\beta = 4.962 \times 10^{-10}$ year^{-1}; ^{40}K = 0.01167 (at %) [12]. Whole-rock samples were used for the analyses.

as Late Miocene (~6 Ma, table). Vast areas (more than 500 km^2) covered by the studied lavas and lavas produced by mostly unnamed centers (the area between Luntos and Kensol rivers, located nearby Yurtinaya Mountain), reflect the large-scale episode of volcanic activity.

The similar ages of early volcanic rocks in Khangar caldera (~7 Ma) and in the Yurtinaya Mountain area (~6 Ma) allow us to assume the simultaneity of the event that led to the initiation of the volcanic activity within SMM at the end of the Miocene. This age limit seems quite logical if we take into account previously published age data that characterize the time of the cessation of the active intrusive process in SMM. The youngest intrusions were formed about 8 Ma (Fig. 1). Therefore, it is obvious that in the Late Miocene (approximately at the Tortonian–Messinian boundary), the activity regime principally changed within SMM. We can suppose that this event might have been caused by large regional or even global endogenous reasons. Most likely, this conversion was caused by the collision of Kamchatka with Kronotsky arc, which started around 7 Ma from the Shipunsky Peninsula attachment [11]. Noteworthy, the volcanic activation in Japan also started 8–6 Ma [9].

So, as a result of our work, the age of the volcanic activity beginning within Sredinny Metamorphic Massif of Kamchatka has been determined (7–6 Ma). Presumably this event was caused if not by global than at least by significant regional reasons. For the first time, it has been established that the eruption of at least two types of rocks took place in the Late Miocene within Sredinny Range of Kamchatka: typical island-arc rocks in the central and northern parts of the Range, and hybrid-type rocks at its southernmost end.

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