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Heavy Clastic Minerals from the Far East Island-Arc Complexes

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Abstract—The results of the study of heavy clastic minerals from the Cretaceous–Paleogene terrigenous complexes of Sikhote-Alin and Kamchatka, as well as from the Cenozoic sediments of the deepwater Vanuatu Trench, are summarized. The data obtained have been interpreted on the basis of their comparison with heavy mineral assemblages of recent sediments deposited in known geodynamic settings. It is shown that the heavy clastic minerals of sedimentary rocks, their relative quantities, and chemical compositions may serve as reliable indicators of different island-arc settings and magmatic processes; these indicators may also be used for identification of such settings in paleobasins of orogenic regions.

Key words: *heavy minerals, island arc, terrigenous rocks, Early Cretaceous, terrane, geodynamic setting, Far East.*

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INTRODUCTION

The authors studied heavy clastic minerals from terrigenous rocks of different origin, including island-arc complexes of the Russian Far East, and from sediments of the Pacific marginal seas in 1978–2005 [3, 7, 9–14].

The island-arc settings in paleobasins are commonly identified making allowance for their geological position, structure and composition of rock associations, and chemistry of volcanic and terrigenous rocks. We made an attempt to do this, making use of only heavy clastic minerals from sedimentary rocks that fill the basins situated in different geodynamic settings of various ages. The analysis of heavy mineral assemblages is a tried tool for recognition of provenances [1, 26]. As has been established by the study of Cenozoic sediments in modern oceans and marginal seas, some specific heavy mineral assemblages and relative amounts of certain minerals may serve as reliable indicators of tectonic and geodynamic settings and magmatic processes inherent to these settings [16, 17, 25–29].

The results obtained are used for paleotectonic reconstructions based on actualistic correlations. This approach is especially helpful for the study of Phanerozoic volcano-sedimentary rocks that make up terranes of doubtful origin.

The island-arc terranes, both ensimatic and ensialic, known in the Far East are favorable for such reconstructions. The island-arc nature of these terranes was established largely from the study of volcanic rocks. In this publication, we made an attempt to demonstrate the island-arc nature of these terranes on the basis of actualistic interpretation of the heavy mineral assemblages contained in sedimentary rocks. It is evident that the data on heavy minerals alone are insufficient for the comprehensive identification of island-arc environments, however, in combination with other information, they may be used as a rather reliable tool.

Thus, this paper is aimed at the confirmation of the hypothesis that a certain assortment of heavy clastic minerals from sedimentary rocks and their quantitative proportions correspond to specific types of island-arc settings and may be used as discriminant criteria for identification of such settings in the geological past.

STUDY OBJECTS AND RESEARCH METHODS

This study is based on the results of examination of heavy clastic minerals from island-arc complexes of the Russian Far East and southwestern Pacific, including the Eocene–Quaternary loose sediments of the deepwater Vanuatu Trench, the Lower Cretaceous and Lower Cretaceous–Cenozoic sedimentary sequences of the Olyutorka Terrane in eastern Kamchatka, and the Kema and Kiselevka–Manoma (Udyl fragment) terranes of Sikhote-Alin (Fig. 1).

The samples were taken by the authors from natural outcrops during fieldwork in 1978–2002. The loose sediments from the deepwater Vanuatu Trench were taken during Cruise 13 of R/V *Akademik A. Nesmeyanov* (1988) along the surveying profiles with hydrostatic and gravitational corers, bottom grabs, and dredges.

The heavy minerals were recovered from sandy–silty rocks with heavy liquids after crushing of samples to 0.25 mm, washing in distilled water, and separation of the 0.01–0.25 mm fractions. The mineral composi-

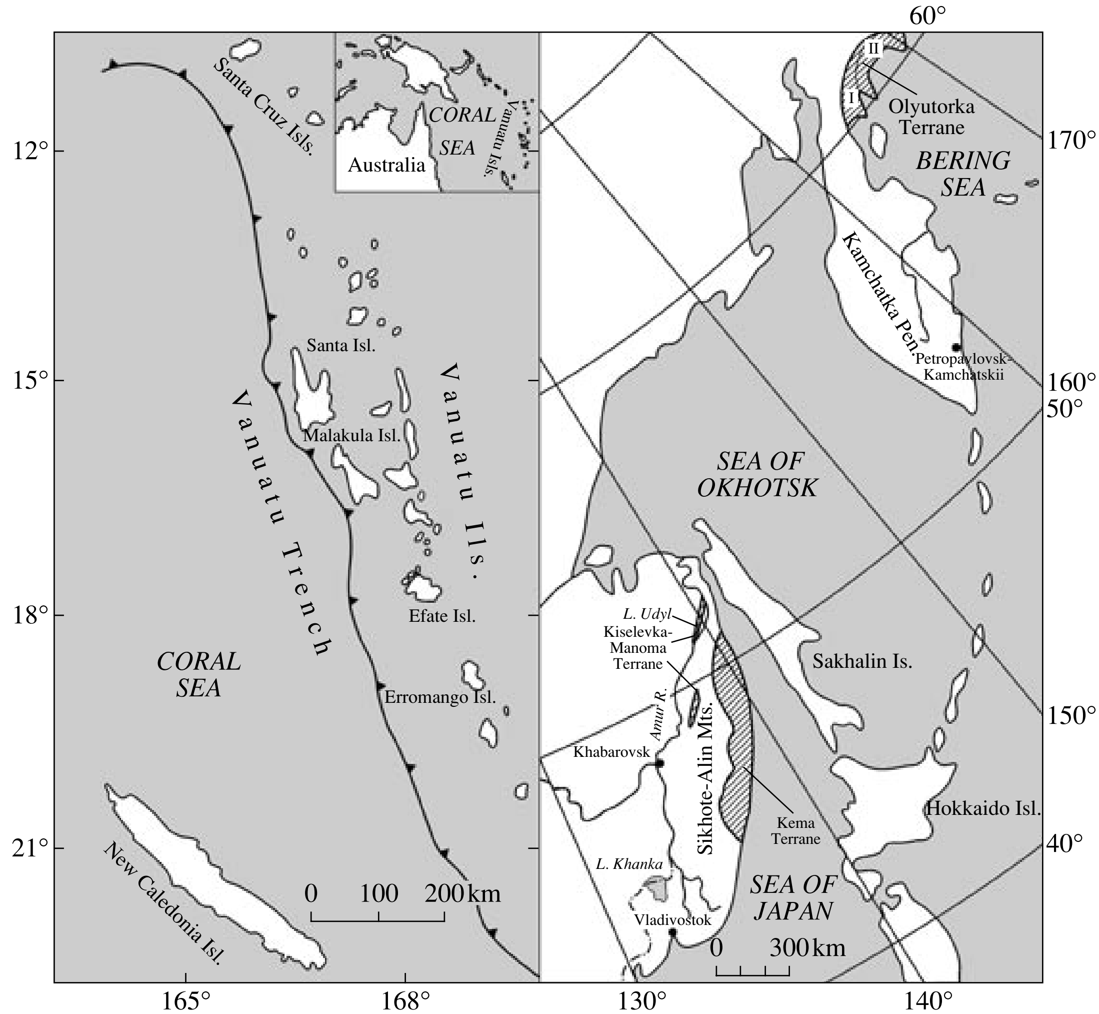

Fig. 1. The index map.
Mineralogical provinces of the Olyutorka Terrane: (I) northern, (II) southern.

tion of the heavy fraction was identified and counted under a microscope in plane light and at crossed polars with the help of immersion liquids. No less than 200 grains of heavy minerals were included in the counting. The chemical composition of the minerals was determined with a JXA-5A microprobe. An original technique that allows recognizing analogues of the present-day geodynamic setting in the geological past and classifying island-arc settings was used in the interpretation of the percentage of heavy minerals and their composition [3, 9, 14–17, 28, 29]. All the analyses were performed at laboratories of the Far East Geological Institute in Vladivostok.

REGIONAL GEOLOGY AND COMPOSITION OF THE STUDIED ROCKS

The deepwater Vanuatu Trench is located in the southwestern Pacific Ocean and extends along the western slope of the Vanuatu island arc [3, 31] for 1600 km. Its width is ~40 km at an isobath of 5500 m, and the maximum depth reaches 9174 m. The trench is characterized by extremely complex topography and consists of a chain of basins down to 7000–9000 m in depth divided by humps 5500–6000 m in depth.

The sediments varying in age from the Eocene to Quaternary were studied (Fig. 2). Four stratigraphic levels are recognized on the biostratigraphic basis: the middle–upper Eocene, the upper Miocene–lower Pliocene, the upper Pliocene, and the Pleistocene–Holocene [3]. The sediments are composed of poorly lithified pelite, silt, and psammite with an admixture of pyroclastic material, foraminifera shells, and nannoplankton.

The absence of the Oligocene–middle Miocene sediments in the trench likely marks a regional break in the sedimentation in the Australia–New Zealand region caused by tectonic activity and a change in the water circulation [3].

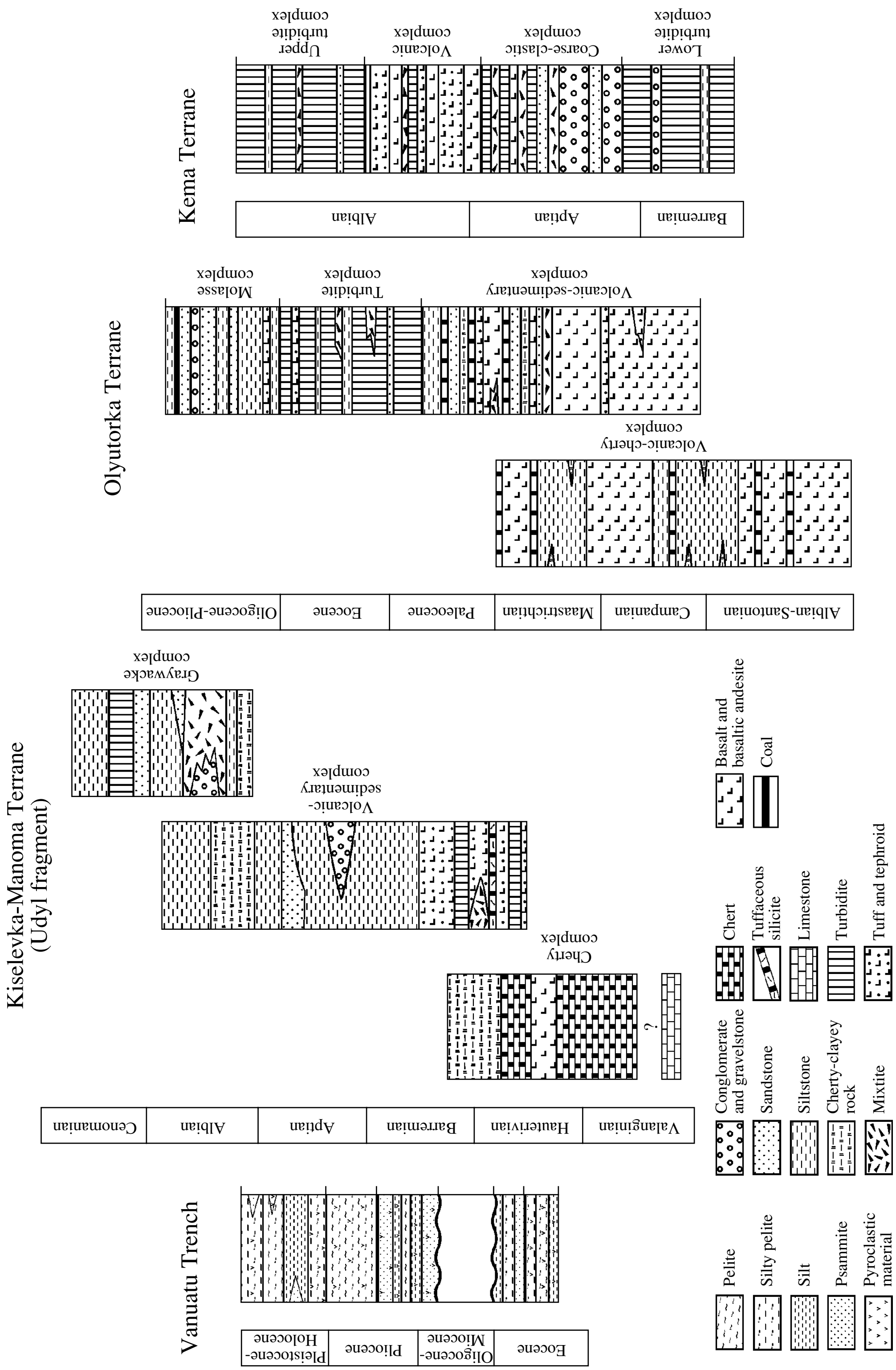

Fig. 2. Summary lithostratigraphic columns of island-arc rocks.

The Kiselevka–Manoma Terrane of the Albian–Cenomanian accretionary prism is situated in the Lower Amur region, where it extends in the northeastern direction for 700 km along the left and right banks of the Amur River as a discontinuous tract 20–40 km wide. The terrane is a series of tectonic sheets composed of the Jurassic and Lower Cretaceous cherty and cherty–clayey rocks with incorporated basalt and limestone bodies and of the Lower Cretaceous siltstone, mudstone, and turbidite [4, 13, 14] (Fig. 2). The Hauterivian–Cenomanian volcanic–sedimentary island-arc sequences that were found at the northeastern flank of the terrane close to Lake Udyl were deposited in various facies environments of the fore- and backarc basins related to the Early Cretaceous epioceanic island-arc system. The following lithotectonic complexes are recognized [13, 14].

The cherty complex is a fragment of oceanic basement of the arc and consists of pelagic radiolarian jasper and chert, their clayey varieties, and less abundant alkali basalt and limestone. *The volcanic–sedimentary complex* is made up of intercalating tuff, tephroids, volcanomictic sandstone, turbidite, mixtite, tuffaceous silicite, clayey and clayey-cherty rocks, and sporadic basalt. *The graywacke complex* is composed largely of sandstone and clayey rocks with embedded tuff, mixtite, turbidite, and contourite units.

The Olyutorka Terrane is located in the southern Koryak Highland and extends in the east-northeastern direction for 500 km along the coast of the Bering Sea. The terrane is an element of the Mesozoic–Cenozoic Sakhalin–Kamchatka orogenic belt and is separated from the Koryak orogenic belt by the Vatyna Thrust Fault [2]. The Lower Cretaceous–Neogene oceanic and island-arc lithotectonic complexes are juxtaposed in this terrane as large allochthonous sheets [21]. These complexes were formed in various facies environments and probably at a great distance from their present-day location. The following rock complexes are recognized [2, 5, 7, 19, 20] (Fig. 2).

The volcanic–cherty complex consists of basalt, hyaloclastite, lava breccia, jasper, chert, and their clayey varieties. The clayey rocks, sandstone, and limestone are less abundant. *The volcanic–sedimentary complex* is composed of basalt, lava breccia, tuff, volcanomictic sandstone, siltstone, chert, and clayey and clayey–cherty rocks. *The turbidite complex* comprises thick turbidite members and the overlying units consisting of siltstone, sandstone, gravelstone, tuff, and mixtite. *The molasse complex* is made up of sandstone, siltstone, gravelstone, conglomerate, clayey rocks, tuff, and coal.

The Kema Terrane is situated in the eastern Sikhote-Alin Range and extends for 850 km along the coast of the Sea of Japan as a tract ~80 km wide. The fragments of the Kema Terrane accessible for observation crop out in erosion windows from under volcanic rocks of the Late Cretaceous East Sikhote-Alin belt. The terrane is composed of Barremian (?)–Albian turbidite, siltstone and mixtite units, and basic lavas and pyroclastic rocks (Fig. 2). This sequence is considered a fill of the backarc basin related to the Moneron–Samarga island-arc system [8–10] and subdivided in the following lithotectonic complexes.

The lower turbidite complex is composed of turbidite members intercalated with siltstone, sandstone, gravelstone, and submarine slump deposits. *The coarse-clastic complex* consists of fine–pebble conglomerate, gravelstone, sandstone, mixtite, and sporadic turbidite members, slump deposits, tuffs, and occasional basaltic flows. *The volcanic complex* is mainly composed of basaltic lavas, tuffs, and tephroids. Volcanomictic sandstones, turbidite members, units of slump deposits and mixtites are rare. *The upper turbidite complex* comprises thick turbidite members with sparse interbeds of sandstone, siltstone, mixtite, and slump deposits.

CONTENTS AND DISTRIBUTION OF HEAVY CLASTIC MINERALS

The distribution of heavy clastic minerals in the studied sedimentary rocks is shown in Fig. 3. The average contents are grouped in compliance with the selected lithotectonic complexes. Rather arbitrarily, all the heavy minerals may be divided into two assemblages. The first, femic (volcanic) assemblage comprises the typical minerals of island-arc volcaniclastic rocks: ortho- and clinopyroxene, hornblende, chromite, magnetite, epidote, and olivine. The second, sialic (granitic–metamorphic) assemblage includes zircon, garnet, tourmaline, epidote, apatite, titanite, rutile, anatase, ilmenite, leucoxene, fluorite, vesuvianite, and corundum.

The deepwater Vanuatu Trench is regarded as a reference object, because this trench immediately adjoins the island arc, and the sediments in the trench contain the heavy clastic minerals that belong only to the femic (volcanic) assemblage.

The most abundant minerals in the Eocene–Quaternary sediments are rather uniform [3]. Because the trench was always fed by products of synsedimentation volcanic activity and subsequent erosion of the volcanic arc, volcaniclastic minerals are predominant: clinopyroxene (30–92%), orthopyroxene (2–43%), magnetite (10–62%), hornblende (0.1–17%), and olivine (up to 10%). Sialic minerals (zircon, titatine, apatite, rutile, ilmenite, leucoxene, and corundum) amount to only <2.5% of the total heavy mineral content indicating that no large sources of sialic material occur in this region.

In the Udyl fragment of the Kiselevka–Manoma Terrane, the contents of heavy minerals in different complexes are drastically distinct [14]. The *cherty complex* is distinguished by the prevalence of green clinopyroxene (up to 79%) in association with other volcaniclastic

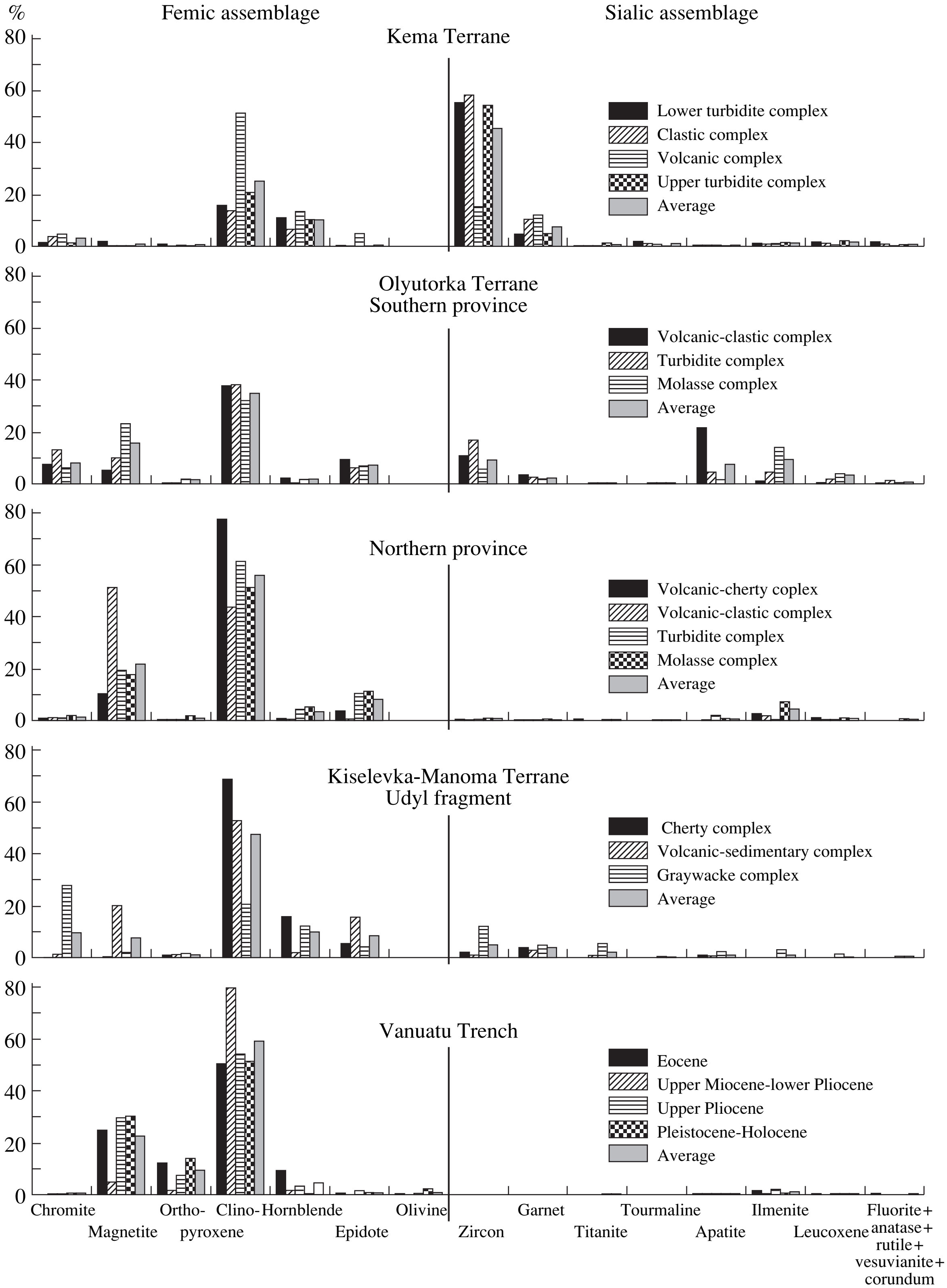

Fig. 3. Distribution of heavy clastic minerals in sedimentary rocks.

minerals: orthopyroxene (up to 5%), hornblende (up to 25%), and magnetite (up to 2%). The usual components of granitic and metamorphic rocks are much less abundant: zircon (up to 9%), garnet (up to 4%), titanite (up to 10%), and apatite (up to 5%). The lower portion of the *volcanic–sedimentary complex* is distinguished by

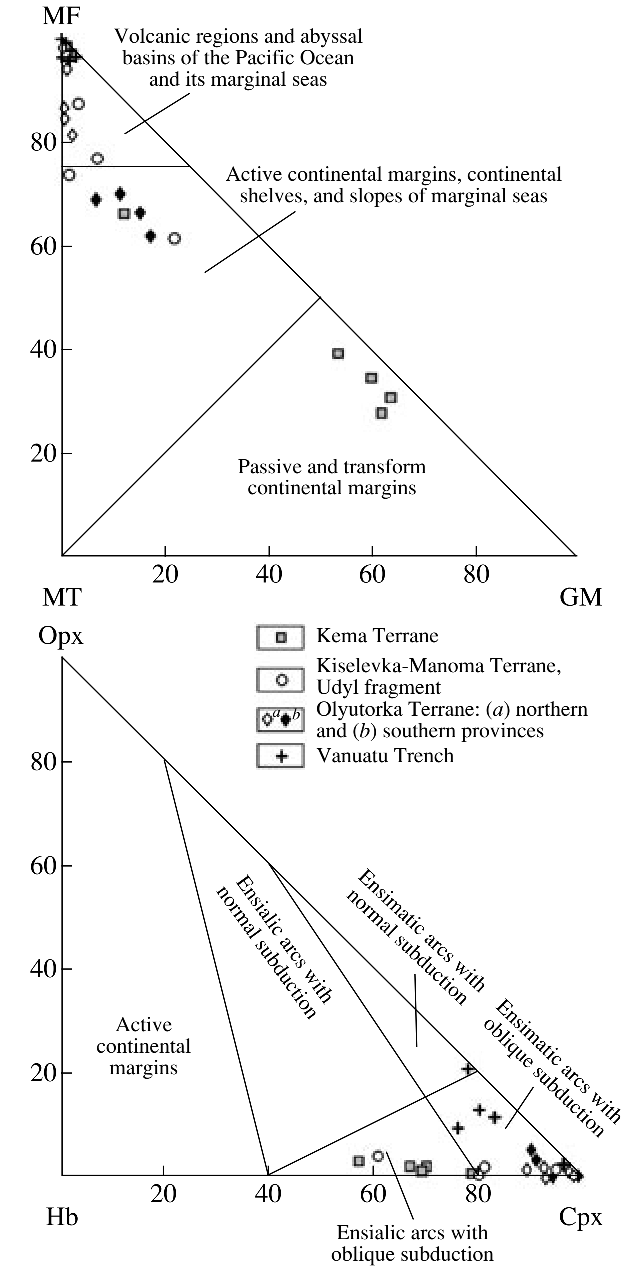

Fig. 4. Proportions of heavy clastic minerals from sandy–silty rocks and recent sediments in various geodynamic settings after [14, 17, 28].

Total contents: (MF) olivine, ortho- and clinopyroxene, and green hornblende; (MT) epidote, garnet, and blue-green amphibole; (GM) zircon, tourmaline, staurolite, kyanite, sillimanite, and andalusite; (Opx) orthopyroxene; (Hb) hornblende; (Cpx) clinopyroxene.

the most primitive set of heavy minerals: clinopyroxene (71–96%), magnetite (up to 36%), hornblende (up to 5%), and orthopyroxene (up to 2%). An appreciable admixture of epidote (up to 43%), garnet (up to 23%), chromite (up to 16%), zircon (up to 12%), apatite (up to 6%), titanite (up to 7%), and rutile (up to 1%) appears in the upper portion of this complex. The proportions of heavy minerals in different parts of the *graywacke complex* are variable. Some rocks are enriched in pyroxenes (up to 56%), amphiboles (up to 22%), and epidote (up to 12%), while others reveal high contents of chromite (50–94%) in association with pyroxene (up to 37%); finally, the third group of rocks contains relatively large amounts of zircon (up to 40%), garnet (up to 22%), titanite (up to 11%), and apatite (up to 7%).

The Olyutorka Terrane is divided into two provinces according to the heavy mineral content [6, 7, 12]. In the *northern province*, the island-arc volcaniclastic assemblage amounts to 90% of all the heavy minerals with the leading role of green clinopyroxene (up to 100%) and a lesser percentage of magnetite (up to 55%), hornblende (up to 30%), and orthopyroxene (up to 7%). In the *southern province*, the contribution of the femic island-arc assemblage is still high. Clinopyroxene dominates here as well, but its percentage is much lower (up to 50%, on average, and up to 80% in particular samples). The magnetite and chromite contents are also rather high (10–35% and 6–14%, respectively), but the hornblende and orthopyroxene contents decrease down to 3–5%. At the same time, the sialic minerals are much more abundant in this province, including zircon (up to 20%, on average), apatite (up to 15%), garnet (up to 10%), rutile (up to 5%), titanite (up to 3%), and tourmaline (up to 3%). Furthermore, corundum, vesuvianite, anatase, allanite, brookite, sillimanite, staurolite, andalusite, kyanite, and fluorite were identified here in contrast with the northern province, where these minerals were not detected.

In the *Kema Terrane*, the contents of heavy minerals and the proportions of their species are widely variable [9, 10, 15]. The highest contribution of the femic assemblage (up to 99% of the total heavy mineral content) is typical of the volcanic complex. Clinopyroxene is predominant (up to 98%); hornblende (up to 44%), orthopyroxene (up to 16%), epidote (up to 11%), and chromite (up to 5%) are less abundant. In other complexes of this terrane, the above minerals were identified in much lesser amounts (32–40%, in total). The clinopyroxene content does not exceed 60%; hornblende, 30%; orthopyroxene, 5%; and epidote, 7%. The sialic mineral assemblage is prevalent (70% of all the heavy minerals on average). Zircon (up to 96% in some samples), garnet (up to 70%), apatite (up to 7%), tourmaline (up to 19%); rutile (up to 4%); titanite (up to 3%), as well as vesuvianite, anatase, and corundum (up to 3% in total) make up this assemblage.

DISCUSSION

The available mineralogical data were interpreted on the basis of the actualistic approach [16, 27–29]. V.P. Nechaev selected a number of minerals-indicators, whose proportions allow distinguishing the rocks of different origin, including those derived from island arcs; the latter may be classified into products of

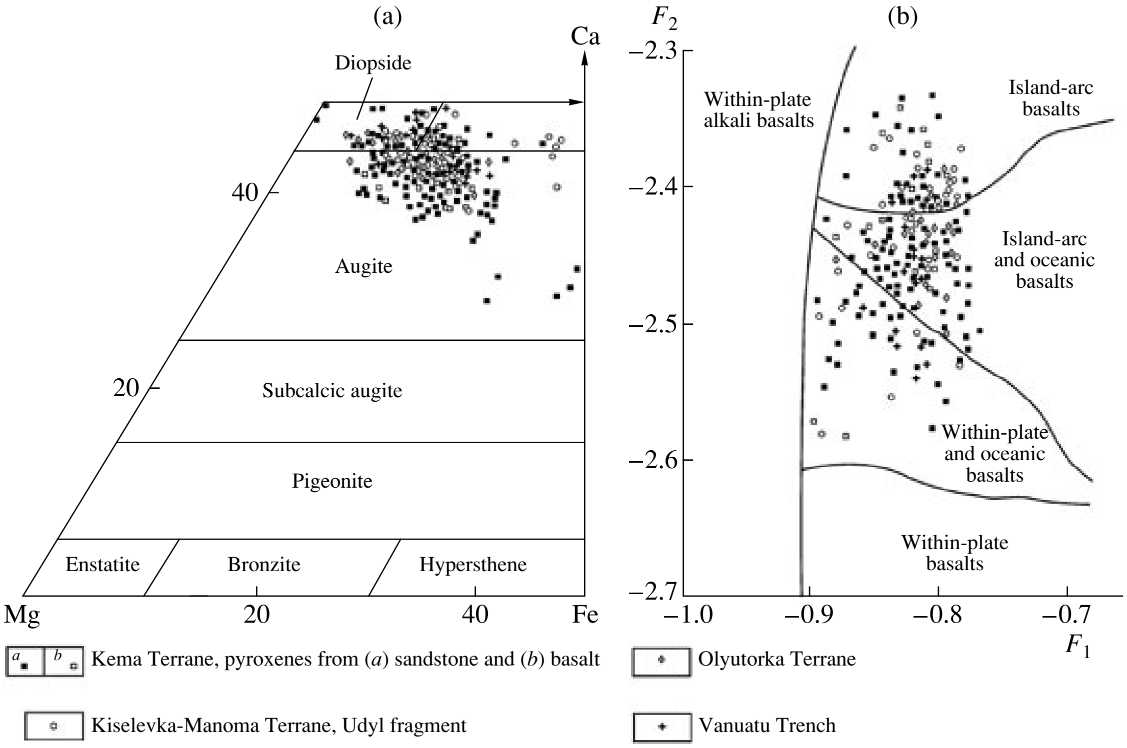

Fig. 5. (a) Composition of clastic clinopyroxenes; (b) Discriminant diagram for clinopyroxenes from basalts in different tectonic settings, after [30].
$F_1 = 40.012SiO_2 - 0.807TiO_2 + 0.0026Al_2O_3 - 0.0012FeO - 0.0026MnO + 0.0087MgO - 0.0128CaO - 0.0419Na_2O$; $F_2 = -0.0496SiO_2 - 0.818TiO_2 - 0.02126Al_2O_3 - 0.0041FeO - 0.1435MnO - 0.0029MgO - 0.0085CaO + 0.0160Na_2O$.

destruction of the arcs underlain by ensialic and ensimatic basements.

The presence or absence of continental and oceanic crusts and their interaction is reliably determined with an MF–MT–GM index (Fig. 4). The proportion of Cpx, Opx, and Hb with the predominance of clinopyroxene is an indicator that provides discrimination of tectonic settings at convergent plate margins, including island arcs, active continental margins, abyssal oceanic basins, and marginal seas (Fig. 4).

While plotting the heavy mineral contents on the MF–MT–GM and Cpx–Hb–Opx diagrams, the following conclusions may be drawn.

The common femic minerals of volcanic rocks (the component MF in the MF–MT–GM diagram) with an extremely small admixture of the continental sialic material are typical of sediments from the *deepwater Vanuatu Trench*. The location of the data points on diagrams (Fig. 4) testifies to the sedimentation under a direct effect of the Vanuatu ensimatic volcanic arc [24]. The low Opx and Hb contents indicate an oblique convergence.

The type of volcanic source may be determined from the chemical composition of the ortho- and clinopyroxenes, hornblende, chromite, and garnet; clinopyroxene is the most informative in this respect. Clinopyroxenes from sediments of the Vanuatu Trench correspond to diopside, augite, and, to a lesser extent, salite in composition (Fig. 5a). In the Nisbett–Pearce diagram [30], most of these clinopyroxenes correspond to the island-arc basalts and partly to the basalts of the oceanic floor, apparently, making up a basement of the island arc (Fig. 5b). In diagram 1 [25], all the clinopyroxene compositions group nearby the boundary line that separates the field of within-plate alkali basalts and basalts of oceanic islands from all the other tholeiitic basalts. Most of the data points formally fall into the field of alkali basalts, but the rather low Ti and Na contents in clinopyroxenes do not allow us to confidently classify them in this way. In discriminant diagram 2, which divides tholeiitic basalts of mid-ocean ridges (MORB) and island-arcs (IAB), all the clinopyroxene compositions fall in the IAB field. Finally, in diagram 3, which is intended for discrimination of calc-alkaline and tholeiitic island-arc basalts, the data points are distributed through both fields. The island-arc character of hornblende is demonstrated by the 10Ti–Al–Fe diagram [27], where the compositions of this mineral are close to amphiboles from basic and intermediate island-arc volcanics owing to their low Cr and Ti contents (Fig. 7b).

Thus, the calc-alkaline and tholeiitic basalts of the ensimatic island arc were the main source of clastic minerals in the middle Eocene–Holocene sediments of

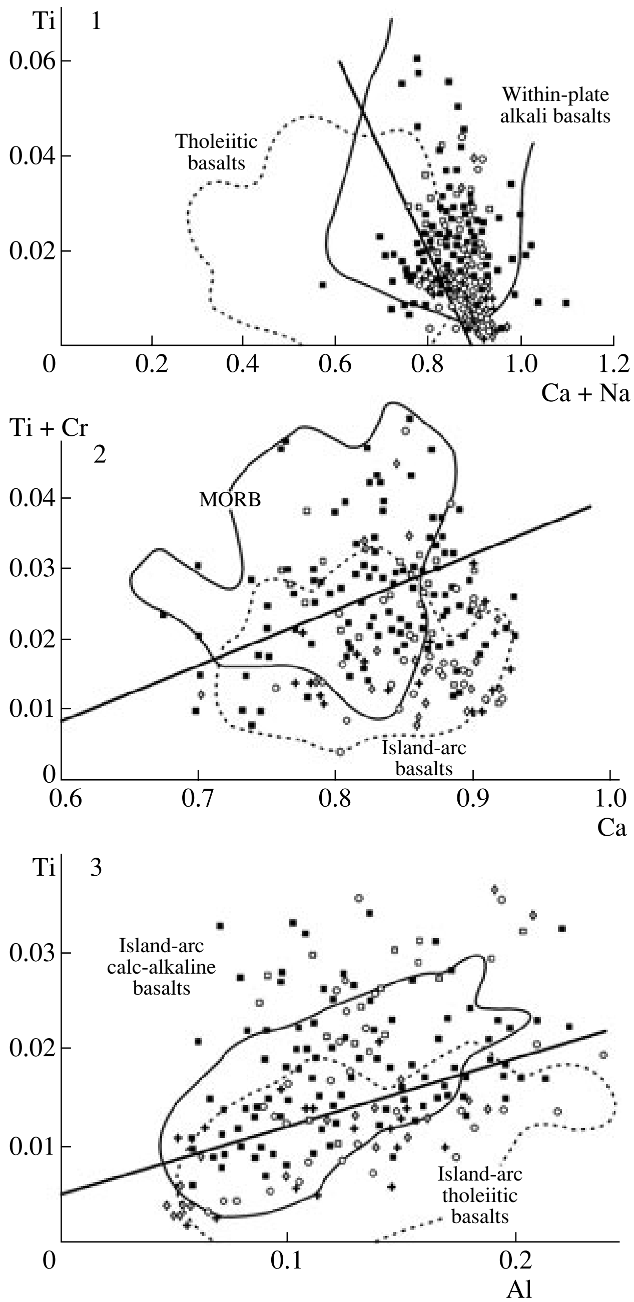

Fig. 6. Discriminant diagrams for clinopyroxenes from basalts in different tectonic settings after [25]. See Fig. 5 for legend. Contents of elements are given in formula units.

the deepwater Vanuatu Trench. The sediments were deposited beyond the zone affected by continental provenances as follows from extremely low contents of sialic minerals.

The heavy mineral assemblages from the Udyl fragment of the *Kiselevka–Manoma Terrane* suggest several sources.

The predominance of the primitive heavy mineral assemblage in the cherty and volcanic–sedimentary complexes (the MF component in the MF–MT–GM diagram; see Fig. 4) with the leading role of clinopyroxene is characteristic of the island-arc volcaniclastic material at the convergent margin with acute angles of the plate convergence (Cpx–Hb–Opx diagram) and indicates a direct effect of an ensimatic arc of the Izu–Bonin type [14, 17, 29]. The combination of MF, MT, and GM components in the cherty complex is typical of deepwater basins of the Pacific marginal seas, where the island-arc volcaniclastic material is mixed with material derived from the continental margin. The volcanic–sedimentary complex is regarded as a clastic apron of the arc, i.e., a fragment of back-arc trough located in the immediate proximity of the arc. The occurrence of an appreciable amount of sialic material in the upper portion of the complex indicates that the arc was close to the continental margin.

In the graywacke complex, the proportions of the components in the MF–MT–GM and Cpx–Hb–Opx diagrams (Fig. 4) correspond to the volcanic arc or active continental margin at an acute angle of plate convergence, as follows from a low orthopyroxene content. The clinopyroxene and chromite compositions testify to the mainly island-arc nature of the terrigenous material (Figs. 5, 6, 7a). At the same time, some chromites were derived from ophiolites of the oceanic crust incorporated into the accretionary prism of the island arc. The occurrence of minerals belonging to the sialic assemblage, in some cases in considerable amounts, indicates a marked effect of a sialic (continental) source. The clastic garnets from this source (Fig. 7c) correspond to almandine in composition and most likely were derived from amphibolite- and even eclogite-facies metamorphic rocks, although felsic plutonic rocks cannot be ruled out [32].

Thus, the provenance of the Udyl fragment of the Kiselevka–Manoma Terrane was heterogeneous. The Cretaceous Udyl ensimatic island arc was the main source of volcaniclastic material, which was mixed with material supplied from the eroded continental margin and ophiolitic complexes.

In the *Olyutorka Terrane,* the femic heavy mineral assemblage (component MF in Fig. 4) dominates, especially as concerns the *northern province.* The localization of data points in the MF–MT–GM and Cpx–Hb–Opx diagrams shows that the sedimentary rocks were deposited under the immediate effect of the ensimatic island arc related to the oblique subduction (low orthopyroxene and hornblende contents). The volcanic–cherty complex accumulated in the environment that corresponds to deepwater basins of Pacific marginal seas, where the island-arc volcaniclastic material accumulates. The island-arc nature of the source is confirmed by the chemical compositions of clinopyroxene, hornblende, and chromite, which are close to those of heavy minerals from the Vanuatu Trench, where the ensimatic island arc was an obvious provenance (Figs. 5, 6, 7a, 7b). The appreciable amount of heavy minerals of the sialic assemblage (component GM) in all the com-

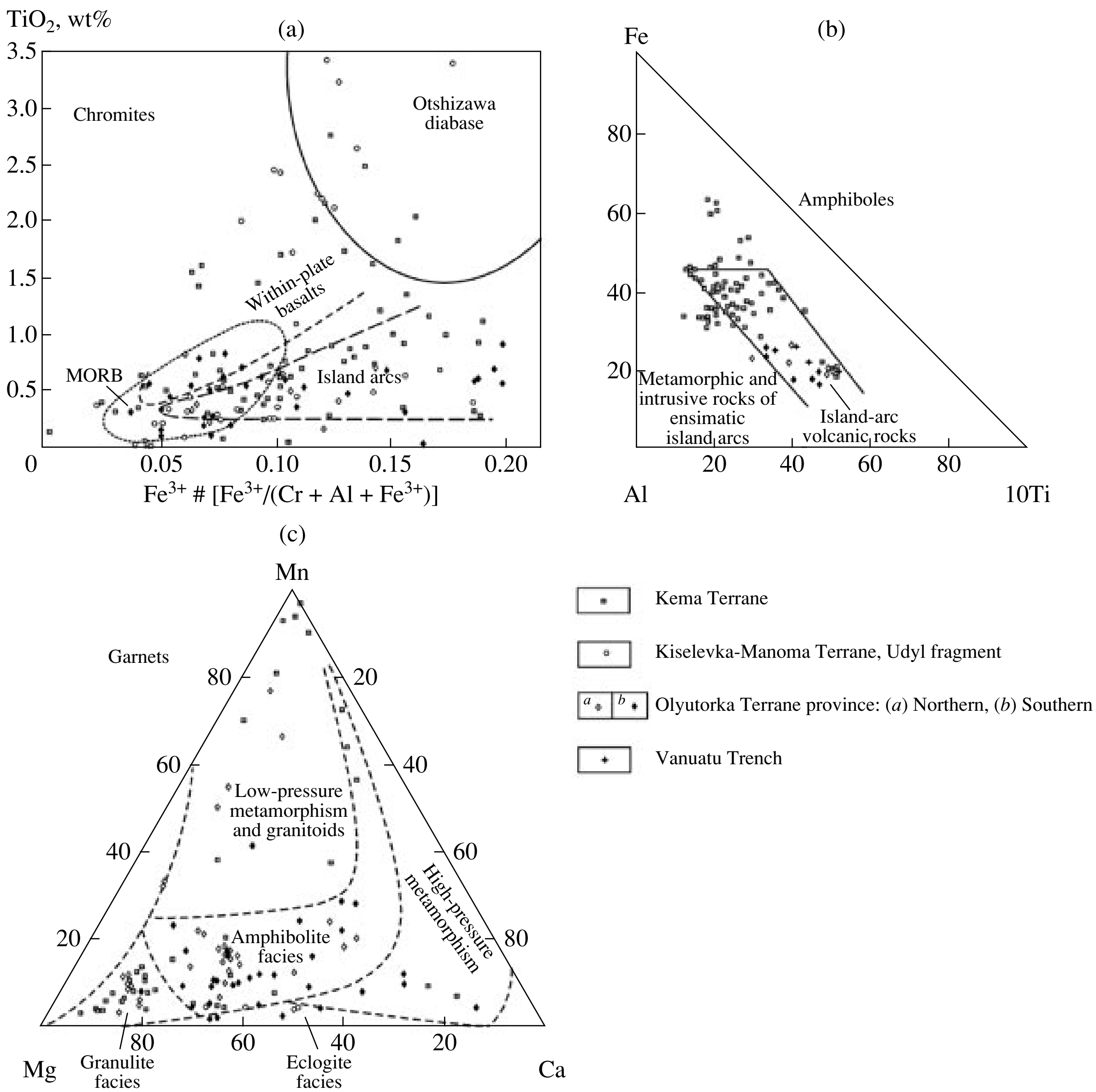

Fig. 7. (a) Discriminant diagram of chromites from basalts and clastic chromites in different tectonic settings, after [23]; (b) compositions of clastic amphiboles and their probable volcanic sources, after [27]; (c) compositions of garnets from different metamorphic rocks and granitoids, after [32].

plexes of the southern province indicates that a sialic (continental) source of the clastic material exerted a permanent effect on the sedimentation. The clastic garnet from this source fits almandine in composition (19.49–22.36 wt % Al_2O_3, 22.10–37.27 wt % FeO + Fe_2O_3) and corresponds to amphibolite, granulite, and even eclogite metamorphic facies (Fig. 7c); thus, this garnet was formed at a great depth and at a high temperature. A block of mature continental crust composed of high-grade metamorphic rocks and, probably, granitoids might have been such a source.

Thus, the assortment and quantitative proportions of heavy clastic minerals and their chemical compositions show that two types of provenances fed the basins of the Olyutorka Terrane. The eroded Cretaceous–Paleogene Achaivayam ensimatic volcanic island arc and synsedimentation volcanic activity were the main source that supplied the clastic material into both basins [22]. The external sialic source was of subordinate importance, but exerted an appreciable effect upon the sedimentation in the southern province. Judging by the diverse heavy minerals derived from the granitic–metamorphic basement, the continental blocks situated to the south of the Olyutorka Terrane, possibly, on the site of the present-day Bering Sea, served as sources in this province.

The volcanic and sialic heavy mineral assemblages coexist in terrigenous rocks of the *Kema Terrane*. The compositions of heavy minerals plotted on the MF–MT–GM and Cpx–Hb–Opx diagrams (Fig. 4) indicate that an ensialic arc and/or active continental margin at an acute angle of plate convergence (low orthopyroxene and amphibole contents) could have been a source. The island-arc character of the source is confirmed by the chemical compositions of clinopyroxene, chromite, and hornblende (Figs. 5, 6, 7a, 7b). In particular, the clinopyroxenes that make up common compositional fields in all the diagrams completely fit clinopyroxenes from the Kema basalts belonging to the high-K calc-alkaline series characteristic of the back zones of island arcs [18]. The eroded basement of the island arc probably was a source of heavy minerals of the sialic assemblage. A fragment of the continental crust was pushed out toward the ocean at that time. Judging from the chemical composition of the garnet (Fig. 7b) largely corresponding to almandine with a small contribution of grossular and spessartine components, the amphibolite- and granulite-facies metamorphic rocks and felsic plutonic rocks made up the basement.

Thus, the composition of heavy minerals and their percentage in rocks from the Kema Terrane show that the Early Cretaceous Moneron–Samarga ensialic island arc [8–10] was a source of clastic material that supplied two contrasting assemblages of heavy minerals in the back-arc basin. The femic (volcanic) assemblage was related to the island-arc volcaniclastic material and syn sedimentation volcanic activity, whereas the sialic assemblage was a product of destruction of metamorphic rocks and felsic plutons in the basement of the arc.

CONCLUSIONS

The assemblages of heavy minerals and their chemical compositions in different Cretaceous–Paleogene complexes of Sichote-Alin and Kamchatka and in Cenozoic sediments of the deepwater Vanuatu Trench testify to the island-arc provenances that fed the sedimentary basins.

The heavy minerals are divided into femic (volcanic) and sialic assemblages. The former is composed of minerals typical of volcaniclastic material while the latter is a product of erosion of granitic–metamorphic complexes.

In sediments of the deepwater Vanuatu Trench, which is considered to be a reference object for island-arc sedimentation, the femic (volcanic) assemblage is sharply prevalent. The eroded calc-alkaline and tholeiitic basalts of the Vanuatu epioceanic island arc and products of synsedimentation volcanic activity served as sources. No large sources of sialic material were established in this region.

The heterogeneous provenance was established for the Udyl fragment of the Kiselevka–Manoma Terrane. The predominant volcaniclastic material was derived from the Udyl ensimatic island arc, and additional material was supplied from the eroded continental margin and ophiolitic complexes.

Two mineralogical provinces fed by contrasting sources are distinguished in the Olyutorka Terrane. The destroyed Cretaceous–Paleogene Achaivayam ensimatic island arc and synsedimentation active volcanoes were the main sources that supplied the clastic material in the basins of both provinces. An external sialic source exerted a lesser but appreciable effect on the sedimentation in the southern province. Blocks of continental crust situated to the south of the Olyutorka Terrane on the site of the present-day Bering Sea served as such a source.

Minerals of the sialic assemblage play an important role along with the typical island-arc assemblage in sedimentary rocks of the Kema Terrane. The Early Cretaceous Moneron–Samarga ensialic island-arc, products of synsedimentation volcanic activity, and the eroded basement of the arc as a block of continental crust pushed out seaward supplied the clastic material into the back-arc basin.

Thus, the heavy clastic minerals of sedimentary rocks, their quantitative proportions, and the chemical compositions of particular minerals are indicators of various island-arc environments and related magmatic processes and serve as criteria for their identification in paleobasins of orogenic regions.

It should be mentioned that the western Paleo-Pacific in the Cretaceous and Paleogene abounded in complexly built ensimatic and ensialic arcs, microcontinents, and oceanic uplifts to a much greater extent than currently. In general, a complex convergent boundary of lithospheric plates existed at that time at the eastern Asian margin.

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Reviewer M.I. Tuchkova

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