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SHALKAR OPHIOLITE COMPLEX, NORTHERN KAZAKHSTAN: STRUCTURAL SETTING, AGE, GEOCHEMISTRY, AND GENESIS

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The Shalkar ophiolite complex consists of a series of tectonic sheets, including lavas, a complex of parallel dikes, layered complex of gabbro and gabbro-pyroxenites intruded by dikes of plagiogranites. The tectonic sheets are subsided northward and are associated with the base of a large tectonic nappe made up of rocks of the Kokchetav microcontinent. The microcontinent and ophiolites are jointly thrust upon the Kokchetav megamelange complex with HP-UHP rocks. It is inferred from the chemical composition and structural position that the Shalkar ophiolites were formed under the conditions of suprasubduction zone of extension and belong to the setting of the initial stage of formation of the Stepnyak island arc. The upper age of the ophiolites is 485±6 Ma as determined for zircons from plagiogranites using the U-Th-Pb SHRIMP method. The age of the Shalkar ophiolites is within 495–485 Ma. This interval is marked by a considerable rearrangement in the subduction zone, which can be due to a jump of subduction zone to the hinterland of the Kokchetav microcontinent and to the origin of a zone of extension within its limits with the formation of ophiolites.

Ophiolites, complex of parallel dikes, gabbro-pyroxenites, basalts, geochemistry, geochronology, Kokchetav microcontinent

INTRODUCTION

The basic-ultrabasic complexes of northern Kazakhstan have a long history of study. In his first reviews, Mikhailov [1] has distinguished: (1) the Shchuchinsk peridotite-pyroxenite complex (chiefly, serpentinites, subordinate gabbroids usually transformed into gabbro-amphibolites and, less frequently, pyroxenites and peridotites), conventionally, of Cambrian age; (2) the Krasnomaisky alkaline-ultrabasic complex (pyroxenites, shonkinites, monzogabbros, syenites, carbonatites, and phlogopite metasomatites), conventionally of Middle-Late Cambrian age; (3) the Zlatogorsky peridotite-pyroxenite-norite complex (dunites, peridotites, troctolites, norites, gabbros, gabbronorite), conventionally of Middle-Late Ordovician age. The Zlatogorsky complex included the Shalkar, Tsurikov, Chkalov, Dubrovsky, Zholdybai, Shat, and other massifs with close rock composition.

With small variations, similar schemes of dismembering of gabbro-ultrabasic rocks were repeated in subsequent works. Since the 1980s, some part of the basic-ultrabasic rocks of Kazakhstan have been referred to as ophiolites. Together with the associated dikes, basalts, and sediments, they were united into relict complexes of paleo-oceanic crust (e.g., [2–4]) but study was given to complexes of the adjacent regions of central, southern, and eastern Kazakhstan. The basic-ultrabasic complexes of northern Kazakhstan were out of study as an ophiolite association.

In 2000–2004, we revealed that the peridotite-pyroxenite bodies attributed to the Shchuchinsk complex are tectonic lenses of ophiolite section participating in the complicated nappe-folded structure of the Kokchetav subduction-collisional zone (Fig. 1). It is composed of terranes of paleosubduction zone and accretionary wedge formed at different depths and juxtaposed in the Early Ordovician [5–7]. Some of them were metamorphosed together with rocks of megamelange complex, e.g., talc-antigorite serpentinites and talc-antigorite schists within

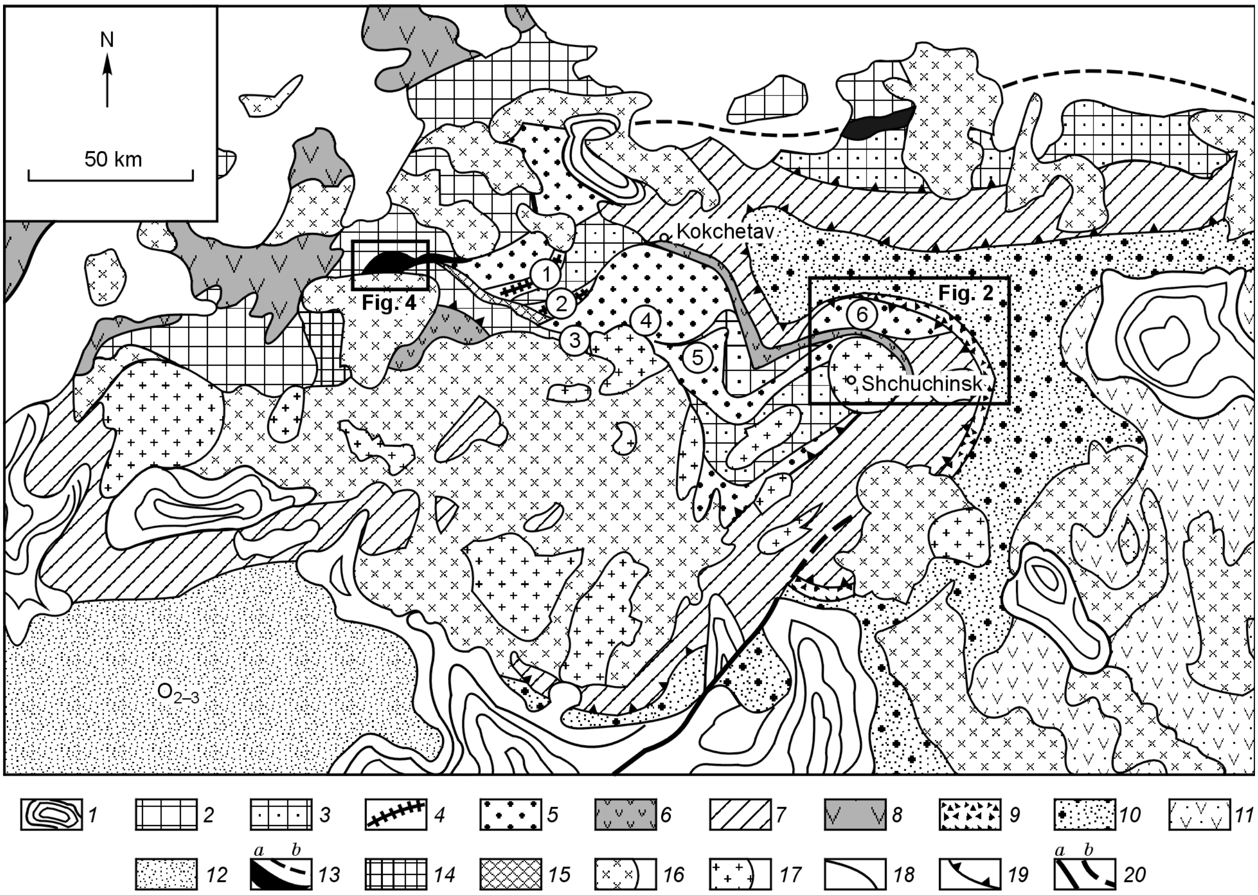

Fig. 1. A tectonic scheme of northern Kazakhstan with localized mafic-ultramafic complexes. ***1*** **— Devonian-Late Paleozoic volcanosedimentary basins;** ***2, 3*** **— fragments of Kokchetav and Shat (northeast of Kokchetav) microcontinents:** ***2*** **— with retrograde metamorphism in greenschist facies,** ***3*** **— with sediments metamorphosed in subduction zone to amphibolite facies;** ***4, 5*** **— megamelange belt (terranes of paleosubduction zone):** ***4*** **— diamondiferous gneisses and coesite eclogites (encircled digits denote terranes: 1 — Barchi, 2 — Kudym-Kol'),** ***5*** **— other terranes contained eclogites, garnet amphibolites, garnet peridotite within granite gneisses and mica schists (terranes: 3 — Sulu-Tobe, 4 — Enbek-Berlyk, 5 — Kulet, 6 — its analogs north of the town of Shchuchinsk);** ***6*** **— Vendian(?) volcanosedimentary rocks in accretionary prism;** ***7*** **— Early Ordovician accretionary prism including fragments of ophiolites of Shchuchinsk complex, conventionally of Vendian-Early Cambrian age;** ***8*** **— Vendian–Cambrian island-arc volcanosedimentary rocks of the Ishim arc;** ***9*** **— Late-Arenigian syntectonic olistostrome;** ***10*** **— Ordovician volcanosedimentary rocks of Stepnyak trough;** ***11*** **— Ordovician volcanogenic units of Stepnyak island arc;** ***12*** **— Middle-Upper Ordovician shelf(?) deposits;** ***13*** **— Late Cambrian–Early Ordovician Shalkar ophiolites and their possible analogs:** ***a*** **— established,** ***b*** **— supposed;** ***14*** **— conventionally Middle-Late Cambrian Krasnomaisky alkali-ultrabasic complex;** ***15*** **— conventionally Middle-Late Ordovician gabbro-pyroxenite-norite Zlatogorsky layered massif;** ***16*** **— Ordovician-Silurian granites;** ***17*** **— Devonian granites;** ***18*** **— deformed planes of Late Cambrian-Early Ordovician faults;** ***19*** **— Late Arenigian-Caradocian frontal overthrust of Kokchetav subduction-collision complex upon Stepnyak trough;** ***20*** **— Late Paleozoic strike-slip faults:** ***a*** **— established,** ***b*** **— supposed.**

and around the Sulu-Tobe terrane made up of mica schists with bodies of eclogites [5]. The peridotite-pyroxenite bodies of the Shchuchinsk complex intruded by dikes of plagiogranites together with serpentinite schists and metabasalts sheets in the greenschist and amphibolite facies of metamorphism contribute more to the structure (see Figs. 1 and 2) of the accretionary prism [5–7]. The ophiolite section is most completely represented (see Figs. 2 and 3) near Zhanatalap Village. The nappe-imbricated structure is composed of serpentinite schist (up to 30 m thick), amphibole gabbro and gabbro-amphibolite (up to 100–120 m) intruded by plagiogranites (up to 20–30 m thick), of pillow-lava and pillow-breccia (up to 100 m thick). The Shchuchinsk complex was not dated, supposedly, it might be of Vendian–Early Cambrian age.

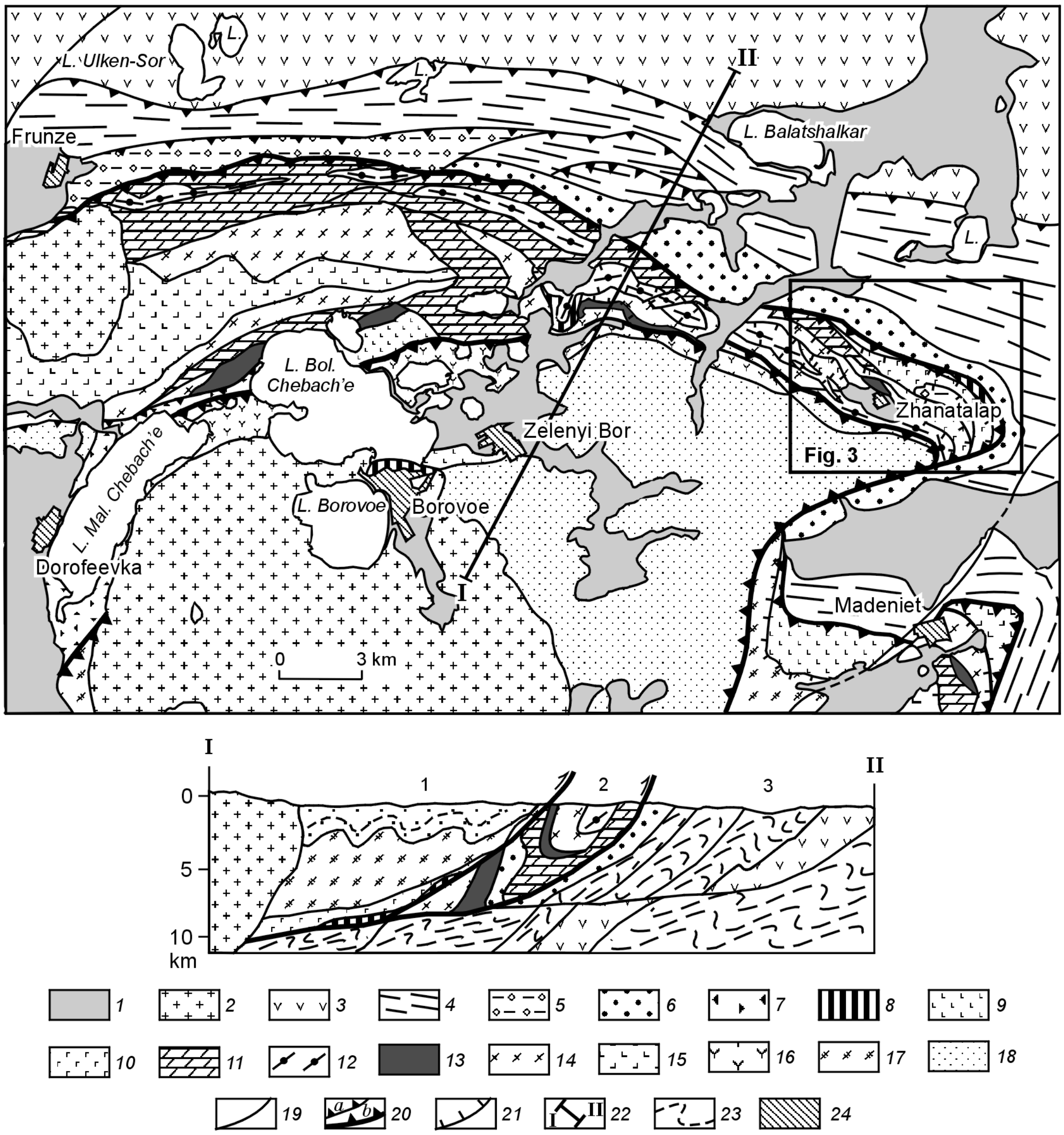

Fig. 2. A geological scheme and section of the zone of junction of the Kokchetav massif and Stepnyak trough and location of ophiolites of the Shchuchinsk complex. ***1*** **— Neogene-Quaternary deposits;** ***2*** **— Devonian granites of Borovoe Massif;** ***3–6*** **— units of Stepnyak Early-Middle Ordovician fore-arc trough:** ***3*** **— Tremadocian silica-volcanogenic,** ***4*** **— Llanvirnian-Early Caradocian silica-siltstone,** ***5*** **— Early Ordovician(?) conglomerates and sandstones,** ***6*** **— Late Arenigian olistostrome;** ***7–16*** **— units of accretionary prism:** ***7*** **— Early Arenigian olistostrome,** ***8–10*** **— Early Vendian-Cambrian Shchuchinsk ophiolite complex:** ***8*** **— serpentinite and serpentinite schists,** ***9*** **— metabasalts,** ***10*** **— gabbro-amphibolites,** ***11*** **— Precambrian graphite-bearing mica schists and amphibole-bearing marbles (Sharyk Formation) subjected to Early Ordovician metamorphism,** ***12*** **— Precambrian granite gneisses subjected to Early Ordovician metamorphism including blastomylonitization and mylonitization,** ***13*** **— Cambrian quartz-muscovite-microcline gneisses with bodies of eclogites and garnet amphibolites,** ***14*****,** ***15*** **— Vendian-Cambrian island-arc(?) complex:** ***14*** **— amphibolites and gneisses,** ***15*** **— metagabbro-amphibolites,** ***16*** **— Vendian-Cambrian(?) island-arc units: andesite-basalt lavas and tuffs, limestones;** ***17*****,** ***18*** **— Precambrian units of Kokchetav microcontinent:** ***17*** **— granite gneiss of basement,** ***18*** **— quartz sandstones and chlorite-sericite schists of cover;** ***19*** **— Late Paleozoic strike-slip faults;** ***20*** **— Early-Middle Ordovician overthrusts:** ***a*** **— in boundary band of Stepnyak trough,** ***b*** **— bordering accretionary prism;** ***21*** **— deformed planes of Early Ordovician overthrusts;** ***22*** **— section line (tectonic units: 1 — Kokchetav microcontinent, 2 — accretionary complex, 3 — Stepnyak fore-arc trough); 23 — dips and strikes of folding in the microcontinent cover;** ***24*** **— populated area.**

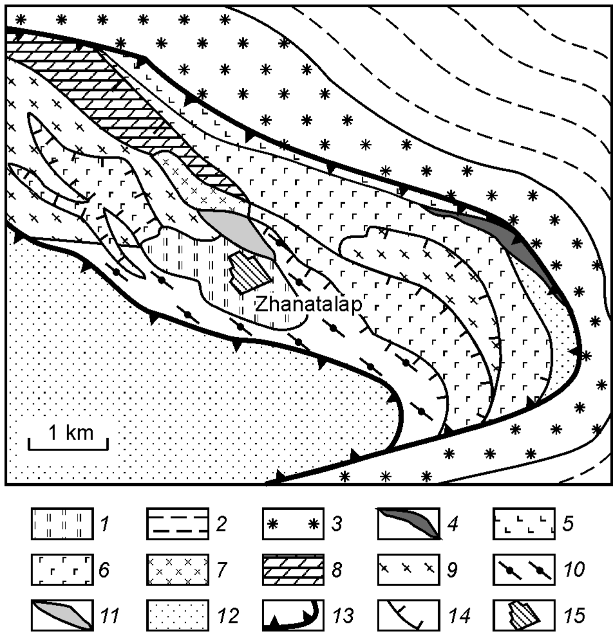

Fig. 3. A geological scheme of occurrence of the Shchuchinsk ophiolites near Zhanatalap Village. ***1*** **— Neogene-Quaternary deposits;** ***2*** **— Llanvirn-Early Caradocian silica-silty units of Stepnyak fore-arc trough;** ***3*** **— Late Arenigian olistostrome;** ***4–7*** **— Shchuchinsk Late Vendian-Cambrian ophiolite complex:** ***4*** **— serpentinite and serpentinite schists,** ***5*** **— metabasalts,** ***6*** **— gabbros,** ***7*** **— plagiogranites;** ***8*** **— Precambrian graphite-bearing micaceous schists and amphibole-bearing marbles (Sharyk Formation);** ***9*** **— Precambrian mylonitized granite gneisses;** ***10*** **— mylonites and blastomylonites on granite gneisses;** ***11*** **— Cambrian quartz-muscovite-microcline gneisses with bodies of garnet amphibolites;** ***12*** **— Precambrian quartz sandstones and chlorite-sericite schists of Kokchetav microcontinent cover;** ***13*** **— Early-Middle Ordovician overthrusts;** ***14*** **— deformed planes of Early Ordovician overthrusts;** ***15*** **— populated area.**

The Krasnomaisky alkaline-ultrabasic complex is represented by intrusive bodies occurring at the boundary of the megamelange belt and by the block of the Kokchetav microcontinent. Its rocks are intensely reworked by polychronous metasomatic processes, with their Rb-Sr age about 460 Ma [8].

Drilling and geophysical data show that the gabbro-pyroxenite-norite rocks of the Zlatogorsky massif is an example of classical layered massif that exhibits well-expressed concentrical inner zoning with elements of magmatic layering and rhythmicity [1].

According to our data, the Shalkar massif and some of the above massifs of the Zlatogorsky complex can be referred to as suprasubduction ophiolites. Unlike oceanic ophiolites exemplified by the Shchuchinsk complex, the suprasubduction ophiolites better preserved their internal structure, including the lower banded pyroxenite-gabbro complex, the middle complex of banded hornblende gabbro, the upper complex of parallel dikes, and basalts associated with siliceous rocks. However, unlike the banded intrusions of the Zlatogorsky massif, they experienced tectonic deformations widely expressed in the Kokchetav subduction-collision zone.

STRUCTURAL POSITION AND SECTION OF THE SHALKAR OPHIOLITES

The Shalkar ophiolites and some outcrops of the Zlatogorsky complex extend north and west of the town of Kokchetav along the boundary of the large block of the Kokchetav microcontinent and megamelange belt (see Figs. 1 and 4). They lie north of Lake Shalkar and are more than 14 km long and 3 to 6 km wide. The ophiolites are surrounded by Late Ordovician and Devonian granites. The volcanic rocks and dikes of ophiolite complex near the contact with the Late Ordovician-Early Silurian granites near Shalkar Village are metamorphosed in a band up to 500 m wide and are intruded by veined bodies. The ophiolites are separated into a series of tectonic sheets,

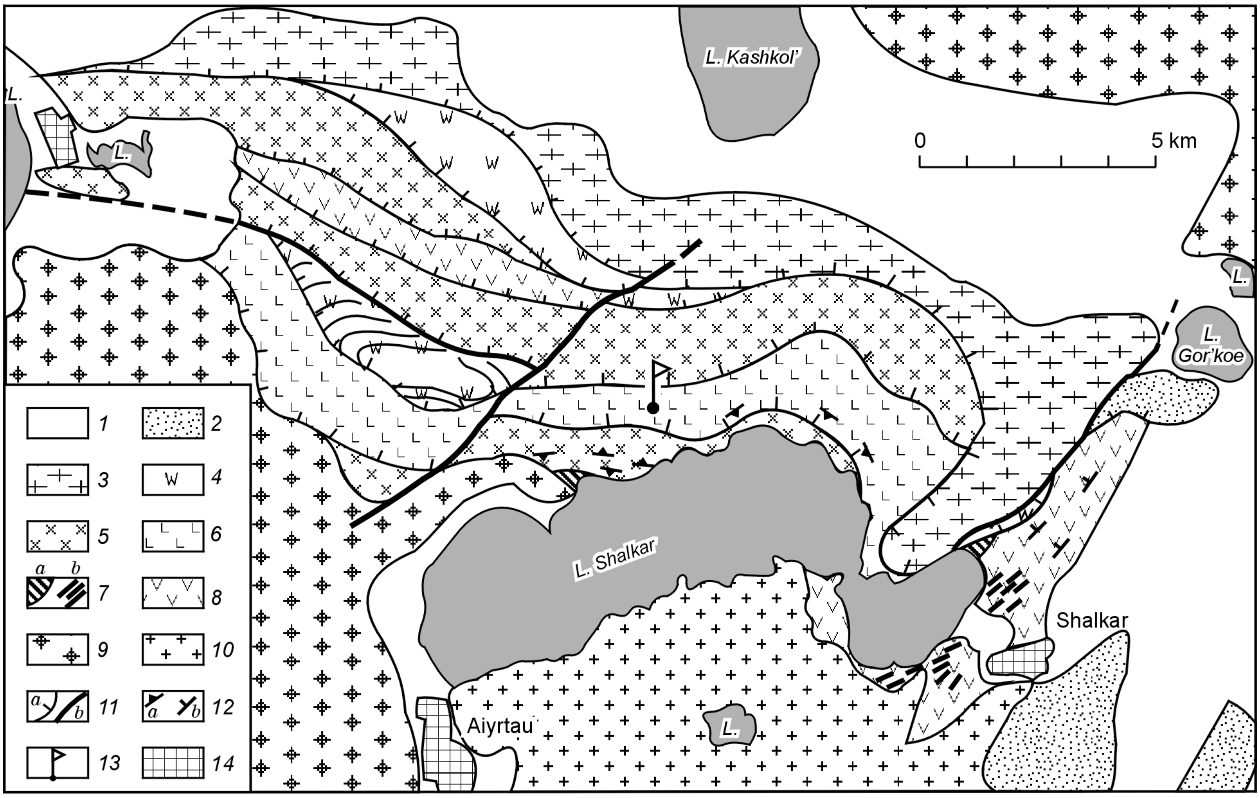

Fig. 4. A scheme of geologic structure of the Shalkar ophiolite complex. ***1*** **— Neogene-Quaternary deposits;** ***2*** **— Middle-Late Ordovician molassa;** ***3, 4*** **— Kokchetav microcontinent:** ***3*** **— granite gneisses,** ***4*** **— quartz sandstones and quartzites of Kokchetav Formation;** ***5–8*** **— Shalkar ophiolite massif:** ***5*** **— lower pyroxenite-gabbro complex,** ***6*** **— middle banded gabbro,** ***7*** **— complex of parallel dikes (*****a*****) and sills (*****b*****),** ***8*** **— basalts with siliceous layers;** ***9*** **— Late Ordovician-Silurian granites and granodiorites of Zerenda complex;** ***10*** **— Early Devonian granites;** ***11*** **— faults:** ***a*** **— Early-Middle Ordovician strike-slip faults,** ***b*** **— Late Paleozoic overthrusts;** ***12*** **— strikes and dips:** ***a*** **— magmatic banding,** ***b*** **— layering;** ***13*** **— sample location of plagiogranites 03-88-2;** ***14*** **— populated area.**

most likely, inverted. As a whole, the tectonic sheets are subsided northward, the basalts and the complex of parallel dikes occupy the lower story, while the lowermost parts of ophiolite sections—the lower banded pyroxenite-gabbro complex and middle complex of weakly banded hornblende gabbro—are at the top of the tectonic package of sheets. The basement is made up of granite-gneisses and metamorphic schists; there are also lenses of quartzites, quartz sandstones, and quartzite-schists of the Kokchetav Formation representing the cover of the Kokchetav microcontinent.

On the basis of detailed mapping we interpret the structure of the Shalkar ophiolites as nappe-imbricated, located at the base of the Kokchetav microcontinent and thrust together with it upon the megamelange belt (see Figs. 1 and 4).

The contacts of the ophiolites with the host rocks and the host rocks themselves are usually hidden. Therefore, this is only one of the possible interpretations. But the internal structure of the massif at the northern shore of Lake Shalkar is exposed well and is interpreted unambiguously. From bottom to top, four tectonic sheets are recognized in the inverted section:

— pillow lavas with siliceous rocks crossed by swarms of subparallel dikes;
— complex of parallel dikes (exposed in fragments on the northern and northeastern shores of the lake);
— amphibole gabbros of weakly banded (lenticular-banded) structure;
— gabbro-pyroxenites of brecciated banded structure.

In composition, the tectonic sheets correspond to the section of ophiolites including the lower gabbro-pyroxenite complex, middle banded gabbro, and the upper complex of parallel dikes and basalts.

The tectonic sheets sandwich lenses of the rocks of the Kokchetav microcontinent, which makes up large areas northwest of the Shalkar ophiolites.

The lower gabbro-pyroxenite complex is exposed on capes of the northern shore of the lake and in quarries northeast of it, at the mark 339 m. The quarry complex is composed of alternating wehrlites, amphibolized pyroxenites, melanocratic to leucocratic gabbros with veins of pegmatoid hornblende gabbros and veins of plagiogranites which were sampled for Zr dating. The contact between the melanocratic brecciated-banded gabbros and the middle unit of more uniform medium-grained amphibole gabbros was observed for more than 1 km along the northern shore of the lake. Along the contact there are zones of deformed migmatite-like rocks with numerous lenses and veins of diorites and plagiogranites, folds of various ranks and flow structures. The predominant strikes and dips of banding suggest that the internal structure of the tectonic sheet dips chiefly southward.

The middle gabbros have nonpersistent lenticular banding crossed by dikes of diabases and gabbro-diabases. The azimuths of banding dip vary from northern to southern to follow gabbro deformations.

The dike complex is represented by several variants: individual dikes and dike swarms in intermediate amphibolized gabbro; complex of parallel dikes (Fig. 5); swarms of parallel dikes in basalts.

The basalt complex is denuded in the eastern part of the lake, where it is intruded by dikes in many places and is recognized in the northwestern part of the massif (by outcrops and debris). Some outcrops well expose pillow lavas and pillow breccias with siliceous cement and separate lenses of hyaloclastites with round glassy fragments. Variolitic texture is distinctly visible in the center of large (up to 0.5 m) pillows.

Of great importance is the discovery of a complex of parallel dikes indicating that the massif is a typical ophiolite which was subject to extension. The dike complex observed on the northwestern shore of the lake near the road (Fig. 5) is represented by parallel dikes of diabases, fine-grained gabbros and diabases 0.2 to 0.5 m thick with one-sided zones of chill and by a screen (or dike?) of medium-grained hornblende gabbros. The azimuth of dike strike is 320–330°. Another outcrop of parallel dikes was observed in some exposures of the northeastern shore of the lake. There are also dikes of acidic composition, which probably were bearing on the manifestation of Devonian granite intrusions.

Swarms of parallel dikes among basalts were observed in a quarry on the eastern termination of the lake, north of Shalkar Village (see Fig. 4). The dikes are represented by alternating gabbros, gabbro-diabases, and diabases, separated by bands of massive and columnar basalts with zones of epidotization. Late dikes of acidic composition, probably, of Devonian age, are also widespread in this region.

As a result of our studies, a typical section of ophiolitic gabbros, gabbro-pyroxenites, dike complex, and basalts have been mapped and described. The section is deformed, overturned, and tectonically sliced, but many features of ophiolites are well preserved (see Fig. 4).

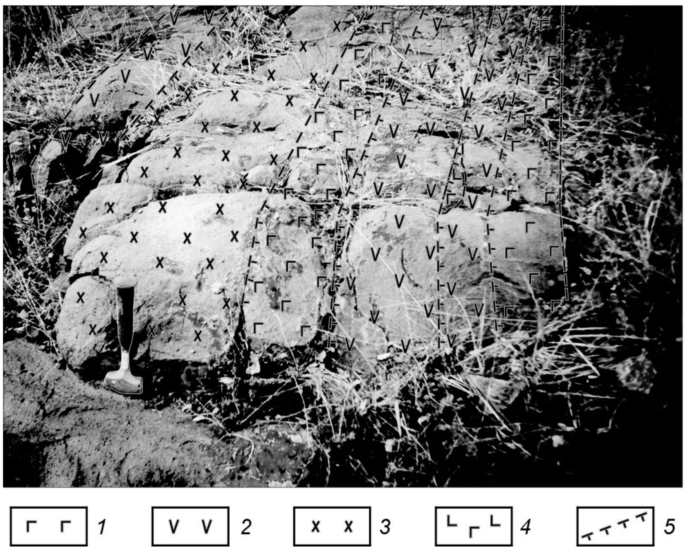

Fig. 5. A photograph of the complex of parallel dikes. ***1*** **— fine-grained gabbro;** ***2*** **— fine-grained diabase;** ***3*** **— coarse-grained diabase;** ***4*** **— medium-grained hornblende gabbro;** ***5*** **— chill zones.**

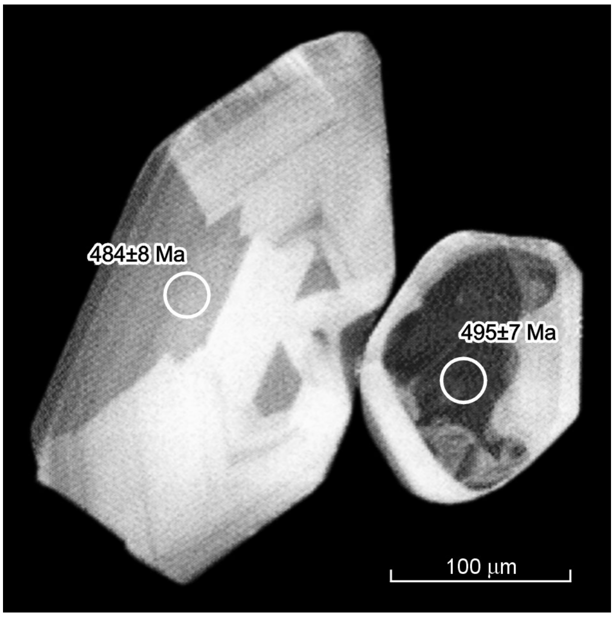

Fig. 6. A cathodoluminescent image of zircon crystals from plagiogranites (sp. 03-88-2).

AGE

To determine the age of the ophiolite association, we studied plagiogranite sample 03-88-2 (located at 53°13′254″ N, 68°23′037″ E) breaking through the gabbro-pyroxenite complex (see Fig. 4). SHRIMP-analysis of zircons from plagiogranites was performed by D. Rubatto at Australian National University. The sample contains crystals of zircon with well-expressed zoning (Fig. 6). Zoning of this kind is typical of magmatic zircons from gabbroids or late differentiates of mafic magmatism such as plagiogranites. Most of studied crystals have zonal structure at margins.

Thirteen U-Th-Pb SHRIMP-analyses were carried out for different crystals. The content of U varies from 53 to 457 ppm, being 100 ppm in the majority of analyses; Th varies from 11 to 248 ppm; Th/U is 0.3–0.6, which is typical of magmatic zircons. The age of crystals varies within 460–495 Ma. Statistical analysis has revealed two late ages, which are bearing on Pb loss. The other eleven analyses using $^{206}Pb/^{238}U$ yield an age of 485±6 Ma with MSWD = 1.6. Analytical results are shown in Fig. 7. There is no difference between ages of the central and marginal parts of crystals, which permits the crystal zoning to be interpreted as a result of magmatic crystallization. This age is interpreted as time of crystallization of plagiogranites, which usually expressed at the last stages of formation of ophiolite associations. In general, the Shalkar ophiolites date from the Late Cambrian-Early Ordovician (495–485 Ma) (Figs. 6 and 7).

GEOCHEMISTRY OF IGNEOUS ROCKS

The rock-forming oxides were determined by the X-ray-fluorescent method on the device “Nauchpribor” in accordance with GOST 41-08-212-82 at the United Institute of Geology, Geophysics, and Mineralogy, Novosibirsk (analyst A.D. Kireev), and rare-earth and trace elements were analyzed by ICP-MA on the Finnigan Element-2 device at the Institute of Geochemistry, Irkutsk (analyst A.Yu. Mitrofanova).

Table 1 reports data on the chemistry of the igneous rocks of the Shalkar ophiolites: complex of parallel dikes (hereafter diabases) and effusives (hereafter basalt andesite). In content of silica, they cover the range from basic to intermediate rocks, and in content of silica and total alkalies (TAS), they belong to basalts, trachybasalts, and basalt trachyandesites. The content and pattern of distribution of rare-earth and trace elements for the explored samples are very close. In contents of rock-forming elements, the basalt trachyandesite is very close to alkaline varieties of volcanites of island arcs (e.g., of the Aleut arc), and the diabases, to high-Ti intraplate basalts [9]. As to trace elements, the studied rocks are distinctly enriched in Ti (1.05 and 2.7 wt.%), Nb (20 ppm), and LREE (41–53 ppm) and depleted in such incompatible elements as Zr, Hf, V, and Eu.

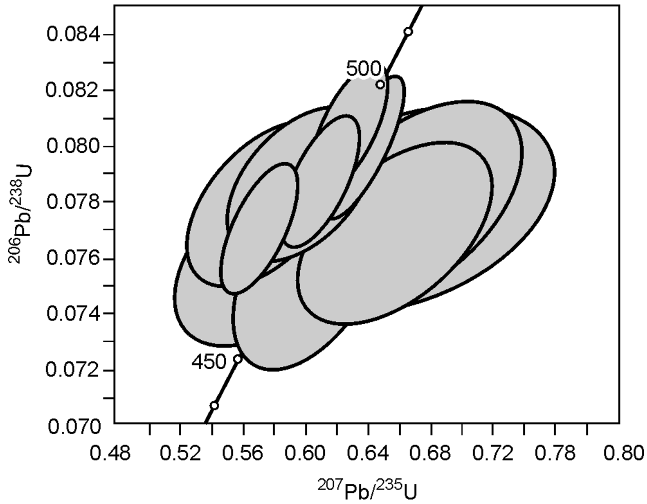

Fig. 7. A concordia diagram of SHRIMP-dating of plagiogranites (sp. 03-88-2).

In the diabases (sp. 03-87-3 and sp. 03-87-4) the contents of TiO_2 and P_2O_5 vary from 2.6 to 2.8 and from 0.7 to 0.9 wt.%, respectively; they contain 14.7 wt.% Al_2O_3, which is less on average than in island-arc tholeiites (IAT). The value of Zr/Nb varies from 10 to 12, i.e., close to those for OIB. Curves of REE distribution (Fig. 8, *a*) show that the diabases are evidently enriched in LREE with $La_{N_{av}} = 43$, $(La/Yb)_N = 5.9–6.1$. Eu minimum exists. The degree of differentiation of LREE and HREE is normal to high: $(La/Sm)_N$ varies from 2.7 to 2.8, and $(Gd/Yb)_N$, from 1.9 to 2.1. It is seen from the distribution of trace elements normalized to primitive mantle (pm) (see Fig. 8, *b*) that the specimens have a Nb minimum relative to La and Th ($(Nb/La)_{pm} = 0.42–0.48$, $(Nb/Th)_{pm} = 0.35–0.27$), which is universally admitted to be typical of the diabases formed in the suprasubduction conditions with participation of the material of continental crust (Th enrichment relative to Nb is higher than La enrichment ($(Th/Nb)_{pm} > (La/Nb)_{pm}$) (see Fig. 8, *b*) [10, 11].

Basalt trachyandesite (sp. 03-85) is characterized by moderate contents of Ti and higher contents of P, with 16.7 wt.% Al_2O_3, which on average is closer to IAT; Zr/Nb = 9, which is still lower than in diabases. The pattern of REE distribution (see Fig. 8, *a*) is characterized by a still greater enrichment in LREE with $La_{N_{av}} = 53.7$, $(La/Yb)_N = 11.3$. There is a distinct Eu minimum. The degree of differentiation of LREE and HREE is high: $(La/Sm)_N = 5$ and $(Gd/Yb)_N = 3.1$. The multicomponent spectrum of trace elements (see Fig. 8) also shows a Nb minimum ($(Nb/La)_{pm} = 0.42$, $(Nb/Th)_{pm} = 0.13$), and Th enrichment relative to Nb is still more distinct (see Fig. 8, *b*).

Increased contents of LREE and Th imply that the crustal component participates in the melt, which is typical of intracontinental and island-arc basalt series, in which, however, the level of these elements is lower [12]. On the other hand, high contents of Ti and Nb suggest that components of recycled subducted slab participated in the melt [13]. Therefore, the geodynamic conditions under which the rocks of this composition might be formed are, most likely, those of back-arc rifting under which the melts were formed with the participation of Nb- and Ti-enriched mantle components in combination with the suprasubduction setting of melt formation with the subsequent trapping of the material of continental crust.

DISCUSSION AND CONCLUSIONS

Ophiolites represented by gabbro-pyroxenite complex, a complex of basalt dikes, and diabases are indicators of rift-spreading structures, and are typical of the settings of open oceans, marginal and back-arc seas (subduction-related zones of extension). The latter appear at the initial stages of formation of ensimatic island arcs when oceanic crust is going down beneath ocean crust. In the process, igneous rocks of basalt-andesite composition with typical boninite type of magmatism form in the island arc. The ophiolite complexes of this kind are widespread in the Ural-Mongolian belt as part of Late Precambrian-Early Paleozoic folded belts [15, 16]. In the case of microcontinent-island arc collision a jump of subduction zone occurs, and a new zone of subduction appears

Table 1

Composition of Rock-forming Oxides and Trace Elements of Igneous Rocks of Shalkar Ophiolites

Component	Specimen		
	03-85	03-87-3	03-87-4
SiO_2, wt.%	55.05	48.59	49.29
TiO_2	1.025	2.584	2.786
Al_2O_3	16.66	13.72	13.3
Fe_2O_3	8.89	14.46	14.83
MnO	0.146	0.22	0.22
MgO	3.94	4.58	4.3
CaO	3.27	8.49	8.23
Na_2O	3.6	2.77	1.81
K_2O	4.4	1.62	1.3
P_2O_5	0.377	0.752	0.892
LOI	2.23	2.05	2.22
Total	99.78	99.92	99.29
La, ppm	53.7	41.0	44.9
Ce	107.1	86.4	97.0
Pr	11.9	11.8	12.7
Nd	41.9	44.3	49.2
Sm	6.7	9.2	10.5
Eu	1.6	2.4	3.0
Gd	12.2	12.0	12.2
Tb	1.3	1.5	1.8
Dy	5.1	7.6	9.2
Ho	1.1	1.7	1.9
Er	2.7	4.4	5.3
Tm	0.4	0.7	0.8
Yb	3.2	4.5	5.1
Lu	0.4	0.6	0.7
Cr	32.6	24.3	23.9
Co	17.1	37.8	36.5
Ni	26.3	25.1	15.5
Sc	23.4	35.0	35.6
V	165	315	325
Rb	85	61	47
Sr	198	321	277
Ba	200	100	100
Ta	1.4	1.3	1.0
Nb	23.5	20.4	19.5
Zr	212	208	241
Hf	4.2	4.8	5.1
Th	20.9	6.9	8.6
Y	29.0	42.0	42.6
U	3.7	1.8	2.0
Pb	8.8	8.7	7.9

Note. Sp. 03-85 — basalt trachyandesites from pillow lavas; basalts of dike complex: sp. 03-87-3 (coarse-grained diabase), sp. 03-97-4 (fine-grained diabase).

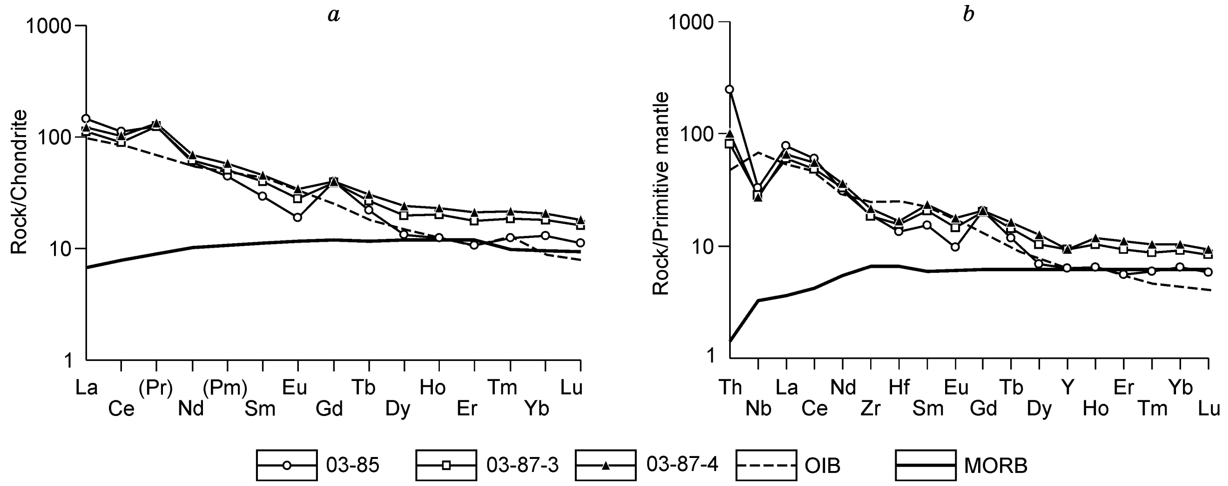

Fig. 8. Patterns of distribution of rare-earth and trace elements in basalts from the complex of parallel dikes and pillow lavas: 03-87-3 — coarse-grained diabase; 03-87-4 — fine-grained diabase, and 03-85 — pillow lava; *a* — chondrite-normalized curves of REE distribution; *b* — multicomponent diagrams of distribution of trace elements normalized to primitive mantle. Norms are borrowed from [14].

beneath the accretionary wedge comprising the microcontinent. In this case the collision setting gives rise to subduction setting, which can lead to the formation of a subduction-related zone of extension and ophiolite associations in them. Settings of this kind remain to be studied. A sum of tectonical, geochronological, and geochemical data permits the Shalkar ophiolite complex to be referred to as this type of geodynamic structures, which marks the initial stage of formation of the new subduction zone in the hinterland of the accreted microcontinent. The period of manifestation of this kind structure should be short, because the deepening of the subduction zone leads to island-arc magmatic formations. By the example of the Shalkar ophiolites, we have estimated it at 10 Myr (495–485 Ma). These formations were followed by the powerful island-arc magmatism of the Ordovician Stepnyak arc. The reported geochemical data of the rocks of dike complex and diabases of the Shalkar complex indicate the complex magmatic system, which can be explained by the suprasubduction origin of the ophiolite association.

Dobretsov et al. [5–7] believe that the Kokchetav metamorphic belt hosting UHP-HP rocks experienced the multistage Vendian-Early Ordovician tectonic evolution. The subduction of the lithosphere of the Paleoasian ocean containing blocks of continental crust and the two-step collision of the Kokchetav microcontinent with the Vendian-Ordovician island-arc system ultimately led to the exhumation of UHP-HP rocks and formation of the Kokchetav massif. In the Vendian-Cambrian the Kokchetav subduction complex formed, which consists of juxtaposed terranes of paleosubduction zone and accretionary wedge originated at different depths. In the period from 495(500)–485 Ma the main tectonic movements were fixed in the accretionary prism and, partly, in the megamelange zone. In the same period, a jump of subduction zone occurred, which led to the formation of the Shalkar suprasubduction ophiolites (495–485 Ma). Then (485–460 Ma) the subduction zone was deepened and, as a result, a fore-arc basin and a new, Stepnyak, island arc formed. Simultaneously, as a consequence of subduction processes the Kokchetav microcontinent tectonically overlapped and deformed the ophiolites thrusting them upon the megamelange belt, which in turn was thrust upon the Stepnyak fore-arc trough [5–7].

Thus, the results of our study show that the Shalkar ophiolite massif is composed of a series of tectonic sheets including basalts, complex of parallel dikes, banded gabbro, layered complex of gabbro-pyroxenites broken by plagiogranite dikes. The tectonic sheets are subsided northward and are confined to the basement of a large nappe made up of rocks of the Kokchetav microcontinent thrust upon the megamelange complex with UHP-HP rocks. Igneous rocks from dikes and effusions are similar in chemical composition, chemical distribution of impurity elements with typical Eu and Ta-Nb minima and higher contents of LREE. Generally, in chemical composition they are characterized as basalts from calc-alkali island-arc to alkaline series of back-arc basins and paleo-oceanic islands. The complex magmatism of the Shalkar ophiolites is probably due to their formation under the conditions of suprasubduction zone of extension and to the fact that they belong to the setting of the initial stage of formation of island arc. The period of formation of the ophiolite massif spans from 495 to 485 Ma. It corresponds to the time of jump of subduction zone into the hinterland of the microcontinent and onset of the Stepnyak island arc [6, 7].

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REFERENCES

1. Mikhailov, N.P. (ed.), *Petrography of Central Kazakhstan. Vol. 1. Intrusive formations of mafic and ultramafic rocks* [in Russian], 360 pp., Nedra, Moscow, 1971.

2. Ermolov, P.V., N.V. Polyansky, and N.L. Dobretsov, Ophiolites of the Chara complex, in *Kazakhstan ophiolites* [in Russian], 103–178, Nauka, Alma Ata, 1981.

3. Yakubchuk, A.S., V.G. Stepanets, M.Z. Novikova, et al., Exposure of axial paleospreading zone in Ordovician ophiolites of Central Kazakhstan, *Dokl. AN SSSR*, **303**, 5, 1198–1202, 1989.

4. Avdeev, A.V., Paleodynamic map of Southern Kazakhstan, *Geologiya i Geofizika (Russian Geology and Geophysics)*, **35**, 7–8, 111–115(93–97), 1994.

5. Dobretsov, N.L., M.M. Buslov, F.I. Zhimulev, A.V. Travin, and A.A. Zayachkovsky, Vendian-Early Ordovician geodynamic evolution and model for exhumation of ultrahigh- and high-pressure rocks from the Kokchetav subduction-collision zone (northern Kazakhstan), *Russian Geology and Geophysics (Geologiya i Geofizika)*, **47**, 4, 424–440(428–553), 2006.

6. Dobretsov N.L., M.M. Buslov, F.I. Zhimulev, and A.V. Travin, The Kokchetav Massif as a deformed Cambrian-Early Caradocian collision-subduction zone, *Dokl. Earth Sci.*, **402**, 501–505, 2005.

7. Dobretsov, N.L., M.M. Buslov, and F.I. Zhimulev, Cambrian-Ordovician tectonic evolution of the Kokchetav metamorphic belt, northern Kazakhstan, *Russian Geology and Geophysics (Geologiya i Geofizika)*, **46**, 8, 785–795(806–816), 2005.

8. Letnikov, F.A., Yu.A. Kostitsyn, N.V. Vladykin, A.A. Zayachkovskii, and E.I. Mishina, Isotopic characteristics of the Krasnyi Mai ultramafic alkaline rock complex, northern Kazakhstan, *Dokl. Earth Sci.*, **399**, 1315–1320, 2004.

9. Frolova, T.I., and I.A. Burikova, *Magmatic formation of modern geotectonic settings* [in Russian], 319 pp., MGU, Moscow, 1997.

10. Arndt, N.T., F. Albarøde, and E.G. Nisbet, Mafic and ultramafic magmatism, in M.J. de Wit and L.D. Ashwal (eds.), *Greenstone Belts*, 233–254, Oxford University Press, Oxford, 1997.

11. Polat, A., R. Kerrich, and D.A. Wyman, The Late Archean Schreiber-Helmo and White River-Dayohessarah greenstone belts, Superior Province: collages of oceanic plateaus, oceanic arcs and subduction-accretion complexes, *Tectonophysics*, **289**, 295–326, 1998.

12. Jenner, G.A., G.R. Dunning, J. Malpas, M. Brown, and T. Brace, Bay of Islands and Little Port complexes, revisited: age, geochemical and isotopic evidence confirm suprasubduction-zone origin, *Can. J. Earth Sci.*, **28**, 1635–1652, 1991.

13. Kerrich, R., A. Polat, D.A. Wyman, and P. Hollins, Trace-element systematics of Mg- to Fe-tholeiitic basalt suites of the Superior Province: implications for Archean mantle reservoirs and greenstone belt genesis, *Lithos*, **46**, 163–187, 1999.

14. Sun, S., and W.F. McDonough, Chemical and isotopic systematics of oceanic basalts: Implications for mantle composition and processes, in A.D. Saunders and M.J. Norry (eds.), *Magmatism in the Ocean Basins. Geol. Soc. London. Spec. Publ.*, **42**, 313–345, 1989.

15. Dobretsov, N.L., E.G. Konnikov, E.V. Sklyarov, and V.N. Medvedev, Marianite-boninite series and evolution of ophiolite magmatism of East Sayan, *Geologiya i Geofizika (Soviet Geology and Geophysics)*, **27**, 12, 29–35(27–33), 1986.

16. Simonov, V.A., N.L. Dobretsov, and M.M. Buslov, Boninite series in structures of the Paleoasian Ocean, *Geologiya i Geofizika (Russian Geology and Geophysics)*, **35**, 7–8, 182–199(157–171), 1994.

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