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Lithology and Depositional Settings of the Terrigenous Sediments along Transform Plate Boundaries: Evidence from the Early Cretaceous Zhuravlevka Terrane in Southern Sikhote Alin

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Abstract—An attempt was made to identify the source areas and depositional settings of the Berriasian–Albian sediments of the Zhuravlevka terrane based on a complex study of the structure and composition of the terrigenous rocks. These sediments are interpreted as formed in a basin related to the regime of the strike-slip transform plate boundaries with a minor volcanic contribution. The granite-metamorphic rocks of the mature continental crust were the main sources of detrital material transported into this basin. At the same time, the data suggest a significant contribution of fragments of the pre-Cretaceous active margin, including remnants of chert and ophiolite nappes of the accretionary wedge. The genetic features of the sediments indicate their formation on the shelf, the submarine continental slope, near its foot, and on the adjacent areas of the basin's plain.

Keywords: terrane, terrigenous rocks, composition, geodynamic setting, transform boundaries, Sikhote Alin.

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INTRODUCTION

One of the most important fundamental problems of modern geology is revealing the paleogeographic and paleogeodynamic settings and the evolution of sedimentary basins whose fragments were found in the terranes accreted to the eastern Eurasian margin. Within the scope of this problem, special attention was focused on the basins that are spatially and genetically related to a setting of transform plate slip. At present, the basins of transform (pull-apart) plate boundaries, their typification, origin, evolution, and their recognition in ancient structures represent a new series of questions, the solutions of which have received great attention in the Russian Far East [1–3, 16–18, 26]. This type of basin can be exemplified by the Early Cretaceous Zhuravlevka terrane (Southern Sikhote Alin) made up of thick deformed terrigenous sequences, which were accumulated without a volcanic contribution.

This paper reports the results of detailed lithological studies of the Lower Cretaceous deposits of the terrane. Data on the structure and composition of the terrigenous rocks were used to decipher the composition of the source areas of the sedimentation basin, as well as the paleogeographic and paleotectonic settings of its formation.

GEOLOGICAL POSITION

The modern structure of Sikhote Alin represents a collage of terranes of different types, which were accreted to the eastern margin of the Asian continent in the Paleozoic and Mesozoic [1, 13, 14, 16, 17, 32]. More than half of Sikhote Alin's territory is made up of Early Cretaceous terranes of different geodynamic nature. Their formation was closely related to the interaction between the Eurasian continent and the Izanagi oceanic plate [1].

The position of the Zhuravlevka terrane is shown in Fig. 1. In the Gur River basin in northern Sikhote Alin, the Zhuravlevka terrane is pinched out with its inferred continuation from the near-mouth part of the Ussuri River northeastward along the right and left banks of the Amur River.

The Berriasian–Albian rocks of the terrane about 11 thou. km in total thickness are represented mainly by terrigenous rocks: sandstones, siltstones, and mudstones; turbidite units; and beds and lenses of conglomerates, gravelstones, mixtites, and siliceous–clayey rocks. The rocks are strongly dislocated and deformed into closely pressed folds of northeastern strike, which were, in turn, split by numerous faults of mainly NNE and submeridional extension with the predominance of sinistral strike-slip displacements along them.

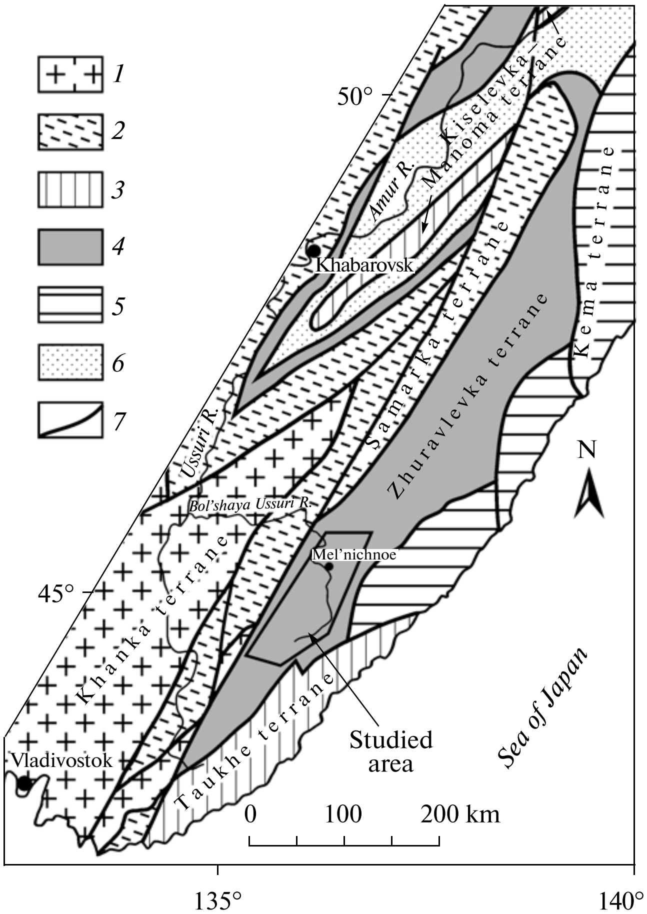

Fig. 1. Terrane scheme of the southern Russian Far East after [8, 17].

(*1–6*) terranes: (1) pre-Mesozoic, (*2*) Jurassic accretionary wedges, (*3*) Early Cretaceous accretionary prisms, (*4*) Early Cretaceous transform boundaries, (*5*) Early Cretaceous island arc, (*6*) Early–Late Cretaceous and Cenozoic, (*7*) faults.

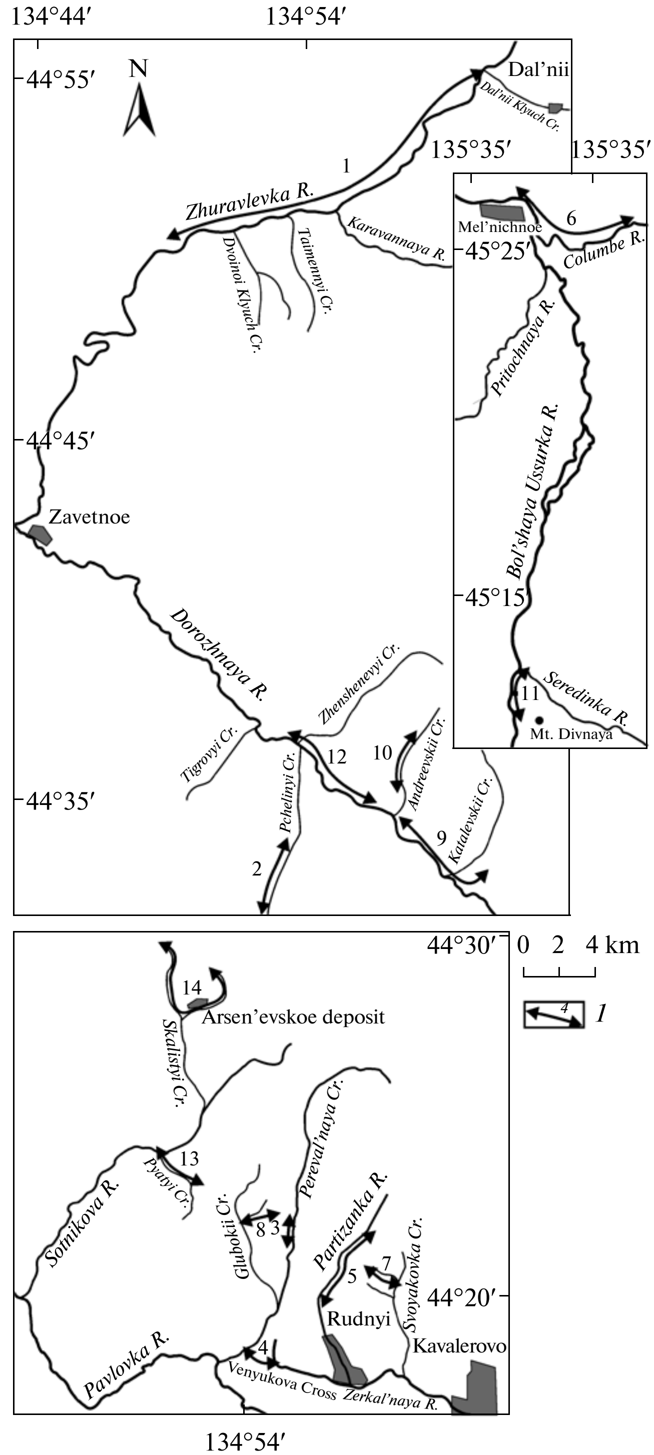

Fig. 2. Scheme of the location of the studied sections of the Zhuravlevka terrane. (*1*) The studied sections and their numbers (see the columns in Fig. 3).

OBJECTS AND METHODS

The objects of this study are the Early Cretaceous terrigenous rocks located in the southern part of the Zhuravlevka terrane. We examined 14 most representative sections more than 75 km long, including natural bank exposures along rivers and mining excavations (Fig. 2). The attitude and structures of the rock were studied in the exposures and in polished specimens. Petrographic studies were applied to select the least altered rocks suitable for the analytical studies.

The petrographic composition was examined using a polarization microscope. The heavy minerals extracted from sandstones were determined by conventional techniques. Only the detrital minerals were involved in the calculations, while the authigenic minerals were omitted from the calculations to maximally reliably identify the composition and relative role of the source areas. The chemical composition of the heavy minerals was determined on a JXA-8100 microprobe. The percentage proportions and chemical compositions of the heavy minerals were interpreted using an original technique that was developed at the Laboratory of Sedimentary Geology of the Far East Branch of the Russian Academy of Sciences and allows the recognition of the ancient analogues of modern geodynamic settings [8, 9, 28, 29]. The major-element compositions of the rocks were determined by traditional wet chemistry. All the analyses were conducted at the laboratories of the Far East Branch of the Russian Academy of Sciences.

STRUCTURE AND COMPOSITION OF THE SECTIONS

Due to their poor exposure, the significant overlapping of the studied deposits by Late Cretaceous volcanic rocks, and the complex tectonic setting, the stratigraphic column of the sediments of the Zhuravlevka terrane was compiled from numerous fragments characterizing the structures of different tectonic blocks (Figs. 2, 3). The sequence is subdivided into eight formations conformably overlaying each other and varying in age from the Berriassian to the late Albian.

The Zhuravlevka Formation (upper Berriasian–lower Valanginian) located at the base of the visible sequence [11] is mainly represented by siltstones and mudstone with sandstone intercalations; the rhythmic alternation of sandstones, siltstones, and mudstones with elementary rhythms (cyclites) from 3–5 cm to 20–30 cm thick; and rare mixtite horizons. Single basaltic flows with within-plate geochemical affinity were described from the section on the left side of the Bikin River [5]. The thickness of the formation is up to 1800 m.

The overlying **Klyuchevskaya Formation** (Valanginian) in terms of lithology was subdivided into five sequences. **Sequence I** (700 m) is made up of inequigranular sandstones with plant detritus and intercalations of sandy siltstones, gravelstones, and conglomerates. **Sequence II** (600 m thick) consists mainly of siltstones with scarce intercalations of sandstones and rhythmic sandstone–siltstone beds. **Sequence III** (570 m thick) consists of sandstones in its lower part and units of rhythmic sandstone–siltstone alternation, as well as individual beds of gravelstones and conglomerates in the upper part. **Sequence IV** (850 m thick) comprises the alternation of inequigranular sandstones and siltstones and mixtite horizons. **Sequence V** (530 m) is built up of siltstones and mudstones sometimes siliceous in composition and containing scarce interbeds of sandstones. The total thickness of the formation is up to 3250 m.

The age of the Zhuravlevka and Klyuchevskaya formations is based on the finds of buchias and more rare ammonites [2, 11].

The Ust-Kolumbe Formation (Hauterivian) comprises fine to medium-grained sandstones with thin siltstone intercalations, as well as units of rhythmically intercalated sandstones and siltstones. The thickness of the formation is up to 2160 m.

The Primankinskaya Formation (Late Hauterivian–Barremian) consists of thin rhythmic alternation of fine grained sandstones and siltstones (the cyclite thickness 3–10 cm) separated by scarce intercalations of medium- to coarse-grained sandstones with abundant plant detritus in the lower part. The upper part is dominated by sandy siltstones with sandstone intercalations. The thickness of the formation is 700 m.

The Hauterivian–Barremian age of the Ust-Kolumbe and Primankinskaya formations is determined only on the basis of scarce finds of prismatic beds and single preserved inocerams [2, 11].

The Katalevskaya Formation (Aptian) consists mainly of thick beds of inequigranular sandstones, which often contain coalified plant detritus and angular fragments of siltstones and are split by units of coarse rhythmic sandstone–siltstone intercalation with the clear predominance of sandstones, as well as intercalations of siltstones, gravelstones, and conglomerates. The thickness of the formation reaches 1560 m.

The Divninskaya Formation (Early Albian) comprises siltstones and mudstones with scarce (up to 30 cm) intercalations of fine-grained sandstones. The siltstones contain coalified plant detritus. The siltstones in the basin of the Bol'shaya Ussurka River occasionally contain rhythmic sandstone–siltstone units with the predominance of the latters, as well as beds of fine to medium-grained sandstones, mixtites, and lenses of gravelstones and conglomerates. The upper part of the section is made up of a mixtite unit consisting of siltstones with clasts of sandstones and cherts of different sizes. The mixtites contain sandstone intercalations with gravelstone lenses. The thickness of the formation is up to 950 m.

The Svetlovodninskaya Formation (early and middle Albian) consists mainly of rhythmic sandstone–siltstone units (150–300 m). The thickness of the rhythms varies from 5–10 to 50–100 cm. The sandstone/siltstone ratio in the rhythms is almost equal with the occasional predominance of one or another component. The monotonous alternating sequence is sometimes interrupted by individual beds of siltstones, mixtites, and sandstones, which are dominant in the lower part of the formation. Its thickness reaches 2000 m.

The Aptian–early Albian age of the Katalevskaya, Divninskaya, and Svetlovodninskaya formations was provided by numerous finds of aucellinaes and ammonites [2, 11].

The Lower Cretaceous sequence of the terrane is crowned by the **Luzhki Formation** (middle and late Albian) consisting of sandstones and sandy siltstones with rare beds and lenses of conglomerates, gravelstones, and siltstones. The age of the formation was established from numerous finds of the characteristic trigonia-actaenella faunal complex [2, 11]. The thickness of the formation is up to 1200 m.

Thus, the Berriassian–Albian sediments of the Zhuravlevka terrane are characterized by the follow-

Fig. 3. Correlation scheme of the studied sections of the Lower Cretaceous sediments of the Zhuravlevka terrane. (*1*) conglomerates and gravelstones; (*2*) sandstones, (*3*) siltstone and mudstones, (*4*) siliceous–clayey rocks, (*5*) rhythmic alternation of sandstones and siltstones, (*6*) mixtites, (*7*) localities of faunal finds after [2, 11].
Numbers of columns correspond to the numbers of sections in Fig. 2.

ing structural and compositional features: (1) a prominent difference between the Berriasian–Valanginian and Hauterivian–Albian portions of the section. The lower part (the Zhuravlevka and Klyuchevskaya formations) is peculiar in the predominance of clay rocks, as well as in the presence of mixtite units and thin basaltic flows. The characteristic features of the Hauterivian–Albian part of the section are the following:

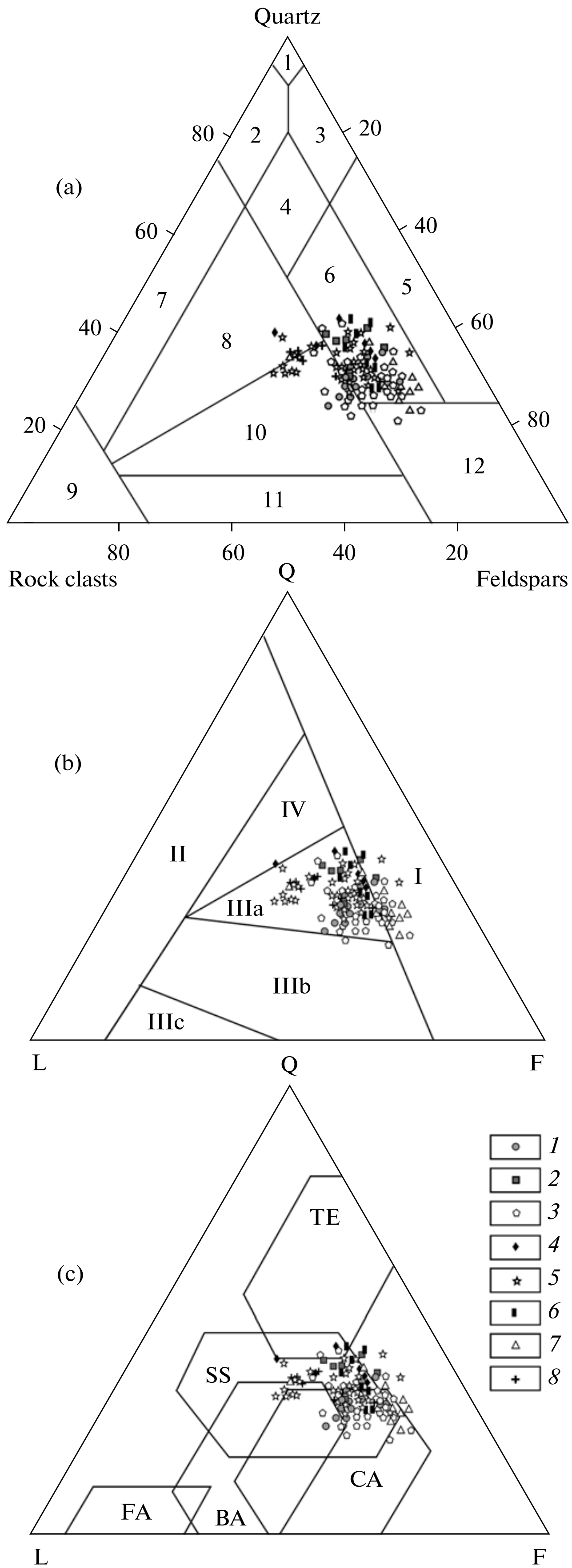

Fig. 4. Rock-forming components of sandstones from the Lower Cretaceous sediments of the Zhuravlevka terrane and their paleogeodynamic interpretation.

(a) Classification diagram of the rock types [19]. Fields: (1–4) quartzose sandstones: (1) monomictic quartzose, (2) siliciclastic–quartzose, (3) feldspar–quartz, (4) mesomictic quartz; (5–6) arkosic sandstones: (5) pure arkoses, (6) graywackes arkoses; (7–11) greywacke sandstones: (7) quartzose graywackes, (8) feldspar–quartz graywackes, (9) graywackes, (10) quartz–feldspathic graywackes, (11) feldspathic graywackes; (12) crystal tuff.

(b) Types of source areas [24]. (I) stable cratons and uplifted basement blocks, (II) remobilized orogens, (III) magmatic arcs ((IIIa) divided, deeply eroded, (IIIb) transitional, (IIIc) undivided, weakly eroded), (IV) mixed source areas.

(c) Types of basin settings [28]. Passive settings (TE—intercontinental rifts and aulacogens); basins of active continental margins conjugated with strike-slip dislocations along transform faults (SS), with continental-margin magmatic arcs (CA), oceanic volcanic arcs (basins: FA—forearc, BA—backarc).

(*1–8*) Formations: (*1*) Zhuravlevka, (*2*) Klyuchevskaya, (*3*) Ust Kolumbe, (*4*) Primankinskaya, (*5*) Katalevskaya, (*6*) Divninskaya, (*7*) Svetlovodninskaya, (*8*) Luzhki.

(1) the predominance of sandstones and the presence of numerous turbidite units, (2) the subdivision of the section into four megarhythms from 1.5 to 3 km thick with the predominance of sandstones at the base and siltstones in the roof, and (3) the notable (up to 13000 m) thickness of the deposits.

THE COMPOSITION OF THE TERRIGENOUS ROCKS AND THEIR GEODYNAMIC INTERPRETATION

The study was focused on the composition of the sandstones because they bear the maximal information on the type and composition of the source areas, as well as on the geodynamic settings of the sedimentation basins. We also took into consideration data on the composition of the clayey–silty and coarse-clastic rocks.

The sandy rocks in all the mentioned formations are usually fine and medium-grained, rarely reaching coarse and gravel size. They are characterized by good sorting, which becomes worse as their grain size increases. Sometimes, the sandstones contain small (up to 2 cm) often angular fragments of siltstones and mudstones evenly scattered through the volume. The sandy grains are usually angular-rounded and semirounded and, more rarely, angular and rounded. The highest degree of roundness is observed in the grains of the felsic intrusive, siliceous, and sedimentary rocks, while those of the volcanic and metamorphic rocks are the least rounded.

In terms of the rock-forming components, all the studied sandstones have a polymictic composition. The clastic part occupies 70–90 vol % and consists of quartz, feldspars, and biotite; clasts of terrigenous, siliceous, carbonate, intrusive, volcanic, and metamor-

Table 1. Contents of rock-forming components in sandstones of the Zhuravlevka terrane (%)

Component	Zhuravlevka Formation (13)	Klyuchevskaya Formation (6)	Ust Kolumbe Formation (28)	Primankinskaya Formation (6)	Katalevskaya Formation (31)	Divninskaya Formation (8)	Svetlovodninskaya Formation (21)	Luzhki Formation (7)
Quartz	24–35 / 29 ± 3.1	30–40 / 36 ± 4.5	21–41 / 29 ± 5.2	34–42 / 37 ± 2.9	26–40 / 33 ± 1.2	28–42 / 35 ± 5.5	23–37 / 30 ± 4.1	29–36 / 33 ± 2.8
K-feldspar	8–15 / 10 ± 2.4	5–6 / 5 ± 0.6	2–19 / 10 ± 5.7	2–7 / 4 ± 1.7	2–16 / 8 ± 1.2	2–11 / 5 ± 3.0	5–23 / 13 ± 6.3	1–6 / 4 ± 1.6
Basic and intermediate plagioclases	0–2 / 1 ± 0.8	2–4 / 3 ± 1.0	0–5 / 2 ± 1.3	1–4 / 2 ± 1.7	0–4 / 2 ± 1.2	0–2 / 1 ± 0.9	0–4 / 1 ± 1.3	0–2 / 1 ± 0.6
Acid plagioclases	32–42 / 37 ± 3.6	30–41 / 36 ± 4.6	28–49 / 39 ± 6.3	21–40 / 34 ± 7.4	21–46 / 35 ± 7.4	31–46 / 40 ± 4.9	26–51 / 38 ± 7.7	30–45 / 36 ± 6.4
Basic and intermediate volcanic rocks	0–3 / 2 ± 0.9	1–2 / 2 ± 0.6	1–4 / 2 ± 1.1	0–2 / 1 ± 0.8	0–2 / 1 ± 0.8	0–2 / 1 ± 1.1	0–3 / 1 ± 1.2	1–3 / 1 ± 0.9
Felsic volcanic rocks	1–4 / 2 ± 1.1	1–4 / 3 ± 1.3	1–7 / 3 ± 1.9	1–4 / 2 ± 1.2	0–4 / 1 ± 1.2	0–3 / 1 ± 1.1	1–4 / 1 ± 1.2	1–4 / 3 ± 1.0
Felsic intrusive rocks	2–7 / 4 ± 1.7	2–5 / 4 ± 1.4	2–10 / 4 ± 2.1	2–8 / 4 ± 2.3	2–9 / 4 ± 1.2	1–4 / 2 ± 1.2	1–7 / 3 ± 1.6	1–2 / 1 ± 0.5
Metamorphic rocks	1–6 / 3 ± 1.6	1–4 / 2 ± 1.5	2–11 / 4 ± 2.4	1–4 / 2 ± 1.0	2–12 / 5 ± 1.2	2–4 / 3 ± 0.7	1–9 / 4 ± 2.0	1–8 / 4 ± 2.7
Cherts	5–15 / 10 ± 3.6	5–9 / 7 ± 1.8	2–14 / 7 ± 2.9	5–10 / 8 ± 2.0	3–24 / 9 ± 1.2	2–10 / 6 ± 2.5	1–7 / 4 ± 1.2	5–16 / 13 ± 3.9
Terrigenous rocks	1–8 / 4 ± 2.0	2–7 / 4 ± 2.4	2–11 / 4 ± 2.2	3–15 / 7 ± 5.6	2–13 / 5 ± 1.2	4–13 / 7 ± 2.8	2–10 / 4 ± 1.7	3–7 / 5 ± 1.5
Carbonate rocks	0–2 / 1 ± 0.5	0–2 / 1 ± 0.8	0–1 / 1 ± 0.2	0–2 / 1 ± 0.8	0–3 / 2 ± 0.9	0–1 / 1 ± 0.2	0–4 / 1 ± 1.2	0–1 / 1 ± 0.2

Notes: no less than 200 grains were calculated in each sample. The numerator shows the ranges of the contents and the denominator, the average contents and mean-squared deviation. The number of samples used in the calculations are shown in parentheses.

phic rocks; and ore minerals. According to the classification diagram of Shutov [19] (Fig. 4a), the sandstones define a single field mainly ascribed to greywacke arkoses and, to lesser extent, to quartz–feldspar and feldspar–quartz graywackes.

Quartz is the predominant component of the sandstones, amounting to from 21 to 42 vol % (Table 1). The most abundant is monocrystalline intrusive quartz represented by equant or weakly elongated grains with numerous very fine gas–liquid inclusions and acicular rutile. Less common are pure, often with wavy extinction, irregularly shaped elongated, angular or weakly rounded grains of volcanic quartz and elongated usually polycrystalline grains of metamorphic quartz with irregular outlines. The content of feldspars in the sandstones varies from 23 to 62%. These are mainly elongated tabular and more rarely equant grains of acid plagioclases: albite and oligoclase. The K-feldspars are mainly dominated by equant pelitic grains of orthoclase, while microcline with cross hatched twinnings occurs significantly more rarely. The basic and intermediate plagioclases are scarce. Rock clasts (from 15 to 45%) contain mainly siliceous and terrigenous rocks with lesser amounts of clasts of metamorphic and felsic igneous rocks and occasional clasts of volcanic and carbonate rocks. The clay component of the sandy rocks in all the formations is fairly uniform and consists mainly of hydromica (up to 90%), as well as smectite and chlorite.

Thus, the rock-forming components of the sandstones suggest that the primary rocks of the main source area during the accumulation of the sediments of the Zhuravlevka terrane were represented by diverse sedimentary, felsic, intrusive, and metamorphic rocks. The mainly arkosic composition of the sandstones indicates the erosion of granite–metamorphic crust. One can suggest that the siliceous and terrigenous rocks, which often compose the most part of the clasts in the sediments, were derived by the erosion of fragments of the Jurassic accretionary wedge (Samarka terrane), which in the modern structure borders the Zhuravlevka terrane in the west-northwest.

The geological interpretation of the composition of the rock-forming components of the sandstones was performed using widely known methods proposed by Dickinson and Suczek, Maynard, and others. It is seen in the diagram of Dickinson and Suczek [24] used to

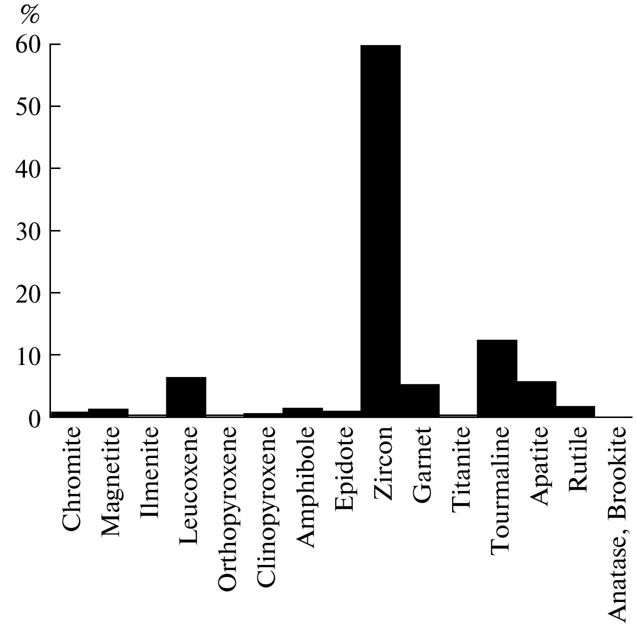

Fig. 5. Distribution of heavy clastic minerals in sandy rocks of the Zhuravlevka terrane.

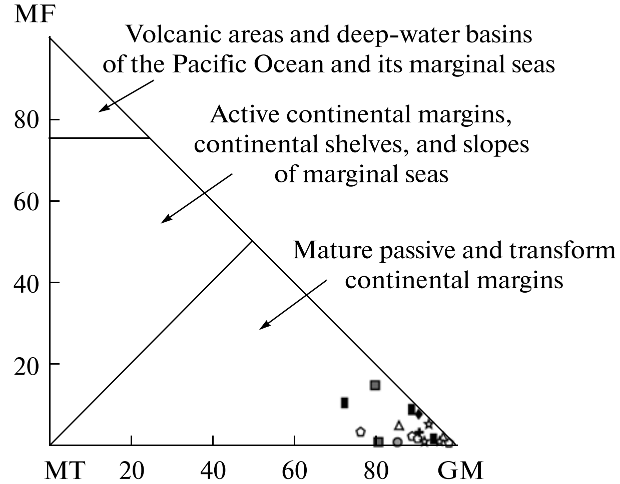

Fig. 6. Comparison of the heavy fraction composition of the sandstones from the Lower Cretaceous sediments of the Zhuravlevka terrane with that of modern sediments from different geodynamic settings [30, 31] (the average contents in the formations are given for the individual sections).

Sum of contents: (MF) olivine, pyroxenes, green hornblende; (MT) epidote, garnet, blue-green amphiboles; (GM) zircon, tourmaline, staurolite, disthene, sillimanite, and andalusite. The symbols are shown in Fig. 4.

discriminate between the tectonic types of source areas (Fig. 4b) that the sandstones of the Zhuravlevka terrane could have been formed via the erosion of the crystalline basement inliers located along the rift belts or transform faults (I), as well as by the erosion of the holocrystalline batholiths that composed the roots of the mature deeply eroded magmatic arcs (IIIa). The geotectonic settings of the sedimentation basins were reconstructed using the diagram of Maynard et al., [28] (Fig. 4c), which demonstrates that the studied sandstones are most close to those of the basins of the Californian-type "nonvolcanic" continental margin complicated by strike-slip transform faults and, partly, to the continental margin magmatic arcs (CA).

Thus, the sedimentation settings reconstructed from the rock-forming components can be generally classed with those of pull-apart basins of continental margins, i.e., settings of transform continental margins [2, 4, 26].

It is known that different tectonic sedimentation settings are characterized by peculiar heavy mineral assemblages [9, 10, 27, 30, 31]. The detrital heavy minerals in the sandstones of the Zhuravlevka terrane account for 0.01–0.8 vol %, occasionally reaching 2%. It should be noted that the mineral composition of the heavy fraction shows insignificant variations throughout the section. The proportions between the average contents of the individual minerals are demonstrated in Fig. 5. All the heavy minerals, with some conditionality, can be subdivided into two mineralogical associations. First, the mainly sialic association often amounting up to 100% of the total heavy minerals consists of minerals related to the disintegration of felsic igneous and metamorphic rocks: zircon, garnet, tourmaline, epidote, titanite, rutile, apatite, anatase, and brookite. The main mineral of the association, zircon, accounts for 60%, reaching 90% in some samples. It is mainly represented by colorless or weakly colored prismatic crystals containing small gas–liquid inclusions, which is a typomorphic sign of zircons from granite rocks [7]. The second and mafic association is observed in subordinate amounts (on average, up to 5% of all the minerals) and consists of typical volcaniclastic minerals: ortho- and clinopyroxenes, hornblende, chromite, and magnetite. The examination of the heavy mineral associations of sandstones of the Zhuravlevka terrane in the *MF–MT–HM* diagram [30, 31] (Fig. 6) shows that their source area was mainly eroded mature continental margin (passive or transform) consisting mainly of felsic and metamorphic rocks. The influence of the volcanic source on the sedimentation was extremely insignificant.

To obtain additional information on the sources of the heavy detrital minerals, we studied the chemical composition of the detrital garnets and chromites (Table 2). The detrital *garnets* from sandstones in composition are mainly almandine and only rarely contain grossular or spessartine components. Judging from the position of the data points in the *Mg–Mn–Ca* diagram [36], they were presumably derived from granulite- and amphibolite-facies metamorphic rocks, as well as from felsic intrusive rocks (Fig. 7). The source of the garnets was presumably mature continental crust made up of deeply metamorphosed rocks and grani-

Table 2. Chemical composition (wt %) of garnets and chromites from sandstones of the Zhuravlevka terrane

Sample no.	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO*	MnO	MgO	CaO	Total
Garnets									
Zh-21/1	36.92	–	21.33	–	35.52	0.57	4.36	0.79	99.49
Zh-21/2	36.91	–	20.85	–	36.09	0.61	4.58	0.74	99.78
Zh-21/3	36.48	–	20.81	–	34.94	2.98	2.64	1.73	99.58
Zh-21/4	36.74	–	21.00	–	35.49	2.60	2.80	1.97	100.60
Zh-21/5	38.95	–	22.38	–	31.46	0.50	4.85	0.83	98.97
Zh-21/6	37.77	–	21.33	–	34.18	2.45	2.77	1.64	100.14
Zh-31/1	43.14	–	40.66	–	10.22	2.16	3.59	–	99.77
Zh-31/2	43.18	0.99	36.62	–	10.56	2.91	5.21	0.33	99.80
Zh-31/3	43.34	0.73	36.99	–	10.20	2.95	5.56	0.27	100.04
Zh-31/4	43.34	0.37	36.64	–	10.13	3.26	5.91	0.34	99.99
Zh-33/1	36.79	–	20.70	–	36.74	1.19	2.77	1.97	100.16
Zh-33/2	37.29	–	20.49	–	35.25	0.89	4.61	1.16	99.69
Zh-33/3	36.93	–	20.85	–	35.28	0.66	4.68	1.04	99.44
Zh-33/4	36.47	–	20.27	–	36.83	1.19	2.70	1.97	99.43
Zh-33/5	41.87	–	23.84	–	26.66	0.63	5.16	1.17	99.33
Zh-33/6	38.31	–	21.13	–	34.39	1.29	2.89	1.96	99.97
Zh-33/7	41.83	–	22.41	–	28.12	0.73	5.58	1.34	100.01
Zh-45	37.04	0.05	20.25	0.07	34.98	1.51	4.08	1.21	99.19
Zh-56/1	37.08	0.07	20.43	0.04	29.63	9.35	2.03	0.60	99.22
Zh-56/2	38.35	0.02	20.81	0.11	29.86	0.56	8.04	1.06	98.82
Zh-56/3	38.00	–	21.25	0.06	30.34	0.53	8.39	1.12	99.69
Zh-56/4	39.43	0.11	21.93	0.14	31.90	0.76	6.98	1.03	102.27
Zh-56/5	38.02	0.01	20.30	0.04	34.75	2.13	4.44	1.04	100.72
Zh-56/6	37.55	0.18	20.71	0.01	33.83	2.21	4.46	0.68	99.63
Zh-57/1	37.19	0.01	20.25	–	34.61	1.59	3.48	2.24	99.38
Zh-57/2	37.11	0.09	20.68	0.14	34.64	1.40	3.58	2.45	100.08
Zh-57/3	36.66	0.09	20.47	0.09	36.85	0.98	1.41	2.87	99.41
Zh-84	37.13	–	20.70	0.06	35.14	0.80	4.09	1.31	99.23
Zh-85	37.92	0.04	21.25	–	30.27	3.70	5.74	1.39	100.32
Zhr-15/1	37.56	–	21.51	–	22.20	10.00	6.81	1.19	99.27
Zhr-15/2	36.34	–	21.28	–	34.76	1.33	4.54	0.78	99.03
Zhr-24/1	37.22	–	21.17	–	31.35	0.90	7.38	1.27	99.29
Zhr-24/2	37.75	–	21.77	–	30.10	0.59	8.36	1.05	99.64
Zhr-63/1	36.35	–	20.92	–	24.74	9.26	2.41	6.55	100.24
Zhr-63/2	37.13	–	21.36	–	31.84	0.71	6.88	1.41	99.33
Zhr-63/3	34.56	0.48	19.08	–	14.48	27.78	0.78	0.83	97.98
Zhr-63/4	34.88	0.45	19.58	–	14.06	28.02	1.10	0.86	98.95
Zhr-88/1	37.94	–	22.16	–	33.23	0.56	6.57	1.14	101.59
Zhr-88/2	37.50	–	21.93	–	33.40	0.53	6.63	1.10	101.08
Chromites									
Zh-1/1	–	–	6.17	64.77	18.66	–	9.41	–	99.01
Zh-1/2	–	–	2.76	68.62	19.58	0.30	8.63	–	99.89
Zh-1/3	–	–	9.48	56.49	25.39	0.82	7.41	–	99.59
Zh-1/4	–	–	3.31	68.43	19.28	0.75	8.33	–	100.10

Table 2. (Contd.)

Sample no.	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO*	MnO	MgO	CaO	Total
Zh-1/5	–	–	9.52	59.25	22.70	–	8.40	–	99.87
Zh-1/6	–	–	9.52	57.14	24.52	0.80	8.34	–	100.32
Zh-2/1	–	–	11.67	60.31	15.32	0.41	11.31	–	99.02
Zh-2/2	–	–	10.76	55.66	25.69	–	6.32	–	98.43
Zh-2/3	–	–	10.38	62.07	16.08	0.46	11.04	–	100.03
Zh-2/4	–	–	10.27	61.90	16.46	0.46	11.08	–	100.17
Zh-2/5	–	–	10.79	56.69	25.12	0.26	7.57	–	100.43
Zh-2/6	–	–	10.49	56.55	25.82	0.32	6.58	–	99.76
Zh-2/7	–	–	11.55	60.37	15.52	0.29	11.67	–	99.40
Zh-2/8	–	–	11.85	58.69	16.88	0.77	10.72	–	98.91
Zh-2/9	–	–	11.57	62.68	13.60	–	11.77	–	99.62
Zh-23/1	–	–	7.35	63.19	19.84	0.53	9.54	–	100.45
Zh-23/2	–	–	6.71	63.16	20.11	0.31	8.36	–	98.64
Zh-23/3	–	–	7.00	64.77	17.90	0.53	10.95	–	101.15
Zh-23/4	–	–	6.52	65.66	18.43	0.38	9.70	–	100.69
Zh-23/5	–	–	6.85	64.61	17.64	0.59	9.54	–	99.23
Zh-23/6	–	–	6.99	65.38	18.43	–	9.01	–	99.81
Zh-30/1	–	–	5.24	64.64	20.54	0.37	8.41	–	99.20
Zh-30/2	–	–	12.93	58.34	17.18	0.25	10.51	–	99.21
Zh-30/3	–	–	5.20	65.29	20.34	0.15	7.71	–	98.68
Zh-30/4	–	–	12.99	57.82	17.58	0.50	10.69	–	99.58
Zh-30/5	–	–	5.20	65.81	19.04	–	8.32	–	98.37
Zh-30/6	–	–	13.47	57.34	18.77	–	10.20	–	99.78
Zh-31/1	–	–	10.88	57.92	21.53	–	7.88	–	98.98
Zh-31/2	–	–	11.24	59.37	20.42	–	7.45	–	98.48
Zh-33/1	–	–	13.69	58.07	14.47	–	12.31	–	98.54
Zh-33/2	–	–	22.50	49.39	13.39	0.23	14.44	–	99.96
Zh-33/3	–	–	14.14	58.16	14.01	0.34	12.67	–	99.32
Zh-33/4	0.18	0.18	6.97	63.96	17.64	–	10.96	–	99.89
Zh-33/5	0.05	0.01	18.35	52.61	17.31	–	11.29	–	99.62
Zh-45/1	0.04	0.44	23.37	43.34	19.97	–	11.50	–	98.65
Zh-45/2	0.05	0.11	17.75	48.04	23.63	–	9.76	–	99.34
Zh-56	0.18	0.48	11.99	52.90	22.52	–	10.50	–	98.56
Zh-64/1	–	0.04	15.23	55.97	14.39	–	12.75	–	98.39
Zh-64/2	0.11	–	15.90	53.63	16.25	–	11.76	–	97.64
Zh-64/3	0.19	0.03	16.09	54.14	15.88	–	11.73	–	98.07
Zh-64/4	0.22	–	13.51	59.23	14.41	–	12.60	–	99.97
Zh-74	0.10	0.20	21.28	43.17	22.68	–	10.55	–	97.99
Zh-76/1	0.33	2.05	10.95	48.32	23.26	–	13.00	–	97.91
Zh-76/2	0.08	0.64	10.66	51.58	26.47	–	9.42	–	98.84
Zh-85	0.10	0.27	14.86	51.04	18.87	–	12.76	–	97.89
Zhr-15	–	0.64	9.94	48.67	31.92	0.64	7.42	–	99.23
Zhr-22	–	2.04	13.00	45.05	27.37	0.78	11.24	–	99.48
Zhr-63	–	–	8.27	64.08	18.03	0.70	9.69	–	100.77

Note: FeO* is total iron. A dash denotes that the elements were not found. The analyses were carried out on a JXA-8100 microprobe at the Far East Geological Institute of the Far East Branch of the Russian Academy of Sciences (analysts N.I. Ekimova and G.B. Molchanova).

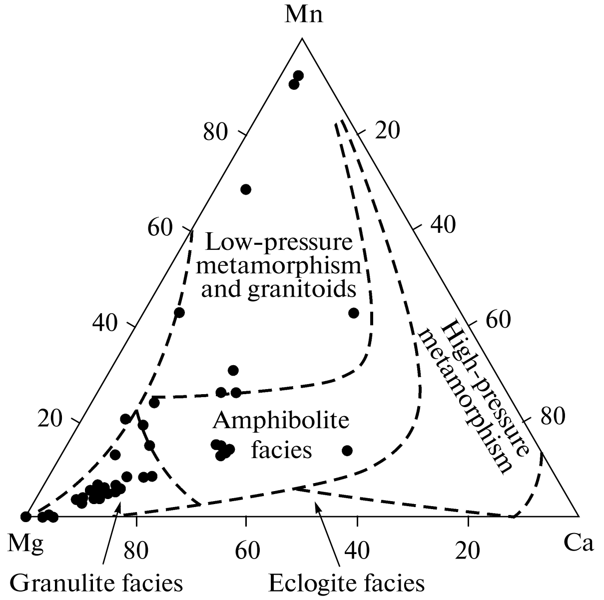

Fig. 7. Diagram of the composition of detrital garnets from different metamorphic rocks and granitoids [36].

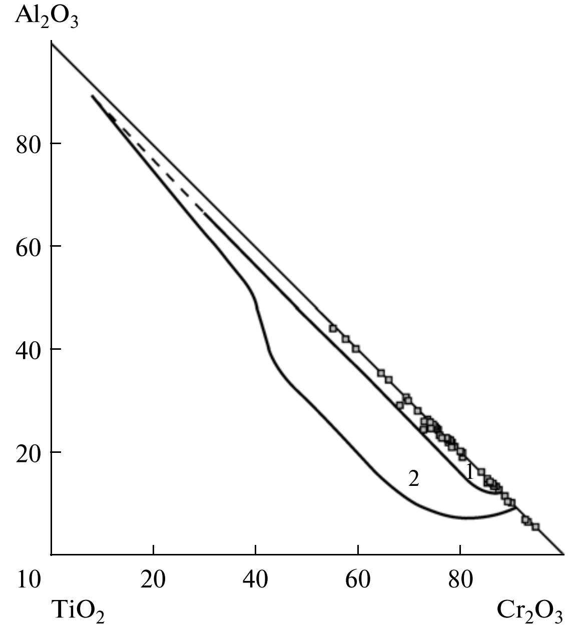

Fig. 8. Diagram showing the composition of detrital chromites from different magmatic rocks [20]. Lines border the fields of chromites from the (1) dunite–harzburgite (Alpine-type) associations and (2) basaltoid ultramafic rocks.

toids. The detrital *chromites* have a fairly uniform chemical composition. Their distinctive feature is the absence of or extremely low titanium content. In the Al_2O_3–Cr_2O_3–$10TiO_2$ diagram [20] (Fig. 8), they correspond to chromites of the dunite–harzburgite alpinotype formation. The chromite sources were presumably ultramafic rocks of ophiolites involved in the Jurassic accretionary wedge of the Samarka terrane, which is located west–northwest of the Zhuravlevka sedimentation basin.

Thus, the heavy mineral composition of the sandstones shows that the main source of detritus was mature continental margin consisting of felsic igneous and metamorphic rocks. Ophiolite complexes possibly representing the fragments of pre-Cretaceous active margins were eroded to a lesser extent.

In terms of chemical composition (Table 3), the sandstones of the Zhuravlevka terrane are fairly homogenous with insignificant variations in individual samples: SiO_2 from 65.55 to 85.90%, TiO_2 0.08–0.53%, Al_2O_3 6.55–15.27%, FeO + Fe_2O_3 0.84–5.97%, MgO 0.21–1.93%, CaO 0.02–5.58%, Na_2O 0.04–5.64%, and K_2O 0.75–3.56%. In terms of these parameters, they are close to felsic igneous rocks and occupy an intermediate position between arkoses and graywackes [15].

Since the absolute contents of the rock-forming oxides reflect the composition of not only the terrigenous rocks but also their cement, their geochemical features are more reliably identified using the most informative petrochemical modulus and module diagrams (Table 3, Fig. 9) [21, 22]. In terms of these criteria, the sandstones are close to each other and characterized by the following features: (1) relatively low maturity (the hydrolyzate module (HM) varies from 0.10 to 0.29), which indicates their formation via the mechanical destruction of the parental rocks with the subordinate role of chemical weathering; (2) a low femic index (the femic module (FM) varies from 0.02 to 0.09), which is well consistent with the low content of basic volcanic clasts but high contents of quartz, siliceous rocks, and granitoids; in terms of this parameter, they are intermediate between graywackes and arkoses; (3) a low Ti content (the titanium module (TM) varies from 0.009 to 0. 042), which is related to the admixture of clasts of felsic igneous rocks with low TM values, as well as with the practically complete absence of basic volcaniclastics; (4) relatively high normative alkalinity (the module of the normative alkalinity (NKM) is from 0.30 to 0.69) typical of arkoses and reflecting sufficiently high contents of micas and feldspars, including potassium ones.

In terms of chemical composition, the clayey–silty rocks are close to sandstones, but they differ from them in the lower contents of SiO_2 (from 58.90 to 73.51%) and Na_2O (0.39–3.59%) but higher Al_2O_3 (11.38–20.79%), TiO_2 (0.18–0.90%), FeO + Fe_2O_3 (1.69–7.14%), CaO (0.08–6.04%), MgO (0.14–2.81%), and K_2O (1.37–5.16%) (Table 3). In addition, the clayey–silty rocks are characterized by higher values of the hydrolyzate (0.21–0.45), femic (0.04–0.17), and titanium (0.022–0.054) modulus but lower values of the module of normative alkalinity (0.28–0.45), which is possibly related to the lower quartz and feldspar contents and higher content of clayey mate-

Table 3. Average chemical composition (wt %) of the terrigenous rocks of the Zhuravlevka terrane on individual studied sections

Sampling locality	*n*	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	L.O.I	H_2O^-	Total	HM	TM	FM	NKM
Sandy rocks																			
Zhuravlevka Formation																			
Zhuravlevka R.	8	75.33	0.21	12.05	1.40	1.20	0.04	0.83	0.58	3.43	2.72	0.10	1.51	0.18	99.58	0.20	0.018	0.05	0.51
Klyuchevskaya Formation																			
Pereval'naya R.	3	80.56	0.19	8.89	1.62	0.48	0.09	0.43	1.38	2.63	1.16	0.14	2.24	0.07	99.84	0.14	0.022	0.03	0.42
Ust Kolumbe Formation																			
Svoyakovka R.	2	73.75	0.27	10.44	1.48	1.01	0.06	1.27	3.24	2.89	1.80	0.19	3.19	0.21	99.80	0.18	0.026	0.05	0.45
Partizanka R.	2	73.84	0.35	9.33	1.99	1.05	0.06	1.27	3.41	2.58	2.00	0.17	3.76	0.26	100.07	0.17	0.038	0.06	0.49
Partizanka R.	5	74.60	0.34	9.04	1.73	0.93	0.07	1.36	3.93	1.14	1.88	0.18	4.45	0.27	99.92	0.16	0.038	0.05	0.33
Kolumbe R.	6	70.29	0.44	14.43	1.56	1.56	0.05	1.11	1.22	4.57	2.52	0.14	1.87	0.10	99.86	0.26	0.030	0.06	0.49
Primankinskaya Formation																			
Svoyakovka R.	4	76.89	0.31	9.87	3.23	0.72	0.07	0.72	1.07	2.67	1.81	0.17	2.16	0.18	99.86	0.19	0.031	0.06	0.45
Katalevskaya Formation																			
Glubokii Cr.– Pereval'naya R.	5	75.10	0.34	12.06	1.65	1.36	0.04	0.68	0.70	2.74	3.03	0.16	1.73	0.24	99.83	0.21	0.028	0.05	0.48
Dorozhnaya R.	6	72.12	0.3	11.59	2.11	0.85	0.05	0.82	2.35	1.4	3.28	0.09	4.4	0.27	99.63	0.21	0.026	0.05	0.40
Bol'shaya Ussurka R.	6	82.92	0.13	7.51	1.51	1.17	0.03	0.47	0.21	1.64	2.19	0.17	1.76	0.19	99.90	0.12	0.017	0.04	0.51
Divninskaya Formation																			
Bol'shaya Ussurka R.	2	80.70	0.17	8.15	1.50	1.29	0.01	0.67	0.07	2.59	1.60	1.05	2.17	0.20	100.17	0.14	0.021	0.04	0.51
Svetlovodninskaya Formation																			
Pyatyi Cr.	5	71.52	0.38	12.61	1.97	1.32	0.13	0.66	2.13	2.86	2.62	0.14	3.27	0.24	99.85	0.23	0.030	0.06	0.43
Dorozhnaya R.	6	72.08	0.26	12.28	1.03	1.61	0.11	0.89	2.29	4.1	2.36	0.11	2.78	0.07	99.97	0.21	0.021	0.05	0.53
Luzhki Formation																			
Skalistyi Cr.	5	70.80	0.58	14.59	1.49	1.28	0.03	0.81	2.25	0.49	3.75	0.24	3.71	0.16	100.18	0.16	0.027	0.03	0.42

Table 3. (Contd.)

Sampling locality	*n*	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	L.O.I	H_2O^-	Total	HM	TM	FM	NKM
Clayey–silty rocks																			
Zhuravlevka Formation																			
Zhuravlevka R.	6	66.20	0.56	16.19	3.00	1.86	0.05	1.70	0.44	2.45	3.38	0.16	3.15	0.44	99.57	0.33	0.034	0.10	0.36
Klyuchevskaya Formation																			
Partizanka R.	2	66.35	0.69	14.77	5.14	0.27	0.19	1.70	1.55	1.61	3.28	0.28	3.95	0.00	99.78	0.32	0.047	0.11	0.33
Venyukova pass	3	67.16	0.58	15.83	3.64	0.42	0.12	0.90	2.24	1.98	2.98	0.22	3.56	0.08	99.71	0.31	0.037	0.08	0.31
Pereval'naya R.	4	67.45	0.62	15.41	2.82	1.59	0.04	1.05	1.62	2.46	3.45	0.23	2.99	0.09	99.82	0.30	0.040	0.08	0.38
Ust Kolumbe Formation																			
Partizanka R.	2	65.65	0.55	12.04	4.04	0.22	0.15	2.48	4.51	1.28	3.13	0.35	5.55	0.30	100.25	0.26	0.046	0.10	0.37
Kolumbe R.	4	64.94	0.58	16.45	3.13	2.26	0.05	1.83	0.58	3.34	3.18	0.19	2.88	0.31	99.72	0.35	0.035	0.11	0.40
Primankinskaya Formation																			
Svoyakovka R.	5	69.30	0.51	13.94	4.19	0.5	0.08	1.32	0.92	2.04	2.82	0.21	3.79	0.04	99.66	0.28	0.037	0.09	0.35
Katalevskaya Formation																			
Glubokii Cr.– Pereval'naya R.	3	64.17	0.77	16.94	2.79	2.41	0.05	1.54	1.14	2.56	3.70	0.24	3.36	0.21	99.88	0.36	0.045	0.11	0.37
Dorozhnaya R.	2	62.17	0.77	18.22	4.08	0.97	0.03	1.27	0.36	1.22	4.75	0.13	5.00	0.71	99.68	0.39	0.042	0.10	0.33
Bol'shaya Ussurka R.	2	66.11	0.59	13.8	3.25	2.53	0.09	1.83	0.69	1.56	3.43	0.85	4.61	0.58	99.92	0.31	0.043	0.12	0.36
Divninskaya Formation																			
Glubokii Cr.– Pereval'naya R.	5	62.98	0.69	15.97	4.23	0.78	0.06	1.88	2.95	2.53	3.39	0.34	3.85	0.07	99.72	0.35	0.043	0.11	0.37
Andreevskii Cr.	4	62.54	0.63	15.94	4.19	1.51	0.04	1.76	1.49	2.03	3.46	0.17	5.41	0.54	99.71	0.36	0.040	0.12	0.349
Bol'shaya Ussurka R.	5	66.10	0.51	12.83	2.1	3.1	0.03	1.63	0.75	2.12	3.28	1.63	5.17	0.82	100.07	0.28	0.040	0.10	0.42
Svetlovodninskaya Formation																			
Pyatyi Cr.	2	62.55	0.7	18.38	3.27	1.84	0.07	1.45	0.35	2.82	3.61	0.37	4.24	0.10	99.75	0.39	0.038	0.11	0.35
Dorozhnaya R.	6	66.10	0.66	16.17	2.35	2.46	0.03	1.91	0.70	2.09	3.93	0.18	3.16	0.20	99.94	0.33	0.041	0.10	0.37
Luzhki Formation																			
Skalistyi Cr.	3	70.80	0.58	14.59	1.49	1.28	0.03	0.81	2.25	0.49	3.75	0.24	3.71	0.16	100.18	0.25	0.040	0.051	0.29

Notes: *n* is the number of analyses. The analyses were performed at the Far East Geological Institute of the Far East Branch of the Russian Academy of Sciences (analysts A.I. Malykina, V.N. Kaminskaya, V.N. Zalevskaya, and V.U. Kramarenko).

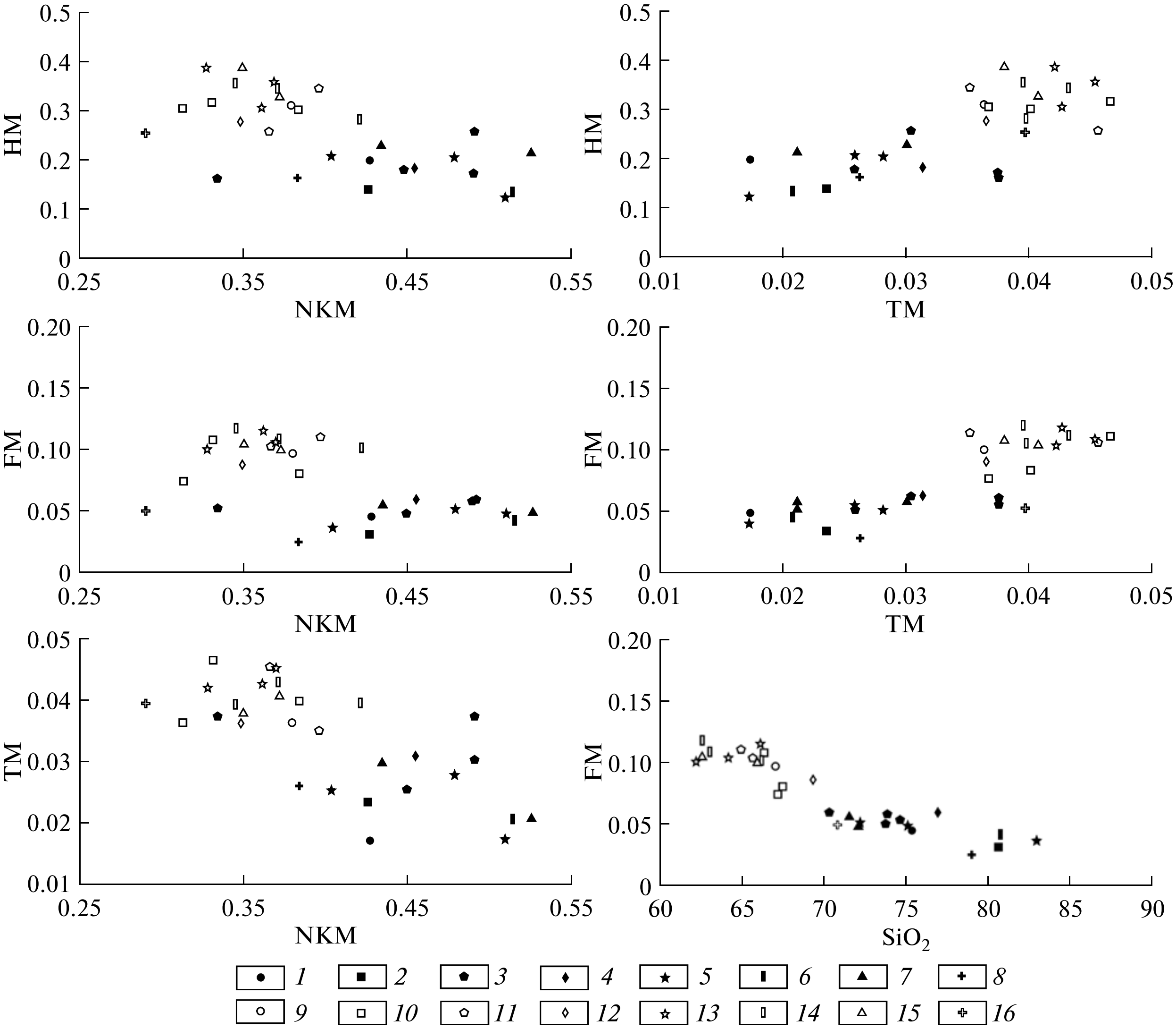

Fig. 9. Module diagrams for sandy and clayey–silty rocks from the Zhuravlevka terrane [21, 22].
(*1–8*) sandy rocks; (*9–16*) clayey–silty rocks. Formations: (*1*, *9*) Zhuravlevka, (*2*, *10*) Klyuchevskaya, (*3*, *11*) Ust Kolumbe; (*4*, *12*) Primankinskaya; (*5*, *13*) Katalevskaya, (*6*, *14*) Divninskaya; (*7*, *15*) Svetlovodninskaya; (*8*, *16*) Luzhki. Modules: (HM) hydrolyzate module ($Al_2O_3 + TiO_2 + Fe_2O_3 + FeO)/SiO_2$, FM femic ($FeO + Fe_2O_3 + MgO/SiO_2$), TM—titanium module ($TiO_2/Al_2O_3$), NKM—normalized alkalinity module ($Na_2O + K_2O/Al_2O_3$).

rial, as well as possibly with the fact that the formation of the terrigenous sediments was not accompanied by significant mechanical differentiation of the pelitic and psammitic fractions [22]. In the the module diagrams (Fig. 9), the clayey–silty rocks are clustered distinctly separately from the field occupied by the sandstones but form with them positive FM–TM and HM–TM correlations and negative HM–NKM, FM–NKM, TM–NKM, and FM–SiO_2 correlations, which indicates the mainly petrogenic (due to erosion of felsic intrusions) nature of the studied rocks.

The genetic interpretation of the chemical composition of the terrigenous rocks is underlain by the same principles as the interpretation of the rock-forming components of the sandstones and is demonstrated in the discrimination diagrams (Fig. 10).

In the diagrams of Bhatia [23] (Fig. 10a) used to separate the sandstones from basins of different tectonic settings, most data points of the Zhuravlevka terranes correspond to or approach the sandstones of active continental margins, which, in the understanding of the author, also include the basins of transform plate margins, including those of the Californian type. Some data points are shifted toward the fields of passive continental margins, which is caused by the sharp enrichment of the sandstones from some levels in clasts of quartz and siliceous rocks. The geotectonic settings of the sedimentation basins are reconstructed

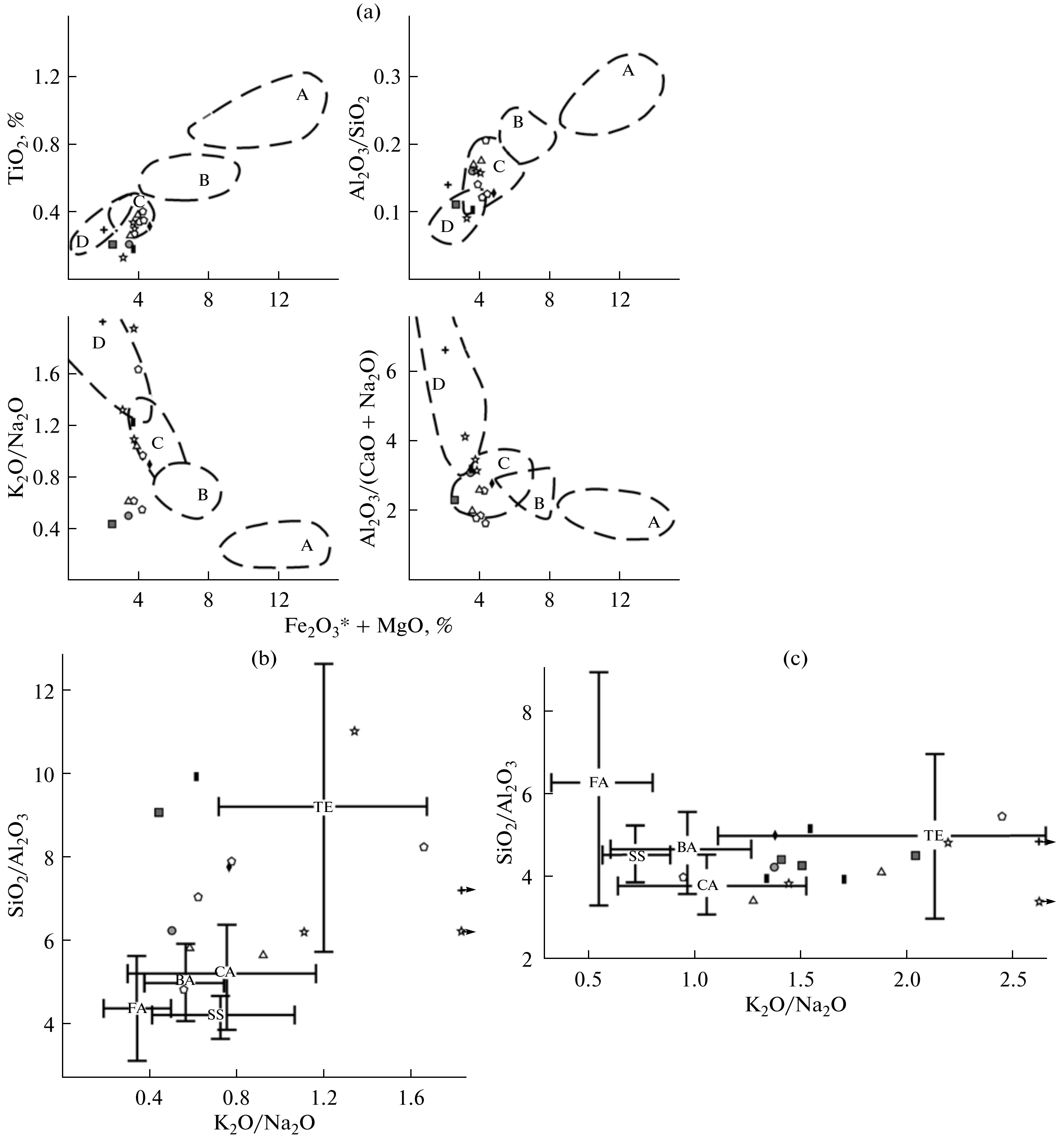

Fig. 10. Diagram of the chemical composition of the sandy and clayey–silty rocks formed in different geodynamic settings.

(a) Types of basins [23]. The dashed lines denote the field of ancient sandstones from basins conjugated with the following: (A) oceanic and (B) continental island arcs and (C) active and (D) passive continental margins. The Fe_2O_3* as total iron.

(b and c) basin settings ((b) for sandy and (c) for clayey-silty rocks) [28]. The intersecting lines are the standard deviations from the average compositions of the modern deep-water sands and clays from different geodynamic settings. For the symbols and abbreviations, see Fig. 4.

using the diagrams of Maynard et al. [28] (Fig. 10b), where the data points of the Zhuravlevka sandstones define a significant scatter, making their interpretation ambiguous. In general, the sandstones occupy an intermediate position between the sands of passive and active continental margin basins.

The paleotectonic interpretation of the chemical composition of the clayey–silty rocks in the diagram

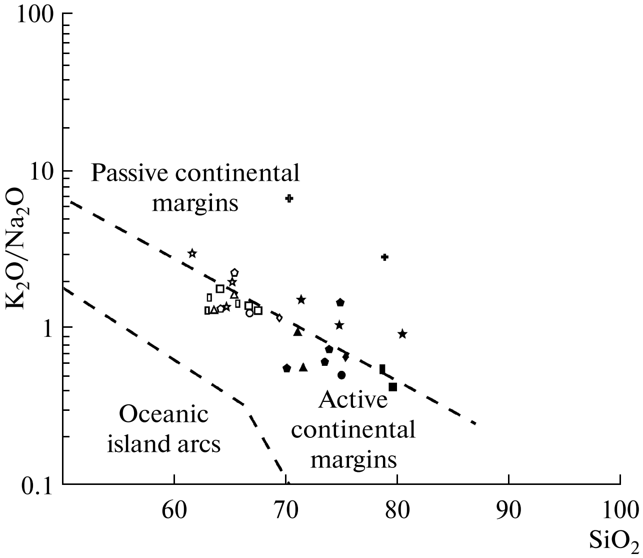

Fig. 11. K_2O/Na_2O–SiO_2 diagram for sandy and clayey–silty rocks from different basin settings [34]. The symbols are shown in Fig. 9.

of Maynard et al. [28] (Fig. 10c) is consistent with the interpretation based on the composition of the sandstones, though it also seems to be ambiguous, since the clayey–silty rocks occupy an intermediate position between the sediments of basins of passive and active continent margins. A more reliable interpretation of the composition of the sandy and clayey–silty rocks can be obtained using the K_2O/Na_2O–SiO_2 diagram proposed by Roser and Korsch [34] (Fig. 11). In this diagram, the data points of the studied rocks mainly fall in the field of basins conjugated with active continental margins and only occasionally in the field of passive margin basins. In general, such an "intermediate" position of the data points of the chemical composition of the terrigenous rocks in all the considered diagrams is probably typical of the sedimentation basins related to settings of strike-slip transform plate boundaries.

Coarse-clastic rocks (conglomerates and gravelstones) occur practically at all the levels of the studied section. Their clasts are mainly represented by siliceous and siliceous–clayey rocks (up to 80%) with lesser amounts of sedimentary (up to 30%), metamorphic, and felsic intrusive rocks (up to 20%). The predominance of psephite-size silicic clasts is explained by their significantly higher resistance to decomposition during weathering as compared to granitoids, which are easily disintegrated into individual components, in particular, the grains of quartz and feldspar predominating in their matrix.

Thus, the composition of the terrigenous rocks of the terrane indicates that the rocks of the source area were mainly represented by felsic igneous and metamorphic rocks. In addition, one can suggest that the source area also contained fragments of the Jurassic accretionary wedge with chert and ophiolite nappes. The sedimentation settings reconstructed from the composition correspond to settings of active continental margins (most probably, basins complicated by strike-slip deformations along transform faults). Formally, the studied rocks in some diagrams are close to the rocks from the basins of passive continental margins, which is presumably related to the contribution of detrital material from different sources rather than to a common geotectonic regime.

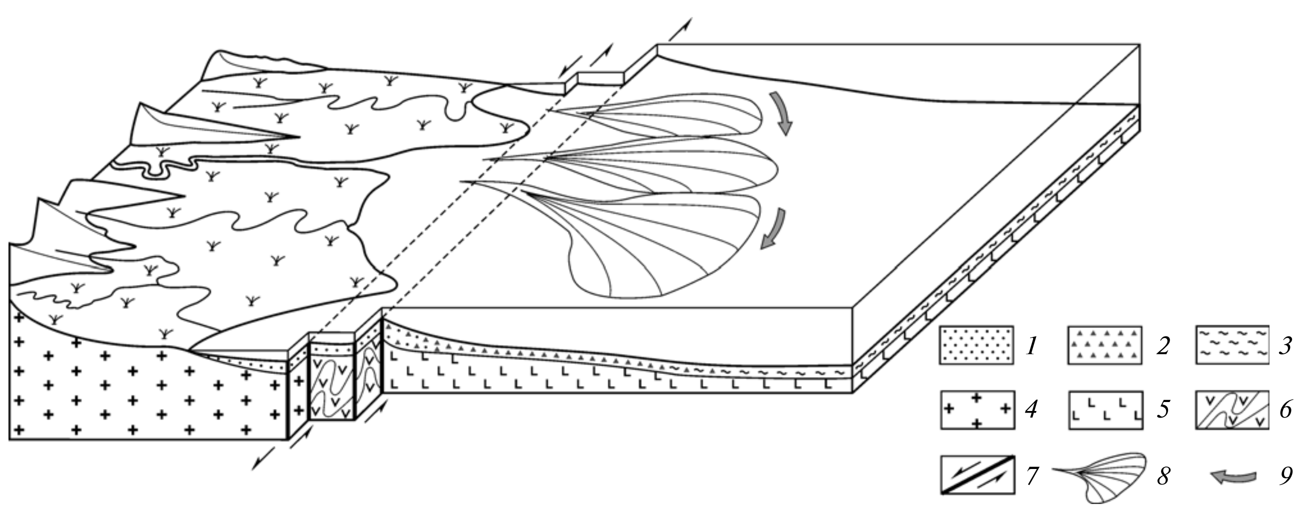

Fig. 12. Model of the sedimentation in the Early Cretaceous (Zhuravlevka terrane). (*1–3*) types of deposits: (*1*) shelf (littoral and sublittoral), (*2*) the subwater slope, its foot, and the adjacent basin plain, (*3*) hemipelagial; (*4–5*) types of the Earth's crust: (*4*) continental, (*5*) oceanic, (*6*) fragments of accretionary prisms; (*7*) sinistral strike-slips; (*8*) underwater fans; (*9*) contour currents.

SETTINGS AND CONDITIONS OF THE ACCUMULATION OF THE TERRIGENOUS ROCKS

The most characteristic feature of the deposits of the Zhuravlevka terrane is the abundance of rhythmically alternating sandstone–siltstone units showing all the typical signs of turbidites. Turbidites often associate with mixtites, sandstones, gravelstones, and fine-grave conglomerates. The chaotic structure, high matrix contents, and the absence of sorting and bedding typical of coarse-clastic rocks indicate their precipitation from high-density granular and debris flows [37]. In addition, turbidites are often associated with the thin horizons of finely intercalated (from 3–5 mm to a few centimeters) siltstone–sandstone units typical of settings of bottom contour currents [35]. Such a genetic set of deposits implies their accumulation in the lower part and near the foot of the underwater slope, as well as on the adjacent areas of the basin's plain (Fig. 12) [6, 35]. The main agents of the transportation and precipitation of the detrital material were gravitational flows of different densities, compositions, and origins, as well as bottom flows that strongly reworked the material delivered into the sedimentation zone by the turbidite flows. The gravitational and bottom-current deposits are usually closely related to the fairly thick sequences of massive silty mudstones, which could be considered as hemipelagic sediments that accumulated in relatively quiet conditions. The thin horizontal or gentle wave bedding observed in the rocks may indicate the insignificant reworking of the material by waves and currents [12]. One more type of sediments that are widely developed in the Zhuravlevka terrane is thick sequences of inequigranular sandstones containing intercalations and lenses of conglomerates and gravelstones, as well as abundant plant detritus and shallow-water fauna. These sediments were presumably accumulated in the relatively shallow-water conditions typical of open-sea littoral and sublittoral settings [12].

DISCUSSION

The data presented above unambiguously indicate that the main source of clastics of the terrigenous rocks of the Zhuravlevka terrane was sialic land. This follows, in particular, from the predominance of quartz and acid plagioclase in the detrital component of the sandstones, as well as the sharp predominance of the sialic association among the heavy clastic minerals. The same is supported by the mainly hydromica composition of the clay minerals both in the cement of the sandstones and in the clayey–silty rocks. This conclusion is consistent with the chemical composition of the detrital garnets, which is typical of deeply metamorphosed rocks and granitoids.

At the same time, a significant role in the composition of the source area presumably belonged to the fragments of the pre-Cretaceous active margins, primarily, accretionary wedges, some structural levels of which contained chert and ophiolite nappes. They can be exemplified by the Jurassic–Early Cretaceous "Samarka"-type accretionary wedges, which are traceable as a practically uninterrupted band along the eastern margin of Asia from the Sea of Okhotsk's coast in the north to Kalimantan Island in the south [29]. Direct confirmation of this can be the high contents of cherts in the detrital component of the sandstones and their complete predominance among the fragments of gravelstones and conglomerates. The same follows from the compositional specifics of the detrital chromites, in particular, their low Ti content typical of ultramafic rocks of ophiolite belts and active margins.

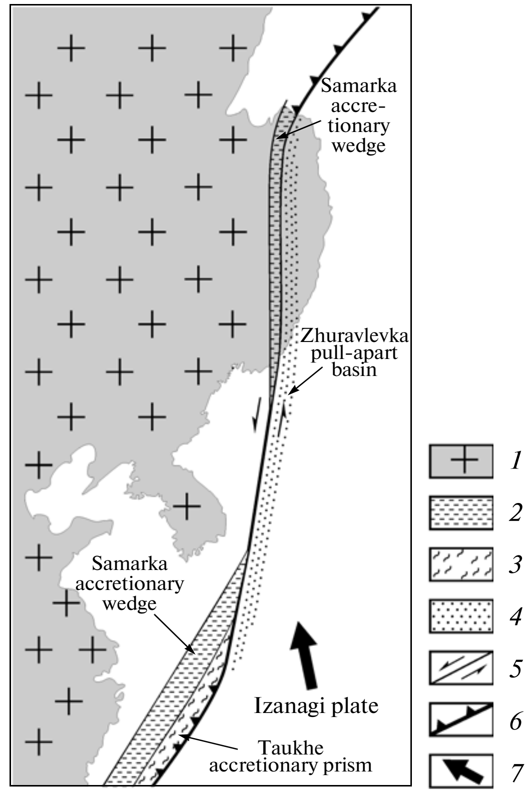

Fig. 13. Geodynamic reconstructions of the eastern Asian margin for the beginning of the Early Cretaceous. (*1*) pre-Jurassic continent, (*2*) Jurassic accretionary prism, (*3*) Early Cretaceous accretionary prism, (*4*) Early Cretaceous continental margin pull-apart basin, (*5*) Tan Lu sinistral strike-slip system, (*6*) subduction zone, (*7*) direction of movement of the Izanagi plate.

The mixing of these two sharply different source areas is also well illustrated in the diagram, which interprets both the composition of the rock-forming minerals and the heavy detrital minerals and the chemical composition of the terrigenous rocks of the Zhuravlevka terrane (Figs. 4, 5, 11, 13). Such mixing is presumably the main characteristic feature of the sedimentation in a transform margin setting, when both marginal parts of continents and the fragments of active continental margins previously accreted to them were involved in the erosion area. For instance, such fragments are the Stikinia and Wrangellia magmatic arcs accreted to the western margin of the North American craton complicated by the Queen Charlotte dextral strike-slip fault [33].

Naturally, such a mixing of different sources is also possible along the Andean-type active margins. The latter is supported by the presence of synsedimentation volcanic material (for instance, tuff horizons), which is practically absent in the rocks of the considered Zhuravlevka terrane.

The combination of fragments of different-age structures related to subduction or a strike-slip transform fault is a widely spread phenomenon within the Pacific margin. The unidirected drift of oceanic plates with respect to differently oriented portions of continental margins provides a wide range of relative convergence angles and, correspondingly, the predominance of a definite type of interaction. A change in the directions of the oceanic plate movements at certain areas of margins can lead to the replacement of subduction by transform strike-slip and vice versa. In the NE-trending Sikhote-Alin segment of the Early Cretaceous margin, the transform strike-slip faulting (and formation of the Zhuravlevka paleobasin) occurred in a setting of near-submeridional (from the south northward) displacements of the Izanagi oceanic plate adjacent to Eurasia (Fig. 13). Prior to and after this process, in the Late Jurassic and Late Cretaceous time, respectively, the Izanagi plate moved in the northwestern and west-northwestern directions [25], which is consistent with the reconstruction of the active margin (Jurassic terranes—fragments of accretionary wedges, and the Eastern Sikhote Alin suprasubduction volcanoplutonic belt) along this area.

CONCLUSIONS

Thus, the structure, composition, and texture of the terrigenous deposits of the Zhuravlevka terrane indicate that the main sources of detrital material in the Early Cretaceous time were eroded granite-metamorphic rocks of mature continental crust. At the same time, the source areas contained significant amounts of fragments of pre-Cretaceous active margin bearing cherts and ophiolite nappes of accretionary wedges. Such a mixed composition of clastics is possibly the main and characteristic feature of the sedimentation in a setting of strike slip transform plate boundaries.

The mainly sialic composition of the detrital material suggests that the considered paleobaisn during its formation was adjacent to the margin of the Eurasian continent. Thick sequences of terrigenous deposits of the terrane, including a large amount of gravitational units, were accumulated on the shelf, underwater continental slope, near its foot, and on the adjacent areas of the basin's plain of the completely oceanward open marginal sea (Fig. 12). Sedimentation occurred simultaneously with the large-scale displacement along the Tan Lu sinistral strike-slip fault intervening between the continental and oceanic plates with the minor role of volcanic processes [1].

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