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The IV-th International Symposium

G.L. Kirillova, B.A. Natal'in, S.V. Zyabrev T. Sakai,
K. Ishida, N. Ishida, T. Ohta, T. Kozai

Upper Jurassic–Cretaceous Deposits of East Asian Continental Margin along the Amur River

FIELD EXCURSION GUIDEBOOK

The 30-th Anniversary of IGCP

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Верхнеюрско-меловые отложения Восточноазиатской континентальной окраины вдоль р. Амур

ПУТЕВОДИТЕЛЬ ГЕОЛОГИЧЕСКОЙ ЭКСКУРСИИ

Хабаровск
2002

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Edited by G.L. Kirillova

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В путеводителе дан краткий геологический очерк, освещающий главные черты позднемезозойской стратиграфии седиментологии, тектоники Приамурья. Приведены описания вещественного состава, фауны, характера дислокаций шести важнейших разрезов вдоль р. Амур.

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PREFACE

The guidebook of the geological field excursion for the IV International Symposium of IGCP 434 «Cretaceous Continental Margin of East Asia: Stratigraphy, Sedimentation and Tectonics» gives the description of the composition and structure of Mesozoic series exposed on the banks of the Amur River. The participants of the Symposium will be shown an accretionary complex including blocks of Upper Paleozoic, Triassic, Jurassic and Lower Cretaceous rocks, which have a melange structure, and also Lower/ Upper Cretaceous complex of a fore-arc basin characterized by a more regular imbricated-thrust structure. The description of the excursion is given in the context of general views of the regional structure of the Far East south.The program of the field excursion is schemed for 8 days.

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GEOLOGICAL OUTLINE OF LATE JURASSIC-CRETACEOUS DEPOSITS IN PRIAMURIE

Cardinal changes in interpretation of the geological structure of Priamurie occurred over the last twenty-year period. Not all the geologists adopted the concept on plate tectonics simultaneously. Nevertheless, since 1978 a considerable progress has been achieved. The presence of exotic blocks of cherts, limestones, and basalts of different age in the terrigenous matrix has been ascertained during the investigations of many researchers (Belyaev, 1978; Bragin, 1987; Shevelev, 1987; and others). Data obtained on conodont and radiolarian microfauna contributed to the development of the geology in the region.

A number of schemes of tectonic zonation for Priamurie and adjacent territories has been proposed for the last 25-year period (Zonenshain et al., 1976; Krasny, 1980; Geological structure ..., 1984; Parfenov, 1984; Parfenov and Natal'in, 1986; Natal'in, 1993; Khanchuk and Ivanov, 1999; Sengor and Natal'in,1996; Utkin, 1991; Khanchuk, 2001 and others).

According to B.A. Natal'in (Natal'in and Zyabrev, 1989), two main sutures: Mongol-Okhotsk and Amur are principally important for understanding of the general structure and Mesozoic tectonic evolution of the region (Fig. 1).

The Mongol-Okhotsk suture has been formed as a result of a collision of tectonic units of the Bureya massif with the active continental margin of the East Siberian continent marked by magmatic complexes of the Triassic-Jurassic Uda-Murgalsk island arc and by the Jurassic (Triassic-Jurassic?) Stanovoy plutonic belt. The age of the suture is defined as Late Jurassic.

The Amur suture separates the fore-arc tectonic units of the Khingan-Okhotsk active continental margin from the Early Mesozoic fold belts of the Sikhote-Alin and the more ancient structures of the Khanka massif.

More recently, at the development of the concept on the terranes and when investigations on geology of the continental margin of southeastern Russia and its transform type were being extended, alongside with the Amur suture other structural lines bounding the terranes came into existence.

The up-date scheme of the tectonic zonation for southern Far East and adjacent territories of A.I. Khanchuk (Fig. 2) includes the latest geological results obtained in Priamurie, Primorye, Sakhalin, and Japan. Unfortunately, the given scheme shows a rather generalized structure of Middle Priamurie as an accretionary prism of the Kiselevka-Manoma terrane. Nevertheless, one can see its structural details on the geological map and scheme of the geological zonation for Priamurie (Figs.3,4) and study it during our geological excursion.

On the basis of the recent investigations we can suppose that the Khabarovsk and Taukhinsky terranes

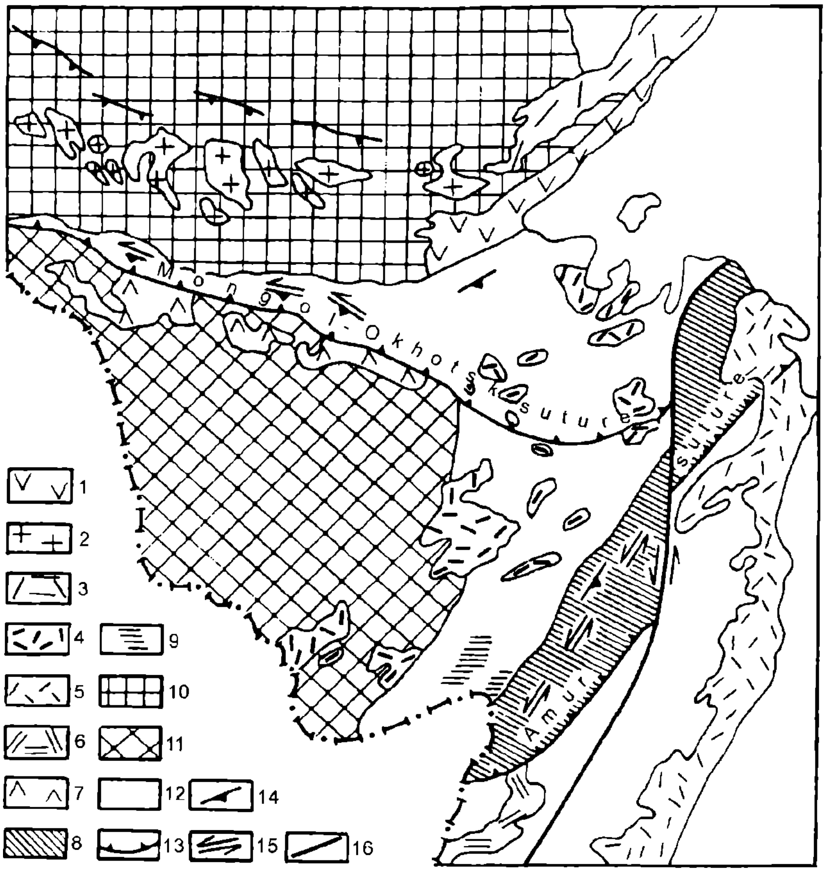


Fig. 1. Mesozoic sutures of the Far East south (after Natal'in and Zyabrev, 1989).

1–7 – magmatic belts of the plate's convergent boundaries: 1 – Triassic-Jurassic Uda-Murgal volcanic island arc, 2 – Stanovoy plutonic belt of the East Siberian continent's Triassic-Jurassic active continental margin, 3 – Okhotsk-Chukotka volcano-plutonic belt of the Asia Cretaceous active continental margin, 4 – Khingan-Okhotsk volcano-plutonic belt of the Asia Early Cretaceous active continental margin, 5 – East Sikhote-Alin volcano-plutonic belt of the Asia Senonian-Paleogene active continental margin, 6 – Alchan volcanic belt of the Sikhote-Alin terrane's Aptian-Albian active continental margin, 7 – Cretaceous Umlekan-Ogodzhinsk collision volcano-plutonic belt; 8–9 – accretionary wedge of the Khingan-Okhotsk active continental margin: 8 – Amur complex, 9 – Khabarovsk complex; 10 – Siberian platform; 11 –Bureya massif; 12 – foldbelts; 13 – suture zones; 14–15 – vergence of collision structures: 14 – folds and thrusts, 15 – strike-slip faults; 16 – Central-Sikhote-Alin strike-slip fault.

(or Khabarovsk complex after Natal'in) are composed of accretionary complexes of nearly the same age and are fragments of a single complex. In the Taukhinsky terrane, the age of the cherts is defined as T_1-J_3 from radiolarians, and that of the siliceous tuffites as J_{2-3} (Golozoubov and Khanchuk, 1995). In the Khabarovsk terrane cherts are assigned to T_1-J_2 based on radiolarians and conodonts (Zyabrev and Matsuoka, 1999). Higher up the section is a Volginian-Early Berriasian olistostrome complex in the clayey matrix. An amount and thickness of the olistostrome horizons are different (Fig. 5). Distribution of the blocks and olistoliths as well as their age are shown in Fig. 6. In the better studied Taukhinsky terrane higher up the section there is distinguished the Berriasian-Lower Valanginian Taukhinsky terrigenous suite divided into three subsuites and conformably overlying Klyuchevsky suite with the age range from upper Lower to Upper Valanginian (Markevich, Konovalov et al., 2000). It is notable that from the southeast to the northwest a common tendency for the both suites is observed: coarse clastic rocks are replaced by fine clastics containing turbidite packets. The same regularity was fragmentally observed by V.A. Dymovich on the northwestern and southeastern slopes of the Samarka terrane in the heads of the Samarga and Kabuli rivers, i.e. in the northeastern termination of the terrane (for location see Fig.2). Abundance of the siliceous clastic material in conglomerates evidences that beginning from the Late Berriasian the Taukhinsky and Samarka terranes were a provenance.

Volginian-Valanginian deposits of the Petropavlovsky suite near the Petropavlosk Lake and those of the Komsomolsky series near Komsomolsk-on-Amur are assigned to the Zhuravlevka terrane (Fig.2).

As to the Early/Late Cretaceous undivided accretionary prism shown in Fig.2, factual materials allow us to consider its structure in more detail (Fig.3, 4).

According to recent concepts of sequence stratigraphy (Vail et al., 1987; Van Wagoner et al., 1990; Graciansky et al., 1998 and others), large complexes for 20-40 Ma which are unconformably bounded and correspond to transgressive-regressive cycles of the second order, have been named a supersequence set. These, in their turn, include supersequences, sequences, and parasequences. Unconformable boundaries of the sequences are marked along the margin of the

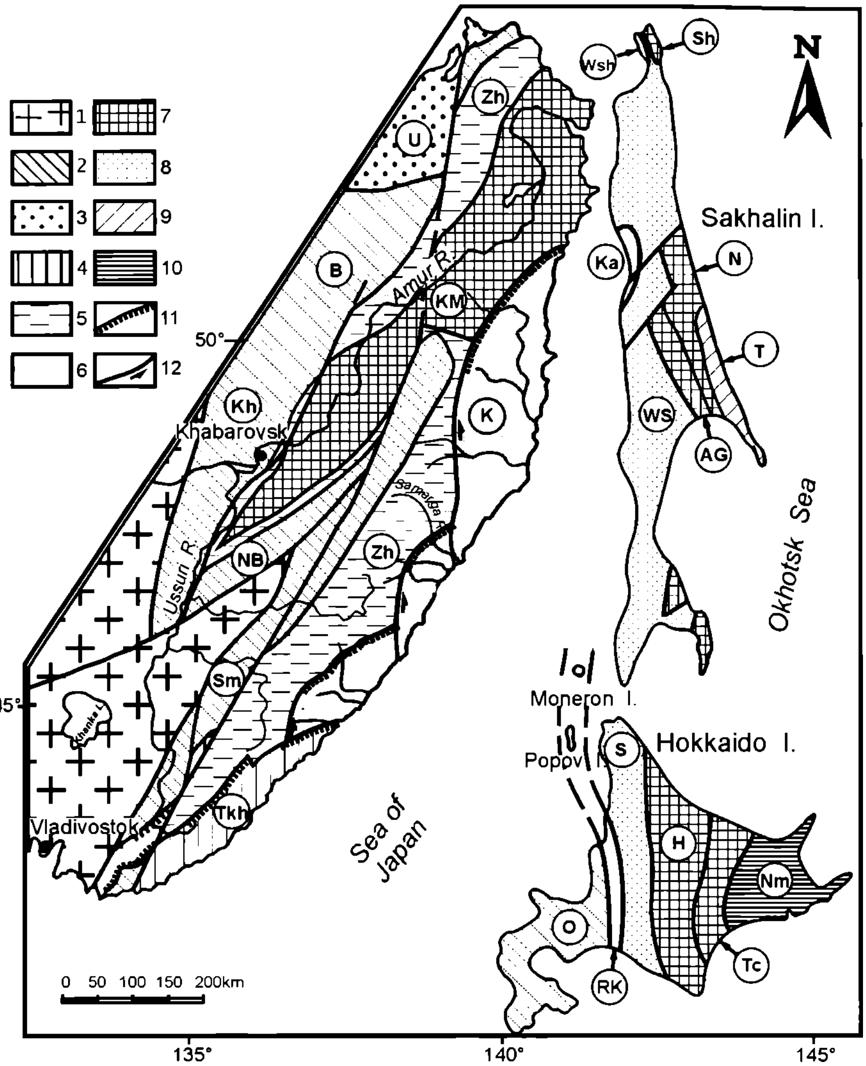


Fig. 2. Scheme of a tectonic zonation of the Far East south of Russia and adjacent territories (after A.I. Khanchuk, 2001 with additions after Richter, 1986; Zyabrev, 1992; Hirano et al., 1992).

1-10 – terranes: 1 – pre-Mesozoic; 2-3 – Jurassic: 2 – of an accretionary prism, 3 – turbidite; 4-6 – Early Cretaceous: 4 – of an accretionary prism, 5 – turbidite, 6 – island-arc; 7-9 – Early/Late Cretaceous: 7 – of an accretionary prism, 8 – turbidite; 9 – island-arc; 10 – Late Cretaceous – Paleogene; 11-12 – faults: 11 – thrusts, 12 – strike-slip faults. Arrows indicate the direction of the movement along the strike-slip faults.

Terranes: Sm – Samarka; NB – Nadanhada – Bikin; Khb – Khabarovsk; B – Badzhal; U – Ulbinsky; KM – Kiselevka-Manoma; Tkh – Taukha; Zh – Zhuravlevsky; K – Kema; WS – West Sakhalin; AG – Aniva-Gomonsky; N – Nabil; Sh – Shmidt; WSh – West Shmidt; Ka – Kamyshov; T – Terpeniya; O – Oshima; RK – Rebun-Kabato; S – Sorachi-Yezo; H – Hidaka; Tc – Tokoro; Nm – Nemuro.

paleobasin and thereafter they are replaced by conformable boundaries. Thus, within the framework of sequence stratigraphy at the present investigation level, the Volginian-Valanginian supersequence set can be distinguished in Priamurie. The lower unconformable pre-Volginian boundary was repeatedly observed on the left bank of the Amur River. It appeared more clearly expressed on the margin of the Bureya massif. In the Bureya river upstreams continental coal-bearing facies of the Dublican suite, the Volginian stage, with time gaps, unconformities and thick-bedded conglomerates at the basement consisting (up to 70%) of pebbly granitoids occur on the Talynndzhansky suite of Callovian-Oxfordian age being accumulated in the coastal-marine environment. When moving eastwards unconformable boundary is replaced by conformable one that can be seen in the Komsomolsk section defining a fore-arc basin environment. In the best

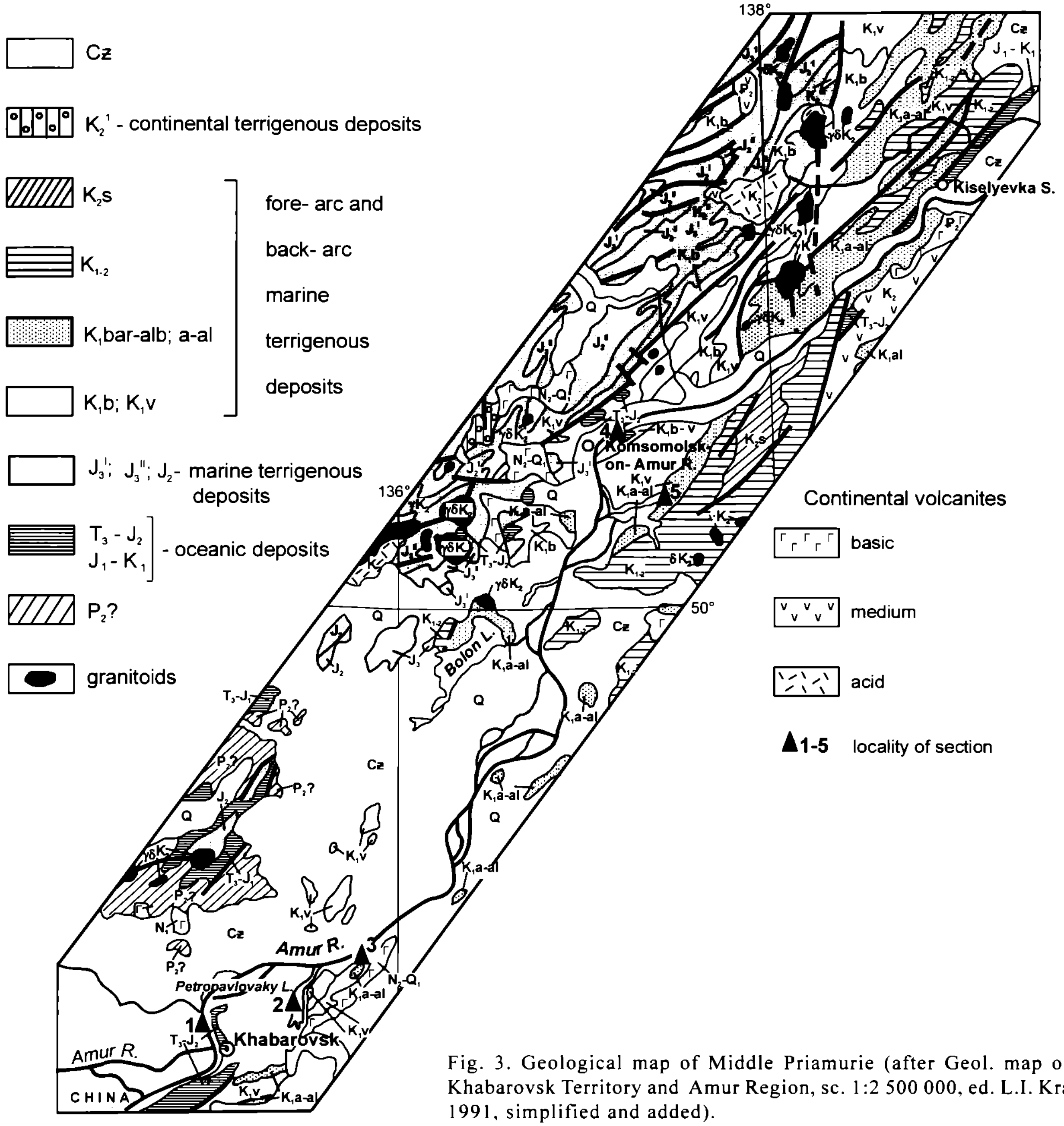


Fig. 3. Geological map of Middle Priamurie (after Geol. map of the Khabarovsk Territory and Amur Region, sc. 1:2 500 000, ed. L.I. Krasny, 1991, simplified and added).

studied sections in Primorye on the basis of the stratigraphic scheme after V.P. Konovalov (Markevich, Konovalov et al., 2000) the Volginian-Valanginian supersequence set is possible to divide into three supersequences, as follows: Volginian-Lower Berriasian, Lower Berriasian-Lower Valanginian, and Lower/ Upper Valanginian (Kirillova, 2000).

The reliable Hauterivian-Barremian deposits are not known in Priamurie. They are supposed to occur within the Gornoprotoksky suite distinguished in the Malyshevo settlement area near Khabarovsk in the south and in the Khummi Lake area, and Gorny channel near Komsomolsk-on-Amur. The suite is defined in a wide age range from the Hauterivian to mid-Albian. Some investigators (Freidin, 1961) distinguished the Largasinsky series including the Gornoprotoksky suite as a lower member (see Fig. 5.2).

Further interpretation of the section in terms of sequence stratigraphy enables us to state that the Hauterivian-Barremian supersequence is absent in Priamurie. Probably the left-lateral strike-slip movements along the transform continental margin resulted in elevation of this area. Southeast in the Sikhote-Alin, Hauterivian-Barremian deposits (Ust-Kolumbinsky and Primankinsky suites) have been reported from a deep part of the paleobasin. The

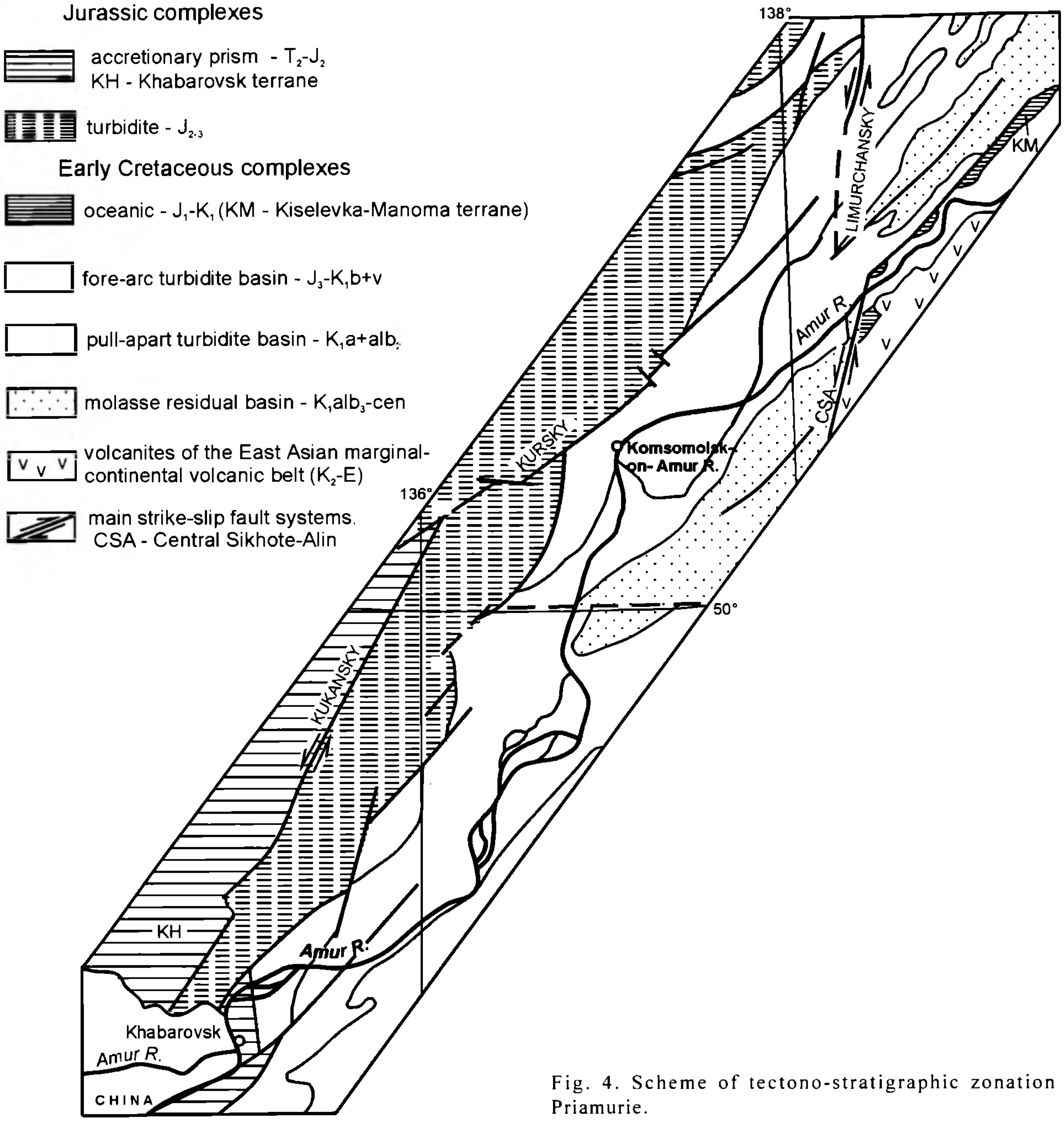


Fig. 4. Scheme of tectono-stratigraphic zonation of Priamurie.

Gornoprotoksky suite represented by mostly turbidites unconformably rests on the suites of the Komsomolsk series. It is often divided into some units being smaller cycles of sedimentation. They are proposed to have being formed in a basin of a pull-apart type during intensive erosion of the adjacent uplifts. The most probable age range of the Gornoprotoksky suite formation is dated as Aptian-mid-Albian.

During mid-Albian time a number of terranes accreted to the continental margin. Folding, overthrust sheets, granitic intrusions took place at that time interval. The subduction zone moved eastwards. Fragments of younger deposits of the oceanic plate are exposed within the Kiselevka-Manoma terrane (Fig.4). The oceanic deposits are assignable to J_1-K_1bar. (Bragin, 1988; Kuzmin and Shevelev, 1990; Khanchuk et al., 1994; Zyabrev, 1994). The youngest cherts are dated as Hauterivian-Early Barremian in age, and siliceous aleuropelites are assigned to the Albian (Zyabrev, 1994). Volcanogenic-siliceous oceanic complex is interpreted as steeply dipping imbricated-thrusted in structure complicated with folds and faults (Zyabrev, 1994).

A supersequence set completing the section combines Upper Albian-Cenomanian (probably the

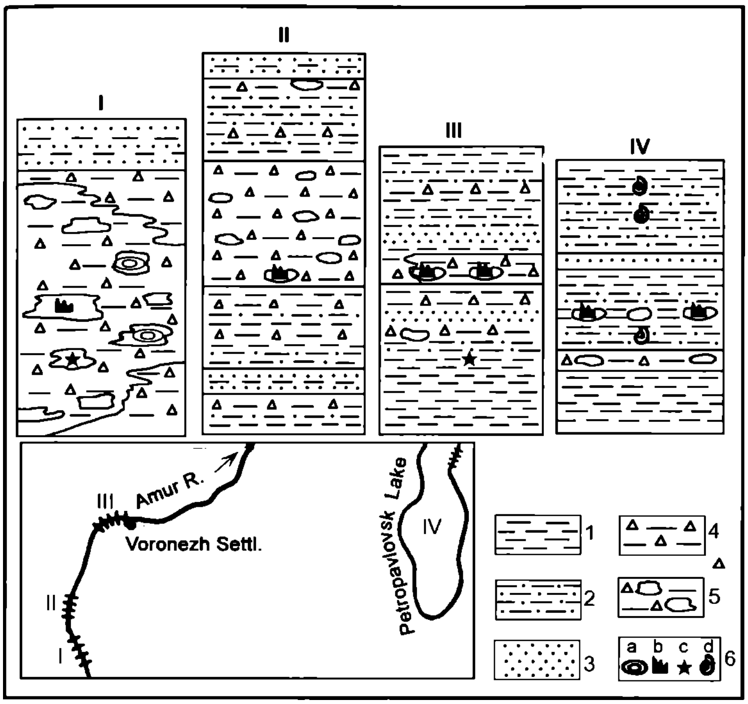


Fig. 5. Stratigraphic columns of Upper Jurassic-Lower Cretaceous deposits (Mixtites..., 1988).

1 – siltstone and tuff siltstone; 2 – rhythmical alternation of siltstone and sandstone; 3 – sandstone; 4 – small mixtite blocks (fragments of about 1 m in size); 5 – large mixtite blocks (fragments of more than 1 m in size); 6 – faunal occurrences of different age: a – foraminifers; b – conodonts, c – radiolarians; d – pelecipods.

I-IV – outcrops: I – outcrops south of the Amur River railway bridge in Khabarovsk; II – outcrops to the north of the Amur River railway bridge; III – outcrops near the Voronezh Settl.; IV – outcrops along the northeastern bank of the Petropavlovsk Lake.

earliest Turonian) deposits beginning with coarse clastic rhythmic deposits of the Sitoginsky suite (1500 m thick) containing thick conglomerates at the basement. Higher up occur predominantly aleuropelitic rocks of the Silasinsky suite with tuff and andesite beds (Kaidalov, 1990) that is evident of the Moneron-Samarga island-arc proximity (Malinovsky et al., 2002). The section is crowned with volcanogenic sedimentary rocks of the Utitsky suite. Upper Albian-Cenomanian supersequence set deposits are characterized by residual back-arc basin sediments (lower terrigenous marine molasse). The deposits are abundant in pelecipod, Crustacea and plant remains. Gastropods, brachipods, and echinoids are minor in amount. The occurrences of ammonites, crinoids and corals are extremely scarce.

The East Sikhote-Alin marginal-continental volcanic belt was being formed in the east of the region beginning from late Albian (Cenomanian) time.

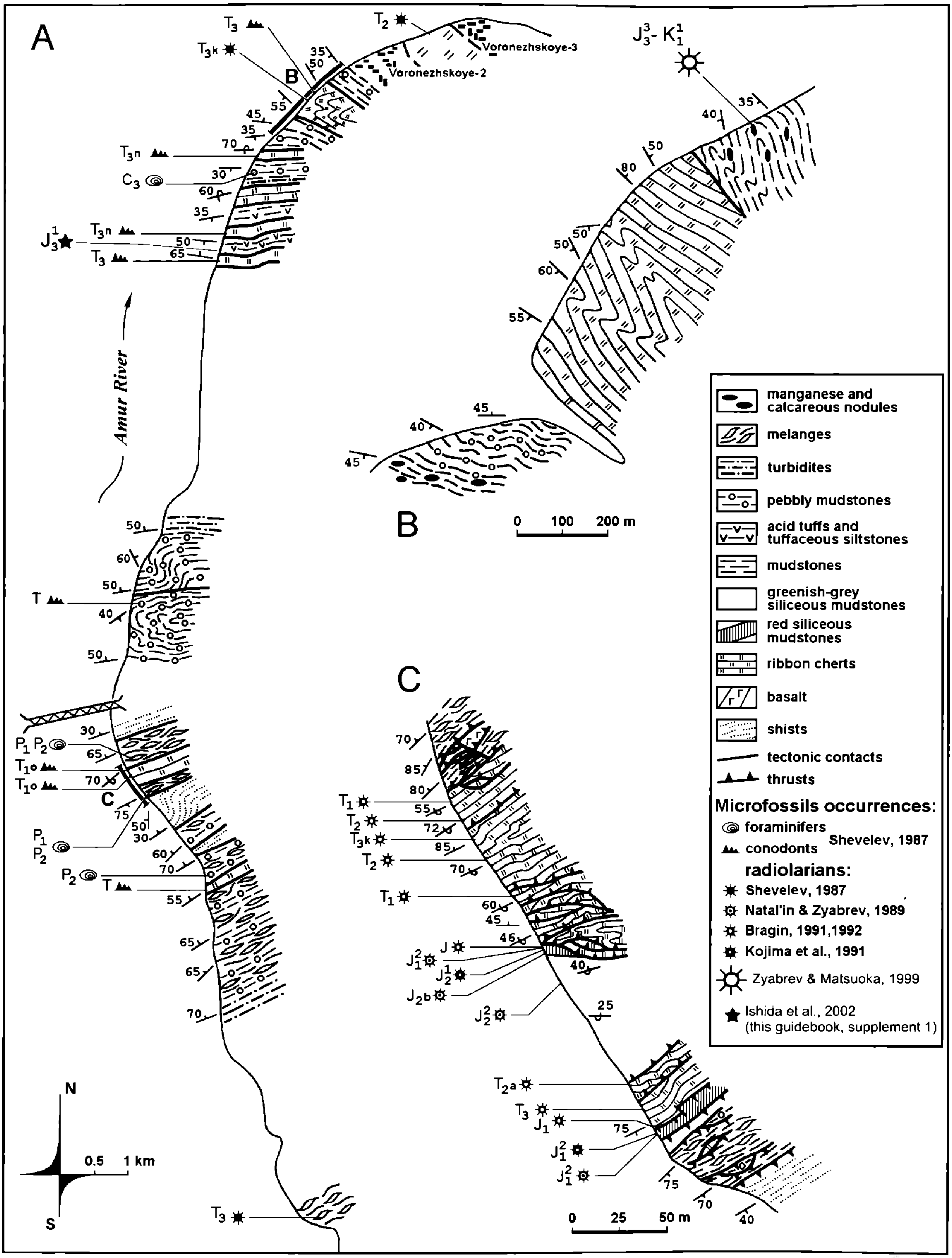
STRUCTURAL FRAMEWORK*

Two complexes of different deformation types are distinguished in Priamurie: the Amur and Khabarovsk (Natal'in and Zyabrev, 1989). The Amur complex comprises Volginian-Cenomanian deposits. The structural style testifies to the uniformity of the Amur complex. It is characetrized by superimposed folding and faulting. The first-stage deformation produced F_1 folds, from close to isoclinal, and S_1' bedding-plane shears. The fold-hinges are gently plunging and the axial planes are steeply dipping. The S_1' cleavage is commonly developed in the F_1 fold cores. It is important to note that younger F_2 folds have a similar shape and orientation, but have no cleavage. The S_1' cleavage is the only criterion by which the F_1 folds are singled out, but as the S_1' cleavage is not penetrative, the close to isoclinal folds are often indexed as F_{1-2}.

Large close to isoclinal folds are distinguished by the younging directions of the beds. The half wavelength of these folds is up to the first hundreds of metres. The S_j shears occur both together with the F_1 folds and in the internal parts of the sheets, which are characterized by homoclinal dippings of the beds. They are usually confined to mudstones or thin-bedded turbidites and are not very thick and not mineralized.

The F_1 folds, S_1 shears and S_1' cleavage have a discrete distribution. They separate the sheets with homoclinal dippings of the beds, which is evident of the formation of the imbricate stack during the first stage of deformation. Thick horizons of olistostromes are observed on the walls of the first-stage deformation zones, and hence, it is reasonable to suppose synchronism of deformation and sedimentation. The

*This section is given with reduction from "Structure of Mesozoic Rocks of the Amur River Valley» (Natal'in and Zyabrev, 1989).



A
B
C
Amur River
Voronezhskoye-3
Voronezhskoye-2
0 100 200 m
0 25 50 m
0.5 1 km
N
S
manganese and calcareous nodules
melanges
turbidites
pebbly mudstones
acid tuffs and tuffaceous siltstones
mudstones
greenish-grey siliceous mudstones
red siliceous mudstones
ribbon cherts
basalt
shists
tectonic contacts
thrusts
Microfossils occurrences:
foraminifers
conodonts
Shevelev, 1987
radiolarians:
Shevelev, 1987
Natal'in & Zyabrev, 1989
Bragin, 1991,1992
Kojima et al., 1991
Zyabrev & Matsuoka, 1999
Ishida et al., 2002
(this guidebook, supplement 1)

presence of olistostromes at different stratigraphic levels suggests great duration of the first-stage deformations. They probably began as early as the late Jurassic and the process was over in the Cenomanian. The synchronism of deformation and sedimentation gives grounds for the supposition that the F_1 axial planes and S_1 shears were primarily flat-lying.

An attempt at assessing the vergence of the first-stage structures was made from the asymmetry of the folds and some other shear criteria. A definite pattern has not been established although in most cases the criteria suggest SE movement.

In the modern structure, bedding, the axial planes of the F_1 folds and S_1 shears have steep dipping. Such orientation of the planar structures is related to the second-stage deformations. Minor F_1 folds were observed to be involved by close F_2 folds with gently plunging hinges and high-angle axial planes. The S_1 cleavage is also involved by the F_2 folds.

Since it is not easy to single out genuine second-stage structures, it is consequently difficult to determine the direction of the movement at this stage. The SE dipping of the beds is most often overturned, and this can be interpreted as a proof of NW vergence. Taking into consideration that the principal first-stage structures were SE directed low-angle thrusts and recumbent folds, our conclusion about the NW movement during the second-stage deformation is not principally at variance with the widespread NW steeply dipping planar structures. For these kinds of orienattion it is sufficient to suggest a less than 90° angle turn from the initial position.

Bedding-plane S_3 ductile strike-slip faults are the main among the third-stage structures. They are associated with asymmetric folds, isoclinal folds, schistosity developed in the fault zones, and boudinage.

Boudinage is extensively developed in the Lower Cretaceous layers. It is expressed by the pinch-and-swell structures of different intensities which grade into dismembered lenticular blocks surrounded by the pelitic matrix. The asymmetric shape of the blocks indicates that the boudinage was caused by a simple shear strain. The boudin shapes are good kinematic indicators of shear sense. They steep dipping longest axes of a three-dimensional shape of the boudins indicate that the boudinage was caused by strike-slip movements in the geological sense.

The S_3 fault zones as well as S_1 shears are mostly confined to pelitic rocks. They are often not thick and composed of phyllonites and tectonized mudstones and shales with a discernible schistosity.

Between large S_3 zones one can observe isoclinal folds with a half wavelength up to 10-20 m. In contrast with the older folds, they have high-angled hinges. The boudins longest axes on the limbs of these folds are parallel to the hinges. Is is interesting to note that the fold pairs are sepaarted along the S_3 shears to considerable distances. Isoclinal folds with steep hinges are superimposed on the older isoclinal folds with low-angle hinges.

Isoclinal folds are rare in the fabric of the third-stage deformation. Folds with interlimb angles more than 30° are spread much wider. Usually they are asymmetric, are attached to the walls of the S_3 zones, or are intrafolial. The sizes of F_3 folds range from the first dozens of centimetres to the first hundreds of metres, occasionally to 1-2 km.

The third-stage structures are discretely spread in the outcrops, but they are penetrative on a regional scale, which suggests that the whole belt of the Lower Cretaceous terrigenous rocks underwent strike-slip movements.

Since the S_3 shears are bedding-plane, it is hard to find marker beds and hence the sense of motion was established by such kinematic criteria as F_3 fold asymmetry, monoclinic symmetry of boudin shapes, duplex structures, etc. In most cases they show a sinistral motion.

It is not easy to establish the age of the second and third deformation stages. They occurred in a span between the Post-Cenomanian and possibly the beginning of the Paleogene. Within the Amur suture, folds have been observed in the Senonian volcanites (Geological structure ..., 1984).

Besides the structures characterized, two more fold generations have been ascertained as well as younger

Fig. 6. Structure of the Khabarovsk complex beside the city of Khabarovsk (Zyabrev and Matsuoka, 1999), (a) Geological route map with microfossil occurrences reported by E. K. Shevelev (Shevelev 1987) and position of exposures shown in (b and c). (b) Detailed structure of the complex near the railway bridge with radiolarian occurrences; modified from Natal'in and Zyabrev 1989. (c) Detailed structure of the complex beside Voronezhskoye village with position of radiolarian-bearing sample SZ-92-V-1. C3, Late Carboniferous; P_1, and P_2, Early and Late Permian, respectively; T_1, Early Triassic; T_1o, Olenekian; T_2, Middle Triassic; T_2a, Anisian; T_3, Late Triassic; T_3k, Carnian; T_3n, Norian; J, Jurassic; J_1, Early Jurassic; $J_{1\text{-}2}$, late Early Jurassic; $J_{1\text{-}2}$, early Middle Jurassic; J_2-$_2$, late Middle Jurassic; J_2b, Bajocian; $J^1{}_3$ – early Upper Jurassic.

1. KHABAROVSK COMPLEX – OUTCROPS OF THE MESOZOIC ACCRETIONARY COMPLEX SOUTH OF THE AMUR R. RAILWAY BRIDGE NEAR KHABAROVSK

The structure of the Khabarovsk complex is very well exemplified by outcrops near the railway bridge in Khabarovsk (Fig. 1.1). The outcrop area begins in the south near the ferry-boat and continues in the northwestern direction.

At the beginning of the route, metasandstones and metamorphic schists are offered to the viewers. These rocks are regarded by Shevelev (1987) as the Upper Permian from the comparison of their lithology against that of the corresponding stratigraphic units of the Central Sikhote-Alin and Primorye. The metasandstones and metamorphic schists (the latter formed over the thin-bedded aleuropelitic rocks) compose a series of uneven intercalation (Fig. 1.2). The thickness of the metaschists varies within a wide range, between a few centimetres and 1-1,5 m. Cross and flaser bedding can often be seen in them (Fig. 1.3). In some places they make packets up to 10 m thick. The metasandstone beds are thicker, up to 20 m.

The paragenesis of the metamorphic minerals includes quartz, albite, muscovite, epidote. It corresponds to the greenschist facies.

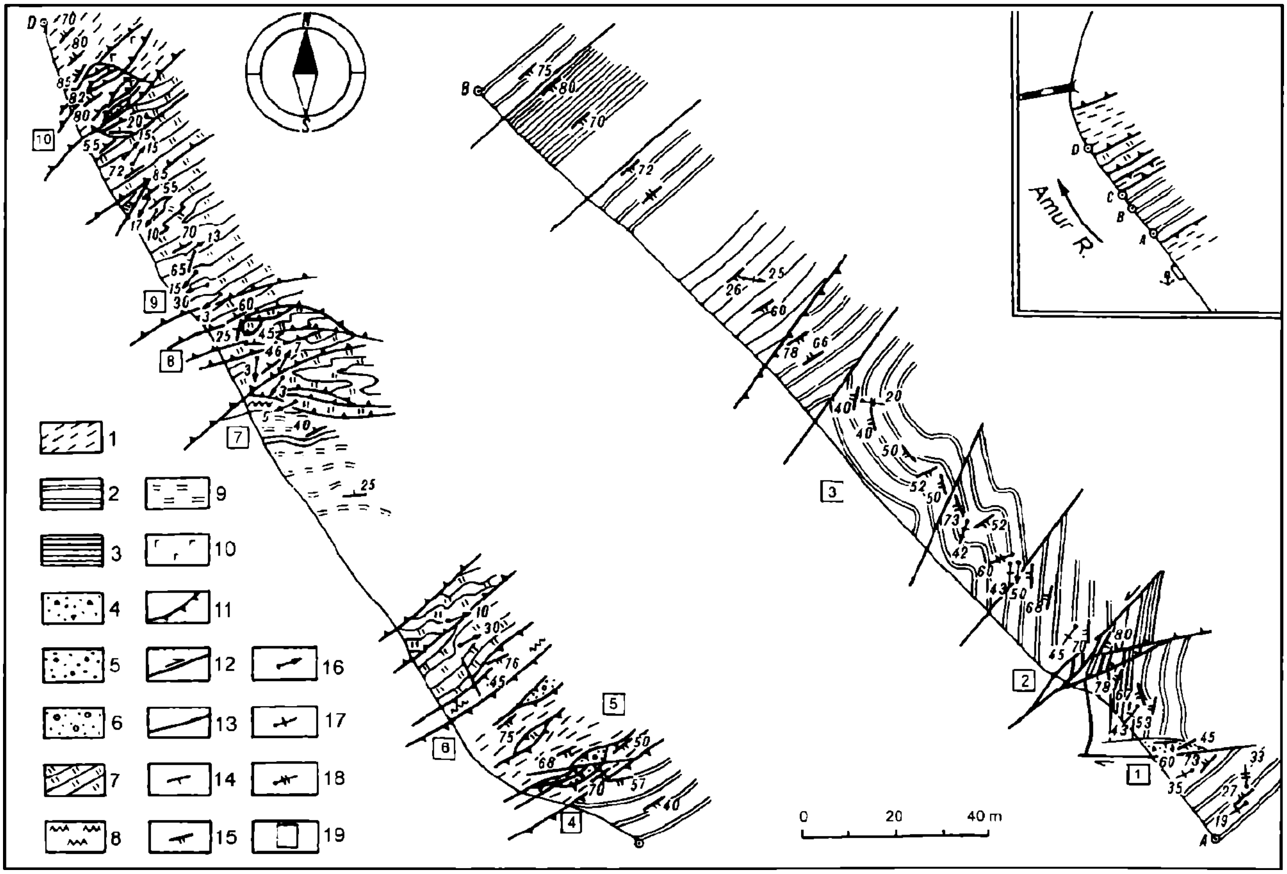


Fig. 1.1. Map of the Khabarovsk complex near the railway bridge in Khabarovsk.

1 – melange matrix; 2 – metasandstones; 3 – metamorphic schists; 4 – olistostrome overlying metamorphic rocks; 5 – olistostrome with red matrix; 6 – olistostrome with pistachio matrix; 7 – cherts; 8 – red cherty argillites; 9 – pistachio shales; 10 – basic volcanics; 11 – thrusts; 12 – strike-slip faults; 13–faults of unclear kinematic type; 14 – strike and dip of a bed; 15 – schistosity attitude: a – strike and dip, b – strike at vertical dip; 16 – plunging of a fold hinge; 17 – plunging of stretching lineation; 18 – plunging of a wrinkle; 19 – stops and their numbers for detailed observation.

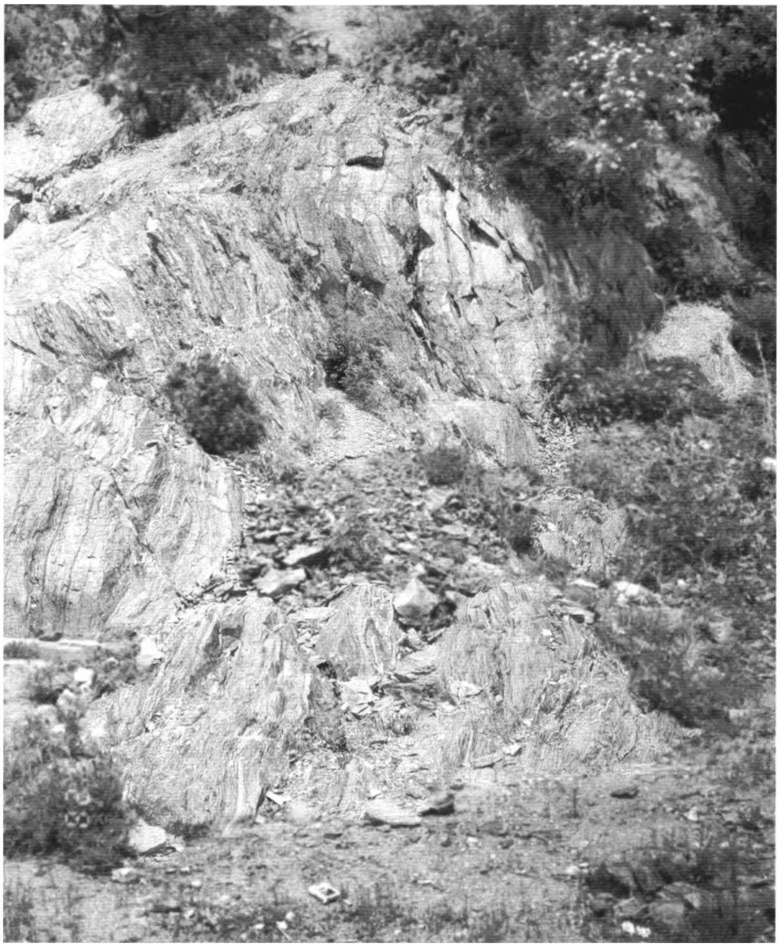


Fig. 1.2. Upper Permian (?) formations, the Amur R. (Here and below are G.L. Kirillova's photos)

The structural and textural features testify to the dynamometamorphic nature of the discussed rocks. The sandstone grains in the thin sections perpendicular to the schistosity are lenticular. The quartz is often polygonized and is characterized by undulating extinction. The plagioclase grains are highly altered, often recrystallized. Bent twins occasinally occur. Partial recrystallization is confined to the thin edges of the clastic grains. The shapes of the grains and the pressure shadow indicate rotation. Along the schistosity planes sometimes dark opaque stuff is developed, which can be regarded as pseudotachylite. In thin sections, two sliding planes can usually be seen, emphasized by identical mineral paragenesis. The absence of cataclasm suggests that the flow of the material may not involve a loss of continuity because sliding occurred through the inter- and intra-grain zones.

The structure of the metamorphic rocks is mainly characterized by a homoclinal attitude. High-angle (60-80°) southeastern dips predominate, although in the southern portions of the outcrops one can observe high-angle northwestern and western dips. Judging by the gradual turns, the western dips were caused by folding, which will be discussed later.

The investigation of fold structures that occur sporadically shows that their ages are different. The earliest folds are synchronous with metamorphism. Schistosity is parallel to their axial planes. Such folds are not observed in the discussed exposure area, but they occur in the metamorphic rocks exposed a little farther to the north.

In the schistosity plane, one can occasionally see a slightly expressed stretching lineation. It has been formed by elongated relics of clastic grains framed by quartz-muscovite aggregates. The lineation plunges to the SW at angles of 45-60°. An attempt to define the shear sense was undertaken on the basis of the grain shapes, pressure shadows and S-C surface. Unfortunately, it is mostly in the area with anomalous northwestern and meridional trends that the stretching lineation is macroscopically observed (Fig. 1.1, Stop 3). Here, the shear criteria reveal movements from the east to the west. These directions are opposite to those typical of the Khabarovsk complex. It is remarkable, however, that they are traces of the earliest

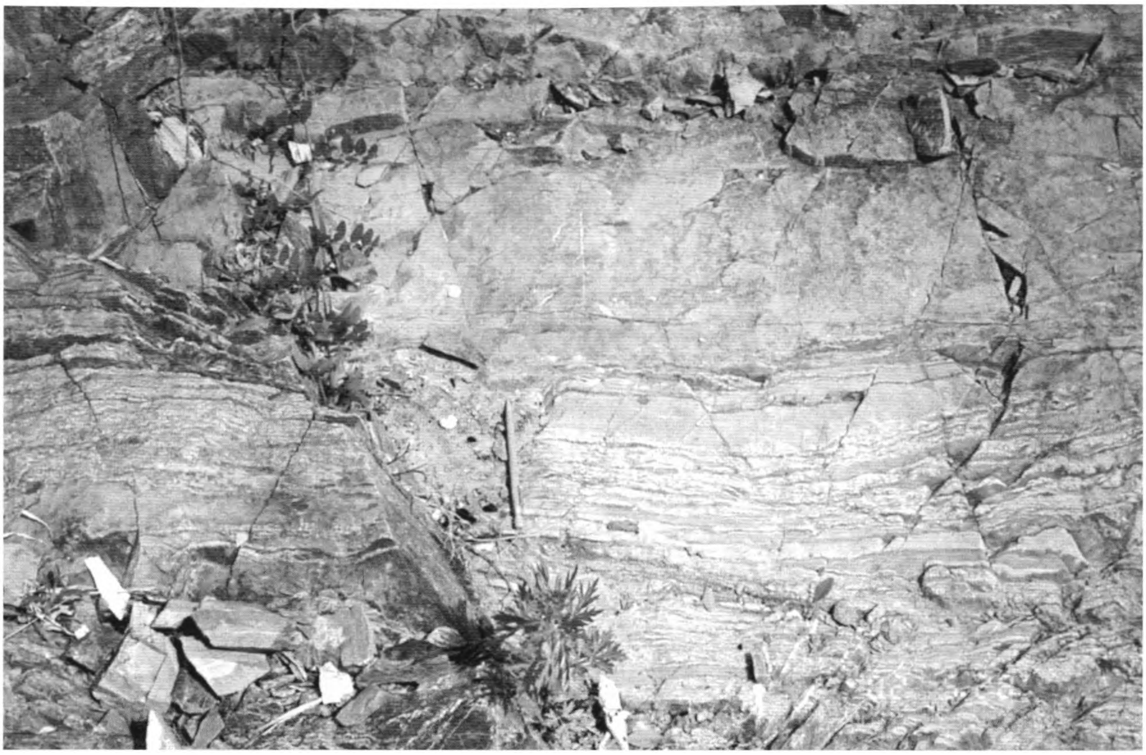


Fig. 1.3. Beds of thin-bedded intercalation with cross and flaser bedding.

movement esatblished in the exposure area.

In addition to the stretching lineation, thin wrinkles with a different orientation are present on the schistosity planes. Their nature is not yet clear either, but together with the schistosity they are involved in small asymmetric tight and open steeply plunging folds (>45°). The viewers can also see such folds in the southern part of the exposure area (Fig.1.1, Stop 2) where folds with a half wavelength up to 10 m can be observed. These are mionor folds on a short westward dipping limb of a similar but larger fold lying between the sheets with homogeneous NE-trends. The limb of the fold is cut in the southeast by the NE-trending left-lateral strike-slip fault; the zone of this fault has a well expressed duplex structure (Fig. 1.1, Stop 2). The asymmetry of this fold also testifies to the sinistral motion. Judging by orientation and position in the general frame of this fold and strike-slip fault, they may correspond to the third-stage structures of the Amur complex, which indicate a wide belt of the left-lateral strike-slip movement along the Amur suture.

Among the brittle deformations in the metamorphic rocks of the Khabarovsk complex, NW-dipping thrusts are notable (Fig. 1.1, Stop 2).

In the band of metasandstone and schist outcrops there are younger sedimentary rocks. In the southern part of the exposure area, metamorphic rocks are cut by an E-W-trending right-lateral strike-slip fault whose gouge is composed of cataclasites up to 1,5 m thick and dips to the south at angles of 70-80°. On the northern wall of the fault metamorphic schists (foliation – WSW 250, P70°) are discordantly (base – SSW 185P60°) overlain by an olistostrome with pebble-size inclusions and exposed thickness of about 0,5 m. The base of the olistostrome is uneven, with minor depressions filled with the material with a higher concentration of coarser clasts. The clasts are not sorted out, they are angular, almost unrounded, represented mainly by sandstones and enclosed in the pelitic matrix. Near the fault the matrix is sheared.

With the help of phase diagnostics by the IRS method, muscovite and quartz have been identified in the matrix. The lattice parameters of mica defined by electronic microscopy show that the muscovite is a 2M+1M mixture. As it is known, the 1M muscovite is typical only of unmetamorphosed sedimentary rocks, hence a sharp metamorphic contrast is between the olistostrome and metamorphic rocks. Opposite to the other pelitic rocks exposed farther to the north, increased contents of K_2O (7,27%), Fe_2O_3 (9,41%), Rb ($95\cdot10^{-3}$%), and Y ($32\cdot10^{-3}$%) were esatblished in the matrix of the olistostrome with the help of a laser mass-spectrometry method.

In the north, the metamorphic rocks are bounded by a SE-dipping fault conformable to the attitude of schistosity in the metamorphic rocks (Fig.1.1, Stop 4). To the north of the fault, the fabric of the complex notably changes, and the structure of the exposed part here is defined as a typical melange. The matrix of the melange (named below as a tectonic matrix) is represented by black intensively sheared pelitic rocks. Their sedimentary nature is various. Together with the layered aleuropelitic rocks containing thin (about 3 cm) boundinaged fine-grained sandstones, the matrix contains a large volume of olistostromes with pebble-size inclusions of variegated cherts, basic volcanites and volcanomictic sandstones enclosed in the black pelitic matrix. The tectonic matrix is supposed to have been formed on the sequence of layered rocks with olistostrome horizons.

Inclusions in the melange are variegated in composition and morphology. Their sizes range widely. Lenses and sheets of ribbon cherts and cherty mudstones, lenses of basic volcanites, limestones, olistostromes of other types, sandstones and massive siltstones occur there.

Five metres to the north of the contact with metamorphic rocks in the black tectonic matrix, a large lens of a fine clastic olistostrome with a red cherty-argillaceous matrix and mainly basaltic pebble-size inclusions occurs (Fig. 1.1, Stop 5). The schistosity in the tectonic matrix envelops the lens of the red olistostrome, inside the lens the schistosity is discordant with its boundaries (Fig. 1.4).

Twenty metres to the north, another lens of a fine-clastic olistostrome is exposed with a pistachio-coloured matrix and occasional larger (up to 0,3 m) inclusions of red cherts.

In this part of the section the tectonic matrix schistosity has regular SE dips which agree with the dips of the schistosity in the northern part of the metamorphic rocks. The same attitude is observed in the tectonic sheet of the cherts cropping out north of the tectonic matrix with lenses of red and pistachio-coloured olistostromes.

The top of the sheet is composed of red scaly argillaceous rocks. On the contact with the tectonic matrix, these rocks are sheared and contain lenses of black schists (Fig. 1.3, Stop 6).

The argillaceous rocks are underlain by red cherts. Thin chert beds (1-4 cm) are intercalated with thinner (0,1-0,5 cm) red mudstones similar to those of the sheet's top. It is notable that the mudstones are not scaly here. The bedding of the southern part of the sheet has a rather stable homoclinal SE dipping. In the inner part there is an intrafolial symmetric fold indicating NW thrusting (Fig. 1.5). In the northern part of the sheet there are numerous close and tight gently plunging folds with N-dipping axial planes. These folds and faults mark SE-directed movement opposite to that from the intrafolial fold. These are the first signs of SE movements, a widespread manifestation of which will also be observed.

Shevelev (1987) found Middle Triassic conodonts in the cherts*. Red mudstones contain a great variety of radiolaria, among which the following were identified**: *Trillus elkornensis* Pessagno et Blome, *Bagotum* sp. aff. *B. modestum* Pessagno et Whalen, *Canoptum anulatum* Pessagno et Poisson, *C. dixoni Pessagno* et *Whalen, C.* sp. aff. *C. dixoni, C. poissoni Pessagno, Canutus indomitus* Pessagno et Whalen, *Droltus* sp. aff. *D. laseekensis* Pessagno et Whalen, *D.* sp. cf. *D. hecatensis* Pessagno et Whalen, *Hsuum* sp., *Lupherium* sp. *A.* Pessagno et Whalen, *1982.*

The complex of these radiolaria corresponds to Late Sinemurian-Pliensbachian, most likely to Pliensbachian age.

Next to a small area without outcrops, pistachio-coloured shales are exposed. This is the first outcrop with NW-dipping bedding. The pistachio-coloured shales (Fig. 1.1, Stop 7) are overlain by red siltstones, but paleontological data show an overturned attitude. Late Bathonian-Middle Callovian radiolaria have been found in the pistachio-coloured shales: *Droltus (?)* sp., *Hsuum inexploratum* Blome, *H.* sp. aff. *H. parasolense* Pessagno et Whalen, *H.* sp. aff. *H. rosebudense* Pessagno et Whalen, *Parvicingula elegans* Pessagno et Whalen, *P* sp. *A.* Blome, *1984, P.* sp. *B* Blome, 1984, *P.* sp. aff. *P schoolhousensis* Pessagno et Whalen, *Ristola* sp. aff. *R. decora* Pessagno et Whalen, *R.* sp. aff. *R. prisca* Blome, *R.* sp. aff. *R. turpicula* Pessagno et Whalen.

The red siltstones observed 0,2 m higher that the contact, contain a complex of radiolarians most likely of Middle Bajocian age: *Pantapellium* sp. *F.* Pessagno et Blome, *1980, Trillus* sp. aff. *T. seidersi* Pessagno et Blome, *T.* sp. aff. *T. elkhornensis* Pessagno et Blome, *Zartus praejonesi* Pessagno et Blome, *Z. jonesi* Pessagno et Blome, *Z.* sp. aff. *Z. imlay* Pessagno et Blome, *Archaeodictyomitra* sp. aff. *A. primigena* Pessagno et Whalen, *Hsuum bellilatatum* Pessagno et Whalen, *H.* sp. *C* Pessagno et Whalen, 1982, *Lupherium officerense* Pessagno et Whalen, *L.* sp. aff. *L. snowshoense* Pessagno et Whalen, *L.* spp., *Parvicingula burnsensis* Pessagno et

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* Localities of faunal occurrences and its age are shown in Fig. 6.

** Here and below are S.V. Zyabrev's definitions.

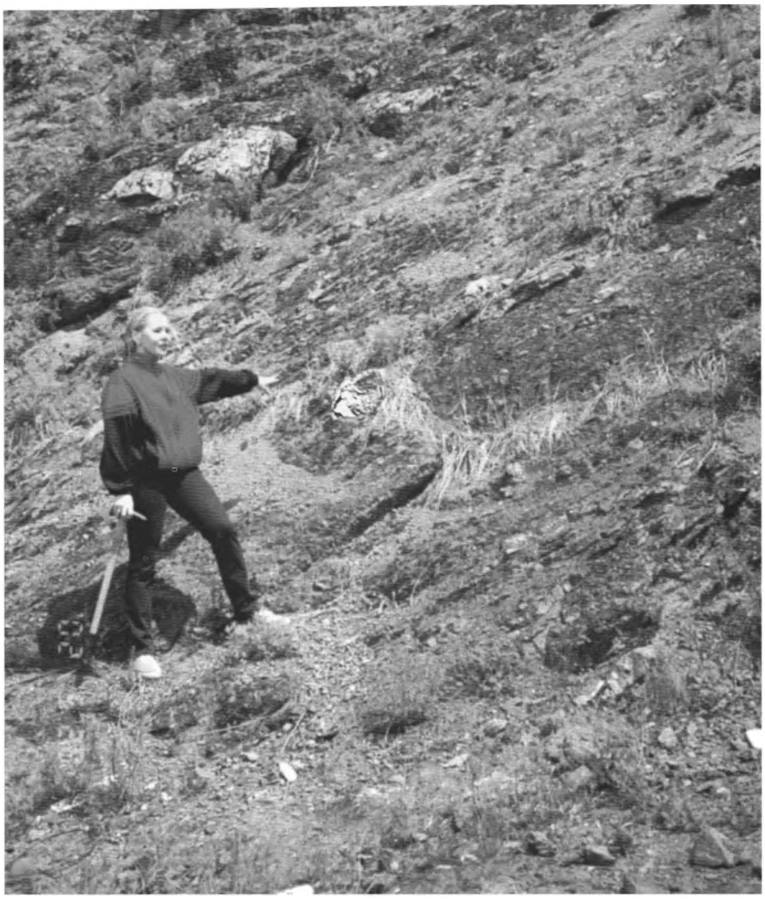

Fig. 1.8. A large block of melange, the Khabarovsk complex, the Amur R.

The surfaces of the inclusions are polished and striated. The lenses are flattened in the plane of the matrix schistosity, their shapes often indicate rotations during deformation processes. Often there are folds in the inner parts of the inclusions. On the whole, their axial planes are conformable to the matrix schistosity, but there are no folds in the matrix.

As it has already been mentioned, the tectonic matrix was formed from various sedimenatry rocks, also layered ones. It includes lenses of olistostromes of different composition with typical matrix-inclusion relationships. Such relationships can be observed in small isometric, but not in large lenticular inclusions in the tectonic matrix. All this testifies to the presence of a tectonic melange of the type known as flow melange.

The slip that resulted in the formation of the tectonic lenses occurred, as a rule, on the surfaces of the tectonic matrix schistosity. In addition, a series of larger shears is present in the outcrops, which disturb both the matrix and the inclusions. The shear zones have SE vergence and are evident of multistaged deformation history.

We consider the Khabarovsk complex at the Amur River railway bridge near Khabarovsk as a tectonic melange. Metamorphic rocks form one of the largest sheets in it. In the south, they border on the same tectonic matrix (Fig. 1.1). Farther northward, one can see smaller sheets of metamorphic rocks enclosed in the tectonic matrix.

Generally, the melange of the Khabarovsk complex is characterized by a wide variation of the inclusion sizes and a different matrix ratio. The extreme members of the range can be observed on the excursion site.

The available information on the age of the matrix is extremely scarce. Ten metres to the south of the second red chert sheet, poorly preserved radiolaria have been found, among which the ones corresponding to the Early Hauterivian-Early Barremian: *Pseudodictyomitra* sp. cf. *P. lilyae* (Tan Sin Hok), *Siphocampium* sp. cf. *S. davidi* Shaat.*

Thus, the tectonic matrix contains terrigenous rocks of the same age as the Amur complex is. It is the basis for suggesting the Khabarovsk complex and the Amur complex to belong to a single subduction complex with different deformation environments in different parts.

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* Later on, S.V. Zyabrev revised his definitions (S.V. Zyabrev and A. Matsuoka, 1999).

RADIOLARIANS FROM THE KHABAROVSK SECTION

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Along the right bank of the Amur River, the Khabarovsk Section starts from the Voronezh-2 settlement to southwest (see Fig. 6). The section is characterized by the accretionary melange facies. Scaly cleavaged-shales and sandstones with various size of chert and limestone blocks show the block-in-matrix texture. The strata trends E-W and dip southward. The lower half of the section shows the highly tectonized feature that the matrix sandy-mudstone contains huge amount of big blocks of chert and lithic sandstone. The upper half of the section is composed of moderately cleavaged-mudstone that frequently intercalates fine sandstone beds of distal turbidites and tuff seams. The mudstone also contains a few small blocks of chert except for the tectonic lenses of sandstone and tuff. Late Jurassic radiolarian fauna was extracted from the matrix tuffaceous-mudstone and tuff block of the upper part of the section. This is the first report about radiolarian age of thetuffaceous mudstone..

Samples: Aug. 9-1A and C

The uppermost part of the section is composed of the dark green tuffaceous shale with small tuff blocks that were caused by the ductile-shear deformation of the bed. The tuffaceous shale (Aug9-1A) yields *Eucyrtidiellum nodosum* Wakita, *Loopus* sp., *Archaeodictyomitra* spp., *Parvicingula* sp., *Svinitzium* spp., *Sethocapsa* spp. and *Tricolocapsa* (?) spp. In addition to the same species as above, *Eucyrtidiellum ptyctum* (Riedel & Sanfilippo) and *Hsuum brevicostatum* (Ozvoldova) were extracted from the tuff block (Aug9-1C). *E. ptyctum* has its range from the middle part of the *Tricolocapsa conexa* Zone to *Loopus primitivus* Zone (Nagai & Mizutani, 1990). Co-occurrence of *E. ptyctum* and *E. nodosum* indicates the UAZ 8 to 10 (Baumgartner et al., 1995). *H. brevicostatum* has its range from the UAZ 3 to 11. *Pseudodictyomitra* (?) sp. D group of Matsuoka (1986) being regarded as the synonym of these primitive types of *Loopus* spp. appears from the upper part of the *Stylocapsa* (?) *spiralis* Zone that is just below the occurrence of Early Kimmeridgian ammonite (*Ataxioceras kurisakense*) in the Outer Zone of SW Japan (Ishida, 1997). Therefore, we estimate that the age of the assemblage is early Late Jurassic.

Sample: Aug.9-6

The same types of *Loopus* sp., *Sethocapsa* spp., *Zhamoidellum* sp., *Williriedellum* sp. and *Gongylothorax* sp. cf. *G. favosus* Dumitrica yielded also from the matrix tuffaceous-mudstone of the upper part of the section (Aug. 9-6).

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The route begins from Khabarovsk in the northeastern direction along the highway Khabarovsk-Komsomolsk-on-Amur to the Anastasievka settlement, then to the north along the road to the Petropavlovka settlement.

Stop 2-1. Outcrops along the northeastern bank of the Petropavlovsk Lake begin south of the pioneer camp. In benches and bank outcrops one can observe mostly schistose aleuropelites with sandstone layers, thin-bedded turbidites, and isolated tuff beds belonging to the lower subsuite of the Petropavlovsky suite (Fig. 2.1, 2.2). The aleuropelites usually without lamination, are predominant. Sometimes bioturbation and trace fossils are seen. The lower part of the suite includes medium to coarse sandstone beds (Fig. 2.3). In the middle part, one can observe olistostrome horizons with scarce olistholites of sandstones, mudstones, marl, gray and green cherts (Fig. 2.4). The size of the fragments varies from 0,5r1cm to 1r1,5 m. In the chert fragments T.V. Klets in 1986 discovered conodonts *Neogondolella* sp. (samlpe 4/1), *Neosparthodus (?) sp., Neogondolella (?) sp.* (sample 4/3) of Triassic age, and *Epigondolella cf. abneptus* (Huckr.), *Ep.* cf. *postera* (Koz et Mostl.) of middle to late Norian. A large olistolith includes of a block of siliceous-clayey shales with limestone lenses about 4 m thick, outcropping in a worked out quarry south of the camp (Fig.2.2). E.P. Brudnitskaya identified *Halobia* cf. *charlyana* Moys., *Halobia?* sp., *Posidonia subwengensis* Kipar., *Otapiria* sp. indet. have been from the limestones, and conodonts *Epigondolella postera* (Koz. et Mostl.), *Ep. abneptis* (Huckr.) of middle to late Norian age from the siliceous-clayey shales. On the whole, these rocks have been defined as Late Triassic to Early Jurassic in age.

In the upper subsuite, among the slates there occur oval marly nodules about 20 cm in diameter (Fig. 2.5), sometimes containing fauna.

Mostly in the upper outcrops of the subsuite medium-bedded turbidites about 5 m thick (Fig. 2.6) occur composed of gray fine sandstones (5-10 cm) and aleuropelites (2–7 cm).

On the age. The Petropavlovsky outcrops were more than once visited by geologists. Collections of fauna and flora were gathered there (Kharitonychev G.I., Nikolsky V.M., Beltenev E.B., Savchenko A.I., and Kapitsa A.A.). Among the fauna predominant are buchiid species. V.I. Vereshchagin and A.A. Kapitsa identified the following forms among them: *Buchia keyserlingi* Lah., *B. inflata* (Toula) Lah., *B. volgensis* Lah., *B. wollossowitschi* Sok., *B. fischeriana* (Orb.), *B. terebratuloides* Lah., *B. crassa* Pavl., *B. uncitoides* Pavl., *B. zyrianica* Sok., *B. bulloides* Lah., *B. seythica* Sok., *B. tolli* Sok., *B. paradoxa Sok., B. sibirica* Sok., *B. crassicollis* Lah., and *B. lahuseni* Pavl. Besides buchiids, sporadical ammonites *Polyptychites* sp. and pelecipod, belemnite fragments occur.

Among the above Buchia species the Valanginian ones appear the most abundant. However, species typical for the Berriasian and Late Jurassic (*Buchia volgensis* (Lah.), *B. fischeriana* (Orb.), and *B.* aff. *terebratuloides* Lah. and others) are also common.

Taking into account the presence of olistostromes among the outcrops of the lower subsuite of the Petropavlovsky suite, one can suppose that the Late

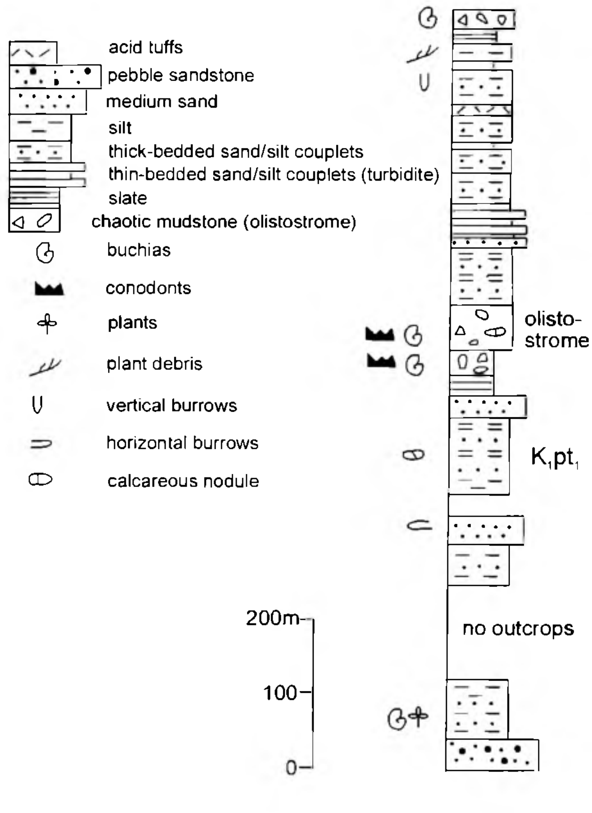


Fig. 2.1. Columnar section of the lower subsuite of the Petropavlovsky suite (the Petropavlovsk Lake).

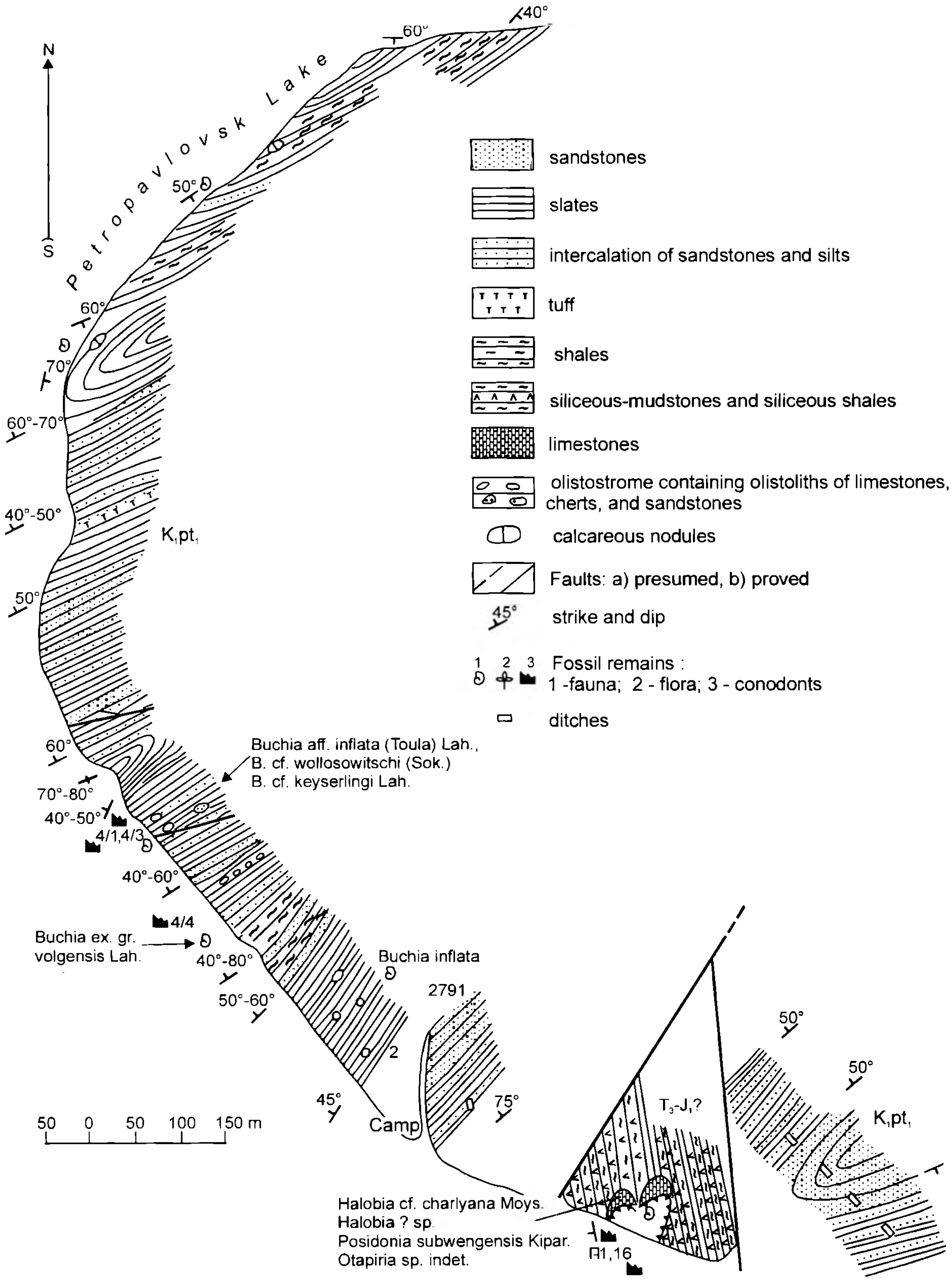


Fig. 2.2. Outcrops of the lower subsuite of the Petropavlovsky suite (K_1pt_1) along the northeastern bank of the Petropavlovsk Lake (after Pozdnyakova, 1965, with additions).

Fig. 2.3 Medium sandstone beds among the aleuropelites. (K_1pt_1)

a

b

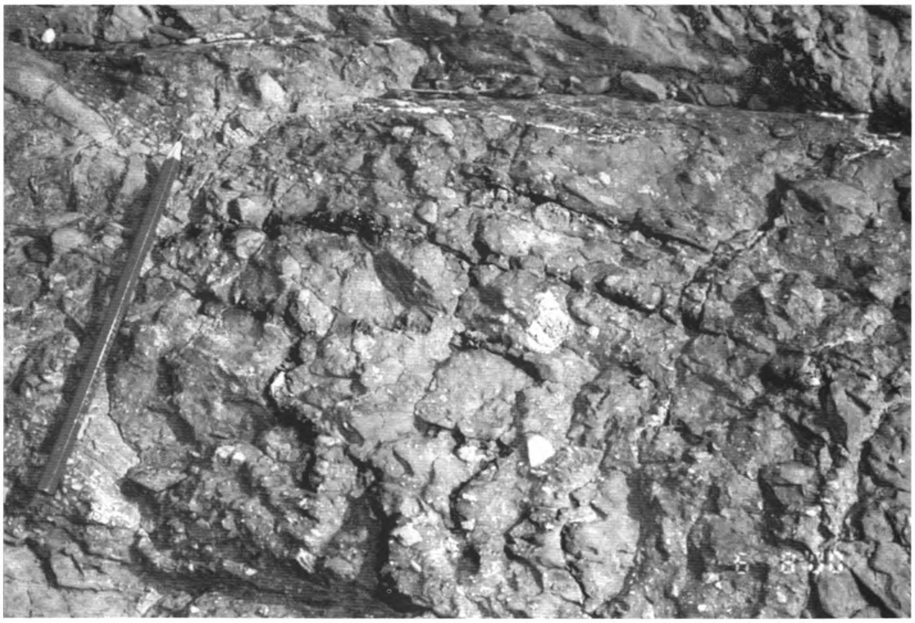


Fig. 2.4. Olistostrome (a) in the middle part of the lower subsuite, the Petropavlovsky suite. Matrix – black aleuropelites. Olistoliths are represented by sandstones, cherts, mudstones, and tuffs. Details of olistostrome structure (b).

Fig. 2.5. Marl nodule among the aleuropelites (K_1pt_1).

Fig. 2.6. Medium-bedded turbidites in the fold hinge are composed of fine sandstones (5-10 cm) and black aleuropelites (2-5 cm). An erosion contact is seen in the middle part of the figure.

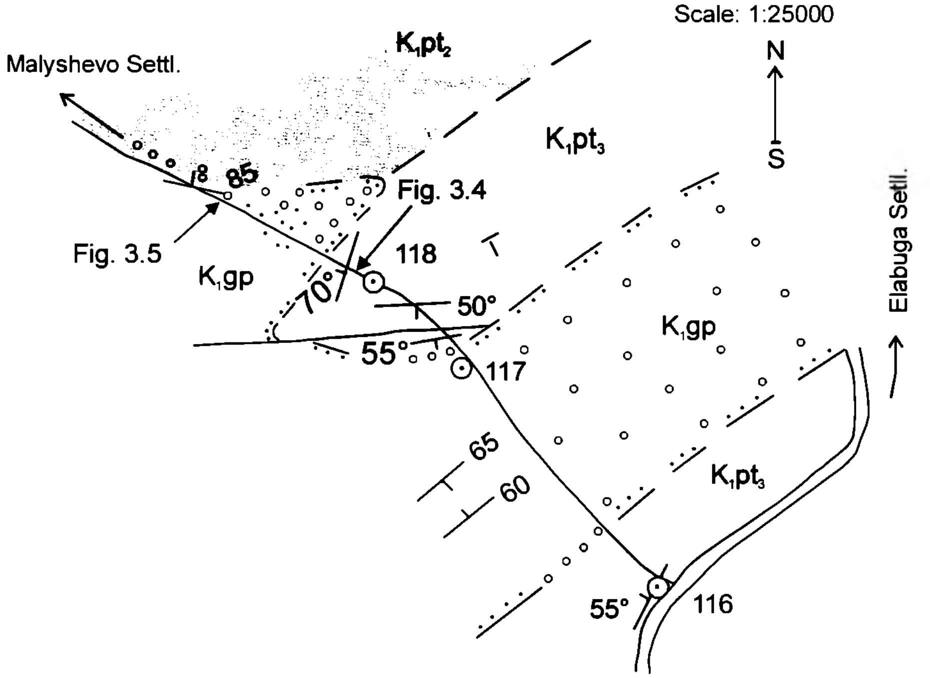


Fig. 3.2. Outcrops of the turbidites of the upper subsuite of the Petropavlovsky suite (K_1pt_3) and basal beds of the Gornoprotoksky suite (K_1gp).

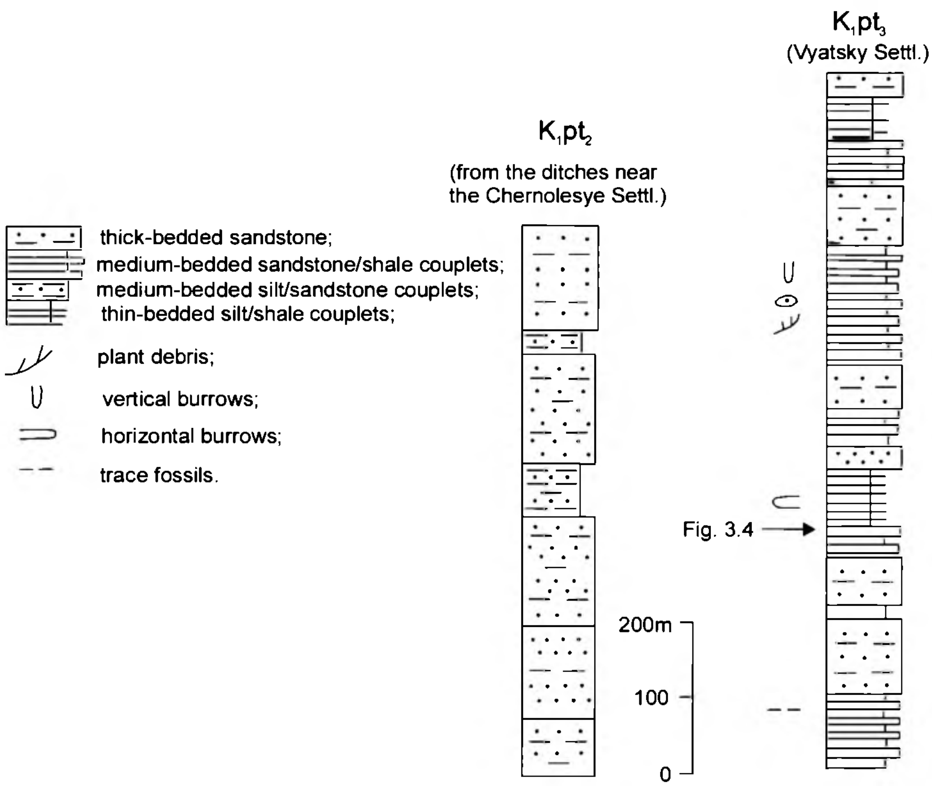


Fig. 3.3. Columnar section of the middle and upper subsuites of the Petropavlovsky suite.

Fig. 3.4. Turbidites of the upper subsuite of the Petropavlovsky suite (K_1pt_3) near the Malyshevo Settl.

Fig. 3.5. Basal conglomerates of the Gornoprotoksky suite (K_1gp) near the Malyshevo Settl.

Approximately in the middle of the interval, the outcrop of the turbidites is cut by a fault zone with a thickness of about 5 m. The rocks appear to be dismembered and bleached in this interval.

The outcrops are followed with a quarry where an uneven eroded contact of the turbidites and conglomerates can be observed. Conglomerate layers of 2–3 m in thickness are exposed in different parts of the quarry. Pebble being rather well rounded, makes up from 10 to 80% (Fig.3.5). The size of the pebble varies from 0,5 to 20 cm in diameter. It is composed of the siliceous rocks (33–50%) represented by white, light gray, dark gray cherts, brownish-red jasper, microquarzite, and white quartz. Volcanic and intrusive rocks (22–45%) represented by granites, granite-porphyry, and quartz albitophyre. Sedimentary rocks (6–45%) include mudstones, sandstones, and siltstones. Cement makes up 20–30% and is represented by feldspathic graywacke.

In the opinion of the geologists involved in studying this region during the geologic mapping at a scale 1:50 000 (Pozdnyakova et al., 1964), sandy/silty series with conglomerates at base being later called the Uktursky (Masibroda et al., 1980) and then Gornoprotoksky suite (Decisions ..., 1990), occurs with erosion and angular unconformity at different horizons of the Petropavlovsky suite and has a different strike (see Fig. 3.1). Unfortunately, only a fragment of a shell *Inoceramus sp. indet* has been recorded from the deposits of the suite. According to M.A. Pergament, it resembles Late Hauterivian inoceramids found on the eastern slopes of the North Sikhote-Alin. Farther south near the Korfovsky settlement, *Tyrmia polinovii* Pryn. common for Early Cretaceous Bureya basin along with *Cladophlebis* sp., *Nucula* sp., and pelecipod and ammonite imprints were detected in similar deposits. However, these hamper the determination of an exact age. A younger age of the suite may be indirectly confirmed by the presence of pebbles of quartz porphyry in conglomerates, that resembles quartz porphyry from the dykes injecting the Valanginian deposits of the Petropavlovsky suite. In addition, rock density of the suite is considerably lower rather than in the underlying Valanginian deposits. At present, the suite is approximately defined as Hauterivian to mid-Albian in age.

Stop 3-3. After the observation of the outcrops we shall take a bus to visit a Nanaian settlement located on the picturesque bank of the Amur River in the Sikachi-Alyan outskirts.

Here during late Stone Age, the first settlement of the ancient tribes appeared testifying to transition of the people to a settled way of life. That was also the time for the ancient art works of worldwide significance to appear.

The Petroglyphs situated here is one of them. One can see basalt boulders embroided with diverse «drawings», featuring birds, animals and facial images. The most ancient of them date back to 12,000 B.C. Petroglyphs similar to Amur ones, are found in Australia, Japan, and America.

In the Sikachi-Alyan one can get to know many historical facts about the origination and evolution of aboriginal Amur population and its cultural heritage.

The display of the museum exhibits starts with archeological collections made up of early and recent excavations either kindly offered by the locals or obtained during the field trips. The ceramic collection vividly mirrors Stone Age, Early Iron Age, and the Middle Age periods.

To feel the ancient mode of life of hospitable Nanai population, the museum offers a separate Nanai ordinary house interior. Cradled under the towering trees is the museum of abode samples of Stone and Iron Ages reflecting culture and mode of life typical for those times. And in the impenetrable thick of the oak grove one can come across detached and stranded wooden idols, right at the place where shamans launch into all pervasitive ritual dances begging the spirits for fortune and luck.

After a visit to the Sikachi-Alyan the visitors will be offered to enjoy a traditional Far Eastern meal.

4. UPPER JURASSIC-LOWER CRETACEOUS FORE-ARC DEPOSITS OF THE KOMSOMOLSK SERIES ALONG THE RIGHT BANK OF THE AMUR RIVER OPPOSITE KOMSOMOLSK-ON-AMUR

Opposite Komsomolsk-on-Amur along the right bank of the Amur River for a distance of over 18 km one can observe almost continuous outcrops of the Upper Jurassic -Lower Cretaceous deposits. This outcrop has long been known as Pivan or Komsomolsky one. During the geological mapping, scale 1:200 000 (1954-1960), this outcrop was studied by many investigators (P.P. Emel'yanov, A.I. Freidin, A.I. Savchenko, E.B. Beltenev, A.A. Kapitsa), numerous faunal occurrences have been found dominating in buchiids, whereas ammonites, inoceramids, and flora are found in a minor amount (Freidin et al., 1961).

A rather homogeneous composition of the terrigenous deposits together with complicated dislocation and absence of the marking horizons made the outcrops difficult to divide and correlate. In the 60s during the geological mapping Upper Jurassic-Lower Cretaceous terrigenous sequence has been subdivided into six suites with a total thickness of 8000 m, as follows: Ulbinsky, Silinsky, Padalinsky, Goryunsky, Pionersky, and Pivan ones. The latter three suites are usually grouped into the Komsomolsky series. Folded structure was interpreted as a limb of a large anticline within which beds have a southeastward dipping. The anticlinal axis was located to the northwest of the Komsomolsky outcrop. Although the localities of buchiid fauna were abundant, a detailed division from them appeared impossible because Volginian and Valanginian species often existed in one locality.

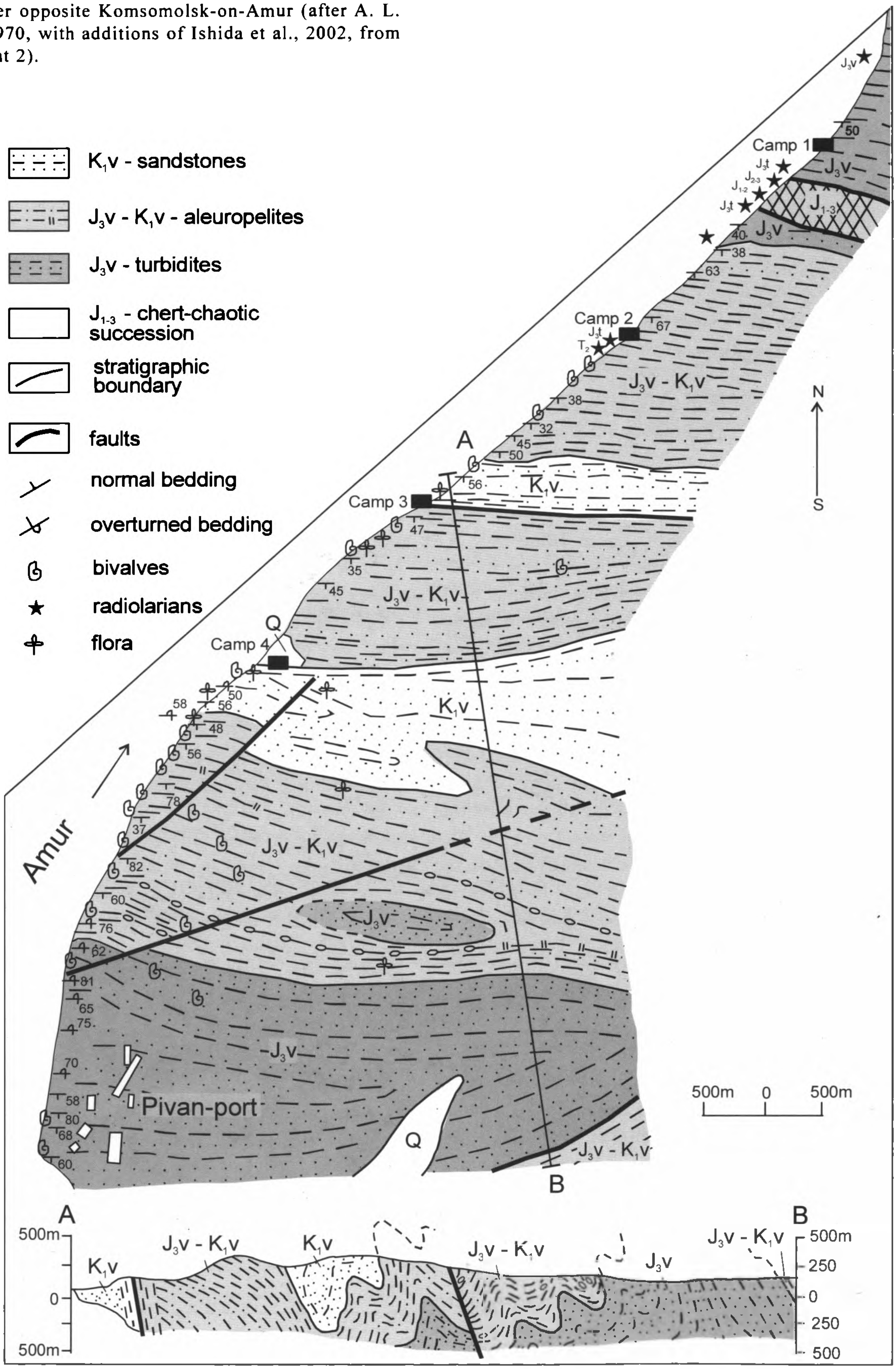
Nonetheless, paleontologists A.A. Kapitsa and L.D.Tretyakova, involved in studying of the sequence and fauna, in the whole, proved in 1965 the previously existed concepts on the monoclinal structure of the sequence. They estimated a total thickness of the suites of the Komsomolsky series as 8500 m.

In 1970 in the vicinity of Komsomolsk-on-Amur, a geological mapping was carried out at a scale 1:50 000 (V.V. Kulakov, A.L. Vokuev, and L.P. Romanova). During the investigations, all the sequences of the suites encountering fauna and flora in them have been analyzed. A folded structure of this territory has been studied in more detail. Four new faunal localities have been established. As a result, it was assumed that Upper Jurassic-Lower Cretaceous formations of co-eval age are well developed on the right and left banks of the Amur River extending from the Myao-Chan Ridge in the west to the Pivan settlement in the east. In addition, a complicated folded structure of the region under study represented by a series of isoclinal folds in NW overturned attitude and cut by faults with mostly northeastern strike (Fig. 4.1) has been proved. According to these investigators, the Ulbinsky, Padalinsky, and Pionersky suites similar in composition, are a single unit. The Silinsky and Pivan suites occurring in the cores of the synclines are supposedly a single unit as well occupying a higher stratigraphical level. As a result, the following stratigraphic scheme has been proposed: a unit of rhythmic intercalation of the rocks (Upper Jurassic, Volginian stage – J_3v) with a thickness of more than 700 m (the lower part of the section has not been studied), siliceous-silty unit* (J_3v-K_1v) with a thickness of 1070 m, and a sandstone unit (K_1v) about 800 m thick (Fig. 4.2).

In 1990 the Komsomolsky section was studied by E.A. Kalinin, a paleontologist from the Khabarovsk mining-geological enterprise. He repeated faunal occurrences in some few localities found by previous investigators and established the recurrence of lithological beds in the section, presence of folds and overthrusts that enabled him to reduce a little the suite thickness. However, in the whole, the section is still open to discussion. Judging by the list of references cited, E.A. Kalinin was not acquainted with the results obtained by V.V. Kulakov and A.L. Vokuev and hence he could not revise and comment their detailed structural construction. Later on, E.A. Kalinin using the methods of some sedimentologists (Stoy, 1990; Walker, 1978, and others), distinguished 17 bed associations or facial groups in the Komsomolsky section giving letter symbols (A-G) to them, but the age succession taken by him from the northeast to the southwest has remained unconfirmed.

* It should be remarked that at that time an exotic nature of the siliceous rocks was yet not clearly understood.

Fig 4.1. Komsomolsky section along the right bank of the Amur River opposite Komsomolsk-on-Amur (after A. L. Vokuev, 1970, with additions of Ishida et al., 2002, from Supplement 2).



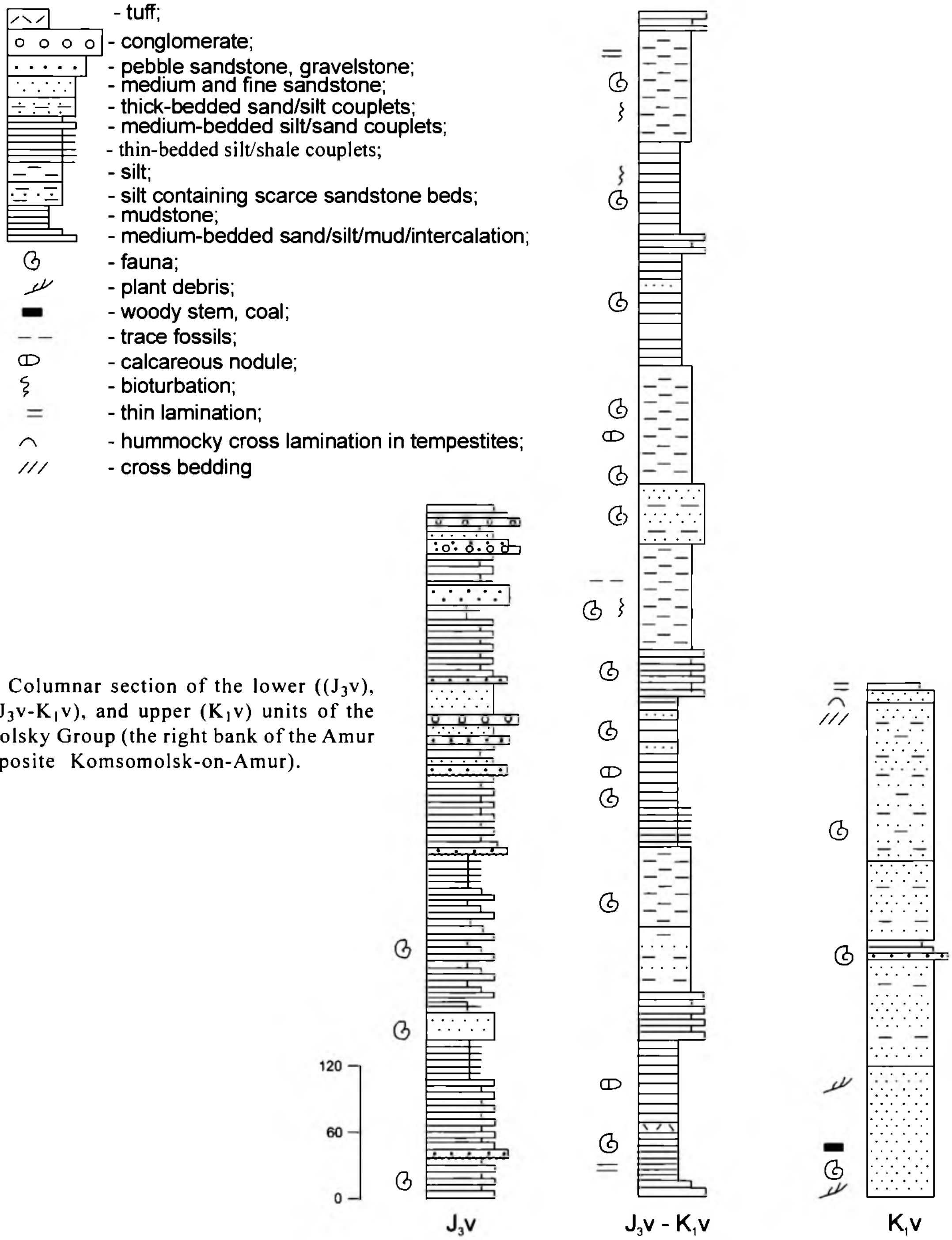


Fig. 4.2. Columnar section of the lower ((J_3v), middle (J_3v-K_1v), and upper (K_1v) units of the Komsomolsky Group (the right bank of the Amur River opposite Komsomolsk-on-Amur).

In June of 2001 the scientists from the Institute of Tectonics and Geophysics of the Far Eastern Branch of the Russian Academy of Sciences G.L. Kirillova, E.A. Kalinin and S.A. Medvedeva visited the Komsomolsky section aiming at investigation of oil and gas potential of these deposits. When examining outcrops in the area of Camp 1, they established an exotic nature of the cherts and variegated shales, revealed some specific features of the texture of the sedimentary beds throughout the section. In addition, mass bioturbation events in black siltstones have been revealed. Black aleuropelites exhibit high bituminosity (Ryazanova, Kirillova, Medvedeva, 2002).

In August of 2001 a joint Russian-Japan expedition Amur-2001 took place, in which G.L. Kirillova, E.A. Kalinin, S.A. Medvedeva and Japanese scientists T.

Sakai, K. Ishida, T. Kozai, T. Ohta, and N. Ishida participated. Among other sections of Priamurie they studied the Komsomolsky section. A mass detailed sampling of the section for radiolarians was carried out beginning from the creek located 1 km to the north of Camp 1 to the Pivan port. Sampling points were plotted on the section made by E.A. Kalinin though its imperfectness as to interpretation of the structure was obvious.

Unfortunately, from more than 100 selected samples only ten samples contain radiolarians. Four of them characterize the terrigenous fine clastic sediments of the unit J_3 and define its age as Late Tithonian-latest Tithonian. The other four samples were extracted from the pelagic bedded-chert and chert band in the siliceous shale in an exotic chert block (J_1-J_3) and date the age of the rocks in the interval from the Early and the earliest Late (early Kimmeridgian) Jurassic. Radiolarians from two samples extracted from another cherty block indicate Middle Triassic age of the cherts. The radiolarians have been identified by K. Ishida and N. Ishida. These data are schematically shown in Fig. 4.1 and described in detail in Supplement 2.

The first interval of the section. The first day we move across the Amur River by a small boat and start examining the outcrops approximately 2 km to the northeast of Camp 1 exposing from the mouth of the creek (Fig. 4.1). We will walk along the right bank of the Amur River for a distance of about 7 km moving from the northeast to southwest.

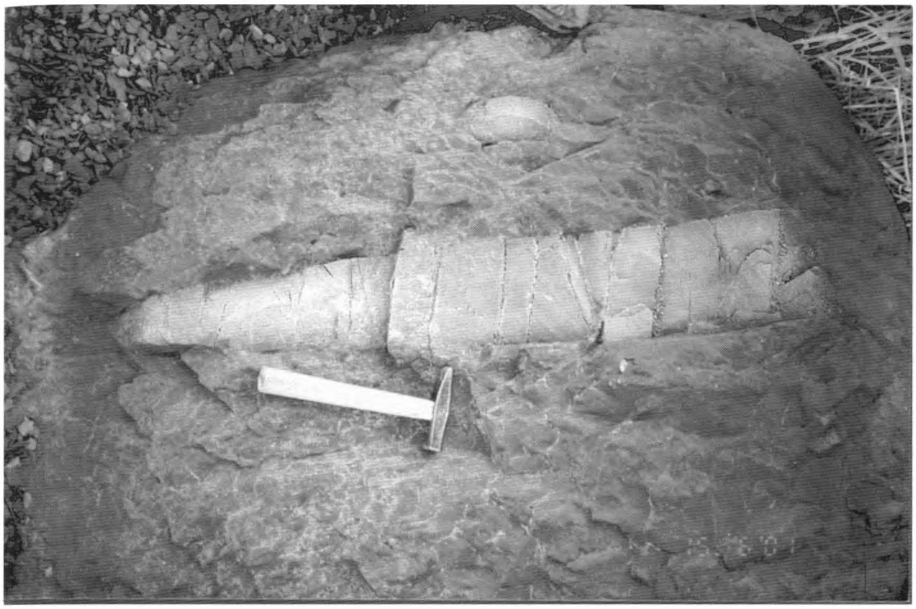
Aleuropelites are predominant on the right bank of the creek. About 100 m to the northeast of the mouth of the creek, one can observe a horizon of mixtites. Matrix and fragments of aleuropelites can sometimes be differred only from thin bedding and colour. Massive (up to 1 m in size) gray sandstones (Fig. 4.3),gray limestone nodules (0,4 m), calcareous sandstones, and thin lenses of green acid tuffs are rare. Farther on before the creek, where Camp 1 is located, predominant are black aleuropelites with sparse bands of compact dark gray siliceous aleuropelites with a thickness of 2-5 cm (Fig. 4.4). Blocks of sandstones, lenses and fragments of limestones are extremely rare. The rocks are highly schistose, deformed into narrow folds and cut by faults.

In this unit,1 km north of Camp 1, radiolarians were extracted from the nodular siliceous mudstone. K. Ishida defined their age as early Late Tithonian – latest Tithonian (see Supplement 2).

In the mouth of the creek where Camp 1 is located black schistose mudstones occur. Then for a distance of approximately 300 m no outcrops are found. Sandstones are dominant in the deluvium. Gradational bedding is sometimes seen in them. In the end of the interval blocks of bedded cherts appear in the deluvium. At the farther 50 m, there are outcrops of gray fine sandstones with packets of thin-bebbed turbidites up to 0,2 m thick (Fig. 4.5). Afterwards about a 50 m distance, the degree of rock schistosity gradually increases. Rocks are metamorphosed, the shales are marked with a lenticular texture (Fig. 4.6). Besides sandstone lenses, lenticular limestones, blocks of gray cherts were detected (Fig. 4.7 a-c). Here might be the main thrust zone. Behind the thrust zone, a chert-clastic succession of oceanic rocks represented by variegated cherts and shales prevails in the section. A detailed description of this part of the section (about 120 m thick) is given in Supplement 2. The descriptions of radiolarian assemblages from the matrix (J_3v-K_1) and fragments (J_2) are reflected there as well. A block of tectonic melange is bounded by faults from both sides. The faults are followed with black phyllitized clayey shales for a distance of about 100 m. V.V. Kulakov and A.A. Vokuev draw the contact between units J_3v and J_3v-K_1v from the top of the bed.

As far as Camp 2 one can observe irregular alternation of gray fine sandstones containing mudstone beds, and beds composed of two- and three-component turbidites (cd, cde) of the unit J_3v-K_1v. The thickness of isolated components varies from 5 to 20 cm. Fine-grained sandstones are indurated and silicified Thin lenticular light green tuff interbeds are sporadically distributed. Silification might be related to the volcanic activity. Often are seen patterns of flow burrows. Non-plutonic sandy dykes about 7 cm thick (Fig. 4.8) occur in the mudstones containing bioturbation traces and phosphatic concretions. K. Ishida found that dark siliceous mudstone yields radiolarians of the latest Tithonian (see Supplement 2). Thereby fragments of indefinable macrofauna occur. In the course of the route one can see small displacements of east-northeastern strike and accompanying Z-shaped folds.

In the area of Camp 2 located in the mouth of the Fedyurkin creek and more farther on over a distance of 100 m, black compact mudstones were exposed. At a distance of 100 m, a dyke of middle volcanites was observed. We did not find any outcops over next 100m (we are likely moving across the fault zone). Nevertheless, gray and green platy cherts appear in a large deluvial block. At a distance of 200 m, gray, greenish-gray, dark gray bedded cherts outcrop among black siliceous mudstones. K.Ishida extracted radiolarians of the lower Ladinian from these cherts (see Supplement 2). Among fragments in the muddy melange



a

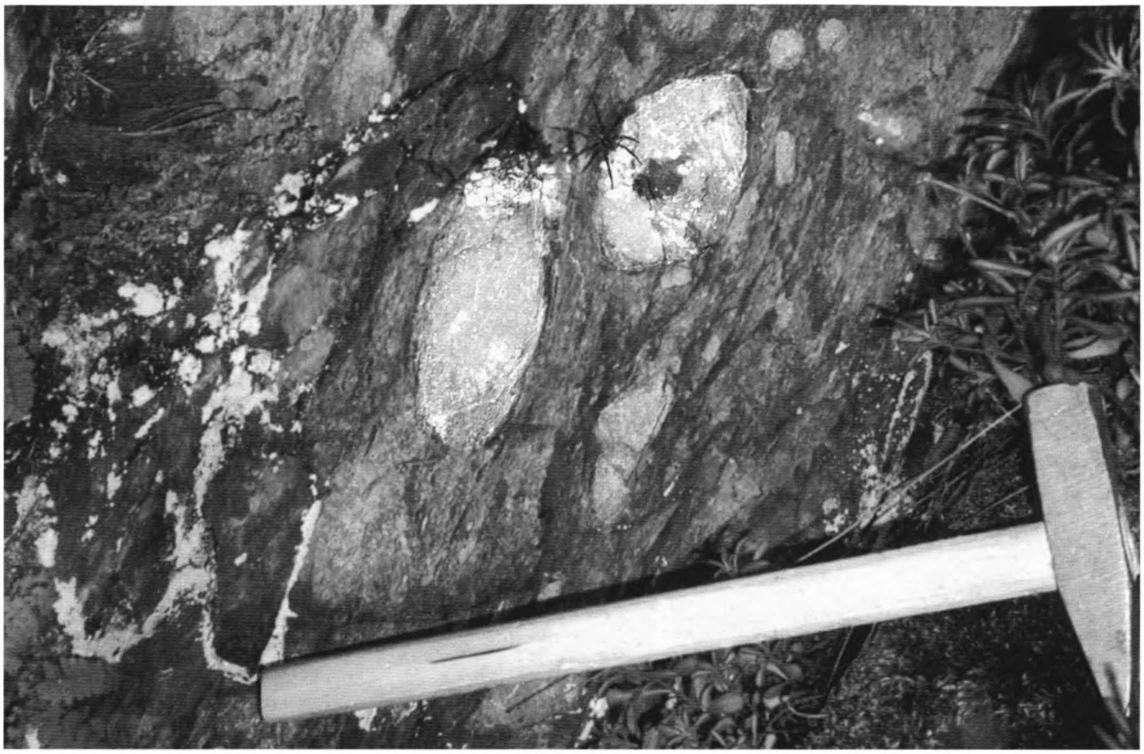
b

Fig. 4.3. Olistostrome with a pelagic matrix and olistoliths of fine sandstones (a) and limestones (b) in the unit J_3v. The Komsomolsky Section.

besides cherts (70%) green tuffs, quartz, and intrusive rocks (gabbro-diorite?) occur. The size of the fragments varies from 0,5r1 to 3r5 cm.

Then follow outcrops of black siltstones, mudstones (Fig. 4.9) with rare marly concretions, sparse laminite beds (1-3 mm thick), and gray siliceous mudstone beds with a thickness of 1-2 cm. Contacts are usually parallel and sometimes wavy. Many researchers draw the contact of the Gorinsky and Pionersky suites between the top of siltstone and mudstone beds.

Then bioturbated black siltstones or silty sandstones with vertical and horizontal burrows, trace fosils, plant debris, and sulphides are predominant in the outcrops. An increased bituminosity has been discovered in these siltstones (Ryazanova and Kirillova, 2002). Siltstone (3-5 cm) and sandstone (5-7 cm) beds alternation can be observed very rarely. In the course of the route fauna of Anopaea and buchiids is found more



a

b

c

Fig. 4.7. Shale melange with lenticular inclusions of cherts and sandstones (a), cherty blocks (b), and limestones (c). Unit J_{1-3}, the Komsomolsky Section.

Fig. 4.8. Neptunic sand dyke in the mudstones, unit J_3v-K_1v, the Komsomolsky Section.

Fig. 4.9. Aleuropelites, unit J_3v-K_1v, the Komsomolsky Section.

Fig. 4.11. Thick-, medium- and thin-bedded turbidite alternation, unit J_3v, the Komsomolsky Section.

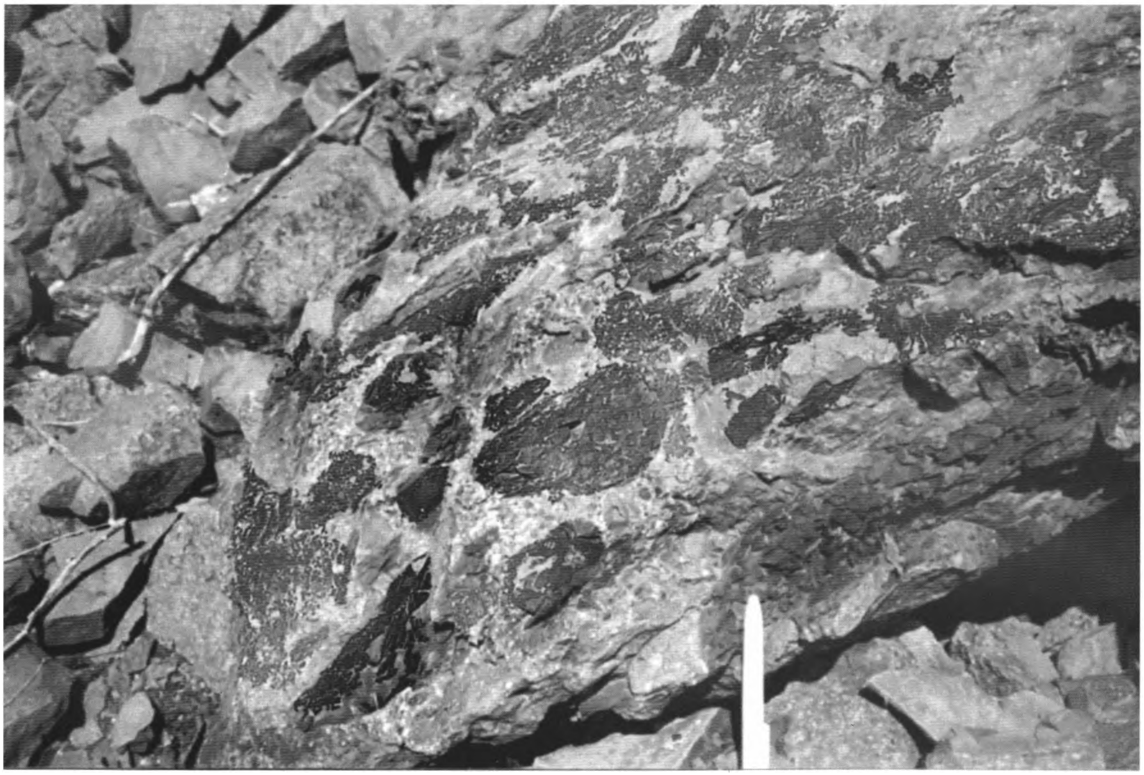


Fig. 4.12. Conglomerates, unit J_3v. Pebble fragments are composed of underlying mudstones (90%).

pivanensis Kap. et Tret., *B. amurensis* Kap. et Tret., *B. sibirica* Keys., *B. crassa* Pavl., *B. inflata* Toula, *B.* cf. *bulloides* Lah., *B.* sp. ex gr. *B. fischeriana* Orb., *B.* cf. *piriformis* Lah., *B.* cf. *tolli* Sok., and *B.* cf. *unchensis* Pavl. Along with the buchiids, there were identified species *Lima consobrina* Orb., *Inoceramus sorneyi* Poch., *In.* aff. *ovatus* Stanton, *In.* aff. *neocomensis* Orb., *In. (Anopaea)* ex gr. *sphenoides* Geras., and *In.* sp. ex *gr. mandibula* Mordv.

The beds are contorted into isoclinal folds and cut by faults, near which the rocks are intensively schistose.

Farther on, according to V.V. Kulakov and A.L. Vokuev, the unit K_1v is exposed in a block bounded with faults. They make up a limb of a turned syncline (Fig. 4.1) that is confirmed by an overturned rock bedding in the outcrops. A normal column section of the unit K_1v is shown in Fig. 4.2. We go on our way northwards. At the beginning of the interval greenish-gray medium (sometimes coarse) sandstones with rare beds of black siltstones about 5 m thick and dark gray fine sandstones with coalificated plant debris including rare fragments of wood stems occur. Higher up the section, the sandstone beds reduced in thickness up to 2 m. Before reaching 300 m to the creek, in the mouth of which Camp 4 is located, thick-bedded intercalation of gray fine sandstones and black siltstones can be observed in the outcrops. The thickness of the beds varies from 0,1 to 1,5 m. At the end of the interval on the left bank of the creek one can examine thin- and medium-bedded tempestites. The beds are 2-10 cm thick. As compared to classical tempestites characterized by a rudaceous composition, in this instance tempestites are composed of thin-bedded greenish-gray siltstones, mudstones, and fine sandstones. Most likely, the provenance was prevailed with fine sedimentary rocks. The tempestites are marked by wide textural varieties: parallel, cross, and wave bedding, hummocky cross stratification, numerous bioturbation traces creating highly complicated patterns in cross and longitudinal sections (Fig. 4.13). Five localities of faunal remains (gastropods and pelecipods) have been found in the exposed interval of the unit K_1v and in one locality flora was discovered. Both fauna and flora are poorly preserved and therefore are not defined. Only at the beginning of the interval near Camp 4 on the left bank of the creek that *Thurmanniceras? thurmanni Pictet* and *Buchia* cf. *fischeriana* Orb. were identified.

Fig. 4.13. Tempestites, unit K_1v. Hummocky cross stratification is seen.

RADIOLARIANS FROM THE KOMSOMOLSK SECTION

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In the Komsomolsk Section, more than 100 rock-samples were examined for extracting radiolarians. Generally, the rock samples from the section are not so rich in radiolarians. However, several samples of fine clastics and pelagic sediments yielded radiolarians that are useful for age determination. This is the first report of radiolarians from the Komsomolsk Section.

Sample: Aug. 1-3 (300-1-5A)

In the layer E1-1-5, siliceous, calcareous and phosphatic nodules are included in the dark silty laminites with siliceous mudstone and pasty acidic tuff. Radiolarians of *Eucyrtidiellum pyramis* (Aita), *Loopus primitivus* (Matsuoka & Yao), *Svinitzium* sp., *Ristola* cf. *altissima* (Ruest), *Cinguloturris cylindra* Kemkin & Rudenko, and *Pantanellium lanceola* (Parona) were extracted from the nodular siliceous mudstone (Fig.1). Based on the co-occurrence of these radiolarians, this radiolarian horizon is correlative with the *Loopus primitivus* Zone (JR8) of Matsuoka & Yang (2000). The occurrence of *Eucyrtidiellum pyramis* and *Pantanellium lanceola* in the zone will be possible to give more precise age constraint that the horizon probably belongs to early Late Tithonian to latest Tithonian.

Sample: Aug. 2-1 (300-5-4)

The melange-type layer is intercalated in the siltstone member of the C2-5-4. The layer is composed of dark laminites with blocks of calcareous marl and cherty siliceous shales. Radiolarians were extracted from the matrical mudstone laminites with tuff seams (Fig. 1). Co-occurrence of *Loopus primitivus* (Matsuoka & Yao), *Cinguloturris cylindra* Kemkin & Rudenko, and *Pantanellium lanceola* (Parona) indicates that the laminites are correlative with the upper part of *Loopus primitivus* Zone (JR8) of Matsuoka & Yang (2000), and probably belong to early Late Tithonian to latest Tithonian.

Sample: Aug. 2-9 (300-5'-1/3)

The lower part of the layers (EGF)1-5'-1/3 shows the typical oceanic-plate stratigraphic succession (more than 70m thick) that is composed of phyllitic beds of bedded-chert (4m), siliceous shale (2m), red shale (11m), green shale (30.3m), black shale with sandstone bands (21m), and the alternation of sandstone and mudstone (5.5m) in ascending order (Fig. 2).

The red shale member (11m) of the succession intercalates a few small bands of red cherts. One of the red chert bands (2cm thick, Aug. 2-9) intercalated in the phyllitic red shale yields the radiolarian assemblage that is characterized by the occurrence of *Eucyrtidiellum ptyctum* (Riedel & Sanfilippo), *Eucyrtidiellum nodosum* Wakita, *Acanthocircus suboblongus suboblongus* (Yao), *Cinguloturris carpatica* Dumitrica, *Archaeodictyomitra apiarium* (Ruest), and *Hsuum maxwelli* Pessagno, with the association of *Archaeodictyomitra* aff. *pseudoscalaris* (Tan) of Matsuoka (1986b), *Archaeodictyomitra suzukii* Aita, *Archaeodictyomitra patricki* Kocher, *Ristola* cf. *procera* (Pessagno), *Tricolocapsa* (?) sp., and *Dictyomitrella* (?) aff. *kamoensis* Mizutani & Kido. Based on the co-occurrence of *Eucyrtidiellum nodosum* Wakita, *Eucyrtidiellum ptyctum* (Riedel & Sanfilippo), *Cinguloturris carpatica* Dumitrica, *Acanthocircus suboblongus suboblongus* (Yao), *Archaeodictyomitra apiarium* (Ruest), and *Hsuum maxwelli* Pessagno, the red shale member (11m) with the red chert band (Aug. 2-9, 2 cm thick) of the succession is correlative with the UAZ 8 to 10 that the ages are estimated to be Middle to Late Callovian to Early Kimmeridgian (Baumgartner & INTERRAD Jurassic-Cretaceous Working Group ed., 1995).

Generally, radiolarians from the cherts, varicolored siliceous shales and mudstones of the

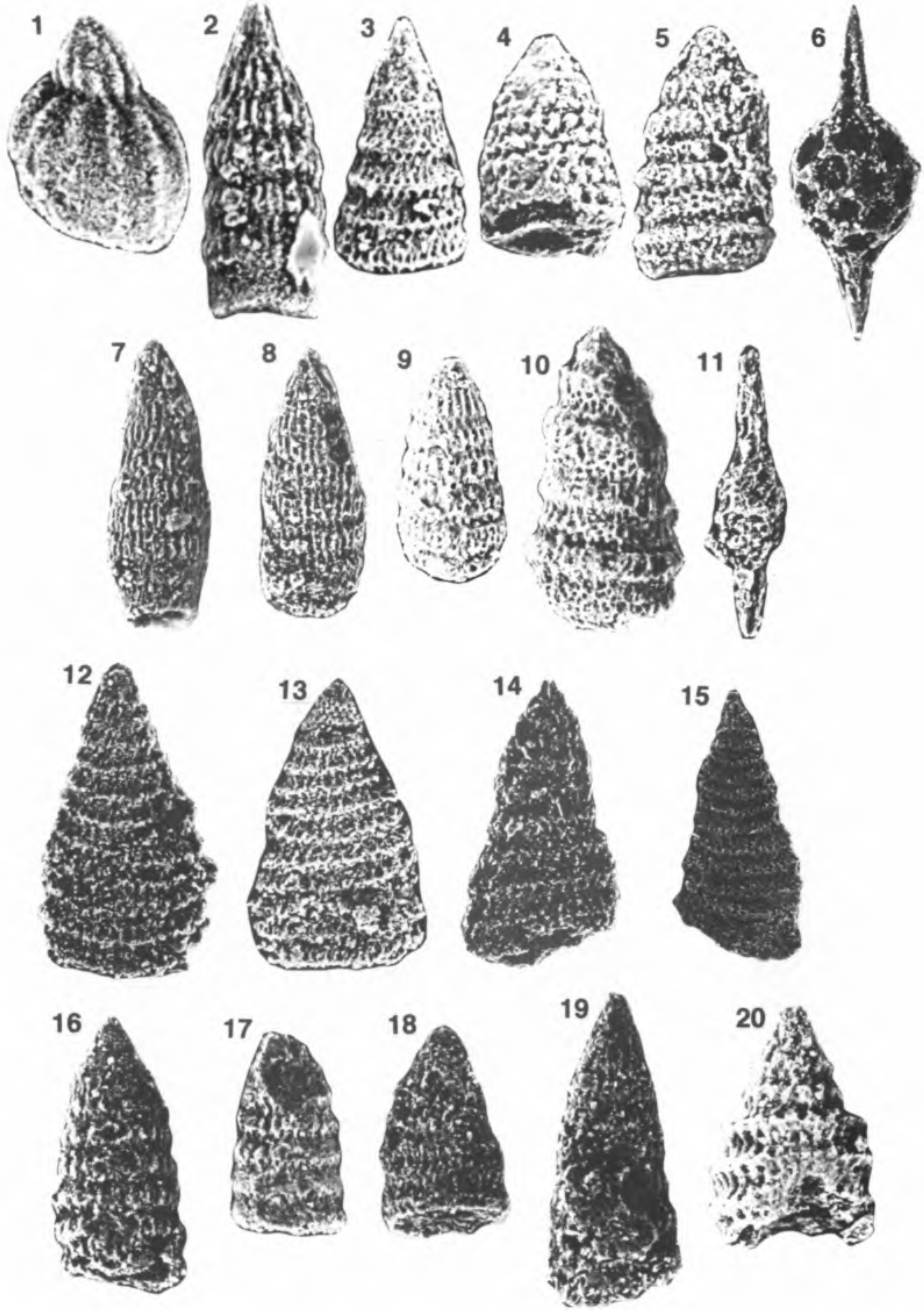
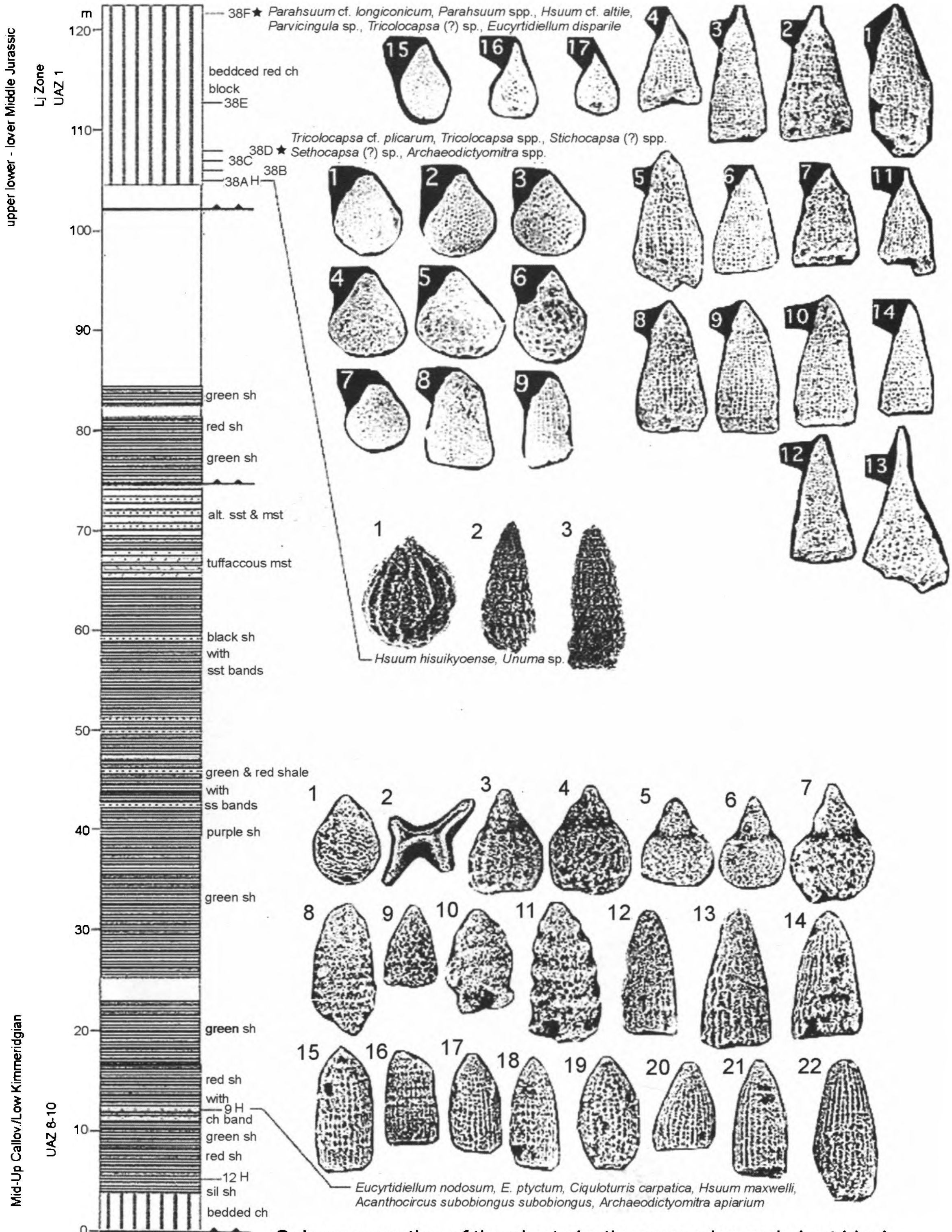


Fig. 1 Late Jurassic – Early Cretaceous radiolarians from the terrigenous fine clastic sediments of the Komsomolsk Section.

1–6: Aug. 1–3, layer E1-1-5. 1: *Eucyrtidiellum pyramis* (Aita); 2: *Loopus primitivus* (Matsuoka & Yao); 3: *Svinitzium* sp.; 4: *Ristola* cf. *altissima* (Ruest); 5: *Cinguloturris cylindra* Kemkin & Rudenko; 6: *Pantanellium lanceola* (Parona)

7–11: Aug. 2-1, layer C2-5-4. 7–9: *Loopus primitivus* (Matsuoka & Yao); 10: *Cinguloturris cylindra* Kemkin & Rudenko; 11: *Pantanellium lanceola* (Parona). 12–15: Aug. 2-40, layer (EGF)1-5'-5. 12–15: *Mirifusus odoghertyi* Jud. 16–20: Aug. 3-3, layers C(B)2-6". 16: *Pseudodictyomitra carpatica* (Lozyniak); 17-19: *Loopus primitivus* (Matsuoka & Yao); 20: *Svinitzium* sp.



Columnar section of the chert-clastic succession and chert block in the Unit (EGF) 1-5' - 1/3, with the radiolarian assemblages succession are too strongly crystallized and deformed to identify. Radiolarians were extracted from only this sample of the succession.

Sample: Aug. 2-38A (300-5'-1/3)

In the layers (EGF)1-5'-1/3, the red bedded-chert block (Aug. 2-38) appears 30m above the top of the chert-clastic succession that shows the typical oceanic-plate stratigraphy (Fig. 2). In between the two, a few meters thick of green and red shales beds are recognized. The lower horizon (Aug.2-38A) in the red bedded-chert block yields radiolarian species of *Hsuum hisuikyoense* Isozaki & Matsuda, and *Unuma* sp. The former species is characteristic in the *Laxtorum* (?) *jurassicum* Zone (JR3: Matsuoka, 1995) that is regarded lower Middle Jurassic (Aalenian).

Sample: Aug. 2-38D (300-5'-1/3)

The assemblage from the 3m upper horizon (Aug. 2-38D) in the red bedded-chert block is dominated by spherical Nassellarians with the association of *Tricolocapsa* cf. *plicarum* Yao, *Tricolocapsa* (?) spp., *Stichocapsa* (?) spp., *Sethocapsa* (?) sp., and *Archaeodictyomitra* spp. (Fig. 2). The dominance of spherical nassellarians suggests that the assemblage belongs to Middle Jurassic.

Sample: Aug. 2-38F (300-5'-1/3)

The assemblage of the 18m upper horizon (Aug. 2-38F) from the base of the red bedded-chert block is dominated by multisegmented Nassellarians with the association of *Parahsuum* cf. *longiconicum* Sashida, *Parahsuum* sp. M in Baumgartner et al. (1995), *Parahsuum* spp., *Parvicingula* sp., *Tricolocapsa* (?) sp., *Hsuum* cf. *altile* Hori & Otsuka, and *Eucyrtidiellum disparile* Nagai & Mizutani (Fig. 2). *Parahsuum* sp. M is known from the UAZ 1-1 (early Middle Aalenian). According to Nagai & Mizutani (1990), *Eucyrtidiellum disparile* has its range in the *Laxtorum* (?) *jurassicum* Zone (JR3) of Matsuoka & Yao (1995).

COMMENTS:

In the layers (EGF)1-5'-1/3, we estimate that the bedded-chert member of the chert-clastic succession probably belong to the Lower to Middle Jurassic, and the top horizon of the bedded-chert member belongs to the upper Middle Jurassic. The red bedded-chert block (Aug. 2-38) has a possibility to be stratigraphically upside down.

Sample: Aug. 2-40 (300-5'-5)

The layer (EGF)1-5'-5 is composed of the alternating slaty beds of mudstone and sandstone. The slaty mudstone yields radiolarian assemblage that is characterized by the abundant occurrence of *Mirifusus odoghertyi* Jud (Fig. 1). The range of the species is known as latest Tithonian to Early Barremian (Baumgartner & INTERRAD J-C Working Group, 1995). We estimate that the horizon belongs to the uppermost Tithonian.

Sample: Aug. 3-3 (300-6")

The bioturbated siliceous dark mudstone layer with phosphatic concretions were sampled from the layers C(D)2-7. The dark siliceous mudstone yields radiolarians of *Loopus primitivus* (Matsuoka & Yao) and *Pseudodictyomitra carpatica* (Lozyniak) (Fig. 1). The co-occurrence of both species clearly indicates that the sampled horizon belongs to the basal part of the *Pseudodictyomitra carpatica* Zone of Matsuoka (2000), and the age is estimated to latest Tithonian. *Svinitzium* sp. is also associated.

Sample: Aug. 3-6B (300-(5"))

The large floated block of chert that derived from the melange of layers C(D)2-(5"). The extracted radiolarians are *Triassocampe postdeweveri* Kozur & Mostler, *Triassocampe deweveri* Nakaseko & Nishimura, *Yeharaia elegans* Nakaseko & Nishimura, and *Yeharaia japonica* Nakaseko & Nishimura (Fig. 3).

Fig. 2 Early – Middle to early Late Jurassic radiolarians from the pelagic sediments (bedded-chert and chert band in siliceous shale) of the Komsomolsk Section.

Horizon 9: Aug. 2–9, chert band in red shale, layer (EGF)1-5'-1/3. 1: *Tricolocapsa* (?) sp.; 2: *Acanthocircus suboblongus suboblongus* (Yao); 3–4: *Eucyrtidiellum ptyctum* (Riedel & Sanfilippo); 5–6: *Eucyrtidiellum nodosum* Wakita; 7: *Eucyrtidiellum* sp.; 8: *Ristola* cf. *procera* (Pessagno); 9: *Dictyomitrella* (?) aff. *kamoensis* Mizutani & Kido; 10–11: *Cinguloturris carpatica* Dumitrica; 12: *Archaeodictyomitra* sp.; 13: *Hsuum maxwelli* Pessagno; 14: *Archaeodictyomitra* aff. *pseudoscalaris* (Tan) of Matsuoka (1986b); 15–18: *Archaeodictyomitra apiarium* (Ruest); 19-20: *Archaeodictyomitra patricki* Kocher; 21-22: *Archaeodictyomitra suzukii* Aita. Horizon 38A: Aug. 2-38A in the red bedded-chert block, layer (EGF)1-5'-1/3. 1: *Unuma* sp.; 2-3: *Hsuum hisuikyoense* Isozaki & Matsuda. Horizon 38D: Aug. 2-38D in the red bedded-chert block, layer (EGF)1-5'-1/3. 1: *Tricolocapsa* cf. *plicarum* Yao; 2-3: *Tricolocapsa* (?) spp.; 4-5, 7: *Stichocapsa* (?) spp.; 6: *Sethocapsa* (?) sp.; 8-9: *Archaeodictyomitra* spp. Horizon 38F: Aug. 2-38F in the red bedded-chert block, layer (EGF)1-5'-1/3. 1-2: *Hsuum* cf. *altile* Hori & Otsuka; 3: *Parahsuum* sp. M in Baumgartner et al. (1995); 4: *Parahsuum* cf. *longiconicum* Sashida; 5-13: *Parahsuum* spp.; 14: *Parvicingula* sp.; 15: *Tricolocapsa* (?) sp.; 16-17: *Eucyrtidiellum disparile* Nagai & Mizutani.

5. LOWER-UPPER CRETACEOUS COARSE DEPOSITS OF A PULL APART BACK-ARC BASIN ON THE HAITER CAPE, THE KHUMMI LAKE

We begin our travel from Komsomolsk-on-Amur by bus in the southeastern direction for a distance of about 40 km, then turn to the Haiter settlement and farther on to the Haiter cape of the Khummi Lake.

On the bank of the lake there are exposed basal beds of the Gornoprotoksky suite, which A.I. Freidin included into the Largasinsky series of coarse rocks with rhythmic structure (Freidin et al., 1961). The age of the Gornoprotoksky suite is still open to discussion (from Hauterivian to Cenomanian). Nevertheless, on the bank of the Gorny channel it has been established that conglomerates of the Gornoprotoksky suite unconformably occurring on the deposits of the Komsomolsk series. Here in 1963 I.P. Boiko described a most representative section of the suite (Fig. 5.1, 5.2). It features a distinct rhythmical composition with several-order cycles. A total thickness of the suite reaches 1400 m. Presence of cross-bedded series and abundant coaly detritus testifies to a shallow-water coastal-marine and possibly deltaic environment of sedimentation.

Stop 5-1. From the river coast upwards the slope one can observe greenish-gray foliated silts with occasional fine pebbles and gravels. Sometimes very thin bedding can be seen. Higher up the slope, there occur thick beds of diverse pebble conglomerates (Fig. 5.3). The pebble is well rounded varying from 0,5r1 to 5r7 cm in size. Conglomerates sometimes contain blocks of turbidites. The pebble consists of sandstones, chert, volcanites, and quartz. Sandstones and mudstones serve as cement. From the pebble orientation (imbricate-structures), it is sometimes possible to reconstruct the the current direction from west to east.

Moving along the lake bank visitors can see amalgamated series of debris flow deposits of different composition. They are coarse turbidites with eroded contacts (Fig. 5.4) and thin-bedded beds with intercalated greenish-gray tobacco-coloured tuffaceous sandstones and thin-laminated siltstones (Fig. 5.5). Cross bedding of various scale can be seen in these beds.

Stop 5-2. 200 m from the last outcrop of Stop 5-1, a monotonous series of black, dark-grayish fine platy schistose aleuropelites is exposed (Fig. 5.6). The rocks are characterized by a very steep nearly vertical dipping. Folds with steeply dipping hinges and distinctly manifested cleavage are often observed.

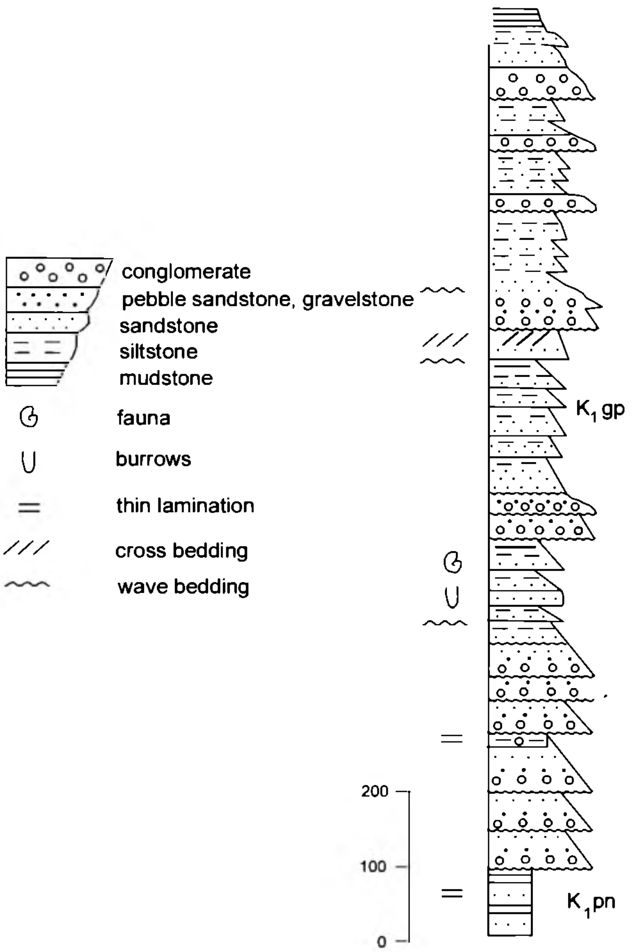


Fig. 5.1. Columnar section of the Gornoprotoksky suite along the Gorny channel, the Amur River.

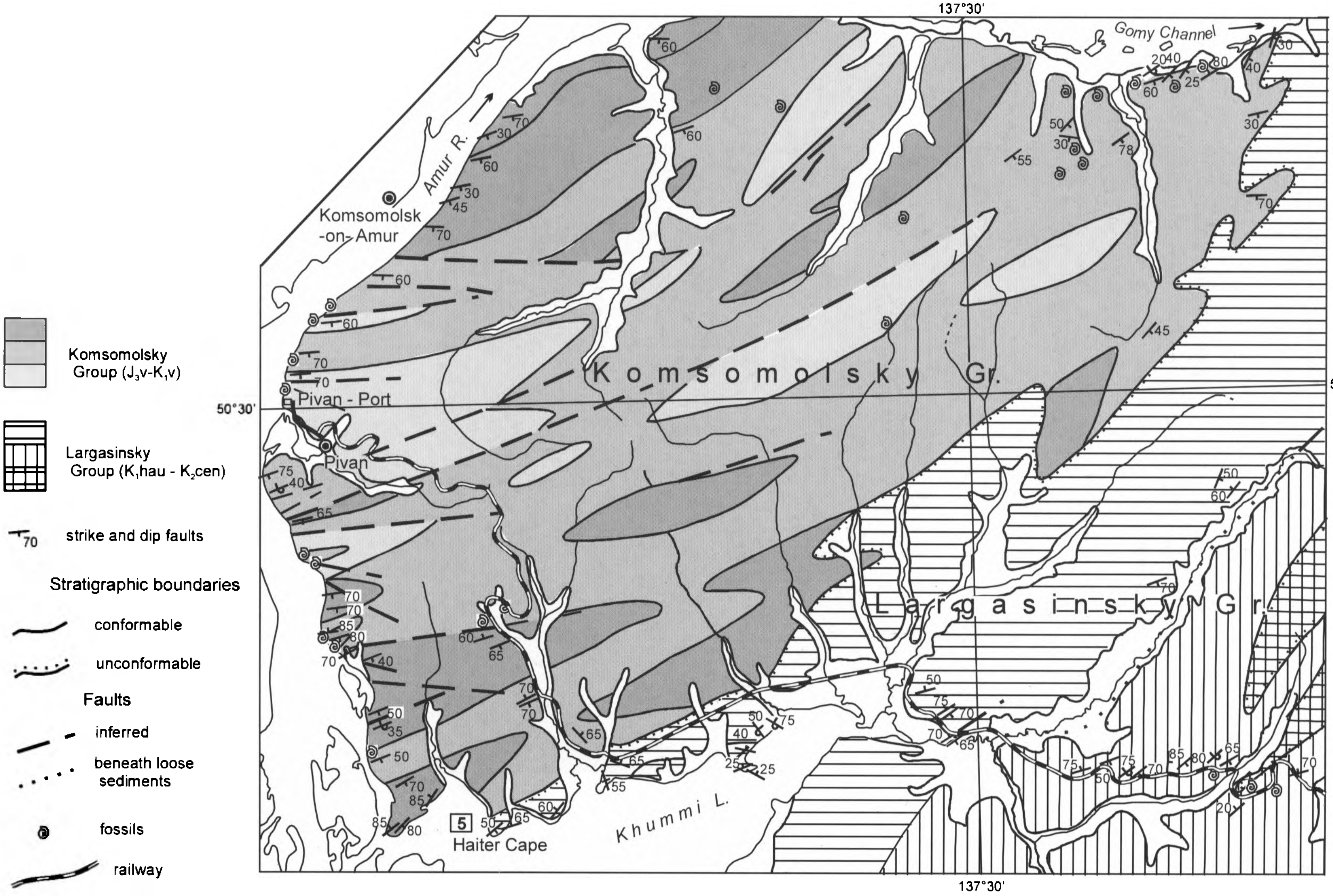


Fig. 5.2. Schematic geological map of the Khummi Lake area (after Freidin et. al, 1961, simplified).

Fig. 5.3. Conglomerates (channel deposits), the Gornoprotoksky suite, Khummi Lake.

Fig. 5.4. Thick-bedded turbidite (abc), the Gornoprotoksky suite, Khummi Lake.

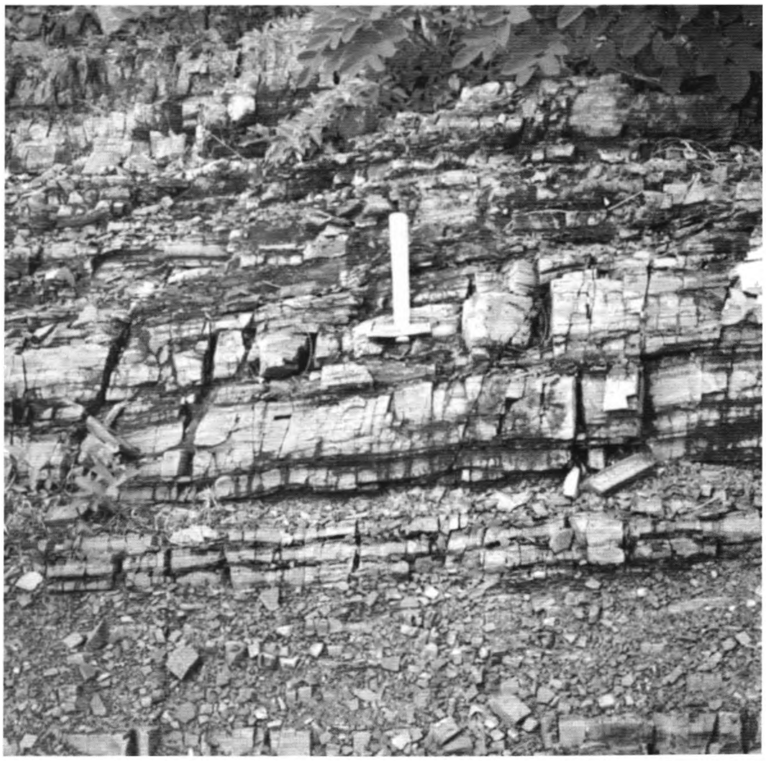


Fig. 5.5. Thin-bedded turbidite, tuffaceous sandstones, and thin-laminated siltstones. Cross bedding is seen. $K_1gp.$, Khummi Lake.

Fig. 5.6. Fine schistose aleuropelites. K_1gp., Khummi Lake.

PRELIMINARY RESULTS OF PETROLOGICAL AND GEOCHEMICAL STUDIES OF THE CRETACEOUS SANDSTONES OF THE KHABAROVSK COMPLEX, KOMSOMOLSKY GROUP AND SITOGINSKY FORMATION

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INTRODUCTION

Petrological and geochemical studies of the sedimentary rocks are a useful tool for examining source rock and tectonic memory of the sedimentary basin (Dickinson et al., 1983; Taylor and McLennan, 1985). They have been widely applied to disrupted convergent margin terranes where basin analysis is troublesome. In many instances, provenance regions of convergent margin basins are destroyed and the only information lies in the sediments. Nevertheless, geochemical results show that active margin sediments positively guides to the nature of such margin (Ishiga and Dozen, 1997; Kiminami et al., 2000; Roser, 2000).

However, chemical and physical modifications of source material limit our final provenance interpretation. Geological factors which significantly affect the chemical composition of the sediments are provenance characteristics, tectonic setting, hydraulic sorting, weathering of source area and diagenesis (Fralick and Kronberg, 1997). Compound effects of these factors result in difficulties to distinguish and separate the provenance memory of the sediments. Accordingly, a single discriminant diagram or calculation technique may not adequately reflect the complexities of the geochemical composition. Particularly, mineralogical fractionation caused by the hydraulic sorting has a considerable effect to modify the source rock composition (Nesbitt and Young, 1996; Argast and Donnelly, 1987; Garcia et al., 1991).

The effect of mechanical sorting on the chemical composition of sediments is not complicated (Taylor and McLennan, 1985). First order effect is separation of sheet minerals from coarse-grained fraction (Argast and Donnelly, 1987; Garcia et al., 1991). In this study, primary investigations are focused on the statistical analysis to evaluate mineralogical fractionation effects. Elements whose major host mineral phase behaved in a hydraulically different manner can be used to measure the intensity of sorting. If chemical modifications by the sorting effect could be modeled for each sedimentary suite, original source material can be simply evaluated by eliminating the sorting effects. Our final goal is to adapt this technique to elucidate the pure provenance signatures of the Late Jurassic to Early Cretaceous sediments of the Far East Russia.

RESULTS OF ANALYTICAL STUDIES

First of all, modal compositions of Late Mesozoic basin-fill deposits and associated accretionary complex in the Komsomolsk and Dural sections (Fig. 1). Framework grain compositions for the Khabarovsk Complex, Vogian to Valanginian Komsomolskaya Group and Albian to Cenomanian Sitoginskaya Formation are quite similar, containing 40% of quartz grains, 40% of feldspar grains and 20% of lithic rock fragment grains in average.

Statistical analysis of geochemical data set introduced by Aitchison (1986). This statistical method using variation and two covariance values were adopted to isolate chemical parameters that are sensitive to the mineralogical fractionation of sediments. High values in variation identify element pairs which show the greatest variability. High positive values in the two covariance indicate strong associations between the elements, where

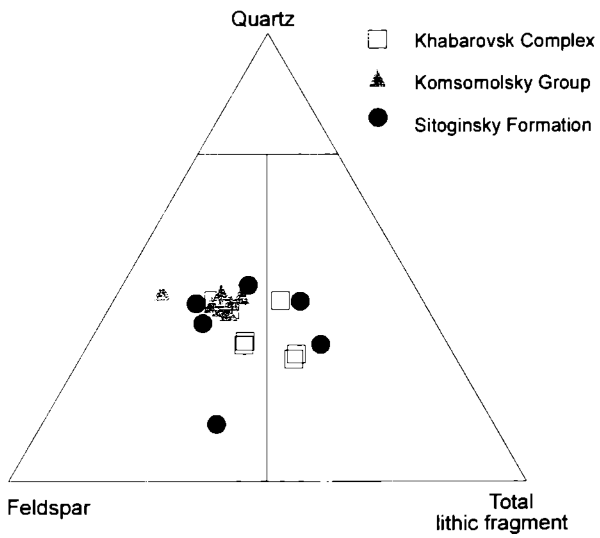


Fig. 1. Modal composition of the sandstones.

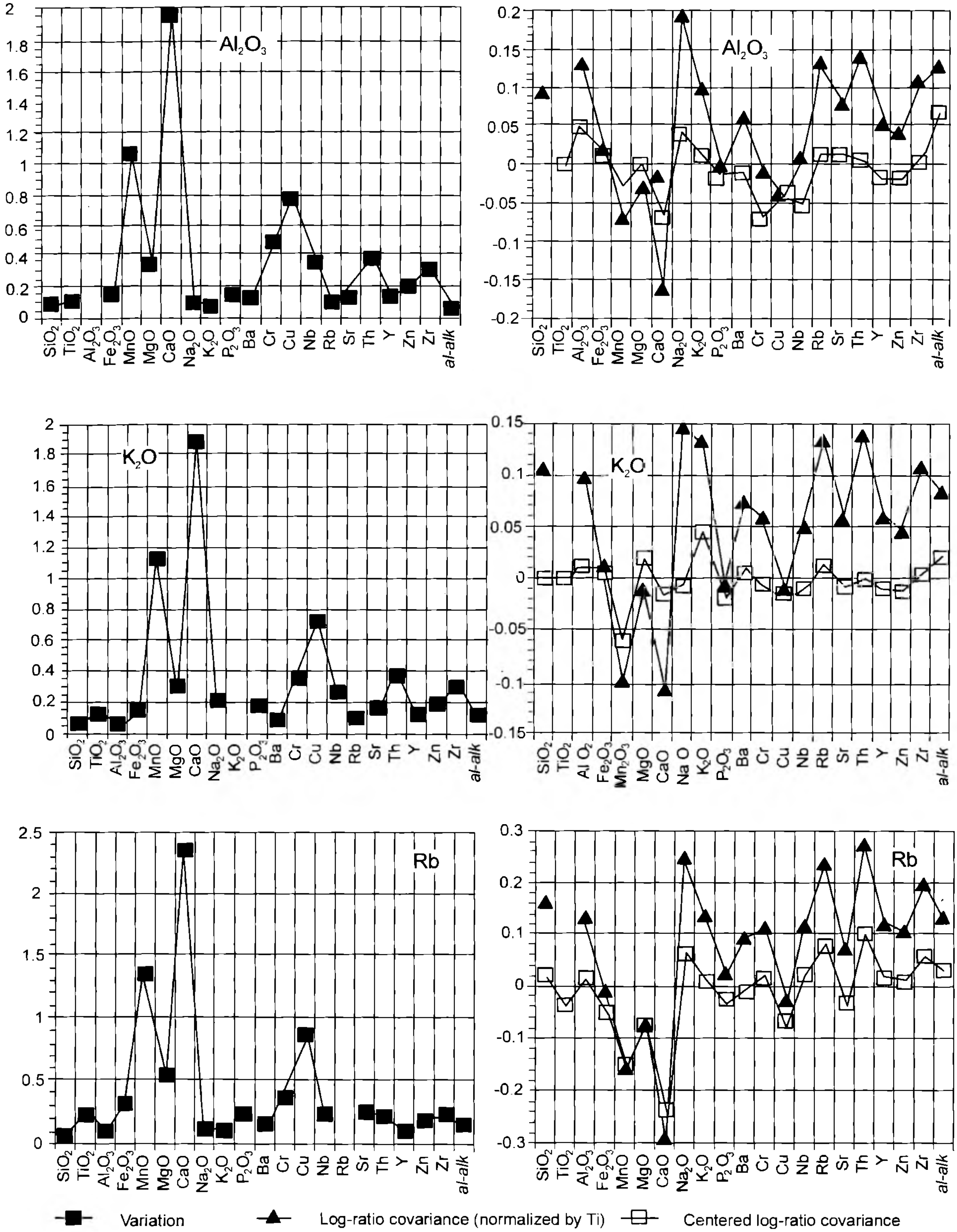


Fig. 3. Variation and covariance structures of the Al_2O_3 group.

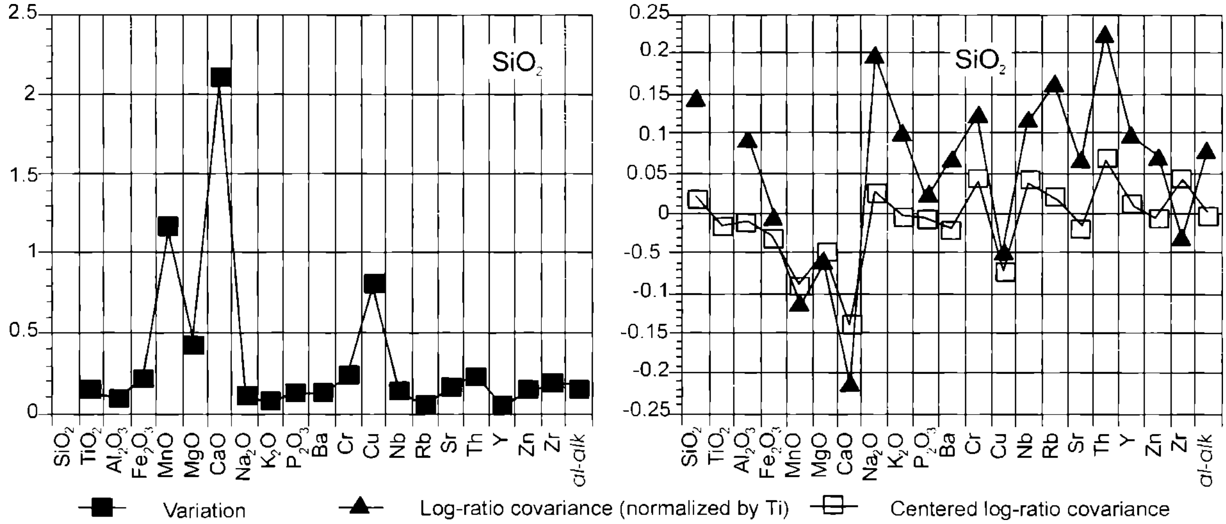


Fig. 4. Variance and covariance structures of SiO_2.

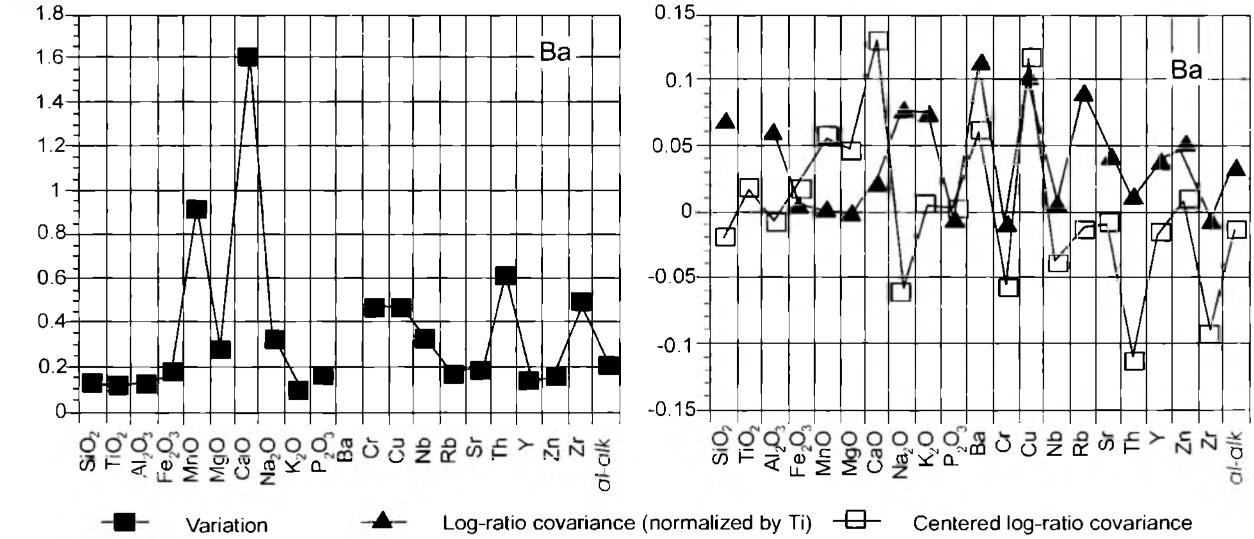


Fig. 5. Variance and covariance structure of Ba.

mud continuum. Sand-mud continuum for the Khabarovsk Complex and Komsomolskaya Group draw tieline connecting illite and quartz compositions. On the other hand, sand-mud continuum of the Sitoginskaya Formation indicates concentration of mafic minerals (Fig. 7) and feldspars (Fig. 8). This sand-mud continuum occupies a similar domain of igneous rock series. Variation in the Sand-mud continuum for the Komsomolskaya Group and Sitoginskaya Formation are not due to the differential hydraulic sorting effect, because intensity of sorting should be confirmed within consecutive sand-mud continuum. Therefore, chemical variances in the Volgian to Valanginian and Albian to Cenomanian successions are the result of change in source area lithology. Usually, it is very difficult to obtain direct information of provenance solely by a single discriminant diagram because of complexities in the sorting effect. Nevertheless, if we elucidate the sorting effect, it is possible to have a clear vision of the source material.

All of the samples from the Far East Russia plot near the composition of appropriate average volcanic rock trend (Fig. 9, 10), suggesting that their chemistry reflects that of volcanic terranes. As seen from Fig. 9, the plots of the Khabarovsk Complex and Komsomolskaya Group do not shift to the mafic trend and show relatively felsic compositions. Using the petrographic criteria on account, there is an evidence of greater cratonic influence in the Komsomolskaya Group. Relatively matured volcanic belt, developed on the continental massif is

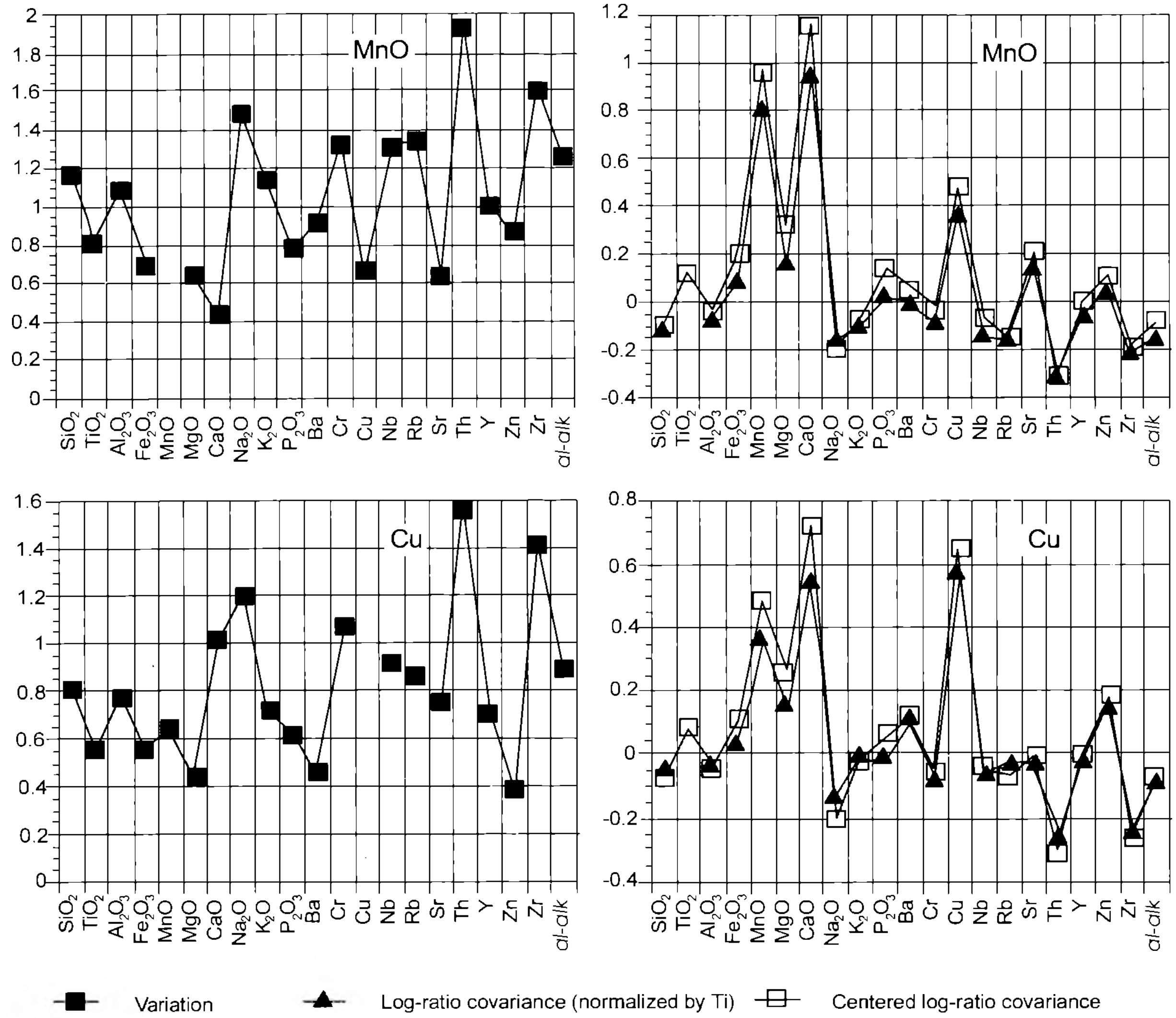


Fig. 6. Variance and covarinance of the MnO element group.

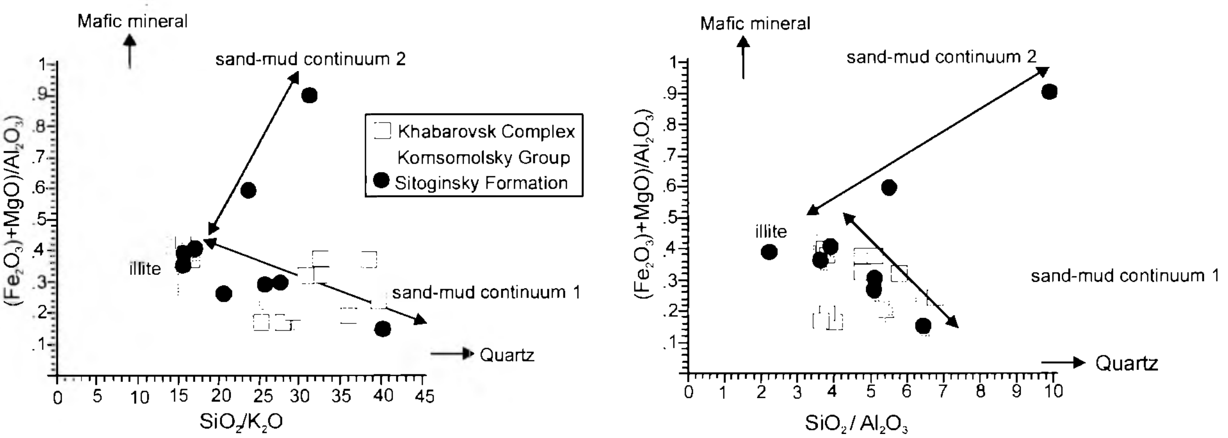


Fig. 7. Sand-mud continuums for the Khabarovsk Complex, Komsomolsk Group and Sitoginsky Formation.

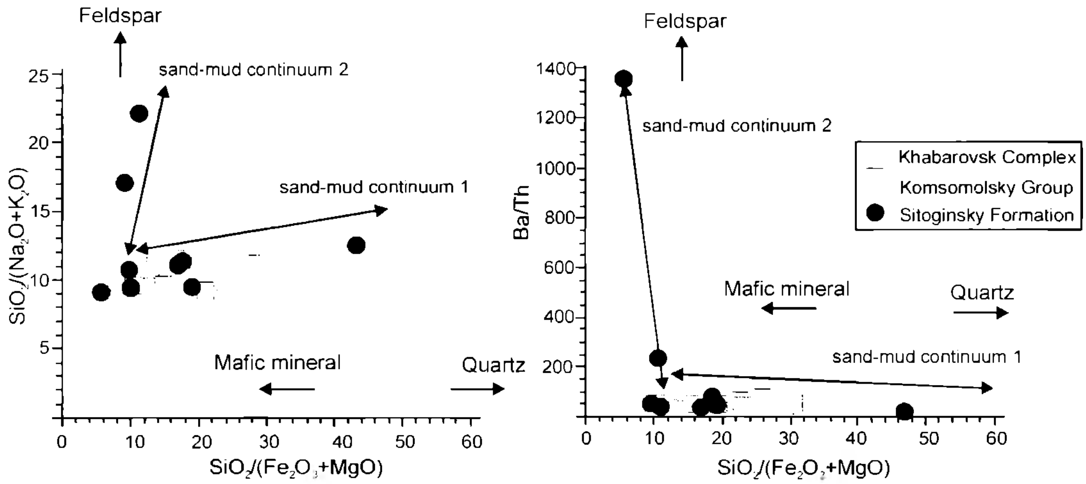
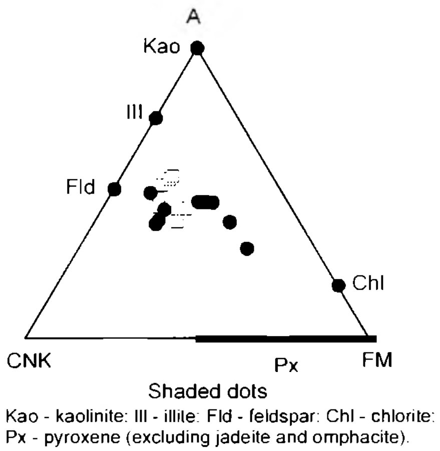
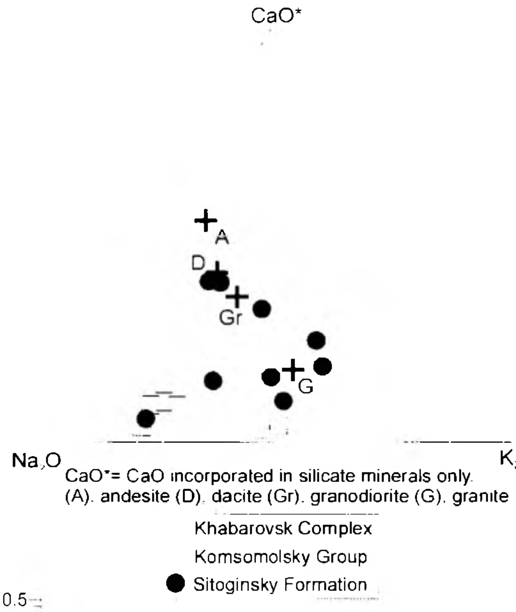
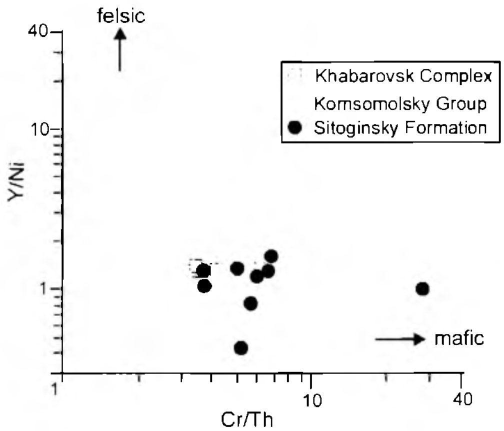


Fig. 8. Sand-mud continuums for the Khabarovsk Complex. Komsomolsk Group and Sitoginsky Formation.







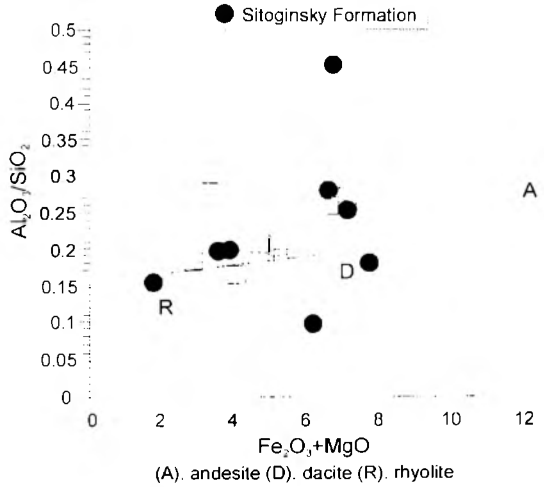


Fig. 9. Major element composition (A) and trace element composition (B) diagram discriminating basicity of the plots.

Fig 10. Plots of major element compositions and average igneous rock compositions.

presumed as a provenance for the Komsomolsk section. In contrast to the Late Jurassic to earliest Cretaceous sediments, sandstones and associated shales from the Sitoginskaya Formation are displaced to the mafic trend (Fig. 9). Sediments of Sitoginskaya Formation are enriched in CaO*, Fe_2O+MgO and depleted in Na_2O, K_2O relative to the granite and rhyolite range (Fig. 10), although some deviations do occur. Geochemical results of the Sitoginskaya Formation strongly suggest an immature volcanic suite unrelated to the continetal massif as the provenance.

COMMENTS

Most of sandstones of the Khabarovsk Complex and associated Komsomolskaya Group in the Komsomolsk section are immature arkose sandstone containing 40% of quartz grains, 40% of feldspar grains and 20% of lithic rock fragment grains in average. Samples of the Komsomolsk section are relatively rich in potassic feldspar, detrital zircon and granite fragments. Almost all of the lithic rock fragments are volcanic rock fragments and cherts. Volcanic rock fragments show intersertal and felsitic to spherulitic texture, indicating intermediate to acidic origin. Geochemistry of the Komsomolskaya Group shows relatively matured composition, rich in incompatible elements. These lines of evidence probably indicate that a volcanic belt developed on the continental massif involved significantly as a source area. Relatively matured Khingan-Okhotsk volcanic-plutonic belt which is developed on the Bureya Massif might be presumed as a provenance for the Komsomolskaya Group. Extraordinarily high sedimentation rate and abundance of arkose sandstones are probably due to the active denudation of the Mongol-Okhotsk Belt along the collisional zone between the Bureya and Siberian blocks.

As in the Komsomolsk section, sandstones of the Sitoginskaya Formation in the Dural section are also arkose in composition and contain abundant intermediate to felsic volcanic rock fragments. Nevertheless, the presumed provenance is different. Sandstones of the Dural section are rich in pyroxene and altered pyroxene (chlorite) as an accessory minerals. Some samples are unusually enriched in pyroxene, attaining more than 20%. Transitional metal and alkaline-earth elements are concentrated in samples of the Dural section. They are compositionally mafic when compared with those of the Komsomolsk section. However, no sign of influence from basic volcanic and metamorphic rocks were detected. Throughout the sequence, sandstones are rich in intermediate volcanic fragments representing low maturity, and can be assigned to the initial stage of recycling process. This is because pyroxene and idiomorphic plagioclase minerals which are not resistant to abrasion and weathering are included in abundance. Accordingly, volcanic activity providing intermediate volcanic rocks is interpreted to be penecontemporanous with deposition. During the Aptian to Albian, the volcanic arc began to form in the eastern Sikhote-Alin. Probably, the detritus was derived from the Moneron-Samarga Volcanic Arc where igneous activities chiefly of intermediate nature dominated.

During the Late Jurassic to early Early Cretaceous, forearc basin turbidites were deposited coeval with the formation of the accretionary complex. After the Aptian age, late Albian-Cenomanian back arc basins began to form in close association with the acme volcanism in the Eastern Sikhote-Alin Volcanic Belt.

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ВЕРХНЕЮРСКО-МЕЛОВЫЕ ОТЛОЖЕНИЯ ВОСТОЧНОАЗИАТСКОЙ КОНТИНЕНТАЛЬНОЙ ОКРАИНЫ ВДОЛЬ Р. АМУР

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