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Clastic Heavy Mineral Assemblages in Permian–Mesozoic Accretionary Cherty and Siliceous–Clayey Complexes of Sikhote Alin

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Abstract—The paper presents results of the study of assemblages of clastic heavy minerals and geochemical features of some assemblages in several Permian–Mesozoic cherty and siliceous–clayey sequences of Sikhote Alin. They are composed of pelagic and hemipelagic sediments of the Panthalassa (Paleopacific) Ocean. Four typical mineral assemblages and their enviroments are established. In one of the ocean segments, where sedimentary cover formed during the Late Paleozoic–Early Cretaceous, the Permian pelagic domain was characterized by the amphibole–pyroxene assemblage with heavy minerals derived from ophiolites. The Triassic–Jurassic stage was marked by development of the clinopyroxene assemblage with heavy minerals derived from intraplate alkaline volcanic complexes. Middle–Late Jurassic hemipelagic sediments host the zircon–clinopyroxene assemblage with a greater role of continental enviroments and the presence of volcanic products of the convergence zone. Another segment of the ocean accumulated red cherts and siliceous–clayey sediments during the Jurassic–Early Cretaceous under the influence of island-arc volcanism.

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Lithostructural complexes or terranes of accretionary prisms formed in the course of subduction of Paleopacific (Panthalassa) oceanic plates are widespread in the Sea of Japan region of the Asian margin (Natal'in, 1991; Khanchuk, 2000; Kemkin, 2003; Kojima and Kametaka, 2000; and others). They are characterized by the wide development of imbricate thrust dislocations and the presence of melanges, chaotic sedimentary rocks, ophiolites, and packets of tectonic slices with fragments of oceanic sedimentary cover showing the typical "oceanic plate stratigraphy" (Berger and Winterer, 1974). The latter sedimentary succession is a most important feature of ancient accretionary prisms (Isozaki et al., 1990; Matsuda and Isozaki, 1991). It is usually composed of the following rocks (from the base to top): pelagic cherts, hemipelagic siliceous mudstones, terrigenous siltstones, and sandstones. It is believed that such a vertical formation series reflects the history of sedimentation on the oceanic crust from its origination in the spreading ridge to its burial in the subduction zone. This succession yields information on sedimentation settings in different poorly studied areas of the ancient ocean.

The study of heavy mineral assemblages combined with the analysis of geochemical features of their certain varieties is a traditional method applied for the determination of enviroments of clastic rocks (Baturin, 1947; Morton, 1991; Morton and Hallsworth, 1994; and others). The composition of terrigenous minerals in fine-grained sediments of modern oceans was used as an indicator of environments (Petelin, 1965; Murdmaa et al., 1979; Popov and Sval'nov, 1981; and others). Recent studies of Cenozoic sediments in the present-day oceans and marginal seas revealed that clastic heavy mineral assemblages are also indicators of tectonic sedimentation settings (Nechaev, 1991; Nechaev and Isphording, 1993; Nechaev and Derkachev, 1995; Derkachev, 1996). Therefore, the study of heavy minerals in ancient oceanic sediments is a sufficiently reliable method for establishing enviroments for different segments of the ocean and geodynamic sedimentation settings. The first attempt of such a research was made for Sikhote Alin using separate samples from Permian and Triassic–Lower Jurassic cherty and siliceous–clayey rocks enclosed in the Jurassic accretionary complex (Nechaev et al., 1997). It was shown that heavy minerals in Permian cherts originated from ophiolites, while heavy minerals in Mesozoic cherts were derived from alkaline basalts of oceanic islands. Differences in enviroments were explained by different tectonic settings at the Permian and Early Mesozoic stages of pelagic facies accumulation in the ancient ocean. Later on, this inference was confirmed by the study of rock-forming components and heavy minerals in interbeds of clastic rocks within platy cherts (Filippov and Kemkin, 2003). It was also established that some hemipelagic sections were influenced by volcanism in the convergence zone (Filippov et al., 2000).

We analyzed heavy mineral assemblages from cherty and siliceous–clayey rocks of several sedimentary sections representing fragments of ancient oceanic plates in accretionary terranes of the Sikhote Alin region with the consideration of geochemical features of some minerals. Results of this study and the available published data make it possible to determine specifics of source areas in different segments of the Panthalassa Ocean and to reconstruct their evolution and impact on sedimentation based on a more representative factual material.

GEOLOGICAL POSITION OF EXAMINED SECTIONS

Ancient crystalline massifs and terranes of accretionary prisms with fragments of the Early Cretaceous transform margin and island-arc basin are main structural elements of the Sikhote Alin and adjacent regions (Khanchuk, 2000; Khanchuk and Kemkin, 2003). In terms of their age, accretionary prisms are subdivided into the Early–Late Jurassic (Samarka, Nadan'khada–Bikin, Khabarovsk, and Badzhal), Late Jurassic–Early Cretaceous (Taukha), and Albian–Cenomanian (Kiselevka–Manoma) terranes. In our opinion, the Taukha, Samarka, Nadan'khada–Bikin, and Badzhal terranes are elements of a common Jurassic–Cretaceous accretionary prism (Fig. 1).

The Samarka and other structurally and tectonically similar terranes of the Jurassic–Cretaceous accretionary prism are composed of Middle Jurassic–Lower Cretaceous turbidite and olistostrome sediments, melange complexes, and allochthonous blocks. The allochthons are represented by Paleozoic ophiolites, Carboniferous–Permian and Upper Triassic limestones, Upper Permian and Upper Triassic terrigenous rocks, and Upper Paleozoic–Jurassic cherts and siliceous mudstones (Khanchuk, 2000). The Kiselevka–Manoma Terrane consists of Aptian–Cenomanian clayey and clastic rocks and Jurassic–Aptian red cherts and cherts associated with basic volcanics and less common limestones (Khanchuk et al., 1994; Zyabrev et al., 1994). In the Lake Udyl area, the terrane incorporates fragments of the Hauterivian–Barremian island arc (Markevich et al., 1996, 1997).

Sedimentary sections of ancient oceanic plates with fine-grained rocks, which served as an object for the study of heavy minerals, are located at different structural levels of the Samarka (Lyamfana Creek, Mt. Amba, Settlement of Breevka, and Katen River), Nadan'khada–Bikin (Ulitka River), Taukha (Pantovyi Creek), and Kiselevka–Manoma (Manoma River) terranes of the Albian–Cenomanian accretionary prisms.

METHODS

Samples of 0.5 to 1.5 kg were taken from fine-grained rocks of the sections mentioned above for the study of heavy minerals. The heavy minerals were extracted by bromoform after the crushing of samples up to fraction 0.25 mm and the subsequent removal of fraction <0.01 mm. The minerals were identified and counted under the microscope in the transmitted and polarized light using immersion liquids. Unfortunately, some samples lacked or contained an insufficient quantity of heavy minerals. The chemical composition of some minerals was determined at the Far East Geological Institute (Vladivostok) using a JXA-5A X-ray microprobe.

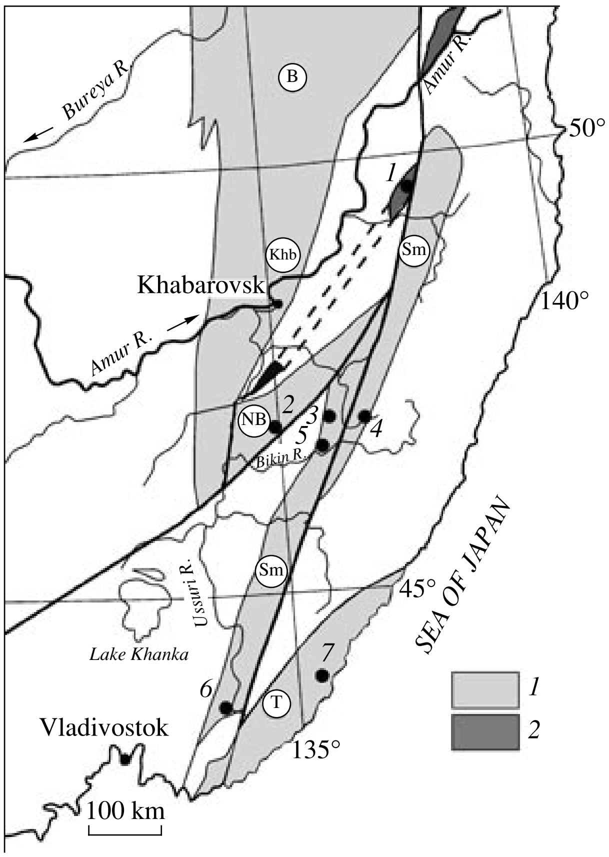

Fig. 1. Location of terranes of accretionary prisms (Khanchuk, 2000) and examined sections. (1) Terranes of the Jurassic–Cretaceous accretionary prism: (B) Badzhal, (Khb) Khabarovsk, (Sm) Samarka, (NB) Nadan'khada–Bikin, (T) Taukha; (2) Kiselevka–Manoma Terrane of the Albian–Cenomanian accretionary prism. Examined sections: (*1*) Manoma River, (*2*) Ulitka River, (*3*) Lyamfana Creek, (*4*) Katen River, (*5*) Mt. Amba, (*6*) Settlement of Breevka, (*7*) Pantovyi Creek.

HEAVY MINERAL ASSEMBLAGES

In total, 62 samples were used for the analysis of heavy mineral assemblages (Table 1). Figure 2 illustrates their stratigraphic position in the examined sections.

Lyamfana Creek. The Lyamfana section is situated in the western part of the Samarka Terrane on the right bank of the Matai River and characterizes the upper

Table 1. Mineral composition (%) of heavy fraction (0.01–0.25 mm) from cherty and siliceous-clayey rocks of accretionary complexes in Sikhote Alin

Sample	Rock	Age	No.	Cpx	Opx	Ol	Hb	Ep	Grn	Zr	Tur	Rt	Sph	Lcx	Ant	Ap	Mt	Ilm	Chr
Lyamfana Creek																			
L45	Silty argillite	J_2bj	205	2.4	–	–	0.5	–	0.5	92.6	0.5	1.0	–	–	–	0.5	–	1.5	0.5
L100	Silty argillite	J_2aal	60	46.8	–	–	3.3	–	23.3	26.6	–	–	–	–	–	–	–	–	–
L101	Silty argillite	J_2aal	65	46.2	–	–	1.5	–	–	52.3	–	–	–	–	–	–	–	–	–
L133	Silty argillite	J_2aal	54	87.0	–	–	3.7	–	–	3.7	–	5.6	–	–	–	–	–	–	–
L186	Siliceous argillite	J_1toa-J_2aal	44	86.4	–	–	2.3	–	–	9.0	–	2.3	–	–	–	–	–	–	–
L251	Siliceous argillite	J_1toa-J_2aal	106	93.4	–	–	6.6	–	–	–	–	–	–	–	–	–	–	–	–
L115	Clayey chert	J_1het-pb$_1$	209	71.8	–	–	4.3	–	1.0	19.1	–	–	–	3.3	–	0.5	–	–	–
L41	Chert	T_3k_2	206	91.5	–	–	3.7	–	–	4.2	–	–	–	0.6	–	–	–	–	–
L81	Chert	T_2l_2	216	96.4	–	–	1.8	–	–	–	–	–	–	–	–	–	1.8	–	–
L79	Chert	T_2an$_3$-l$_1$	89	95.5	–	–	4.5	–	–	–	–	–	–	–	–	–	–	–	–
L49	Chert	T_2	205	19.0	–	–	1.0	–	–	79.5	0.5	–	–	–	–	–	–	–	
L52	Chert	T_2	253	13.0	–	–	1.2	–	3.5	77.2	0.8	0.8	–	3.5	–	–	–	–	–
L62	Chert	T_2an	219	4.5	–	–	1.0	–	3.2	83.1	0.5	1.4	–	3.6	–	–	–	1.8	0.9
L263	Chert	T_2	439	83.4	11.4	–	5.0	0.2	–	–	–	–	–	–	–	–	–	–	–
L64	Chert	T_2an$_2$	190	84.7	–	–	10.0	–	–	5.3	–	–	–	–	–	–	–	–	–
L27	Chert	T_2an$_2$	25	60.0	–	–	8.0	–	4.0	24.0	–	–	–	4.0	–	–	–	–	–
L206	Chert	P_2	136	94.9	–	–	4.4	0.7	–	–	–	–	–	–	–	–	–	–	–
Mt. Amba																			
37–54	Silty argillite	J_1pb$_2$-toa$_1$	85	24.7	–	–	8.2	1.2	2.2	16.5	1.2	–	–	–	10.6	–	33.0	2.4	–
37–47	Tuffite	J_1pb$_2$-toa$_1$	98	35.8	–	–	2.0	8.2	2.0	50.0	–	–	–	1.0	1.0	–	–	–	–
37–46	Tuffite	J_1pb$_2$-toa$_1$	152	80.7	0.7	1.3	5.3	0.7	0.7	2.0	–	–	0.7	–	–	–	7.9	–	–
37–45	Clayey jasper	J_1pb$_2$-toa$_1$	60	40.0	–	–	25.0	3.3	–	–	–	–	–	–	–	–	31.7	–	–
37–44	Clayey jasper	J_1pb$_2$-toa$_1$	222	86.0	–	–	0.5	1.4	–	0.5	–	–	0.5	–	–	0.5	10.1	0.5	–
37–43	Clayey jasper	J_1pb$_2$-toa$_1$	55	76.5	–	–	12.7	1.8	3.6	1.8	–	–	–	–	–	1.8	1.8	–	–
37–70	Siliceous argillite	J_1pb$_2$-toa$_1$	79	79.7	2.5	–	11.4	3.8	–	–	1.3	–	–	–	–	1.3	–	–	–
37–76	Jasper	J_1?	32	71.8	–	–	15.6	–	–	–	–	–	–	–	6.3	–	6.3	–	–
37–67	Jasper	T_3n_3	428	87.2	–	–	6.1	0.7	0.2	–	–	–	–	–	–	–	0.7	5.1	–
37–69	Chert	T_3k	151	76.8	–	–	17.9	–	–	1.3	–	–	–	–	–	0.7	3.3	–	–
37–16	Chert	P_2dr	60	73.3	1.7	–	20.0	5.0	–	–	–	–	–	–	–	–	–	–	–
37–35	Jasper	P_1yht	373	10.5	14.7	0.5	70.0	1.1	–	0.3	–	–	–	–	–	0.3	0.3	1.6	0.8
Settlement of Breevka																			
Br-1	Silty argillite	J_2btj	66	10.6	–	3.0	1.5	–	3.0	81.8	–	–	–	–	–	–	–	–	–
Br-3	Siliceous argillite	J_2aal-bj	208	85.8	0.5	1.0	2.0	1.0	–	8.7	–	–	0.5	–	–	0.5	–	–	–
Br4	Siliceous argillite	J_2aal-bj	33	24.3	15.2	–	3.0	9.1	12.1	33.3	–	–	–	–	–	3.0	–	–	–

Table 1. (Contd.)

Sample	Rock	Age	No.	Cpx	Opx	Ol	Hb	Ep	Grn	Zr	Tur	Rt	Sph	Lcx	Ant	Ap	Mt	Ilm	Chr
VN1/5	Chert	T_3	79	82.3	5.0	–	3.8	–	1.3	7.6	–	–	–	–	–	–	–	–	–
VN1/4	Chert	T_3	140	8.6	2.8	–	59.0	6.4	2.1	14.4	–	–	–	2.1	–	–	0.3	4.3	–
VN1/3	Chert	T_2l_2	71	2.8	1.4	–	2.8	1.4	–	7.0	–	–	–	4.2	–	77.6	–	–	2.8
VN1/1	Chert	T_2l_1	67	59.6	10.4	10.5	10.5	1.5	1.5	3.0	–	1.5	–	1.0	–	–	0.5	–	–
VN1/6	Chert	T_2an_3-l_1	252	2.0	1.6	–	26.5	10.7	2.0	45.3	–	–	–	1.6	–	1.2	–	9.1	–
Katen River																			
K3	Silty argillite	J_2cl	96	–	–	–	–	4.2	3.1	15.6	–	–	2.1	5.2	–	–	–	69.8	–
K2	Siliceous argillite	J_2bt	164	1.2	1.2		0.6	6.6	3.0	21.3	–	0.6	0.6	6.0	–	–	–	58.9	–
K1	Siliceous argillite	J_2bt	71	–	–	–	–	–	2.8	43.4	–	–	1.4	–	–	1.4	–	51.0	–
K82	Clayey chert	J_2bj	180	6.1	5.0	–	87.9	0.5	0.5	–	–	–	–	–	–	–	–	–	–
K30	Chert	T_2l	63	1.6	1.6	–	–	11.1	1.6	26.9	–	–	1.6	–	–	–	–	55.6	–
Ulitka River																			
38/5	Siliceous argillite	J_3t	367	75.7	0.6	–	–	16.9	3.2	1.1	–	–	–	0.3	–	–	1.4	0.8	–
41/10	Siliceous argillite	J_3t	202	33.1	–	–	–	–	6.1	0.8	–	–	–	–	–	–	60.0	–	–
41/11	Siliceous argillite	J_3t	300	1.3	–	–	0.3	–	0.7	85.3	2.7	–	–	–	–	9.7	–	–	–
41/8	Clayey chert	J_3ox-km	72	26.4	–	–	11.1	12.5	2.8	47.2	–	–	–	–	–	–	–	–	–
Pantovyi Creek																			
64–3	Chert	P_2dr	32	84.4	–	–	9.4	6.2	–	–	–	–	–	–	–	–	–	–	–
25–5	Chert	P_2mr	35	28.6	–	–	51.4	–	5.7	5.7	–	–	–	–		2.9	5.7	–	–
25–16	Jasper	P_2mr	427	7.2	–	–	88.5	–	0.5	0.5	–	–	–	0.7	–	0.5	1.6	0.5	–
25–53	Jasper	P_2kb	103	54.3	–	–	30.1	1.7	1.7	5.8	–	–	–		–	1.7	2.9	1.9	–
25–122	Jasper	P_1bl	415	87.5	0.2	–	11.1	0.2	0.2	0.2	–	–	0.2	–	–	–	0.2	0.2	–
25–161	Jasper	P_1yht	453	5.3	–	0.4	85.8	0.4	0.4	1.5	–	–	–	0.2	1.3	0.7	1.1	1.8	1.1
25–188	Jasper	P_1sk	54	79.5	–	–	13.0	5.6	–	1.9	–	–	–	–	–	–	–	–	–
Manoma River																			
M71	Chert	K_1ht	83	68.8	–	–	2.4	–	3.6	13.2	–	–	2.4	–	–	2.4	7.2	–	–
M60	Clayey chert	K_1v	271	98.9	0.7	–	–	–	–	–	–	–	–	–	–	0.4	–	–	–
M57	Tuffite	K_1v	140	95.8	–	–	1.4	–	–	2.1	–	–	–	–	–	0.7	–	–	–
M2	Clastic siliceous rock	J_3?	201	42.9	16.9	–	20.9	5.5	1.0	3.5	–	–	5.5	0.4	–	3.0	0.4	–	–
M33	Jasper	J_2bj	268	98.9	–	–	1.1	–	–	–	–	–	–	–	–	–	–	–	–
M4	Jasper	J_2aal-bj	177	31.0	18.9	4.8	29.5	1.1	–	3.4	–	–	7.9	–	–	0.6	2.8	–	–
M43	Jasper	J_2aal	281	0.7	1.1	–	96.0	1.1	0.7	–	–	–	–	–	–	0.4	–	–	–
M18	Jasper	J_1pb-toa	214	27.2	32.2	–	35.5	–	–	1.4	–	–	–	–	–	–	3.7	–	–
M36	Jasper	J_1het-pb	120	95.8	4.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Note: (Cpx) Clinopyroxene; (Opx) orthopyroxene; (Ol) olivine; (Hb) hornblende; (Ep) epidote; (Grn) garnet; (Zr) zircon; (Tur) tourmaline; (Sph) sphene; (Lcx) leucoxene; (Ap) apatite; (Mt) magnetite; (Ilm) ilmenite; (Chr) chromite; (No.) number of grains; (–) not detected.

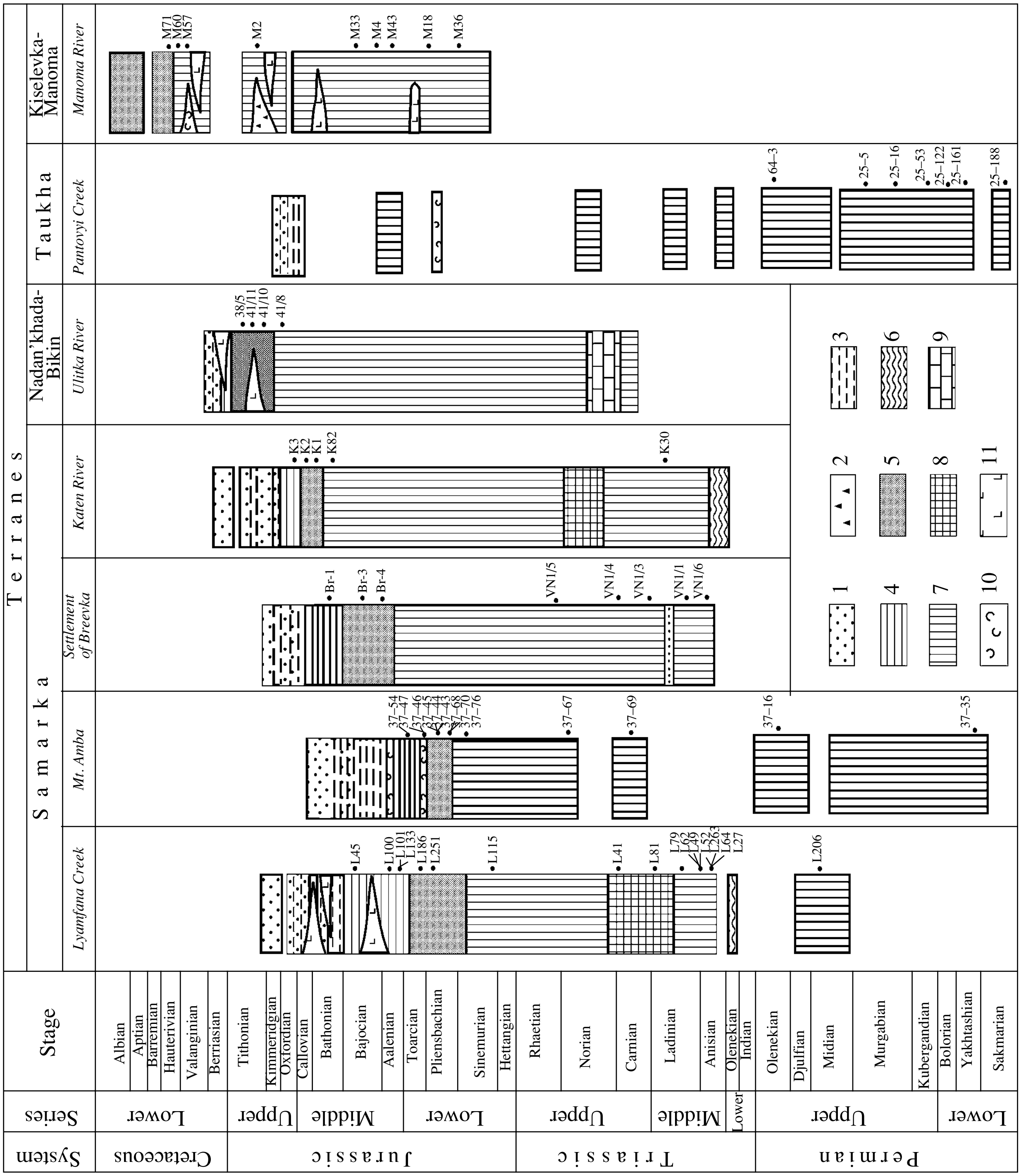

Fig. 2. Lithostratigraphic columns of examined sections in terranes of accretionary prisms in Sikhote Alin and stratigraphic position of samples collected for the analysis of heavy minerals. (1) Sandstone; (2) clastic siliceous rocks; (3) siltstone; (4) silty mudstones; (5) siliceous mudstones; (6) siliceous mudstones with carboniferous cherts; (7) cherts and red cherts; (8) redeposited cherts and cryptic hiatuses; (9) limestones; (10) tuffites; (11) basic volcanics.

structural level of the accretionary prism (Kemkin and Filippov, 2002). The section includes the following rocks (from the base to top): Upper Permian cherts, Lower Triassic siliceous mudstones and carboniferous cherts, Middle Triassic–Lower Jurassic cherts, Pliensbachian–Toarcian siliceous mudstones, Middle Jurassic silty mudstones, and Middle–Upper Jurassic siltstones and sandstones (Filippov et al., 2001). The terrigenous rocks host basic volcanics. Triassic cherts include a cryptic stratigraphic hiatus and associated redeposited cherts at the upper Ladinian–Carnian level (Burii et al., 1990; Burii and Filippov, 1991). The heavy mineral assemblage in Permian, Triassic, and Lower Jurassic cherts and siliceous mudstones consists of dominant angular green and pale green clinopyroxene grains (up to 96%); subordinate hornblende and leucoxene; and rare orthopyroxene, epidote, magnetite, ilmenite, and chromite (Table 1). Middle Triassic cherts contain abundant zircon grains (24–83%) associated with garnet and tourmaline. Zircon occurs as small irregular, usually colorless (occasionally, pale) crystals. The mineral assemblage from the Middle Jurassic silty mudstones is characterized by depletion in pyroxenes and hornblende and drastic enrichment in light pink (rarely, brown) zircon crystals with the coefficient of elongation equal to 1.5–2.5. In some samples, zircon is accompanied by abundant light pink garnet.

Mt. Amba. The Amba section in the Samarka Terrane (Fig. 2) includes the following rocks (from the base to top): Lower Permian red cherts with ferruginous–siliceous rocks, Upper Permian cherts, Upper Triassic–Lower Jurassic cherts and red cherts, Pliensbachian siliceous mudstones and clayey red cherts, Toarcian silty mudstones, and Middle Jurassic siltstones and sandstones (Filippov et al., 2000). Siliceous–clayey varieties enclose tuffite beds. Fine-grained rocks of this section are characterized by the hornblende–clinopyroxene assemblage with subordinate orthopyroxene, epidote, and magnetite. Garnet, zircon, apatite, and ilmenite are rare (Table 1). Permian siliceous rocks contain green clinopyroxene. Contents of orthopyroxene and hornblende are higher. Brown and fulvous clinopyroxene prevails in Upper Triassic and Lower Jurassic rocks, where the share of its green variety decreases to 10%. Tuffites and clayey rocks from the upper part of the section are enriched in zircon.

Settlement of Breevka. The Breevka lithostratigraphic succession consists of the following units (Fig. 2): Ladinian–Middle Jurassic cherts with interbeds of dolomites and sandstones, Aalenian–Bajocian silty mudstones, and Middle–Upper Jurassic siltstones with sandstone interbeds (Kemkin and Rudenko, 1998). Heavy mineral assemblages from these rocks are highly variable (Table 1). Green clinopyroxene prevails in some samples. Hornblende or zircon predominates in other samples. One sample contains abundant apatite. High zircon concentrations are noted in cherts from the lower part of the section and in siliceous–clayey rocks of its upper part. Zircon occurs as small irregular grains in cherts. In siliceous–clayey varieties, it is usually found as colorless to yellowish crystals or their fragments with the coefficient of elongation equal to 1.5–2.5. Orthopyroxene, olivine, epidote, garnet, and leucoxene are common.

Katen River. The Katen section located in the eastern part of the Samarka Terrane includes the following succession: Olenekian–Anisian siliceous mudstones with carboniferous cherts, Middle Triassic–Middle Jurassic cherts and red cherts, Bathonian–Callovian siliceous mudstones, Callovian–Oxfordian silty mudstones, and Upper Jurassic–Lower Cretaceous siltstones and sandstones (Filippov et al., 2001). Cherts are depleted in heavy minerals. One sample contains abundant brown hornblende. Another sample is enriched in ilmenite (55%) and zircon (Table 1). The zircon–ilmenite assemblage predominates in siliceous mudstones. Zircon occurs as colorless to light pink crystals and their fragments with insignificant elongation. Crystals with smoothed apexes and edges, as well as irregular grains, are rare. Pyroxenes and hornblende are subordinate in the mudstones.

Ulitka River. The Ulitka lithostratigraphic succession in the Nadan'khada–Bikin Terrane includes the following units (Fig. 2): Upper Triassic cherts and red cherts with limestone lenses; Kimmeridgian–Tithonian siliceous mudstones; and Berriasian silty mudstones, siltstones, and sandstones (Filippov and Kemkin, 2004). The heavy mineral assemblage in Upper Jurassic siliceous–clayey rocks consists of abundant clinopyroxene (30–70%) and subordinate magnetite, hornblende, and epidote. Some samples are enriched in light pink zircon (Table 1).

Pantovyi Creek. The Pantovyi section located in the Taukha Terrane is characterized by an intricate geological structure (Rudenko and Panasenko, 1990; Panasenko and Rudenko, 1998). Permian cherts and red cherts of a wide stratigraphic (Sakmarian–Doramshanian) range are widespread. The heavy mineral assemblage of these rocks is dominated by green clinopyroxene and green or brown hornblende associated with the subordinate epidote, garnet, zircon, apatite, magnetite, and ilmenite (Table 1).

Manoma River. The Manoma section characterizes the central part of the Kiselevka–Manoma Terrane of the Albian–Cenomanian accretionary prism. The section includes Jurassic–Lower Cretaceous red cherts with alkaline basalts, Aptian siliceous mudstones (Fig. 2), and rare interbeds of siliceous clastic rocks and tuffites (Filippov, 2001). The section is dominated by the amphibole–pyroxene assemblage (Table 1). Green pyroxene grains usually constitute up to 90% of the assemblage. Sample M33 is enriched in brown pyroxene. Hornblende is usually black and less commonly green or brown. These minerals are associated with orthopyroxene (up to 32%). Epidote, garnet, zircon,

Table 2. Chemical composition (wt %) of some heavy minerals from cherty and siliceous-clayey rocks of accretionary complexes in Sikhote Alin

Sample	Rock	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	Total
						Olivine						
Mt. Amba												
37–46	Tuffite	38.39	0.01	0.06	–	20.29	0.28	39.44	–	0.02	–	98.49
37–35	Jasper	39.13	0.02	0.59	–	22.32	0.40	40.03	0.03	0.03	–	102.55
Settlement of Breevka												
Br1	Silty argillite	37.50	0.24	0.21	0.02	26.21	0.40	35.97	0.43	0.04	0.01	101.04
Br3	Siliceous argillite	37.14	0.64	0.20	–	34.86	0.40	25.94	0.15	0.01	0.03	99.37
Br3	Siliceous argillite	37.80	0.11	0.20	0.07	25.38	0.30	32.19	0.16	0.03	–	96.25
Br3	Siliceous argillite	37.96	0.26	0.20	0.04	18.98	0.34	37.61	0.50	0.03	0.01	95.96
Br3	Siliceous argillite	41.09	0.07	0.13	0.02	13.26	0.17	46.40	–	0.02	0.01	101.17
Br3	Siliceous argillite	42.38	0.08	0.17	0.02	9.69	0.15	45.81	–	0.03	–	98.34
Br3	Siliceous argillite	38.87	0.36	0.08	0.05	21.58	0.30	40.10	0.20	0.08	0.01	101.61
VN1/5	Chert	40.74	0.10	–	–	13.33	0.09	46.61	0.02	–	–	100.82
VN1/1	Chert	40.64	0.07	0.15	0.08	13.62	0.17	45.66	0.02	–	0.01	100.42
VN1/1	Chert	40.18	0.07	0.18	0.20	14.18	0.22	43.97	–	0.05	0.02	99.06
VN1/1	Chert	43.29	0.08	0.12	0.06	8.49	0.12	48.40	0.01	0.02	0.02	100.60
Pantovyi Creek												
25–161	Jasper	38.23	0.06	0.02	–	21.48	0.37	40.10	0.01	0.01	0.02	100.30
Manoma River												
M4	Jasper	37.38	0.05	0.10	–	24.77	0.31	36.61	0.19	–	0.01	99.24
M4	Jasper	36.24	0.05	0.07	0.01	27.32	0.33	35.05	0.22	–	0.02	99.10
						Clinopyroxene						
Lyamfana Creek												
L133	Silty argillite	50.87	0.83	2.94	0.03	6.89	0.31	13.72	23.12	0.34	0.01	99.06
L133	Silty argillite	51.37	0.69	2.92	0.02	6.95	0.31	13.81	23.17	0.40	–	99.65
L133	Silty argillite	50.81	0.94	3.59	0.02	7.47	0.32	14.28	23.23	0.38	0.01	101.04
L100	Silty argillite	52.79	0.44	1.41	0.14	6.96	0.19	16.76	22.11	0.37	–	101.06
L101	Silty argillite	52.22	0.62	3.58	1.40	5.46	0.16	17.89	17.39	0.39	–	99.11
L101	Silty argillite	52.49	0.63	3.58	1.36	4.71	0.15	17.05	18.58	0.35	0.01	98.92
L186	Siliceous argillite	51.55	0.37	4.38	0.62	4.27	0.15	16.43	22.55	0.31	–	100.63
L186	Siliceous argillite	52.13	0.36	4.14	0.56	4.27	0.14	16.27	23.27	0.26	–	101.41
L186	Siliceous argillite	51.79	0.63	4.13	0.07	10.64	0.47	13.50	19.57	0.56	0.07	101.41
L251	Siliceous argillite	53.02	0.49	2.52	0.65	4.60	0.17	17.24	21.11	0.30	0.01	99.90
L251	Siliceous argillite	52.91	0.42	2.29	0.60	4.58	0.16	17.31	21.15	0.29	–	99.70
L41	Chert	49.48	0.78	3.83	0.01	10.79	0.27	13.83	19.99	0.37	–	99.34
L41	Chert	52.46	0.81	1.29	0.01	9.88	0.49	14.32	22.08	0.36	0.01	101.49
L41	Chert	51.81	0.48	3.50	0.44	4.34	0.12	15.92	24.31	0.31	–	101.21
L41	Chert	52.78	0.25	1.18	–	7.09	0.22	14.71	24.14	0.20	–	100.56
L41	Chert	52.85	0.55	1.87	0.01	6.40	0.24	14.08	24.48	0.18	0.01	100.21
L41	Chert	49.28	0.54	3.19	0.71	5.08	0.09	16.52	23.61	0.10	–	99.12
L41	Chert	49.51	0.66	3.43	–	8.13	0.22	14.01	23.60	0.28	–	99.87
L41	Chert	50.78	0.29	0.98	–	8.68	0.18	15.65	22.95	0.30	–	99.84
L41	Chert	49.60	0.44	2.39	0.13	6.33	0.16	18.29	21.95	0.11	–	99.39
L81	Chert	51.97	0.58	1.86	0.05	8.97	0.19	12.83	22.85	0.42	–	99.73
L81	Chert	49.57	0.74	4.67	0.24	7.77	0.19	14.54	21.43	0.32	–	99.48
L81	Chert	52.41	0.66	2.18	0.02	8.67	0.21	12.76	22.33	0.36	–	99.61
L79	Chert	50.45	0.89	3.75	0.03	7.37	0.31	13.39	23.01	0.46	0.01	99.50

Table 2. (Contd.)

Sample	Rock	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	Total
L79	Chert	49.93	0.82	4.46	0.07	7.76	0.26	14.19	21.03	0.27	0.01	98.78
L79	Chert	50.29	0.77	3.59	0.04	7.55	0.31	13.62	23.19	0.41	–	99.79
L49	Chert	50.27	0.72	3.75	0.03	7.50	0.28	13.44	23.11	0.1	–	99.51
L49	Chert	53.82	0.87	1.38	0.79	5.22	0.15	17.16	20.73	0.29	–	100.22
L49	Chert	50.23	0.78	3.39	0.03	7.48	0.32	13.34	22.92	0.33	–	98.80
L49	Chert	53.74	0.57	0.88	0.05	6.55	0.25	14.84	22.79	0.58	0.01	100.28
L52	Chert	52.73	0.29	1.53	0.04	7.08	0.28	14.41	22.50	0.35	–	99.19
L52	Chert	50.37	0.70	3.12	0.02	7.34	0.28	13.48	22.78	0.40	–	98.48
L52	Chert	50.30	0.75	3.08	0.03	7.41	0.34	13.00	22.89	0.39	–	98.17
L263	Chert	52.50	0.19	2.05	0.70	4.77	0.17	17.09	21.32	0.18	–	98.97
L263	Chert	52.58	0.44	4.76	0.53	3.83	0.14	16.99	21.11	0.34	0.01	100.73
L263	Chert	53.78	0.16	2.01	0.77	4.45	0.12	16.83	20.50	1.12	0.01	98.76
L263	Chert	53.21	0.16	2.31	0.46	4.84	0.15	17.28	21.25	0.14	0.01	99.78
L263	Chert	52.51	0.43	4.58	0.58	4.08	0.14	14.83	22.06	0.37	0.01	99.60
L263	Chert	51.94	0.64	3.11	0.11	8.11	0.17	13.07	22.54	0.59	0.01	100.29
L263	Chert	53.03	0.95	3.02	0.73	5.18	0.16	16.84	20.78	0.41	–	101.11
L64	Chert	49.54	1.46	3.56	0.94	5.32	0.11	14.73	22.41	0.46	–	98.54
L64	Chert	47.69	3.58	5.29	0.04	7.14	0.12	13.57	22.61	0.62	–	100.66
L64	Chert	49.91	1.79	3.08	0.63	5.66	0.13	13.27	22.56	0.41	–	97.43
L64	Chert	51.75	1.25	2.75	1.22	4.66	0.12	15.25	21.40	0.41	–	98.82
L27	Chert	50.94	0.57	2.69	–	8.10	0.27	14.05	23.99	0.40	–	101.01
L27	Chert	51.46	0.55	1.88	0.05	8.56	0.16	13.07	23.93	0.56	–	100.20
L27	Chert	51.98	0.48	1.66	0.04	8.58	0.18	13.37	24.49	0.60	–	101.37
L206	Chert	53.67	0.15	0.72	0.85	4.76	0.16	19.20	19.55	0.12	–	99.19
L206	Chert	53.25	0.16	1.52	0.39	5.24	0.20	16.72	21.41	0.12	–	99.02
L206	Chert	53.30	0.14	1.45	0.49	5.18	0.17	17.00	21.43	0.12	–	99.30
L206	Chert	54.05	0.19	2.32	0.51	9.52	0.29	20.30	11.65	0.77	0.13	99.72
Mt. Amba												
37–47	Tuffite	51.40	1.40	2.31	–	8.65	0.28	14.34	21.25	0.44	–	100.07
37–45	Clayey jasper	51.36	1.34	2.32	–	8.59	0.26	15.77	21.77	0.52	0.01	101.94
37–45	Clayey jasper	50.74	1.60	2.61	–	11.38	0.48	12.97	20.84	0.64	0.02	101.28
37–45	Clayey jasper	51.37	0.13	2.51	–	4.67	0.16	18.52	22.66	0.27	0.03	100.32
37–45	Clayey jasper	51.61	0.19	1.04	–	5.23	0.29	19.67	22.57	0.20	0.04	100.84
37–44	Clayey jasper	50.10	1.01	2.67	–	6.76	0.19	16.25	21.83	0.45	0.01	99.27
37–44	Clayey jasper	50.99	1.04	2.33	–	7.86	0.27	16.55	21.74	0.42	0.02	101.22
37–44	Clayey jasper	50.52	1.14	3.81	–	6.39	0.21	15.79	21.92	0.40	–	100.18
37–43	Clayey jasper	51.42	1.30	2.88	–	6.91	0.18	16.74	21.67	1.51	0.07	102.68
37–70	Siliceous argillite	50.80	1.23	3.09	–	7.21	0.16	16.48	22.05	0.52	0.02	101.56
37–70	Siliceous argillite	52.45	1.10	2.31	–	6.64	0.18	16.65	21.88	0.40	0.02	101.63
37–67	Jasper	49.08	1.35	2.58	–	7.72	0.18	16.02	21.19	0.58	0.02	98.72
37–67	Jasper	50.25	1.16	2.57	–	6.26	0.18	16.67	20.86	0.43	0.02	98.40
37–67	Jasper	49.05	1.72	3.72	–	7.62	0.19	15.58	21.70	0.49	0.01	100.08
37–69	Chert	51.55	0.96	4.11	–	7.45	0.18	15.55	22.03	0.56	0.03	102.42
37–69	Chert	51.02	1.62	4.09	–	7.64	0.24	15.31	21.75	0.56	0.02	102.25
37–69	Chert	50.46	1.77	3.79	–	8.77	0.21	14.67	21.31	0.52	0.03	101.53
37–35	Jasper	50.34	0.62	5.37	1.09	4.30	0.17	14.66	21.51	0.84	0.01	98.91
37–35	Jasper	52.13	0.21	1.79	0.31	4.65	0.16	15.60	21.26	0.46	–	96.57
37–35	Jasper	51.88	0.47	4.06	–	9.90	0.43	12.62	21.34	0.76	0.02	101.48

Table 2. (Contd.)

Sample	Rock	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	Total
Settlement of Breevka												
Br3	Siliceous argillite	53.62	0.25	1.39	0.76	3.72	0.04	17.37	22.69	0.28	0.01	100.13
Br3	Siliceous argillite	52.99	0.27	1.42	0.57	3.81	0.06	16.80	23.06	0.22	–	99.20
Br3	Siliceous argillite	52.65	0.30	1.65	0.74	3.94	0.05	17.15	23.24	0.25	0.01	99.97
Br3	Siliceous argillite	51.37	1.35	2.38	0.48	5.70	0.05	15.97	22.15	0.47	0.01	99.95
Br3	Siliceous argillite	51.75	0.53	2.95	0.41	5.27	0.06	16.13	23.02	0.33	0.01	100.45
Br3	Siliceous argillite	52.93	0.59	2.13	0.24	6.30	0.13	17.46	20.52	0.35	0.01	100.66
Br3	Siliceous argillite	49.41	2.46	4.06	0.61	10.73	0.10	15.10	18.78	0.43	0.01	101.69
Br3	Siliceous argillite	51.41	1.69	1.50	0.10	7.90	0.24	13.54	21.82	0.27	0.01	98.49
Br4	Siliceous argillite	50.68	0.66	3.21	–	9.26	0.21	15.20	19.58	0.39	–	99.18
VN1/5	Chert	51.92	0.38	2.86	1.01	3.55	0.04	16.41	23.27	0.28	0.01	99.73
VN1/5	Chert	51.70	0.47	4.03	1.21	3.40	0.04	16.32	21.90	0.41	0.01	99.49
VN1/5	Chert	52.32	0.46	3.52	1.28	3.23	0.06	16.57	22.01	0.33	0.01	99.78
VN1/5	Chert	53.02	0.47	2.96	1.20	3.41	0.06	16.61	22.63	0.33	–	100.69
VN1/4	Chert	48.85	1.02	5.40	0.32	6.43	0.12	14.60	23.56	0.10	0.01	100.40
VN1/4	Chert	49.75	0.41	2.46	0.19	6.82	0.15	17.37	21.71	0.23	–	99.09
VN1/1	Chert	50.87	0.21	2.37	0.16	4.69	0.16	16.33	23.41	0.22	0.02	98.44
VN1/6	Chert	53.18	0.50	3.02	1.02	3.47	0.07	16.52	22.41	0.37	0.01	100.58
Ulitka River												
38/5	Siliceous argillite	51.29	0.70	3.88	0.29	9.05	0.18	14.57	20.65	0.31	–	100.92
38/5	Siliceous argillite	50.88	0.78	3.45	0.11	9.11	0.19	14.66	20.35	0.30	–	99.83
38/5	Siliceous argillite	48.93	0.80	5.18	0.25	8.04	0.18	15.09	20.80	0.31	–	99.59
38/5	Siliceous argillite	50.06	0.72	2.81	0.07	8.87	0.38	14.08	21.43	0.41	–	99.02
41/10	Siliceous argillite	50.84	0.55	3.36	0.22	7.50	0.28	15.02	21.49	0.38	0.02	99.65
41/10	Siliceous argillite	50.66	0.45	4.40	0.24	7.00	0.18	14.82	20.73	0.27	0.01	98.76
41/10	Siliceous argillite	51.57	0.62	3.35	0.03	9.40	0.31	14.40	20.96	0.35	0.05	101.05
41/8	Clayey chert	49.17	0.81	3.86	0.03	9.30	0.28	13.62	21.03	0.49	–	98.61
41/8	Clayey chert	50.86	1.30	2.93	0.31	7.01	0.15	15.29	21.73	0.44	–	100.03
41/8	Clayey chert	51.65	0.83	2.02	0.70	8.06	0.24	17.40	17.86	0.34	0.02	99.12
Pantovyi Creek												
25–5	Chert	50.90	0.57	1.71	–	8.06	0.13	16.90	20.47	1.23	0.07	100.04
25–5	Chert	53.95	0.18	0.71	–	4.96	0.19	17.08	23.31	0.17	0.03	100.58
25–16	Jasper	51.65	0.27	2.45	–	5.26	0.17	18.06	21.80	0.17	–	99.83
25–16	Jasper	50.77	–	0.59	–	5.94	0.19	15.48	25.44	0.04	0.02	98.47
25–53	Jasper	55.20	0.05	0.47	–	5.40	0.26	16.47	22.38	0.13	0.02	100.38
25–53	Jasper	50.54	0.30	2.08	–	4.95	0.19	17.51	23.74	0.19	0.03	99.53
25–53	Jasper	50.34	0.37	0.89	–	4.89	0.14	17.38	23.82	0.50	0.02	98.35
25–122	Jasper	52.43	0.12	1.20	–	4.18	0.16	18.90	23.79	0.09	0.02	100.89
25–122	Jasper	52.06	0.28	1.60	–	5.76	0.20	16.47	23.88	0.21	0.03	100.49
25–161	Jasper	50.49	0.23	6.12	1.05	3.00	0.10	16.82	22.47	0.29	–	100.57
25–161	Jasper	53.18	0.20	6.01	1.13	4.00	0.11	20.72	15.87	0.29	–	101.51
25–188	Jasper	51.29	0.11	1.15	–	6.75	0.21	15.42	22.69	1.03	0.06	98.71
25–188	Jasper	50.68	0.03	3.96	–	8.29	0.49	15.28	22.07	1.35	0.07	102.22
Manoma River												
M71	Chert	53.00	0.90	4.90	0.13	7.18	0.11	13.35	19.69	0.25	0.01	99.52
M71	Chert	55.03	0.40	3.21	0.25	6.18	0.07	13.94	20.57	0.18	0.02	99.83
M71	Chert	52.71	0.44	3.37	0.01	10.48	0.25	14.73	18.15	0.17	0.01	100.32
M60	Clayey chert	52.66	0.36	2.76	0.14	9.25	0.13	15.40	19.67	0.20	–	100.57

Table 2. (Contd.)

Sample	Rock	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	Total
M60	Clayey chert	51.45	0.41	3.47	0.31	7.58	0.07	14.94	21.93	0.25	–	100.41
M60	Clayey chert	51.42	0.44	4.26	0.19	8.74	0.14	14.88	19.68	0.22	0.01	99.99
M60	Clayey chert	53.09	0.34	2.25	0.04	11.63	0.26	14.97	16.49	0.25	1.05	100.37
M57	Tuffite	51.88	0.67	5.52	0.07	10.27	0.14	11.63	20.30	0.41	0.02	100.89
M57	Tuffite	52.96	0.70	3.61	–	9.38	0.14	13.10	20.65	0.31	0.02	100.86
M57	Tuffite	51.49	0.39	2.46	–	10.30	0.20	15.87	18.55	0.16	–	99.42
M57	Tuffite	50.04	0.70	5.12	–	10.18	0.15	14.11	20.18	0.25	–	100.73
M57	Tuffite	52.91	0.15	2.72	0.28	4.66	0.05	17.07	22.86	0.09	–	100.79
M33	Jasper	50.45	0.72	4.66	–	9.52	0.06	13.79	21.09	0.26	0.01	100.55
M33	Jasper	50.77	0.83	4.73	–	8.74	0.07	13.80	21.25	0.26	0.01	100.46
M33	Jasper	50.01	0.82	5.11	0.03	6.91	0.06	14.58	22.60	0.28	–	100.41
M33	Jasper	51.25	0.84	5.30	0.31	5.80	0.05	14.30	22.60	0.19	–	100.64
M33	Jasper	54.47	0.46	2.71	0.02	5.18	0.05	15.01	22.21	0.19	–	100.31
M4	Jasper	55.18	0.02	1.47	0.42	4.16	0.07	15.87	22.66	0.09	–	99.95
M4	Jasper	54.41	0.07	1.33	0.21	5.18	0.09	15.35	22.41	0.11	0.01	99.18
M4	Jasper	55.32	0.01	0.95	0.40	3.40	0.05	17.45	22.20	0.03	0.01	99.81
M4	Jasper	55.29	0.02	0.92	0.45	3.35	0.07	17.34	23.48	0.06	–	100.98
M4	Jasper	55.60	0.02	0.87	0.42	3.22	0.07	17.63	23.57	0.06	–	101.45
M4	Jasper	53.68	0.08	1.35	0.30	5.51	0.10	16.35	23.28	0.09	–	100.74
M4	Jasper	55.02	0.05	0.62	0.75	3.43	0.08	18.60	21.11	–	0.02	99.63
M4	Jasper	54.96	0.05	0.85	0.45	3.66	0.06	16.67	22.83	0.05	0.01	99.55
M4	Jasper	52.67	0.10	1.37	0.20	5.57	0.07	16.25	23.10	0.13	0.03	99.46
M4	Jasper	54.76	0.82	0.58	–	32.76	–	–	–	10.95	–	99.88
M18	Jasper	52.84	0.26	0.95	–	10.73	0.37	14.86	19.85	0.21	–	100.07
M18	Jasper	52.69	0.51	1.75	–	9.83	0.25	14.96	20.44	0.21	–	100.65
M18	Jasper	52.94	0.52	1.48	–	11.82	0.36	13.66	19.49	0.20	–	100.49
M36	Jasper	48.17	2.32	3.76	0.22	11.86	0.19	13.19	20.74	0.25	0.01	100.72
M36	Jasper	48.75	1.98	4.54	0.20	11.26	0.20	13.36	19.96	0.27	0.04	100.54
M36	Jasper	48.81	2.17	4.05	0.27	11.85	0.17	13.38	19.48	0.28	0.02	100.48
M36	Jasper	48.40	2.11	3.50	0.10	12.43	0.20	14.54	18.92	0.23	0.02	100.44
M36	Jasper	49.04	1.87	3.50	0.14	12.07	0.22	13.29	20.58	0.26	0.02	100.97
						Orthopyroxene						
Lyamfana Creek												
L263	Chert	57.74	0.14	1.24	0.45	8.52	0.22	31.42	1.78	0.03	–	101.35
L263	Chert	55.84	0.14	1.04	0.42	9.63	0.23	31.14	2.04	0.03	–	100.51
Mt. Amba												
37–35	Jasper	53.85	0.31	3.84	0.21	12.07	0.30	29.92	1.18	0.04	–	101.72
37–35	Jasper	52.76	0.29	4.37	0.26	11.86	0.29	27.79	1.36	0.18	0.03	98.88
37–35	Jasper	51.93	0.37	4.87	0.20	11.50	0.24	28.05	0.83	0.07	–	98.06
37–35	Jasper	51.82	0.07	4.63	0.06	12.42	0.31	28.02	1.08	0.04	–	98.45
37–35	Jasper	53.16	0.16	4.13	–	12.92	0.35	29.39	1.80	0.03	–	101.94
37–35	Jasper	55.49	0.30	3.91	–	11.18	0.30	28.641	1.10	0.06	0.03	101.00
Settlement of Breevka												
Br4	Siliceous argillite	53.71	0.44	1.73	0.01	16.72	0.30	24.63	1.94	0.02	–	99.78
Br4	Siliceous argillite	53.66	0.29	2.32	0.03	18.95	0.60	23.26	1.43	0.06	–	99.69
VN1/1	Chert	58.10	0.10	1.82	0.12	7.02	0.15	32.60	0.51	–	–	100.43
VN1/1	Chert	57.74	0.11	1.70	0.17	7.27	0.17	32.71	0.37	0.02	–	100.25

Table 2. (Contd.)

Sample	Rock	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	Total
Pantovyi Creek												
25–161	Jasper	53.91	0.18	2.95	0.16	14.07	0.37	28,,78	0.74	0.03	–	101.19
25–161	Jasper	54.51	0.04	2.83	0.04	13.96	0.35	28.68	0.74	0.03	–	101.18
25–161	Jasper	53.61	0.06	3.56	–	12.45	0.28	29.70	0.69	0.01	–	100.36
25–161	Jasper	53.44	0.03	2.95	–	13.03	0.41	29.89	0.56	0.04	–	100.35
25–161	Jasper	52.54	0.02	2.44	–	14.33	0.38	29.88	0.53	0.22	0.04	100.38
Manoma River												
M4	Jasper	53.45	0.28	0.54	–	21.71	0.67	21.39	1.67	–	0.02	99.29
M18	Jasper	54.14	0.21	0.74	–	22.46	0.80	20.83	1.30	0.03	–	100.51
M18	Jasper	54.12	0.27	0.67	0.01	23.04	0.79	19.17	1.92	0.04	–	100.04
M18	Jasper	53.95	0.25	0.64	–	22.92	1.04	18.95	1.53	0.05	–	99.34
M18	Jasper	54.09	0.28	0.62	0.03	26.03	0.90	16.71	2.16	0.05	0.01	100.88
M18	Jasper	65.02	0.30	0.67	0.01	19.07	0.63	22.07	1.96	0.02	–	100.76
						Amphibole						
Mt. Amba												
37–46	Tuffite	43.49	1.23	14.55	–	6.37	0.12	19.62	13.25	2.10	0.72	101.45
37–70	Siliceous argillite	53.58	0.27	1.60	–	10.49	0.45	17.49	13.36	0.51	0.16	97.71
37–67	Jasper	47.72	0.25	8.03	–	11.12	0.33	17.35	11.97	1.18	0.42	98.37
37–35	Jasper	41.44	3.81	14.56	0.36	7.81	0.14	16.02	11.33	2.93	0.49	98.91
37–35	Jasper	42.91	2.28	13.28	–	11.89	0.21	14.39	11.74	2.49	0.16	99.35
37–35	Jasper	47.67	0.03	12.17	–	8.17	0.18	17.27	11.61	1.37	0.04	98.51
37–35	Jasper	44.33	0.82	14.07	0.50	6.85	0.13	15.41	11.27	2.33	0.70	96.41
37–35	Jasper	42.21	2.59	13.81	–	7.74	0.14	16.42	11.18	2.94	0.74	97.82
37–35	Jasper	44.15	0.54	14.85	0.28	6.37	0.12	17.89	11.50	2.77	0.48	98.95
37–35	Jasper	44.09	0.33	15.72	–	6.90	0.10	16.88	11.88	2.82	0.42	99.14
Settlement of Breevka												
VN1/4	Chert	44.95	0.08	11.89	0.01	10.11	0.10	14.34	12.02	1.65	0.23	95.38
VN1/4	Chert	44.85	0.34	11.55	0.10	7.80	0.19	16.06	12.16	1.63	0.09	94.78
VN1/4	Chert	46.45	0.49	12.67	0.11	7.72	0.06	15.48	12.64	1.94	0.07	97.64
VN1/4	Chert	42.90	2.20	13.54	0.08	9.50	0.11	14.88	12.29	1.89	0.13	97.54
VN1/4	Chert	42.68	2.43	13.25	0.08	10.82	0.08	14.07	12.30	1.91	0.99	98.61
VN1/4	Chert	43.24	2.51	13.24	0.05	11.56	0.13	14.89	11.53	1.94	0.17	99.26
VN1/4	Chert	49.31	1.83	10.98	0.06	10.70	0.12	12.54	10.11	1.80	0.14	97.58
VN1/6	Chert	43.41	0.90	15.31	0.27	6.68	0.06	16.43	12.01	1.45	0.09	96.63
VN1/6	Chert	41.34	1.40	14.26	0.02	9.93	0.07	13.92	11.93	1.77	0.15	94.78
VN1/6	Chert	42.81	2.66	12.77	–	11.58	0.13	13.42	11.21	1.84	0.11	96.53
VN1/6	Chert	43.77	1.82	7.30	0.01	22.33	0.35	8.18	10.55	1.54	0.84	96.69
VN1/6	Chert	41.40	2.27	14.51	–	9.84	0.09	14.76	11.03	1.87	0.16	95.93
VN1/6	Chert	42.42	2.145	12.60	0.05	13.61	0.18	12.34	10.41	1.63	0.29	95.68
Katen River												
K82	Clayey chert	40.33	6.74	12.55	0.03	14.34	0.22	9.70	12.66	1.84	1.50	99.90
K82	Clayey chert	40.14	6.88	12.21	–	11.97	0.10	11.88	13.42	2.11	1.48	100.19
K82	Clayey chert	41.66	8.27	10.39	–	12.19	0.34	11.13	12.13	1.55	1.79	99.47
K82	Clayey chert	40.08	5.50	12.62	0.02	13.36	0.35	11.53	12.84	1.70	1.19	99.18
K82	Clayey chert	41.20	6.78	10.28	0.03	12.01	0.15	12.26	13.22	1.89	1.46	99.28
Pantovyi Creek												
25–161	Jasper	52.21	0.62	1.85	0.66	11.60	0.20	16.19	12.47	0.24	0.01	96.05
25–161	Jasper	43.48	1.59	11.18	0.69	9.76	0.15	15.80	11.85	2.53	0.11	97.14

Table 2. (Contd.)

Sample	Rock	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	Total
25–161	Jasper	43.73	1.90	12.93	0.12	10.01	0.19	13.61	11.99	1.72	0.20	96.40
25–161	Jasper	43.85	0.39	12.83	0.40	13.33	0.18	13.16	12.18	2.20	0.07	98.59
25–161	Jasper	42.40	3.92	14.04	0.59	7.58	0.17	15.03	11.25	2.85	0.61	98.45
25–161	Jasper	42.70	2.32	12.60	1.31	10.00	0.19	16.51	10.71	2.73	0.28	99.35
25–161	Jasper	47.49	0.37	10.35	0.07	10.99	0.13	14.12	14.28	1.42	0.03	99.25
25–161	Jasper	54.96	0.26	2.55	0.06	11.81	0.25	16.98	12.79	0.34	0.02	100.02
25–161	Jasper	43.75	2.82	13.43	–	10.79	0.18	14.56	11.77	2.06	0.15	99.51
25–161	Jasper	41.97	2.14	13.13	–	10.40	0.15	14.26	11.55	2.45	0.18	96.23
25–161	Jasper	42.46	2.32	12.56	0.01	10.95	0.18	14.32	11.47	2.60	0.15	97.02
25–161	Jasper	43.79	1.07	11.88	–	7.21	0.13	18.42	11.16	2.78	0.49	96.93
25–161	Jasper	44.14	0.05	12.82	–	8.97	0.16	16.24	11.57	2.36	0.03	96.34
25–161	Jasper	49.24	0.08	9.85	–	7.01	0.16	18.86	12.15	1.50	0.01	98.86
25–161	Jasper	45.69	0.44	13.38	–	5.81	0.13	19.93	12.12	2.76	0.25	100.31
Manoma River												
M71	Chert	38.71	6.19	14.05	–	11.38	0.09	12.83	12.65	1.90	1.12	98.92
M71	Chert	38.78	6.24	12.95	–	11.33	0.16	13.01	12.94	1.99	1.04	98.45
M71	Chert	38.69	6.77	13.80	–	11.87	0.07	12.42	12.99	2.00	1.13	99.75
M4	Jasper	52.24	0.77	0.51	–	32.27	0.10	–	0.05	6.29	1.96	94.22
M4	Jasper	52.25	0.44	0.52	0.01	31.09	0.25	0.01	0.07	6.12	2.40	92.97
M18	Jasper	51.61	1.16	0.40	–	32.55	0.40	–	0.01	7.07	2.73	95.66
M43	Jasper	39.15	5.85	12.14	–	10.99	0.09	12.10	12.71	1.84	1.01	95.88
M43	Jasper	37.82	6.34	13.00	–	13.62	0.10	9.93	12.62	1.96	1.04	96.43
M43	Jasper	40.87	4.52	10.83	–	11.02	0.14	12.57	12.80	1.87	0.95	95.60
M43	Jasper	39.11	5.45	11.03	–	11.78	0.19	12.57	12.76	1.83	0.96	95.69
M43	Jasper	39.47	7.46	10.22	–	12.17	0.15	14.12	11.83	1.19	0.89	97.50
M43	Jasper	40.69	6.35	13.78	0.05	10.63	0.13	13.59	12.46	1.72	1.11	100.50
M43	Jasper	40.47	6.26	13.17	0.02	11.97	0.14	11.74	12.60	1.86	1.27	99.50
M43	Jasper	39.78	6.68	13.77	0.03	11.16	0.14	12.60	12.78	1.91	1.31	100.39
						Garnet						
Lyamfana Creek												
L100	Silty argillite	37.09	0.52	21.03	0.08	33.57	0.95	3.46	2.67	0.06	0.01	99.45
L100	Silty argillite	38.22	0.45	21.32	0.07	32.07	0.66	6.88	1.64	0.04	0.02	101.36
L100	Silty argillite	35.04	0.45	21.81	0.05	32.97	1.13	4.39	1.91	0.06	0.03	99.82
L100	Silty argillite	38.00	0.46	19.24	0.14	33.06	0.71	7.14	1.55	0.05	0.02	100.36
L100	Silty argillite	37.01	0.50	18.39	0.04	39.70	0.95	3.01	1.22	0.04	0.02	100.87
L100	Silty argillite	36.45	0.35	19.55	0.05	37.92	0.30	3.76	3.52	0.05	0.01	101.93
L100	Silty argillite	37.07	0.40	19.90	0.07	34.74	0.97	6.77	1.30	0.04	0.01	101.27
L100	Silty argillite	37.04	0.39	19.38	0.09	32.95	0.51	8.32	1.19	0.04	–	99.90
Settlement of Breevka												
Br1	Silty argillite	37.14	0.28	20.06	0.01	33.07	0.31	1.28	6.66	0.22	0.02	98.85
Br1	Silty argillite	37.48	0.32	20.27	0.05	29.99	7.57	1.30	0.98	0.04	0.02	98.02
Br1	Silty argillite	37.54	0.58	20.87	0.04	25.46	7.05	2.63	5.22	0.05	0.02	99.45
Br1	Silty argillite	37.11	0.22	22.83	0.05	31.53	6.35	1.59	0.71	0.04	0.03	100.47
Ulitka River												
41/10	Siliceous argillite	38.32	0.34	18.73	0.05	33.71	2.11	1.28	4.92	–	0.02	99.58
41/10	Siliceous argillite	39.03	0.31	18.29	0.06	33.86	2.38	1.17	4.52	–	0.02	99.65
41/10	Siliceous argillite	38.39	0.45	18.51	0.05	33.92	3.08	2.07	4.15	–	0.02	100.64
41/10	Siliceous argillite	37.19	0.46	19.49	0.06	34.79	1.92	1.43	4.79	–	0.06	100.07

Note: (FeO*) Total iron was analyzed as FeO; (–) not detected.

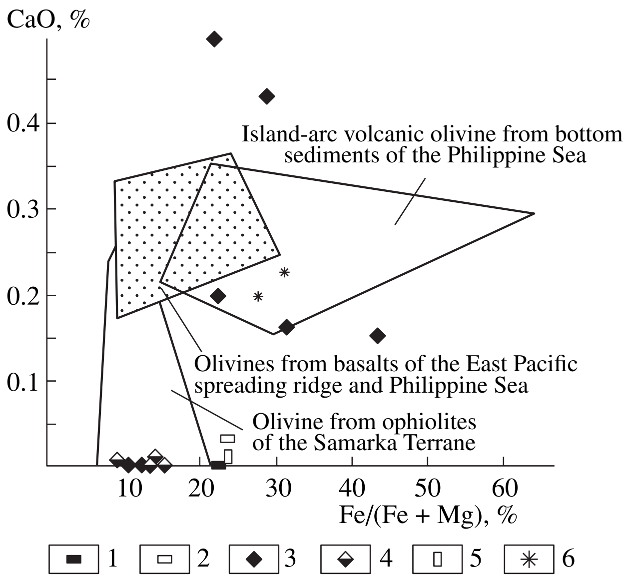

Fig. 3. The CaO–Fe/(Fe + Mg) diagram for olivine from cherty and siliceous–clayey rocks of accretionary prisms in Sikhote Alin. Compositional fields of olivine from possible parent rocks, after (Nechaev et al., 1997). (1–6) Olivine from: (1) Jurassic tuffites of the Mt. Amba section, (2) Permian cherts of the Mt. Amba section, (3) Jurassic siliceous mudstones of the Settlement of Breevka section, (4) Triassic cherts of the Settlement of Breevka area, (5) Permian cherts of the Pantovyi Creek section, (6) Jurassic red cherts of the Manoma River section.

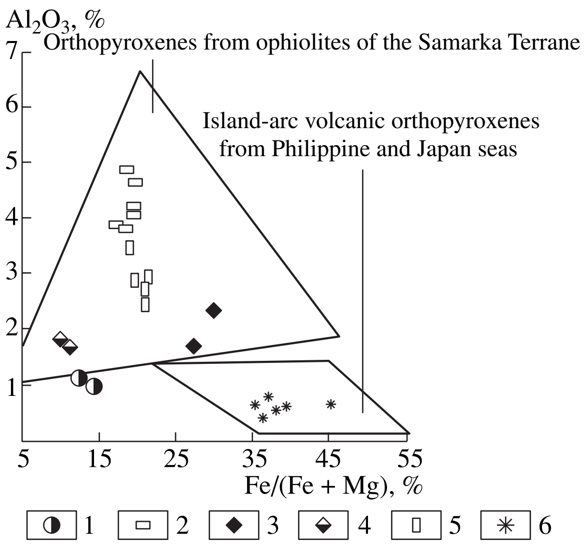

Fig. 4. The Al_2O_3–Fe/(Fe + Mg) diagram for orthopyroxene from cherty and siliceous–clayey rocks of accretionary prisms in Sikhote Alin. Compositional fields of orthopyroxene from possible parent rocks, after (Nechaev et al., 1997). (1–6) Orthopyroxene from: (1) Triassic cherts of the Lyamfana section, (2) Permian cherts of the Amba section, (3) Jurassic siliceous mudstones of the Settlement of Breevka section, (4) Triassic cherts of the Settlement of Breevka area, (5) Permian cherts of the Pantovyi Creek section, (6) Jurassic red cherts of the Manoma River section.

sphene, leucoxene, olivine, apatite, and magnetite are rare.

GEOCHEMISTRY OF HEAVY MINERALS AND THEIR PARENT ROCKS

The chemical composition of some heavy minerals is important for the determination of their parent rocks and elucidation of the geology of source areas (Morton, 1991). We studied geochemical features of olivine, clinopyroxene, orthopyroxene, hornblende, and garnet (Table 2).

Olivine. The examined samples contain two olivine groups. The first group includes the low-Ca olivine from Permian red cherts of the Amba and Pantovyi areas, Jurassic tuffites of the Amba section, Triassic cherts, and Jurassic clayey rocks of the Breevka area. These olivines are similar to their counterparts from ultramafic and mafic igneous rocks from the ophiolitic complex of the Samarka Terrane (Fig. 3). The second group includes Ca- and Fe-rich olivines from red cherts of the Manoma section and siliceous–clayey rocks of the Breevka area. In the CaO–Fe/(Fe + Mg) diagram, data points of these Ca- and Fe-rich olivines are located within or near the boundaries of the field of island-arc volcanic olivines from bottom sediments of the Philippine Sea and Sea of Japan (hereafter, Philippine and Japan seas).

Orthopyroxene from red cherts of the Manoma section is characterized by the maximal FeO content and low SiO_2 contents. Thus, the Manoma orthopyroxene corresponds to island-arc orthopyroxenes from bottom sediments of Philippine and Japan seas (Fig. 4). Orthopyroxenes from other sections differ in terms of the Al_2O_3 content, but their data points fall into the orthopyroxene field of Middle Paleozoic ophiolites from the Samarka Terrane.

Hornblende. Hornblendes from the examined samples are divided into three groups in terms of their chemical composition. Hornblendes from the Amba, Breevka, and Pantovyi sections (first group) are characterized by low Ti and moderate Na contents (Fig. 5a). The Ti content is higher in hornblende from siliceous cherts of the Katen River area (second group). The majority of hornblendes from Jurassic red cherts of the Manoma section are similar to the second group, but some of them are enriched in Na and are attributed to riebeckite (third group). Hornblendes of the first group fall into the field of amphibolites from the ophiolitic complex of the Samarka Terrane, which is partly overlapped with the field of island-arc volcanic hornblendes from bottom sediments of Philippine and Japan seas (Fig. 5b). The high-Ti hornblendes probably originated from alkaline igneous rocks.

Clinopyroxene. Clastic clinopyroxenes from the examined sections are largely represented by augite,

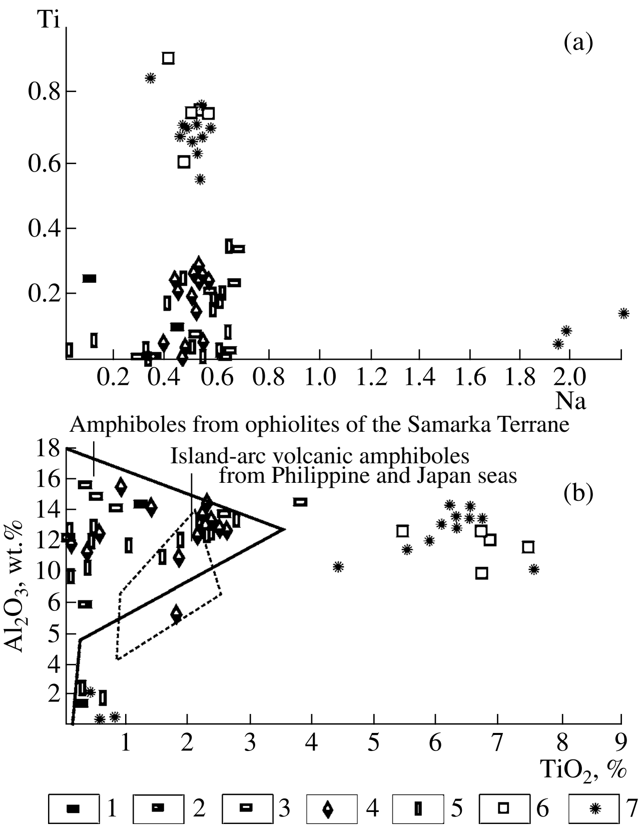

Fig. 5. (a) Variations in Na and Ti contents and (b) the Al_2O_3–TiO_2 diagram for hornblende from cherty and siliceous–clayey rocks of accretionary prisms in Sikhote Alin. Compositional fields of hornblende from possible parent rocks, after (Nechaev et al., 1997). (1–7) Hornblende from: (1) Jurassic tuffites and siliceous mudstones of the Mt. Amba section; (2) Triassic red cherts of the Mount Amba section, (3) Permian red cherts of the Mt. Amba section, (4) Triassic cherts of the Settlement of Breevka area, (5) Permian red cherts of the Pantovyi Creek section, (6) Jurassic cherts of the Katen River section, (7) Jurassic and Cretaceous siliciliths of the Manoma River section.

diopside, and subordinate Ti-augite. Hettangian–Pliensbachian red cherts of the Manoma section yielded aegirine (Sample M4). Discrimination diagrams (Leterrier et al., 1982; Nechaev et al., 1996) indicate magmatic sources of clinopyroxenes.

Clastic clinopyroxenes from cherty and siliceous–clayey rocks of the Lyamfana and Amba sections are genetically different. Most of the Permian clinopyroxenes evidently originated from tholeiitic basalts and ultramafic rocks of the ophiolitic complex, but some clinopyroxenes could be derived from island-arc basalts (Fig. 6). Alkaline rocks served as the source for the majority of clinopyroxenes from Triassic–Jurassic cherty and siliceous clayey rocks. Some clinopyroxenes were derived from island-arc basalts, while the high-Cr variety was derived from MORB tholeiites.

Clinopyroxenes from the Permian cherts and red cherts of the Pantovyi section are grouped near the boundary between alkaline and normal basalts (Fig. 7a). They formally belong to the group of alkaline basalts. However, low Ti and Na contents suggest that the Pantovyi clinopyroxenes are most likely derived

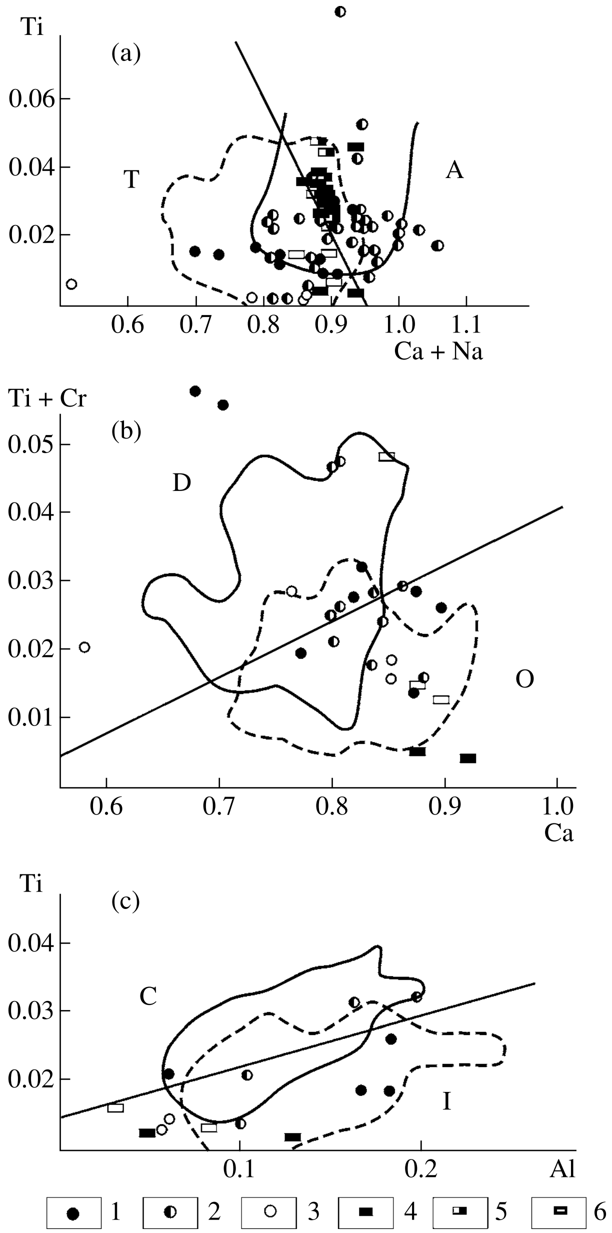

Fig. 6. Discrimination diagrams for clinopyroxenes from basalts of different tectonic settings, after (Leterrier et al., 1982). (a) Clinopyroxenes from normal basalts (T) and alkaline intracontinental basalts and basalts of oceanic islands (A); (b) clinopyroxenes from basalts of continental-margin, island-arc (O), and MORB basalts, abyssal tholeiites, and transitional rifts (D); (c) clinopyroxenes from calc-alkaline (C) and tholeiitic basalts of continental-margin and island arcs (I). Elements are given in formula units. Clinopyroxene from: (1) Jurassic siliceous–clayey rocks, (2) Triassic cherts, (3) Permian cherts, (4) Jurassic siliceous–clayey rocks, (5) Triassic cherts, (6) Permian cherts. (1–3) Lyamfana section; (4–6) Mt. Amba section.

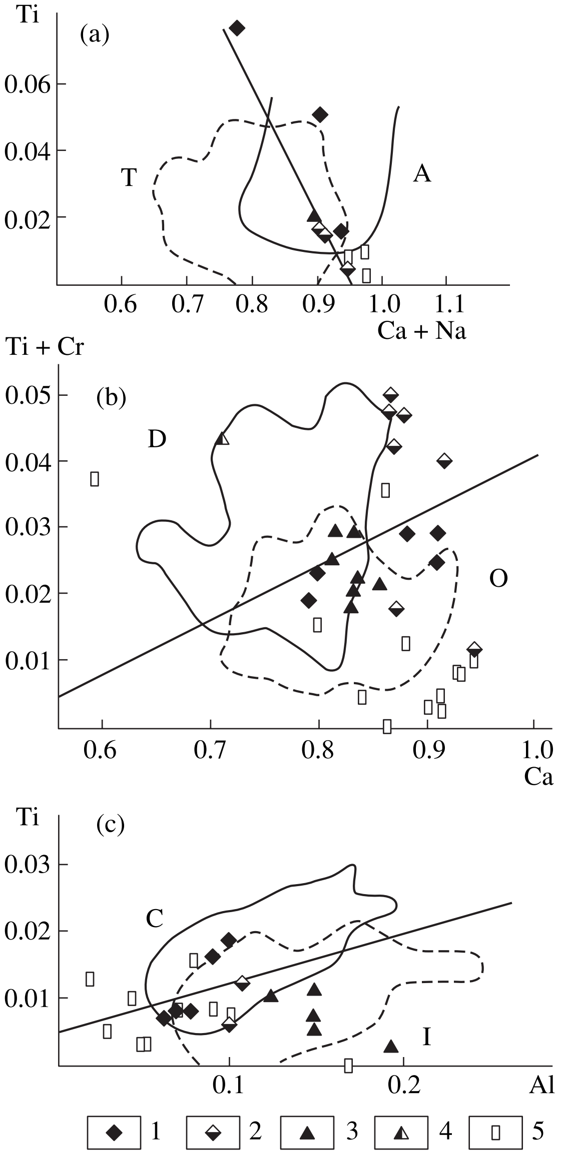

Fig. 7. Discrimination diagrams for clinopyroxenes from basalts of different tectonic settings, after (Leterrier et al., 1982). For explanations, see Fig. 6. Clinopyroxene from: (1) Jurassic siliceous–clayey rocks of the Settlement of Breevka section, (2) Triassic cherts of the Settlement of Breevka section, (3) Jurassic siliceous–clayey rocks of the Ulitka River section, (4) Jurassic cherts of the Ulitka River section, (5) Permian cherts and red cherts of the Pantovyi Creek section.

from normal basalts. Most of these clinopyroxenes are apparently of island-arc origin, although some of them could be derived from MORB tholeiites. Triassic–Jurassic cherty and siliceous–clayey rocks contain clinopyroxenes derived from different sources: (1) tholeiitic basalts (Jurassic and Triassic cherts of the Breevka and Ulitka areas); (2) island-arc rocks (Jurassic siliceous–clayey rocks of the same areas); (3) alkaline basalts with high Ti contents (Jurassic siliceous–clayey rocks and Triassic cherts of the Breevka section and Jurassic siliceous cherts of the Ulitka area).

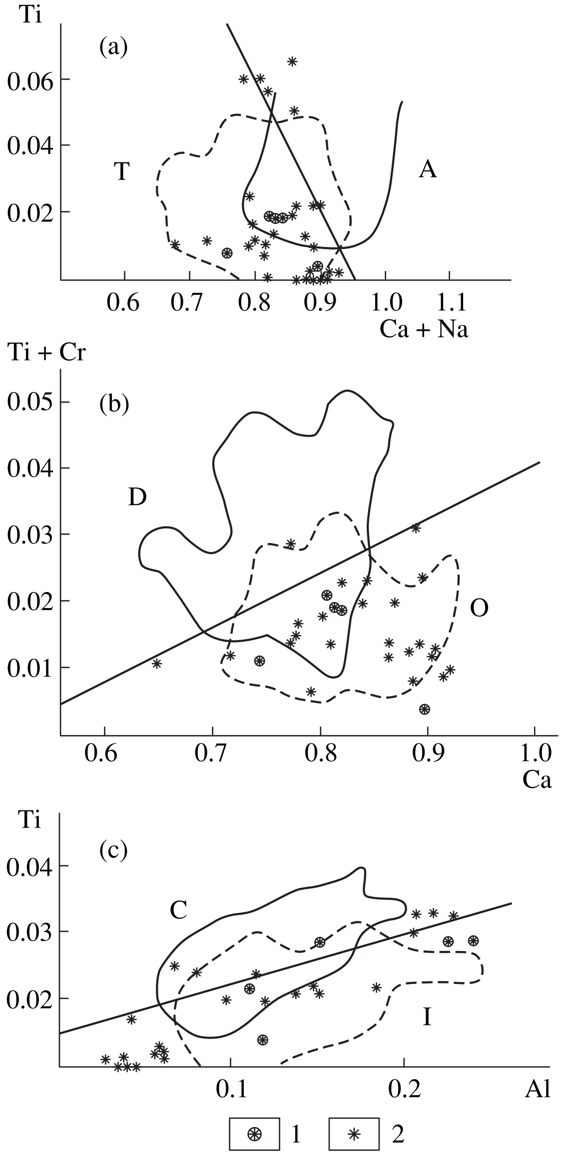

Fig. 8. Discrimination diagrams for clinopyroxenes from basalts of different tectonic settings, after (Leterrier et al., 1982). For explanations, see Fig. 6. Clinopyroxenes from the Manoma River section: (1) from Cretaceous tuffites, (2) from Cretaceous and Jurassic siliceous rocks.

In the Manoma River area, clastic clinopyroxenes are largely of island-arc origin (Fig. 8). Only some clinopyroxenes from Jurassic cherts are classed with minerals of alkaline volcanics.

The Al_2O_3–TiO_2 diagram also indicates similar sources for clastic clinopyroxenes (Fig. 9). Permian clinopyroxenes are mainly derived from ophiolitic complexes. A subordinate share of this mineral is related to island-arc volcanics. Sources for Triassic–Jurassic clinopyroxenes from cherty and siliceous rocks are more diverse. Their significant share is derived from alkaline basalts. Island-arc rocks serve as the source for most clinopyroxenes from Cretaceous and Jurassic

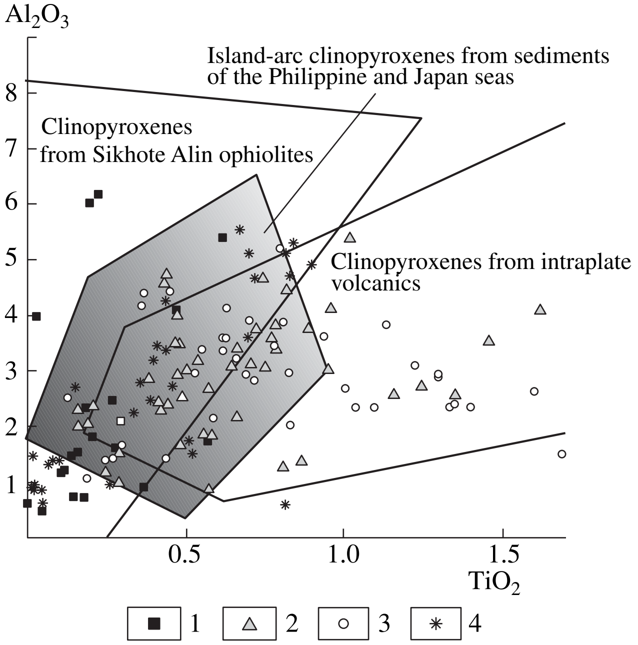

Fig. 9. The Al_2O_3–TiO_2 diagram for clinopyroxene from cherty and siliceous–clayey rocks of accretionary prisms in Sikhote Alin. Compositional fields of clinopyroxene from possible parent rocks, after (Nechaev et al., 1997). Clinopyroxenes from terranes of the Jurassic–Early Cretaceous accretionary prism: (1) Permian cherts and red cherts, (2) Triassic–Jurassic cherts and red cherts, (3) Jurassic siliceous–clayey rocks; (4) clinopyroxenes from Cretaceous and Jurassic rocks of the Kiselevka–Manoma Terrane of the Middle Cretaceous accretionary prism.

sequences of the Manoma River area. Some pale green diopsides with low Al_2O_3 and TiO_2 contents and high MgO contents from Permian red cherts of the Pantovyi section and Jurassic red cherts of the Manoma section, which were determined as minerals of island-arc basalts in the diagram of Leterrier et al. (1982), appeared to be clinopyroxenes of the ultramafic ophiolitic complex (Fig. 9).

Garnet. The examined garnets are represented by almandine associated in some samples with subordinate pyrope or spessartine. They are most likely related to acid volcanics and granites (Fig. 10). Some grains are probably derived from metamorphic rocks.

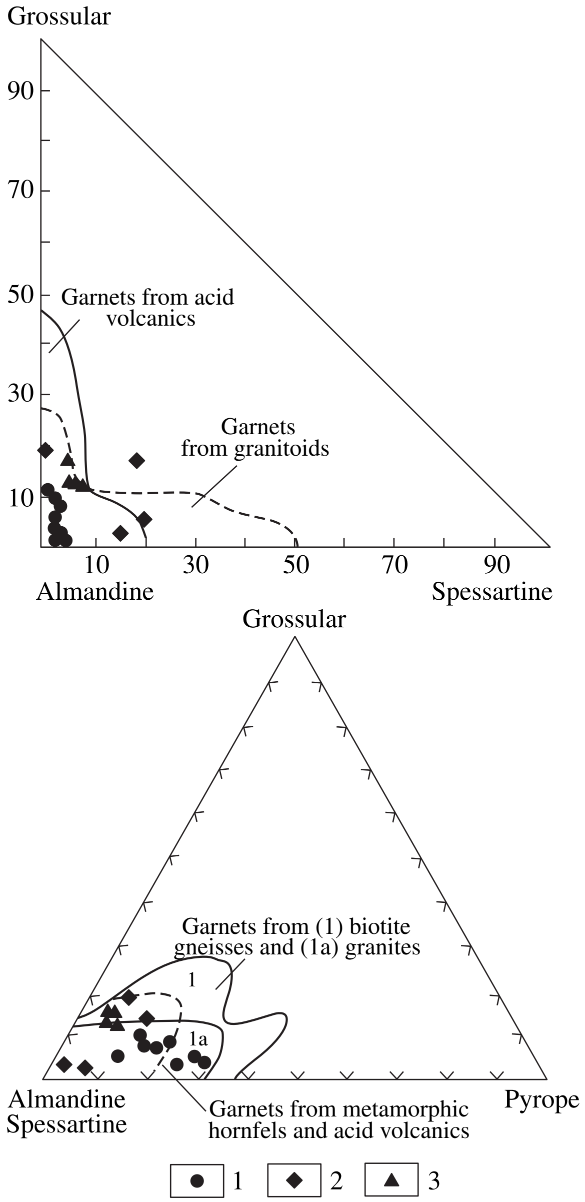

Fig. 10. Compositional diagrams of garnet from siliceous–clayey rocks of accretionary prisms in Sikhote Alin. Compositional fields of garnet from acid volcanic and metamorphic rocks, after (Sobolev, 1964). (1) Lyamfana Creek section, (2) Settlement of Breevka section, (3) Ulitka River section.

ENVIROMENT OF THE PANTHALASSA OCEAN

Heavy mineral assemblages in the examined sections and chemical compositions of some minerals provide insights into source areas for two main sedimentation domains of the Panthalassa Ocean. The pelagic sedimentation domain mainly accumulated cherts, while the hemipelagic domain was characterized by clayey rocks (Murdmaa, 1987). The sedimentary cover of the ancient oceanic plate in the Jurassic–Early Cretaceous accretionary prism includes Permian and Triassic–Jurassic pelagic cherts and Jurassic hemipelagic siliceous mudstones and silty mudstones. Jurassic–Lower Cretaceous pelagic red cherts are widespread in the Albian–Cenomanian accretionary prism (Fig. 2).

Permian pelagic silicites of the Jurassic–Early Cretaceous accretionary prism host the amphibole–pyroxene assemblage (Table 1), which is similar at a first approximation to the heavy mineral assemblage from Cenozoic and recent sediments deposited in the pelagic domain of the Pacific and its marginal seas (Fig. 11). Chemical compositions of minerals from this assemblage indicate their origin from igneous rocks of two

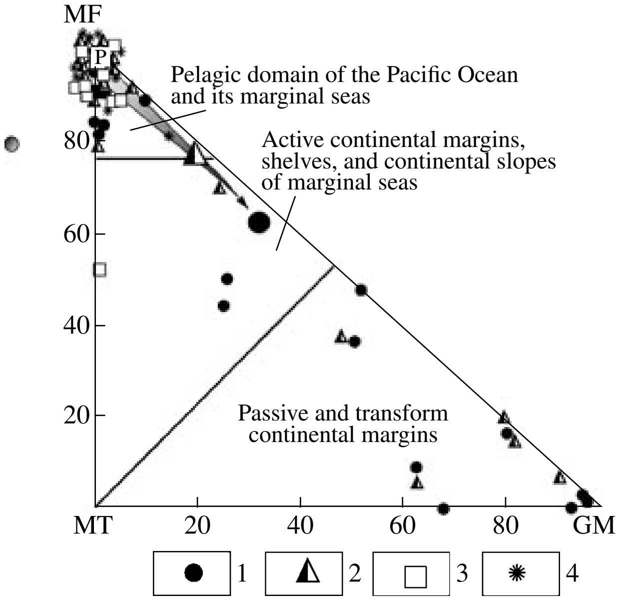

Fig. 11. Comparison of heavy mineral assemblages from recent sediments of different geodynamic settings and siliceous–clayey rocks in accretionary complexes of Sikhote Alin in the MF–GM–MT diagram, after (Nechaev and Isphording, 1993). (MF) Sum of olivine, pyroxene, green and black hornblende contents; (GM) sum of zircon and tourmaline contents; (MT) sum of epidote, garnet and amphibole contents. (1–3) Clastic heavy mineral assemblages in terranes of the Jurassic–Early Cretaceous accretionary prism: (1) Jurassic siliceous–clayey rocks, (2) Triassic–Jurassic cherts and red cherts, (3) Permian cherts and red cherts; (4) the same assemblages in Cretaceous and Jurassic rocks of the Kiselevka–Manoma Terrane of the Middle Cretaceous accretionary prism. Larger symbols designate average values of the clastic heavy mineral assemblages in Permian (P), Triassic (T), and Jurassic (J) rocks.

types. Olivines, orthopyroxenes, and amphiboles from the majority of red cherts and cherts are chemically similar to their counterparts from the ultramafic association of Middle Paleozoic ophiolites in the Samarka Terrane (Figs. 3–5). A similar source can also be assumed for the majority of clinopyroxenes from these rocks (Figs. 6, 7, 9). Clinopyroxenes from some Permian cherts of the Pantovyi and Lyamfana areas are probably derived from volcanics of continental margin or island arcs (Figs. 6, 7). These rocks also contain pyroclastic material represented by fragments of chloritized volcanic glass.

Thus, enviroments of Permian cherty rocks of the Panthalassa Ocean contained abundant ophiolitic complexes. Their erosion products are also observed in sandstone interbeds among Permian cherts (Filippov and Kemkin, 2003). This is atypical of the pelagic domain in the present-day oceans, where clastic material of ultramafic rocks is confined to local areas of rift zones and transform or other active faults (Murdmaa, 1976; Murdmaa et al., 1979). Some samples contain clinopyroxene derived from island-arc volcanics and pyroclastic material, suggesting that the pelagic sedimentation domain was locally influenced by volcanism of convergent zones.

Heavy minerals in Triassic–Jurassic pelagic cherts were derived from parent rocks largely characterized by the clinopyroxene assemblage with high contents of hornblende or zircon (Table 1). Owing to the abundance of zircon, data point of average mineral composition of this assemblage lies at the boundary between the heavy minerals from Cenozoic and recent pelagic sediments of the Pacific and its marginal seas, on the one hand, and the clinopyroxene assemblage from sediments of active continental margins, on the other hand (Fig. 11). The high content of zircon associated with garnet and tourmaline is recorded in some Middle Triassic (mainly, Anisian) cherts and Jurassic clayey cherts. Zircon occurs as small irregular grains in Middle Triassic rocks and as well-developed crystals with insignificant elongation in Jurassic rocks. The source of zircon for Middle Triassic cherts is unclear. Zircons in Jurassic clayey cherts are probably derived from acid volcanics.

Another peculiar feature of the Triassic–Jurassic pelagic domain is the prevalence of alkaline basalts in enviroment. This is suggested by the abundance of high-Ti clinopyroxenes (Figs. 6, 7). Erosion of alkaline volcanic edifices in the Triassic is also evident from the composition of rare sandstone interbeds among cherts of the Breevka section (Filippov and Kemkin, 2003). This is atypical of sediments of the present-day Pacific, where alkaline volcanic material is confined to the periphery of the Hawaiian-type volcanic edifices (Markov et al., 1989; 1992). Tholeiitic basalts and ophiolites served as the subordinate source. This is evident from the composition of olivine, orthopyroxene, and hornblende in Triassic cherts of the Breevka and Lyamfana sections (Figs. 3–5). Samples from these rocks also contain clinopyroxenes with high Cr concentrations. Some cherts yield clinopyroxenes of the island-arc basalt type associated with clinopyroxenes derived from alkaline and tholeiitic basalts (Figs. 6, 7). However, their parent rocks could be represented by end differentiation members of tholeiitic or alkaline magma.

The Jurassic hemipelagic siliceous–clayey sediments are characterized by the zircon–clinopyroxene assemblage with high contents of hornblende, garnet, ilmenite, or magnetite in some samples (Table 1). This heavy mineral assemblage is similar to that from Cenozoic and recent sediments of active continental margins (Fig. 11). Zircon in these rocks is represented by colorless or pale crystals with the coefficient of elongation equal to 1.5–2.5. Similar morphological features are also typical of zircons from granitoids (Lyakhovich, 1968; Krasnobaev, 1986). Garnets associated with zircon are apparently derived from acid igneous rocks (Fig. 10). Olivines, clinopyroxenes, and orthopyroxenes associated with these minerals were derived from volcanics of island arcs or continental margins (Figs. 3, 4, 6, 7).

Thus, the continental marginal volcanic belt was most likely the main enviroment for Jurassic siliceous–clayey rocks. The role of minerals from alkaline basalts and ophiolitic complexes in Jurassic hemipelagic sediments was insignificant.

In general, the Panthalassa Ocean segment with the Paleozoic–Early Cretaceous sedimentary cover is related to the following mineralogical provinces. In the Permian, ophiolitic complexes were the main source rocks of clastic heavy minerals. At the Triassic–Jurassic sedimentation stage, volcanic edifices of alkaline basalts were the main source, while ophiolitic complexes played a subordinate role. Middle Triassic cherts also contain minerals of the sialic crust (zircon and garnet). As the oceanic plate approaches the convergence zone, one can see a gradual increase in the contribution of continental sources and subduction-related volcanism to hemipelagic sediments.

Thus, the Triassic–Jurassic Panthalassa Ocean differed from its Permian ancestor by the development of intraplate magmatism and less intense volcanism in convergent plate margins. The replacement of enviroment at the Paleozoic–Mesozoic boundary supports the notion of the significant structural reorganization of oceanic crustal blocks, transformation of the Paleopacific Ocean configuration, and change of hydrodynamic regime at that time (Suzuki et al, 1998; Bragin, 2000; Ezaki and Yao, 2000; and others). This event is also reflected in various geochemical features of Permian and Triassic cherts (Kunimaru et al., 1998).

Jurassic–Lower Cretaceous pelagic sediments of the Albian–Cenomanian accretionary prism include the amphibole–pyroxene assemblage (Table 1), which is similar to that from Permian cherts of the Jurassic accretionary prism. This assemblage corresponds to the heavy mineral assemblage from Cenozoic and recent pelagic sediments of the Pacific and its marginal seas (Fig. 11). It should be noted that minerals derived from the ophiolitic complex prevail in the Permian cherts and red cherts. In contrast, pyroxenes, amphiboles, and olivines with characteristics of island-arc rocks predominate in Jurassic–Lower Cretaceous rocks of the Manoma section (Figs. 3, 8). In addition, some samples contain alkaline hornblende and brown clinopyroxene with high Ti contents, suggesting the erosion of some intraplate volcanic oceanic islands. Alkaline basalts with such characteristics occur among siliceous rocks of the Kiselevka–Manoma Terrane (Voinova et al., 1994). Thus, Jurassic–Lower Cretaceous rocks of the Manoma River area represent the mineralogical enviroment of the Panthalassa Ocean, which was under the prolonged influence of island-arc volcanism.

CONCLUSIONS

Four types of clastic heavy mineral assemblages and their source areas are defined in the Permian–Mesozoic cherty and siliceous–clayey rocks that make up different accretionary complexes of Sikhote Alin and characterize pelagic and hemipelagic sedimentation domains of the Panthalassa Ocean.

In the oceanic segment with the Late Paleozoic–Early Cretaceous sedimentary cover, the Permian pelagic domain is characterized by the amphibole–pyroxene assemblage. Heavy minerals of this assemblage were mainly derived from ophiolitic complexes. The Triassic–Jurassic stage is marked by the clinopyroxene assemblage with heavy minerals largely derived from intraplate volcanic complexes. In addition, some areas of the pelagic domain received material from the eroded sialic crust. The zircon–clinopyroxene assemblage in the Middle–Upper Jurassic hemipelagic complexes records the enhanced influence of continental sources and volcanic belts of convergent margins.

Another segment of the Pacific Ocean, where red cherts and siliceous–clayey sediments associated with basic volcanics and limestones were accumulated in the Jurassic–Early Cretaceous, is characterized by the island-arc amphibole–pyroxene assemblage. Underwater volcanic edifices or islands composed of alkaline intraplate basalts, as well as ophiolitic complexes, served as the secondary sources of clastic heavy minerals.

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