Main Jurassic geological events along the eastern Paleo-Asian continental margin*

Igor' V. KEMKIN[1] and SHA Jingeng[2]**

(1. Far East Geological Institute, Far Eastern Branch of Russian Academy of Sciences, Vladivostok, prospect 100-letiya Vladivostoka, 159, Russia; 2. LPS, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China)

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Abstract The Jurassic is a period of intensive accretion along the eastern and southeastern margins of the Asian continent. The emphasis of the present study is the review of the Jurassic prism structure of the Russian Far Eastern Pacific Asian margin and comparison with its equivalent in the Japanese archipelago. The Jurassic accretion processes and geodynamic evolution of the Paleo-Asian continent eastern margins are outlined in the paper. During this period, the different ages and different facies fragments of the Paleo-Pacific, such as abyssal plain, intraoceanic volcanic seamountains and oceanic plateaux, were accreted onto the eastern margin of the Paleo-Asian continent as a result of step-wise subduction of oceanic lithosphere. Together with ocean-margin terrigenous deposits (trench-fill turbidites), these paleooceanic fragments formed a thick tectono-sedimentary complex of the Jurassic accretionary prism, causing the size of the continent to be expanded by an increase along its eastern margin.

Keywords: Jurassic, accretionary prism, Sikhote-Alin, Nadankhada-Alin, Japan, geological events, continental margin, East and Southeast Asia.

The hypothesis that the Pacific eastern Asian margins of the Siberian and Sino-Korean cratons represent a collage of terranes of different origins and different ages, accreted during the Mesozoic to Cenozoic, has been confirmed by numerous authors[1–20].

These terranes include fragments of ancient passive continental margins, volcanic island and magmatic continental-margin arcs, back- and fore-arc basins, accretionary prisms and turbidite basins. The ancient accretionary prisms were directly formed in the interactive zone between the Paleoasian and Paleo-Pacific lithospheric plates and contain information about the succession and characters of geological events.

Accretionary prisms are characterized by a complicated imbricate-thrusted structure, caused by the processes of offscraping (slicing of subducting trench deposits in the front part of the prism) and underplating (duplicating of oceanic rocks at the base of the prism), and also by post-accretionary deformation including thrusts and strike-slip faults[8,21–25]. For this reason, accretionary prisms yield tectono-sedimentary complexes having complicated structures, such as repeated alternations of tectonic slices (plates), blocks consisting of marine (pelagic and hemipelagic deposits and also fragments of seamounts and plateaus), oceanic-margin (turbidites), and chaotic (mélange and olistostromes) formations.

The importance of studying these ancient accretionary prisms resides in that specification of their geological structure and decoding the geodynamic evolution of the region composed of such prisms, enables their correlation with other geological events along the Paleoasian-Paleopacific convergent boundary.

Biostratigraphy, lithology and structural geology of the ancient prism terranes advantageously complement other approaches, such as geophysical and deep-water drilling methods, practiced in the study of modern prisms, by adding a time dimension.

Jurassic accretionary prism exposures can be followed from the south coast of the Uda Gulf to the north, through Priamurie and Sikhote-Alin (southern Russian Far East), Nadankhada (NE China), Japan and the Ryukyu islands, to Palawan Island (Philippines) in the south (Fig. 1)[11,15,16,26–37]. In Sikhote-Alin and Japan this prism has been thoroughly investigated. A brief account of the structure of the prism, the accretion process and the geodynamic evolution of the Asian continental margin are presented

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** To whom correspondence should be addressed. E-mail: jgsha@nigpas.ac.cn

and discussed below.

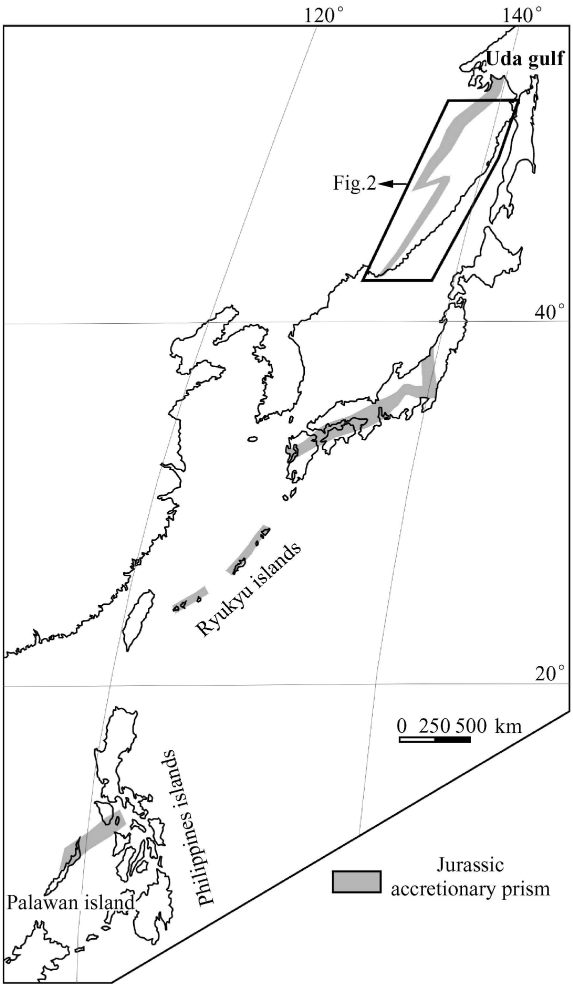

Fig. 1. Map showing Jurassic accretionary prism of East and Southeast Asia.

1 Brief description of the Sikhote-Alin-Priamurie Jurassic prism terranes

In the Sikhote-Alin-Priamurie region the Jurassic prism is represented by four terranes: Samarka, Nadankhada-Bikin, Khabarovsk, and Badzhal (Fig. 2). Up to now the Samarka and Nadankhada-Bikin terranes are well known, but the others are poorly investigated.

1.1 Samarka terrane

The Samarka terrane, with a width of up to 100 km, extends along the eastern edge of the Bureya-Jiamusi-Khanka superterrane, from the northern coast of the Sea of Japan to the east bank of Heilong (Amur) River. It is sandwiched between the large left-lateral strike-slip Arsen'evsky and Central Sikhote-Alin faults in its southern part, and between the Central Sikhote-Alin and Katen-Choukensky faults in its northern part (Fig. 2).

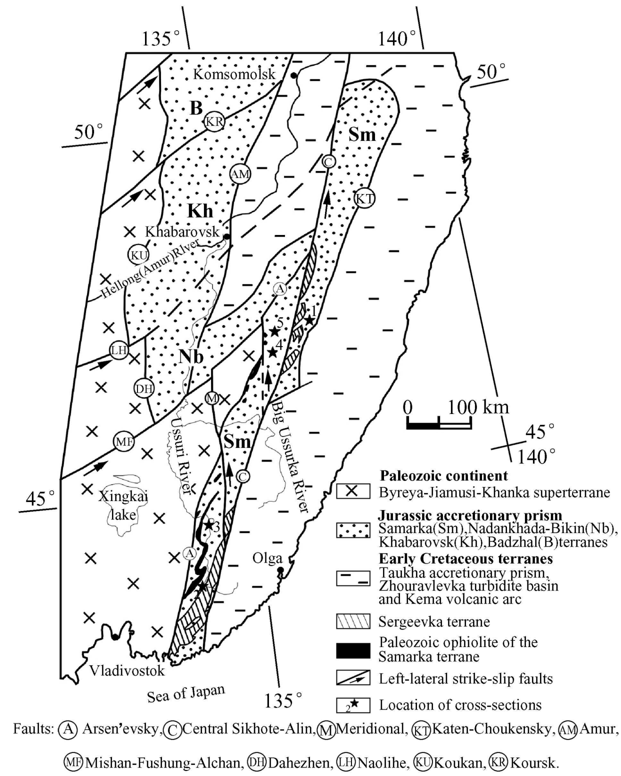

Fig. 2. Terranes of the Jurassic accretionary prism of the Sikhote-Alin-Priamurie region (modified from Kemkin and Filippov[34]).

Based on detailed biostratigraphic research (using radiolarian fauna, see Figs. 3, 4) of the transitive layers between the pelagic and oceanic-margin deposits in various tectonic slices, the Samarka terrane has been dismembered into five tectono-stratigraphic units, reflecting the process of consecutive accretion of marine formations formed at different times and in different facies. Based on the composition of the tectono-stratigraphic units, the Samarka terrane can be allocated into two: the Eldovaka subterrane composed of the lower to middle structural levels and the Sebouchar subterrane comprising the upper structural level[34].

1.1.1 Eldovaka subterrane

The Eldovaka subterrane, i. e. the lower and middle structural levels of the Samarka terrane, is composed of repeated alternating slices (Fig. 5) of Middle to Late Jurassic sandstone and siltstone, bedded cherts ranging from Late Permian to Early to Middle Jurassic aod " chaotic " formations (i. e. mélange formations containing different-sized lumps (clasts) and blocks of siltstones, sandstones, basalts,

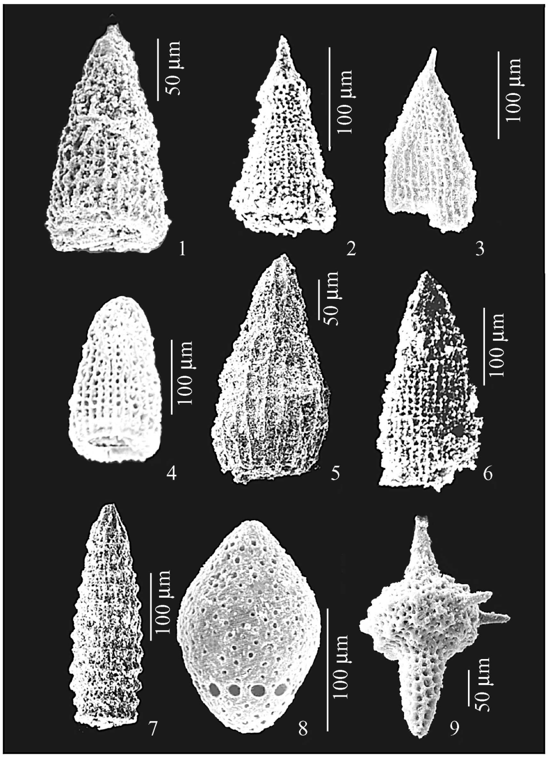

Fig. 3. Some important Early and Middle Jurassic radiolarians from Sikhote-Alin-Priamurie region. 1, *Parahsuum simplum* Yao, sample 3Dg-8; 2, *Parahsuum longiconicum* Sashida, sample 3Dg-86-13; 3, *Parahsuum levicostatum* Takemura, sample A02X-3/7; 4, *Parahsuum ovale* Hori et Yao, sample 3Dg-5; 5, *Hsuum matsuokai* Isozaki et Matsuda, sample R-8; 6, *Parahsuum grande* Hori et Yao, sample 3Dg-86-13; 7, *Transhsuum medium* Takemura, sample R-10; 8, *Tricolocapsa fusiformis* Yao, sample Br-9; 9, *Podobursa polyacantha* (Fishli), sample Be-7.

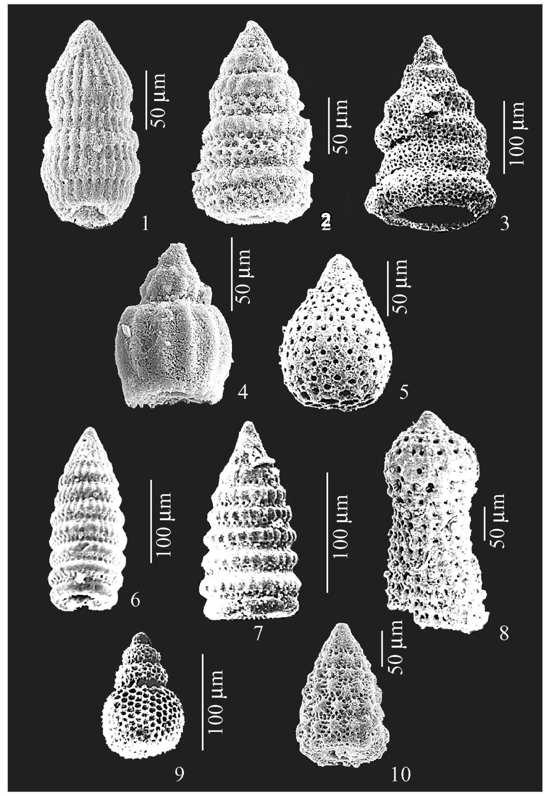

Fig. 4. Some important Late Jurassic and Early Cretaceous radiolarians from Sikhote-Alin-Priamurie region. 1, *Archaeodictyomitra minoensis* (Mizutani), sample C-56; 2, *Cinguloturris cylindra* Kemkin et Rudenko, sample Be-5; 3, *Spongocapsula perampla* (Rust), sample C-74; 4, *Eucyrtidiellum pyramis* (Aita), sample Be-6; 5, *Stichocapsa pseudoconvexa* Kemkin et Taketani, sample 2R-4; 6, *Pseudodictyomitra lilyae* (Tan), sample Da-25; 7, *Pseudodictyomitra carpatica* (Lozyniak), sample C-54; 8, *Ristola cretacea* (Baumgartner), sample 3Dg-11; 9, *Sethocapsa horokanaiensis* Kawabata, sample C-54; 10, *Xitus spicularius* (Aliev), sample Be-12.

gabbro, Early Permian, Triassic, Jurassic cherts and Carboniferous-Permian limestones). In separate slices a gradual transition from cherts to terrigenous rocks can be observed (Fig. 6). According to the age of the transitional beds in such slices, the Eldovaka subterrane was divided into four tectono-sedimentary complexes[34]. They are, in ascending order: the Katen, Breevka, Saratovka and Amba-Matay formations.

1.1.1.1 Katen Formation

The chert-terrigenous sequence of the Katen Formation comprises the easternmost part of the Samarka terrane and shows monoclinal dip to the northwest (Location 1 in Figs 2, 7). The cross-section of this unit is outlined in the following in ascending order:

1. Grey clayish cherts (14 m); 2. alternating (1—5 cm thick each alternation) of light grey clayish cherts and black clayish phthanite (8 m); 3. various bedded greenish grey (1—7 cm, occasionally up to 10 cm thick each bed) cherts (75 m); 4. clayish jasper (5 m); 5. grey siliceous mudstones (40 m); 6. dark grey mudstones and muddy siltstones (20 m); 7. alternation of siltstones and sandstones (10 m); 8. fine-medium-grained sandstones (200 m).

The age of the cherts range from Olenekian (Early Triassic) to Bathonian-Callovian (Middle Jurassic) based on abundant conodonts[38], such as *Neospathodus* cf. *homeri* (Bender), *Oncodella* cf. *obuti*, *Neogondolella* cf. *mombergensis* (Tatge), *Paragondolella* cf. *polygnathiformis*, *Metapolygnathus* cf. *communisti*, *Metapolygnathus* cf. *vialovi* Buryi, *Metapolygnathus* cf. *nodosus*, *Metapolygnathus echinatus*, *Metapolygnathus* cf. *primitia*,

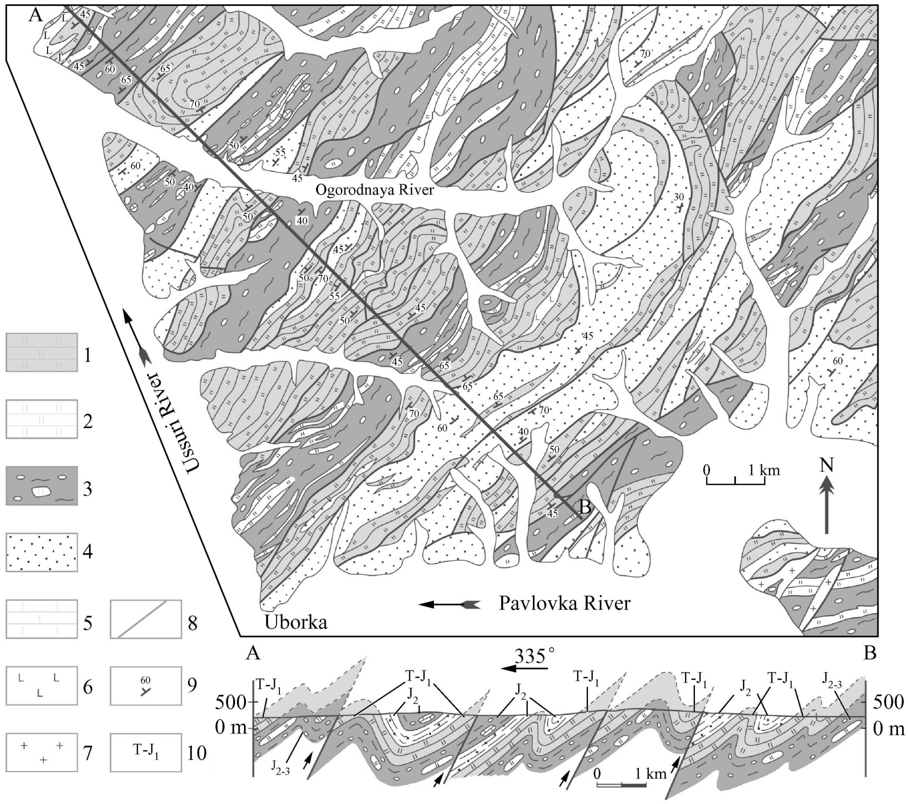

Fig. 5. Scheme of geological structure of the Ussuri-Pavlovka area (modified from Golozoubov and Mel'nikov[89]). 1, Slices of Permian, Triassic and Early Jurassic cherts; 2, Lumps (clasts) and blocks of Permian, Triassic and Early Jurassic cherts in subduction mélange; 3 and 4, Middle-Late Jurassic turbidite and mélange formation: 3 is Subduction mélange, 4 is Siltstone-sandstone alternation; 5, Lumps (clasts) and blocks of Carboniferous-Permian limestones in subduction mélange; 6, Basalts; 7, Late Cretaceous granites; 8, Faults; 9, Elements of rock occurrence; 10, Age of deposits.

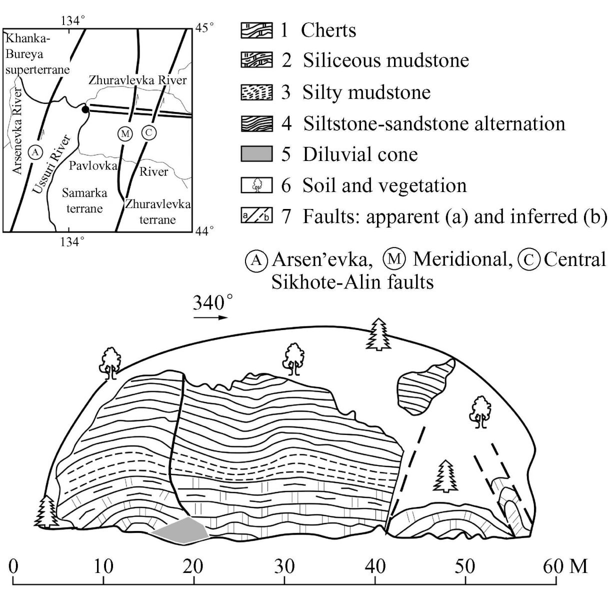

Fig. 6. Structure of the chert-terrigenous sequence near the Saratovka village (magnified from the black dot in the figure above).

Epigondolella aff. *bidentata* Mosher, *Misikella hernsteini* (Mosher) and radiolarians[34], such as *Laxtorum* (?) *jurassicum* Isozaki & Matsuda, *Transhsuum hisuikyoense* Isozaki & Matsuda, *Transhsuum* cf. *medium* Takemura, *Archaeodictyomitra exigua* Blome, *Guexella* sp., *Eucyrtidiellum* sp., *Solenotruma* (?) sp., *Tricolocapsa* sp. The Late Triassic part of the section is represented by alternating cherts and thin layers (1—3 to 7—10 cm thick each layer) of grey pelitomorphic limestones with cherty limestones interbeds.

The siliceous mudstones (5) contain Bathonian-Callovian radiolarians, *Tricolocapsa fusiformis* Yao, *Tricolocapsa* ex gr. *plicarum* Yao, *Tricolocapsa plicarum* Yao, *Guexella nudata*, *Eucyrtidiellum unumaensis* Yao, *Dictyomitrella* (?) *kamoensis* Mizutani et Kido, *Tricolocapsa* sp[34].

The mudstones and siltstones (6) yielded Oxfordian-Tithonian radiolarians, *Archaeodictyomitra minoensis* (Mizutani), *Zhamoidellum* cf. *ovum* Dumitrica, *Triactoma blakei* (Pessagno), *Mirifusus* sp., *Ristola* sp., *Parvicingula* sp. and *Sethocapsa* sp.[38]

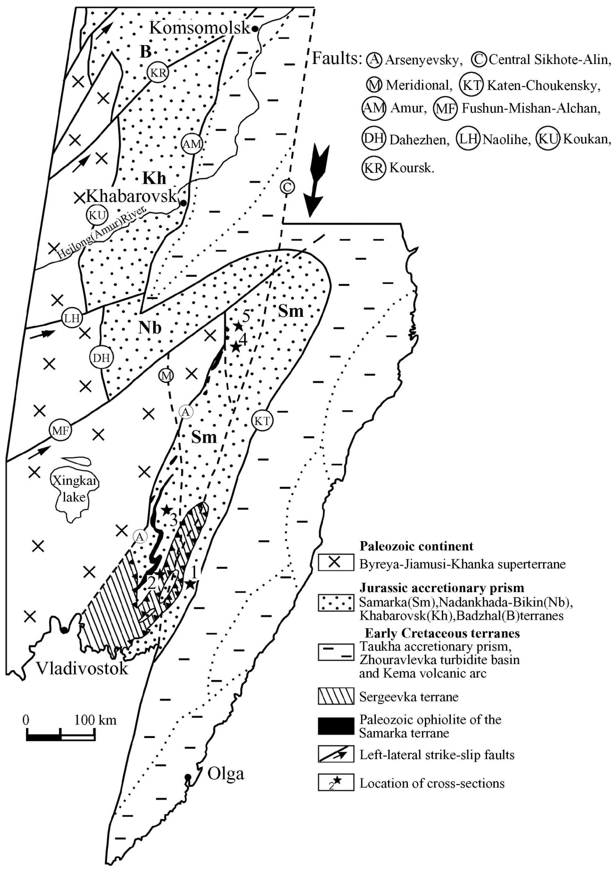

Fig. 7. Geological reconstruction of the Sikhote-Alin region with the effect of left-lateral strike-slip movement along the Central Sikhote-Aline fault removed (modified from Kemkin and Filippov[34]).

1.1.1.2 Breevka Formation

In ascending order, the Breevka Formation (Location 2 in Figs. 2, 7) is composed of the following rocks:

1. Grey and yellowish cherts (70 m); 2. greenish, yellowish, and grey siliceous mudstones (3 m); 3. dark grey mudstones and muddy siltstones (5 m); 4. siltstones in lower, alternating siltstones and sandstones in upper (65 m).

The majority of the outcrop is represented by grey bedded cherts. The bedding is caused by thin (1—3 mm thick) clayey interbeds. The thickness of the chert beds varies from 1—2 cm in the low and upper but 3—10 cm in middle of the section. The exposed strata show a monoclinal dip to the northwest (dip azimuth is 345°, dip angle is 50°—60°). In the lower part of the chert section the clastic layer (about 10 cm thick) is embedded within the grey bedded cherts. The clastic layer shows graded bedding. Grain size of the lower part is more then 0.5 mm, whereas that of the upper part is about 0.1—0.3 mm. The clastic grains are composed mainly of basalt, volcanic glass, chert, siliceous mudstone, and plagioclase. The cherts change smoothly into terrigenous rock through siliceous mudstone. Micropaleontological data[39] show that the age of the chert part is from Anisisan (Middle Triassic) to Aalenian-Bajocian (Middle Jurassic). The cherts contain abundant conodonts, *Gondolella excelsa* (Mosher), *Oertlispongus* sp., *Gladigondolella* sp., *Budurovignathus hungaricus* Kozur, *Paragondolella excelsa* (Mosher), *Paragondolella trammeri*, *Neogondolella hucreidei* Kozur, *Budurovignathus* sp., *Neogondolella* sp., and radiolarians *Pseudostylosphaera coccostyla compacta* (Nakaseko et Nishimura), *Pseudostylosphaera coccostyla* gr. Kozur, *Pseudostylosphaera* spp., *Triassocampe scalaris* Dumitrica, Kozur et Mostler, *Triassocampe deweveri* gr. (Nakaseko et Nishimura), *Triassocampe* aff. *nova* Yao, *Triassocampe* spp., *Yeharaia annulata* Nakaseko et Nishimura, *Yeharaia triassica* Kozur et Mostler, *Yeharaia* spp., *Annulotriassocampe campanilis longiporata* Kozur et Mostler, *Annulotriassocampe campanilis* gr. Kozur et Mostler, *Annulotriassocampe* ex gr. *euladinika* Kozur et Mostler, *Annulotriassocampe* spp., *Sarla dispiralis* Bragin, *Eptingium* sp., *Tiborella foliata gr*. (Dumitrica, Kozur et Mostler), *Parasepsagon* sp., *Arhaeospongoprunum brevispinosum* Kozur, *Canoptum triassicum Yao*, *Canoptum* sp., *Haeckelicyrtium* sp., *Tricolocapsa fusiformis* Yao, *Tricolocapsa* sp., *Parahsuum* cf. *grande* Hori et Yao, *Parahsuum* cf. *levicostatum* Takemura, *Parahsuum simplum Yao*, *Parahsuum* sp., *Stichocapsa convexa* Yao, *Tripocyclia* (?) *japonica* (Nakaseko et Nishimura), *Sethocapsa* (?) sp., *Syringocapsa* sp. and *Emiluvia* sp.[39]

The siliceous mudstones contain Bajocian radiolarians, *Tricolocapsa ruesti* Tan Sin Hok, *Tricolocapsa* sp., *Hsuum medium* (Takemura), *Hsuum fukazawaense* Sashida, *Hsuum* cf. *fukazawaense* Sashida, *Hsuum* sp., *Stichocapsa convexa* Yao, *Milax* sp.[39]

The mudstones are characterized by Bajocian-Bathonian radiolarians, *Tricolocapsa fusiformis* Yao, *Tricolocapsa ruesti* Tan Sin Hok, *Tricolocapsa plicarum* Yao, *Tricolocapsa* aff. *plicarum* Yao, *Tricolocapsa* sp., *Arhaeodictyomitra* cf. *exigua* Blome, *Archaeodictyomitra* aff. *prisca* Kozur et

Mostler, *Archaeodictyomitra* sp., *Eucyrtidiellum* aff. *disparile* Nagai et Mizutani, *Eucyrtidiellum*, *unumaense* Yao, *Stichocapsa convexa* Yao, *Hsuum* sp.[39]

The siltstones are characterized by Callovian radiolarians, *Thanarla* aff. *conica* (Aliev), *Sethocapsa* sp., *Podobursa* sp., *Protunuma* cf. *japonica* Matsuoka et Yao, *Archaeodictyomitra* sp., *Hsuum* sp., *Tricolocapsa* sp., *Parvicingula* sp., *Hsuum* ex. gr. *maxwelli* Pessagno, *Orbiculiforma* sp., *Tripocyclia* sp., *Stichocapsa convexa* Yao, *Stichomitra* aff. *tairai* Aita, *Dictyomitrella kamoensis* Mizutani et Kido, *Gongylothorax* ex gr. *oblongus* Yao, *Haliodictia* (?) *hojnosi* Riedel et Sanfilippo, *Tritrabs* sp., *Angulobracchia* sp., *Hsuum robustum* Pessagno et Whalen, *Hsuum belliatulum* Pessagno et Whalen, *Hsuum brevicostatum* (Ozvoldova)[39].

1.1.1.3 Saratovka Formation

This formation represents a middle structural level of the Samarka terrane (Location 3 in Figs 2, 7). The outcrop of this unit is only 18 m thick of chert-terrigenous beds as follows (see also Fig. 6):

1. Grey bedded cherts (4 m); 2. greenish-grey siliceous mudstones (3 m); 3. dark grey massive mudstones (3 m); 4. black bedded muddy siltstones and siltstones (8 m).

The strata of Saratovka Formation also show a monoclinal dip to the northwest. According to radiolarian faunal data, the age of the exposed cherts is Pliensbachian-Toarcian[40]. The cherts contain the following radiolarians, *Hsuum medium* (Takemura), *Hsuum altile* Hori et Otsuka, *Hsuum* sp., *Parahsuum longiconicum* Sashida, *Parahsuum magnum* Takemura, *Parahsuum simplum* Yao, *Parahsuum levicostatum* Takemura, *Parahsuum officerence* (Pessagno et Whalen), *Parahsuum* sp., *Mesosaturnalis* sp., *Hsuum medium* (Takemura), *Hsuum altile* Hori et Otsuka, *Hsuum* sp., *Parahsuum longiconicum* Sashida, *Parahsuum magnum* Takemura, *Parahsuum simplum* Yao, *Parahsuum levicostatum* Takemura, *Parahsuum officerence* (Pessagno et Whalen), *Parahsuum* sp., *Mesosaturnalis* sp., *Tricolocapsa* sp., *Parvicingula nanoconica* Hori et Otsuka, *Parvicingula* sp., *Parares* sp., *Napora* sp., *Andromeda* sp., *Tritrabs* sp., *Bagotum* sp. and *Tripocyclia* sp.

According to the extracted radiolarians, *Parahsuum officerence* (Pessagno et Whalen), *Parahsuum* sp., *Hsuum medium* (Takemura), *Hsuum hisuikyoense* Isozaki et Matsuda, *Hsuum altile* Hori et Otsuka *Hsuum* sp., *Parvicingula* sp. and *Tricolocapsa* sp., the siliceous mudstones are Aalenian-Early Bajocian in age.

The succeeding mudstones contain other radiolarians, *Hsuum robustum* Pessagno et Whalen, *Hsuum hisuikyoense* Isozaki et Matsuda, *Hsuum matsuokai* Isozaki et Matsuda, *Hsuum belliatulum* Pessagno et Whalen, *Hsuum maxwelli* Pessagno, *Hsuum* sp., *Parvicingula* sp., *Tricolocapsa fusiformis* Yao, *Tricolocapsa* sp., *Andromeda* sp., *Cyrtocapsa mastoidea* Yao, *Stichocapsa japonica* Yao, *Protunuma fusiformis* Ishikawa et Yao, *Parahsuum grande* Hori et Yao and *Parahsuum* sp. The assessment of this assemblage specifies an age range between Middle Bajocian and Bathonian.

The upper siltstones are characterized by the following Bathonian-Callovian radiolarians, *Hsuum* ex gr. *maxwelli* Pessagno, *Hsuum* sp. and *Tricolocapsa* sp. and *Parvicingula* sp.[40].

1.1.1.4 Amba-Matay Formation

The Amba-Matay Formation is the uppermost structural level of the Eldovaka subterrane (Locations 4 and 5 in Figs 2, 7). The geological structures of this formation are generaly similar to those of the three above-described formations, but Late Permian chert slices also occur in this Formation. The age of these slices is indicated by conodonts such as *Isarcicella* cf. *isarcica* (Huckriede) and *Spathognathodus* (?) cf. *divergens* Bender et Stoppel and radiolarians including *Phaenicosphaera* ex gr. *mammilla* Shehg et Wang, *Sphaeroidea* gen. et sp. indet, *Follicucullus falx* De Wever et Caridroit, *Follicucullus porrectus* Rudenko and *Follicucullus* sp.[41]. The relationship between the Permian and Mesozoic pelagic deposits, however, is unclear, because the contact is faulted. Contrarily, the Mesozoic pelagic formations conformably grade into turbidites. Furthermore, the lithological composition of the terrigenous part of this formation varies with the area.

For example, in the Amba Mountain area (Location 4 in Figs 2, 7), the Amba-Matay Formation consists of the following rocks:

1. Greenish-grey bedded cherts with a calcaren-

ite lens (30 cm thick) (6 m); 2. grey bedded cherts changing upward into reddish jaspers (14 m); 3. bedded clay jaspers (4 m); 4. brown and greenish-grey siliceous mudstones (22 m); 5. dark grey mudstones and muddy siltstones (8 m); 6. black bedded siltstones changing into alternating siltstones and sandstones (30 m).

Late Triassic radiolarians, such as *Spongosaturnalis elegans* Kozur et Mostler, *Canoptum triassicum* Yao, *Tripocyclia japonica* Nakaseko et Nishimura, *Acanthocyrens hexagonus* (Yao), *Triassocampe* sp. and *Tripocyclia* sp. were extracted from chert(1 and 2)[41].

The bedded clay jaspers and siliceous mudstones (3, 4) contain Late Pliensbachian-Early Toarcian radiolarians, *Bagotum* cf. *modestum* Pessagno et Whalen, *Bagotum* sp., *Broctus* cf. *ruesti* Yeh, *Broctus* sp., *Canoptum anulatum* Pessagno et Poisson, *Canoptum* aff. *dixoni* Pessagno et Whalen, *Canoptum poissoni* Pessagno, *Canoptum* cf., *rugosum* Pessagno et Poisson, *Canoptum* sp., *Drulanta* (?) sp., *Eucyrtidiellum* sp., *Gorgansium* sp., *Katroma* sp., *Lantus sixi* Yeh, *Mesosaturnalis* sp., *Orbiculiforma* sp., *Parahsuum* cf. *kanyoense* Sashida, *Parahsuum ovale* Hori et Yao, *Parahsuum simplum Yao*, *Parahsuum takarazawaense* Sashida, *Parahsuum* sp., *Praeconocaryomma* sp., *Santonaella* sp., *Staurolonche* sp., *Tetratrabs* sp., *Tricolocapsa* sp., *Trillus* sp.[34].

The same radiolarian species above were also found in the first layers of mudstones (5).

The age of muddy siltstones and siltstones (5—6) is not yet known, because no fossils have been extracted from them.

On the west bank of the Matay River (Location 5 in Figs 2, 7) the chert slices are also Late Permian and Triassic-Early Jurassic in age[38]. The relationship between the Permian and Mesozoic pelagic deposits is also unclear, but taking into account their joint occurrence, it is considered that both are fragments of a single sequence of sedimentary cover of a paleooceanic plate. The Mesozoic part of the cross-section is outlined as follows:

1. Phthanites and clayish cherts (12 m); 2. grey-dark grey thin and medium-bedded (1—7 cm thick each bed) cherts (30 m); 3. greenish-grey clayish cherts (6 m); 4. dark grey siliceous mudstones with a 6-meter interbed hyaloclastite (18 m); 5. dark grey mudstones and muddy siltstones (40 m); 6. greenish-grey hyaloclastite (50 m); 7. siltstones changing above the section into alternating siltstones and sandstones (50 m); 8. greenish-grey hyaloclastite (20 m); 9. alternating siltstones and sandstones (40 m); 10. basalts and diabases (100 m); 11. mélange formations containing different-sized lumps (clasts) and blocks of siltstones, sandstones, basalts, Early Permian cherts and Carboniferous-Permian limestones (150 m).

The cherts (1 and 2) contain abundant conodonts, *Neogondolella* cf. *cornuta* Budurov et Stefanov, *Neospathodus kockeli* (Tatge), *Gladigondolella tethydis* (Huckriede), *Paragondolella* cf. *bifurcata* Budurov et Stefanov, *Neogondolella* sp., *Neogondolella mombergensis* (Tatge), *Paragondolella excelsa* Mosher, *Gladigondolella* sp., *Neogondolella constricta* (Clark et Mosher), *Neogondolella excentrica* Budurov et Stefanov, *Carinella japonica* (Hayashi), *Neogondolella* cf. *pridaensis* (Nicora, Kozur, Mietto), *Paragondolella hanbulogi* Sudar et Budurov, *Metapolygnatus spathulatus* (Hayashi), *Paragondolella navicula* (Huckriede), *Neogondolella mostleri* Kozur, *Neogondolella pseudolonga* Kovach et Kozur, *Epigondolella bidentata* Mosher, *Paragondolella* sp. and *Misikella hernsteini* (Mosher) and radiolarians, *Capnodoce* cf. *anapetes* De Wever and *Triassocampe* sp., indicating an age range from Olenekian (Early Triassic) to Rhaetian (Late Triassic)[42,43].

Clayish cherts and siliceous mudstones (3 and 4) contain Early Jurassic radiolarians, *Parahsuum simplum*, *Parahsuum ovale*, *Tricolocapsa* sp. and *Canoptum* sp.

The mudstones and muddy siltstones (5) are characterized by Toarcian-Aalenian radiolarians, *Parahsuum* cf. *cruciferum* Takemura, *Transhsuum medium* Takemura, *Hsuum hisuikyoense* Isozaki et Matsuda, *Hsuum matsuokai* Isozaki et Matsuda, *Hsuum* sp., *Tricolocapsa* sp. and *Laxtorum* (?) *jurassicum* Isozaki et Matsuda, *Katroma* sp.

Bajocian-Bathonian radiolarians, such as *Hsuum* cf. *primum* Takemura, *Hsuum* cf. *belliatulum* Pessagno et Whalen, *Transhsuum medium* Takemura, *Stichocapsa convexa* Yao, *Stichocapsa japonica* Yao, *Parvicingula* sp. and *Tricolocapsa* sp., were extracted from siltstones[42].

It is thus clear that the radiolarians have indicated that the time accretion of the marine fragmental units described above is getting younger from upper to the lower, from Toarcian-Bathonian to Bajocian-Callovian, Bathonian-Callovian and Oxfordian-Tithonian. This fact indicates a successive accretion of the different-remoted from the spreading centre the fragments of the paleooceanic plate.

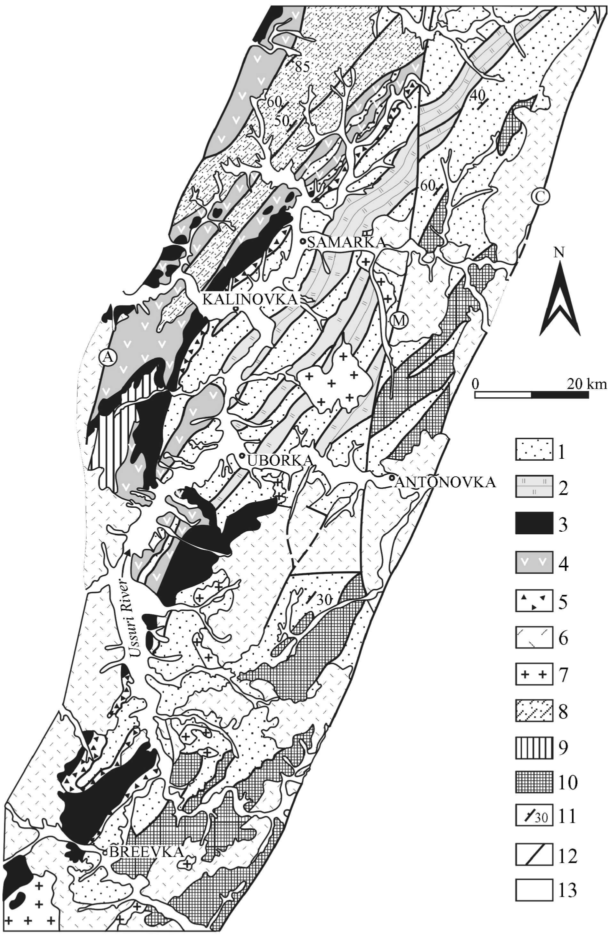

Fig. 8. Geological map of the southern part of the Samarka terrane (modified from Khanchuk et al. [46]). 1, Early-Late Jurassic turbidite and mélange formation of the Samarka terrane; 2, Slices of Permian, Triassic and Early Jurassic cherts; 3, Middle Paleozoic gabbro-ultramafic rocks of the Kalinovka Formation; 4, Basalts associated with Permian aleuroargillites and Carboniferous to Permian cherts and limestones of the Sebouchar Formation; 5, Permian sandstones with interspersed beds of siltstone of the Udeka Formation; 6, Late Cretaceous volcanites; 7, Late Cretaceous granites; 8, Early-Late Jurassic fore-arc basin turbidites; 9, Permian to Triassic shallow-sea (shelf) formations of the overlapping complexes of the Bureya-Jiamusi-Khanka superterrane; 10, Pre-Devonian gabbro-gneisses with overlapping Permian to Jurassic shallow-sea (shelf) formations of the Sergeevka terrane; 11, Elements of rock occurrence; 12, Faults; 13, Quaternary deposit. The capital letters in the circles are the first letters of fault names: A, Arsen'evskyi; M, Meridional; C, Central Sikhote-Alin.

1.1.2 Sebouchar subterrane

This is the upper structural level of Samarka terrane. It is composed of alternating tectonic slices (Figs. 8, 9), consisting mainly of marine formations that are represented by separated fragments of ophiolitic association and terrigenous deposits (turbidites). The marine fragments comprise: (1) Middle Paleozoic gabbro and ultramafic rocks (Kalinovka Formation); (2) basalts associated with Carboniferous to Permian limestones, cherts, and Late Permian black aleuroargillites (Sebouchar Formation); and (3) Late Permian greenish-grey and light green sandstones alternated with the same colour siltstones (Udeka Formation). The slices of the ophiolitic association caused by the mantle plume intrusion, are interpreted as fragments of a paleooceanic plateau[44]. On the heights and islands of this plateau the carbonate rocks were formed, and in hollows surrounding these heights the cherts and clay deposits were accumulated. According to the radiolarian fauna extracted from the aleuroargillites overlapping the ophiolite slices, the accretion of the plateau was carried out in the Early Jurassic.

1.1.2.1 Udeka Formation

The Udeka Formation occupies the lowermost structural position in the Sebouchar subterrane. This unit consists of alternating greenish-grey sandstones and dark green shale with minor amounts of black shale. It is 600 to 1000 m thick. The sandstone is a poorly-sorted wacke with plagioclase, K-feldspar and lithic fragments including granites, volcanic glass, felsites and metamorphic rocks. The content of the chlorite-hydromica mixture in the matrix is 25%—35%. This formation is of Late Permian age based on conodont and radiolarian fossils[45], and always occurs as a thrust slice below the Kalinovka ophiolite or the Sebuchar Formation and above the mélange of the Amba-Matay Formation.

1.1.2.2 Sebouchar Formation

The Sebuchar Formation sits between mélanges of the Amba-Matay Formation and the Kalinovka Formation and is represented by a series of slices of basalts, cherts, limestones and black shales. According to their geochemical features, the basalts are oceanic tholeiites[46]. In separate slices, the cherts and limestones or black aleuroargillite sediments overlap the basalts. The chert yielded Carboniferous con-

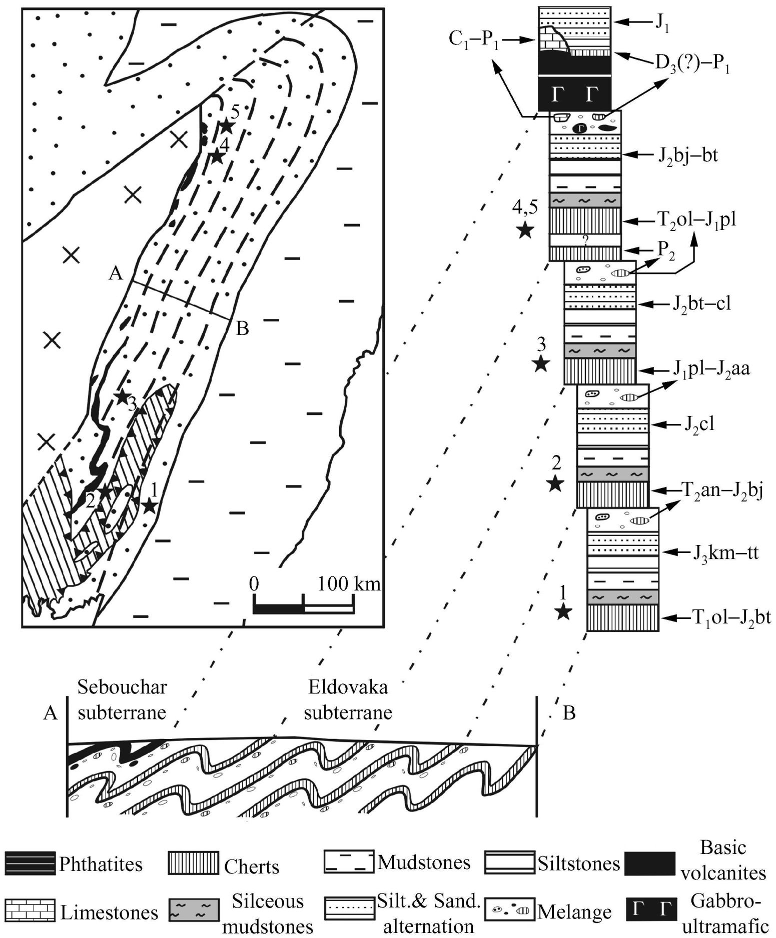

Fig. 9. Generalized cross-section of the Samarka terrane (modified from Kemkin and Filippov[34]).

odonts and Permian radiolarians[47]. The limestones contain Carboniferous and Permian fusulinaceans and algae[47]. The black shales, which are sometimes poorly bedded, yield Middle to Late Permian radiolarians[47].

1.1.2.3 Kalinovka Formation

The Kalinovka Formation, thrusted over the Sebouchar and Udeka formations and mélange of the Amba-Matay Formation, is represented by a series of relatively large slices of gabbro-ultramafics rocks extending in a northeastern direction for about 200 km (see Figs. 2, 8). It is subdivided into a lower part composed of serpentinized harzburgite and dunite, and an upper part composed of plagioclase dunite, wehrlite, clinopyroxenite, troctolite, olivine gabbro and norite[46]. Geochemical and mineralogical characteristics of the rocks indicate that the ophiolite was part of the lower crust of oceanic plateau[44].

The radiometric age of the Kalinovka ophiolite was measured using the K-Ar method by various researchers[31]. It varies from 100 Ma to 410 ± 9 Ma, and the authors think that 410 ± 9 Ma is probably the more reliable age.

1.2 Nadankhada-Bikin terrane

The Nadankhada-Bikin (N-B) terrane is located in the area between the Black River mouth and the Naolihe River mouth in the lower reaches of the Ussuri River. This terrane is separated from Bureya-Jiamusi-Khanka superterrane by the Dahezhen fault in the west and by the Misha-Fushung-Alchan fault in the south. The Naolihe fault and the Arsen'evsky fault separate it from the Khabarovsk and Samarka terranes respectively, and it stretches northeastward along the northwest edge of the Bureya-Jiamusi-Khanka superterrane (Fig. 2). The N-B terrane is 60 km wide and about 350 km long and subdivided into two parts: the south part, located in China, i.e. Nadankhada, and the north part, located in Russia, i.e. Bikin.

1.2.1 Nadankhada part

According to the available data[26,27,30,33,48—53], the rocks of the Nadankhada area of the N-B terrane consist of repeated alternations of terrigenous (turbidite and mélange) and marine formations. The marine formations are represented by slices of separate fragments of the ophiolitic association (the so-called Dahezhen ophiolite) and cherts.

The separated fragments of the ophiolitic association comprise the upper structural level of the terrane in Nadankhada and represent a series of isolated different-sized slices consisting of serpentinized ultramafic rocks, gabbro and basalts. The basalts are typical oceanic tholeiites. The Carboniferous-Permian limestones can be observed overlapping the separate basalt slices. According to the mineralogical-geochemical features, the Dahezhen ophiolite is very similar to the Kalinovka ophiolite of the Samarka terrane and corresponds to that in the Sebouchar subterrane.

The other marine formations are represented by chert slices. There exist gradual transitions from chert to terrigenous rocks in the separate slices. The chert in the chert-clastic sequences is of Middle Triassic to Early Jurassic (Pliensbachian) age. The terrigenous rocks overlapping the cherts are Middle Jurassic in age[33]. The age of the transitional layers, according to the radiolarian faunal data, is Pliensbachian-Toarcian, which allows us to correlate these sequences with Amba-Matay Formation of the Eldovaka subterrane.

1.2.2 Bikin part

The Bikin part of Nadankhada-Bikin terrane is mainly composed of repeatedly alternating slices consisting of bedded cherts, terrigenous rocks and chaotic beds. The age of the cherts in the different slices varies from Middle Triassic to Middle Jurassic. The age of the terrigenous rocks ranges from Early to Late Jurassic. Based on biostratigraphic research data from the transitive layers, three tectono-stratigraphic units are allocated within this part of N-B terrane. They are, in ascending order, the Ulitka Formation, the Ussuri Formation and the Khor Formation.

1.2.2.1 Ulitka Formation

The Ulitka Formation is the lower structural level of N-B terrane and distributed in the central and northeastern areas of Bikin. In ascending order, this formation is outlined as follows:

1. Grey, light grey and pink-grey bedded cherts (60 m); 2. grey and light grey limestones and cherty bedded limestones (40 m); 3. grey and light grey bedded cherts (40 m); 4. grey and greenish-grey massive clayish cherts (24 m); 5. light greenish-grey slightly layered siliceous mudstones (12 m); 6. dark grey layered mudstones, aleuroargillites and siltstones (80 m).

According to the conodonts, *Paragondolella* cf. *exselsa* (Mosher), *Epigondolella tadpole* Hayashi and *Paragondolella* cf. *polygnathiformis* Budurov & Stefanov, the age of the cherts of layer 1 is Middle to Late Triassic (Anisian-Carnian).

The limestones contain late Carnian-early Norian conodonts including *Metapolygnathus* aff. *vialovi* Buryi.

Clay cherts and siliceous mudstones yield Middle to Late Jurassic (Bathonian-Kimmeridgian) radiolarians, *Mirifusus bailey* Pessagno, *Mirifusus guadalupensis* Pessagno, *Pseudodictyomitra* sp., *Spongocapsula* sp., *Eucyrtidiellum* sp. are allocated.

Siltstones yield the Late Jurassic-Berriassian macrofauna, *Buchia* cf. *fischeriana*, *Buchia* cf. *subfischeriana* and *Thracia* spp.[54].

1.2.2.2 Ussuri Formation

This Formation is located in the western part of Bikin and structurally it occurs above the Ulitka Formation. It is composed of the following four beds:

1. Alternating grey and dark grey cherts (1—7 cm thick each bed) and yellowish-grey siliceous mudstones (0.5—5 cm thick each bed) (30 m); 2. grey bedded cherts (66 m); 3. grey and dark grey clayish cherts and siliceous mudstones (30 m); 4. black aleuroargillites and siltstones (130 m).

The cherts of this formation contain Middle to Late Triassic conodonts, *Neogondolella cornuta* Budurov, *Neogondolella constricta* (Mosher et Clark) and *Neospathodus kockeli* (Tatge).

Aleuroargillites, according to the radiolarian fauna, consisting of *Parahsuum* sp., *Archaeodictyomitra* cf. *rigida* Pessagno, *Tricolocapsa* sp., *Arhaeospongoprunum* sp., *Protunuma* sp., *Hsu*-

um sp., *Diacanthocapsa normalis* Yao, *Stichocapsa* sp., *Podobursa triviale* (Zhamoida), *Gongylothorax oblongus* Yao and *Eucyrtidiellum* sp., are Middle Jurassic in age.

1.2.2.3 Khor Formation

The Khor Formation, the uppermost structural level of Nadankhada-Bikin terrane, is distributed in the south-southeastern and eastern parts of Bikin. This formation consists of the following beds in ascending order:

1. Grey, light grey, yellowish-grey and red-brown bedded cherts (70 m); 2. brown and red-brown massive clayish cherts and siliceous mudstones (25 m); 3. repeatedly alternating dark grey siltstones and light grey sandstones with layers of basic volcanites consisting of hyaloclastites, tuffs, basalt lavas and pikritobasalts, which are 10—100 m thick (600 m); 4. muddy siltstone containing lumps (clasts) and blocks of Permian and Triassic cherts, Carboniferous limestones, basalts, and also siltstones and sandstones (200 m).

Based on conodonts, *Neogondolella constricta* (Mosher et Clark), *Neogondolella* aff. *auriformis* Kov., *Neogondolella polygnathiformis* (Budurov et Stefan), *Neogondolella foliata inclinata* Kov., *Metapolygnathus* (?) *mostliri* (Kozur), *Epigondolella primitia* Mosher, *Epigondolella abneptis* (Huck.), *Epigondolella postera* (Kozur et Mostler), *Epigondolella bidentata* Mosher, *Parvigondolella andrusovi* (Kozur et Mostler), *Misikella hernsteini* (Mostler) and *Misikella posthernsteini* Kozur et Mock and radiolarians, *Emiluvia* (?) *helicata* (Nakaseko et Nishimura), *Tripocyclia deweveri* (Nakaseko et Nishimura), *Bikinella* cf. *sabaluwae* Tikhomirova, *Saturnosphaera acifer* Tikhomirova and *Saturnosphaera gracilis* Tikhomirova, the cherts are Middle to Late Triassic (Anisian-Rhaetian) in age[43].

Clay cherts and siliceous mudstones contain Early Jurassic (Pliensbachian) radiolarians, *Protopsium* cf. *ispartaensis* Pessagno et Poisson, *Stylocapsa* sp., *Tricolocapsa* sp., *Eucyrtidiellum unumaensis* Yao, *Stichocapsa* sp. and *Bagotum* cf. *modestum* Pessagno et Whalen.

In the siltstones, the Middle Jurassic radiolarians, *Tricolocapsa* sp., *Gongylothorax sakawaensis* Yao, *Eucyrtidiellum* sp., *Diacantocapsa normalis* Yao, *Protunuma turbo* Matsuoka, *Tricolocapsa tetragona* Matsuoka, and *Stichocapsa* sp. have been recognized[55].

The lithology and age of rock associations, and the structural position of all formations allow us to correlate them with the separate tectono-stratigraphic units of the Eldovaka subterrane (Samarka terrane). The Ulitka Formation at the lower structural level of the terrane is correlated to the Katen Formation (the lowermost tectono-stratigraphic unit of the Eldovaka subterrane). The Ussuri Formation can be compared with the Breevka or Saratovka Formation. The Khor Formation of the uppermost structural level of the terrane is very similar to the Amba-Matay Formation of the Eldovaka subterrane.

1.3 Khabarovsk terrane

The Khabarovsk terrane with a width of 100—130 km stretches from the valley of the Naolihe River fault northward to Vandan Ridge along the eastern margin of northern part of the Bureya-Jiamusi-Khanka superterrane. It is sandwiched between the Koukan fault zone in the west and the Amur fault system in the east, and bordered by the Koursk fault in the north and the Lyaolihe fault in the south (Fig. 2). Most of this terrane is covered by Holocene alluvial deposits or inflows of the Heilong (Amur) River and for this reason the Khabarovsk terrane is poorly investigated. Based on analysis of the radiolarian data of the transitional layers between the pelagic and oceanic-margin deposits, two tectono-stratigraphic units have so far been allocated within the terrane. They are the Khabarovsk Formation (upper) and the Ussuri-Khekhtsir Formation (lower). These units consist of the same lithology, but are different in the age of the chert-terrigenous sequences.

1.3.1 Khabarovsk Formation

The Khabarovsk Formation, the uppermost structural level of Khabarovsk terrane, is recorded in the western part of the terrane. In ascending order, the section of this formation comprises the following units:

1. Grey and yellowish-grey clayish cherts and cherts with black phthanites interbeds (20 m); 2. grey, yellowish-grey, pink-grey and brown-red bedded cherts (70 m); 3. brown-red siliceous mudstones (10 m); 4. greenish-gray mudstones and muddy siltstones (40 m); 5. alternating light grey sandstones

and grey and dark grey siltstones containing tuffs interbeds and carbonate-manganese concretions (800 m).

Clayish cherts and bedded cherts of layers 1 and 2 contain abundant conodonts, *Neogondolella navicula* (Huckriede), *Neogondolella nodosa* (Hayashi), *Neogondolella polygnathiformis* Budurov et Stephanov, *Neogondolella foliata* (Budurov), *Neogondolella exelsa* (Mosher), *Neogondolella hoslashensis* (Tatge), *Epigondolella primitiva* (Hayashi) and *Epigondolella abneptis* (Huckriede), and radiolarians, *Plafkerium cochleatum* (Nakaseko et Nishimura), *Sarla dispiralis* Bragin, *Triassocampe nova* Yao, *Triassocampe* sp., *Capnodoce* sp., *Praeconocaryomma immodica* Pessagno and *Hsuum* sp., indicating a Late Olenekian to Lower Jurassic age[56—60].

The age of the siliceous mudstones, according to a radiolarian fauna composed of *Pantanellium* sp., *Trillus* aff. *seidersi* Pessagno et Whalen, *Trillus* aff. *elkhornensis* Pessagno et Blome, *Zartus praejonesi* Pessagno et Blome, *Zartus jonesi* Pessagno et Blome, *Zartus* aff. *imlay* Pessagno et Blome, *Archaeodictyomitra* aff. *primigena* Pessagno et Whalen, *Hsuum bellilatatum* Pessagno et Whalen, *Hsuum* sp., *Parahsuum officerense* (Pessagno et Whalen), *Lupherium* aff. *snowshoense* Pessagno et Whalen, *Lupherium* sp., *Parvicingula burnsensis* Pessagno et Whalen, *Parvicingula matura* Pessagno et Whalen, *Parvicingula* aff. *media* Pessagno et Whalen, *Parvicingula* aff. *sodaensis* Pessagno et Whalen, *Parvicingula* cf. *grantensis* Pessagno et Whalen and *Parvicingula* sp., is Aalenian-Bajocian age[58,59].

In the mudstones and muddy siltstones, Bathonian-Middle Callovian radiolarians, *Droltus* sp., *Hsuum inexploratum* Blome, *Hsuum* aff. *parasolense* Pessagno et Whalen, *Hsuum* aff. *rosebudense* Pessagno et Whalen, *Parvicingula elegans* Pessagno et Whalen, *Parvicingula* aff. *schoolhousensis* Pessagno et Whalen, *Parvicingula* sp., *Ristola* aff. *decora* Pessagno et Whalen, *Ristola* aff. *prisca* Blome and *Ristola* aff. *turpicula* Pessagno et Whalen were extracted[60].

The siltstones with tuff interbeds contain Oxford-Kimmeridgian radiolarians, *Eucyrtidiellum nodosum* Wakita, *Loopus* sp., *Archaeodictyomitra* sp., *Parvicingula* sp., *Svinitzium* sp., *Sethocapsa* sp., *Tricolocapsa* sp., *Eucyrtidielum ptictum* (Riedel et Sanfilippo), *Transhsuum brevicostatum* gr. (Ozvoldova), *Williriedellum* sp., *Zhamoidellum* sp. and *Gongylothorax favorus* Dumitrica[61].

The siltstones with concretions contain Tithonian radiolarians, *Loopus* sp., *Pseudodictyomitra carpatica* (Lozyniak), *Loopus primitivus* Matsuoka & Yao), *Pseudodictyomitra* ex gr. *leptoconica* (Foreman), *Pseudodictyomitra* ex gr. *nuda* Shaaf, *Pseudodictyomitra lilyae* (Tan), *Wrangellium depressum* (Baumgartner), *Wrangellium okamurai* (Mizutani), *Archaeodictyomitra minoensis* (Mizutani), *Archaeodictyomitra* ex gr. *apiarium* (Rust), *Archaeodictyomitra sixi* Yang, *Cinguloturris carpatica* Dumitrica, *Cinguloturris cylindra* Kemkin et Rudenko, *Xitus gifuensis* Misutani, *Mirifusus chenodes* (Renz), *Parvicingula mashitaensis* Mizutani, *Parvicingula boesii* gr. (Parona), *Eucyrtidiellum ozaiense* (Aita), *Eucyrtidiellum pyramis* (Aita), *Eucyrtidielum ptictum* (Riedel et Sanfilippo), *Protunuma japonicus* Matsuoka et Yao, *Theocorys rensae* Schaaf, *Sethocapsa horokanaiensis* Kawabata, *Sethocapsa* sp., *Stichocapsa* sp., *Solenotryma* (?) *ichikawai* Matsuoka et Yao, *Williriedellum carpathicum* Dumitrica, *Williriedellum crystallinum* Dumitrica, *Zhamoidellum ovum* Dumitrica and *Pantanellium lanceola* (Parona)[62].

1.3.2 Ussuri-Khekhtsir Formation

This structural unit is located in the southern and southeastern parts of the Khabarovsk terrane and occurs structurally lower than the Khabarovsk Formation. The section of this formation is outlined as follows in ascending order:

1. Light greenish-gray thin-bedded cherts (4 m); 2. alternating dark greenish-gray siliceous mudstones and light greenish-gray clayish cherts (3—7 cm each layer) (1.5 m); 3. greenish-gray siliceous mudstones (5 m); 4. dark greenish-gray massive muddy siltstones and siltstones (14 m).

In the cherts and clayish cherts of this unit, Late Bajocian radiolarians, *Archaeodictyomitra exigua* Blome, *Archaeodictyomitra* sp., *Archaeospongoprunum* sp., *Archicapsa* cf. *pachyderma* Tan Sin Hok, *Dictyomitrella kamoensis* Mizutani et Kido, *Emiluvia* cf. *premyogii* Baumgartner, *Eucyrtidiellum quinatum* Takemura, *Eucyrtidiellum* *unumaense* Yao, *Eucyrtidielum ptictum* (Riedel et Sanfilippo), *Gongylothorax* sp., *Paronaella* sp., *Parvicingula dhimenaensis* s.l. Baumgartner, *Parvicingula* sp., *Podobursa* sp., *Protunuma* sp., *Protunuma* cf. *turbo* Matsuoka, *Protunuma fusiformis* Ichikawa & Yao, *Protunuma turbo* Matsuoka, *Sethocapsa funatoensis* Aita, *Stichocapsa* aff. *japonica* Yao, *Stichocapsa* cf. *convexa* Yao, *Stichocapsa* cf. *japonica* Yao, *Stichocapsa* ex gr. *cribata* Hinde, *Stichocapsa japonica* Yao, *Stichomitra* ex gr. *mediocris* (Tan), *Transhsuum brevicostatum* gr. (Ozvoldova), *Transhsuum maxwelli* gr. (Pessagno), *Triactoma* cf. *blakei* (Pessagno), *Tricolocapsa* aff. *conexa* Matsuoka, *Tricolocapsa* cf. *conexa* Matsuoka, *Tricolocapsa* cf. *fusiformis* Yao, *Tricolocapsa* cf. *multispinosa* Sashida, *Tricolocapsa fusiformis* Yao, *Tricolocapsa plicarum* Yao, *Tricolocapsa* sp., *Unuma* cf. *echinatus* Ichikawa et Yao, *Unuma typicus* Ichikawa et Yao, *Xiphostylus* sp., *Xitus* sp. and *Yamatoum* cf. *spinosum* Takemura have been recognized.

The siliceous mudstones contain Late Bajocian to Early Bathonian radiolarians *Dictyomitrella kamoensis* Mizutani et Kido, *Sethocapsa* sp., *Stichocapsa japonica* Yao, *Stichomitra* sp., *Tricolocapsa* cf. *fusiformis* Yao, *Tricolocapsa* sp. and *Xitus* sp.

The siltstones contain abundant Early Bathonian radiolarians, *Archaeodictyomitra* cf. *elliptica* Vishnevskaya, *Archaeodictyomitra* cf. *exigua* Blome, *Archaeodictyomitra exigua* Blome, *Archaeodictyomitra* sp., *Archicapsa* cf. *pachyderma* Tan Sin Hok, *Dictyomitrella* aff. *kamoensis* Mizutani et Kido, *Dictyomitrella kamoensis* Mizutani et Kido, *Eucyrtidiellum unumaense* Yao, *Eucyrtidielum* sp., *Hsuum belliatulum* Pessagno & Whalen, *Hsuum* cf. *belliatulum* Pessagno & Whalen, *Pantanellium* sp., *Parahsuum* cf. *officerence* (Pessagno & Whalen), *Parahsuum* sp., *Paronaella* sp., *Parvicingula* cf. *dhimenaensis* s.l. Baumgartner, *Parvicingula* sp., *Podobursa* sp., *Protunuma* sp., *Protunuma fusiformis* Ichikawa & Yao, *Protunuma turbo* Matsuoka, *Sethocapsa funatoensis* Aita, *Sethocapsa* sp., *Stichocapsa* cf. *japonica* Yao, *Stichocapsa convexa* Yao, *Stichocapsa* ex gr. *cribata* Hinde, *Stichocapsa japonica* Yao, *Stichomitra* ex gr. *mediocris* (Tan), *Stichomitra* sp., *Stylocapsa* cf. *testa* Matsuoka, *Transhsuum brevicostatum* gr. (Ozvoldova), *Transhsuum maxwelli* gr. (Pessagno), *Tricolocapsa* aff. *conexa* Matsuoka, *Tricolocapsa* cf. *fusiformis* Yao, *Tricolocapsa* cf. *plicarum* Yao, *Tricolocapsa conexa* Matsuoka, *Tricolocapsa fusiformis* Yao, *Tricolocapsa multispinosa* Sashida, *Tricolocapsa plicarum* Yao, *Tricolocapsa* sp., *Unuma* cf. *echinatus* Ichikawa et Yao, *Unuma echinatus* Ichikawa et Yao, *Xiphostylus* sp. and *Xitus* sp.).

The lithology and age of the formations of the Khabarovsk terrane allow us to correlate the Khabarovsk Formation to the Saratovka Formation, and the Ussuri-Khekhtsir Formation to the Breevka Formation of the Eldovaka subterrane.

1.4 Badzhal terrane

The Badzhal terrane sandwiched between the Central Sikhote-Alin and Koukan faults, and bounded by the Koursk fault in the south and the Khingan fault in the north is a poorly investigated fragment of the Jurassic accretionary prism.

Tectono-stratigraphic units have not previously been allocated in the Badzhal terrane. However, it is known that the Badzhal terrane is composed of repeatedly alternating slices comprising bedded cherts and terrigenous rocks[63]. The age of the cherts varies from Late Permian to Middle Jurassic, whereas the age of the clastic rocks is Middle to Late Jurassic. Furthermore, in the southwest part of this terrane, the slices are composed of basalts associated with Carboniferous to Permian limestones and Permian cherts are also recognized. These data allow us to consider that the Badzhal terrane has a structure resembling that of the Samarka terrane.

2 Comparison to the Jurassic prism of the Japanese Islands

Fragments of the Jurassic accretionary prism in Japan include the Mino, Tamba, Ashio, Sambagawa and Northern Chichibu, Ultra-Tamba and, partially, Maizuru terranes (Fig. 10). The first five are analogous with the lower and middle structural levels of the Samarka terrane in the Sikhote-Alin region, i.e. the Eldovaka subterrane. The rock associations in the Ultra-Tamba terrane and in the Maizuru terrane in part resemble the upper structural level of the Samarka terrane, i.e. the Sebouchar subterrane[64—66].

2.1 Mino terrane

The Mino terrane is located in the eastern part of the Inner Zone of Japan (Fig. 10). It is subdivided into lower and upper structural units. The upper structural unit outcrops in the northwest part of the Mino terrane and it has been investigated in the Neo River area in detail[50]. This unit including different-sized lumps (clasts) and blocks, and basalt slices, which is overlain by Permian limestones and Permian and Triassic cherts, represents a mélange formation consisting of mudstones and shale.

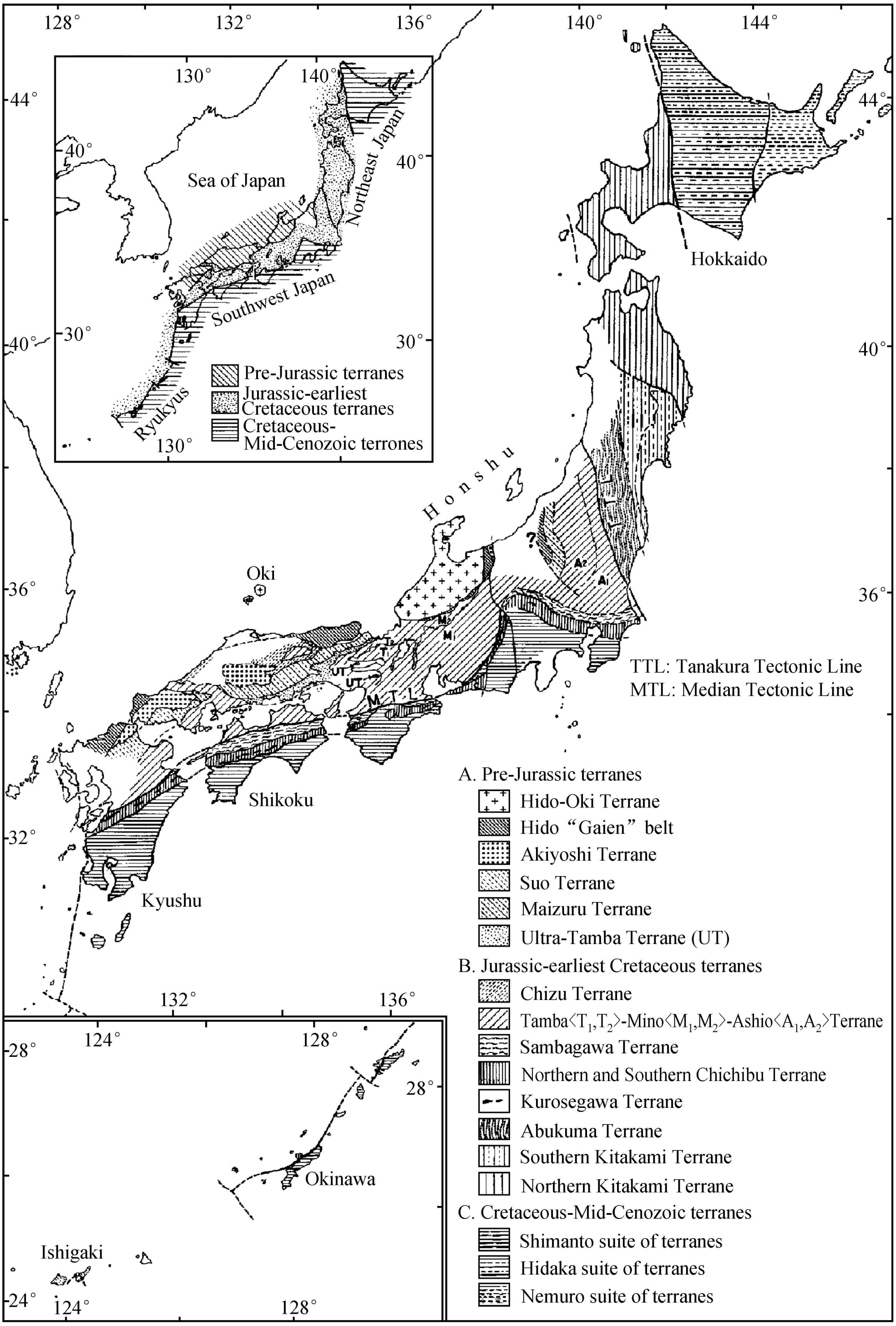

Fig. 10. Scheme of terranes of Japan (after Ichikawa et al. [29]).

The lower structural unit is characterized by an exceptional chert-terrigenous composition. The age of the cherts ranges from Middle Triassic to Early Jurassic, whereas the age of siliceous mudstones and siltstones overlying the cherts is Middle-Late Jurassic on the basis of radiolarians contained in the cherts. In the Kiso River area, the chert-terrigenous sequence forms a four-time recurring package[67,68].

It is quite clear that the upper and lower structural units of the Mino terrane are completely equivalent to those of the Samarka terrane of the Sikhote-Alin region.

2.2 Tamba terrane

The Tamba terrane comprises the central part of the Inner Zone of Japan (Fig. 10). Based on both lithology and the age of the rock associations, it was subdivided into two tectono-stratigraphic units: Type I and Type II suites of the Tamba Group[69]. The Type I suite consists mainly of slices (plate) of Triassic-Middle Jurassic cherts alternating with Late Jurassic terrigenous (turbidite) deposits. The Type II suite is characterized by the presence of slices of Late Permian cherts, partly associated with basalts, and also Triassic cherts in the Early-Middle Jurassic terrigenous deposits and chaotic formations. The chaotic rocks are represented by aleuroargillites containing variously-sized lumps, blocks and fragments of Permian and Triassic cherts, Carboniferous to Permian limestones, basalts, and siltstones and sandstones as well.

The tectono-stratigraphic units of the Tamba terrane are correlated with those of the Samarka terrane of Sikhote-Alin. The Type I suite is very similar to the Saratovka and Breevra formations and the Type II suite is comparable with the Amba-Matay Formation of the Eldovaka subterrane, Samarka terrane, Sikhote-Alin region.

2.3 Ashio terrane

The Ashio terrane is the northeastern extension of the Mino terrane (Fig. 10). It is separated from the latter by the Fossa-Magna Tectonic Line (fault). According to the data of Kamata[70], the southern part of the Ashio terrane consists of three tectono-stratigraphic units. The first two units (Kurohone-Kiryu and Omama complexes), distributed in the northwestern part, are chaotic formations, of which the matrix is characterized by the presence of Middle Jurassic radiolarians. The slices, lumps and fragments of this mélange consist of basalts, Carboniferous-Permian limestones, Permian and Middle Triassic to Early Jurassic cherts, Middle Jurassic siliceous mudstones, and also sandstones and siltstones. Although these two units have an analogous lithological composition, they differ from each other in the ratio and age of the rock-fragments. In the Kurohone-Kiryu Complex the chert slices and clasts prevail, whereas in the Omama Complex basalts and limestones predominate. Furthermore, in the Kurohone-Kiryu Complex Permian cherts have not yet been found.

A third tectono-stratigraphic unit (Kuzu Complex) is composed of a package of repeatedly alternating fragments of chert-terrigenous sequences. Terrigenous rocks can be observed gradually changing into cherts through siliceous mudstones. The age of the cherts varies with the slice, ranging from late Middle Triassic to early Middle Jurassic. The transitional layers (siliceous mudstones) contain Middle Jurassic radiolarians. The mudstones and siltstones are characterized by middle Middle-early Late Jurassic radiolarians[70]. It is easy to see that the formations of the southern part of the Ashio terrane are similar to those of the Amba-Matay, Saratovka and Breevka formations of the Samarka terrane of the Sikhote-Alin region.

Koike et al.[71] described the fragments of chert-terrigenous sequences alternating with the chaotic horizons in the northeast part of the Ashio terrane. The age of the cherts is Early Triassic-Middle Jurassic, but the transitional beds (greenish-grey siliceous mudstones) contain late Jurassic radiolarians. In the chaotic horizons, together with cherts, siliceous mudstones, sandstones and siltstones, there exist clasts and blocks of pelitomorphic limestones with cherty limestone interbeds containing Late Ladinian to Norian conodonts. The analogous chert-terrigenous formations with layers of pelitomorphic limestones embedded by the Triassic cherts are characteristic of the lowermost tectono-stratigraphic unit of the Eldovaka subterrane, Samarka terrane (Katen Formation) in the Sikhote-Alin region.

2.4 Sambagawa terrane

The Sambagawa terrane is placed in the northern part of the Outer Zone of southwest Japan (Fig. 10). It is limited by the Median Tectonic Line (fault) to the north, but in the south, it contacts the Northern Chichibu terrane with a thrust zone. The rocks of the Sambagawa terrane have undergone intensive metamorphism of high P/T type. This terrane consists of lower and upper structural units, which are different from each other in age and lithologic composition[72]. The lower unit (Sambagawa series) is a package of tectonic slices composed of metamorphic schists derived from pelitic-psammitic rocks, cherts, basic rocks (basalts) and limestones. In the pelitic schists, Jurassic radiolarians are found, and from carbonate schists, Late Triassic conodonts were extracted[73]. The absence of Paleozoic rocks in the Sambagawa series and the presence of Triassic carbonate schists (derived from the pelitomorphic limestones), and Late Jurassic cherts[74] provide us with basic information to consider that this unit is analogous with the lower structural unit of the Samarka terrane (Katen Formation) of the Sikhote-Alin region, but strongly metamorphosed. On it, in particular, indicate also the Late Jurassic age of the cherts, that is established in the western part of Shikoku island[74].

The upper unit (Mikabu series) mainly comprises basalts associated with cherts and limestones, ultra basic and basic volcanic rocks, underlying pelitic-psammitic schists containing clasts, blocks and fragments of ophiolitic association rocks mentioned above. These Mikabu ophiolites are considered to be a fragment of oceanic plateau accreted to the Asian eastern margin[24]. Late Jurassic radiolarians from cherty xenoliths in the basalt flows have been described by Sakakibara et al. [75]. Late Jurassic radiolarians were also extracted from the matrix of the chaotic pelitic-psammitic schists underlying the ophiolites[76].

2.5 Northern Chichibu terrane

The Northern Chichibu terrane is more than 10 km wide and separated from the Sambagawa terrane to the north and from the Kurosegawa terrane to the south by thrust zones (Fig. 10). As a whole, it consists of a series of tectonic slices and blocks with thrust and strike-slip borders that are composed mainly of chaotic (mélange) formations. In the central part of Shikoku island the terrane is subdivided into two tectono-stratigraphic units[77].

The lower unit (Niyodogawa Formation) consists mainly of pelitic-psammitic schists containing large slices and different-sized clasts and blocks of chert, basalt, sandstone and limestone. These chaotic formations alternate with a normally bedded sandstone-siltstone sequence. The chert fragments contain both Permian and Triassic microfauna. The limestone clasts are Late Carboniferous to Early Permian in age[77]. Permian cherts, as well as limestones, are often associated with basalt blocks. In the large slices of Triassic chert, a gradual transition from cherts to siliceous mudstones is frequently observed. In the siliceous mudstones and siltstone layers of the sandstone-siltstone sequences, Early Jurassic radiolarians have been found.

The upper structural unit (Nakatsuyama Formation), by contrast, is mainly represented by large slices of basalt associated with Late Carboniferous to Early Permian cherts and limestones, and chaotic formations as well as containing clasts and fragments of the above-mentioned rocks. Separate clasts and blocks of cherts are Triassic to Early Jurassic in age. In separate chert fragments the transition from Permian to Triassic layers is present. From the matrix of the chaotic formations Jurassic radiolarians have been extracted.

Lithologic-biostratigraphic and structural characteristics of the rock associations of the Northern Chichibu terrane show a completely identical sequence to the upper structural unit, the Amba-Matay Formation of the Eldovaka subterrane (Samarka terrane, Sikhote-Alin region).

2.6 Ultra-Tamba terrane

The Ultra-Tamba terrane, a nappe between the Maizuru terrane (in the north) and Mino-Tamba terranes (in the south), is located in the northern part of the Inner Zone of Japan (Fig. 10). The rock associations are subdivided into three units[78], in tectonically ascending order : UT 1 (Hikami Formation); UT 2 (Oi Formation); and UT 3 (Kozuki Formation). The Hikami and Kozuki formations are respectively correlated with the Udeka and Sebouchar formations of the Sebouchar subterrane of the Samarka terrane (Sikhote-Alin region)[64—66].

2.6.1 Hikami Formation

The Hikami Formation, part of the lowermost nappe sheet of the Ultra-Tamba terrane, is thrusted over the rocks of the Mino-Tamba terranes, while it is covered by the Oi or Kozuki formations of the Ultra-Tamba terrane or the ophiolitic rocks of the Maizuru terrane[78]. It is 500 m thick, and mainly composed of light green or greenish-gray sandstone with minor shale interbeds. The sandstone is a wacke with calcareous matrix, and contains poorly-sorted angular quartz grains, plagioclase, K-feldspar and lithic fragments. The lithic fragments are composed of acidic to intermediate plutonic rocks, sandstone, siltstone, mica schist and quartz schist[79]. The shale intercalations yield late Middle to early Late Permian radiolarians[78].

2.6.2 Kozuki Formation

The Kozuki Formation of the Ultra-Tamba terrane consists mainly of basic volcanic rocks associated with black shale, cherts, limestones, acidic tuff and sandstone[78]. The formation is thrust over the Hikami and Oi formations, and is tectonically covered by the Yakuno ophiolite. Late Middle to early Late Permian radiolarians, such as *Follicucullus charveti*, *F. bipartitus*, *F. scholasticus* morphotype I and *F. s.* morphotype II, occur in the shale and cherts[78,80]. Late Carboniferous corals and fusulinaceans have been reported from limestone lenses in the basic volcanic rocks[81].

2.6.3 Oi Formation

The Oi Formation is the middle structural unit of the Ultra-Tamba terrane[78]. It includes three groups of deposits that differ in lithology. The lower member is represented by Permian pinky to red bedded cherts, changing upwards the section by siliceous mudstones. The middle member of the Oi Formation is represented by turbidites (thin interbedding of silty sandstones, siltstones and mudstones). The upper member consist of mélange formations (black phylitic schists containing clasts, blocks and fragments of sandstones, cherts, and siliceous mudstones. It should be noted that all rocks of the Oi Formation are strongly deformed, because it always occurs as a thrust slice below the nappes of Yakuno ophiolites and above the slices of Hikami Formation. As a whole the Oi Formation represents a mélange containing large plates of Permian cherts that are derived, probably, from cherts of the Kozuki Formation.

2.6.4 Yakuno ophiolite

The Yakuno ophiolite, which thrusts over the rocks of the Ultra-Tamba terrane is distributed in the southern zone of the Maizuru terrane and consists of harzburgite, dunite, gabbro and basalt[82]. Geochemical analyses have indicated that there are two series of the ophiolites: a T (transitional)-MORB series and an island arc tholeiite series[83]. The mafic and ultramafic rocks are metamorphosed in the prehnite-pumpellyite and granulite facies. The Yakuno ophiolites are regarded as part of an unusually thick oceanic crust[84]. The age of the ophiolite, according to K-Ar, Rb-Sr, U-Pb and Sm-Nd dating, varies from 250 Ma to 426 ± 37 Ma[85—87].

Based on the similarities of lithology, age and tectonic position, we consider the Yakuno ophiolite to be analogous to the Kalinovka ophiolite of the Kalinovka Formation (Sebouchar subterrane, Samarka terrane, Sikhote-Alin region).

3 Anatomy of the Jurassic prism and main geological events along the eastern Paleoasian continental margin

This brief description of the Jurassic prism along the eastern Paleo-Asian continental margin has demonstrated that the Jurassic prism terranes of both the Sikhote-Alin-Priamurie and Japan regions are very similar in lithology, geologic structure, age, as well as faunal assemblages. These similarities have indicated that a single subduction-accretionary system extended along the Asian and Pacific margins in the Jurassic[26,27,36,45,46,53] in which the Jurassic prism was formed. In the modern ideas of the structure zone of Eastern and Southeastern Asia, this prism represents a tectonic package of repeated alternations of tectonic slices and blocks (stacked slices) consisting of marine (pelagic and hemipelagic deposits, fragments of seamountains and heights), oceanic-marginal turbidites and subduction mélange (chaotic) formations. Detailed lithological, biostratigraphic and structural researches have enabled us to reconstruct the primary stratigraphic succession of deposits forming these slices, i.e. pelagic-hemipelagic-terrigenous. Moreover, fossil ages in the different tectonic slices, and especially in the transitional beds between the pelagic and terrigenous rocks (i.e. hemipelagic formations) show that there exist in the Jurassic prism several Oceanic Plate Stratigraphic sequences of different ages. For example, in the Samarka terrane, the age of the transitional beds corresponds to Late Pliensbachian-Early Toarcian, Aalenian-Early Bajocian, Toarcian-Bajocian, Bajocian and Bathonian-Callovian (Fig. 11), indicating a successive process of accretion. In other words, the Jurassic prism structure is not a simple alternation of tectonic slices and blocks with different ages and lithology. Actually, such a structure is a natural recurrence of fragments having a different age (or having a different distance from the spreading center of the paleooceanic plate) in the primary sedimentary cover section of an ancient oceanic plate (Fig. 9).

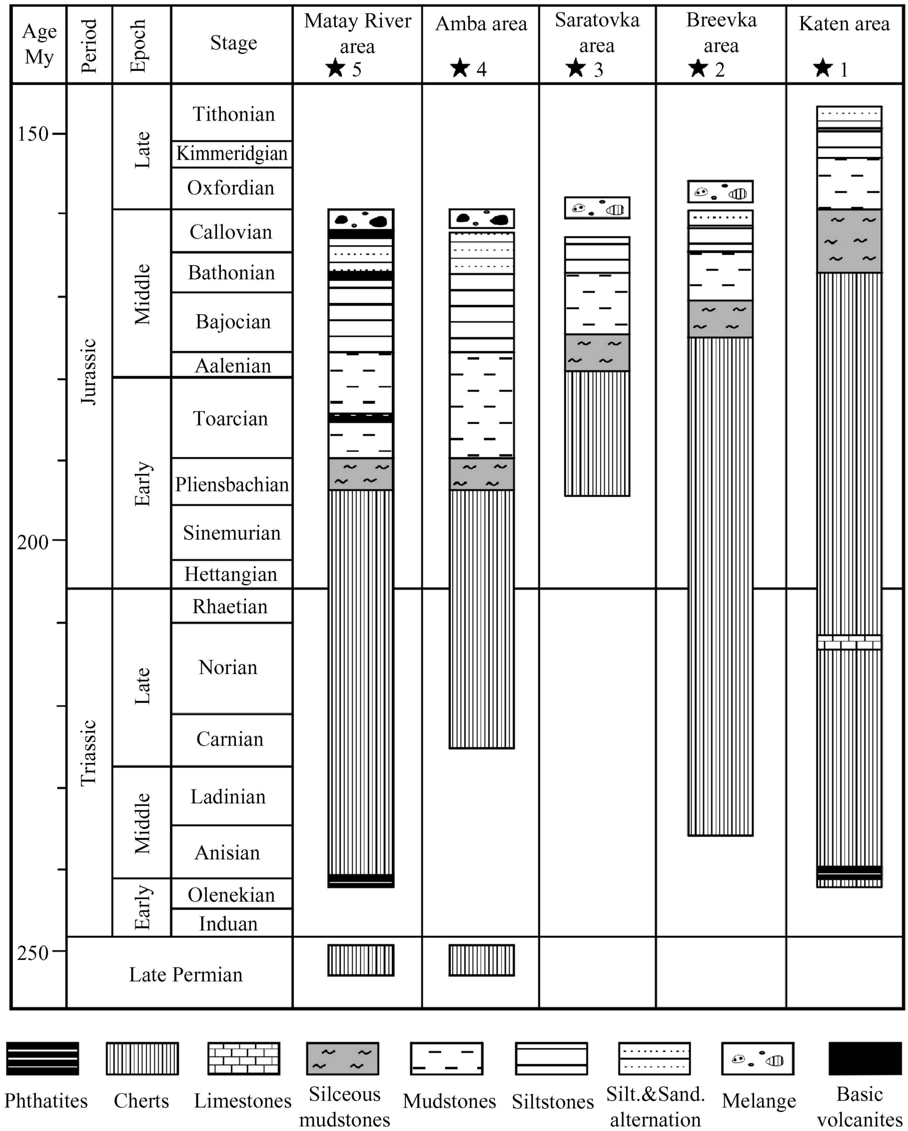

Fig. 11. Tectono-stratigraphic columns of chert-terrigenous sequences of Samarka terrane.

Although the primary tectono-stratigraphic succession of the prism has been broken by numerous faults, such as strike-slip and thrusts, complicating the reconstruction of the true structure, minimally, six tectono-sedimentary complexes (Paleozoic ophiolite, four chert-terrigenous sequences and Late Jurassic ophiolite) forming different structural levels of the Jurassic prism have been recognized. Each of these complexes consists of marine deposits smoothly grading upward into terrigenous (oceanic-margin) rocks. According to faunal microfossil research, the ages of the transitional beds, as well as the cherts and terrigenous deposits, correspond to the time of accretion of the paleooceanic formations, gradually becoming younger from the upper structural level to the lower one. This means that the youngest formation (unit) is situated in the lowest structural level of the Jurassic prism cross-section (Fig. 9). In the other words, as a whole, the apparent stratigraphy of the Jurassic prism is structurally inverted. The relatively younger units comprise the lower structural level of the prism whereas older units comprise the higher structural levels of the prism. However, in each tectono-stratigraphic unit, the stratigraphic succession of deposits is normal : the lower, the older, or, the upper, the younger.

Such a structure of the Jurassic prism, consistent with what is known of modern accretionary prisms, resulted from consecutive accretion of fragments coming different distances from the fragmental spreading center of the paleooceanic plate during their subduction under the continent or island arc. The most remote fragment from the spreading center (oldest fragment) of the oceanic plate was accreted first and was underplated in the future by younger units. As a result, the package of tectono-sedimentary complexes (or tectono-stratigraphic units) was formed.

By analyzing the structure and composition of these different levels of the prism in Sikhote-Alin and Japan, the Jurassic history and geological events of the east margin of Paleo-Asian continent can be revealed. In the Early Jurassic, the eastern margin of the Paleo-Asian continent was an active margin of Andean-type. Along the margin, the accretion of an oceanic plateau happened (Fig. 12). However, this oceanic plateau could not be completely subducted because of the morphologically positive structure. The oceanic plateau was broken by faults into a series of thrust structures, jointing the continental margin (analogous to the present accretion of the Dai-ichi Kashima guyot in the Japanese trench or the Zenisu Ridge in Nankai trench[88]). In the Sikhote-Alin-Nadankhada-Alin regions, the fragments of this plateau are represented by the Kalinovka and Dahezhen ophiolite, and in Japan by the Yakuno ophiolite.

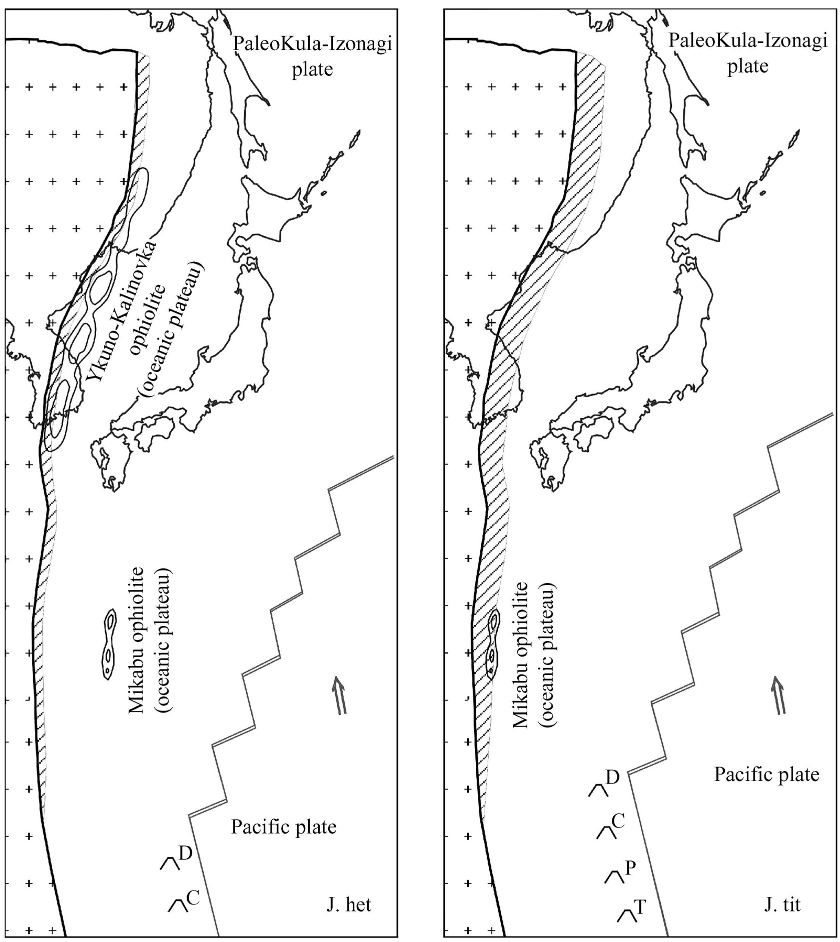

Fig. 12. Paleogeodynamic situation along the Paleo-Asian continent eastern margin in Jurassic (modified from Khanchuk and Kemkin[36]).

During the Middle and Late Jurassic, the geodynamic mode along the active eastern Paleo-Asian continental margin was still of Andean-type, but this time, the geological movements are characterized by an accretion of fragments having different ages of morphologically even parts (i.e. different sites of the abyssal plain) of the paleooceanic plate. The accreted paleooceanic fragments of these periods are represented by chert-terrigenous sequences, which differ from each other only by the age of transitional beds between the chert and the terrigenous rocks.

By the end of the Jurassic, a new oceanic plateau, the Mikabu ophiolites, was accreted onto the southern part of the Jurassic subduction zone. The fragments of the plateau were established in the Sambagawa terrane.

Consequently, during the Jurassic, the continent along the eastern and southeastern Paleo-Asian margin was essentially expanded with the consecutive accretion of Paleo-Pacific formations with different ages and different facies.

4 Conclusions

The Jurassic is an important period in the geological evolution and formation of the geological structure of the East and Southeast Asian continental margin when diverse fragments formed in various facies of the abyssal plain, intra-oceanic volcanic seamountains and oceanic plateaus of the Paleo-Pacific were accreted to the eastern margin of the Paleo-Asian continent as a result of subduction of oceanic lithosphere. Together with the ocean-marginal terrigenous deposits (trench-fill turbidites) they formed a thick tectono-sedimentary complex of the Jurassic accretionary prism. Based on biostratigraphic and structural research, a multi-layered cake-like recurrence structure of this prism was established. This structure is a result of the natural recurrence of fragments each with a different age of primary cross-section of sedimentary cover from an ancient oceanic plate. A special feature of the prism structure is that the younger "layers" (tectono-stratigraphic units) comprise the lower structural level of the prism whereas older units comprise the higher one. This is caused by the consecutive accretion of fragments the origin of which was at different distances from the fragmental spreading centre of the paleooceanic plate. Each such tectono-stratigraphic unit reflects a certain stage of Jurassic prism formation and characterizes a certain geological event in the eastern Paleo-Asian continental margin evolution. The main Jurassic accretion events that occured along the eastern Paleo-Asian continental margin are: (1) accretion of fragments of the Paleozoic oceanic plateau in the Early Jurassic; (2) accretion of the different sites and ages of Upper Permian to Middle Jurassic abyssal plain in Middle-Late Jurassic; (3) accretion of the Late Jurassic oceanic plateau at the end of Late Jurassic.

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