Structure and genesis of the Taukha Mesozoic accretionary prism (southern Sikhote-Alin, Russia)

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ABSTRACT
Based on a study of several sections of the Taukha terrane in southern Sikhote-Alin comprising lithologic, structural and paleontological analysis, the structure and stratigraphy of the terrane was reconstructed. Three structural units are defined for the terrane, each with a discrete origin. Each unit consists of a paleo-oceanic plate formations gradually changing above on a section by terrigenous rocks, which are further replaced by an olistostrome. Radiolarian age data for the accretionary prism indicates that fragments of a late Devonian-Permian, Early Triassic-Late Jurassic and Late Jurassic-Early Cretaceous paleo-oceanic plate were consecutively accreted into the prism.

KEY WORDS
Terrane,
accretionary prism,
accretion,
tectonostratigraphy,
radiolaria,
olistostrome.

RÉSUMÉ
Structure et genèse du prisme d'accrétion mésozoïque de Taukha (Sud Sikhote-Alin, Russie).
À partir d'études lithologiques, structurales et paléontologiques, la structure et la stratigraphie du terrain accrété de Taukha (Russie) ont pu être établies. Trois unités structurales ont été définies ; chacune consiste en une série océanique devenant graduellement terrigène, surmontée par un olistostrome. Les datations obtenues montrent que ces trois fragments ont été successivement accrétés dans un prisme d'accrétion ; les unités ont des âges de plus en plus jeunes : Dévonien supérieur à Permien, Trias inférieur à Jurassique supérieur et Jurassique supérieur à début du Crétacé.

MOTS CLÉS
Terranes,
prisme d'accrétion,
accrétion,
tectonostratigraphie,
radiolaires,
olistostrome.

INTRODUCTION

Ancient accretionary prisms occur along the Asian Pacific margin (Natal'in & Faure 1991; Faure & Natal'in 1992; Faure *et al*. 1995; Nokleberg *et al.* 1998; Parfenov *et al.* 1998) and formed in zones of interaction between continental and oceanic lithospheric structural slices. The study of ancient accretionary prisms is important for reconstruction of geodynamic evolution, as well as for correlation of geological events in a continent/ocean transition zone. The Taukha terrane is interpreted as an accretionary prism that forms the southeastern part of the Sikhote-Alin accretionary system. We use the term "terrane" according to Nokleberg *et al.* (1998). Terrane is a fault-bounded geologic entity or fragment that is characterized by a distinctive geologic history that differs markedly from that of adjacent terranes. The Taukha terrane is overlapped with unconformable relationships by Late Cretaceous volcanic and volcano-sedimentary rocks, and crops out only in isolated anticlines core (Fig. 1). Faults occur between the Taukha terrane and the adjacent Samarka and Zhouravlevka terranes. The Taukha terrane consists of alternating Early Cretaceous turbidite and olistostromal deposits, and older, Late Devonian to Early Cretaceous marine, and rarely continental margin units (Yushmanov 1986; Parnyakov 1988; Kosygin 1988; Khanchuk *et al.* 1988; Kemkin 1989; Golozoubov *et al.* 1992; Kemkin & Khanchuk 1993). The marine rocks mainly consist of chert and carbonate that occur in extensive structural slices, up to several tens of kilometers long and from 1 to 4 km wide. The marine rocks occur within turbidites and also as lumps and fragments in the olistostrome. The thickness of structural slices varies from tens to several hundreds of meters. The thick slices consist of several repetitions of chert or carbonate sequences.

These units were previously interpreted as accretionary prisms formations (Khanchuk *et al.* 1988; Khanchuk *et al.* 1989a; Kemkin 1989). Nevertheless, remaining questions are linked to the internal structure of the terrane, as well as to geodynamic conditions and genesis. What are the structural positions of olistostrome horizons in the various sections? What are the ages and stratigraphic positions of the various marine formations? What is the age of other rock units in the terrane? What was the timing of accretion process? How did various structural slices constitute within the terrane?

RESULTS OF RESEARCHES

The composition and structure of individual sections of the Taukha terrane, their correlation, the reconstruction of the original section of the prism and its genesis are the main goals of this study. Twelve individual sections were studied along the banks of the Roudnaya, Avvakoumovka, Margaritovka, Chernaya, Mirnaya, Zerkalnaya, and Vysokogorskaya rivers. In the study area, the strata are crumpled into asymmetric folds of variable amplitude that are often overturned and trend to the northeast. The axial planes of the folds exhibit northwest vergence and mirror of the folding is sloping dip to the southeast. Regional deformation has resulted exposing the lower structural units of the terrane to the northwest and the upper structural units to the southeast. The structure of the terrane is depicted in various cross sections (Fig. 2). To the northwest, near the boundary with the Zhouravlevka terrane (areas of Kavalerovka, Mirnaya and Vysokogorskaya rivers), the structure of the Taukha terrane is as follows (Fig. 2A): units at the base of the section consist of marine rocks of the Erdagouskaya suite that is composed of basalts (about 100 m thick) and overlapping chert and chert-shale (several tens of meters thick); late Callovian-early Oxfordian radiolaria occur in chert lenses in the basalt flows (Tikhomirova 1986); overlapping chert contains numerous radiolaria (Simanenko *et al.* 1999) ranging from Late Jurassic (Oxfordian) to Early Cretaceous (Berriasian).

The chert gradually grades upward into chert-mudstone, mudstone and siltstone, and flysch that consists of alternating medium- to fine-grained sandstone and siltstone turbidite. The chert-

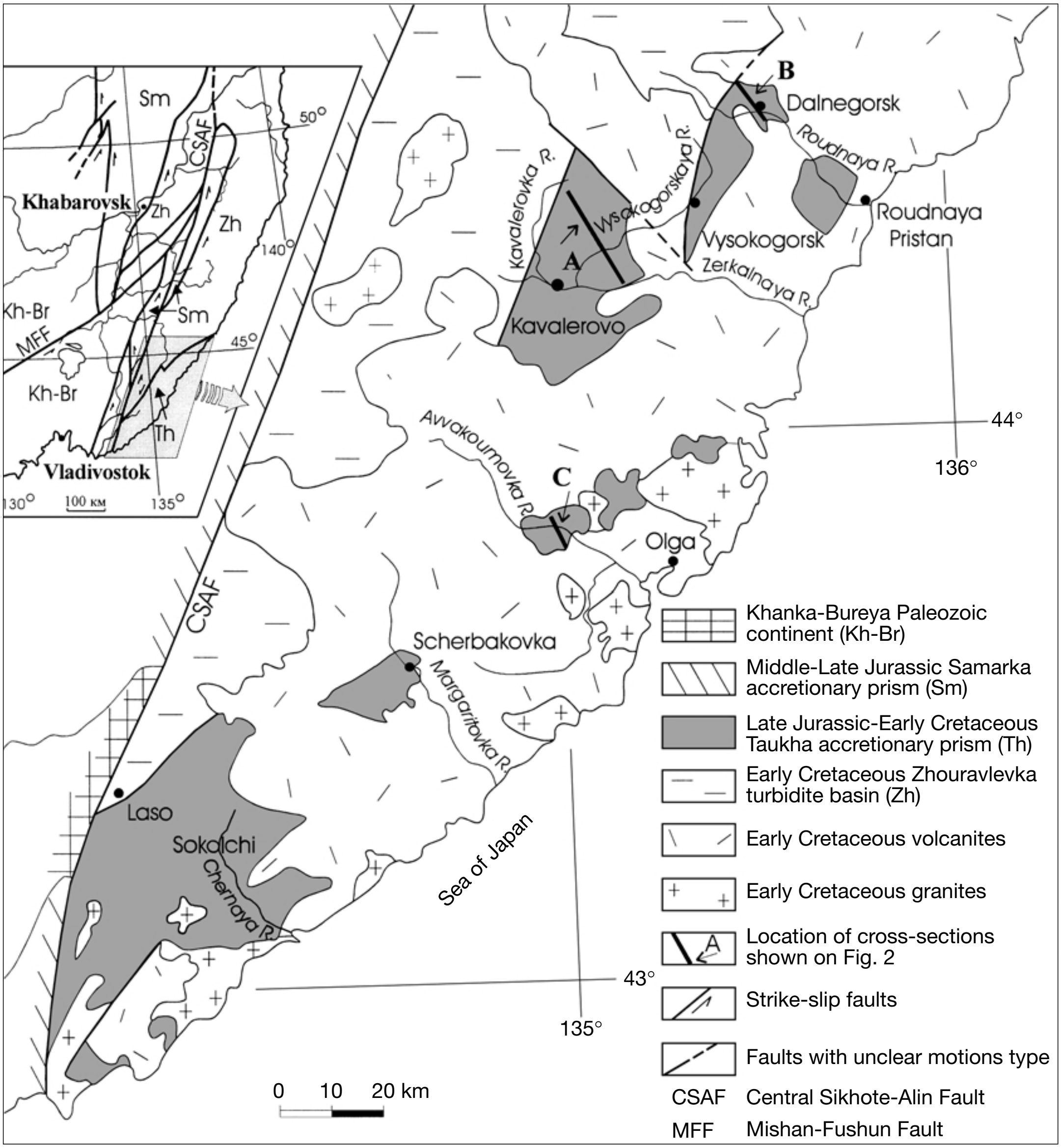

FIG. 1. — Regional tectonic map for the southeastern part of the southern Sikhote-Alin region.

mudstone contains the following radiolarians: *Archaeodictyomitra apiarium* (Rust), *Ar. broweri* (Tan), *Ar. vulgaris* Pessagno, *Ar. excellens* (Tan), *Archaeodictyomitra* sp., *Cinguloturris cylindra* Kemkin & Rudenko, *Cinguloturris* sp., *Holocryptocanium barbui* Dumitrica, *Mirifusus* sp., *Obesacapsula* sp., *Pantanellium lanceola* (Parona), *Parvicingula boesii* (Parona), *Parvicingula* sp., *Podobursa* cf. *triacantha* (Fishli), *Pseudodictyomitra carpatica* (Lozynyak), *Ps.* cf. *carpatica* (Lozynyak), *Ps. primitiva* Matsuoka & Yao, *Ps.* ex gr. *leptoconica* (Foreman), *Pseudodictyomitra* sp., *Ristola* sp., *Sethocapsa* cf. *uterculus* (Parona), *Sethocapsa* sp., *Stichocapsa* ex gr. *cribata* Hinde, *Thanarla* cf. *conica* (Aliev), *Tritrabs* sp., etc. This radiolarian assemblage (according to Pessagno 1977; Mizutani 1981; Matsuoka & Yao 1985; Aita & Okada 1986; Aita 1987; Kawabata 1988; Matsuoka 1992; Matsuoka 1995; Baumgartner *et al.* 1995, etc.) indicates an Early Cretaceous (Berriasian-Valanginian) age. The age of the turbidite according to the occurrence of *ammonoid* and *Buchia* faunas is Berriasian to Valanginian (Golozoubov *et al.* 1992). The thickness of terrigenous rocks is estimated at 2 500 m (Golozoubov & Khanchuk 1995). However, the turbidite may be tectonically repeated.

Upwards, the turbidite grades into olistostrome. The contact between the turbidite and olistostrome is conformable and is well-exposed in the upper part of Balaganny creek (Golozoubov *et al.* 1992). The olistostrome is a chaotic deposit composed of aleuropelitic or aleuropsammitic detritus, and contains variably-size and variably-age blocks and fragments. Olistholiths comprise up to 40% of rock volume and consist of Permian, and Middle to Late Triassic limestone, basalt, Triassic and Jurassic chert, and Middle to Late Triassic and Early Cretaceous terrigenous rocks. Lithologic composition and age of olistoliths allow correlation with rocks from overlying marine units. The age of olistostrome is Valanginian to Barremian according to the radiolaria extracted from a olistostrome matrix near Vysokogorsk Town. The radiolarian assemblage is similar to those in the olistostrome at Dalnegorsk (Kemkin *et al.* 1997).

The olistostromal deposits are overlapped by marine units that consist of Middle and Late Triassic limestone with high-Ti alkaline basalts at the base, and four repeating chert-turbidite sequences. The limestones are typical reef-forming rocks having features characteristics of "paleoguyot" fragments (Khanchuk *et al.* 1989a, b). The chert rocks, on the contrary, are fragments of abyssal plain sedimentary sequences. The cherts and overlapping turbidite constitute the Gorboushinskaya suite. The cherts consist of various gray and rare pink or red bedded chert and clay-chert. Bedding consists of thin clay layers (1 to 3 mm thick). The thickness of chert layers varies from 1.5 to 2 cm, up to 3 to 5 cm and less often up to 7 to 10 cm. The estimated actual thickness of a complete chert section is about 70 m, although within the different structural slices, the coeval fragments of chert are structurally repeated. Based on radiolaria, the age of chert ranges from Early Triassic to Late Jurassic. More detailed biostratigraphy of the "Gorbousha" cherts was studied in the Dalnegorsk area described below. The chert is gradationally overlain by cherty mudstone and mudstone, and by turbidites. These chert-terrigenous sequences are repeated four times, and the repetition of this "Gorbousha" section occurs practically in all areas of the Taukha accretionary prism. However, it is not known yet if the repetition is the result of syn-folding thrusting or successive accretion. The thickness of overlying turbidites in various structural slices ranges from 350 up to 700 m.

The Taukha terrane exhibits similar structure in the Roudnaya river basin in the Dalnegorsk area, where the middle part of the section crops out (Fig. 2B). The lower structural levels are cut by a fault. The lower part of the section is an Early Cretaceous olistostrome that is identical to that in the Vysokogorskaya river basin. The olistholiths here also consist of variably-size and variably-age blocks and fragments of Middle and Late Triassic, reef-forming limestone that is quite often associated with basalt, Triassic to Jurassic chert, basalts, and Late Jurassic to Early Cretaceous "Gorbousha" terrigenous rocks. Based on radiolaria fauna, the age of olistostrome matrix is Valanginian and Barremian (Kemkin *et al.* 1997). Upwards, the olistostromal deposits are overlapped by marine units that consist of a four-fold, repeated chert-turbidite sequence of the Gorboushinskaya suite. The cherts contains numerous conodonts (Volokhin *et al.* 1990) and radiolarians (Bragin 1991; Kemkin & Kemkina 1998) ranging from Early Triassic to Late Jurassic (early Kimmeridgian) inclusive. The chert grades into chert-mudstone bearing middle Kimmeridgian to middle Tithonian radiolaria, and into mudstone bearing late Tithonian radiolaria (Kemkin 1996;

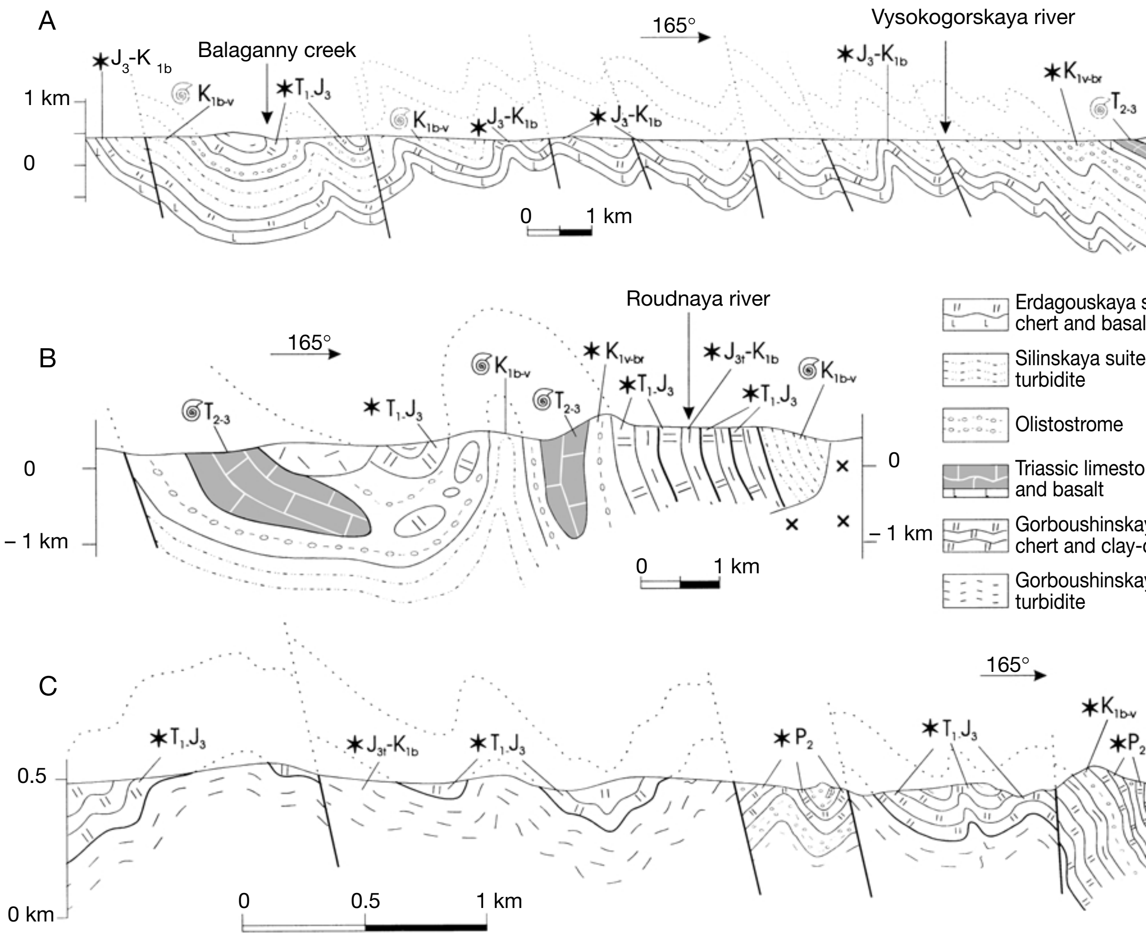

FIG. 2. — Cross-sections across the Taukha terrane; **A**, Kavalerovo area; **B**, Dalnegorsk area; **C**, Olga

Kemkin & Kemkina 1998). The overlying alternating siltstone and sandstone contain Early Cretaceous radiolaria.

The upper structural levels of the Taukha terrane crop out in the Avvakoumovka river basin (Fig. 2C). The lower part of the section consists of chert and terrigenous rocks which lithological features and age data are similar to the Gorboushinskaya suite. The "Gorbousha" turbidites are conformably overlain by the Skalistorechenskaya suite consisting of olistostromal deposits that are overlapped by structural slices of marine rocks. The olistostrome structure and olistolith composition are identical to the underlying Triassic limestone and the Gorboushinskaya suite. However, the age of olistoliths and olistostrome matrix are sharply different. They are composed of blocks, fragments, and small structural slices of Devonian, Carboniferous and Early Permian limestone, basalt, Carboniferous and Permian chert, and terrigenous rocks (sandstone and siltstone). The age of carbonate rocks is based on foraminifera (Nikitina 1971). The cherts contains conodonts (Rybalka 1987). The terrigenous olistoliths are not yet dated. The olistostromal age is Berriasian to Valanginian, according to the following radiolaria assemblage: *Archaeodictyomitra excellens* (Tan), *Archaeodictyomitra* sp., *Cinguloturris* sp., *Crucella* sp., *Hsuum* sp., *Napora* sp., *Paronaella* sp., *Pseudodictyomitra primitiva* Matsuoka & Yao, *Pseudodictyomitra carpatica* (Lozyniak), *Stylosphaera* (?) cf. *macroxiphus* (Rust), *Tritrabs* sp., *Triactoma* sp. The lower age boundary is defined by the occurrence of *Pseudodictyomitra carpatica* (Lozyniak) for which the first appearance corresponds to the end of late Tithonian (Matsuoka 1995). The upper age boundary is limited by *Pseudodictyomitra primitiva* Matsuoka & Yao, which is not known in units younger than Valanginian. This radiolarian assemblage corresponds to the *Pseudodictyomitra carpatica* zone (Matsuoka 1995). The same olistostrome, with blocks and fragments of Paleozoic chert and carbonate, were also studied in the Margaritovka river area (Scherbakovka village) and Pantovyi creek basin (Zarod mountain area).

The olistostromal deposits are overlapped by a thick plate (about 400 m thick) of marine rocks consisting of basalt and overlying reef-forming limestones called the Foudinov Kamen mountain formation. The age of the limestone ranges from Late Devonian to Late Carboniferous. Late Cretaceous volcanic rocks unconformably overlap the Foudinov Kamen mountain limestone. However, in the Zarod mountain area, Paleozoic (Early Carboniferous to Early Permian) limestone grades upwards into a series of structural slices of chert and overlying turbidites. The chert in the various structural slices are Permian, Triassic, or Early to Middle Jurassic (Rudenko & Panasenko 1990). The turbidites contain radiolaria such as *Archaeodictyomitra* sp., *Archaeospongoprunum* sp., *Mirifusus* sp., *Parvicingula* sp., *Podobursa* sp., *Sethocapsa* sp., *Tritrabs* sp. This radiolarian association characterizes a wide age interval, from Late Jurassic to Early Cretaceous. However, the absence of *Pseudodictyomitra* genus representatives suggests a Late Jurassic age for the turbidites. Unfortunately, we did not observe olistostrome formations overlying Late Jurassic turbidites in any area. These deposits are probably overlapped everywhere by Late Cretaceous volcanic rocks.

DISCUSSION

The Taukha terrane consists of units of various ages and facies that represent alternations of paleocontinental-margin and marine rocks. The age of marine fragments ranges from Late Devonian to Early Cretaceous (Berriasian), whereas the age of terrigenous rocks is in part Late Jurassic, but mostly Early Cretaceous. The main feature of the structure of the terrane is that older marine formations and, correspondingly, overlapping terrigenous rocks (including olistostromes) comprise the upper structural levels of terrane, and younger units comprise the base (Fig. 2). Thus, as a whole, the apparent stratigraphy of the Taukha terrane is structurally inverted. But within each structural units the stratigraphic succession is normal (from older to younger).

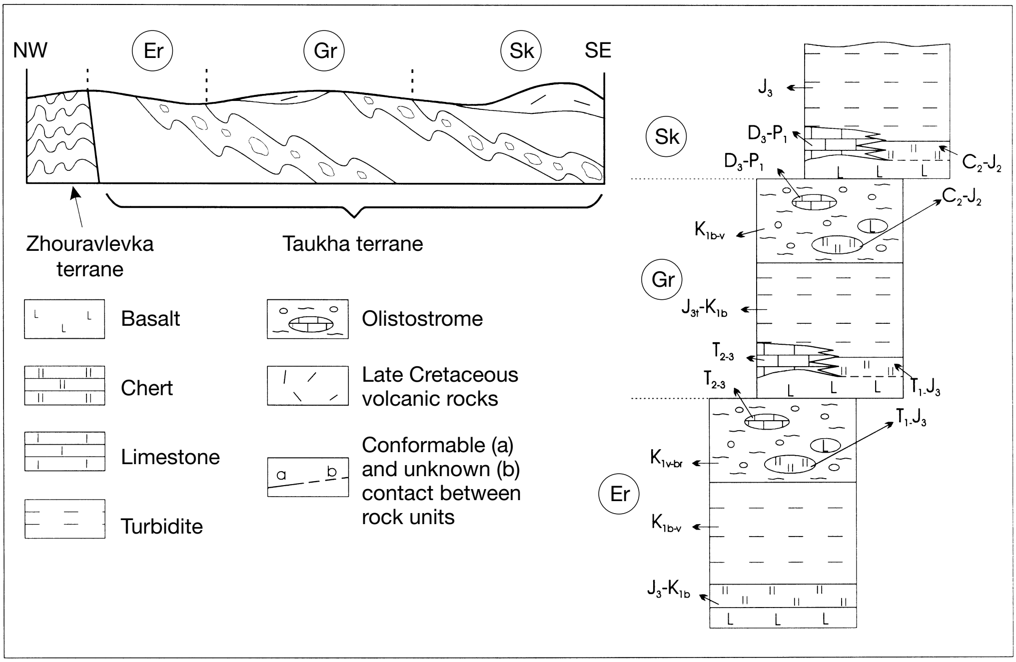

FIG. 3. — Generalized cross-section of the Taukha terrane and stratigraphic columns. Abbreviations: **Er**, Erdagouskaya unit; **Gr**, Gorboushinskaya unit; **Sk**, Skalistorechenskaya unit.

There are three main structural sections in the terrane (Fig. 3). But there may be more structural sections, if changes in ages of chert-turbidite sequences in each of four "Gorbousha" structural slices can be established. Similar structures occur in modern accretionary prisms formed along internal slope of modern convergent margins (Fujioka *et al.* 1988; Huene *et al.* 1982; Ogawa 1985). Such structures form during oceanic plate subduction. Older units are accreted first and are underplated by accreted younger units. According to this model, the Taukha terrane structure seems consistent and permits us to identify the Taukha terrane as an ancient accretionary prism.

The age data for the marine rocks supports the interpretation that the Late Devonian to Permian, Early Triassic to Late Jurassic, and Late Jurassic-Berriasian fragments of marine plates were consecutively accreted into the Taukha accretionary prism. The time of beginning of subduction and, correspondingly, subsequent accretion of each marine structural slice are correlated with the age of overlapping terrigenous rocks. Probably, the times of accretions of marine fragments correspond to times of olistostrome formation. In this case, the Paleozoic (Devonian to Permian) marine plate fragments were accreted in the Late Jurassic. The Early Triassic to Late Jurassic and Late Jurassic to Berriasian marine plate fragments were accreted in Berriasian-Valanginian and Valanginian-Barremian times, respectively.

Thus, the Taukha accretionary prism consists of a minimum of three structural units that differ both in age of accreted marine fragments and time of subduction. In the accretionary prism, the structural units are separated by horizons of olistostrome. The relatively younger units composing the lower structural level of the Taukha prism are located at the northwest part of the terrane and older its units composing the higher structural levels are located at the southeast part of the terrane. Thus, the growth (or younging) of

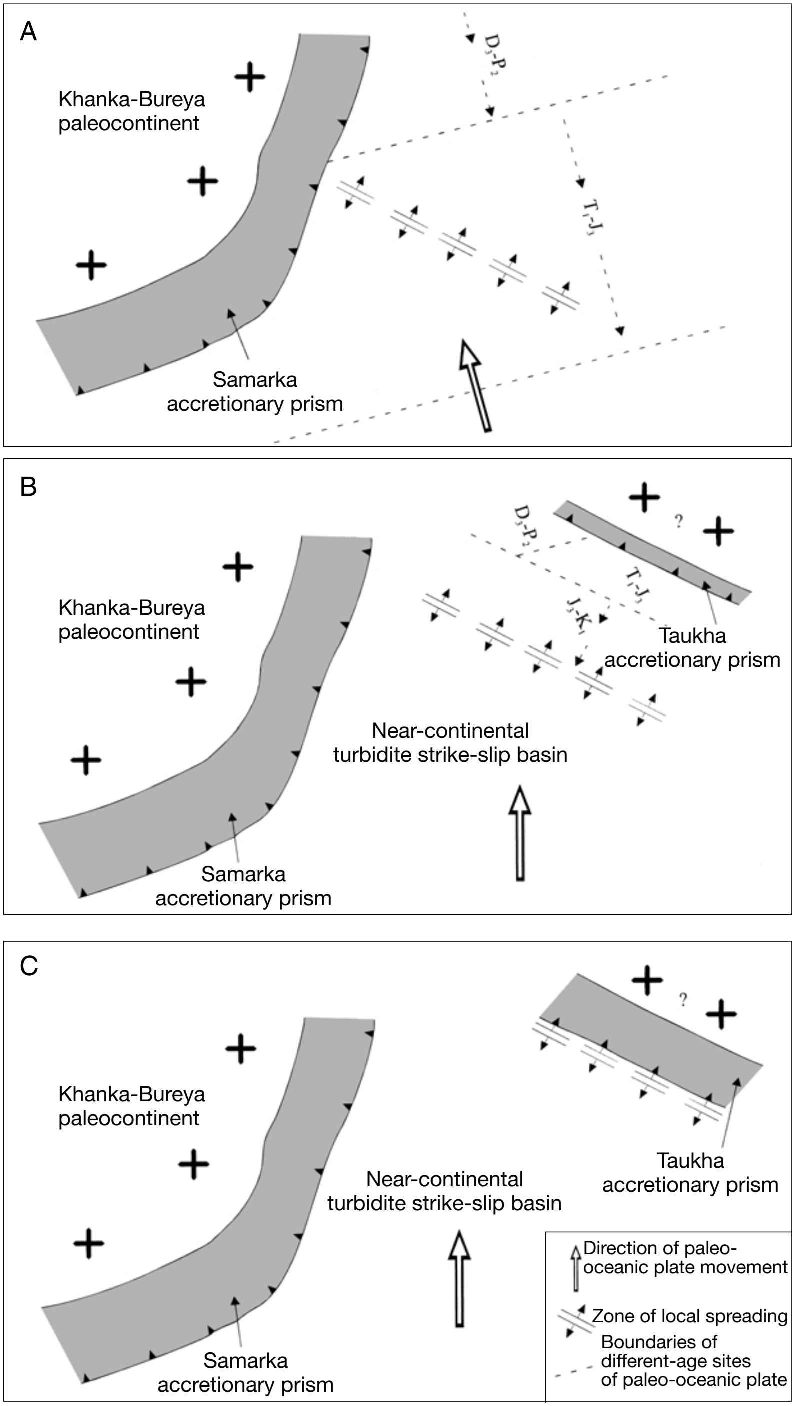

FIG. 4. — Paleogeodynamic position along eastern margin of Khanka-Bureya paleocontinent at the end of the Jurassic and beginning of Cretaceous; **A**, Callovian-Oxfordian; **B**, Berriasian-Valanginian; **C**, Valanginian-Barremian.

prism section is realized to the northwest whereas the prevalent (principal) dip of the prism strata is realized to opposite side (Fig. 2). Such prism structure allows to conclude that the subduction of a marine plate and corresponding formation of the Taukha accretionary prism did not occur under the Khanka-Bureya superterrane (a paleocontinent) to the West, but under an unknown paleocontinent or island arc to the East. A geodynamic model for formation of the Taukha prism is presently difficult to reconstruct. Local sea-floor spreading zone probably occurred near a Jurassic subduction zone during the Middle to Late Jurassic, with a change of direction of the oceanic plate (Fig. 4). Supporting this idea is the composition of Erdagouskaya suite basalts that suggests formation in marginal sea spreading zones (Simanenko *et al.* 1999).

The Taukha suite conglomerates are also indirect evidence supporting this idea. The Taukha suite is coeval to the Taukha accretionary prism turbidite, but accumulated under shallow-water (shelf) conditions. The deposits of the Taukha suite contain abundant Berriasian to Valanginian flora and macrofauna. These units are thrust over various structural units of the Taukha prism. Among the conglomerate pebbles, especially in the southern and eastern areas, gabbro, granite, and metamorphic rocks prevail. These rocks are more common in the Sergeevka terrane located to South, and in the southern Kitakami terrane in Japan. Inference of an unknown paleocontinent to the East of the Khanka-Bureya paleocontinent in the Early Cretaceous was originally interpreted by Markevich (1970, 1978). The Anuy microcontinent located at the northern Sikhote-Alin is probably a fragment of that paleocontinent. In the Anuy river area, ophiolites underlain by metamorphic rocks have been described and interpreted as evidence for collision of the Anuy microcontinent with West Sikhote-Alin at the Early Cretaceous time (Faure & Natal'in 1992; Faure *et al.* 1995, etc.). At the end of the Early Cretaceous (from Barremian to Albian), the Taukha prism was accreted to the eastern margin of the Khanka-Bureya paleocontinent, along with the Zhouravlevka and Samarka terranes, then overlapped by Late Cretaceous volcanitic rocks.

CONCLUSION

The Taukha accretionary prism consists of various accreted fragments of marine rocks that have a wide range of age. Data on age of marine units and overlying continental-margin deposits permits to establish the age of accretion of each fragment. The Taukha accretionary prism contains several structural units. Three major structural slices are recognized. Each slice consists of marine formations that grade upward into terrigenous rocks of continental-margin origin that are replaced by olistostromes that formed during the subduction of a younger marine plate under an older marine plate. Three stages of formation of the Taukha prism are defined. In the Late Jurassic, fragments of a Paleozoic (Devonian to Permian) marine plate were accreted. In the Berriasian to Valanginian, and Valanginian to Barremian, fragments of Early Triassic to Late Jurassic and Late Jurassic to Berriasian marine plate were accreted. Comparative study of individual sections leads to reconstruct a complete accretionary prism and to specify the geological structure of the southeastern part of the Sikhote-Alin region.

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