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GEOLOGY

# Age and Paleogeodynamic Nature of the Kalinovka Ophiolite Complex, Sikhote-Alin Orogenic Belt

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**Abstract**—The Sikhote–Alin orogenic belt hosts ophiolites, which are confined to the upper structural level of the Jurassic accretionary prism; however, their age and paleogeodynamic formation conditions are a matter of debate. We present the results of isotopic–geochronological and petrological–geochemical study of rocks of the Breevka and Chuguevka gabbro-ultramafic massifs of the Kalinovka ophiolite complex. These massifs formed in the Late Permian rather than in the Devonian–Carboniferous as was suggested previously. The geochemical features of rocks indicate their formation most likely in an island arc system. Taking into account these results, we can conclude that the upper structural level of the Jurassic accretionary prism of the Sikhote–Alin orogenic belt hosts various rock complexes of the oceanic lithosphere distinct in age and the geodynamic setting. The Breevka and Chuguevka gabbro-ultramafic massifs are fragments of the Late Permian ophiolite complex, which formed in different parts of the island arc system (back-arc or intra-arc basins).

**Keywords:** ophiolites, geochronology, paleogeodynamics, Kalinovka complex, Sikhote–Alin

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Ophiolites, which are representatives of an ancient oceanic lithosphere assembled in a continental structure, are an important element in paleotectonic interpretations. The geological, geochemical, and other features of ophiolite complexes indicate those parental structures (mid-oceanic ridges, back-arc, and intra-arc basins of island arc systems), where an ancient oceanic crust formed. One of the main problems in the study of ophiolites is related to the determination of the age of both ophiolite complexes and their fragments.

The Sikhote–Alin orogenic belt hosts fragments of ophiolite complexes, which are confined to the upper structural level of the Jurassic accretionary prism composed of the Middle Jurassic turbidite–olistostrome sequences with blocks of rocks of the paleooceanic lithosphere [6, 7, 10, 16]. Three ophilote massifs are recognized from north to south: Dachechzhen, Bikin, and Kalinovka.

The Kalinovka complex occurs as a chain of gabbro-ultramafic massifs and is extended for ~200 km from south to north from the settlement of Verkhnyaya Breevka to the basin of the Otkosnaya River (Fig. 1). The largest massifs (>20 km long) are Samarka, Chuguevka, and Breevka [12]. The massifs are characterized by relatively full fragments of sections composed of a peridotite–troctolite association of ophiolites. Their lower part includes serpentinized dunite and harzburgite with overlying plagioclase dunite, wehrlite, clinopyroxenite, troctolite, and olivine gabbronorite. The gabbroic part of the section is composed of amphibole, two-pyroxene, and clinopyroxene gabbro, as well as plagiogranite veins. The gabbroids have tectonic contact with the overlying basalts, which are conformably crowned by sedimentary rocks including hyaloclastites, edaphogenic rocks, banded cherts, and limestones [10].

The age of ophiolites is determined as the end of the Devonian and the beginning of Carboniferous, because the cherts, which lie directly on massive basalts, contain conodonts of the end of the Devonian and the limestones at the contact with pillow basalts host Visean foraminifers [7, 10]. The age of gabbroids was analyzed using only the K–Ar method and until the 1980s varied from 90 to 360 Ma according to the unpublished reports of a geological survey. According to [7], the age of hornblende from pegmatitic gabbro of the Breevka massif is 410 ± 9 Ma. The age of graphic pegmatites intruding the gabbroids of the Chuguevka massif is 406 Ma [4]. These data, however, contradict the data of Japanese researchers on the age of hornblende (230 Ma) from metagabbro sampled near the settlement of Medvezhii Kut (area of the settlement of Verkhnyaya Breevka) [15].

We analyzed the isotopic age of gabbroids of the Breevka and Chuguevka gabbro-ultramafic massifs. For U–Pb dating of zircon of the Breevka massif, we

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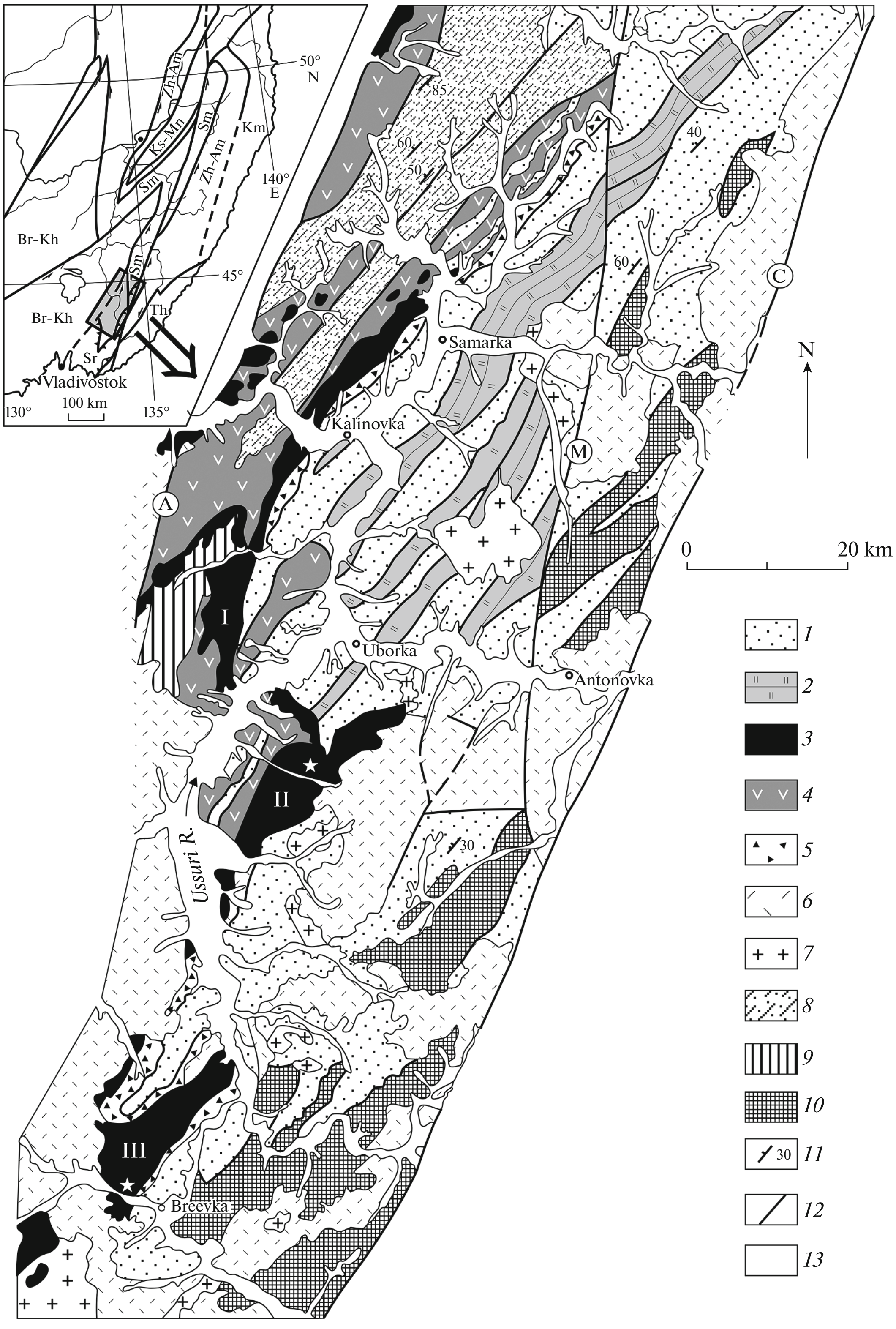


**Fig. 1.** Gabbro-ultramafic massifs of the Kalinovka ophiolite complex in the southern part of the Sikhote-Alin orogenic belt after [10]. I, Samarka; II, Chuguevka; III, Breevka. *1*, Jurassic turbidite-olistostrome rocks of the Samarka accretionary prism; *2*, Permian, Triassic, and Late Jurassic chert; *3*, ophiolite gabbroic and ultramafic rocks; *4*, basalt and diabase in association with chert and limestone; *5*, Permian sandstone; *6*, Late Cretaceous volcanic rocks; *7*, Late Cretaceous granite; *8*, Jurassic turbidite; *9*, Permian–Triassic shallow (shelf) sediments; *10*, Sergeevka gabbroids and overlapping Permian–Triassic shelf sediments; *11*, bedding elements; *12*, faults (A, Arsen'ev; M, Meridional'nyi; C, Central Sikhote-Alin); *13*, Quaternary sediments. Inset with terranes: Br–Kh, Bureya–Khanka; Sr, Sergeevka; Sm, Samarka; Th, Taukha; Zh–Am, Zhuravlevka–Amur; Km, Kema; Ks–Mn, Kiselevsk–Manoma. Stars show sampling sites.

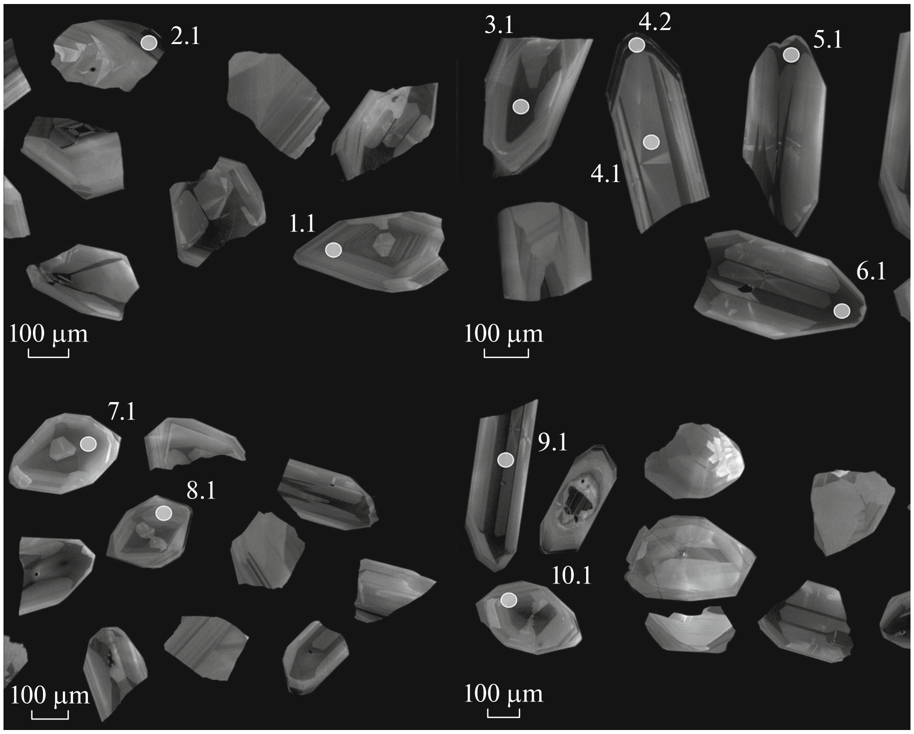


**Fig. 2.** Cathodoluminescence images of zircon grains sampled for U–Pb SIMS SHRIMP II geochronological studies from pegmatitic gabbro of the Breevka massif. Sample numbers in the figure correspond to the analyses in Table 2.

took a sample of giant-grained pegmatitic gabbro composed of variously oriented hornblende crystals up to 10–15 cm in size with interstitial plagioclase in area of the settlement of Verkhnyaya Breevka. The accessory zircon was extracted from the sample using crushing, magnetic separation, and separation in heavy liquids. The zircon grains were further manually sampled under a binocular microscope. The zircon grains are fragments (rare prismatic crystals) of transparent yellowish crystals up to 350 μm in size (Fig. 2). The prismatic crystals exhibit typical igneous growth zonation in cathodoluminescence images.

The largest grains were selected for the laser ablation inductively coupled plasma mass spectrometry (LA ICP MS) isotope dating in the Primor'e Center of Local Elemental and Isotope Analysis, Far East Geological Institute, Far East Branch, Russian Academy of Sciences (Vladivostok), following the method of [1]. The isotopic results are shown in Figs. 3a and 3b and Table 1. In total, 35 zircon grains were sampled and 22 points were analyzed in various grains. In the diagram with concordia (Fig. 3a), 17 points form a compact area with a concordant age of 255 ± 6 Ma and the average weighted age estimation is 253 ± 4 Ma (Fig. 3b).

Zircons from the same sample (Fig. 2) were also studied on a SHRIMP-II ion microprobe in the Center of Isotope Studies of the Russian Geological Research Institute (St. Petersburg) following a certified method. The results of the studies are given in Figs. 3c and 3d and Table 2. In total, 11 analyses were obtained for ten zircon grains. In the isotope diagram with concordia, the area of the concordant age value corresponds to 264 ± 2 Ma (Fig. 3c). A similar value was obtained for the average weighted age (Fig. 3d). It should be noted that points 2.1 and 4.2 yielded a positive Th/U ratio (Table 2). It can indicate either incorrect measurements in the grain margins or possible metamorphism (within the analytical error, which coincides with this age value).

For $^{40}Ar/^{39}Ar$ dating of the Chuguevka massif in area of the Stepanov 2 Creek, we took a sample of banded amphibole norite, which is mainly composed of plagioclase, orthopyroxene, and amphibole. The analysis was conducted for plagioclase and amphibole, as well as amphibole and pyroxene, in one sampling. The $^{40}Ar/^{39}Ar$ age was analyzed by a gradual heating method in the Isotopic Laboratory of the Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences (Novosibirsk), on a Noble gas 5400 mass spectrometer (Micromass, Great Britain) and an Argus multicollector mass-spectrometer (GV-Instruments, Great Britain) following the method of [9]. The results are given in Fig. 4 and Table 3. In the Ar spectrum of plagioclase by four steps, the plateau corresponds to 77% of released $^{39}Ar$ and the age of 154.5 ± 5.3 Ma. It should be emphasized that, according to the current ideas [6, 16], the fragments of the

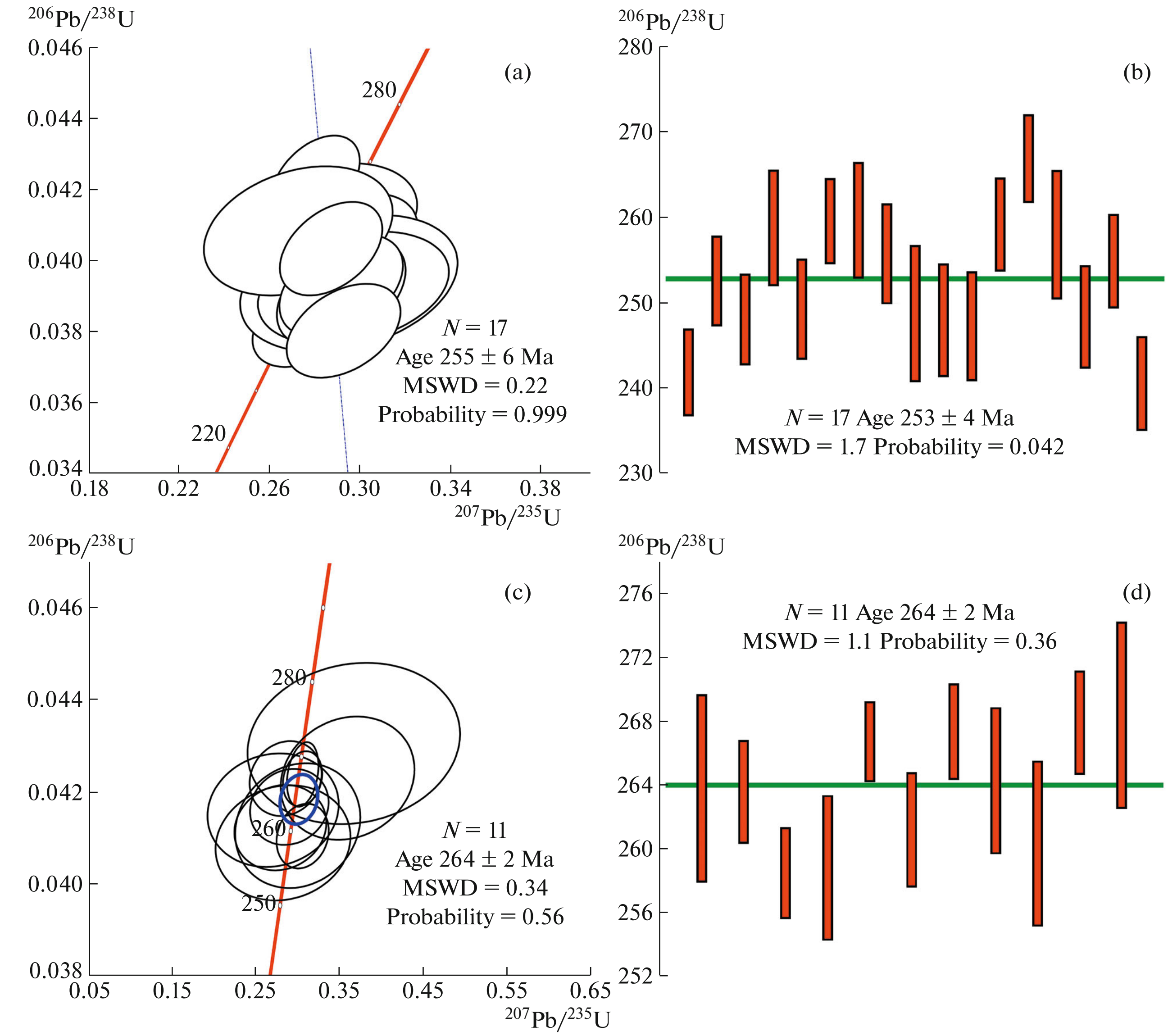


**Fig. 3.** Diagrams with concordia and average weighted ages for local U–Pb LA ICP MS (a and b) and SIMS SHRIMP II (c and d) analyses of accessory zircon from pegmatitic gabbro of the Breevka massif. *N*, number of analytical points; MSWD, mean square weighted deviation; error of 1σ.

ophiolite association were accreted at the end of the Early Jurassic and the beginning of the Middle Jurassic (~180–170 Ma). Our age probably reflects a thermal event that was related to the intrusion of alkaline mafic–ultramafic rocks; therefore, it does not belong to the age of the formation of the Chuguevka massif. Other samples yielded no results corresponding to the criteria of the age plateau. At the same time, the Ar spectrum of each sample at the final step exhibits areas (pseudoplateau) with a Late Permian or Middle Triassic age. In particular, the last step, which forms a pseudoplateau (by amphibole), corresponds to 83% of released $^{39}Ar$ and corresponds to the age of 254.1 ± 4 Ma. Taking into account the results of U–Pb dating of the Breevka gabbroids, we can suggest the age of the formation of the Chuguevka massif in the range of 264–254 Ma.

The paleotectonic model of the formation of the Kalinovka ophiolites remains debatable. It was previously considered that they formed in a spreading zone of a paleoocean (pull-apart basin) and were further displaced to the basement of an island-arc slope of a Late Paleozoic island arc [3]. In addition, it is suggested from the association of the Kalinovka gabbroids and ultramafic rocks with high-Ti basalts that the ophiolite complex formed in the basement of an oceanic plateau, the rise of which was caused by intrusion of a mantle plume [7, 10, 11]. Our results suggest

**Table 1.** Results of LA ICP MS U–Pb geochronological studies of accessory zircon from pegmatitic gabbro of the Breevka massif

| No. | Th/U | Isotope ratio | | | | Rho | Age, Ma | | | | *D*, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $^{207}Pb/^{235}U$ | 1σ, ±% | $^{206}Pb/^{238}U$ | 1σ, ±% | | $^{207}Pb/^{235}U$ | 1σ, abs | $^{206}Pb/^{238}U$ | 1σ, abs | |
| 1 | 0.3 | 0.2758 | 5.5521 | 0.0382 | 2.1193 | 0.4 | 247 | 12 | 242 | 5 | −2.3 |
| 2 | 0.2 | 0.2804 | 5.7248 | 0.0399 | 2.1032 | 0.4 | 251 | 13 | 253 | 5 | 0.6 |
| 4 | 0.2 | 0.2803 | 5.8219 | 0.0392 | 2.1418 | 0.4 | 251 | 13 | 248 | 5 | −1.2 |
| 5 | 0.2 | 0.2734 | 7.9438 | 0.0410 | 2.6374 | 0.3 | 245 | 17 | 259 | 7 | 5.1 |
| 6 | 0.2 | 0.2883 | 6.2255 | 0.0394 | 2.3592 | 0.4 | 257 | 14 | 249 | 6 | −3.2 |
| 7 | 0.3 | 0.3008 | 4.8534 | 0.0411 | 1.9231 | 0.4 | 267 | 11 | 260 | 5 | −2.9 |
| 8 | 0.2 | 0.2852 | 9.2729 | 0.0411 | 2.6284 | 0.3 | 255 | 21 | 260 | 7 | 1.8 |
| 9 | 0.2 | 0.2963 | 6.5181 | 0.0405 | 2.2986 | 0.4 | 264 | 15 | 256 | 6 | −3.1 |
| 12 | 0.3 | 0.2951 | 10.7407 | 0.0393 | 3.2283 | 0.3 | 263 | 25 | 249 | 8 | −5.6 |
| 13 | 0.2 | 0.2972 | 9.3721 | 0.0392 | 2.6779 | 0.3 | 264 | 22 | 248 | 7 | −6.6 |
| 14 | 0.2 | 0.2918 | 6.4366 | 0.0391 | 2.6094 | 0.4 | 260 | 15 | 247 | 6 | −5.2 |
| 15 | 0.3 | 0.2838 | 5.5640 | 0.0410 | 2.1214 | 0.4 | 254 | 12 | 259 | 5 | 2.1 |
| 16 | 0.3 | 0.2805 | 4.5887 | 0.0423 | 1.9404 | 0.4 | 251 | 10 | 267 | 5 | 5.9 |
| 18 | 0.2 | 0.2728 | 10.0968 | 0.0408 | 2.9397 | 0.3 | 245 | 22 | 258 | 7 | 5 |
| 20 | 0.2 | 0.2917 | 6.1699 | 0.0393 | 2.4446 | 0.4 | 260 | 14 | 248 | 6 | −4.7 |
| 21 | 0.2 | 0.2873 | 5.1967 | 0.0403 | 2.1577 | 0.4 | 256 | 12 | 255 | 5 | −0.6 |
| 22 | 0.3 | 0.2928 | 5.6795 | 0.0380 | 2.2889 | 0.4 | 261 | 13 | 241 | 5 | −8.4 |

Rho is the coefficient of the correlation of ratios $^{207}Pb/^{235}U–^{206}Pb/^{238}U$; D is Discordance (1 – $^{207}Pb/^{235}U$ : $^{206}Pb/^{238}U$) × 100.

**Table 2.** Results of U–Pb SIMS SHRIMP II geochronological studies of accessory zircon from pegmatitic gabbro of the Breevka massif

| No. | $^{206}Pb_c$, % | Content, ppm | | | $^{232}Th/^{238}U$ | Isotope ratio | | | | | | | | Rho | Age, Ma | | | | *D* % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $^{206}Pb^*$ | U | Th | | $^{238}U/^{206}Pb$ | 1σ, ±% | $^{207}Pb/^{206}Pb$ | 1σ, ±% | (1) $^{207}Pb/^{235}U$ | 1σ, ±% | (1) $^{206}Pb/^{238}U$ | 1σ, ±% | | (1) $^{206}Pb/^{238}U$ | 1σ, abs | (2) $^{206}Pb/^{238}U$ | 1σ, abs | |
| 1.1 | 0.87 | 1.93 | 53 | 14 | 0.27 | 23.43 | 2 | 0.0686 | 11 | 0.36 | 15 | 0.0423 | 2.1 | 0.142 | 267.1 | ±5.5 | 263.8 | ±5.8 | 148 |
| 2.1 | 0.79 | 6.93 | 192 | 15 | 0.08 | 23.8 | 1.2 | 0.0568 | 5 | 0.29 | 11 | 0.04168 | 1.3 | 0.122 | 263.2 | ±3.4 | 263.6 | ±3.2 | –17 |
| 3.1 | 0.69 | 6.2 | 175 | 47 | 0.28 | 24.19 | 1.1 | 0.0596 | 3.6 | 0.306 | 6.7 | 0.04105 | 1.1 | 0.168 | 259.3 | ±2.9 | 258.5 | ±2.8 | 44 |
| 4.1 | 1.71 | 2.45 | 69 | 16 | 0.24 | 24.03 | 1.7 | 0.0639 | 5.4 | 0.283 | 19 | 0.0409 | 2 | 0.107 | 258.4 | ±5.1 | 258.8 | ±4.5 | –23 |
| 4.2 | 0.42 | 9.13 | 250 | 6 | 0.02 | 23.55 | 0.9 | 0.0558 | 3.1 | 0.306 | 5.1 | 0.04229 | 0.93 | 0.184 | 267 | ±2.4 | 266.7 | ±2.4 | 14 |
| 5.1 | 1.06 | 7.37 | 206 | 71 | 0.35 | 24 | 1.3 | 0.0577 | 5.7 | 0.279 | 13 | 0.04123 | 1.5 | 0.114 | 260.5 | ±3.8 | 261.2 | ±3.5 | –40 |
| 6.1 | 0.00 | 6.34 | 174 | 49 | 0.29 | 23.59 | 1.1 | 0.0524 | 3.9 | 0.306 | 4 | 0.04238 | 1.1 | 0.270 | 267.6 | ±2.9 | 267.3 | ±3 | 13 |
| 7.1 | 1.63 | 2.6 | 72 | 19 | 0.27 | 23.64 | 1.6 | 0.0604 | 5.5 | 0.271 | 19 | 0.04161 | 2 | 0.102 | 262.8 | ±5 | 264.2 | ±4.4 | –78 |
| 8.1 | 1.61 | 1.83 | 51 | 11 | 0.23 | 23.84 | 1.9 | 0.0656 | 6.1 | 0.3 | 16 | 0.04127 | 2.2 | 0.132 | 260.7 | ±5.5 | 260.3 | ±5.1 | 22 |
| 9.1 | 0.80 | 5.49 | 150 | 43 | 0.30 | 23.45 | 1.2 | 0.0554 | 4.8 | 0.286 | 9.9 | 0.0423 | 1.3 | 0.128 | 267 | ±3.3 | 267.9 | ±3.2 | –45 |
| 10.1 | 2.59 | 1.62 | 43 | 9 | 0.22 | 22.62 | 2.1 | 0.0824 | 6.1 | 0.367 | 23 | 0.0431 | 2.7 | 0.117 | 271.8 | ±7.1 | 268.4 | ±5.8 | 146 |

$Pb_c$ and Pb* are common and radiogenic lead; (1) correlation by $^{204}Pb$; (2) correlation for correspondence of the $^{206}Pb/^{238}U–^{207}Pb/^{235}U$ ratio to the concordant age.

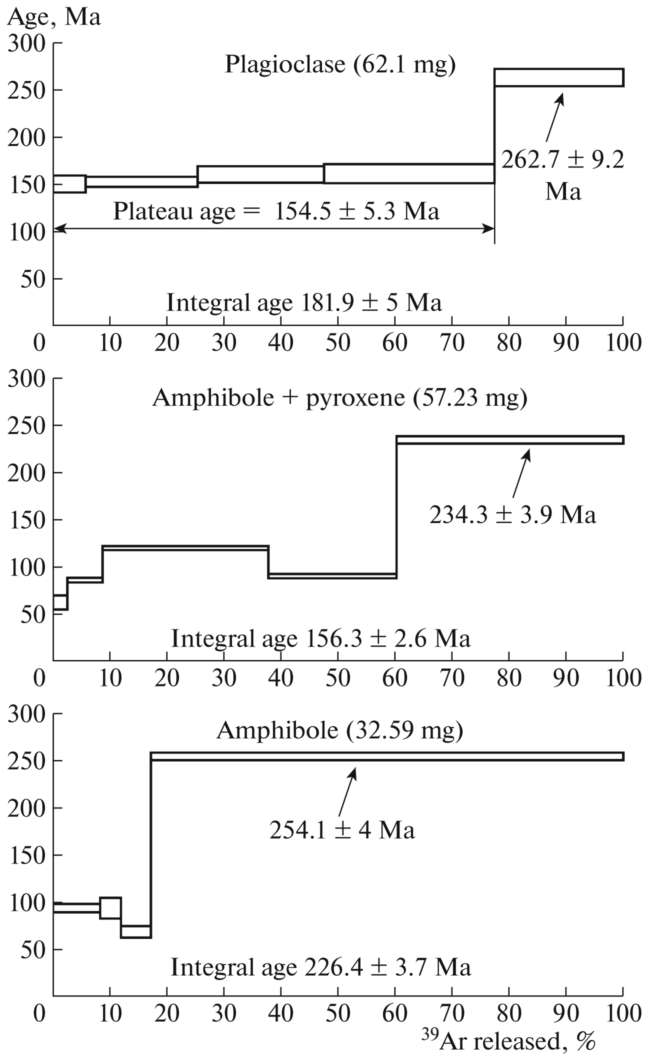


**Fig. 4.** Age $^{40}Ar/^{39}Ar$ spectra of minerals from amphibole norite of the Chuguevka massif.

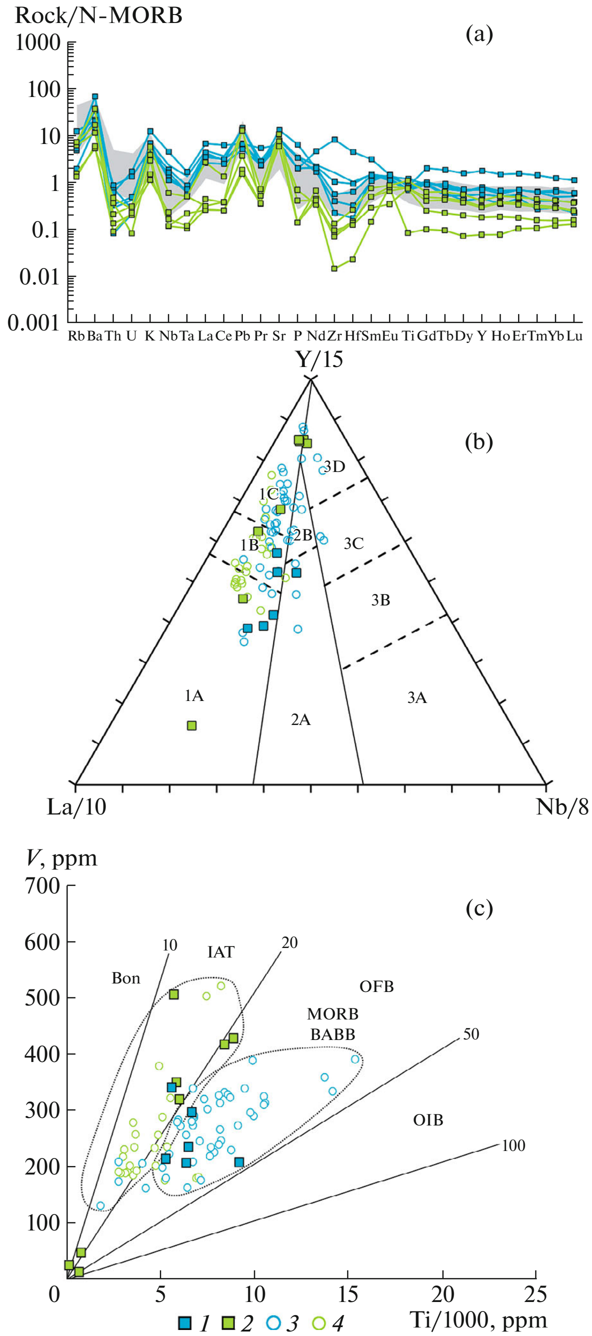


**Fig. 5.** Diagrams for gabbroids from the Kalinovka, Dachechzhen [13, 19], and Yakuno [18] ophiolite complexes. *1*, *2*, Chuguevka and Breevka massifs of the Kalinovka complex, respectively; *3*, Yakuno gabbroids; *4*, Dachechzhen gabbroids. (a) N-MORB-normalized [20] trace element contents in gabbroids of the Chuguevka and Breevka massifs of the Kalinovka complex. The composition of the Dachechzhen gabbroids is marked by the field. (b) La/10–Y/15–Nb/8 diagram [14]. Fields: 1A, calc-alkali island-arc basalt (CAB); 1C, IAT; 1B, overlapping of 1A and 1C fields; 2A, continental basalt; 2B, back-arc tholeiite; 3A, calc-alkali basalt of intracontinental rifts; 3B and 3C, E-MORB (3B, enriched; 3C, weakly enriched); 3D, N-MORB. (c) Ti/V plot [17]. Green, fields of the Breevka massif and Dachechzhen complex; blue, fields of the Chuguevka massif and Yakuno ophiolites.

another interpretation of the geodynamic setting of the Kalinovka ophiolite complex.

Mantle restites among the ultramafic rocks of the Chuguevka and Breevka gabbro-ultramafic massifs are rare, and the basement of sections is composed of cumulative peridotites, troctolites, or pyroxenites. This structure is not typical of the oceanic plateau complexes and, in contrast, is characteristic of ophiolites from subduction zones (back-arc and intra-arc basins of island arc systems).

Trace element patterns of the Kalinovka gabbroids (Fig. 5a) exhibit typical Rb, Ba, K, Pb, and Sr maxima and Th, U, Nb, Ta, Zr, and Hf minima similar to the compositions of island arc basalts. In discriminant diagrams (Figs. 5b, 5c), their compositions correspond to the fields of island-arc rocks and are close to the compositions of gabbroids from the Late Permian Yakuno (Japan) and Dachechzhen (China) ophiolite

**Table 3.** Results of $^{40}Ar/^{39}Ar$ dating of the mineral fractions from amphibole norite of the Chuguevka massif

| $T$°, C | $^{40}Ar$, $10^{-9}$ ncm$^3$ | $^{40}Ar/^{39}Ar$ | ±1σ | $^{38}Ar/^{39}Ar$ | ±1σ | $^{37}Ar/^{39}Ar$ | ±1σ | $^{36}Ar/^{39}Ar$ | ±1σ | Ca/K | Σ $^{39}Ar$ (%) | Age (Ma) | ±1σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amphibole (32.59 mg) | | | | | | | | | | | | | |
| J = 0.006469 ± 0.000109; integral age = 226.4 ± 3.7 Ma | | | | | | | | | | | | | |
| 800 | 78.4 | 79.3 | 0.102 | 0.072 | 0.00121 | 0.0230 | 0.0018 | 0.2405 | 0.00130 | 0.1 | 8.3 | 94.1 | 4.4 |
| 850 | 23.5 | 53.9 | 0.180 | 0.059 | 0.00407 | 0.0255 | 0.0055 | 0.1544 | 0.00336 | 0.1 | 11.9 | 94.0 | 11.0 |
| 1000 | 24.8 | 39.5 | 0.072 | 0.053 | 0.00241 | 0.0286 | 0.0022 | 0.1134 | 0.00179 | 0.1 | 17.2 | 68.9 | 6.0 |
| 1130 | 262.6 | 26.6 | 0.007 | 0.018 | 0.00012 | 0.0137 | 0.0001 | 0.0110 | 0.00024 | 0.05 | 100.0 | 254.2 | 4.1 |
| Amphibole + pyroxene (57.23 mg) | | | | | | | | | | | | | |
| J = 0.006379 ± 0.000106; integral age = 156.3 ± 2.6 Ma | | | | | | | | | | | | | |
| 500 | 34.8 | 50.2 | 0.117 | 0.090 | 0.00116 | 7.9247 | 0.5045 | 0.1513 | 0.00229 | 28.5 | 2.6 | 62.4 | 7.5 |
| 700 | 80.1 | 48.0 | 0.028 | 0.058 | 0.00083 | 5.1283 | 0.1703 | 0.1364 | 0.00061 | 18.5 | 8.7 | 86.0 | 2.4 |
| 850 | 486.9 | 62.0 | 0.019 | 0.047 | 0.00017 | 1.2941 | 0.0608 | 0.1732 | 0.00027 | 4.7 | 37.8 | 119.9 | 2.1 |
| 1000 | 125.8 | 20.7 | 0.011 | 0.030 | 0.00011 | 4.5610 | 0.0708 | 0.0428 | 0.00057 | 16.42 | 60.3 | 90.3 | 2.4 |
| 1130 | 280.2 | 26.1 | 0.011 | 0.024 | 0.00005 | 5.04 | 0.05 | 0.0147 | 0.00051 | 18.13 | 100.0 | 234.3 | 4.0 |
| Plagioclase (62.10 mg) | | | | | | | | | | | | | |
| J = 0.006437 ± 0.000108; integral age = 181.9 ± 5.0 Ma | | | | | | | | | | | | | |
| 500 | 44.3 | 65.8 | 0.179 | 0.066 | 0.00271 | 12.1 | 0.5 | 0.1771 | 0.00277 | 43.6 | 5.7 | 150.0 | 9.0 |
| 650 | 43.3 | 18.8 | 0.024 | 0.022 | 0.00053 | 14.8 | 0.2 | 0.0173 | 0.00149 | 53.1 | 25.4 | 152.3 | 5.3 |
| 800 | 49.8 | 19.1 | 0.038 | 0.026 | 0.00066 | 31.2 | 0.1 | 0.0159 | 0.00267 | 112.4 | 47.6 | 160.0 | 8.8 |
| 1000 | 60.6 | 17.3 | 0.041 | 0.030 | 0.00055 | 35.6 | 0.1 | 0.0095 | 0.00310 | 128.25 | 77.4 | 160.9 | 10.1 |
| 1130 | 86.7 | 32.7 | 0.069 | 0.029 | 0.00061 | 31.8 | 0.1 | 0.0284 | 0.00277 | 114.60 | 100.0 | 262.7 | 9.2 |

*T* is temperature, error of ±1°C; time (t) for each step was 10 min; J, "J-factor," a parameter that characterizes the neutral flux value.

complexes. Both these complexes, as well as the Kalinovka complex, are confined to the upper structural level of the same accretionary prism [6]. It is considered that the Dachechzhen complex formed in a supra-subduction setting [13, 19], whereas the Yakuno ophiolites were part of a back-arc basin [18]. Following our Chinese and Japanese colleagues, we suggest that the island arc system is the most likely geodynamic setting for the formation of the Kalinovka complex. The gabbroids of the Chuguevka massif are more alkaline (Fig. 5a) close to N-MORB (Fig. 5b) and probably formed in back-arc or intra-arc basins, whereas the gabbroids of the Breevka massif are remnants of the crust of this basin reworked by island arc magma (tholeiite–boninite–adakite series).

The analysis of the published data [2, 5, 8] shows that the volcanic rocks tectonically associated with gabbro-ultramafic massifs host oceanic island and spreading basalts, which are associated with Carboniferous–Permian limestones and Permian pelagic cherts, respectively. The island-arc volcanic rocks in the structure of the section of the Jurassic prism are extremely rare and include two types: (i) basalts with mixed (suprasubduction and oceanic) features, which probably formed during back-arc spreading, are found in the Samarka Terrane in association with Permian cherts and (ii) suprasubduction volcanic rocks (dacitic lava breccias), the petrogeochemical features of which are typical of suprasubduction volcanic rocks of probably Permian age, are found in a mélange of the Khabarovsk Terrane [2].

Thus, the upper structural level of the Jurassic accretionary prism of the Sikhote-Alin orogenic belt includes several oceanic complexes of various age and setting, which were transformed into small separated slices and blocks as a result of subduction. The Breevka and Chuguevka gabbro-ultramafic massifs are fragments of the Late Permian ophiolite complex, which formed in different parts of the island-arc system (back-arc or intra-arc basins). The oceanic island basalts associated with Carboniferous–Permian limestones probably belong to the older complex of the oceanic plateau. In this case, we can suggest that subduction erosion occurred prior to the formation of the accretionary prism. During subduction of the oceanic plate beneath the island arc, the regime of subduction accretion gave way to subduction erosion of the main part of the Permian island arc system and its submergence beneath the continental margin, whereas small fragments of it (Kalinovka complex) were included in the Jurassic accretionary prism.

Our results of isotopic–geochronological studies indicate that the Breevka and Chuguevka gabbro-ultramafic massifs of the Kalinovka complex formed in the Late Permian rather than in the Devonian–Carboniferous as was suggested previously. The geochemical features of rocks of the Breevka and Chuguevka massifs indicate an island arc system as the most likely geodynamic setting of their formation.

## FUNDING

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## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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