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Structure of terranes in a Jurassic accretionary prism in the Sikhote-Alin-Amur area: implications for the Jurassic geodynamic history of the Asian eastern margin

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Abstract

A Jurassic accretionary prism in the Sikhote-Alin-Amur area is an assembly of terranes which are tectonic-sedimentary complexes consisting of multiple strongly deformed fragments of an oceanic plate. The stack of tectonic-stratigraphic units (complexes) in the prism section records its geodynamic history, each unit being signature of a geologic event on the Paleoasian eastern margin. The succession of accretion events brought together fragments of a Paleozoic oceanic plateau in the Early Jurassic and abyssal plain fragments of different ages in Middle and Late Jurassic time.

Keywords: Accretionary prism; terrane; tectonostratigraphic unit; accretion; subduction; subduction melange; radiolarian analysis; Sikhote-Alin

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Introduction

There has been ample recent published evidence (Kemkin, 2006, 2007; Kemkin and Filippov, 2001; Kemkin and Kemkina, 2000; Kemkin and Sha, 2006; Khanchuk, 1994, 2000; Khanchuk et al., 1988, 1989; Khanchuk and Ivanov, 1999; Khanchuk and Kemkin, 2003; Kirillova, 2002; Natal'in, 1991, 1993; Natal'in and For, 1991; Natal'in and Zyabrev, 1989; Zyabrev, 1998; Zyabrev et al., 2005; etc.) that the Asian eastern margin, including the Sikhote-Alin, Nadanhada-Alin (northeastern China) and Amur areas, has a complex structure interpreted as a collage of terranes, different in age and origin (Fig. 1), which accreted to the eastern Paleoasian continental margin in Mesozoic-Cenozoic time. The terranes involve fragments of passive continental margins, volcanic and continental-margin arcs, forearc and backarc basins, accretionary prisms, and turbidite basins of transform margins. Of special interest are pre-Cenozoic accretionary prisms which are authentic markers of subduction of oceanic lithosphere at convergent plate boundaries.

Accretionary prisms develop at the foot of continental and island-arc slopes by successive accretion of sedimentary blocks and elevated parts of subducting oceanic plates. Subduction of an oceanic plate beneath a continent or an island arc is commonly attendant with intense deformation of the accumulated sediments. The process begins with bulldozing of shallowest terrigenous sediments (trench turbidite) in the frontal part of the slope foot (Fig. 2) and their ensuing imbrication into multiple tectonic slices. Then the section below the imbrication zone sinks down and becomes folded into small disharmonic recumbent folds with their axes dipping toward the trench. Folding continues until the sediments reach their strength limit and become prone to failure, and the primary sedimentary section experiences repeated underplating and duplication along the faults to produce a complex imbricate structure (Berzin et al., 1994; Hashimoto and Kimura, 1999; Kimura, 1997; Kimura and Mukai, 1991; Moore and Byrne, 1987: Seely et al., 1974; Sokolov, 1992, 1997; Sokolov et al., 2001). Thus there forms a stack of tectonic-sedimentary complexes each consisting of multiple alternating slices and blocks of oceanic (pelagic and hemipelagic sediments and seamount fragments) and ocean-margin (sand-shale) facies and melange with olistostromes (Fig. 3).

Developing in zones of direct plate interaction, accretionary prisms bear signature of the succession and character of their causative events. Therefore, the structure of the prisms has many important implications, including their own architecture and history, the geology and history of the host areas, the succession of accretionary events, features of the accretionary

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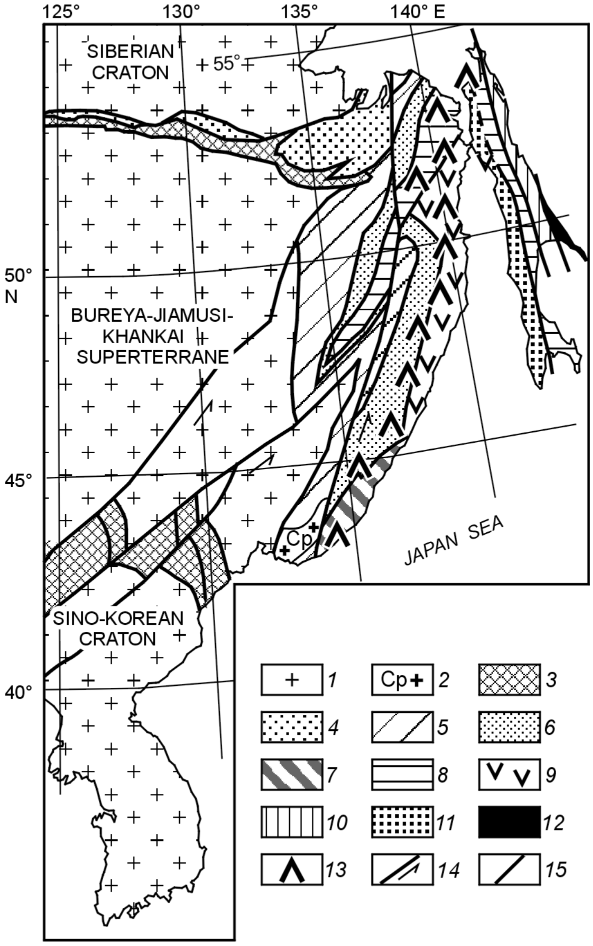

Fig. 1. Generalized tectonics of Sikhote-Alin-Amur area and its surroundings, modified after (Kemkin, 2006). *1*, *2* — Paleozoic continental blocks: Bureya-Jiamusi-Hanka superterrane, Sino-Korean and Siberian cratons (*1*), Sergeevka terrane (fragment of an Early Paleozoic continental margin) (*2*); *3* — Permian-Triassic accretionary prisms; *4* — Jurassic turbidite basin (Ulban and Un'ya-Bom terranes); *5* — Jurassic accretionary prism (Samarka, Nadanhada-Bikin, Khabarovsk and Badzhal terranes); *6* — Early Cretaceous turbidite basin (Zhuravlevka-Amur terrane); *7* — Tithonian-Hauterivian accretionary prism (Taukha terrane); *8* — Hauterivian-Albian accretionary prism (Kiselevka-Manoma and Aniva-Gomon terranes); *9* — Hauterivian-Albian island arc (Kema, Kamyshovka, and Shmidt terranes); *10* — Late Cretaceous accretionary prism (Nabilsky terrane); *11* — Late Cretaceous forearc basin (West Sakhalin terrane); *12* — Late Cretaceous island arc (Terpeniya terrane); *13* — Late Cretaceous volcanic arc (East Sikhote-Alin volcanic belt); *14* — left-lateral strike-slip faults; *15* — other faults.

process in different places of the convergent boundaries, correlation of geological events at the collision zone, and, eventually, the geodynamic evolution of the respective continental margin. This study provides data on the structure of a Jurassic accretionary prism in the Sikhote-Alin-Amur area and its geodynamic implications.

Methods

Identifying the stratigraphic sequence of accretionary prisms, as well as reconstructing the primary sedimentary section of an accreted oceanic plate and the accretion history, require detailed biostratigraphic analysis and correlation among different prism sections which are most often lithologically uniform but intricately deformed. Sediments in accretionary prisms, by their formation conditions, commonly lack macroscopic faunal evidence, and their biostratigraphy thus bases uniquely on microfauna evidence (conodonts, radiolarians, and foraminifers). Radiolarians are an advantageous group of fossils being free from time or facies limitations unlike conodonts which disappear in the latest Triassic or foraminifers which are restricted to seamounts above the level of carbonate compensation. Radiolarians are present in both deep-sea (pelagic and hemipelagic) and relatively shallow (ocean-margin) facies and are the only faunal group found in some types of sediments (e.g., in siliceous or siliceous-argillaceous rocks).

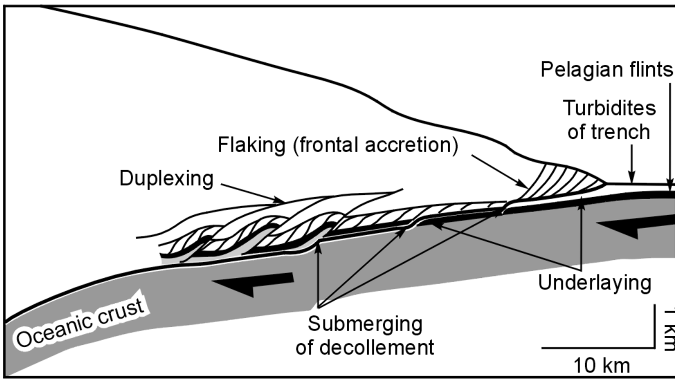

Fig. 2. Model of an accretionary prism, after (Hashimoto and Kimura, 1999).

The radiolarian analysis, as a specific case of biostratigraphic studies, is used to divide accretionary prisms into tectonic-stratigraphic units of different ages corresponding to specific accretion events. On their way from the origin (spreading zone) to burial (subduction zone) place, oceanic plates traverse various facies zones, and their sections thus document the successive change from pelagic through hemipelagic to ocean-margin sediments. Each group of rocks in this sequence of oceanic plate stratigraphy bears different pieces of information. Namely, hemipelagic siliceous mudstones and mudstones record the point when some part of the oceanic plate approaches the convergent boundary while trench turbidites mark the onset of subduction and subsequent accretion of its sedimentary blocks. Therefore, the ages of rocks in different tectonic slices of accretionary prisms have bearing on the chronology of accretion events and the tectonostratigraphic division with each unit corresponding to certain evolution stage. Further correlation of these units can provide more rigorous constraints on the prism structure and history.

Structure of the Jurassic accretionary prism in the Sikhote-Alin-Amur area

The Jurassic accretionary prism in the Sikhote-Alin-Amur area includes the Samarka, Nadanhada-Bikin, Khabarovsk, and Badzhal terranes (Fig. 4).

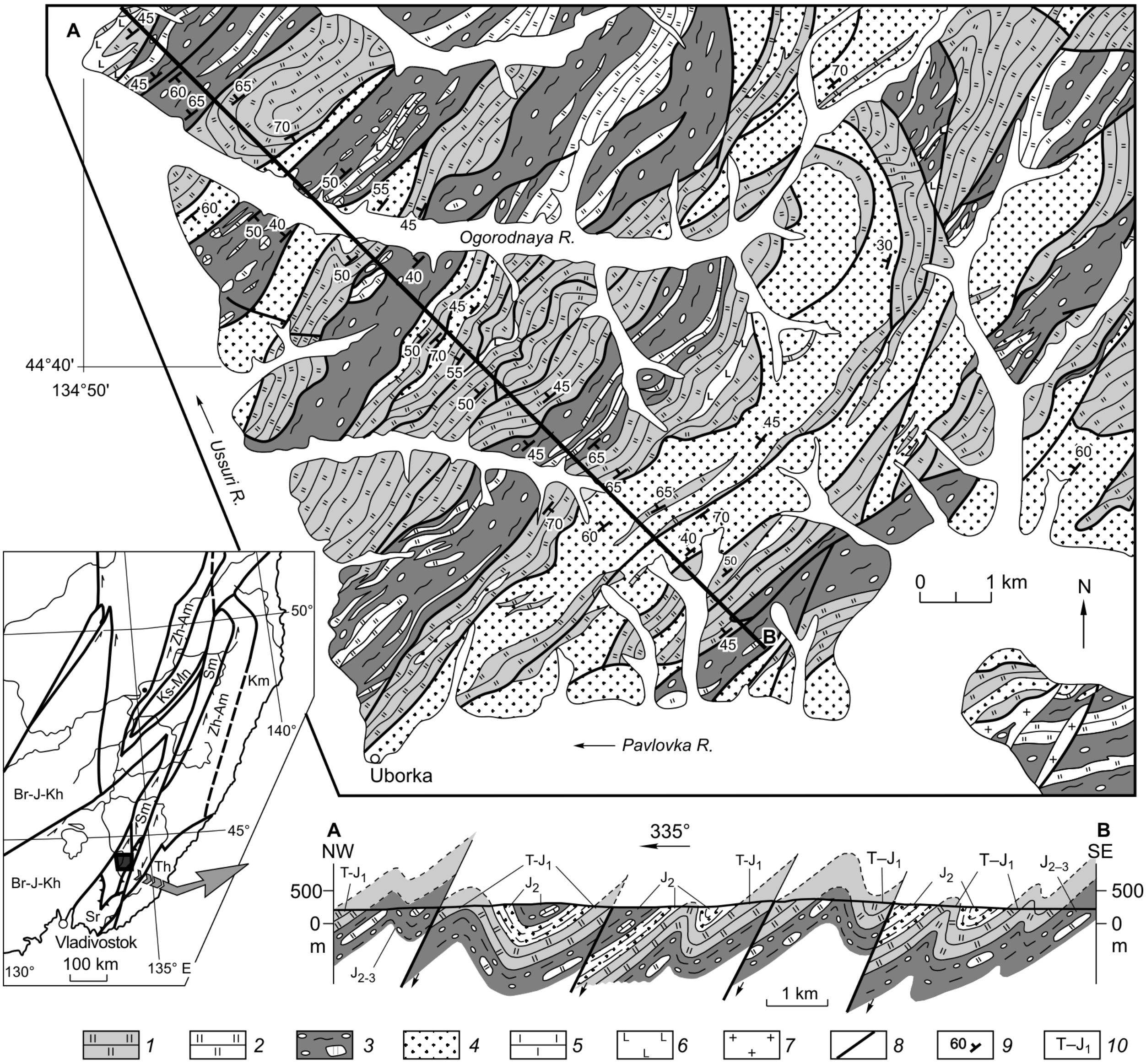

Fig. 3. Generalized geology of Ussuri–Pavlovka interfluve, after (Golozubov and Mel'nikov, 1986), with additions. *1* — slices of Permian, Triassic, and Early Jurassic cherts; *2* — blocks of Permian, Triassic, and Early Jurassic cherts in subduction melange; *3*, *4* — Middle-Late Jurassic turbidite and melange: subduction melange (*3*) and alternating sandstone and siltstone (*4*); *5* — blocks of Carboniferous-Permian limestone in subduction melange; *6* — basalt; *7* — Late Cretaceous granite; *8* — faults; *9* — attitude; *10* — ages of sediments. Letters in inset stand for terrane names: Br-J-H — Bureya-Jiamusi-Hanka superterrane, Sm — Samarka, Th — Taukha, Sr — Sergeevka, Zh-Am — Zhuravlevka-Amur, Km — Kema, and Ks-Mn — Kiselevka-Manoma terranes.

The **Samarka terrane** extends in a 100 km wide NE belt along the eastern edge of the Bureya-Jiamusi-Hanka superterrane from the southern Primorie coast to the right side of the lower Amur River (Fig. 4).

The terrane (Figs. 3 and 5) is a layer cake-like stack of steeply dipping tectonic slices of different thicknesses and lithologies (terrigenous sandstone and siltstone, banded chert, siliceous mudstone, subduction melange with olistostromes, and less abundant basalt and gabbro-ultramafic rocks). The rocks are split into multiple lenses, intensely foliated, occasionally mylonitized along the slice margins, and asymmetrically folded in the slice interior; the folds are often recumbent with northeast vergent axes but the limbs dipping gently in the NW direction. This folding geometry provided exposure of the terrane's upper slices in the west-northwestern and the lowermost ones in the east-southeastern parts of the area. The Samarka terrane is divided into the Eldovaka and Sebuchar subterranes according to lithological difference between the slices in its upper and lower section (Kemkin and Filippov, 2002).

The *Eldovaka subterrane* makes up the lower-middle section of the Samarka terrane and is composed of Early-Late Jurassic sand-clay and melange deposits interbedding with Late Permian, Triassic-Early Jurassic, and Triassic-Middle Jurassic cherts (Filippov et al., 2001; Kemkin and Golozubov, 1996; Kemkin and Khanchuk, 1992, 1993; Kemkin and

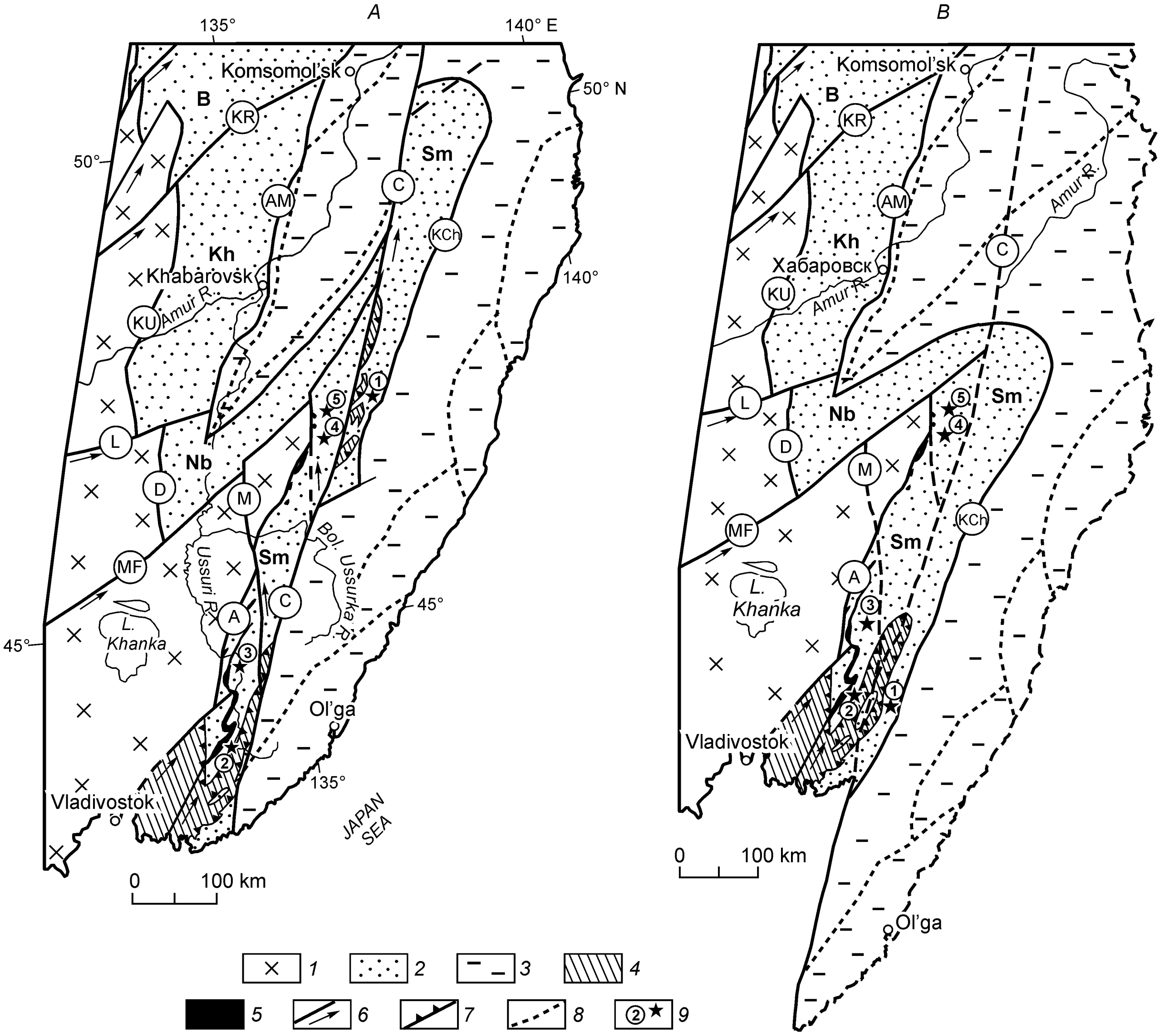

Fig. 4. Terranes of Jurassic accretionary prism, after (Kemkin and Filippov, 2001) and their configuration of today (*A*) and in Late Albian time (prior to left-lateral motion on Central Sikhote-Alin fault) (*B*). *1* — Bureya-Jiamusi-Hanka superterrane; *2* — terranes of Jurassic accretionary prism; *3* — Early Cretaceous terranes; *4* — Sergeevka terrane of Early Paleozoic continental margin; *5* — Middle Paleozoic ophiolite of Samarka terrane; *6* — left-lateral strike-slip faults; *7* — thrusts; *8* — boundaries of Early Cretaceous terranes; *9* — location of type sections in Samarka terrane (1 — middle reaches of Katen River), 2 — left side of Medvedka River near Breevka Village, 3 — left side of Ussuri River opposite Saratovka Village, 4 — right side of Bikin River, near Mt. Amba, 5 — right side of Matai River). Letters in circles stand for fault names: C — Central Sikhote-Alin, A — Arsen'evsk, M — Meridionalnyi, MF — Mishan-Fushung, KCh — Katen-Chuken, KR — Kursk, L — Laolihe, D — Dahezheng; fault zones: AM — Amur, KU — Kukan. Terranes of Jurassic accretionary prism: Sm — Samarka, Nb — Nadanhada-Bikin, Kh — Khabarovsk, B — Badzhal.

Rudenko, 1998; Mazarovich, 1985; Smirnova and Lepeshko, 1991; Volokhin et al., 1990). Some slices have tholeiite basalt at their base conformably overlain by chert. Most slices consist of a single lithology but some contain rather complete fragments of the primary stratigraphic sequence with banded chert at the base passing upsection to sandstone and siltstone through all intermediate lithologies. Proceeding from the ages of rocks (e.g., Filippov et al., 2001; Kemkin and Golozubov, 1996; Kemkin and Rudenko, 1998), especially those of the transitional layers in the chert-terrigenous sequence, the Eldovaka subterrane was subdivided into four (Katen, Breevka, Saratovka, and Amba-Matai) tectonostratigraphic complexes each being a record of a certain evolution stage of the prism.

The Katen Formation found in the terrane's easternmost part lies at the base of its section (1 in Fig. 4). It is composed (up the section) of Lower Triassic (Olenekian) to Middle Jurassic (Bathonian) chert and jasper, Bathonian-Callovian siliceous mudstone, and Oxfordian-Tithonian mudstone and silty mudstone, which pass upward to siltstone interbedding with sandstone and further to fine and medium-grained sandstone. The complex is remarkable by the presence of thinly (1–3 to 7–10 cm) interbedded gray chert and gray pelitic limestone at the Upper Norian level of the chert sequence.

The Breevka Formation lies above the Katen Formation (2 in Fig. 4) and consists of Middle Triassic (Anisian) to Middle Jurassic (Aalenian-Bajocian) chert, Bajocian siliceous mudstone, Bajocian-Bathonian silty mudstone and Callovian mud-

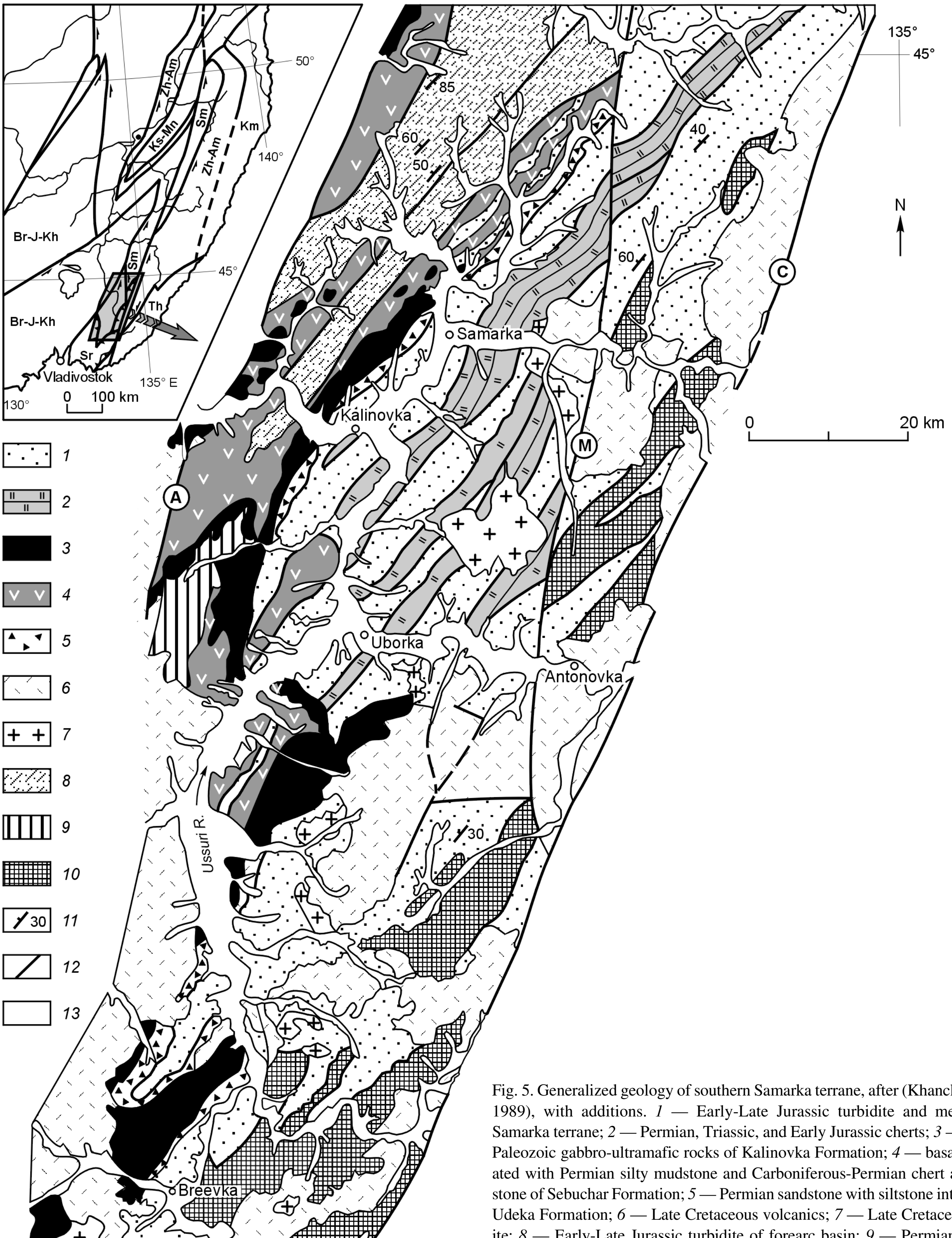

Fig. 5. Generalized geology of southern Samarka terrane, after (Khanchuk et al., 1989), with additions. *1* — Early-Late Jurassic turbidite and melange of Samarka terrane; *2* — Permian, Triassic, and Early Jurassic cherts; *3* — Middle Paleozoic gabbro-ultramafic rocks of Kalinovka Formation; *4* — basalt associated with Permian silty mudstone and Carboniferous-Permian chert and limestone of Sebuchar Formation; *5* — Permian sandstone with siltstone interbeds of Udeka Formation; *6* — Late Cretaceous volcanics; *7* — Late Cretaceous granite; *8* — Early-Late Jurassic turbidite of forearc basin; *9* — Permian-Triassic shallow marine (shelf) facies overlying sediments of Bureya-Jiamusi-Hanka superterrane; *10* — pre-Devonian gabbro-gneisses and overlying Permian-Jurassic shallow-marine (shelf) facies of Sergeevka terrane; *11* — attitude; *12* — faults; *13* — Quaternary sediments. Letters stand for fault names: A — Arsen'ev, M — Meridionalnyi, C — Central Sikhote-Alin. For names of terranes see Fig. 3.

stone grading upsection to thinly interbedded mudstone and sandstone. This section underlies slices of silty-pelitic melange with enclosed chert and sandstone blocks and clasts.

The Saratovka Formation oversteps the Breevka Formation (3 in Fig. 4) and consists of Late Permian chert at the base overlain, along a fault surface, by Middle Triassic (Anisian) to Early Jurassic (Pliensbachian-Toarcian) cherts that give way to Aalenian-Early Bajocian siliceous mudstone and Middle Bajocian-Late Bathonian mudstone and Bathonian-Callovian silty mudstone and siltstone passing upsection to turbidites (Golozubov and Mel'nikov, 1986; Kemkin and Golozubov, 1996; Volokhin et al., 1990).

The Amba-Matai Formation is the upper unit of the Eldovaka subterrane (or the top of the middle section of the Samarka terrane). It has Early-Late Permian chert and jasper at its base overlain by Mesozoic chert with jasper interbeds spanning ages from Early Triassic (Olenekian) to Early Jurassic (Pliensbachian) which pass to Late Pliensbachian-Early Toarican siliceous mudstone, Toarcian-Aalenian mudstone, and on to Bajocian-Bathonian siltstone underlying interbedded siltstone and sandstone; up the section there is melange of siltstone with blocks and clasts of Carboniferous-Permian limestone, Permian and Triassic-Jurassic chert, sandstone, basalt, and gabbro.

The terrigenous and transitional strata of the complex slightly vary in structure and composition in different areas. Namely, siliceous mudstone, mudstone, and siltstone in the right side of the Matai River (5 in Fig. 4) contain hyaloclastic, basalt, and dolerite interbeds of different thicknesses.

The *Sebuchar subterrane* builds the upper section of the Samarka terrane (Figs. 4, 5) and consists of alternating terrigenous and melange layers, and dispersed fragments of a formerly single ophiolite suite. The latter are Middle Paleozoic gabbro and ultramafic rocks (Kalinovka Formation), basalt, often in association with overlying Carboniferous-Permian carbonates and chert, Late Permian black shale (Sebuchar Formation), and Late Permian greenish-gray and dark olive sandstone and siltstone (Udeka Formation).

The Udeka Formation occupies the lower section of the Sebuchar subterrane. The 600–1000 m thick complex extends in a narrow NE strip along the eastern border of the Kalinovka ophiolite (Fig. 5) and is composed of greenish-gray outsized sandstone with up to 20–30 m thick interbeds of dark olive siltstone and scarce thin layers of black silty mudstone. The formation has an age constrained by Late Permian microfauna assemblages (Kemkin and Khanchuk, 1993) and tectonically overlies the rocks of the Amba-Matai Formation, which are, in turn, overlain, likewise along a fault, either by the Kalinovka gabbro or by the Sebuchar volcanic-siliceous rocks.

The Kalinovka Formation of gabbro and ultramafic rocks is made up of several relatively large tectonic slices (Fig. 5) lying, along fault surfaces, over the Udeka Formation or over the terrigenous-melange rocks of the Eldovaka subterrane. The slices preserve relatively complete ophiolite suites (Khanchuk et al., 1989) with serpentinized harzburgite and dunite at the base underlying plagioclase dunite, wehrlite, clinopyroxenite, troctolite, and olivine gabbronorite, and with two-pyroxene, clinopyroxene, and amphibole gabbro in the middle section. Chemically and mineralogically, the ophiolite suite shows an affinity of an oceanic plateau produced by a mantle plume (Khanchuk and Panchenko, 1991). The gabbroids of the complex have ages corresponding to the Silurian-Devonian boundary (Golozubov and Mel'nikov, 1986; Kemkin and Khanchuk, 1993).

The Sebuchar Formation is composed of several basaltic-sedimentary slices and involves the basaltic-sedimentary part of the ophiolite suite (Fig. 5). The slices most often have sheared and spillitized basalt at the base, with a chemistry of oceanic tholeiites (Khanchuk et al., 1989), lying either under Carboniferous-Permian chert and limestone (that replace each other according to facies change) or under Permian mudstone. Rocks in some slices have more complicated facies relationships as basalt can give way to chert which, in turn, can pass to mudstone. The basalt layers are conformably overlain by sediments (unless disturbed by later tectonic events). Some slices are of a single lithology being composed uniquely of basalt, silty-pelitic rocks or chert. Terrigenous rocks interbedding with oceanic-plateau fragments bear Early Jurassic radiolarians.

The **Nadanhada-Bikin terrane** occupies an area between the Chernaya Rechka and Naolihe mouths in the lower reaches of the Ussuri River (Fig. 6). It extends for almost 350 km in a ~ 60 km wide NE belt along the northwestern edge of a promontory of the Bureya-Jiamusi-Hanka superterrane (Fig. 1). The terrane is divided along the Ussuri valley into the Chinese southwestern (Nadanhada) and Russian northeastern (Bikin) parts.

Southwestern (Nadanhada) part of terrane. The Nadanhada Range (Fig. 6) consists of intricately alternating slices of terrigenous (sand, shale, and melange) rocks and chert (Shao et al., 1990,1992) folded in asymmetric recumbent folds that change in orientation from NE to N-S and then to NW in the southwest of the area. The chert rocks within the slices range in age from the Middle Triassic to the Early Pliensbachian (Yang and Mizutani, 1991; Yang et al., 1993). Some slices exhibit gradual chert-to-terrigenous transitions in exposed sections, where banded chert successively grades into siliceous mudstone, mudstone, and silty mudstone. There are Late Pliensbachian radiolarians found in siliceous mudstone, Aalenian assemblages in mudstone, and Bathonian-Callovian species in siltstone. Thus, the ages of the transitional chert-to-terrigenous layers span the Late Pliensbachian-Toarcian stages of the Early Jurassic.

The overlying terrigenous rocks are rhythmically interbedded medium or fine sandstone and siltstone, and melange. The latter consists of outsized blocks and clasts of Carboniferous-Permian limestone and basalt, Triassic chert, gabbro, and serpentinized ultramafic rocks in a foliated silty-mudstone matrix.

Among the melange in the extreme southwestern part of the area (Fig. 6) there occur abundant rocks of a Paleozoic ophiolite suite known as the Dahezheng complex. They exist as stacked slices of different sizes composed of serpentinite, gabbro, and basalt, the latter being conformably overlain by

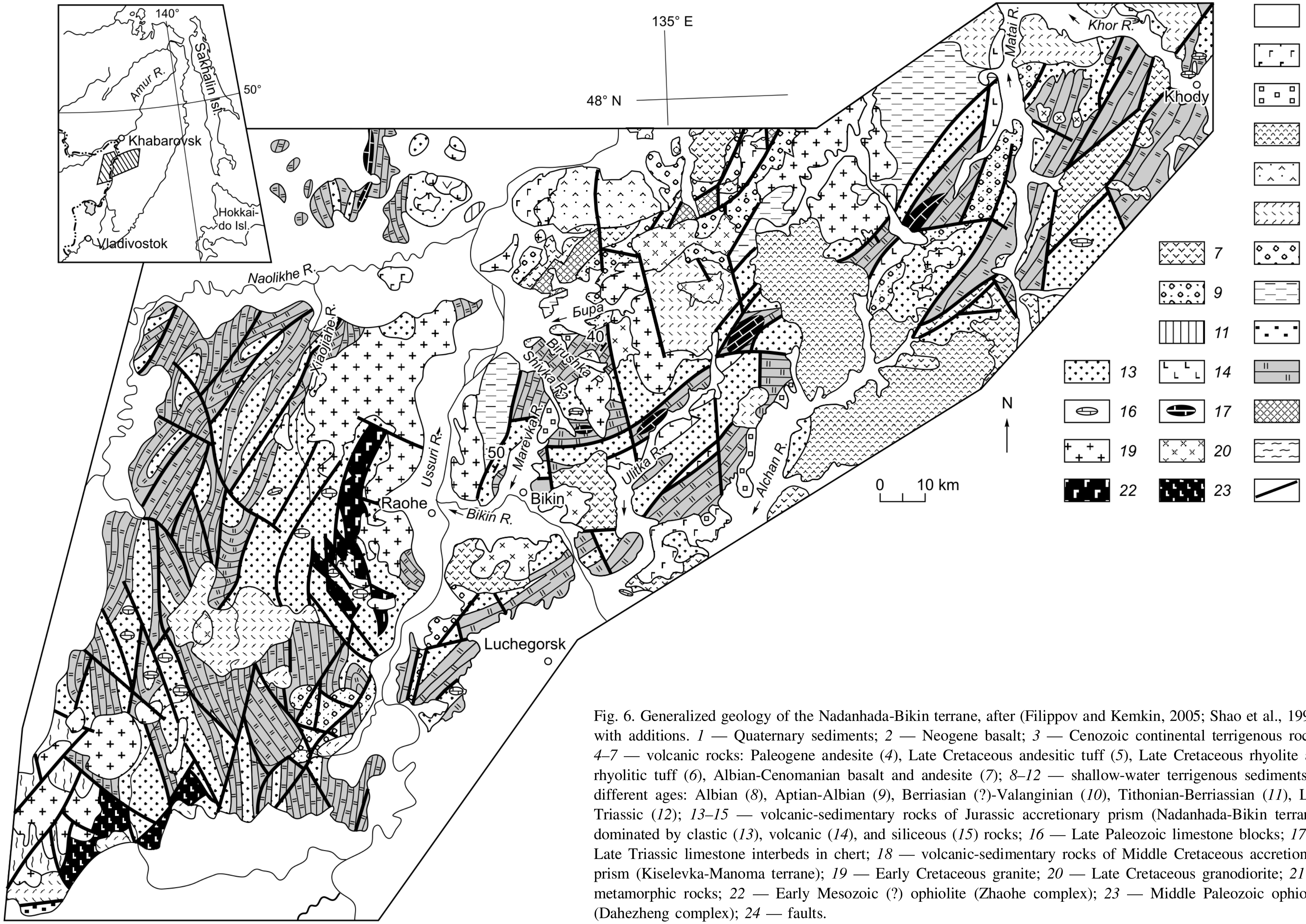

Fig. 6. Generalized geology of the Nadanhada-Bikin terrane, after (Filippov and Kemkin, 2005; Shao et al., 1990), with additions. *1* — Quaternary sediments; *2* — Neogene basalt; *3* — Cenozoic continental terrigenous rocks; *4–7* — volcanic rocks: Paleogene andesite (*4*), Late Cretaceous andesitic tuff (*5*), Late Cretaceous rhyolite and rhyolitic tuff (*6*), Albian-Cenomanian basalt and andesite (*7*); *8–12* — shallow-water terrigenous sediments of different ages: Albian (*8*), Aptian-Albian (*9*), Berriasian (?)-Valanginian (*10*), Tithonian-Berriassian (*11*), Late Triassic (*12*); *13–15* — volcanic-sedimentary rocks of Jurassic accretionary prism (Nadanhada-Bikin terrane), dominated by clastic (*13*), volcanic (*14*), and siliceous (*15*) rocks; *16* — Late Paleozoic limestone blocks; *17* — Late Triassic limestone interbeds in chert; *18* — volcanic-sedimentary rocks of Middle Cretaceous accretionary prism (Kiselevka-Manoma terrane); *19* — Early Cretaceous granite; *20* — Late Cretaceous granodiorite; *21* — metamorphic rocks; *22* — Early Mesozoic (?) ophiolite (Zhaohe complex); *23* — Middle Paleozoic ophiolite (Dahezheng complex); *24* — faults.

limestone bearing Upper Carboniferous or Lower Permian faunas. The ultramafic-gabbro member of the suite is a peridotite-gabbronorite assemblage. The Dahezheng ophiolite is chemically and mineralogically identical to the Kalinovka ophiolite (Khanchuk, 1993).

The lithology, structure, and ages of the chert-terrigenous sequence, as well as its spatial association with exotic melange blocks and dispersed Paleozoic ophiolite fragments suggest that the tectonostratigraphic units present in the Nadanhada area correspond to the upper section of the Jurassic accretionary prism. Fragments of the Dahezheng ophiolite correlate with the Sebuchar subterrane of the Samarka terrane (Kalinovka and Sebuchar complexes) and the chert-terrigenous sequence correlates with the upper unit of the Eldovaka subterrane (Amba-Matai complex).

The **northeastern (Bikin) part of terrane** likewise consists of intricately interbedded chert and terrigenous rocks (Fig. 6). The latter occasionally, mostly in the southeastern part of the area, host layers of mafic volcanics and melange. The volcanic-siliceous-terrigenous complex is intensely folded in NE (or locally N-S) striking asymmetric folds of different amplitudes. The folds have northwest vergent axes and southeast oriented limbs in the central and eastern parts of the area and, on the contrary, southeast vergent axes and the limbs gently dipping northwestward in the terrane's west. According to the general structural framework, the Bikin part of the terrane involves rocks of the lower section in its center and northeast and those of the upper section in the southeast and in the west. It includes three (Ulitka, Ussuri, and Khor) tectonostratigraphic units distinguished according to the ages of transitional layers in the chert-terrigenous sequences and to the lithologies of rocks (Filippov, 1990; Filippov and Kemkin, 2004).

The Ulitka Formation occurs in the terrane's central and northeastern parts and makes up the lower section. It consists of banded cherts which span ages from Anisian to Bathonian and give way up the section to Bathonian-Kimmeridgian siliceous mudstone and mudstone and further to Late Jurassic-Early Berriasian siltstone and sandstone alternating with siltstone. The chert section contains an up to 40 m thick pelitic limestone interbed at the Late Carnian-Early Norian level.

The Ussuri Formation constitutes the middle part of the section and occupies the western part of the area in the right side of the Ussuri River. At the base of the formation there is Triassic (from the Early Anisian) banded chert which gives way up the section to siliceous mudstone and Middle Jurassic silty mudstone, siltstone, and sandstone-siltstone interbeds.

The Khor Formation is found in the terrane's south-southeast, east, and partly southwest making the upper unit in the section. It consists of Triassic (from Anisian to Rhaetian) and Early Jurassic chert which passes to Pliensbachian siliceous mudstone and up to Middle Jurassic silty mudstone and siltstone below a sequence of interbedding siltstone and sandstone. Terrigenous rocks are intercalated with basic volcanics (10–40 m thick, some members up to 100 m thick) composed of hyaloclastic rocks, tuff, and basaltic or picritic lavas. In addition, siltstones host a melange of Paleozoic limestone, basalt, sandstone, and chert blocks and clasts.

According to their lithology, structural framework, and ages, the three complexes in the Bikin part of the terrane correlate with the tectonostratigraphic units of the Samarka terrane, namely, the correlation is between the Ulitka and Katen, Ussuri and Breevka, and Khor and Amba-Matai complexes, respectively; the two latter complexes both have mafic volcanics in the terrigenous component and melange bearing exotic (Paleozoic) clasts.

The **Khabarovsk terrane** delineates the eastern margin of the northern Bureya-Jiamusi-Hanka superterrane in a 100–130 km wide NE strip from the Naolihe River in the south to the Vandan Range in the north (Fig. 4). The greatest part of the terrane is buried under the fluvial deposits of the Amur, of its left tributaries, and the Ussuri. A few isolated outcrops are restricted to bluffs along the Amur (near the city of Khabarovsk and at Voronezhskoe-2 Village) and Ussuri (within the Khekhtsir Reserve) rivers, the Dva Brata (Russian for *Two Brothers*) Hill, at the Krasnaya Rechka railway station, and within the Vandan Range. The exposed structure of the terrane appears as a stack of tectonic slices with blocks of different sizes composed of siliceous and siliceous-argillaceous rocks, metamorphosed sandstone and shale, and fresh sandstone, siltstone, volcanics, and melange (Bragin, 1991; Ishida et al., 2002; Natal'in and Zyabrev, 1989; Shevelev, 1987; Zyabrev and Matsuoka, 1999). The terrane includes two reliably identified tectonostratigraphic units of the Khabarovsk-Voronezhskoe and Ussuri-Khekhtsir complexes (Kemkin et al., 2006).

The Khabarovsk-Voronezhskoe section reconstructed from its fragments exposed in numerous bluffs along the Amur right side consists of Early Triassic (Olenekian) to Early Jurassic chert and jasper at the base overlain by Aalenian-Bajocian (Kojima et al., 1991; Natal'in and Zyabrev, 1989; Wakita et al., 1992) siliceous mudstone grading into Late Bathonian-Middle Callovian mudstone and silty mudstone. Further upsection there lie Oxfordian-Kimmeridgian (Ishida et al., 2002) siltstone with tuffite interbeds and Tithonian (Zyabrev and Matsuoka, 1999) siltstone with carbonate-manganese and clay-carbonate nodules. The section is topped by thinly interbedded sandstone and siltstone with layers of melange.

The Ussuri-Khekhtsir section (Kemkin et al., 2006) studied in an outcrop in the right side of the Ussuri mouth (western foothills of the Bol'shoi Khekhtsir Range) begins with banded chert. The lower age limit of the latter remains uncertain because of strong recrystallization and the upper limit is at the Aalenian-Early Bajocian. The basal strata are overlain by Late Bajocian clayey chert giving way to Late Bajocian-Early Bathonian siliceous mudstone and Early Bathonian mudstone. At the top there is dark gray siltstone grading into siltstone-sandstone interbeds.

The two tectonostratigraphic units of the Khabarovsk terrane correlate, respectively, with the Saratovka and Breevka units of the Samarka terrane according to integrate lithological and chronological data. Note that there are exposures of Triassic banded chert found in the northern foothills of the

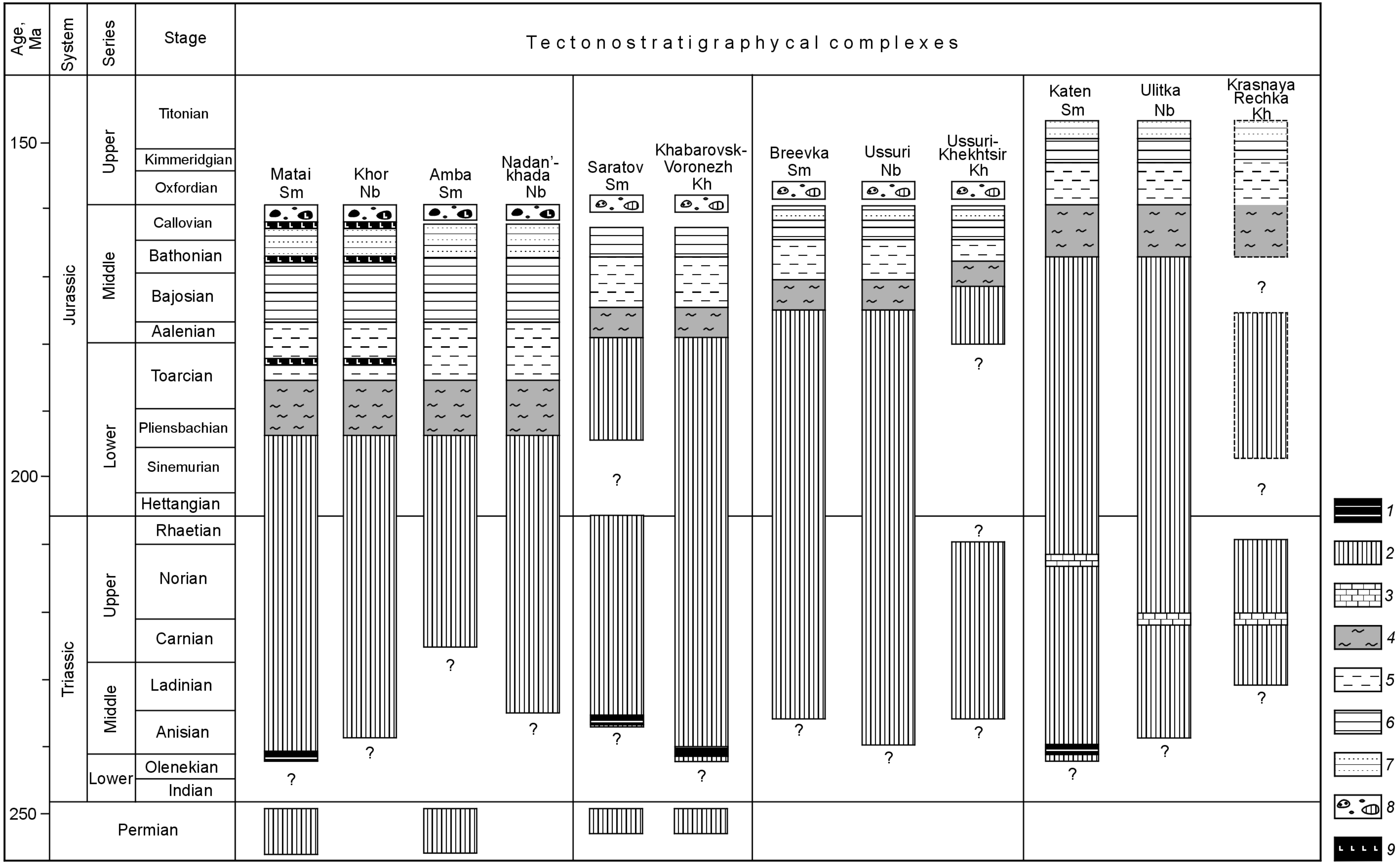

Fig. 7. Flow chart of tectonic-stratigraphic units of terranes in Jurassic accretionary prism, Sikhote-Alin-Amur area. *1* — siliceous rocks; *2* — chert; *3* — limestone; *4* — siliceous mudstone; *5* — mudstone; *6* — siltstone with scarce sandstone interbeds; *7* — alternating siltstone and sandstone; *8* — subduction melange; *9* — basic volcanic (basalt and hyaloclastic) rocks. Abbreviations stand for terrane names: Sm — Samarka, Nb — Nanhanda-Bikin, Kh — Khabarovsk.

Bol'shoi Khekhtsir Range (Dva Brata Hill) which bear pelitic limestone at the Carnian-Norian level (Klets, 1995). A siliceous-carbonate complex of a similar age is known also in China (Wang et al., 1986) in the left side of the Naolihe mouth in the southernmost part of the Khabarovsk terrane. The chert component in the chert-terrigenous sequence of the Jurassic accretionary prism has this lithology only in the lower section of the Samarka and Nadanhada-Bikin terranes (Katen and Ulitka complexes). Therefore, the Khabarovsk terrane may include at least one more tectonostratigraphic unit (Krasnaya Rechka complex).

The **Badzhal terrane** sited north of the Khabarovsk terrane (Fig. 4) remains the least explored element of the Jurassic accretionary prism. No tectonostratigraphic units have been distinguished so far in its structure but it is known to consist of multiple alternating chert and terrigenous layers (Kirillova, 2002). The cherts have Late Permian, Triassic, and Triassic-Middle Jurassic ages and the terrigenous rocks are Middle-Late Jurassic. In the southwestern part of the terrane there are mapped basalts associated with Carboniferous-Permian limestone and Permian chert. Thus, the Badzhal terrane has a structure similar to that of the Samarka terrane.

Discussion and conclusions

The described terranes of the Jurassic accretionary prism in the Sikhote-Alin-Amur area share many features of similarity in the stacking patterns of geographically dispersed sections within the prism, the lithology of respective rock complexes, and even the fauna species. This similarity indicates that there was a single subduction-accretionary system along the Pacific margin of Asia, which in Jurassic time marked the zone of Asia-Pacific collision and was the origin place of the accretionary prism we studied. The prism exists in the present framework of the Asian margin as stacked tectonic slices of different sizes composed of either oceanic (pelagic and hemipelagic deposits and fragments of an oceanic plateau) or ocean-margin (terrigenous rocks), or subduction melange complexes. The primary stratigraphic sequence of rocks in the slices, as identified through detailed lithological-biostratigraphic and structural studies, is from pelagic to hemipelagic and then to terrigenous deposits. The available ages of rocks from different slices correspond to fragments of several primary oceanic plate stratigraphy sequences which show progressive younging (Fig. 7) and, hence, record the succession of accretionary events. For instance, the Late Pliensbachian-Early Toarcian, Aalenian-Early Bajocian, Bajocian and Bathonian-Callovian transitional layers in the tectonic-stratigraphic units of the Samarka terrane document successive accretion of paleooceanic complexes to the Asian continental margin. Therefore, the Jurassic prism represents an ordered sequence of intricately deformed fragments of the oceanic plate primary sedimentary section with their ages proportional to distances from the spreading center rather than being a random collage of facies of different ages.

Although the original stratigraphic sequence is disturbed, in the today's Sikhote-Alin framework, by numerous faults of strike-slip, thrust, and normal geometries, the prism structure has been identified as consisting of at least five units. They are fragments of Paleozoic ophiolite suites and four chert-terrigenous sequences with different ages of both rock complexes and accretion events. In each unit, the section begins with oceanic deposits that gradually pass upward to terrigenous rocks. Note that the prism as a whole appears to show an inverse stratification with the oldest complexes in its upper section and the youngest ones at its base, though the stratigraphic sequence is normal (from old to young) within each separate unit. This pattern is the same as in modern accretionary prisms which form at the base of trench slopes along convergent plate boundaries as a result of successive accretion of oceanic lithosphere. Accretion normally begins with the fragments of a subducting oceanic plate that are the farthest from the spreading center and, hence, the oldest. Then progressively younger plate fragments accrete beneath the previously accreted ones to produce a stack of slices.

The reported data on the structure of the Jurassic accretionary prism have implications for its history and, correspondingly, for key geological events on the Paleoasian margin. In the Early Jurassic the eastern part of Asia was an Andean-type active margin which experienced accretion of an oceanic plateau. The plateau, being an elevated topographic feature, eluded complete subduction but imbricated into several slices along a system of low-angle decollements, whereby the lower slices partially underplated the upper ones and accreted to the continental margin, in the same way as in the case of the modern accretion of the Daiichi Kashima seamount in the Japan trench or the Zenisu Ridge in the Nankai trough (Fujioka et al., 1988). Fragments of that plateau now appear as the Kalinovka ophiolite in Sikhote-Alin and as Dahezheng ophiolite in Nadanhada-Alin. In the Middle and Late Jurassic, subduction involved the part of the oceanic plate with poorly dissected topography. The accreted oceanic fragments of that time exist as chert-terrigenous sequences which differ one from another only in gradually younging ages of the chert-to-terrigenous transitional strata.

Thus, the Paleoasian continent grew significantly through the Jurassic by successive accretion of Paleopacific units of different ages and facies to its eastern margin.

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