

Late Cretaceous Granitoids of the Mainitskii Terrane (Eastern Koryak Highlands): Age, Geochemical Features, and Geodynamics

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Abstract—New U–Pb geochronological and geochemical data for granitoids of the Mainitskii terrane of the Koryak folded region are presented. It is shown that granitoids intrude the folded-thrust structures of the Mainitskii terrane, which include ophiolites of the Late Paleozoic–Late Mesozoic and volcanogenic–siliceous–terrigenous deposits of the Middle Jurassic–Turonian. Granitoids belong to low-alkaline quartz diorites and I-type granodiorites, compose the Late Cretaceous volcanic–plutonic association, and were formed in a convergent margin. The U–Pb ages of zircons are 82–90 Ma.

Keywords: granitoids, U–Th–Pb ages, zircon, Late Cretaceous, Koryak Highlands, Circum-Pacific belt, Mainitskii terrane, tectonic reconstructions

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The Koryak folded region is a large accretionary fold-cover structure in the Pacific belt. The Middle Paleozoic–Paleogene structural-formational assemblages are integrated within its boundaries into covers, which are overthrust in the southerly direction. In the southern part of the region, the lower structural position is occupied by the Econai cover system. It consists of the Yanranai and Econai terranes. The formation time of the Econai covers is considered to be pre-Maastrichtian based on the neoautochthon age. Structurally higher is the Koryak cover system, which includes the Mainitskii and Alkatvaam terranes and was developed at the Cretaceous–Paleogene boundary [6, 11].

Granitoids in the folded region are associated with (1) pre-mid Cretaceous (Late Paleozoic–Barremian) ophiolite complexes of supra-subduction and oceanic origin [9]; (2) Maastrichtian–Early Miocene post-accretionary volcano–plutonic assemblages [15].

There are no reliable geochronological dates or data on the composition of trace elements for the Late Cretaceous (Barremian–Maastrichtian) granitoids. Late Cretaceous intrusive bodies in the eastern part of the Koryak Highlands are represented as gabbroids, quartz monzonites, and granitoids of the granodio-

rite–granite formation on the maps [3–5]. In the Koryak–Kuril series of sheets, granitoids are recognized as the Varapelinskii plutonic assemblage. These rocks occur as belts of small (0.5–2 km long) dikes and stock-like bodies (5–30 km in diameter). Individual dikes of subvolcanic andesites are described. The intrusive bodies mainly extend in the northwesterly and northeasterly directions. They intrude the fold-thrust assemblages of the Mainitskii, Alkatvaam, and Econai terranes, down to the Maastrichtian deposits (Fig. 1). No intrusive bodies were mapped within the Paleogene deposits. The K–Ar radiological ages of granodiorite–porphyry rocks are 78–88 Ma [5], near the Tamvatnei Massif in the Mainitskii terrane, the rock age is 85 ± 1 Ma (K–Ar method) [4]. Petrochemically, these rocks belong to the calc-alkaline series, which is typical of the geodynamic settings in active margins and island arcs [8].

On more recent 1 : 500000 maps [2], there are no Late Cretaceous intrusive bodies. The Late Cretaceous granitoids displayed previously on earlier maps and described previously have been incorporated into the Miocene Vilyuneiveem plutonic complex, dated at about 15 Ma using the U–Pb method in the central part of the Koryak Highlands [10].

Alexandrov identified [1] the Late Cretaceous Lozovsk Formation, composed of basalt–andesite–dacite covers, their tuffs, and tuff–terrigenous rocks 400–600 m thick. They are mainly small isolated structures. The rock age was based on the kainotype appearance of rocks and unconformable subhorizontal bedding on the Paleozoic–Early Cretaceous rocks. Later on, based on the finds of Hettangian–Sinemu-

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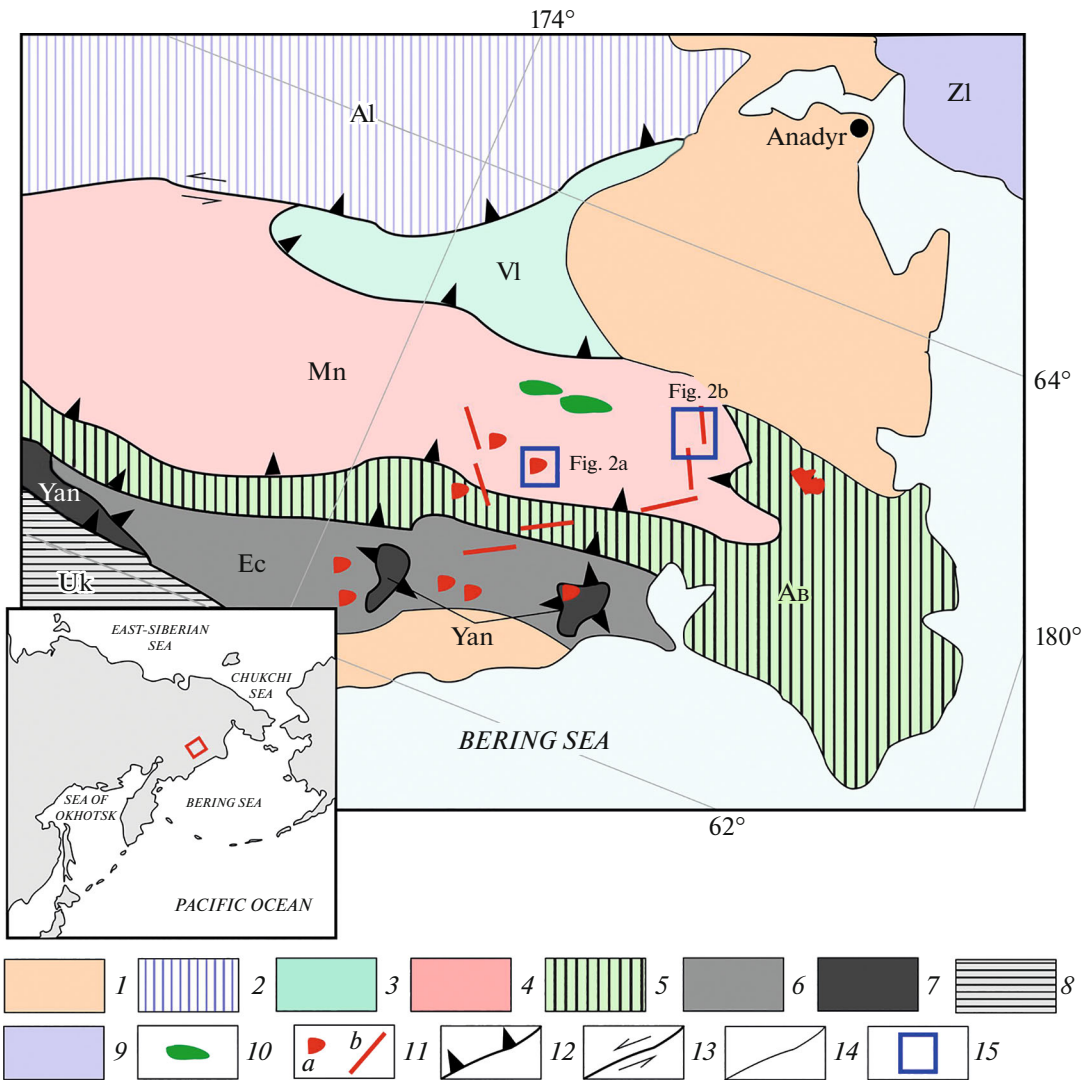


Fig. 1. Tectonic scheme of the Koryak Highlands (from [12]). (1) Paleogene–Quaternary deposits; (2) Middle Jurassic–Turonian volcanic–siliceous–terrigenous deposits; (3) Albian–Danian terrigenous deposits; (4) Late Paleozoic–Late Mesozoic ophiolites; Middle Jurassic–Turonian volcanic–siliceous–terrigenous and terrigenous deposits; (5) Late Paleozoic–Early Mesozoic ophiolites; Upper Jurassic–Paleocene terrigenous deposits; (6) Late Paleozoic–Early Jurassic ophiolites; Upper Jurassic–Paleocene terrigenous deposits; (7) Late Jurassic–Late Cretaceous terrigenous deposits; Oxfordian–Campanian basaltic–siliceous rocks; (8) Santonian–Paleocene terrigenous deposits; (9) Upper Jurassic–Valanginian volcanic rocks and tuff–terrigenous deposits; (10, 11) Late Cretaceous magmatic rock bodies out of scale: (10) volcanic rocks; (11) granitoids: (a) stocks; (b) dikes; (12) overthrusts, imbricates along the dip direction; (13) strike–slip faults; (14) stratigraphic unconformity; (15) the study area. Terranes: Western Kamchatka folded region: Zl is Zolotogorskii; Koryak folded region: Al is Alganskii; Vi is Velikorechenskii; Mn is Mainitskii; Av is Alkatvaam; Ec is Econai; Yan is Yanranai; Olyutor–Kamchatka folded region: Uk is Ukelayat.

rian radiolarians from siltstones in the vicinity of Ugryumoi Mountain, the Lozovsk Formation was classified as Early Jurassic [13].

In thematic studies [7, 9], mid-Cretaceous accretionary plagiogranites were identified within the Econai and Yanranai terranes. Their age was determined by thrust contacts with the assemblages of the Econai cover system, the Yanranai accretionary prism, and the unconformable bedding of the basal horizons in the overlying neautochthon (from the Santonian–Campanian to the Late Maastrichtian). The forma-

tion of such granites reflects the major accretion phases of the oceanic assemblages and occurs immediately after formation of the cover.

This work presents for the first time U–Pb geochronological and geochemical data for the granitoids of the Mainitskii terrane in the Koryak folded region, aiming to refine their age, identify the geochemical typology of granitoids and the geodynamic setting of their formation, as well as to specify the details of paleotectonic reconstructions for the Asian continent's margin in the Late Cretaceous.

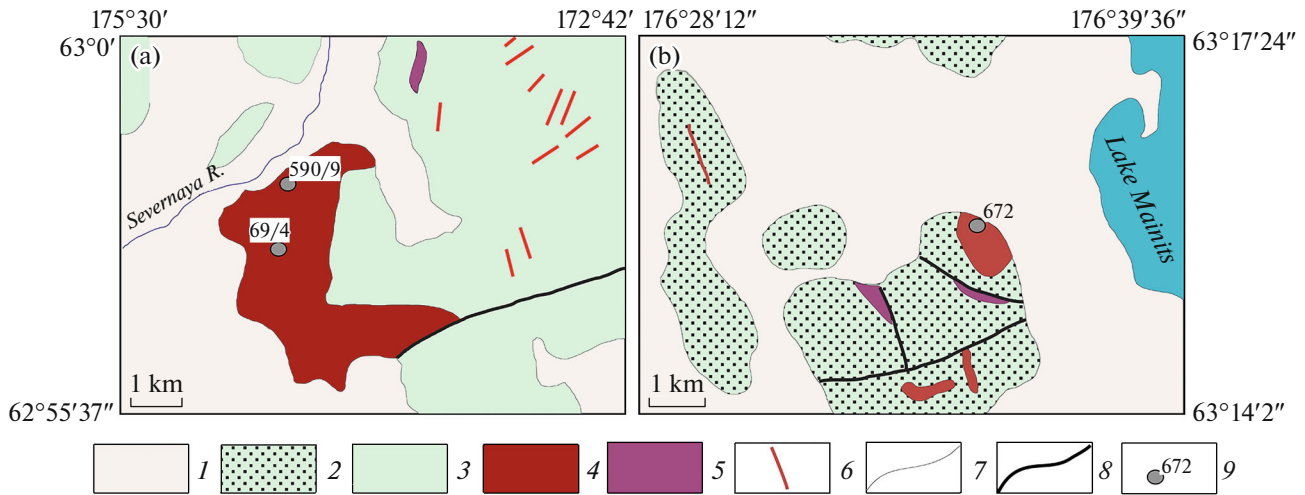


Fig. 2. Diagrams of the geological structures for (a) the Severnaya River and (b) Mainits Lake of the Mainitskii terrane from [1, 3–5] updated. (1) Quaternary deposits; (2, 3) terrigenous and volcanic–siliceous deposits: (2) Callovian–Hauterivian, Topolevskaya Formation; (3) Albian–Turonian, Kuibiveem series; (4) stocks of plagiogranites and granodiorites; (5) diorite porphyrites; (6) granitoid dikes; (7) geological boundaries; (8) faults; (9) sites of geochronological sampling and their numbers.

The Mainitskii terrane has a cover structure. Its assemblages are thrust northward over the Albian–Danian terrigenous deposits of the Velikorechensk terrane in the northwest and southward over the Upper Jurassic–Paleocene terrigenous and volcanic–sedimentary deposits of the Alkatvaam terrane in the east and southeast (Fig. 1) [12]. The boundary between the Mainitskii and Alganskii terranes has a strike–slip character.

The Mainitskii terrane consists of Late Paleozoic–Early Cretaceous ophiolites, serpentinite mélanges, and Middle Jurassic–Early Cretaceous volcanic–siliceous–terrigenous deposits [12]. They are unconformably covered by Albian–Upper Cretaceous flyschoid beds, which are considered to be a post-amalgamation weakly deformed cover [12]. The latter are overlaid by Paleocene–Miocene volcanic–sedimentary and terrigenous beds of continental origin.

The granitoid bodies were studied in the southeastern (Fig. 2a, Severnaya River) and eastern (Fig. 2b, Mainits Lake) parts of the Mainitskii terrane (Table 1).

On the left bank of the Severnaya River (Fig. 2a), granodiorites are exposed as a stock-like body with a diameter of ~4 km. The granodiorites intrude Albian–

Turonian terrigenous deposits of the Kuibiveem series. The stock is adjacent to dikes of quartz diorite porphyrites, gabbro dolerites, and plagiogranites trending northeastward and northward.

On the western shore of Mainits Lake (Fig. 2b), plagiogranites and granodiorite porphyrites form dikes and stock-like bodies elongated in the north–northwesterly direction. The size of these bodies rarely exceeds 1–2 km. The granitoids intrude volcanic–terrigenous deposits of the Callovian–Hauterivian Topolevskaya Formation.

U–Pb dating of zircons was conducted using a SHRIMP-II secondary ion microprobe at the Center for Isotope Research (CIR) of the Federal State Unitary Enterprise Karpinsky Russian Geological Research Institute. The U and Pb isotopic ratios were measured by the standard procedure adopted at CIR and described in [21]. Concordia diagrams are presented in Fig. 3, and the corresponding analytical data are summarized in Appendix 1.

For individual accessory zircon grains from the granodiorites (samples 590/9, 69/4, 672), we obtained close values of the $^{206}\text{Pb}/^{238}\text{U}$ age from 82.3 ± 0.7 to 86.5 ± 2.2 Ma. One value from sample 69/4 is higher

Table 1. Referencing of the sampling points to the coordinates

Sample no.	Areas	Rock	Coordinates		U–Pb age
			N	E	
590/9	Severnaya River	granodiorite–porphyry	62°59′38.7″	175°37′03.1″	84.7 ± 0.5
69/4		granodiorite–porphyry	62°57′30.1″	175°38′47.7″	82.8 ± 0.5
672	Mainits Lake	porphyritic granodiorites	63°15′57.2″	176°35′20.5″	83.3 ± 0.4
548	Ugryumaya Mountain	andesites	63°18′25.6″	175°51′23.8″	85 ± 0.5

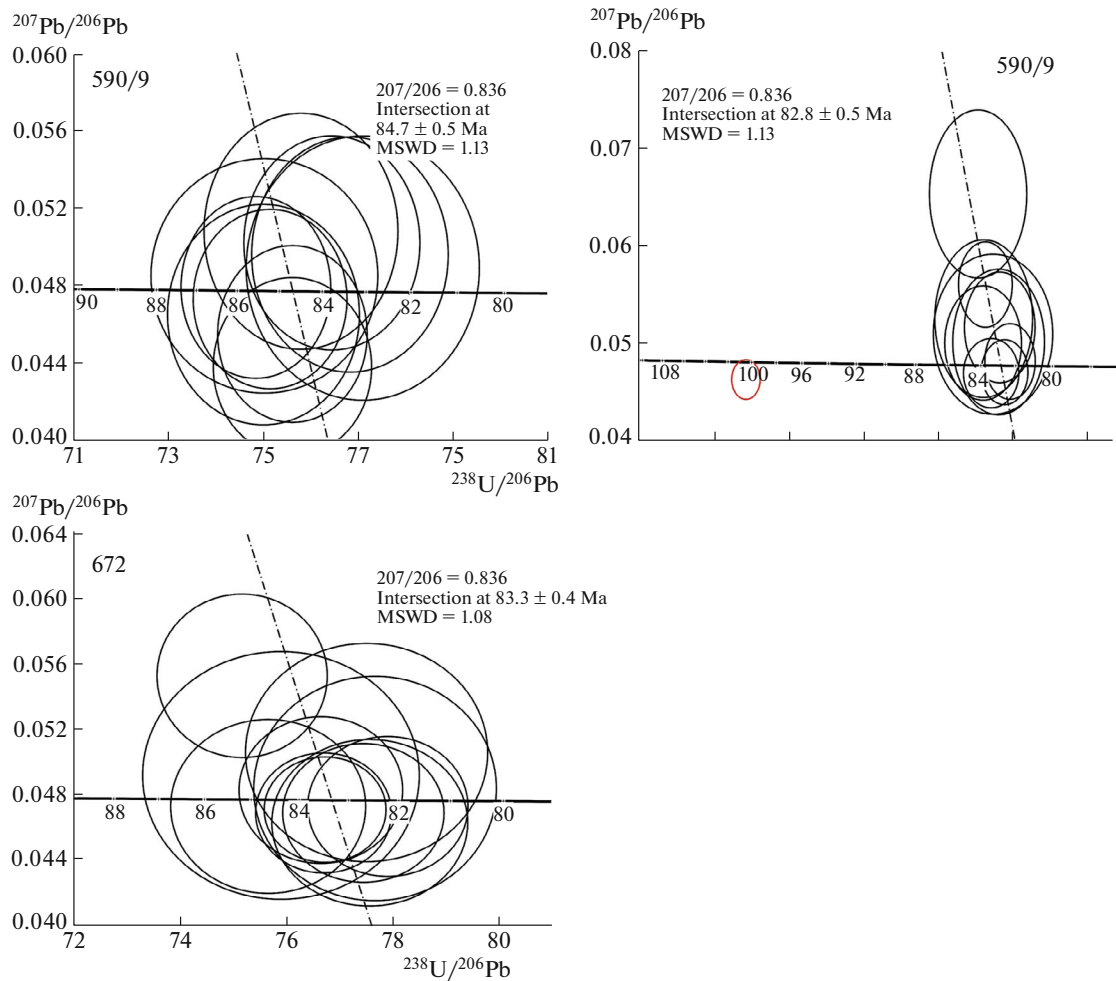


Fig. 3. Concordia diagrams for zircon from the Late Cretaceous granitoids of the Mainitskii terrane in the Koryak folded region. The age values are given in Ma; the indicated uncertainty and the ellipse sizes correspond to 2σ . The result excluded from the calculation is shown in red ellipses.

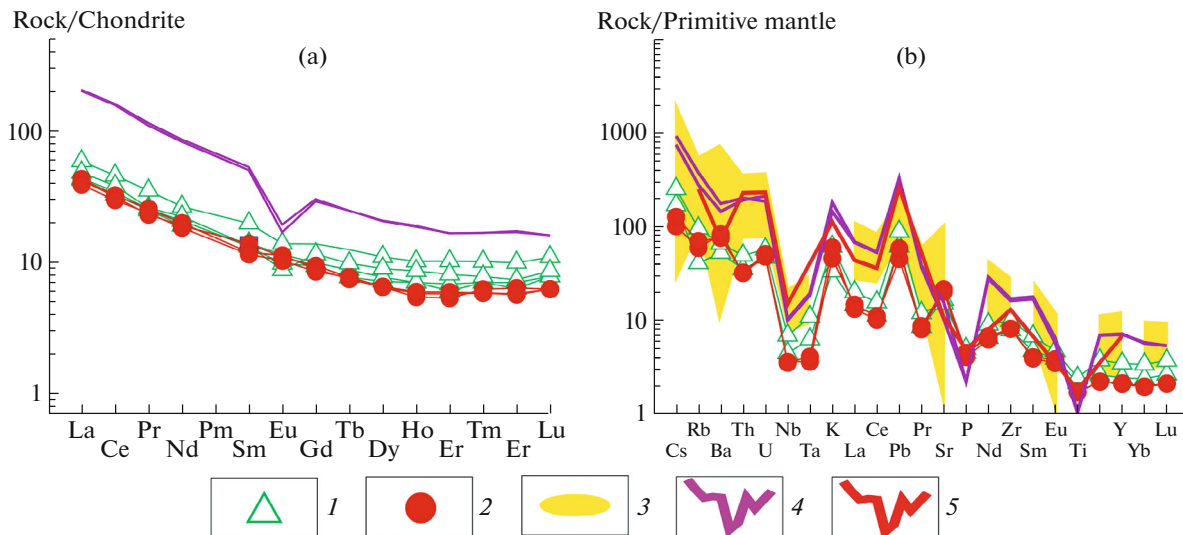


Fig. 4. (a) Chondrite-normalized REE distributions and (b) spidergrams of rare elements normalized to the composition of primitive mantle of granitoids from the Severnaya River and Mainits Lake, Koryakia. (1, 2) Granitoids: (1) Severnaya River, (2) Mainits Lake; (3) Cretaceous acidic volcanic rocks in the OCVB [14]; (4) Albian volcanic rocks in the OCVB [14]; (5) intermediate composition of I-type granite [16].

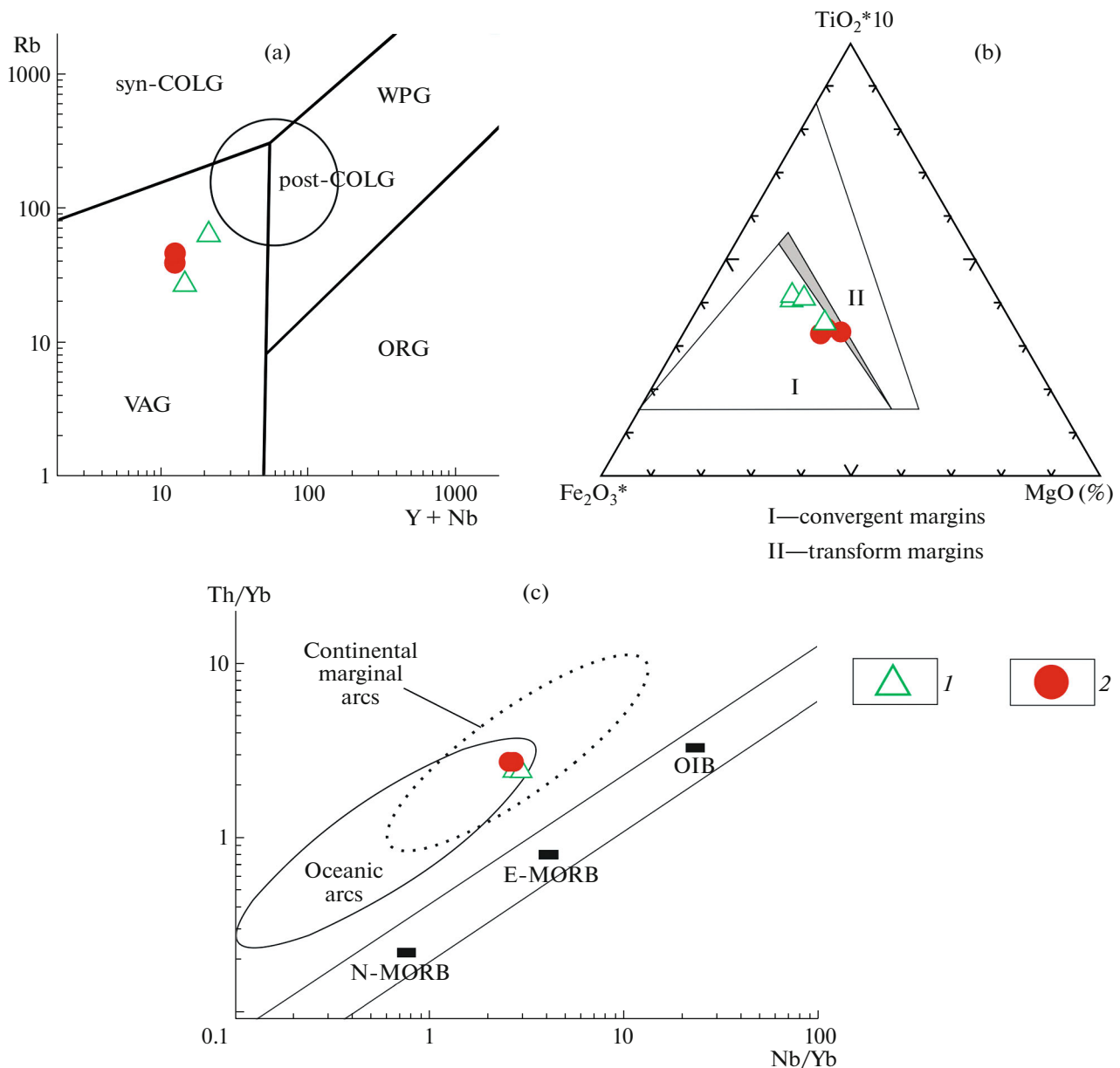


Fig. 5. Diagrams of (a) Rb–(Y+Nb) [20], (b) Fe_2O_3^* – TiO_2^*10 –MgO [18], and (c) Th/Yb–Nb/Yb [19] for granitoids of the Severnaya River and Mainits Lake, Koryakia. (1, 2) Granitoids: (1) Severnaya River, (2) Mainits Lake.

(100.7 ± 0.5 Ma), but it was excluded from the calculation of the rock age since the measured zircon grain has traces of metamict decay and is characterized by high contents of radiogenic ^{206}Pb (up to 20.4%) and U (1510 g/t). In the concordia diagrams, the isotopic ratios in zircon form discordia lines intersecting the concordia at points of 84.7 ± 0.5 Ma (sample 590/9), 82.8 ± 0.5 Ma (sample 69/4), and 83.3 ± 0.4 Ma (sample 672) (Fig. 3). These age estimates correspond to the Santonian and Campanian epochs.

The granitoids of the Severnaya River and Mainits Lake are characterized by contents of SiO_2 equal to 62.23–64.50% and total alkalis of ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) in

the range of 4.36–5.88 wt %. According to the ratio of SiO_2 to the total alkalis ($\text{Na}_2\text{O} + \text{K}_2\text{O}$), all the granitoids belong to low and normal alkali rocks, such as low-alkali quartz diorites and granodiorites. In terms of normative minerals of Ab, An, and Or, they are classified as tonalites. The covariances of K_2O – SiO_2 indicate that they are medium-potassium rocks with $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios in the range of 1.66–3.29 and characterize a sodium type of alkalinity. According to the classification of Frost et al. [17], granitoids belong to magnesian ($\text{Fe}^* = 0.50$ – 0.68), calcareous, and meta-luminous rocks ($\text{ASI} = 0.98$ – 1.05). These characteristics correspond to the I-type granites.

The concentrations of trace elements in the granitoids are characterized by low Zr (82–112 g/t), low Nb (2.56–5.00 g/t), low Rb (26.35–61.72 g/t), high Sr (323–461 g/t), high Ba (373–589 g/t), high Cr (28–79 g/t), high V (93–101 g/t), high Ni (11–39 g/t), low Y (9.8–11.3 g/t), and low total contents of rare earth elements (REEs) (47–73 g/t) (Appendix 2).

The granitoids have similar fractionated patterns of REE distribution, with light rare earth element (LREE) enrichment, heavy rare earth element (HREE) depletion ($La_N/Yb_N = 5.91–7.58$), and a minor negative ($Eu/Eu^* = 0.72–0.96$) or positive ($Eu/Eu^* = 1.03; 1.11$) Eu anomaly (Fig. 4a).

The spidergrams of the trace elements normalized to the composition of the primitive mantle for the granitoids of the Severnaya River and Mainits Lake are characterized by enrichment with large-ion lithophile elements relative to highly charged and minimum Nb, Ta, P, and Ti (Fig. 4b). These spidergrams are similar to the ones for Cretaceous acid volcanic rocks in the Okhotsk–Chukotka Volcanic Belt (OCVB), including rocks of Albian age and I-type granites of intermediate composition (Fig. 4b).

In the diagrams that differentiate the granites of various petrogeochemical types, the points of granitoid compositions are located in the fields of I- and S-type granites differentiated to varying degrees and differing clearly from A-type granites.

The points of compositions of the intrusive bodies in the diagrams that separate the granitoids with respect to the geodynamic setting of their formation (Fig. 5) indicate that they were formed in a setting of a convergent margin or an island-arc setting.

The obtained U–Pb dates confirm the Late Cretaceous (82–90 million years) age of granitoid magmatism within the Koryak folded region. According to our observations, the Late Cretaceous intrusive bodies intersect the fold–thrust structures of the Mainitskii terrane and are close in age to the granitoid intrusions that cut through the pre-Santonian–Campanian and pre–Late Maastrichtian cover assemblages of the Alk-atvaam, Econai, and Yanranai terranes [3–5, 9].

Therefore, the geological setting and the age of the rocks do not contradict their accretionary nature [9] and formation following the development of the cover. In this case, the structural unconformity at the Late Albian level for the assemblages of the Alganskii and Mainitskii terranes [12] may reflect the process of their amalgamation, while the Late Cretaceous events are related to the accretion of the terrane to the Asian continent.

However, the geochemical characteristics of the granitoids indicate their formation in a setting of the convergent margin. If, in the future, the Late Cretaceous age and suprasubduction origin of the volcanic rocks in the Lozovsk Formation are confirmed [1], we will talk about the Late Cretaceous volcanic–plutonic association of suprasubduction genesis. Today, the

U–Pb dates of andesites from this stratum in the area of Ugrymaya Mountain show an age of 85 ± 1 Ma and will be the subject of future investigations. The amalgamated terranes of the Koryak folded region could have been the basement for the Late Cretaceous suprasubduction volcanic structure.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

SUPPLEMENTARY INFORMATION

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