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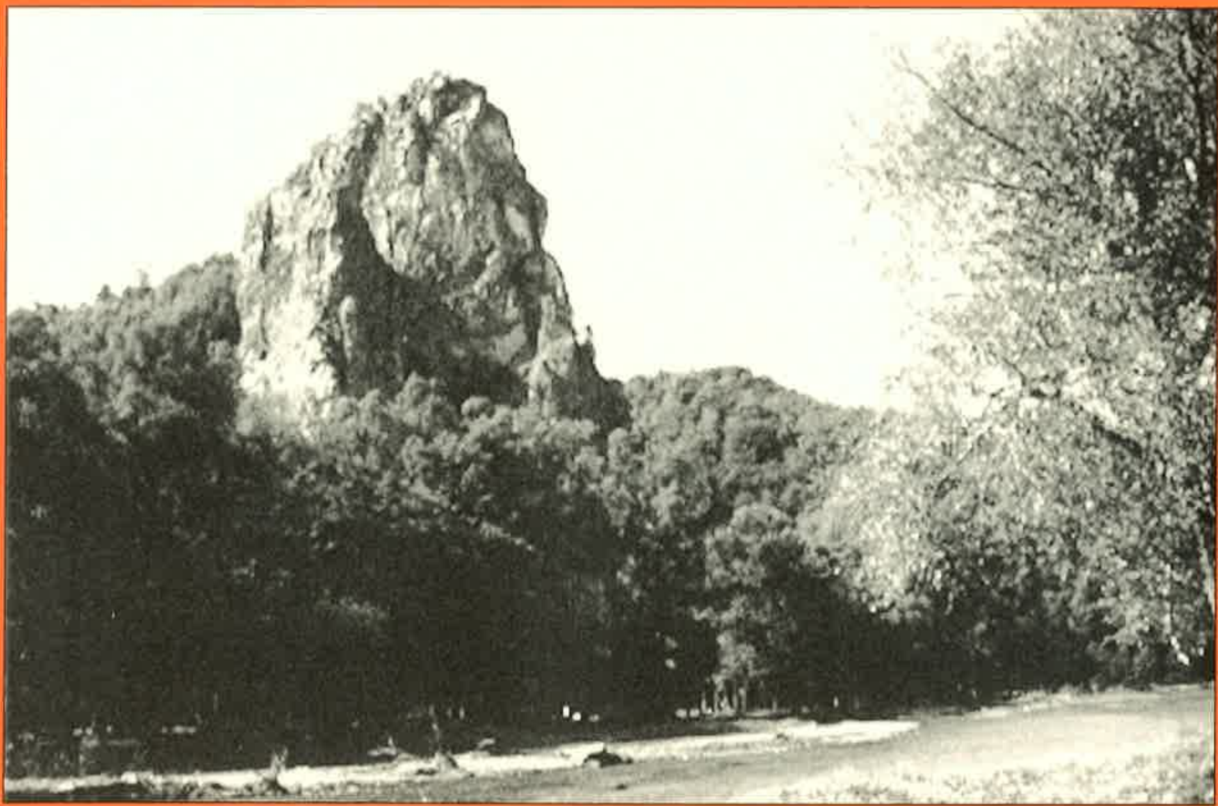
Late Paleozoic and Early Mesozoic Circum-Pacific Events: Biostratigraphy, Tectonic and Ore Deposits of Primoryie (Far East Russia)

IGCP Project 272

Editors: A. Baud, I. Popova, J.M. Dickins, S. Lucas and Y. Zakharov



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Contribution of the IGCP Project 272.

Cover page:
Arsenyev Rock on Zerkal'naya River, a giant Carboniferous to Permian (Bashkirian - Artinskian) fossiliferous limestone olistolite. The surrounding Taiga forest is on Valanginian to Barremian flyschoid matrix.

Late Paleozoic and Early Mesozoic Circum-Pacific Events: Biostratigraphy, Tectonic and Ore Deposits of Primoryie (Far East Russia)

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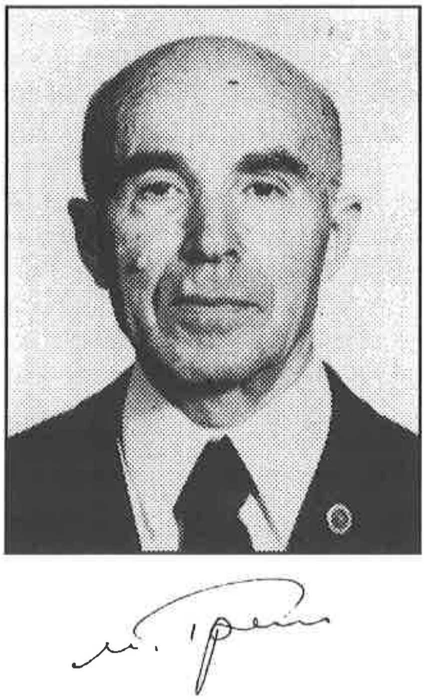
Mémoires de Géologie (Lausanne), No. 30, 1997

IN MEMORIAM MENDEL N. GRAMM (10.12.1910 - 2.05.1997)



Mendel N. Gramm was born in Mariupol, Russia on December 15, 1910. He grew up in the southern USSR and graduated from Azerbaydzhan Industrial Institute (Baku) in 1938. His long geological and paleontological career began in Middle Asia when he lived in Kokand and Tashkent. In 1941-1945 he served in the hydrogeological military detachment in Iran.

In Middle Asia he did his first (candidate) dissertation and was awarded the scientific degree in 1949. His doctoral dissertation on Cenozoic ostracodes was done in 1961, just before his moving to Vladivostok, where he organized the first paleontological laboratory in the Far Eastern Filial of the USSR Academy of Sciences (Siberian Branch), complying with Prof. N. P. Vasilkovsky's request, who also was a migrant from Middle Asia. He organized not only the laboratory, but also the scientific school. He became a professor of paleontology and stratigraphy in 1970.

His famous book «Inner structure of the Paleozoic ostracode shells», published in Leningrad «Nauka» in 1984, has stood the test of time, it is used in many countries today. I personally heard very complimentary words about Gramm's detailed works from Prof. Alexander Tollmann, when I met him and Dr. Edith Kristan-Tollmann in China in September 1987. They were lucky enough to be his correspondents during many years. Prof. M.N. Gramm took part only in few international meetings partly because he had strained relations with some nomenclatura people from the USSR Academy of Sciences in Moscow and some communist leaders in Vladivostok. I should like to comment on only one of his life's events. When V.A. Krassilov, one of his favourite graduate students, who is a famous paleobotanist now, had some problems on his travelling to Moscow to defend his thesis, because the Academy usually did not make any financial support in such cases, Prof. M.N. Gramm wrote them to Moscow that «... if the soviet laws are so neglected, they need to be changed». Such an action was a big political crime at that time in spite of the Khruschev's political thaw. They did show him soon that the Soviet laws must be respected. Prof. M.N. Gramm had donated his whole life to research and education. He was a honest, uncompromised and resonably kind man in both work and family life (his wife died only last year, they leave two sons). I am proud that he was my teacher during a quarter of a century. He ended both his life and scientific work at May 2 of 1997.

Y. Zakharov

FOREWORD

The International Field Conference on Permian-Triassic Biostratigraphy and Tectonics of the IGCP Project 272 was held in Vladivostok, September 6-12, 1992. It was the first opening of the Vladivostok area for foreign geologists. Thirty three specialists were interested, but only thirteen were able to attend this Conference and the field trip afterwards. The participants came from Australia, China, Italy, Japan, Switzerland and Vietnam. From the Russian side, there were more than thirty scientists participating at the Conference sessions and seven at the field trip. This Meeting was sponsored by UNESCO, IGCP Project 272 «Late Paleozoic and Early Mesozoic Circum-Pacific Bio-Geological Events» and by the Russian Academy of Sciences, Far East Branch (Far Eastern Geological Institute). The Organizing Committee comprised Prof. Y. Zakharov (Chairman), Dr. A. Baud, (Vice Chairman) and Dr. G.V. Kotlyar (Vice Chairman). The Local Committee, including Profs. Y. Zakharov, A.I. Khanchuk and I.V. Panchenko, had been congratulated for the excellent organization of the Field Conference, despite difficulties associated with bad weather (hurricane with a serious consequences). The unforgettable Field trip gave to the participants a unique opportunity to visit Upper Permian and Triassic sections of the Russian Island, the Ussurian Gulf and the Vladivostok area, those of the Partizansk and Nachodka areas and the famous Dalnegorsk Cretaceous olistostrome with Permian and Triassic blocks of fossiliferous limestones and radiolarites.

Twenty nine abstracts were published in the Abstract book and seven were added during the Conference sessions. The organizing committee has taken the decision to publish the materials of the presentations made during this meeting.

From September 1992 to the end of 1994 we received more than twenty nine manuscripts. The review process took about three years. Dr. J.M. Dickins (Canberra) and Dr. S. Lucas (Albuquerque) were in charge of the English edition of the texts and some reviews. Dr. I. Popova together with Prof. Y. Zakharov worked on the corrections of all articles and some graphics. The edition of the first model of this issue of the «Mémoires de Géologie» and corrections of the last one was made by Dr. I. Popova. The final model of the volume was made by Mr. K. König.

The articles of this volume are presenting data on Tectonics, Biostratigraphy, Paleogeography, Sedimentology, Magmatism and Ore deposits of the Russian Far East territory. The first two papers of this volume give an overview on tectonics and magmatism of Primorye. The next papers comment on the Permian and Triassic paleogeography and biostratigraphy of the Primoryie based on ammonoids, conodonts, radiolaria, flora, ostracods, sphinctozoans and corals data. The ore-bearing deposits and the sedimentology of a heavy minerals of the Sikhote-Alin Mountains are the subject of the last two papers.

We warmly acknowledge the reviewers, their advices was of great help to the editorial board for choosing among submitted papers and for improvements of the manuscripts. They are (except the editing board): Prof. P. Baumgartner (Lausanne), Prof. J. Broutin (Paris 6), Prof. H. Bucher (Lyon), Dr. E. Carter (Vancouver), Dr. S. Crasquin (Paris 6), Dr. P. Dumitrica (Berne), Prof. J. Guex (Lausanne), Dr. F. Hirsch (Jerusalem), Prof. H. Kerp (Münster), Dr. H. Kozur (Budapest), N. Meisser (Lausanne), Dr. B. Senowbary-Daryan (Erlangen) and Prof. P. Thélin (Lausanne).

Thanks to the Geological Museum and to the Institute of Geology and Paleontology, Lausanne University, for supporting part of the cost of the editing works and publication.

We are grateful to the Swiss Academy of Sciences for the generous publishing financial support.

A. Baud, I. Popova, J. Dickins, S. Lucas, Y. Zakharov

CONTENTS

PERMIAN AND TRIASSIC ROCKS IN TERRANES OF THE SOUTHERN FAR EAST RUSSIA

Alexander I. KHANCHUK and Ivan V. PANCHENKO

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Abstract

In the Burea-Khanka accretionary system, some assemblages, overlapping pre-Devonian terranes, consist of Permian and Triassic rocks. Permian volcanic and sedimentary deposits are characterized by a paleotectonic zonation: island arc and rifting back-arc basin. That epicontinental island-arc system formed near the tropical belt; in the very late Permian, it accreted to the Sino-Korean craton, forming the North China-Amur continent. Triassic rocks form predominantly clastic shallow-water and land deposits at the transform margin of the North China-Amur continent, shifted to the north, towards the Siberian Craton during Triassic time. In the Sikhote-Alin Area and Sakhalin Island, Jurassic and Cretaceous accretionary wedge terranes include Permian-Triassic cherts, Middle to Upper Triassic cherts, interbedded with pelagic limestones, associated with oceanic basalt, and Permian and Middle Triassic limestones in paleoguyot caps. Permian and Triassic rocks are, apparently, fragments of equatorial paleo-Pacific area, which experienced rearrangements in the very late Permian to early Triassic time and, possibly, abrupt shallowing.

1. Introduction

The Burea-Khanka, Sikhote-Alin, and Sakhalin accretionary systems, including Permian and Triassic rocks, are distinguished in the southern Far East Russia from west to east (Fig. 1).

2. Description

The Burea-Khanka system consists of pre-Devonian terranes, Permian and Triassic rocks are a part of overlap assemblages (Fig. 2). Permian deposits are principally represented by the uppermost lower and upper series. Near-shore volcanic and sedimentary deposits predominate, characterized by paleogeodynamic zonation: volcanic arc - backarc basin (Khanchuk et al., 1989a), which could be illustrated in detail in southern Primorye. In the east, within the Sergeevka terrane, near the town of Nakhodka, spherical bodies of Midian limestone associated with turbidite-type graded-bedding deposits occur. Limestone contains abundant crinoids, has no clear reef facies, and forms, apparently, olistoliths in younger clastic rocks. Locally, limestone allochthon is detected by doubling of sections. A vivid example is Senkina Shapka limestone (Chandalaz formation) in the southern outskirts of the town of Partizansk. We observe two limestone thrust sheets, tilted to the south and separated by a siltstone sequence of unknown age. Each thrust sheet includes four similar foraminifera zones from north to south (Kotlyar, Zakharov, 1989).

To the east, differentiated sodium basalt, andesite, and dacite of calc-alkaline series outcrop (Sitsa formation), followed by potassium-sodic and potassium basalt, andesite, and rhyolite of calc-alkaline and shoshonite series (Vladivostok formation) (Levashev, 1991), stretching almost continuously from the city of Vladivostok far to the north, along the margin of the Burea-Khanka terrane collage. Further to the west, within the Laoelin-Grodekovo terrane, Late Permian pillow basalts occur, associated with mudstone (Barabash formation). Basalt dominates in the lower part of the section, and felsic lava and tuff in the upper part. Basalt contains high TiO (up to 2%) and AlO (17%) (Vrzhosek, 1984), which is typical of rift basalt.

Triassic deposits are uniform shallow-water clastic deposits, interbedded with coal and limestone. In Lower Triassic section, species composition of Early Triassic Tethyan ammonoids in such remote from each other regions as the outskirts of the city of Vladivostok and the northern side of the Amur River in the Small Khingan Ridge completely coinside (Zakharov, 1977). Only in the Chinese part of the Laoelin-Grodekovo terrane, Late Triassic (?) surficial felsic volcanic rocks of unknown geodynamic nature are distinguished.

In the Sikhote-Alin system, Permian and Triassic rocks form allochthons in Middle Jurassic to Berriasian and Neocomian accretionary wedge terranes (Fig. 3). Two major Permian and Triassic rock types are distinguished among inclusions.

The first rock type is Late Permian clastic rocks and limestone and Triassic clastic rocks, comparable with coeval overlap assemblages of the marginal part of the Burea-Khanka terrane collage. The second rock type consists of paleo-oceanic chert and limestone. Jurassic accretionary wedge terranes include Early Permian chert and limestone, forming the upper sedimentary portion of Devonian ophiolite (Khanchuk et al., 1989a) and Upper Permian chert, interbedded with dolomite (Volokhin et al., 1990) (Samarka terrane). Triassic rocks are represented by either chert Samarka (Volokhin et al., 1990; Khanchuk et

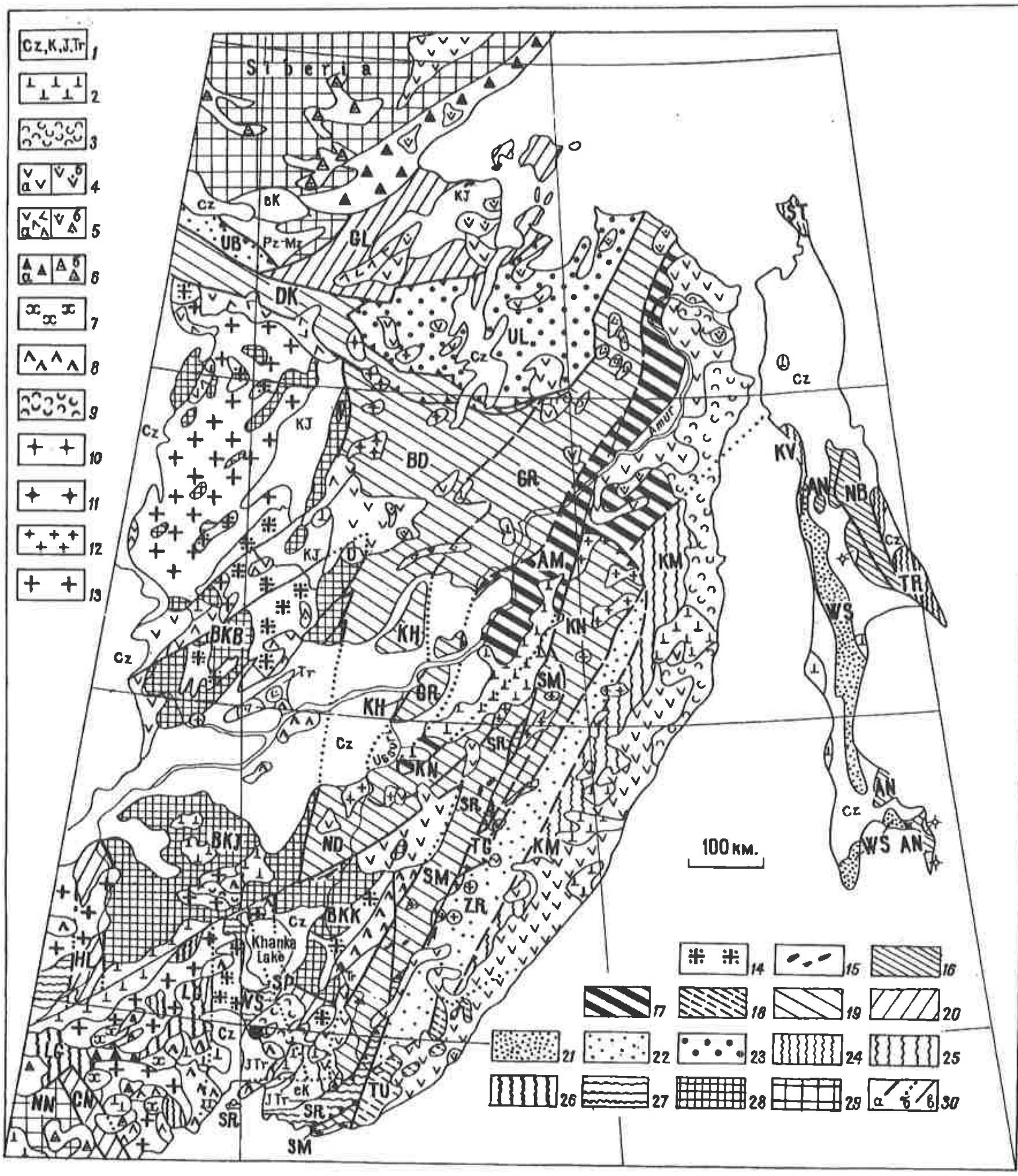

Fig. 1. Tectono-stratigraphic terranes and overlap assemblages (sediment sequences with volcanic and plutonic rocks) to the south of the Siberian craton.

The map of the northern Sikhote-Alin and Mongol-Okhotsk areas is compiled (together with N.V. Ognyanov) using the tectonic map by B.A. Natal'in (1991); the map of Sakhalin Island is compiled by A.V. Rikhter (1986).

Overlap assemblages: 1 - sedimentary deposits, age shown; 2-9 - volcanic (a) and plutonic (b) rocks (2 - Pliocene-Quaternary within plate, 3 - Eocene-Miocene postsubduction, 4 - Late Albian-Paleocene subductionary, 5 - Aptian-Albian subductionary, 6 - Middle to Late Jurassic subductionary, 7 - Late Triassic of unknown origin, 8 - Late Permian subductionary, 9 - Devonian-Middle Carboniferous rifting); 10-12 - collision granites: (10 - Eocene, 11 - Late Cretaceous, 12 - Early Cretaceous); 13 - Late Permian subductionary and collision granites, unclassified; 14 - Pre-Devonian collsion granite; 15 - Late Jurassic-Neocomian alkalic withinplate ultramafic and gabbroic Kondyor-type rocks. Terranes: 16-20 - Accretionary wedge (16 - Late Albian-Paleocene, 17 - Aptian-Albian, 18 - Neocomian, 19 - Middle Jurassic-Berriasian, 20 - Paleozoic); 21-23 - Turbidite basins (21 - Late Albian-Paleocene, 22 - Early Cretaceous, 23 - Jurassic); 24-26 - Island arcs (24 - Late Cretaceous, 25 - Aptian-Middle Albian, 26 - Early Silurian); 27 - Cambrian-Early Ordovician marginal-continental volcanic and plutonic arcs; 28 - Precambrian continental margins; 29 - Cratons. 30 - Faults: a - determined and inferred boundaries of terranes, b - overlapped, c - within terranes (teeth show the dip of thrusts, arrows strike-slip faults).

Terranes: AM - Lower Amur, AN - Aniva, BD - Badzhal, BKB, BKL, and BKK - Burea, Jiamusi, and Kabarga subterranes of the Burea-Kabarga terrane, CN - Chongijin, DK - Dzhagda-Kerbi, GL - Galam, GR - Gorin, HL - Heilongjiang, KH - Khabarovsk, KN - Khungari, KM - Kema, KV - Kamyshov, LG - Laoelin-Grodekovo, NB - Nabil, ND - Nadankhada, NN - Nannim, SM - Samarka, SP - Spassk, SR - Sergeevka, ST - Schmidta, TG - Tiger, TR - Terpeniya, TU - Taukha, UB - Un'ya-Boma, UL - Ulban, VS - Voznesenka, WS - West-Sakhalin, ZR - Zhuravlevka.

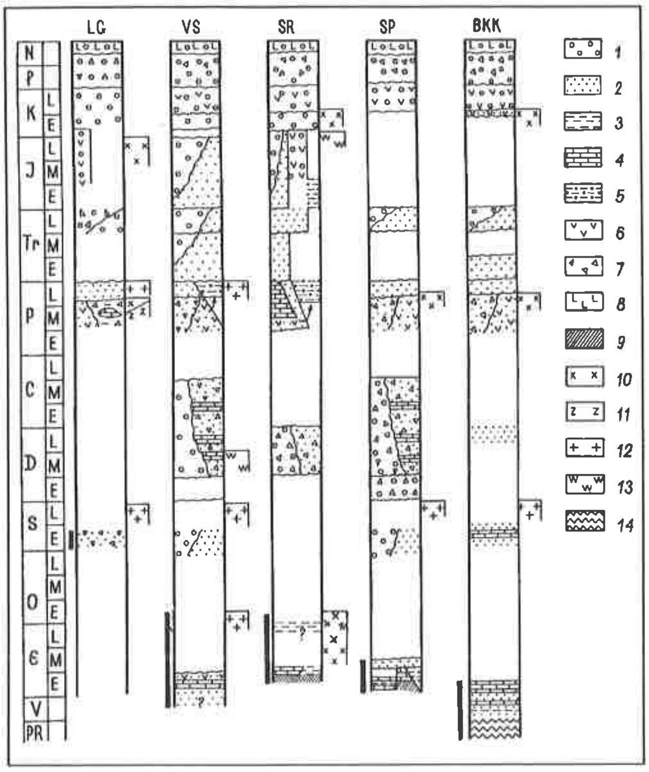

Fig. 2. Tectono-stratigraphic columns of terranes belonging to the Burea-Khanka superterrane.

1 - non-marine clastic deposits; 2 - shallow-water marine and near-shore clastic deposits; 3 - deep-water clastic deposits; 4 - limestone; 5 - turbidite and olistostrome; 6 - subductional volcanic rocks; 7 - high-alumina volcanic rocks of marginal continental and back-arc tension zones; 8 - withinplate basalt; 9 - ophiolite; 10 - subductional gabbro and plagiogranites; 11 - subductional ultramafic rocks; 12 - collisional granite; 13 - withinplate ultramafic and gabbroic rocks; 14 - Precambrian crystalline rocks.

Terranes: BKK- Kabarga subterrane, LG - Laoelin-Grodekovo, SP - Spassk, SR - Sergeevka, and VS - Voznesenka.

al., 1989a), Nadankhada (Kojima, 1989), and Khabarovsk (Bragin, 1991) terranes, or Middle to Late Triassic chert, interbedded with pelagic limestone, as it takes place in the Khungari and Gorin terranes (Volokhin et al., 1989). No transition from Permian to Triassic rocks was observed in corresponding blocks.

In the Taukha Neocomian accretionary wedge terrane, inclusions of Permian and Triassic paleo-oceanic cherts are abundant (Volokhin et al., 1990; Khanchuk et al., 1989b; Golozubov et al., 1992). A block of Permian and Triassic cherts was described in the Taukha terrane, but the nature of the boundary between Permian and Triassic rocks still needs to be determined (Rudenko and Panasenko, 1990). The lowermost beds of the paleo-oceanic Triassic rocks consist of clay chert (Volokhin et al., 1990). The Taukha terrane includes large blocks of Permian and Triassic limestone, which form paleoguyot fragments. Paleoguyots include no late Permian to early Triassic limestone (Khanchuk et al., 1989a). The Taukha terrane also includes fragments of shallow-water clastic Permian and Middle to Late Triassic rocks.

In the Sakhalin Island, the Aniva Alb-Cenomanian accretionary wedge terrane includes olistoliths of Permian limestone, fragments of Late Triassic guyots, and Middle to Late Triassic cherts (Rikhter, 1986; Khanchuk et al., 1989a; Bragin, 1991).

Permian volcanic and sedimentary deposits of the Burea-Khanka system formed in the Japan-type environment. During Late Permian time, that island-arc system occurred, judging by the composition of Permian flora and fauna, in subtropical zone, at 5.3-16.7° paleolatitudes, according to paleomagnetic survey (at 24.2° during Early Induan) (Zakharov and Sokarev, 1991). Paleomagnetic characteristics of Late Permian deposits match those of Late Permian Sino-Korean craton and accretionary fold belts of Mongolia. The co-ordinate of the paleomagnetic pole for those Late Permian deposits cluster in the area of France and differ sharply from the co-ordinate of the paleomagnetic pole of the Russian and Siberian cratons, which fall within southern Kamchatka area (Zhao et al., 1990). At the end of Permian time, the Burea-Khanka island-arc system presumably accreted to the Sino-Korean craton, suggested by the cessastion of volcanic activity and the intrusion of anatectic granite. This resulted in the origin of the North China-Amur continent between Laurasia and Gondwana. During Triassic time, the Burea-Khanka continental margin shifted towards the Siberian craton due to the counter clockwise rotation of the North China-Amur continent (Zonenshain et al., 1990). Early to Middle Triassic fauna of the Burea-Khanka continent is of the Thetyan type. During the Carnian time, Thetyan and Boreal fauna mixed. Norian fauna of Boreal type was similar to that of the Siberian craton (Zakharov, 1977; Burij et al., 1990; Zakharov and Sokarev, 1991). Geological evidence suggests that the Burea-Khanka continental margin collided

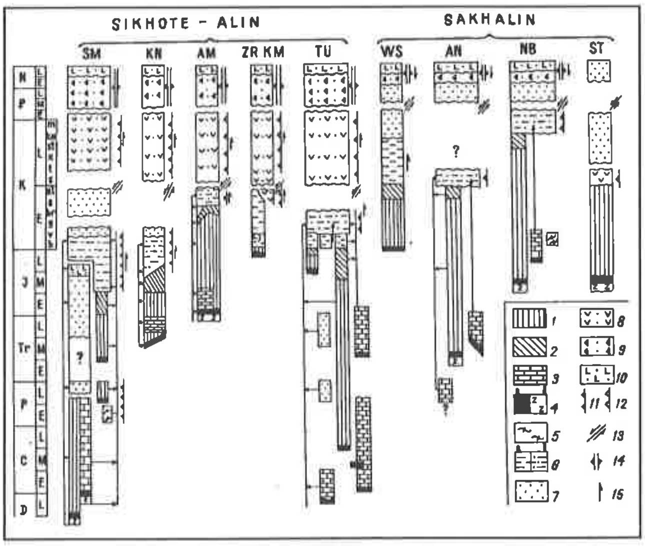

Fig. 3. Tectono-stratigraphic columns of terranes and overlap assemblages of the Sikhote-Alin (SM, KN, AM, ZR, KM, TU) and Sakhalin (WS, AN, NB, ST) accretionary systems.

1-4 - oceanic rocks (1 - chert, 2 - siliceous mudstone, 3 - reef or pelagic limestone, 4a - basalt, and 4b - gabbroic and ultramafic rocks); 5 - metamorphic rocks of subduction zones; 6a - turbidite, 6b - turbidite and olistostrome (melange); 7 - shelf clastic rocks; 8-10 - volcanic rocks (8 - subductional, 9 - postsubductional, and 10 - withinplate); 11-15 geodynamic environment (11 - subduction-accretion, 12 - postaccretionary volcanic arc, 13 - collision, 14 - postsubduction and withinplate tension, and 15 - left-lateral strike-slip fault).

For the terrane map, see Fig. 1.

with the Siberian craton during Middle Jurassic (Natal'in, 1991).

During Middle Jurassic time, the geodynamic environment of the eastern Eurasia margin changed abruptly, resulting in the origin of a system of circum-Pacific active continetal margins and intraoceanic island arcs. Subduction processes formed Jurassic to Cretaceous accretionary wedges of the Sikhote-Alin area and Sakhalin Island. These accretionary wedges include fragments of the paleo-Pacific oceanic crust. The composition of fauna in limestone suggests that Permian and Triassic paleooceanic rocks formed near the equator.

At the end of Permian - beginning of Triassic, the paleo-Pacific region experienced a catastrophic change of tectonic environment. The growth of paleoguyot limestone caps terminated at that time. They were growing continuously from Late Devonian almost till the end of Permian time. New guyot caps appeared only at the beginning of Middle Triassic time. Early Triassic is characterized by a sharp growth of clay admixture in chert. In the Pacific framework of the North-East Russia, paleo-oceanic Triassic cherts include blocks of Carboniferous to Permian paleoguyot limestone (Sokolov, 1985). These data suggest an abrupt shallowing of the paleo-Pacific.

Acknowledgements

Authors are grateful to Prof. P. Baumgartner and Dr. S. Lucas for review. We are indebted to Mrs. L. I. Kovbas for the translation of this text into English.

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EARLY MESOZOIC MAGMATISM OF TECTONIC PROCESS ACTIVATION IN EASTERN ASIA

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Abstract

In Early-Middle Mesozoic time, the north-east part of the Asian continent underwent tectonic activation resulting in the formation of Late Jurassic rifting troughs accompanied by basaltic volcanism. The opening of the continental crust and the formation of the oceanic floor were most significant in sutures (South-Anyui and Ilin-Tass). Character of the microelement distribution of the basalt suggests that they were formed within thick sialic crust.

1. Introduction

The Early Mesozoic period of the continental geoblock reconstruction of Asia coincides with the wide-scale breakdown of Gondwana in the south extension and splitting of the Eastern Africa part, separation of continents adjacent to Antarctica, and beginning of spreading between India and Australia, etc. The reconstruction began at the Late Permian - Early Triassic boundary and it was multiphase, reaching its culmination during the Middle Mesozoic, and continuing to a lesser degree during the late Mesozoic.

The breakdown of Gondwana in its western and southern parts was accompanied by basaltic magmatism-formation of tremendous continental areas of plateau-basalt: Karoo dolerites in South Africa and Tasmania, Ferry tholeiites of Antarctica and so on. Enormous volumes of tholeiites erupted on the surface support the large-scale processes of extension, as the analysis of basalt composition shows the similarity of the latter to the oceanic tholeiites of the Pacific troughs. The source of the melting could be the rocks of the upper mantle, which were non-uniform in composition and the melting of which was not connected with the ascending underflow (plume), but resulted from the change of geodynamic regime-transition from compression to extension (Fallon et al., 1991; Alabaster and Storey, 1991).

The processes of Gondwana breakdown at the beginning and middle of the Mesozoic in its western and southern parts were not comparable to those in the north and east. In the northern and eastern parts of Asia, the single super-continent Eurasia formed due to Indian-Sinian (T-J_1) and Kimmerian movements. The tectonics of Eurasia in the middle and late Mesozoic, corresponding to the epoch of Gondwana breakdown in the south and to the start of the Pacific plate migration in the north, resulted in its breaking apart. According to geodynamic regime, such zones were accompanied by either basaltic or calc-alkaline moderate-acid volcanism.

In the continental part of East Asia, the processes of the Mesozoic (Late Jurassic - Early Cretaceous) stage were shown by the formation of sub-latitudinal rifting structures, inherited sutures separating the continental plates and individual geoblocks within the cores of ancient massifs. They include (from north to south): (1) North-Oloi (South Anyui) separating Kolyma and East-Chukotka massifs; (2) Ilin-Tass - between Kolyma massif Siberian platform; (3) Ogodzha-Umlekan (Mongol-Okhotsk) - between Aldan shield and Bureya massif; (4) Inshan-Yanshan - between Bureya massif and Central-Chinese platform; (5) Tsinlin - between Central-Chinese and Yangtsze platforms (Fig. 1).

Besides sub-latitudinal structures, a series of linear structures of the north-east trend originated. They are confined to transcurrent deep faults along the joint of ancient platforms and folded belts or the margins of massifs that became active in the early Yanshan epoch of tectogenesis. Among these are rift-like troughs along the Tang-Lu fault system within the eastern margin of the North-Chinese platform and Yangtze paraplatform, along the Alchan deep fault and others along the eastern margin of Khanka massif and Kukan fault in the eastern belt of the Bureya massif. The fault system along the eastern belt of the Omolon massif falls in this category also. In rift-like depressions and grabens, the sheets and fractured bodies of picrite-alkaline-basaltic and meimechite-picrite formations were developed.

Simultaneously or somewhat later, in the zones of continental block collision in Late Jurassic - Early Cretaceous and Early Cretaceous time, the island-arc belts of calc-alkaline volcanism formed. Such belts of Andean type are the Oloi on the northern margin of the Omolon massif and the Uyadin-Yasachnin belt on the southwestern margin of the Kolyma-Omolon microcontinent (Fig. 2).

The intensification of movement of both the whole Eurasian continent and its individual microcontinents in the south-east and contrary movement of the Pacific plate in the north in Neocomian time, gave rise to the compressional conditions in the collision zones and the formation of granitoid plutonic belts in the southern Aldan shield along the framework of the Kolyma block (the Main Kolymian granitoid belt) and in the south Yangtze platform. Along the eastern margin of the Eurasian continent

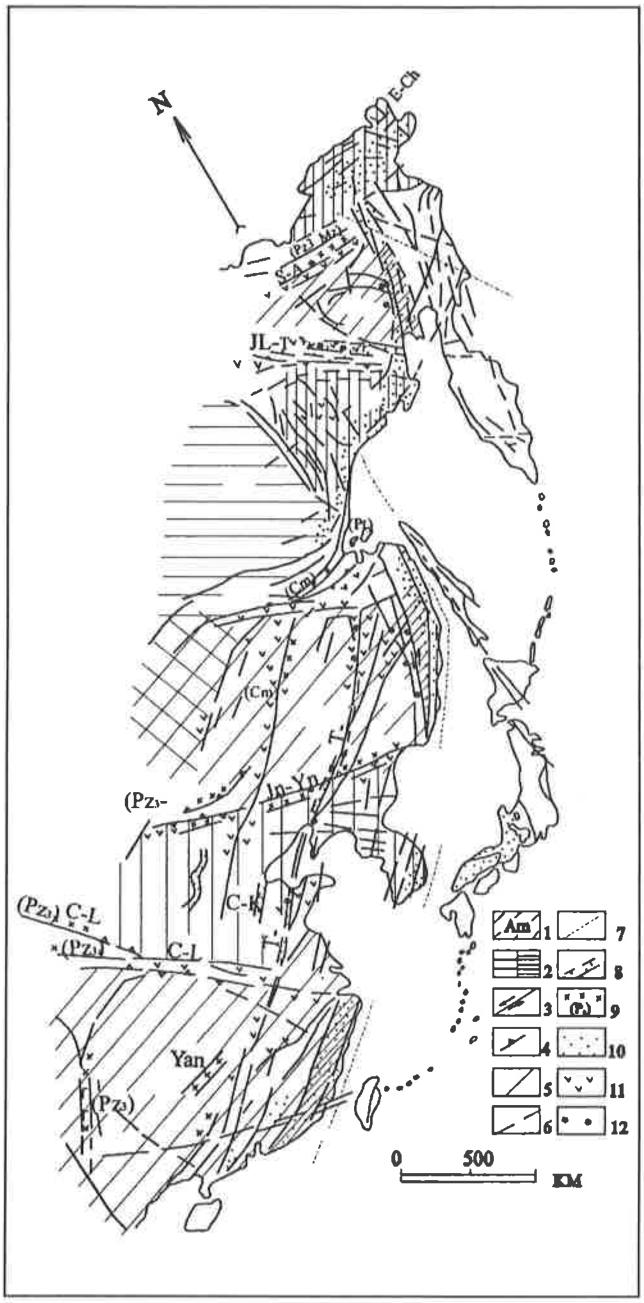

Fig. 1. The scheme of the main structural elements of the East Asia continent.

1 - Geoblocks: Al - Aldan, Oh - Okhotsk, Om - Omolon, Am - Amur, S-K - Sino-Korean, Yan - Yangtze. 2 - Mesozoic folded complexes. 3 - deep faults. 4 - zones of interblock collisions. 5, 6 - regional fault zones. 7 - boundary of the continental block. 8 - Meso-Cenozoic continental rifts. 9 - magmatic rocks complexes of the collision zones and sutures and their age: S-A - South Anyui, Il-T - Ilin-Tass, M-O - Mongol-Okhotsk, In-Yn - Inshan-Yanshan, C-L - Tsilin. 10 - marginal-continental volcanic belts - Okhotsk-Chukotka, East-Sikhote-Alin, East Korea, South-East Chines. 11 - intracontinental volcanic belts. 12 - Late Jurassic rift magmatic complexes.

in the Late Jurassic-Neocomian, the island arcs - Uda-Murgal and East-Chinese (?) - formed. Unlike other regions of East Asia, in Sikhote-Alin along the margin of the Khanka massif, the Moneron-Samarga island arc formed somewhat later, in the Early Cretaceous (Simanenko, 1990).

The main structural elements controlling the formation of island arcs along the active margins of East Asia were seismofocal deep faults with planes dipping under the continent (Shilo and Umitbaev, 1977; Umitbaev, 1986). By the end of the Early Cretaceous, the direction of the movement of the Eurasian continental block and the Pacific plate sharply changed, and major faults of the north-east trend were transformed into wrench faults (Utkin, 1980).

These events favoured the marginal-continental systems of volcanic belts - Okhotsk-Chukotka, East-Sikhote-Alin, Pusan and South-East-China united into the East-Asian volcanic lineament - with the structure restricting the ocean-continent transition zones (Volcanic belts ..., 1984; Belyi, 1977, 1978)

2. Structures and Magmatism

Late Jurassic magmatic structures of north-eastern Asia, reflecting, on the one hand, the geological regime of the region and, on the other hand, deep processes related to the migration of continental masses, are the least known ones and deserve special attention in respect to the geological events in the Circum-Pacific during the early and middle Mesozoic. The analysis of magmatic formations of this time is of interest as the composition of the rocks reflects the character of geodynamic environments (Pearce and Cann, 1973).

As was mentioned above, in the northern part of the Eurasina continent where, along the zone of sutures, the North-American and Eurasian plates join, the Late Jurassic lineal structure of active basaltic volcanism was outlined (Figs. 2, 3). The nature of this linear structure is defined ambiguously (Parfenov, 1991; Surnin, 1990; Lychagin et al., 1989).

In pre-Late Jurassic time, during the Ordovician and Silurian Periods, the Omolon massif and Kolyma and Omulevsk blocks were part of the Siberian continent, and then in the middle Paleozoic were separated due to the rifting. Since the late Paleozoic and during the Jurassic, they were joined with the Siberian continent again. This event is considered the collision of the hypothetical island arc and the passive margin of the Siberian continental block (Parfenov, 1991). Migration of the North-American plate to the south-west resulted in the formation of the Kolyma-Omolon microcontinent in the Middle Jurassic and united the Eurasian continent in Late Jurassic time. Collision at this time produced the Uyadin-Yasachnaya island arc and Ilin-Tass black-arc basin with a complex of basaltic rocks. In Early Cretaceous time, along the boundaries of the Kolyma-Omolon block, the plutonic belt of granitoids (Big batholithic belt of Kolyma) was formed, and had no effusive analogues. In this case, the Ilin-Tass basalts were attributed to the formation of a back-arc basin (Parfenov, 1991).

Geological data show that the formation of the Ilin-Tass basin and simultaneous eruption of basalt started later (Fig.3) than the formation of the Uyadin-Yasachnaya epoch and was connected with the beginning of the extension process behind the arc in the Ulakhan-Arga-Tass and Ilin-Tass fault zones (Fig. 3). Along faults, rifting depressions were formed. It seems that the Ilin-Tass rift has significantly less width. Its boundary is defined by a system of regional faults that separate it in the south from orogenic structures of the Uyadin-Yasachnaya island arc of the Darpir magmatic zone (Lychagin et al., 1989) composed

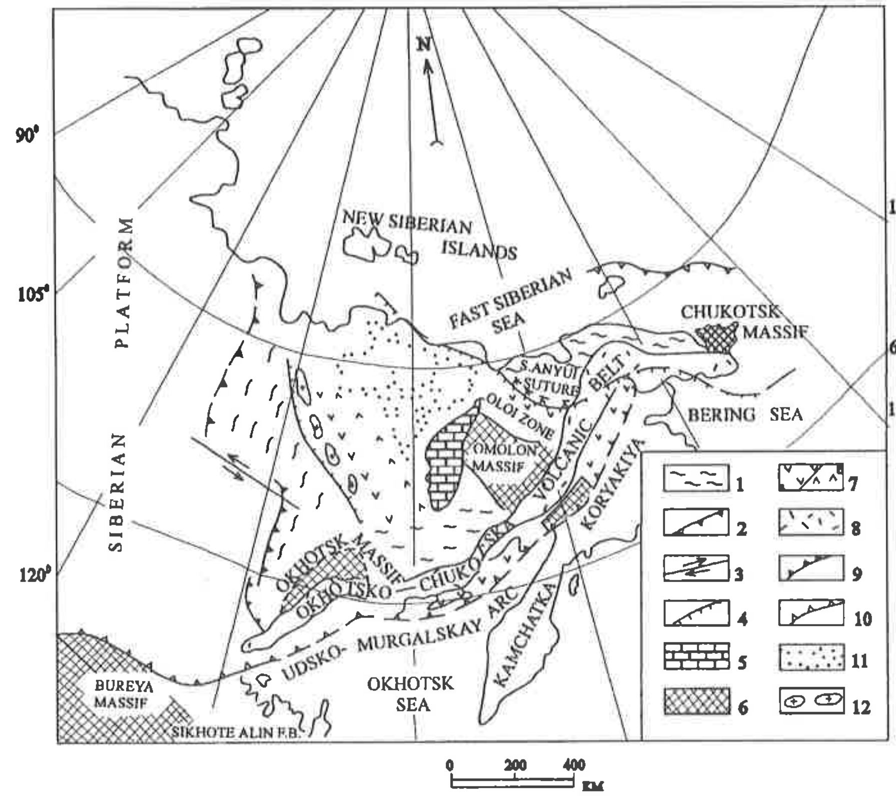

Fig. 2. The scheme of the tectonic position of Verkhoyansk-Kolyma region of North East Asia (Parfenov, 1991; with the author's additions).

1 - Mesozoic folded complexes. 2 - Cretaceous active continental margin. 3 - faults and wrench-fault zones. 4 - boundary of the passive Mesozoic margin. 5 - Kolyma block of Kolyma-Omolon massif. 6 - massifs with pre-Riphean basement. 7 - Late J_3-K_1 island arc and rift belts: a - Uda-Murgal, Uyadin-Yasachnaya arc, b - South-Anyui and Ilin-Tass rifts. 8 - Okhotsk-Chukotka Late Mesozoic belts. 9 - Early Mesozoic active continental margin. 10 - Cretaceous active continental margin. 11 - Late Cenozoic sediments. 12 - Kolymian plutonic belt of granitoids.

predominantly of andesite and rhyolite formations of calc-alkali series similar to paleoisland complexes in petro-geochemical characteristics. Basaltoids gravitate to the northern slopes of grabens and changed by andesite facies towards the south-west. The rock composition of andesite formation is not discussed in this paper.

In the Ilin-Tass zone, basaltoids predominate in the composition of volcanic series. Small bodies, dikes and intrusions of picrites, gabbro-dolerites, and diabases are common. In addition, in the section of basalt complexes, acidic rocks - rhyolites and islandites - gravitating to the tops of the sheets, are known. Petrochemical and micro-element composition allow attribution of the rocks to the picrite-basaltic series of increased alkalinity typical of rifts developed on hard basement. The rock series of Ilin-Tass are characterized by transitional types similar in composition on the one hand to the subalkaline series of continental rifts and on the other hand to the trachybasalts of island arcs. This peculiarity possibly reflects the geodynamic regime of the Ilin-Tass rift system developed on the margin of the Kolyma-Omolon massif and located directly in the collision zone of the Verkhoyan massive margin of the Siberian platform and Kolyma massif, involved in the North-American plate, the migration of which to the south-west in Late Jurassic time conditioned the formation of the Uyadin-Yasachnaya arc, and slowed down by the end of the Jurassic-Ilin-Tass rift.

To determine the degree of melting, J. Shaw's method (Shaw, 1970) and Treul's and Joron's experiments were used. The investigation showed the small degree of mantle melting (initial material was about 2%) and ascent of poorly differentiated picritic magmas (Table 1).

Along the northern boundary of the Kolyma-Omolon block during Late Jurassic time, the South-Anyui suture occurred as the zone of separation of two ancient massifs - Omolon and East-Chukotka - within the North-American plate. On the passive margin of the East-Chukotka massif, the miogeosynclinal Chukotka folded area formed. During the Mesozoic, it was the zone of crustal opening and formation of rifting oceanic basin with oceanic crust (Volcanic Belts ..., 1984).

As distinct from the Ilin-Tass rift, the South-Anyui rift trough was characterized by the great depth of the crustal opening. The rocks of the rift basement, at later stages of its development, were obducted and represented by protrusions of ultrabasites and gabbro-plagiogranites of the Uyamkanda and Gromadninsk-Vurguemei massif (Figs. 4, 5). In the Anyui rift trough, in Late Jurassic time, the rocks of sedimentary-volcanogenic deep-sea formations were deposited, the upper parts of which are represented by the sheets (central zone) of tholeiitic series. Simultaneously, on the rift slopes in subcontinental facies in the rift troughs, the picrite-trachybasaltic complex (Oloi zone) was formed, the main members of which were similar to meimechite-

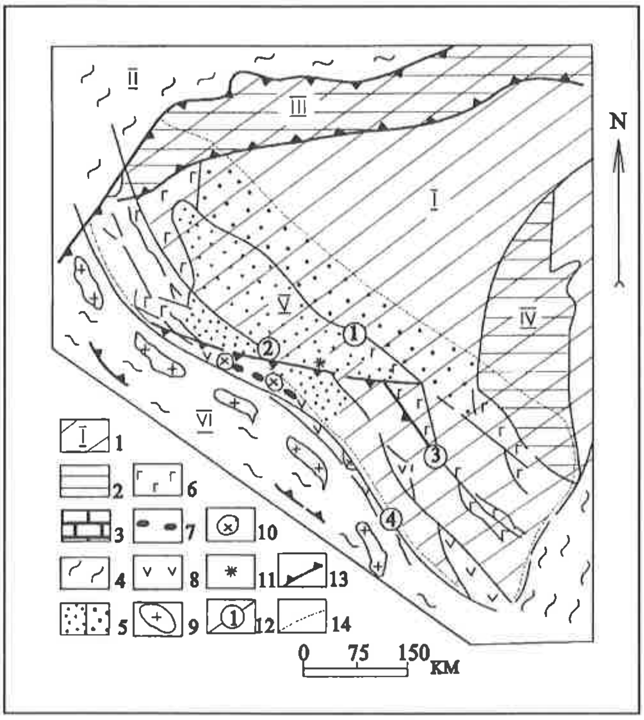

Fig. 3. The scheme of the structure of Ilin-Tass rift systems (Surnin, 1990; Lychagin et al., 1989, with the author's additions).

1 - Omolon-Kolyma block: I - Kolyma-Omolon median massif; II - folded complexes of Verkhoyansk system; III - Polousnensk rise; IV - Kolyma rise; V - Ilin-Tass rift; VI - Inzayali-Debin synclinorium and Kolymian batholitic belts. 2, 3 - ancient rises. 4 - miogeosynclinal folded complexes. 5 - sedimentary formations of Late Jurassic-Early Cretaceous age. 6, 7 - picrite-alkaline-basaltic complex of Ilin-Tass rift. 8 - Uyadino-Yasachinsky island-arc (Darpir zone). 9 - granitoids. 10 - extrusive of Late Cretaceous age. 11 - Quaternary basaltic volcanoes. 12 - deep faults (1 - Ilin-Tassky; 2 - Umlekhansky; 3 - Arga-Tassky; 4 - Darpirsky). 13 - collision zones. 14 - boundary of active zone of J_3-K_1 volcanism.

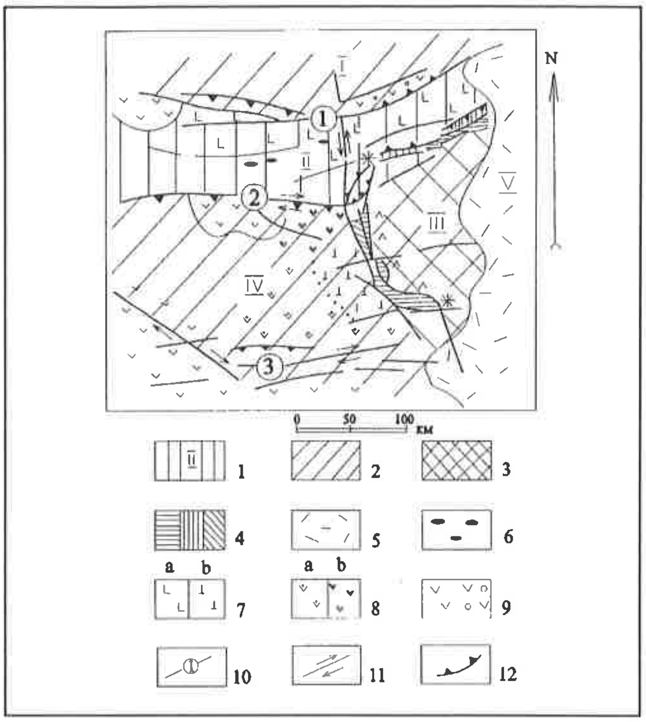

Fig. 4. The scheme of the structure of South-Anyui rift system (data of Natal'in, 1984, with the author's additions).

1 - Zones: I - South-Anyui and Nutesyn island arc; II - Cetnral rift zone (geosynclinal trough); III - Yablon massif; IV - Oloi zone; V - Okhotsk-Chukotka volcanic belt. 2 - Folded complexes of Verkhoyano-Chukotskaya system. 3 - rises of Yablon massif. 4 - melanocratic basement. 5 - volcanites of Okhotsk-Chukotka belt. 6 - Obducted massifs of the Central zone. 7 - basalts and tholeiites (a) of the Central zone and thachybasalts (b) of Nenkan graben. 8 - andesite-basalts (a) and trachyandesites (b) of continental grabens. 9 - andesites of Nutesynsk island arc. 10 - deep faults: 1 - Anyui; 2 - Angara; 3 - Berezovskian. 11 - wrench-fault zones. 12 - collision zones and direction of movement along them. Asterisks indicate Quaternary volcanoes.

picrites, and in the South-Anyui zone (Nutesyn), the basalt-andesite complex was formed. The intrusive complex - Egdegkich - differentiated from biotite-bearing pyroxenites to alkaline syenites corresponds to the volcanic complex (Table 1).

On the south slope of the rift, at the Jurassic-Cretaceous boundary, under the collision of the passive margin of the Omolon massif and oceanic floor of the Anyui sea, there formed the Oloi island-arc system with a basalt-andesite complex similar to the calc-alkaline series of the modern island arcs in its petrogeochemical parameters (low titanium and niobium contents, high alumina contents). Petrochemical features of magmatic formations are discussed only for the Late Jurassic stage of magmatism pronounced in both the rifting deep-sea trough and the rifting troughs on the continental margin of the Omolon massif.

When analysing the rocks of the Central South-Anyui (Nutesyn), and Oloi zones of magmatism, one can trace clear petrogeochemical zonation. High sodium content (superposed), low potassium and titanium content, but high iron content characterise the basalts of the central zone that make them similar to oceanic tholeiites. In the South-Anyui zone these characteristics are kept, but potassium content increases and strontium content steadily grows; i.e., the features of rocks of the calc-alkaline series appear.

In the Oloi zone, adjacent structurally to the central zone, in the sections of the series (lower parts), tholeiitic varieties are common, but the extent of change is significantly less. The spectrum of rare-earth elements is characterized by increasing Ce and Yb contents. In the rocks of the basement represented by ultrabasalts and the laminated complex by basite composition, high Ce and low Yb contents are noted. Thus, the high ratio of light and heavy REE is preserved. It is significantly higher (1.5-1.7) than in the initial mantle (Wood, 1979) but similar to that of tholeiitic basalts of the central zone.

The picrite-trachybasaltic complex, characteristic of the upper horizons of rifting troughs, differs widely from all the other ones in high potassium and high content of large-ion lithophylic elements (LIL), which makes the most magnesian rocks of the complex similar to meimechite-picrites, and ferriferrous varieties - to trachybasalts of the rift zones of continental areas. It is characteristic to a greater degree of the rocks of the Egdegkich differentiated complex.

Data on magmatism and petrogeochemistry make it possible to reconstruct the geodynamic regime of the

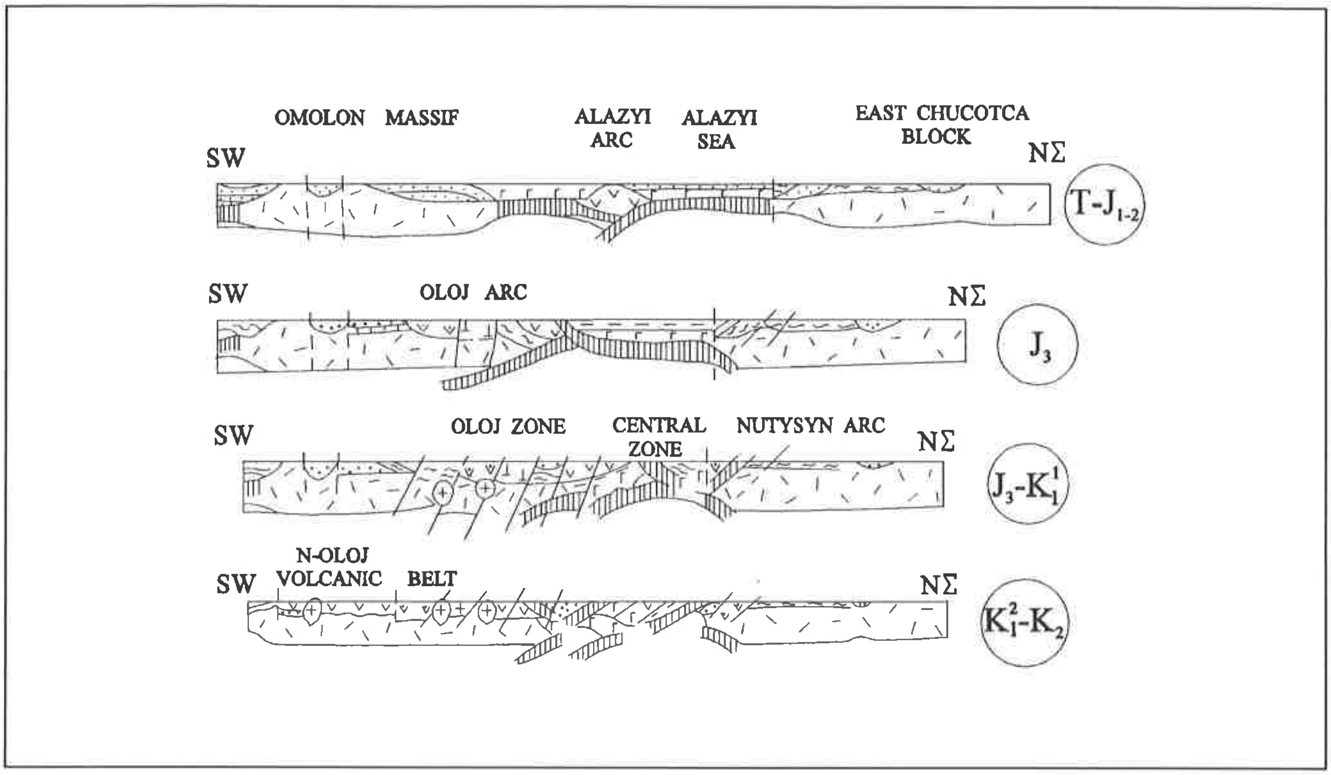

Fig. 5. Tectonic reconstruction illustrating the tectonic evolution of the South-Anyui rift system. See. Fig. 4 for location.

Age symbols: $T\text{-}J_{1\text{-}2}$ - Triassic-Early-Middle Jurassic; J_3 - Oxfordian-Kimmeridgian; $J_3\text{-}K_1^1$ - Late Jurassic-Early Cretaceous; $K_1^2\text{-}K_2$ - Albian-Late Cretaceous.

formation. Tholeiites of the central zone may be attributed to oceanic ones and related to the rift trough, the opening of which was rather rapid and the melting of the source was more significant; that could have been at a great rate of extension.

The participation of the crustal material in the melting was minimal. In the South-Anyui zone, the role of the crustal material in magma petrogenesis increases, as not only the blocks of the oceanic crust, but the continental material also, were involved in the collision process. It is most characteristic of the rocks of the picrite-trachybasalt series (Rb/Sr > 0.15). The melting of the substratum rocks does not exceed 1.5%, which may take place at a small rate of rift-forming extension (Shaw, 1970).

In the system of the near-fault rift troughs, on the setting of ancient massifs or within the active eastern margins, the complex of effusive and subvolcanic intrusions of diverse petrochemical composition was formed. But all of them are characterized by subalkaline or alkaline composition (Table 1).

Along the east margin of Khanka massif (Fig. 1), in the near-fault grabens and troughs, the sheets and extrusions of the rocks of Venyukovo and Kultukha complexes (J_3, Fig. 5) are known, represented by meimechite - picrite-alkaline basaltic and trachybasaltic complexes. Meimechite-alkaline-basaltic rocks are most completely represented in the rifting troughs that originated on the crystalline rocks of the eastern margin of the Khanka massif. Alkaline-ultrabasic effusives make up the upper part of the Triassic-Jurassic terrigenous-cherty-volcanogenic section. The meimechite-picritic complex (Kultukha complex) (Table 2) is represented by the sheet intrusive facies and volcanic pipes. They change in composition from ultrabasic varieties to kaersutite basalts with higher potassium and titanium content, which make them similar to kaersutite basalts of the Venyukovo complex. Wide distribution of the complex over the total margin of the Khanka massif testifies to the significant opening of the rifting trough in the rocks of the crystalline basement and significant melting degree of the melanocratic substratum.

To the north-east of the Khanka massif, within the margin of the Bureya crystalline block, and Omolon massif (Fig. 2), in the late Jurassic-Early Cretaceous, in narrow rifting troughs, the picrite-alkaline-basaltic complexes formed (Dayan, Omolon, Maloelgakhchan, Karboschan, and others), represented by both sheet and extrusive-intrusive facies. The latter are characterized by strongly differentiated intrusion type: from alkaline gabbro and biotite-bearing pyroxenite to alkaline syenite. As a rule, the opening of the crust and melanocratic basement was insignificant but deeper. The exceptions are near-fault graben troughs in the Omolon massif (Khulichan, Karboschan) related to sub-latitudinal extension-fault zones (Oloi-Berezovian, Omcukchan, and others). According to geochemical data, the degree of substratum melting did not exceed 1.5% for the extrusive formations of the Omolon complex and was somewhat higher (1.5-2 %) for the sheet rocks of the Karboschan and Maloelgakchan complexes related to sub-latitudinal faults (Table 2).

The north-east part of the Asian margin's structure of extension, mentioned above, does not exhaust the total diversity of manifestation of Late Jurassic and Late Jurassic-Early Cretaceous magmatism connected with tectonic reconstruction conditioned by the boundary of the supercontinent and oceanic plate, but gives a certain idea of the scale of this process.

3. Conclusions

The analysis of the structural features of the Late Jurassic magmatism manifest in the northern part of the Eurasian continental block, related to the new epoch of tectono-magmatic, and comparison with analogous structures in the Southern Hemisphere, show that the scale of the destruction processes in that period were significantly smaller.

The most significant extension of the continental blocks to the point of the opening of the oceanic crust took place along sub-latitudinal sutures - South-Anyui and Ilin-Tass. In the South-Anyui, the geosynclinal rifting trough formed under deep-sea conditions with the manifestation of tholeiitic magmatism. The rocks (central zone) are similar in composition to oceanic tholeiites and MORB. In the Ilin-Tass rift, which is second to the previous one in size, the opening of the oceanic floor was not so deep and the rift trough was controlled by the zone of deep faults on its slopes. The rocks differ from those of the South-Anyui trough in their more alkaline composition.

The extension along the eastern margin of the continental block, within hard massifs and on its periphery were of local importance. Rift valleys were characterized by small opening, with the exception of the margin of the Khanka massif, where the trough was vast and deep, but the rock complex (meimechite-picritic) shows that it developed on the crystalline basement. The trans-regional system of deep faults trending from north to east, to which the manifestations of alkaline magmatism were restricted, at a later time in the middle and late Mesozoic, was a wrench-fault zone under the increase of contrary relative movements of the Asian continent to the south and the Pacific plate to the north.

In the conjugate zones of rift extension, simultaneously, before, or somewhat later in the collision zones, the island arc systems with the manifestation of volcanism of calc-alkaline series (Uyadin-Yasachnaya, Nutesyn, and other) were formed. On the slopes of the rift valleys in some cases (Oloi zone of the South-Anyui geosynclinal trough) the rift grabens formed, magmatism of which was characterized by high potassium alkalinity.

The composition of magmatic rocks, connected with tectonic movements of this super-region, and their microelement composition, suggest that the formation of the rift troughs took place on continental basement. The opening of the rift valleys and the rate of the extension (judging by the degree of substratum melting) were different for each block, and the character of the movements was controlled by block mobility.

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Table 1

Table 1
Chemical composition and trace element content in magmatic rocks from the South-Anyui and Ilin-Tass rift zones

	1	2	3	4	5	6
SiO_2 (wt.%)	49.01	49.58	45.24	48.29	51.11	46.60
TiO_2	2.01	2.12	1.09	1.04	1.96	0.74
Al_2O_3	14.79	15.20	15.54	16.84	13.37	10.83
Fe_2O_3	5.68	6.19	2.07	1.51	3.2	4.53
FeO	7.42	5.01	7.20	7.25	8.01	6.11
MnO	0.26	0.20	0.17	0.11	0.12	0.18
MgO	5.88	4.87	12.01	7.53	5.93	15.74
CaO	5.96	7.73	11.02	11.93	10.65	8.56
Na_2O	5.59	5.52	1.61	2.13	2.56	1.12
K_2O	0.01	0.01	0.06	0.15	0.01	1.91
H_2O^-	0.13	0.09	0.25	0.14	0.06	0.57
P_2O_5	0.10	0.32	0.04	0.17	0.15	0.34
LOI	3.04	3.38	3.62	2.58	3.56	2.57
Total	99.88	100.22	99.92	99.67	100.69	99.80
Rb (ppm)	nd	nd	nd	nd	nd	89
Sr	130	150	150	300	50	610
Ba	340	160	280	280	240	375
Zr	100	120	90	120	130	108
Nb	nd	nd	nd	nd	nd	29
La	4	4	14	20	5	31
Ce	7	31	20	21	23	22
Nd	nd	nd	nd	nd	nd	27
Sm	3.1	6.1	3.8	4.6	5.8	nd
Eu	4.15	2.25	1.66	1.67	1.0	nd
Tb	1.86	1.77	1	1.5	0.5	nd
Yb	1.2	1.53	2.6	6.5	2.82	nd
Lu	0.43	0.18	0.18	0.63	0.43	nd
REE	21.74	46.83	43.24	55.9	38.55	nd
Ba/Sr	2.6	1.06	1.8	0.9	4.4	0.61
La/Yb	3.3	2.61	5.38	3	1.77	nd

Table 1 (continued)

	7	8	9	10	11
SiO_2	49.1	46.14	48.68	46.71	42.56
TiO_2	0.76	5.23	2.56	2.71	1.08
Al_2O_3	12.78	13.53	15.06	16.16	12.67
Fe_2O_3	2.34	4.33	2.04	5.22	2.13
FeO	8.14	6.2	10.38	6.58	8.99
MnO	0.17	0.14	0.64	0.19	0.22
MgO	8.99	4.5	6.14	6.0	18.2
CaO	8.99	8.91	5.04	9.2	6.64
Na_2O	2.43	2.99	4.87	3.25	1.24
K_2O	2.64	1.55	0.42	0.64	1.09
H_2O^-	0.2	0.77	0.38	nd	5.25
P_2O_5	0.44	1.78	0.44	0.49	0.01
LOI	2.91	5.21	3.51	2.81	0.21
Total	99.98	101.28	100.16	99.96	100.32
Rb	67	nd	15	10	30
Sr	554	380	280	370	490
Ba	440	250	200	410	370
Zr	101	130	90	nd	91
Nb	17	nd	nd	nd	15
La	35	23	29	21	11
Ce	27	35	55	43	69
Nd	27	nd	nd	nd	31
Sm	nd	9.1	7	8.9	11.4
Eu	nd	3.6	1.9	1.9	1.2
Tb	nd	1.9	1.8	3.1	1.5
Yb	nd	1.6	2.1	2.7	1.7
Lu	nd	0.7	0.9	0.48	0.14
REE	nd	74.9	97.7	81.08	126.94
Ba/Sr	0.79	0.66	0.71	nd	nd
La/Yb	nd	14.38	13.81	7.78	6.47

South-Anyui rift, Central zone: 1,2 - basatls; South-Anyui (Nutesyn) zone: 3,4 - basalts; Oloi zone: 5 - basalt; North Oloi zone, Nenkan graben : 6 - picrite, 7 - trahybasal; Ilin-Tass rift (8-11): 8 - basalt of the outer zone (Innakhatin graben), 9 - alkaline basalt of the inner zone (Elekchan graben), 10,11 - picrite and picrite-dolerite of the inner zone (Elekchan graben). Chemical analysis of rocks No 1-5 and No 8-11 by Natal'in, 1984; Lychagin et al., 1989: Surnin, 1990.

Table 2

Table 2
Chemical composition and trace element contents in magmatic rocks from rift zones of the crystal massifs

	1	2	3	4	5	6	7
SiO_2	46.24	45.65	39.12	48.43	48.32	49.01	50.21
TiO_2	1.05	1.23	1.09	2.68	2.56	2.23	1.38
Al_2O_3	17.01	16.95	4.85	11.46	12.67	15.26	18.38
Fe_2O_3	7.00	6.80	6.54	3.35	5.10	4.59	6.00
FeO	5.57	6.48	6.86	8.29	5.57	8.19	4.89
MnO	0.21	0.42	0.26	0.23	0.23	0.22	0.18
MgO	5.75	5.51	29.76	8.66	7.72	7.37	5.18
CaO	10.86	11.39	5.13	10.97	8.87	8.60	8.44
Na_2O	2.74	2.20	0.41	2.64	2.57	3.45	3.45
K_2O	2.00	1.68	0.25	0.57	2.46	0.75	1.56
H_2O^-	0.46	0.76	nd	nd	nd	nd	nd
P_2O_5	0.45	0.37	nd	nd	0.69	0.30	0.33
LOI	2.11	0.68	5.51	3.20	3.18	nd	nd
Total	101.45	100.12	99.78	100.48	99.94	99.97	100.00
Rb	48	54				47	70
Sr	691	701				916	932
Ba	231	320				460	724
Zr	94	87				182	221
Nb	16	14				27	46
La	37	32				61	49
Ce	19	21				64	65
Nd	37	43				55	60
Sm	nd	nd				nd	9.0
Eu	nd	nd				nd	nd
Tb	nd	nd				nd	nd
Yb	nd	nd				nd	3.5
Y	50	53				45	40
Ba/Sr	0.33	0.46				0.50	0.78
La/Yb	nd	nd				nd	nd

Khanka massif, Venyukovo complex: 1,2 - trahybasalts; Kultukha complex: 3 - meimechite, 4 - basalt; Bureua massif, Dayan complex: 5 - alcaline basalt;
Omolon massif (6-7); Karboschan complex. 6 - trahybasalt ; Maloelgakchan complex: 7 - trahybasalt.
Chemical analysis No 3 and 7 by Surnin, 1990; No 4,5 - from "Volcanic belts ..., 1984".

HEAVY CLASTIC MINERALS IN UPPER PALEOZOIC-LOWER MESOZOIC BEDDED CHERTS OF THE SIKHOTE-ALIN TERRANES, RUSSIAN FAR EAST

(First Attempt of Study)

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Abstract

This report is based on 33 heavy-mineral analyses combined with microprobe analyses of olivine, pyroxene, amphibole and garnet. The heavy minerals are *the first* extracted from Upper Paleozoic-Lower Mesozoic bedded cherts and associated sedimentary rocks situated in the Samarka and Taukha Accretionary-Wedge Terranes (the Sikhote-Alin Mountains, southern Russian Far East). Actualistic interpretation of the data enables us to define tectonic settings at the place and time of these rocks deposition. Permian chert contains the association of olivine, Mg-orthopyroxene, Mg-clinopyroxene, amphibole, garnet and spinel derived from metaophiolites. It indicates the tectonic setting is like that in the modern intraoceanic collision zones. The Ti-clinopyroxene assemblage from Upper Triassic-Lower Jurassic cherts, mudstones and tuffs, which is derived from the within-plate basalts, points to the intraoceanic seamounts and fracture zones. Mesozoic deposits contain also zircon, tourmaline and sphene which amount is increasing with time. It likely reflects drifting of the depositional places from intraoceanic to passive-continental-margin conditions along tectonic zones oblique to the continent-ocean border. Heavy-mineral analysis of the pelagic deposits such as chert, limestone and claystone is recommended for wide use in order to define tectonic settings associated with the ancient oceanic and deep-sea basins as well as the global geological evolution.

1. Introduction

The previous investigation of Cenozoic (mainly Quaternary) marine sediments in the oceanic and marginal-sea environments has revealed that their heavy-clastic-mineral assemblages are reliable indicators of tectonic settings at and around their depositional places (Nechaev and Derkachev, 1989; Nechaev, 1991a,b; Nechaev and Isphording, 1993). These data may be compared with those related to the ancient sedimentary rocks in order to define geological history of the ocean and continental margins. One of the advantages in such a study is that any kind of sedimentary deposits, not only sands and sandstones used for the similar purposes traditionally (for instance, Dickinson, 1985 and references therein), may serve as a source of the interesting information. Heavy mineral analyses of claystones and calcareous oozes have already been used to correlate major tectonic, volcanic and hydrothermal events in the Cenozoic history of the Philippine and Japan Seas (Nechaev, 1991a). In our present work, we extended the study to the Permian-Lower Jurassic bedded cherts and associated rocks situated as tectonic inclusions in the accretionary-wedge terranes of Sikhote-Alin (southern Russian Far East).

Origin of siliceous deposits located now on the Circum-Pacific continental margins is of great interest since many researchers consider them as relicts of the ancient oceans. There is an animated discussion of this matter because most of Paleozoic and Mesozoic siliceous rocks may not be comparable with pelagic sediments accumulated in the present ocean and seas. The major differences consist in the following: the ancient siliceous deposits are chiefly poor in terrigenous components and bedded in structure whereas siliceous sediments in the modern ocean are also rather pure but homogeneous in structure and those in marginal seas are bedded but contain abundant terrigenous material (Hein and Karl, 1983 and references therein). However, comparison between modern and ancient siliceous deposits and associated rocks based on their sequence, structure, geochemistry, and biofossils (chiefly Radiolaria) have allowed researchers to conclude that all of them accumulated in the areas of high bioproductivity (Jones and Murchey, 1986, and references therein). Such areas may be located in various plate-tectonic settings. The suggestions on a tectonic situation related to the origin of the ancient pelagic deposits are inferred mainly on evidence from the associated rocks. For instance, chert associated with ophiolites are believed to be originated in basins with the oceanic-type earth's crust. Indeed, certain magmatic rocks can serve as reliable indicators of tectonic settings but, in many cases, it is a problem to prove that sedimentary deposits located near them in terranes were associated with them originally. Thus, it is necessary to find evidence on the tectonic environment from the siliceous deposits themselves.

On these pages, we will introduce interested researchers to an untraditional way of studying bedded cherts and associated sedimentary rocks to define tectonic settings around their depositional places. *As far we know, this is the first attempt to study the accessory clastic minerals in siliceous deposits.*

2. Data and Methods

Samples used in this study were collected during the field works carried out by teams of the Yuzhno-Primorskaya Geologos'emochnaya Expeditsiya (Geological Survey «Primorgeologiya»), and Far East Geological Institute (Russian Academy of Sciences) for the last five years (Fig. 1).

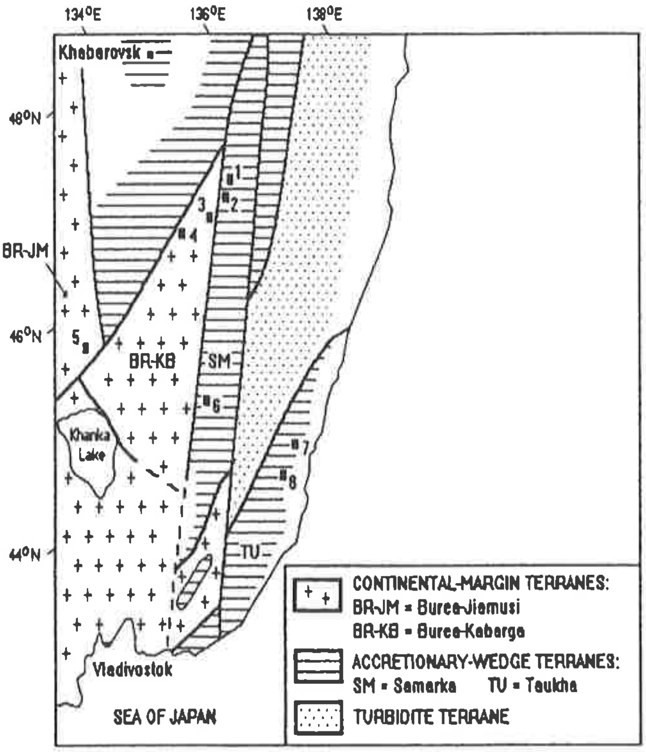

Fig. 1. Map of Terranes in the Sikhote-Alin and Adjacent Territores (simplified from Khanchuk et al., 1991; and Khanchuk, 1992). Solid lines indicate borders between terranes. Letters in caps indicate the studied terranes. Numbers indicate the studied areas (see Fig. 3 for information about lithology and stratigraphy at these locations).

Dating of all the rocks collected were made by Eugene S. Panasenko (Yuzhno-Primorskaya Geologos'emochnaya Expeditsiya) and Valeria S. Rudenko (Far East Geological Institute) on the basis of the radiolarian analysis (Panasenko et al., 1990; Rudenko and Panasenko, 1990 a,b,c).

For the mineralogical analyses, a 0.01-0.25 mm fraction was separated from the sedimentary rocks by sieving after the rough crushing. Afterwards, heavy minerals were extracted from the fraction in 2.9 g/cm^3 of tribromomethane. The heavy minerals were identified using the petrographic microscope. The mineral composition was determined by counting (Table 1). Authigenic minerals and lithoclasts were not counted. When necessary, mineral identification was carried out with help of immersion oils and an electron-microprobe analyzer. All the mineralogical analyses were made by Valentina I. Tikhonova, Nina V. Trushkova, and Vladimir I. Taskaev in laboratories of the Far East Geological Institute.

Unfortunately, the samples used for the heavy-mineral analysis were not intended for that initially. As a result, some of them were not large enough (less than 1 kg) for extracting representative amount of heavy clastic minerals (at least 200 grains). Nevertheless, we consider them suitable for this study where the main purpose is to find a way to further investigations.

The methods of the heavy-mineral-analysis interpretation were described in the previous publications (Nechaev and Derkachev, 1989; Nechaev, 1991a,b; Nechaev and Isphording, 1993). Here, we would like to emphasize that they consist in definition of the quantitative interrelationships between the following mineral assemblages:

(1) GM – indicatory minerals of acidic magmatic (granitic) and metamorphic complexes (zircon, tourmaline, monazite, staurolite, andalusite, sillimanite and kyanite);

(2) MT – common minerals from basic metamorphics such as greenshists and amphibolites (pale and blue-green amphiboles, epidote and garnet);

(3) MF – common mafic minerals of magmatic rocks (olivine, all pyroxenes and green-brown hornblende);

The dominating GM is characteristic of modern sediments on passive continental margins. MF is prevailing in the present Pacific region including: (1) spreading zones like that on the East Pacific Rise where olivine is the most abundant; (2) hot spots and fracture zones like the Hawaiian and Clarion ones where brown Ti-rich augite (Cpx1) is indicative, and (3) island arcs, active continental margins, and deep basins inside the ocean and in marginal seas where association of orthopyroxene (Opx), green clinopyroxene (mostly augite - Cpx2) and common hornblende (Hb) is dominant. Note that all the listed mafic minerals are mainly volcanic in origin. As an anomaly, MF containing olivine, orthopyroxene, green clinopyroxene (mostly diopside - Cpx2) and common hornblende (Hb), all derived from metaophiolites, is characteristic of sediments in the plate-collision zones occurring now in areas of the Yap Trench (the western Pacific) and Amirantus Trench (Indian Ocean) and in the northwestern Philippine Sea (Daito Basin) in Middle Eocene.

In the present work, it is important to specify the arc-volcaniclastic and metaophiolitic associations both of which contain orthopyroxene, clinopyroxene and hornblende. For this purpose, we used the microprobe analyses of clastic minerals from the studied sedimentary rocks (Table 2) in comparison to those from magmatic and metamorphic rocks, which they are most likely derived from. In addition, microprobe analyses of minerals from the Cenozoic sediments of the Philippine and Japan Seas, which are undoubtedly island-arc volcaniclastic in origin (Nechaev, 1987 and 1991a,b), and those from Cenozoic sediments of the Amirantus Trench (Indian Ocean), derived probably from metaophiolites (Derkachev, personal communication), were involved in this comparison.

3. Geological Setting

According to the modern tectonic scheme (Fig. 1), the Sikhote-Alin and adjacent regions consist of terranes divided into three types: continental-margin, accretionary-wedge, and turbidite (Khanchuk et al., 1989, 1991).

The Burea-Kabarga and Burea-Jiamusi Terranes are parts of the continental-margin superterrane containing: (1) Proterozoic gneisses, marble, and amphibolites, (2) Late Precambrian and Cambrian clastic rocks intensely metamorphosed at epidote-amphibolite and greenshist facies; (3) Devonian-Early Cretaceous shallow-sea and continental clastic deposits associated with subduction- and rift-related magmatic rocks of the Devonian and Permian age (Fig. 2). The rocks are intruded by the Silurian collision-related and Permian subduction-related granites. The shallow-sea and non-marine sandstones of the Late-Carboniferous, Late-Triassic and Late-Jurassic ages are arkosic in composition. Among heavy clastic minerals of these rocks, zircon and tourmaline (GM components) are dominating (see below).

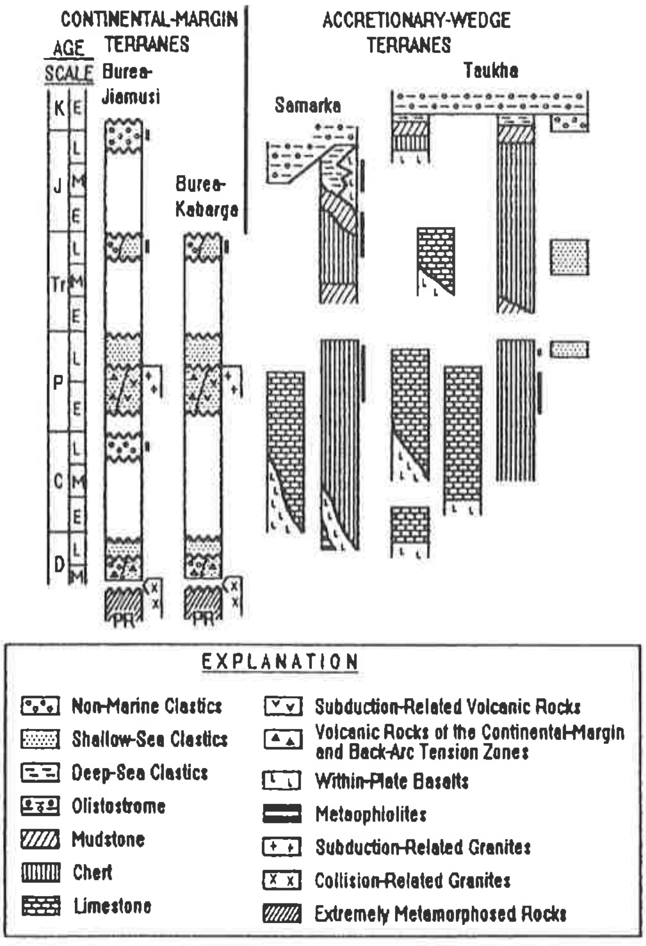

Fig. 2. Tectono-Stratigraphic Columns of the Continental-Margin and Accretionary-Wedge Terranes Showing the Sample-Collecting Areas (solid lines next to the right side of columns).

The turbidite terrane contains the Berriasian-Albian turbidites and the Aptian-Albian volcanic-arc rocks resting upon the Late Jurassic oceanic-crust fragments. Mineralogy of the turbidite sandstones in this terrane is close to those of Upper Paleozoic and Mesozoic sandstones from the continental-margin terranes (Markevich, 1978).

The Samarka and Taukha Terranes, which deposits were involved in this study, are sections of the accretionary-wedge system consisting of the turbidite-olistostrome matrix and synsedimentation allochthonous inclusions (Fig. 2). The Samarka-Terrane turbidite-olistostromes are Mid-Late Jurassic to Early Cretaceous in age (Khanchuk et al., 1989). The allochthons consist of: (1) Middle Paleozoic ophiolites associated with chert containing the Late Devonian-Permian radiolarians and conodonts, and limestones with the Carboniferous-Permian foraminifers; (2) Late Permian and Mid-Late Triassic clastic rocks; and (3) siliceous deposits with the Late Permian-Early Jurassic radiolarians and conodonts associated with the within-plate volcanic rocks (Mazarovich, 1985; Golozubov and Melnikov, 1986; Khanchuk et al., 1989; Volokhin et al., 1989). Petrology and structure of ultramafic and gabbroic rocks indicate that the Samarka-Terrane ophiolites were formed under the high pressure that might be on deep horizons of a thick oceanic-plateau crust (Khanchuk and Panchenko, 1991) or in the stress conditions related to the tectonic movements between blocks of the oceanic crust (Vysotskiy and Okovity, 1990). As a result, some of mafic minerals from these ophiolites are specific in chemical composition. In particular, certain pyroxenes and amphiboles have rather high contents of Al_2O_3. Thus, we can distinguish them among all the studied clastic minerals for this research.

The Taukha Terrane is close in composition and structure to the Samarka Terrane but has three specific distinctions: (1) its turbidites and olistostromes are younger (Valanginian to Barremian); (2) no gabbro and ultrabasic rocks were found there; and (3) large blocks of reef limestones associated with high-titanium basalts and hyaloclastites, all considered as fragments of the Paleozoic and Early Mesozoic seamounts, are characteristic of this terrane (Khanchuk et al., 1989, and references therein).

The studied siliceous deposits are located in the accretionary-wedge terranes either as tectonic units in the imbricated-thrust structures of melange or as blocks and clasts in olistostromes. In such conditions, only the micropaleontological study in addition to detailed lithological descriptions has allowed their original stratigraphy to be defined in general (Rybalka, 1987; Buryi, 1989; Volokhin et al, 1989; Rudenko and Panasenko, 1990a,b,c; see Fig. 3).

The Permian siliceous deposits are commonly bedded in structure. As usual, the beds are 2.5-6 cm in thickness and consist of gray, olive-gray and reddish-brown chert. The interbedded layers (up to 1-2 cm in thickness, usually 0.5-1 mm) are represented by siliceous mudstones. The reddish-brown cherts are the most often in the lower stratigraphic units where they have the banded-laminae structure formed by the alternation of beds and laminaes (1-2 mm in thickness) with various contents of iron hydroxides. All the cherts contain radiolarians and sponge spicules. Occasionally, conodonts are found. Commonly, Radiolaria are the prevailing biofossils in cherts but, sometimes, the sponge spicules dominate (Rudenko and Panasenko, 1990a,b,c). In cherts of the Sakmarian and Midian age, clasts of the altered volcanic glass are presented. Locally, volcanic glass is associated with psammitic grains of hyaloclastites and redeposited cherts (Sample 37-35, the Amba-Mount location, Samarka Terrane).

The Triassic-Lower Jurassic bedded cherts are gray, dark gray, and, rarely, reddish-brown. Like the Permian ones, they commonly contain radiolarians and, not so often, conodonts. No sponge spicules were found. The stratigraphic transition between Paleozoic and Mesozoic deposits has not been found in the studied outcrops but, in some locations where the earliest Triassic sequences are revealed, siliceous rocks relatively rich in terrigenous material (mud-, clay- and siltstones), underlie cherts (Volokhin, 1985 and Volokhin et al., 1989). Upwards, the Lower Jurassic cherts are gradually replaced by siliceous mudstones and then terrigenous silt- and sandstones of the Lower-Jurassic to Lower-Cretaceous age (Fig. 2 and 3).

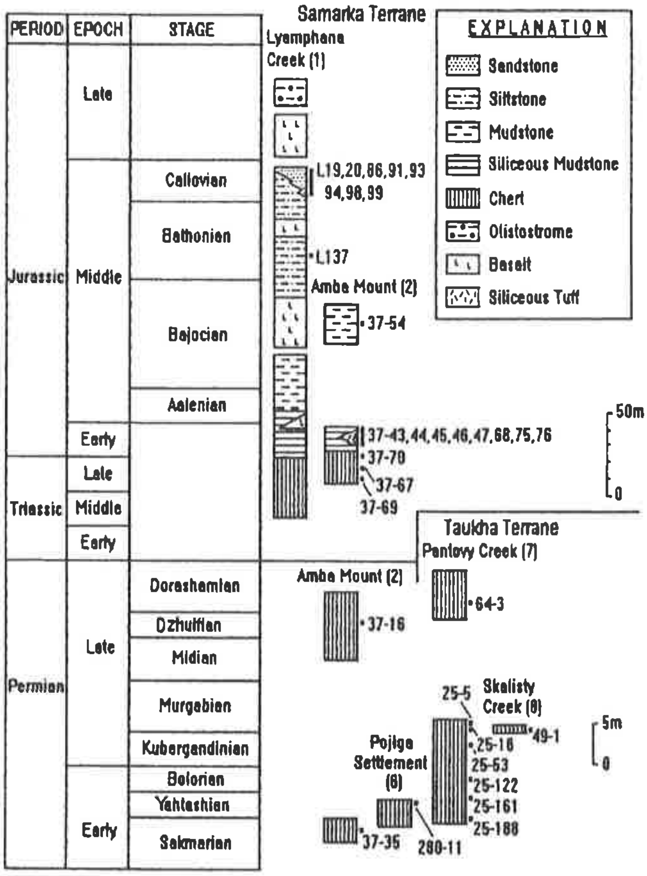

Fig. 3. Lithology and Stratigraphy at the Studied Areas of the Samarka and Taukha Terranes Showing the Sample-Collecting Points. Numbers in brackets indicate the studied areas, numbers next to the sample-collecting points indicate samples (see Table 1 for the heavy-mineral compositions of the sampled rocks).

The Lower-Jurassic siliceous mudstones are bedded and (or) homogeneous in structure, gray or reddish-brown in color, and radiolarian in composition. As a terrigenous component, they contain clay and silt (mostly quartz and feldspar). Among siliceous mudstones of the Amba Mount, there are layers of acidic tuff containing the silt- and sand-size clasts of altered volcanic glass and felsite (50-60%) in addition to the common constituents of siliceous mudstones (Fig. 3, samples 36-46 and 36-47).

In the Lyamphana-Creek location, the Middle Jurassic siltstones interbedded with thin (up to 1 m) layers of sandstones are associated with basic volcanic rocks: hyaloclastites, high-titanium basalts, picrite-basalts and diabases. There, the Bajocian-Bathonian sandstones consist mainly of the lithoclasts represented by cherts (90%), siltstones, claystones and tuffs. In the upper sections, sandstones are arkosic. In average composition, they have: quartz — 28%, feldspar — 40%, and lithoclasts — 32%. There are rather big amounts (up to 40%) of the andesite and dacite grains among lithoclasts in these rocks.

4. Results

We have studied heavy-mineral compositions in 3 samples of the Permian cherts, 3 samples of Triassic cherts, 8 samples of Upper-Triassic to Early Jurassic siliceous mudstones and tuffs, 2 samples of the Middle Jurassic siltstones and 9 samples of the Middle-Jurassic sandstones from 2 locations in the Samarka Terrane, and 8 samples of the Permian cherts from 2 locations in the Taukha Terrane, that is a total of 33 analyses (Table 1).

In order to learn what these analyses indicate in general, we should compare them with the average heavy-mineral compositions of Quaternary sediments from different plate-tectonic settings of the world. For this comparison, the GM-MT-MF interrelationship is used (Fig. 4). The composition of the Carboniferous-Jurassic sandstones from Burea-Kabarga and Burea-Jiamusi terranes are shown on Fig. 4 to represent the continental-margin provenance. Our evidence suggests that most of the studied siliceous deposits, in which the MF assemblage is dominant, are comparable with modern sediments accumulated in the oceanic and deep-marginal-sea conditions or on the active continental margins and island arcs whereas most of the overlying terrigenous rocks with the prevailing GM assemblage correspond to the passive-continental-margin environment. One of Upper Triassic-Lower Jurassic siliceous tuffs (Sample 37-47) as well as the Bajocian mudstone (37-54) and Bathonian siltstone (L137) representing the transitional layers between siliceous and

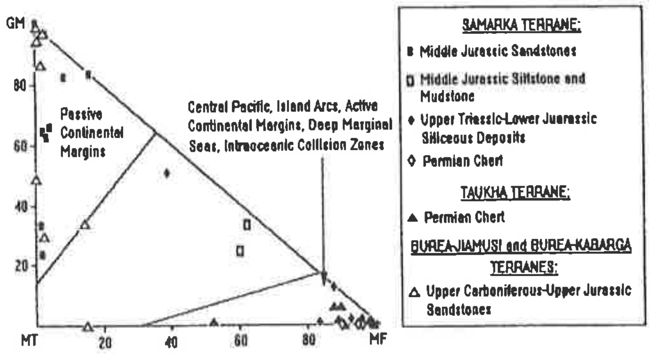

Fig. 4. GM-MT-MF Interrelationships in Sedimentary Rocks from the Continental-Margin and Accretionary-Wedge Terranes (points) in Comparison with Those in Quaternary Sediments of the Different-Type Tectonic Settings of the World (fields). The latter are determined on the basis of average compositions compiled from the literature (Aleksina, 1962; Isphording, 1963; Lee et al., 1988; Lisitsyn, 1966; Martens, 1928; McMaster, 1954; Murdmaa and Kazakova, 1980; Murdmaa et al., 1980; Nechaev and Derkachev, 1989; Nechaev, 1991a,b; Petelin, 1957; Sato, 1980; Scheidegger et al., 1973; Suzuki, 1975). In addition, the personal data of Alexander N. Derkachev (Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences) were used for delineation of the fields.

terrigenous deposits (Fig. 3) are also transitional in heavy-mineral composition (Fig. 4). Thus, we may suppose that Upper Triassic-Middle Jurassic sedimentary rocks recorded either the gradual approach of the oceanic-plate or island-arc blocks to the continent or the conversion of active continental margin into the passive one.

To understand better, what were the tectonic settings around depositional places of the Permian and Mesozoic siliceous rocks, the heavy-mineral characteristics (Hb-(Ol+Cpx2+Opx)-Cpx1) of these rocks may be compared with those of the Cenozoic (mostly Quaternary) sediments from the areas representing the major types of plate boundaries and within-oceanic-plate zones. It is shown on Fig. 5 that heavy-mineral assemblages of Mesozoic siliceous deposits are close to those of sediments accumulated in the intraoceanic fracture zones like the Clarion and Clipperton ones or in the areas of intraoceanic ridges and rises like the Hawaiian Ridge and Magellan Rise. The Permian cherts contain the Ol-Cpx2-Opx-Hb assemblage corresponding to the following tectonic settings: (1) convergent plate boundaries including the deep-marginal-sea, island-arc and trench regions in the northwestern Pacific and oceanic basins like the East

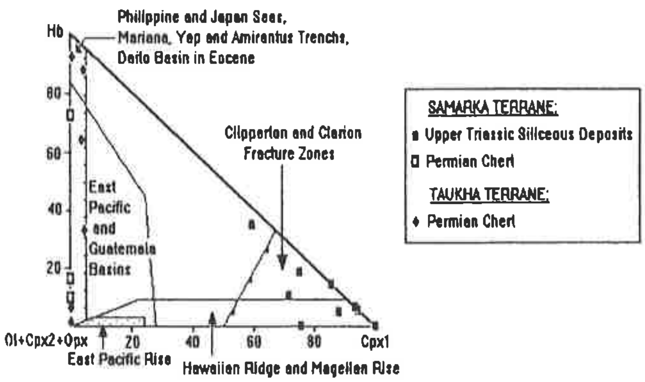

Fig. 5. Hb-(Ol+Cpx2+Opx)-Cpx1 Interrelationships in Siliceous Deposits from the Samarka and Taukha Terranes (points) in Comparison with Those in Cenozoic Sediments of the Certain-Type Tectonic Settings of the World (fields). The latter are determined on the basis of data from the literature (Murdmaa and Kazakova, 1980; Murdmaa et al., 1980; Nechaev and Derkachev, 1989; Nechaev, 1991a,b; Sato, 1980). In addition, the personal data of Alexander N. Derkachev (Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences) were used for delineation of the fields.

Pacific and Guatemala where the dominant heavy clastic minerals are arc-type volcaniclastic in origin (Nechaev and Derkachev, 1989, Nechaev, 1991a,b); (2) intraoceanic collision zones like those occuring now in areas of the Yap and Amirantus Trenchs, and in areas of the Daito Basin in the Middle Eocene (Philippine Sea) where the metaophiolitic minerals are predominant (Murdmaa et al., 1980; Sato, 1980; Nechaev, 1991a,b; Derkachev, personal communication).

To define the major sources of mafic minerals from the Mesozoic and Paleozoic siliceous rocks closer and to check our previous suggestions, we used the microprobe analyses (Table 2). On Fig. 6-9, the most distinctive chemical characteristics indicating olivine (Ol - Fig. 6), brown and green clinopyroxenes (Cpx1 and Cpx2 - Fig. 7), orthopyroxene (Opx - Fig. 8) and amphiboles (Hb and Am - Fig. 9) from magmatic and metamorphic rocks of the possible sources are shown. We can see that most of mafic minerals from the studied siliceous rocks are close in chemical composition to those from metamorphosed gabbroic and ultramafic rocks (metaophiolites) and metabasalts of the Samarka and Taukha Terranes. Moreover, the metabasaltic assemblage (Cpx1-Hb-Am) is prevailing in Triassic-Lower Jurassic siliceous mudstones and tuffs whereas the metaophiolitic one (Ol-Cpx2-Opx-Hb-Am) is dominant in Permian cherts. It should be noted that there are some additional clastic minerals completing the metaophiolitic assemblage of the studied sedimentary rocks. These are Ca-Fe garnet (grossular-andradite), spinel (hercynite), and ilmenite (see Table 2) close in chemical composition to those from metaophiolites of the Samarka Terrane (Vysotskiy and Okovity, 1990; Khanchuk and Panchenko, 1991), as well as sphene and magnetite (Table 1).

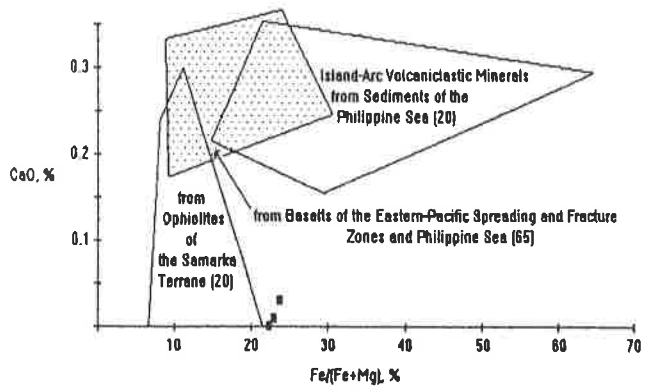

Fig. 6. Comparison between Olivines from the Studied Siliceous Deposits (points) and Those from the Magmatic and Metamorphic Rocks of the Possible Provenances and Certain-Type Tectonic Settings (fields). Number in brackets indicates number of the microprobe analyses used to outline the fields. The data were compiled from Bougault et al. (1982), Dick et al. (1980), Dmitriev (1980), Fodor and Klaus (1975), Fodor and Rosendahl (1980), Fodor et al. (1980), Khanchuk and Panchenko (1991), Mattey and Muir (1980), Mattey et al. (1981), Nechaev (1987 and 1991a), Ridley et al. (1974), Sharaskin (1982), Thompson and Humphris (1980), Vysotskiy (1989), Vysotskiy and Okovity (1990), Zakariadze et al. (1981). In addition, the personal data bases of this papers authors and Alexander N. Derkachev (Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences) were used for delineation of the fields.

Note that, the fields of minerals indicating different types of magmatic and metamorphic rocks on Fig. 6-9 are, in many cases, overlapping. What is more, some compositions of clastic minerals from the siliceous deposits are situated outside (but close to) fields of the defined source-rock minerals. Thus, we can not make our previous definitions for all of the analyzed grains, but the data presented enables us to determine the major mineral assemblages.

Cpx1 dominating in Mesozoic siliceous deposits and metabasalts of the Samarka and Taukha Terranes is close in composition to clinopyroxene from volcanic rocks of the spreading, hot-spot and fracture zones located in the ocean and marginal seas (Fig. 7). It confirms our previous supposition that the heavy-mineral assemblage from Upper Triassic-Lower Jurassic siliceous mudstones and tuffs indicates the tectonic settings of intraoceanic fracture zones or seamounts (see Fig. 5). Unfortunately, we can not define this situation more accurately because minerals in volcanic rocks from both of these settings are similar.

Olivine, green clinopyroxene, orthopyroxene and amphiboles (Ol-Cpx2-Opx-Hb-Am) dominant in Permian cherts and derived mostly from metaophiolites are of the same type as those from sediments of the Amirantus Trench where the local intraoceanic collision is happening (Fig. 6-9). Therefore, we suggest that Permian cherts of the Samarka and Taukha Terranes were deposited nearby some collision zone. This collision was most likely intraoceanic (that is between blocks of simatic or ensimatic lithosphere) since Permian cherts of the Samarka and Taukha Terranes are totally lacking of heavy minerals indicative of the sialic rock material (GM assemblage). It is impossible to answer if this collision was regional or global because our data characterize only one region. However, most likely it was not local since the Permian rocks have been sampled for this study in four locations situated rather far one from the others and in two different terranes. We have to extend the research to the other regions to define the extent of the Permian collision.

Thus, our evidence suggests that bedded cherts of the Sikhote-Alin accretionary-wedge terranes were deposited most likely in the intraoceanic conditions far away from any continental margins including that containing the Burea-Kabarga and Burea-Jiamusi Terranes located now in close vicinity. In the Permian, the deposition took place in or nearby some tectonic collision zone at least regional in scale. Because of the lack in data, we do not know what happened just after. However, in the Late Triassic, the tectonic situation recorded by cherts was quite different. Since that time to Early Jurassic, the siliceous deposits were accumulated in the ocean either close to seamounts like the Hawaiian ones or in fracture zones like those in the modern Eastern Pacific. At the same time and in Middle Jurassic, the depositional places were drifting to the continent. In the Callovian time when terrigenous sands had become a dominating type of sediments, they were situated obviously nearby the continental margin represented by the Burea-Kabarga and Burea-Jiamusi Terranes. Afterwards, the accretion recorded by Mid-Upper Jurassic olistostromes started.

It should be noted here that the indicated approach of the oceanic depositional area to continent was not closely

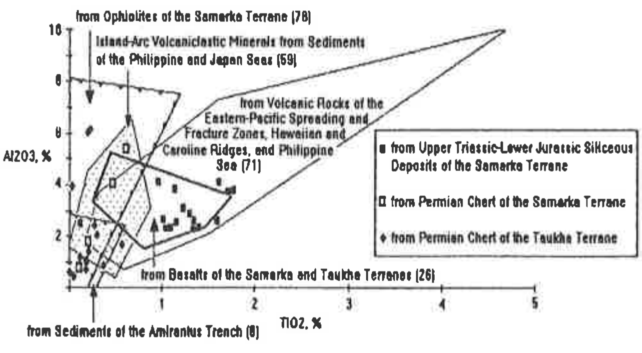

Fig. 7. Comparison between Clinopyroxenes from the Studied Siliceous Deposits (points) and Those from Magmatic and Metamorphic Rocks of the Possible Provenances and Certain-Type Tectonic Settings (fields). Number in brackets indicates number of the microprobe analyses used to outline the fields. The sources of data are referenced on Fig. 6.

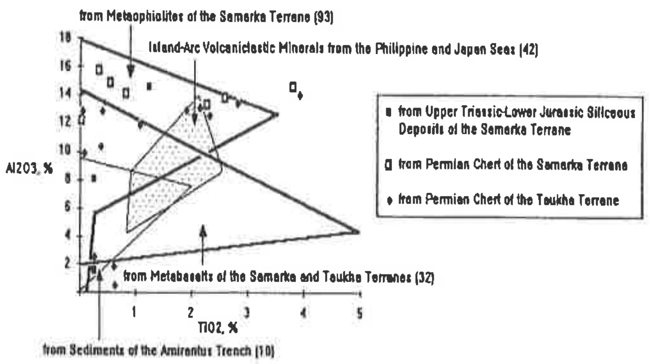

Fig. 9. Comparison between Amphiboles (Hb and Am) from the Studied Siliceous Deposits (points) and Those from Magmatic and Metamorphic Rocks of the Possible Provenances and Certain-Type Tectonic Settings (fields). Number in brackets indicates number of the microprobe analyses used to outline the fields. The sources of data are referenced on Fig. 6.

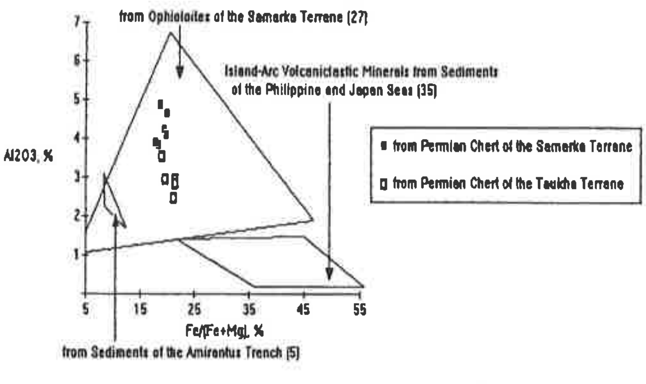

Fig. 8. Comparison between Orthopyroxenes from the Studied Siliceous Deposits (points) and Those from Magmatic and Metamorphic Rocks of the Possible Provenances and Certain-Type Tectonic Settings (fields). Number in brackets indicates number of the microprobe analyses used to outline the fields. The sources of data are referenced on Fig. 6.

connected with normal subduction. Otherwise, we must have found the widespread mineral assemblage derived from the subduction-related volcanism (Cpx2-Opx-Hb) in the studied Mesozoic deposits as it was defined in modern sediments of the western Pacific (Nechaev and Derkachev, 1989; Nechaev, 1991a,b). Tectonic movements oblique to the ancient continent-ocean border might be more appropriate for explanation of this phenomena. They completely correspond to the combination of basalt-derived clinopyroxene (Cpx1) and sialic rocks-derived zircon, tourmaline and sphene in transitional layers between siliceous (pelagic) and terrigenous (shallow-sea) units of the examined sequence (see heavy-mineral compositions of siliceous mudstones and tuffs in Table 1).

Table 1

Percentage of Heavy Clastic Minerals in the 0.01-0.25 mm Fraction from Sedimentary Rocks of the Samarka and Taukha Terranes

Age	Lithology	Sample	Ol	Cpx1	Cpx2	Opx	Hb	Am	Ep	Grn	Zr	Trm	Sph	Rt	An	Lcx	Ap	Mt	Ilm	Sp	No.
Lyamphana Creek (1), Samarka Terrane																					
J2Bth-Clv	Sandstone	L19	---	---	---	---	---	---	---	---	98.0	1.5	---	0.5	---	---	---	---	---	---	200
J2Bth-Clv	Sandstone	L20	---	---	0.4	---	---	---	1.1	13.7	4.3	0.4	45.5	---	---	25.3	3.6	---	4.7	1.1	277
J2Bth-Clv	Sandstone	L86	---	---	9.2	0.4	0.7	---	0.4	---	52.8	0.7	---	---	---	24.3	1.1	---	8.5	2.1	284
J2Bth-Clv	Sandstone	L89	---	---	0.5	0.5	1.6	---	---	30.8	55.3	2.9	1.4	0.5	---	---	1.4	---	4.8	1.6	208
J2Bth-Clv	Sandstone	L91	---	---	1.8	---	0.4	---	---	15.6	30.0	4.2	---	0.7	0.4	6.8	1.3	---	37.9	0.9	454
J2Bth-Clv	Sandstone	L93	---	---	2.6	---	---	---	---	29.2	46.2	6.1	---	1.3	0.3	3.8	1.3	---	8.3	1.6	312
J2Bth-Clv	Sandstone	L94	---	---	1.8	0.3	3.9	---	0.7	4.9	50.7	0.3	0.3	0.3	---	8.2	0.7	---	28.0	0.7	304
J2Bth-Clv	Sandstone	L98	---	---	0.6	---	0.9	---	---	55.5	23.4	4.6	---	0.3	---	2.9	1.2	---	9.8	0.9	346
J2Bth-Clv	Sandstone	L99	---	---	1.5	---	0.2	---	---	0.2	31.7	8.4	---	---	---	---	1.5	---	57.6	---	417
J2Bth	Siltstone	L137	---	---	35.0	2.6	2.6	---	---	10.3	16.2	---	---	---	---	---	0.9	---	23.1	9.4	117
Amba Mount (2), Samarka Terrane																					
J2	Sil. mudst.	37-54	---	24.7	---	---	8.2	---	1.2	1.2	16.5	1.2	---	---	10.6	---	---	34.1	2.4	---	85
J1	Sil. mudst.	37-43	---	76.4	---	---	12.7	---	1.8	3.6	1.8	---	---	---	---	---	1.8	1.8	---	---	55
J1	Sil. mudst.	37-44	---	86.0	---	---	0.5	---	1.4	---	0.5	---	0.5	---	---	---	0.5	10.4	0.5	---	222
J1	Sil. mudst.	37-68	---	66.4	16.6	---	10.6	---	0.7	0.4	0.7	---	---	---	---	---	0.4	1.8	1.8	1.1	271
Tr3-J1	Sil. mudst.	37-45	---	36.7	3.3	---	21.7	3.3	3.3	---	---	---	---	---	---	---	---	31.7	---	---	60
Tr3-J1	Sil. tuff	37-46	1.3	77.0	3.9	0.7	4.6	0.7	0.7	0.7	2.0	---	0.7	---	---	---	---	7.9	---	---	152
Tr3-J1	Sil. tuff	37-47	---	35.7	0.0	---	2.0	---	8.2	2.0	50.0	---	---	---	1.0	1.0	---	---	---	---	98
Tr3-J1	Sil. mudst.	37-70	---	62.0	17.7	2.5	---	11.4	3.8	---	---	1.3	---	---	---	---	1.3	---	---	---	79
Tr3-J1	Sil. mudst.	37-75	---	38.9	---	---	---	---	---	---	5.6	---	5.6	---	27.8	---	5.6	16.7	---	---	18
Tr3-J1	Chert	37-76	---	65.6	6.3	---	15.6	---	---	---	---	---	---	---	6.3	---	---	6.3	---	---	32
Tr3Nor	Chert	37-67	---	87.1	---	---	6.1	---	0.7	0.2	---	---	---	---	---	---	---	0.7	5.1	---	428
Tr3Crn-Nor	Chert	37-69	---	70.9	6.0	---	17.9	---	---	---	1.3	---	---	---	---	---	0.7	3.3	---	---	151
P2Dzl	Chert	37-16	---	---	73.3	1.7	15.0	5.0	5.0	---	---	---	---	---	---	---	---	---	---	---	60
P1Sak	Chert	37-35	0.5	---	10.5	14.7	67.3	2.7	1.1	---	0.3	---	---	---	---	---	0.3	0.3	1.6	0.8	373
Pojiga Settlement (6), Samarka Terrane																					
P1Yht	Chert	280-11	---	---	85.1	---	9.6	2.1	3.2	---	---	---	---	---	---	---	---	---	---	---	94
Pantovy Creek (7), Taukha Terrane																					
P2Dor	Chert	64-3	---	---	84.4	---	6.3	3.1	6.3	---	---	---	---	---	---	---	---	---	---	---	32
P2Mrg	Chert	25-5	---	2.9	25.7	---	51.4	---	---	5.7	5.7	---	---	---	---	---	2.9	5.7	---	---	35
P2Mrg	Chert	25-16	---	0.2	7.0	---	88.5	---	---	0.5	0.5	---	---	---	0.2	0.7	0.5	1.4	0.5	---	427
P2Kub	Chert	25-53	---	3.9	52.4	---	28.2	1.9	1.7	1.7	5.8	---	---	---	---	---	1.7	2.9	1.9	---	103
P1Bol	Chert	25-122	---	---	87.2	0.2	11.1	---	0.2	0.2	0.2	---	0.2	---	---	---	---	0.2	0.2	---	415
P1Yht	Chert	25-161	0.4	2.0	3.3	---	43.3	42.4	0.4	0.4	1.5	---	---	---	1.3	0.2	0.7	1.1	1.8	1.1	453
P1Sak	Chert	25-188	---	---	79.6	---	9.3	3.7	5.6	---	1.9	---	---	---	---	---	---	---	---	---	54
Skalisty Creek (8), Taukha Terrane																					
P2Mrg	Chert	49-1	---	---	97.6	---	2.0	---	0.5	---	---	---	---	---	---	---	---	---	---	---	205

Note: - Ol = olivine; Cpx = clinopyroxene (1-brown, 2-green); Opx = orthopyroxene; Hb = green and brown amphibole; Am = pale-colored amphibole; Ep = epidote (group); Grn = garnet; Zr = zircon; Trm = tourmaline; Sph = sphene; Rt = rutile; An = anatase; Lcx = leucoxene; Ap = apatite; Mt = magnetite; Ilm = ilmenite; Sp = spinel; No. = number of grains counted; --- = not found.

Table 2

Electron Microprobe Analyses (%) of Clastic Minerals from Sedimentary Rocks of the Samarka and Taukha Terranes

Source	Tr_3-J_1 siliceous deposits of the Samarka Terrane																
Mineral	Ol	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx1	Cpx2
Sample	37-46	37-43	37-44	37-44	37-44	37-45	37-45	37-47	37-70	37-70	37-67	37-67	37-67	37-69	37-69	37-69	37-45
SiO_2	38.39	51.42	50.10	50.99	50.52	51.36	50.74	51.40	50.80	52.45	49.08	50.25	49.05	51.55	51.02	50.46	51.37
TiO_2	0.01	1.30	1.01	1.04	1.14	1.34	1.60	1.40	1.23	1.10	1.35	1.16	1.72	0.96	1.62	1.77	0.13
Al_2O_3	0.06	2.88	2.67	2.33	3.81	2.32	2.61	2.31	3.09	2.31	2.58	2.57	3.72	4.11	4.09	3.79	2.51
Cr_2O_3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
FeO	20.29	6.91	6.76	7.86	6.39	8.59	11.38	8.65	7.21	6.64	7.72	6.26	7.62	7.45	7.64	8.77	4.67
MnO	0.28	0.18	0.19	0.27	0.21	0.26	0.48	0.28	0.16	0.18	0.18	0.18	0.19	0.18	0.24	0.21	0.16
MgO	39.44	16.74	16.25	16.55	15.79	15.77	12.97	14.34	16.48	16.65	16.02	16.67	15.58	15.55	15.31	14.67	18.52
CaO	---	21.67	21.83	21.74	21.92	21.77	20.84	21.25	22.05	21.88	21.19	20.86	21.70	22.03	21.75	21.31	22.66
Na_2O	0.02	1.51	0.45	0.42	0.40	0.52	0.64	0.44	0.52	0.40	0.58	0.43	0.49	0.56	0.56	0.52	0.27
K_2O	---	0.07	0.01	0.02	---	0.01	0.02	---	0.02	0.02	0.02	0.02	0.01	0.03	0.02	0.03	0.03
Total	98.49	102.68	99.27	101.22	100.18	101.94	101.28	100.07	101.56	101.63	98.72	98.40	100.08	102.42	102.25	101.53	100.32

Source	Tr_3-J_1 siliceous deposits of the Samarka Terrane							P chert of the Samarka Terrane								
Mineral	Cpx2	Hb	Hb	Hb	Grn	Grn	Ilm	Ol	Cpx2	Cpx2	Cpx2	Cpx2	Opx	Opx	Opx	Opx
Sample	37-45	37-46	37-70	37-67	37-47	37-47	37-68	37-35	37-16	37-35	37-35	37-35	37-35	37-35	37-35	37-35
SiO_2	51.61	43.49	53.38	47.72	39.35	39.59	---	39.13	50.43	50.34	52.13	51.88	53.85	52.76	51.93	51.82
TiO_2	0.19	1.23	0.27	0.25	0.24	0.02	51.90	0.02	0.11	0.62	0.21	0.47	0.31	0.29	0.37	0.07
Al_2O_3	1.04	14.55	1.60	8.03	22.84	23.19	0.16	0.59	0.77	5.37	1.79	4.06	3.84	4.37	4.87	4.63
Cr_2O_3	---	---	---	---	...	...	0.02	---	---	1.09	0.31	---	0.21	0.26	0.20	0.06
FeO	5.23	6.37	10.49	11.12	11.54	11.40	47.91	22.32	6.92	4.30	4.65	9.90	12.07	11.86	11.50	12.42
MnO	0.29	0.12	0.45	0.33	0.48	0.42	0.12	0.40	0.24	0.17	0.16	0.43	0.30	0.29	0.24	0.31
MgO	19.67	19.62	17.49	17.35	...	...	0.61	40.03	16.59	14.66	15.60	12.62	29.92	27.49	28.05	28.02
CaO	22.57	13.25	13.36	11.97	23.45	23.81	---	0.03	25.67	21.51	21.26	21.34	1.18	1.36	0.83	1.08
Na_2O	0.20	2.10	0.51	1.18	...	0.02	---	0.03	0.82	0.84	0.46	0.76	0.04	0.18	0.07	0.04
K_2O	0.04	0.72	0.16	0.42	0.02	0.03	---	---	0.01	0.01	---	0.02	---	0.03	---	---
Total	100.84	101.45	97.71	98.37	97.92	98.48	100.73	102.55	101.56	98.91	96.57	101.48	101.72	98.88	98.06	98.45

Source	P chert of the Samarka Terrane (continued)											P chert of the Taukha Terrane				
Mineral	Opx	Opx	Hb	Hb	Hb	Hb	Hb	Am	Am	Sp	Sp	Ol	Cpx2	Cpx2	Cpx2	Cpx2
Sample	37-35	37-35	37-35	37-35	37-35	37-35	37-35	37-35	37-35	37-35	37-35	25-161	49-1	25-5	25-5	25-16
SiO_2	53.16	55.49	41.44	42.91	47.67	44.33	42.21	44.15	44.09	---	---	38.23	54.67	50.90	53.95	51.65
TiO2	0.16	0.30	3.81	2.28	0.03	0.82	2.59	0.54	0.33	---	---	0.06	0.21	0.57	0.18	0.27
Al_2O_3	4.13	3.91	14.58	13.28	12.17	14.07	13.81	14.85	15.72	62.01	61.97	0.02	1.43	1.71	0.71	2.45
Cr_2O_3	---	---	0.36	---	---	0.50	---	0.28	---	---	---	---	---	---	---	---
FeO	12.92	11.18	7.81	11.89	8.17	6.85	7.74	6.37	6.90	21.52	22.46	21.48	6.88	8.06	4.96	5.26
MnO	0.35	0.30	0.14	0.21	0.18	0.13	0.14	0.12	0.10	0.11	0.19	0.37	0.23	0.13	0.19	0.17
MgO	29.39	28.64	16.02	14.39	17.27	15.41	16.42	17.89	16.88	13.64	13.68	40.10	17.79	16.90	17.08	18.06
CaO	1.80	1.10	11.33	11.74	11.61	11.27	11.18	11.50	11.88	---	---	0.01	18.61	20.47	23.31	21.80
Na_2O	0.03	0.05	2.93	2.49	1.37	2.33	2.94	2.77	2.82	---	---	0.01	0.22	1.23	0.17	0.17
K_2O	---	0.03	0.49	0.16	0.04	0.70	0.79	0.48	0.42	---	---	0.02	0.01	0.07	0.03	---
Total	101.94	101.00	98.91	99.35	98.51	96.41	97.82	98.95	99.14	97.28	98.3	100.30	100.05	100.04	100.58	99.83

Table 2 (continued)

Electron Microprobe Analyses (%) of Clastic Minerals from Sedimentary Rocks of the Samaeka and Taukha Terranes

Source P chert of the Taukha Terrane (continued)

Mineral	Cpx2	Cpx2	Cpx2	Cpx2	Cpx2	Cpx2	Cpx2	Cpx2	Cpx2	Cpx2	Opx	Opx	Opx	Opx	Opx	Hb	Hb
Sample	25-16	25-53	25-53	25-53	25-122	25-122	25-161	25-161	25-188	25-188	25-161	25-161	25-161	25-161	25-161	25-161	25-161
SiO2	50.77	55.20	50.54	50.34	52.43	52.06	50.49	53.18	51.29	50.68	53.91	54.51	53.61	53.44	52.54	52.21	43.48
TiO2	---	0.05	0.30	0.37	0.12	0.28	0.23	0.20	0.11	0.03	0.18	0.04	0.06	0.03	0.02	0.62	1.59
Al2O3	0.59	0.47	2.08	0.89	1.20	1.60	6.12	6.01	1.15	3.96	2.95	2.83	3.56	2.95	2.44	1.85	11.18
Cr2O3	---	---	---	---	---	---	1.05	1.13	---	---	0.16	0.04	---	---	---	0.66	0.69
FeO	5.94	5.40	4.95	4.89	4.18	5.76	3.00	4.00	6.75	8.29	14.07	13.96	12.45	13.03	14.33	11.60	9.76
MnO	0.19	0.26	0.19	0.14	0.16	0.20	0.10	0.11	0.21	0.49	0.37	0.35	0.28	0.41	0.38	0.20	0.15
MgO	15.48	16.47	17.51	17.38	18.90	16.47	16.82	20.72	15.42	15.28	28.78	28.68	29.70	29.89	29.88	16.19	15.80
CaO	25.44	22.38	23.74	23.82	23.79	23.88	22.47	15.87	22.69	22.07	0.74	0.74	0.69	0.56	0.53	12.47	11.85
Na2O	0.04	0.13	0.19	0.50	0.09	0.21	0.29	0.29	1.03	1.35	0.03	0.03	0.01	0.04	0.22	0.24	2.53
K2O	0.02	0.02	0.03	0.02	0.02	0.03	---	---	0.06	0.07	---	---	---	---	0.04	0.01	0.11
Total	98.47	100.38	99.53	98.35	100.89	100.49	100.57	101.51	98.71	102.22	101.19	101.18	100.36	100.35	100.38	96.05	97.14

Source P chert of the Taukha Terrane (continued)

Mineral	Hb	Hb	Hb	Hb	Hb	Hb	Hb	Hb	Hb	Hb	Hb	Am	Am	Am	Ilm	Ilm
Sample	25-161	25-161	25-161	25-161	25-161	25-161	25-161	25-161	25-161	25-161	25-188	25-161	25-161	25-161	25-122	25-188
SiO2	43.73	43.85	42.40	42.70	47.49	54.96	43.75	41.97	42.46	43.79	47.33	44.14	49.24	45.69	---	---
TiO2	1.90	0.39	3.92	2.32	0.37	0.26	2.82	2.14	2.32	1.07	0.63	0.05	0.08	0.44	52.10	46.80
Al2O3	12.93	12.83	14.04	12.60	10.35	2.55	13.43	13.13	12.56	11.88	0.51	12.82	9.85	13.38	0.11	0.30
Cr2O3	0.12	0.40	0.59	1.31	0.07	0.06	---	---	0.01	---	---	---	---	---	0.18	0.02
FeO	10.01	13.33	7.58	10.00	10.99	11.81	10.79	10.40	10.95	7.21	14.06	8.97	7.01	5.81	47.53	47.19
MnO	0.19	0.18	0.17	0.19	0.13	0.25	0.18	0.15	0.18	0.13	0.16	0.16	0.16	0.13	0.35	2.88
MgO	13.61	13.16	15.03	16.51	14.12	16.98	14.56	14.26	14.32	18.42	21.14	16.24	18.86	19.93	0.04	0.18
CaO	11.99	12.18	11.26	10.71	14.28	12.79	11.77	11.55	11.47	11.16	11.82	11.57	12.15	12.12	---	---
Na2O	1.72	2.20	2.85	2.73	1.42	0.34	2.06	2.45	2.60	2.78	0.72	2.36	1.50	2.76	---	---
K2O	0.20	0.07	0.61	0.28	0.03	0.02	0.15	0.18	0.15	0.49	0.32	0.03	0.01	0.25	---	---
Total	96.40	98.59	98.45	99.35	99.25	100.02	99.51	96.23	97.02	96.93	96.69	96.34	98.86	100.51	100.31	97.37

Note: Ol = olivine; Cpx = clinopyroxene (1-brown, 2-green); Hb = green and brown amphibole; Am = pale-colored amphibole; Grn = garnet; Ilm = ilmenite; Sp = spinel; --- = not found.

5. Discussion

One of the major problems in geology of the Sikhote-Alin and adjacent territories is: whether all of the deposits were accumulated close to each other or whether there were big distances between some of them at the time of deposition. We have tried to come closer to resolving this problem by using of the actualistic approach. At the same time, we recognize that geological conditions in the past might be somewhat different from the present. For instance, heavy-clastic-mineral assemblages rich in the high-titanium basalt or ophiolitic components (Cpx1 or Ol-Cpx2-Opx-Hb-Am), indicating the specific areas of the modern oceans, might be distributed much more widely in the Early Mesozoic and Late Paleozoic oceans. Now, they are poor in sediments from most of the oceanic and marginal-sea basins where the arc-type volcaniclastic minerals or terrigenous material suppress them. However, the subduction-related volcanism and continental erosion might be not so widely developed in the mentioned periods of the past. Then, intraoceanic seamounts, ridges, and fracture zones would be the major sources of heavy clastic minerals into any basins outside the continent. If this is the case, some of our suggestions made in the «RESULTS» section would not be correct. To check them, we have to extend this study to the other regions. Wide comparison of heavy-clastic-mineral assemblages from Paleozoic and Mesozoic sedimentary rocks with those from the Cenozoic sediments could also improve our understanding of the global geological evolution.

Finally, we would like to debate the possible argument against using the heavy clastic minerals as indicators of tectonic settings. Many researchers believe that so called intrastratal solution distorts original heavy-mineral compositions of sediments with time by destroying their components in different degree (Pettijohn, 1941 and many others later). Olivine and pyroxenes are recognized as the most unstable in pore water minerals whereas garnet, zircon, tourmaline and sphene are considered as the most stable ones. We do not totally oppose this opinion but our analyses indicating sporadic olivine and the pyroxene-rich assemblages in Upper Paleozoic and Lower Mesozoic deposits and the assemblages rich in garnet, zircon, tourmaline and sphene in the overlaying sedimentary rocks (see Table 1) convince us that intrastratal solution has not altered the studied compositions significantly.

6. Conclusion

The actualistic interpretation of heavy-clastic mineral assemblages from sedimentary rocks of the Samarka and Taukha Terranes enables us to obtain new information on tectonic settings surrounding their depositional place. In particular, the association of olivine, orthopyroxene, green clinopyroxene, amphibole, garnet and spinel from Permian cherts indicates a tectonic setting like that in the modern intraoceanic collision zones. The Ti-rich clinopyroxene assemblage of Upper Triassic-Lower Jurassic cherts, mudstones and tuffs points to the intraoceanic seamounts and fracture zones like those in the central and eastern Pacific. Increasing amounts of terrigenous minerals (zircon, tourmaline, sphene) in Upper Triassic-Middle Jurassic deposits reflect drifting from intraoceanic to passive-continental-margin conditions that was probably connected with tectonic movements oblique to the continent-ocean border.

Because of the lack in data, we did not try to define origin of the studied deposits in detail. It was not a purpose of this investigation. The major task was to interest other researchers in study of heavy-clastic minerals from sedimentary rocks probably oceanic or deep-sea in origin. We also hoped to interest researchers in cooperation on this matter.

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PALEOGEOGRAPHY OF TRIASSIC SEDIMENTATION IN SOUTH PRIMORYE

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Abstract

The stratigraphy and conditions of Triassic deposit formation in South Primorye are discussed.

1. Introduction

The Primorye region is in the field of Paleozoic folding, at the joint of the structures between of the East-Asian folded area and the Pacific north-west sector. Triassic sedimentation in South Primorye took place in superimposed depressions: the Suifun river basin, located in the south margin of Khanka crystalline massif, and the Suputinka and Petrovka River basins, occupying the territory of the present day water areas Amur and Ussuri Gulfs and river basins draining into them (Fig. 1).

The deposits have long attracted the geologists' attention because of their fauna and flora fossil remains and the presence of economic minerals. The first finding of ammonoids by V.P. Margaritov in 1886 near Vladivostok and the fauna collection of D.L. Ivanov caused K. Diner and A. Bittner to become interested in them.

M.K. Eliashevich (1922) prospecting for coal in the Mongugai deposits, distinguished Ussuri (Lower and Middle Triassic) and Mongugai (Upper Triassic) divisions. A.N. Krishtofovich (1932), studying the flora of Far East Mesozoic deposits, determined Mongugai association of Triassic flora.

A lot of credit must go to L.D. Kiparisova (1961, 1972), who studied and described in detail a large association of cephalopod and bivalve mollusks and gave paleontological grounds of Triassic stratigraphy in Primorye region.

The author of this paper studied Triassic deposits of Primorye since 1938 (Burij, 1948). The results of these investigations have been presented in numeraus publications (Burij, 1956, 1959, 1968a, 1968b, 1972, 1973; Burij and Zharnikova, 1961, 1972, 1980, 1990; Burij and al. 1968, 1990; Korobkov and Zharnikova, 1970; Zarnikova and Buryi, 1973). N.K. Zharnikova in collaboration with the author, collected, defined, and in part monographically described a large mollusk collection. For the first time in Triassic deposits of Primorye, she discovered the remains of bryozoans, foraminifers, ostracods, bellerophon gastropods, anaptychi, and conodonts (Zharnikova 1981, 1985). The conodonts have been of great importance for the study of Triassic biostratigraphy of Primorye (Buryi, 1975, 1979, 1989). The author, when describing the rocks, took into account the sedimentology of the fossil-bearing units (Korzh, 1959; Kaplan, 1965, 1966 and L.D. Miroshnikov, 1969). Since 1963, Y.D. Zakharov studied ammonoids and stratigraphy of the Lower Triassic in South Primorye (1967, 1968, 1978). Triassic deposits were investigated by many geologists, mentioned in the historical review by L.D. Kiparisova (1972).

Below, I give the characteristics of Triassic from Suputinka and Petrovka River basins, where all the three divisions and stages are represented. Five Triassic horisons and seven suits have been recognized in South Primorye (Burij et al., 1977, 1993).

2. Stratigraphy

2.1. South Primorye Area, Suputinka and Petrovka River basins

2.1.1. Lower Triassic

Lower Triassic deposits occur unconformably on the Upper Paleozoic marine layers. The problem of interrelation of the formations was long debatable. There were two points of view: conformable and non-conformable bedding. Burij and Zarnikova (1989) recently studied the problem on the example of the sections of boundary layers. This study did show that in all sections there were basal layers consisting of conglomerates or sedimentation breccias.

The basal layers of the south-west part of South Primorye Zone are represented by conglomerates occurring in the basement of the Induan Stage. There is the break in the sedimentation here (from the Upper Dorashamian to the Olenekian).

The most representative sedimentation breccias were found in the Artemovka River basin (near the former village of Novokhatunichi), in the northeast part of the Suputinka depression. Upper Permian deposits are represented by thick (up to 900 m) series of calcareous sandstones with the remains of bryozoans and goniatites of Lyudyanza Horizon. In the overlying mudstones and fucoid siltstones, the remains of Permian cephalopods were found (*Eumedlicotlia* ex gr. *primas* Waagen, *Neogeoceras* *thaumastum* Ruzh., *Propinacoceras hidium* Ruzh.) (Zakharov and Pavlov, 1986). Above Permian fucoid siltstones, Triassic basal layers occur consisting of thin interbedding of sandstones, siltstones, and sedimentation breccias of total thickness 30 m. Among breccias, a well-rounded limestones block was found. It is characterized by Lyudyanzian bryozoans (*Fistulipora* sp., *Eridopora* sp., *Pseudobatostomella novelia* Kis., *Rhabdomeson consimmile* Bassler) and foraminifers (*Reichelina?* sp.). Above, siltstones occur with Olenekian molluscs: *Posidonia ussurica* Kipar., *?Xenoceltites* cf. *minutes* Waag., *Claraia* cf. *aurita* (Hauer), as well as a form resembling *Dieneroceras dieneri* Hyat and Smith (small and bad preserved ceratite). Thus, the break in the marine sedimentation appeared to take place, since Late Dorashamian to Olenekian time. In South Primorye, the rejuvenation of the basal layers obviously became apparent as Early Triassic transgression moved from the south-west to the north-east.

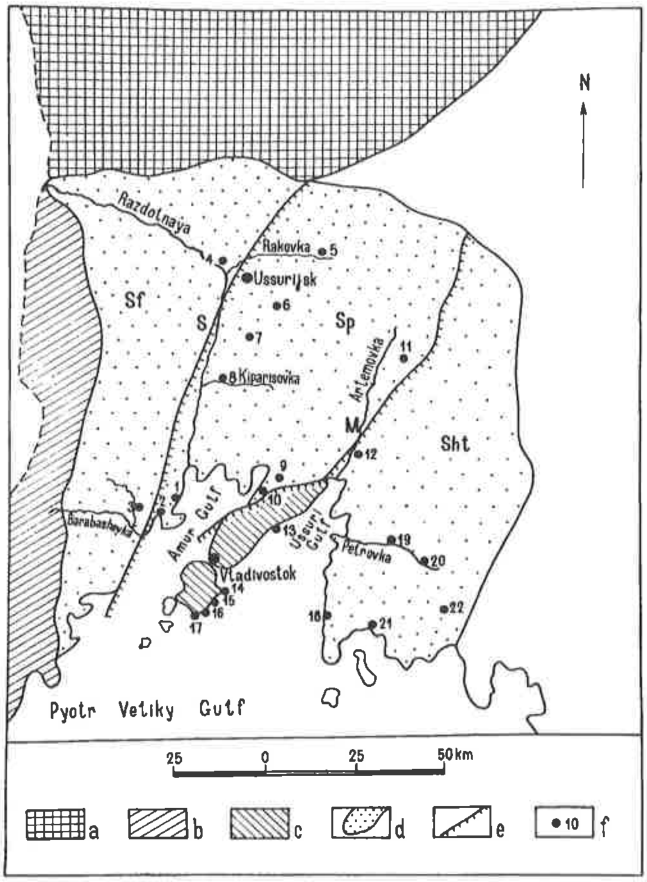

Fig. 1. The scheme of the distribution of depressions in Triassic time in the South Primorye. a - Khanka massif; b - Khasan-Barabash-Grodekovo mountain region; c - Murav'evsky anticlinorium; d - Triassic depressions: Sf - Suifun, Sp - Suputinka, Sht-Shitukhe. e - faults: S - Suifun, M - Murav'evsky. f - main sections: 1 - Atlasov Cape, 2 - Amba River, 3 - Fillipovka Village (Barabashevka - Mongugai River), 4 - Borisovka Village (Parametric Hole 1), 5 - Rakovka River, 6 - Komarovka River (Suputinka), 7 - Perevoznaya River, 8 - Kiparisovka River (Traktornyi Creek), 9 - Peschanka River (Podgorodnenka deposit), 10 - Bogataya River (Sadgorod deposit), 11 - Artemovka River (Novokhatunichi Village), 12 - Artemovka River (Shkotovo deposit), 13 - Lazurnaya Bay, Seryi Cape, 14 - Karazin Cape, 15 - Chersky Cape, 16 - Chernyshev Bay, 17 - Tobizin Peninsula, 18 - Golyi Cape, 19 - Pandrovka River, 20 - Petrovka River, Petrovka Village (Litovka River), 21 - Abrek Bay, 22 - Volchanets Village.

The deposits of Induan and Olenekian stages are determined in Lower Triassic of the region.

Induan Stage
(Lazurnian Horizon, *Gyronites subdharmus* Zone)

The most representative section of the Induan was discovered in the rocky scarps of the Ussuri Gulf west shore to the south of Lazurnaya Bay. Various-pebbled basal conglomerates with lens-like interbeds of sandstones and organic-rich limestones outcrop along the shore from Seryi Cape to Kitovaya and De-Livron Bays. In this conglomerats, the mollusk remains of the Induan were found: *Grypoceras* cf. *hexagonale* Dien., *Xenodiscus nicolai* Dien., *Anodontophora canalensis* (Cat.), *Neoschizodus laevigatus* (Ziet.), *Gervillia exporrecta* Leps. The thickness is up to 30 m. Above the conglomerate is a series of greenish-gray polimictic sandstones with limestone interbeds that contain bivalve and cephalopod mollusks, bellerophon, gastropods and conodonts (fossils are: *Nucula goldfussi* (Alb.), *Eumorphotis multiformis* Bittn., *Myalina schamarae* Bittn., *M. putiatinensis* Kipar., *Leptochondria minima* Kipar., *Neoschizodus laevigatus* (Ziet.), *Anodontophora fassaensis* Wissm., *A. elongata* Schloth., *Xenodiscus* cf. *nicolai* (Dien.), *Lytophiceras* cf. *kilenense* Spath, *L.* cf. *schamarae* Dien., *L.* cf. *sakuntala* Dien., *Mesohedenstroemia* aff. *planata* Chao, *Gyronites subdharmus* Kipar., *G.* cf. *evolutus* Waag., *Meekoceras* cf. *boreale* Dien., *Koninckites varaha* Dien., *K. timorensis* (Wann.), *Neogondolella carinata* (Clark), *Hadrodontina subsymmetrica* (Müller). The thickness is more than 116 m.

Olenekian Stage

The deposits of the Olenekian Stage, studied and described in detail from stratotypical sections in the Tobizin Peninsula and Chernyshev Bay (Russian Island), were divided into Tobizin and Chenyshev Horizons by lithological composition and characteristic fauna associationes (Burij et al., 1977, 1993).

Tobizin Horizon is mainly represented by polimictic sandstone with calcareous interbeds overfilled with shells of bivalve and ammonoid mollusks. The lower part of this horizon in the Primorye region is characterized by the following ammonoid association: *Parahedenstroemia acuta* (Krafft.), *Hedenstroemia bosphorensis* (Zakh.), *Ussuria schamarae* Kipar., *Parussuria compressa* (Hyatt and Smith), *Meekoceras gracilitatis* White, *M. subcristatum* Kipar., *Arctoceras tuberculatum* (Smith), *Flemingites cirratus* (White), *Owenites koenini* Hyatt and Smith, *Prosphingites ali* Arthaber, *P. orientalis* Kipar., *P. magnumbilicatus* Kipar. and other (*Artoceras tuberculatum* Zone, corresponding to the Zone of *Hedenstroemia bosphorensis* according to Y.D. Zakharov). The upper part of the Horizon contains the remains of the following ammonoids: *Dieneroceras chaoi* Kipar., *Meekoceras gracilitatis* White, *M. subcristatum* Kipar., *Koninckites timorensis* (Wanner), *Proptychites (Discoproptychites) septentrionalis* Dien., *P. (Proptychites) robinsoni* Kipar., *Owenites koeneni* Hyatt and Smith, *Prosphingites* aff. *orientalis* Kipar., *Nannites sinuosus* Burij and Zharn., *Paranannites suboviformis* Kipar., *Anasibirites nevolini*

Burij and Zharn., *Pseudoowenites nevolini* Burij and Zharn., *Kashmirites maritimus* Burij and Zharn., *Arctoprionites tyrreli* Spath, *A. nodosus (Freb.)*, *Gurleyites freboldi* Spath, *G. maichensis* Burij and Zharn., *Anasibirites dichotomus* Waag., *A. angulosus* (Waag.), *A. popovi* Burij and Zharn., *A. ovsianikovi* Burij and Zharn., *A. elegans* Burij and Zharn., *A. desertorum* Spath, *Wasatchites orientalis* Spath, *W. tridentini* Spath, *W. vlasovi* Burij and Zharn. (*Anasibirites nevolini* Zone).

Chernyshev Horizon in its lower part is composed of polymictic sandstones with interbeds of coquina and a bed of brachyopod limestone. This part of the horizon is identified as the Zone of *Tirolites cassianus* (Burij and Zharnikova, 1981). The following species compose the ammonoid association: *Xenoceltites minutus* (Waagen), *Tchernyschevites costatus* (Zakh.), *Meekoceras subcristatum* Kipar., *Kazakhstanites sonticus* (Zakh.), *Tirolites cassianus* (Quenst.). The upper layers of the horizon, consisting mainly of dark-gray siltstones with interbeds of organic-rich limestones, represent the *Columbites parisianus* Zone (*Neocolumbites insignis* and *Subcolumbites multiformis* Zones, according to Y.D. Zakharov). Characteristic ammonoids association of this Zone includes: *Prosphingites globosus* Kipar., *P. insularis* Kipar., *Khvalynites unicus* (Kipar.), *Hemilecanites discoideus* Burij and Zharn., *Columbites parisianus* Hyatt and Smith, *C. ussuriensis* Burij and Zharn., *Subcolumbites multiformis* Kipar., *Neocolumbites insignis* Zakh., *N. grammi* Zakh., *Procolumbites subquadratus* Burij and Zharn., *Arnautoceltites gracilis* (Kipar.), *Leiophylites praematurus* Kipar., *Palaeophyllites skorochodi* Burij and Zharn., *Olenekoceras miroshnikovi* (Burij and Zharn.), *O. meridianus* (Zakh.), *Hellenites praematurus* (Arth.), *H. tschernyschewiensis* Zakh., *Megaphyllites* cf. *immaturus* Kipar.

The layers of the Chernyshev Horizon (300 to 600 m thick) complete the section of the lower Triassic in Suputinka and Petrovka River basins. The absence of analogous representatives of genera characteristic of the Zone of *Olenekites spiniplicatus* (with the exception of *Olenekoceras* and *Svalbardiceras*), that forms the uppermost the section of Lower Triassic in Artic Siberia, is apparently explained by Pre-Anisian washout which will be discussed below.

2.1.2. Middle Triassic

It is necessary to discuss in more detail the relation between the Middle and Lower Triassic, before describing Middle Triassic deposits. Contrary to the existing opinion on conformable occurrence of Middle Triassic deposits, I stated my belief that on the boundary of these epochs there was a break in the sedimentation in the region, when basal conglomerates up to 30 m thick formed (Burij, 1959). As this conclusion caused distrust, we gave special attention to addressing this question during later field works.

The representative section of Anisian basal layers is observed near the Village of Petrovka on the right bank of the Petrovka rivers, to the east of Vladivostok-Nakhodka road. In the extended rock scarps, there is a series of siltstones and sandstones (more than 200 m thick) with Olenekian fauna: *Anaxenaspis* cf. *orientalis* Dien., *Dieneroceras ovalis* Chao, *D. chaoi* Kipar., *Danubites* sp.

Stratigraphically above, a thick (up to 60 m) packet of sedimentary breccia occurs, composed of chaotic accumulation of Lower Triassic sandstones and siltstones blocks. Individual blocks (to 10 m) are cemented with smaller angular fragments of sandstones, siltstones, and limestones. Well-rounded pebbles of sedimentary rocks are also found. There is no evidence that these breccias are of tectonic origin. The rocks occur normally without tectonic dislocations. The remains of Early Triassic fauna were found in the blocks of sandstones and siltstones: *Trematoceras* cf. *subcampanile* Kipar., *Anasibirites* sp., *Palaeoneilo prynadai* Kipar., *P. elliptica praecursor* Frech, *Pteria ussurica* Kipar., *Anodontophora fassaensis* Wissm. Above the breccia packet, there is a series (about 200 m thick) of dark-gray banded siltstones and sandstones of the Anisian stage, which is characterized by *Danubites* cf. *naumanni* Mojs., *Acrochordiceras* (*Paracrochordiceras*) sp. indand., *Leiophyllites pradyumna* Dien.

The Triassic section on the east shore of Ussuri Gulf to the north of the Golyi (Kom-Pikho-Sakho) Cape is also of interest. In the rocky scarp, Lower Triassic deposits contain typical fauna of the Induan and Olenekian. Above these layers, on the very top of the scarp, M.E. Kaplan in 1965 found out conglomerates and sedimentary breccias that were superposed by siltstones of Chernyshev Horizon (Lower Triassic). Anisian basal layers are composed of random accumulation of angular fragments of black siltstones and gray sandstones cemented with greenish-gray sandy cement. There are also carbonate concretions variously oriented relatively to bedding and the grains of glauconite can be observed among the pebbles. In the angular fragments of sandstone, there are Olenekian *Xenoceltites* cf. *spitbergensis* Spath., and plant remains (*Pleuromeia*).

Above the sedimentary breccia layer (2 m thick), fine-grained massive sandstones (30 m) occur. In the lower part of this sandstone there are thin siltstone interbeds which become thicker higher in the section. In this sedimentary packet there are numerous interbeds of the sedimentary breccia containing the fragments of black siltstones (to 12 cm) and rare pebbles. In the black siltstone interbeds superposing the sandstones, the remains of brachiopods, gastropods and plant remains (*Neocalamites*) as well as anaptychi typical of Anisian Stage were found (Korobkov and Zharnikova, 1970).

Above this rocks lies a series (more than 120 m) of Anisian - age sediments. The section is completed by conglomerates and sandstones of Chigan formation of the Upper Jurassic. In the basal conglomerates of the Chigan formation there are large (to 10-15 cm) fragments of coal (possibly, Shitukhe formation of the Upper Triassic).

Similar basal conglomerates also occur at the basement of Anisian deposits in the Bogataya and Rakovka River basins. In the sections of Russian Island, conglomerates are absent and Anisian basal layers are represented by sedimentary breccia (0.2-0.8 m) composed of accumulation of angular fragments of black siltstones with numerous grains of glauconite (?), fragments and entire shells of bivalve, brachiopods, gastropods, and remains of fishes and other vertebrates. According to Y. D. Zakharov, certain features of fauna succession of the Zones of *Subcolumbites multiformis* of Lower Triassic and *Ussuriphyllites amurensis* of Anisian Stage and presence of *Prohungarites* in the bottom of the Anisian testify to the absence of a break in sedimentation at the end of Early and beginning of Middle Triassic, at least in part of the South Primorye territory

Anisian Stage

The deposits of the Anisian Stage are represented by thick series of siltstones and sandstones (Karazin Horizon), overlain by a series of typical arkose quartzite-like sandstones (Chersky Horizon).

The Karazin Horizon, which at its base contains the sedimentary breccias, in its stratotypical section, near the Karazin Cape, is represented by greywacke and gray to dark-gray spotted, bedded, and banded sandstones. On the sandstone bedding planes, there are numerous accumulations of algae, and traces of mudeaters and other benthic animals. There are also large (up to 0.5-0.7 m in diameter) calcareous concretions-septaria with the remains of ammonoids and bivalves. In the middle part of the series, large (to 1 m long) imprints of equisandum stems (*Neocalamites*) are present. The thickness of the horizon is 250-300 m. A vast collection of cephalopods, bivalve mollusks, and conodonts were collected from the deposits of the horizon.

The summary biostratigraphic section of the Anisian Stage is believed to be the following. In 1987, in the very lower layers, cropping out on the west shore of Amur Gulf (Atlasov Cape), Y.D. Zakharov distinguished the Zone of *Ussuriphyllites amurensis* characterized by *Ussuriphyllites amurensis* (Kipar.), *Leiophyllites praematurus* Kipar., *Parapopanoceras* gen. and sp. indet., *Megaphyllites atlasoviensis* Zakh., *Prohungarites popovi* (Kipar.), *Lenotropites? solimani* (Toula), *Arctohungarites primoriensis* Zakh. Our data show the deposits of Russian Island with *Paracrochordiceras* n. sp. and *Japonites* cf. *planiplicatus* Mojs. to be of the same stratigraphic level. Characteristic ammonoid association allows us to attribute this Zone to the lower Substage of the general scale (Aegean). Above there are the deposits attributed by Y.D. Zakharov to Zone of *Leiophillites pradyumna*. This Zone is characterized by *Tropigastrites sublahontanum* Zakh., *Leiophyllites pradyumna* (Dien.), *Hollandites tozeri* Zakh., *Japonites russkiensis* Zakh., *Beyrichites* cf. *osmonti* Smith., etc. This Zone is comparable with lower and middle parts of the middle (Bithinian) Substage. The next in the section is the Zone of *Acrocordiceras kiparisovae* distinguished by N.K. Zharnikova in 1970 (*Phyllocladiscites basarginensis* Zone according to Y.D. Zakharov), that includes *Parasageceras discoidale* Welter, *Leiophylites suessi* (Mojs.), *Acrochordiceras kiparisovae* Zharn., *A. orientale* Zharn., *Ptychites austro-ussuriensis* Kipar., *Discoptychites reductus* (Mojs.), *Malletoptychites durandii* Dien., *Sturia ussurica* Burij and Zharn., *Ussurites yabei* Dien., *Phyllocladiscites basarginensis* Zakh. and other allowing us to attribute these deposits to the upper part of the middle Pelsonian Substage.

Paraceratites trinodosus Zone, distinguished also by N.K. Zharnikova, contains *Paraceratites trinodosus* (Mojs.), *P.* ex gr. *binodosus* (Hauer), *Discoptychites reductus* Mojs., *Anagymnites acutus* (Hauer), *A. lamarcki* (Oppel), *Monophyllites sphaerophyllus* (Hauer), and *Daonella sturi* (Ben.) characteristic of the lower part of the upper Substage (Lower Illyrian).

Chersky Horizon is defined by the author where it crops out in coastal rocky scarps between Bogdanovich Bay and the Chersky Cape on Russian Island. The Horizon is composed of monotonous white and light-gray middle- and coarse-grained arkose sandstones with quartz-like appearance. In the lower part of the horizon, in the siltstone interbed, M.V. Korzh found a fragment of *Ussurites* cf. *sichoticus* Dien (determination of L.D. Kiparisova). We found the indeterminable bivalve in the siltstone, interbed in the middle part of the horizon (in Y.D. Zakharov's opinion, these sediments are Ladinian in age). In the sandstones, one can observe wave-cut signs, charred plant detritus, and well-rounded pebbles of igneous rocks. All this evidence indicates the formation of this series in a shallow sea. The thickness of the series is 30-500 m.

Ladinian Stage

Unconformable deposits of the Ladinian Stage superpose washout deposits of the Chersky Horizon. Ladinian basal layers are represented by conglomerates (Surazhevka Village - 60 m) or coquina (Bogataya River - 2 m). In deposits of the Ladinian Stage, three members are distinguished (upwards):

a) the member of siltstones and clay shales with Ladinian bivalves and ammonoids (we distinguished it as Sputnik formation);

b) the members of arkose and quartz-like sandstones with lens-like beds of siltstones, containing fauna of Ladinian Stage and coal beds (this member represents the lower Kiparisovka formation);

c) the member of platy siltstones and sandstones representing the upper Kiparisovka formation.

It is unclear if the two upper members belong to the Ladinian stage. Firstly, L.D. Kiparisova attributed them to Ladinian (1972). S.A. Shorokhova, A.N. Oleinikov, T.M. Okuneva, and N.G. Melnikov consider them to be Carnian.

Sputnik formation is believe to be the lowest subdivision of the Ladinian. It is composed of siltstones, mudstones with concretions, and interbeds of fine-grained sandstones. In sandstones on the west coast of Amur Gulf (between the Atlasov and Ugolnyi Capes) in sandstones, the remains of *Ichthyosaurus* skeleton, were found. In mudstones of South Primorye, there are abundant remains of cephalopod and bivalve mollusks: *Trematoceras* sp. indet., *Gymnotoceras* aff. *paucicostata* Yabe and Shim., *G. medvedevi* Kipar., *Hungarites* aff. *bitingensis* Smith., *Protrachyceras* aff. *furcatum* Muenst., *Ptychites* aff. *mangala* Dien., *Sturia* sp. indet., *Atractites* sp. indand., *Nucula, Pteria, Entolium, Lima, Dentalina, Frondicularis, Daonella, Leptochondria, Leda, Plagiostoma.* The thickness of the formation is 300 m.

Kiparisovka formation was distinguished by the author in Ladinian Stage (Burij, 1956, 1968a,b). The Lower part is represented by arkose and quartz sandstones with lens-like coal beds and fucoid siltstones with fauna. Near the coal beds, one can find the following plant remains: *Neocalamites* sp., *Cladophlebis* cf. *stenolopha* Brick, *Taeniopteris stenophylla* Krisht. (determination of I.N. Srebrodolskaja and S.A. Shorochova), as well as *Taeniopteris stenophylla* Krisht. var. *mongugaica* Srebrod., *T.* cf. *lanceolata* Oishi var. *minima* Srebrod., *Neocalamites hoerensis* (Schimp.), *Equisendites* sp., *Todites giganteus* (Oishi), *Clathropteris* sp., *Podozamites* ex gr. *lanceolata* (L.and.H.), *Pytiop hyllum* ex gr. *nordensiskioldii* (Heer and Nath.).

The Traktorny Creek section: in the siltstones interbeded among sandstones, plant remains were found, which V.A. Krassilov attributed to *Neocalamites* sp., *Cladophlebis* sp., *Clayhropteris meniscioides* Brongn., *Ctemozamites* sp., *Anomozamites minor* (Brongn.). Above them, in a packet of fucoid siltstones at the same creek, we found the remains of bivalve fauna *Daonella moussoni* (Merian), *D. densisuleata* Yabe and Zhim. and brachiopods *Pennospiriferina pasifica* Dagys (determination of A.S. Dagys). N.G. Melnikov believes that between these layers there is a big disturbance, and following A.N. Oleinikov and S.A. Shorokhova data, he casts some doubt on the presence of coals within the Kiparisovka formation.

The Upper part is characterized by finely interbedded platy sandstones and siltstones. On the right bank of the Bogataya River (Lesnoi Creek) in platy rocks, underlying a coal bed stripped by exploring shafts and an adit in 1952, a fragment of bivalve *Daonella* was found (Burij, 1959). N.G. Melnikov explains this fact by bedding-plane trust fault structure of the area. The total thickness of the Kiparisovka formation is about 500-700 m.

2.1.3. Upper Triassic
Carnian Stage

Sadgorod formation is represented by typical coal-bearing, aerial-fresh-water deposits of Lyanchikha, Podgorodnenka, and Surazhevka coal deposits (Burij, 1959, 1973). The following layers are distinguished in the formation: a) basal-conglomerates (1 to 60 m thick), b) lower coal-bearing packet of sandstones, siltstones, and argillites with coal beds and plant remains (280 m), c) middle coal-free packet of medium-grained sandstones and siltstone interbeds (122 m), d) upper coal-bearing packet with coal beds (240 m), e) the series of bedded greenish-gray sandstones with interbeds of coaly shale (more than 115 m).

The plant remains are represented by Mongugai association: *Cladophlebis gigantea* Oishi, *Taeniopteris imuscula* Srebrod., *T. stenophylla* Krisht. var. *mongugaica* Srebrod., *T. lantschihensis* Srebrod., *T. paraspathilata* Srebrod., *Parajacutiella mongugaica* Srebrod., etc. (determination of I.N. Srebrodolskaja), as well as by the representatives of *Neocalamites, Toites, Pseudoctenis, Phoenicopsis, Pityophyllum*, and *Carpolites* (data of S.A. Shorokhova).

Norian Stage
Peschanka formation

The marine formations composed of polymictic sandstones and siltstones superpose different layers of Sadgorod formation. In the middle part of the formation, there is a bed (8 m) of breccia consisting of fragments of andesites, andesite tuffs and andesite porphyrites with small pebbles of effusive rocks. This bed is prominent in the sections on the west part of Suputinka River depression.

The deposits of the formation contain a large fauna associaton of bivalves, brachiopods, gasropods, nautiloids, whose forms are characteristic of the Norian Stage. L.D. Kiparisova distinguished the layers with (1) *Oxytoma ziteli, O. mojsisovicsi* and *Tozapecten suzukii* (150-200 m), (2) *Otapiria ussuriensis* (about 200 m), and (3) *«Monotis» scutiformis* (100-120 m). On my oppinion the formation thickness does not exceed 200-300 m.

Amba formation

Above the marine layers of the Peschanka formation, coal-bearing aerial-fresh-water formations of Amba formation are present. Its stratotype section was studied and described in detail from the railway hollow of the Khasan branch of the Far East railway, on the right bank of the Amba River. The formation is composed of sandstones and siltstones with beds and interbeds of coal and coaly shale. The association of the plant remains, which are different than those exposed near village Sadgorod is represented by the forms of *Dipteridaceae* (data of I.N. Srebrodolskaja): *Clathopteris meniscioides* Brongn., *Dictyophillum nathorstii* Zeill., *D. mongugaicum* Srebrod., *Thinfeldia ambabiraensis* Srebrod., *Drepanozamites nilssoni* (Nath.) Harris, *Podozamites scenkii* Hr. The thickness of the formation is 400 m.

Perevozninskian formation

This formation is represented by polymictic sandstones and siltstones containing numerous Norian fossils: *Monotis ochotica* (Keys.), *M. jakutica* (Tell.), *Oxytoma mojsisovcsi* (Tell.), *Tosapecten subhiemalis* Kipar., *Entolium kolymaense* Kipar., *Palaeocardita* cf. *mansuyi* Reed. The thickness is more than 120 m. Above, unconformable marine formations of the Lower Jurassic occur.

2.3. Shitukhinskaya depression

Upper Triassic
Shitukhe formation

In the Petrovka River up-stream (former Shitukhe River) and in the watershed area of it and Litovka River, there is a series (250 m) of continental and marine deposits of the Shitukhe formation (Burago et al., 1969; Konovalova and Shorokhova, 1990). The deposits of the formation occur unconformably on the marine Anisian. In the lower part, a packet (27 m) of various-grained polymictic sandstones with plant remains outcrops, above which there are siltstones and sandstones with bivalve fossils. Total thickness is 200 m. In the basement of the latter, a lens-like layer of conglomerates and breccias (to 2 m) occurs. According to I.N. Srebrodolskaja and S.A. Shorokhova numerous collected plant remains are very similar to Upper Triassic (Mongugai) flora.

Later, S.A.Shorokhova and V.A. Krassilov collected and monographically described a large plant collection represented by forms known from Early Lias association of the Zone of *Taumatopteris*.

T.M. Okuneva (1977) collected and described bivalves: *Cardita ovula* Kittl, *C. indigirkensis* Kipar., *C. primorensis* Okun., *Modiolus vozini* Tikh., *M. kutinskensis* Efim., *M.* ex gr. *minutus* Goldf., *Myophoriopis rostriformis* Tikh., *Lima (Lima) transversa* Polub., *Anodontophora* sp. The study of the bivalves association allowed T.M. Okuneva to determine the age of the Shitukhe formation as Upper Triassic.

In my opinion, there is a good reason to attribute the layers with plant remains to the Rhaetion. The exposed association of the plant remains of the Zone of *Taumatopteris* corresponds, apparently, to the fourth stratigraphic interval in development of Eurasian flora (from Middle Norian to the end of Triassic) distinguished by I.A. Dobruskina (1980).

Similar layers of the Shitukhe formation outcrop along the Petrovka River middle course, on its right bank in the rock outcrop of basal layers of the Anisian Stage described above. A coal-bearing formation (about 100 m thick), in which A. I. Savchenok found the remains of Mongugai flora: (*Neocalamites carrerei* Zeiler and *Czekanowskia rigida* Heer) overlies an Anisian small-pebbled conglomerates. The same layers can be found downstream along the Artemovka River.

2.3 West Primorskaya Area

2.3.1. Suifun

On the right bank of the Razdolnaya River, the Triassic is represented by only continental aerial-fresh-water, coal-bearing deposits.

In the middle course of the Barabashevka River (former Mongugai River), Mongugai coal deposit has been known since the end of the last century. Up to 1922, this coal deposit was mined by small inclined pits. The coal-bearing deposits were attributed by M.K. Eliashevich to the Mongugai Stage of the Upper Triassic, and A.N. Krishtofovich identified the Mongugai plant association.

The section investigated in this study, is represented by (1) a series of platy sandstones and siltstones occurring unconformably on the Upper Permian Barabash formation, which contains basal conglomerates (10 m) at its base, and (2) Mongugai coal-bearing Suite. The latter includes the following divisions: a) basal conglomerates consisting of well-rounded pebbles of effusive and intrusive rocks, felsite-porphyry, tuff-breccias, as well as sandstones and siltstones; the thickness is 5 to 80 m; b) lower coal-bearing part composed of sandstones, gritstones, siltstones, tuff interbeds and coal beds. The plant remains, found in the deposits of the formation, are represented by Mongugai association similar to the Sadgorod formation: *Cladophlebis gigantea* Oishi., *Taeniopteris stenophylia* var. *mongugaica* Srebrod., *T. paraspathulata* Srebrod.; the thickness is 350 to 400 m; c) middle coal-free part consists of sandstones, siltstones, and argillites. In the middle part of the part, there was found a bed (1.4 to 3.4 m thick) of tuff-breccia comprised of angular fragments of crystalline-clastic andesite tuff, andesite, and andesite porphyrites. These breccias are nearly identical in stratigraphic position and petrographic composition to those in the middle part of the Peschankinskaya formation of Suputinka depression; the thickness is 250 m; d) upper coal-bearing part consists of polimict sandstones, siltstones, and coal beds. The plant remains, according to I.N. Srebrodolskaja are similar to those from Amba formation of Suputinka depression.

In this section the deposits of the Ladinian Stage (analogues of the upper part of the Kiparisovka formation) and Carnian-Norian layers of Mongugai formation (analogues of the Sadgorod and Amba formation) are described. The total thickness of the Triassic is more than 1200 m. Similar section of the continental Triassic was recently obtained from the hole near the Village of Borisovka to the north-west of Ussurijsk Town. The following Triassic sequences occur on the Upper Permian rocks of the Barabash formation:

Table 1

Triassic continental, coal-bearing deposits near the Village of Borisovka, Suifun River depression (Parametric Hole).

Lithology	Thickness
1. Basal conglomerates consisting of pebbles of Permian rocks (diabases, tuffs, and tuff-breccias)	85 m
2. Polymictic sandstones with the interbeds of siltstones and coaly argillites	75 m
3. Siltstones with interbeds of quartz and arkose sandstones, coaly argillites, and coal beds. Plant remains of Mongugai association: *Equsandites* sp. (S.A. Shorohova's determination) were found	96 m
4. Quartz and arkose obliguely laminated sandstones, coaly argillites, and coal interbeds with *Cladophlebis* sp. and *Taeniopteris* sp.	182 m
5. Siltstones with interbeds of coaly argillites with plant remains *Cladophlebis* cf. *gigantea* Oishi and *G.* sp. of Mongugai association	37 m
6. Platy sandstones and siltstones similar to the rocks of upper part of Kiparisovka formation	195 m
7. Coal-bearing packet consisting of polymictic and arkosic sandstones, siltstones, interbeds of argillites, fine-pebble conglomerates and coaly argillites, and coal beds with plant remains *Padozamites* cf. *schenkii* Heer of Mongugai association	147 m
8. Polymictic and arkosic sandstones with interbeds of siltstones and fine-pebble conglomerate	73 m
9. Coal-bearing packet with *Cladophlebis* cf. *gigantea* Oishi, and *Phoenicopsis* sp.	160 m
10. Basal conglomerates of the Lower Cretaceous	250 m

On the author's point of view the Triassic in this section is represented by following subdivisions: a) basal conglomerates (85 m), b) lower part of the Kiparisovka formation (390 m), c) upper part of the Kiparisovka formation (195 m), and d) coal-bearing Sadgorod (Mongugai) formation (430 m).

3. Paleogeography

The description of Triassic stratigraphy of South Primorye, given above, shows well that the sedimentation took place under several paleogeographic conditions. In the sections, we observe diverse facies composition of the sediments and alternation of coastal-sea and continental deposits. Probably, it is a result of the Tethyan sea level fluctuations in the first half of Triassic period (including Ladinian time) and Boreal ones during Norian time. In Carnian, there was a break in the sea sedimentation in South Primorye, favouring the coal accumulation.

3.1. Early Triassic

The beginning of Early Triassic time (Induan) was marked by small subsidence of South Primorye, that apparently allowed the waters of Lower Yantsze basin, China, to penetrate there (data of Lyu Khung-Yung).

During the transgression of Lower Triassic sea into the troughs, the intense washout of Paleozoic sedimentary-volcanogenic series and granites occurred, accompanied by the formation of basal layers. Successive development of transgression came from south-west to north-east and was accompanied by rejuvenation of basal layers and change of the rock thickness and lithological composition.

In Vladivostok latitude, in the «mouth» part of Amur and Ussuri paleogulfs, typical basal conglomerates 150 m thick formed in the Atlasov Cape (Amur Gulf west coast) and up to 50 m thick near the Golyi Cape (Ussuri Gulf east coast). The conglomerates originated from mobile coarse gravel of the surf zone and marked the beginning of transgression. In the south-west part of the troughs, the break in the sea sedimentation occured between Late Dorashamian and beginning of Induan.

In the north-east part of the troughs of Suputinka and Petrovka River depressions, in the Rakovka and Artemovka River basins, the break was more prolonged, from Late Dorashamian to Olenekian. The basal layers are represented by alternating sandstones, siltstones, and sedimentation breccias with a total thickness of up to 30 m. The presence of detritus, coarse plant remains, desiccation fissures in siltstones filled with sandy material, and big boulders of Upper Permian limestones makes it possible to distinguish in them the layers of continental and sea sedimentation in the closing stage of Early Triassic transgression (Burij and Zharnikova, 1989).

At the beginning of Induan, the sea was shallow-water with numerous rocky islands bein the sources of washdown. In middle Induan, the erosive activity of the sea weakened, and the accumulation of sands and siltstones of the Lazurnian Horizon, characterized by bivalve and cephalopod fauna of Tethyan type, took place.

The basin of Pyotr Velikii Gulf was shallow-water in Lazurnian time and all sediments of the horizon deposited in the shelf area. It is supported by the presence of the signs of rewashing organogenic coquina, desiccation fissures, ripples, and other.

The source areas supplying the terrigeneous material during Early Triassic time were located in the immediate vicinity of the regions of sedimentation.

At the beginning of Olenekian, the sea basin became deeper and fine-grained predominantly terrigeneous and party chemogenic sediments (calcareous nodules) accumulated. At the end of Early Triassic (Chernyshev time) in the basin, predominantly fine-grained terrigeneous and chemogenic formations continued to deposit. The rocks of Chernyshev Horizon are represented by thin-laminated and microlaminated varieties of dark-gray and black color. They contain numerous carbonate concretions and entire interbeds of limestones with ammonoid, bivalve, brachiopod, and plant remains. The presence of stratification and microlamination is conditioned by repeated supply of material and possibly seasonal changes in the sea basin regime.

Fauna of the Chernyshev Horizon is rather abundant and diverse. Along with the large ammonoid association, bivalves are also found. The fauna character testifies to the fact that in this time the communication between the South-Primorye basin and Tethys was significantly expanded.

In the rocks of the horizon, there are the remains of *Pleuromeia* and *Neocalamites*, undoubtedly brought in from the land. This fact is of great importance for the elucidation of the question of the climate and relief of the territory adjacent to the sea. A.N. Krishtofovich believed that Early Triassic flora in South Primorye occupied the sand dunes spreaded along the sea coast. These data suggest the climate of the region in Early Triassic time was hot and the region was a desert.

3.2. Middle Triassic

Middle Triassic epoch in Far East was marked by changes in physico-geographical environment of sedimentation, probably caused by the tectonic movements accompanying partial sea regression. Significant contraction of the sea area happened in the Korean Peninsula and in South China, where the sea retreated from the Lower Yantsze basin to the south-west. The short term regression took place at the boundary of Early Triassic and Anisian in South Primorye also (Burij and Zharnikova, 1977). The evidence for this fact is the basal layers in the basement of Karazin Horizon represented by conglomerates or sedimentation breccias. The basin during Anisian was not deep and even somewhat more shallow-water than in Olenekian. It is supported by the lithological composition of the Karazin Horizon and the presence of characteristic banding, algae imprints, traces of creeping of worms and other benthic animals, as well as, the imprints of equisetum aerial plants *Neocalamites*.

By the end of Anisian time, there was a strong drop of a sea level. In the adjacent land, new topographic highs appeared, as a result in of an erosional activity increase. In the region, the series of Shersky horizon, composed of monotonous white and light-gray arkose sandstones 100 to 500-700 m thick, started to accumulate. During the formation of arkose sandstones, acid intrusive rocks of Muravyevsky Ridge of Khanka crystalline massif and granites of Grodekovsky batholith were, apparently uplifted.

Ladinian time was marked by further regression of the sea. The lower layers of Ladinian Stage (Sputnik Horizon) occur in more regions than just the Suputinka River depression. Accurate X-ray structural analyses show that clay fraction of Daonella shales consisted entirely of hydromica, kaolinite, and chlorite, that were deposited in the coastal shallow-water zone. The remains of the plant stems and unsorted fragmental material also testify to the proximity of the region during the process of outwash sources sedimentation. The significant fresh-water influence took place, apparently, during Ladinian time.

Data given above show, that during the time-interval of Sputnik Horizon deposition the sea basin was a shallow lagoon freshened by abundant supply of, the river waters which removed thin terrigeneous mud, microelements, clastic material, and plant remains from the land. During the formation of the deposits, the relief of the region was smoothed and in the course of time it attained the features of a peneplain. Tectonic movements fluctuated and did not allow for the formation of rudaceous rocks.

In Middle Triassic, tectonism resulted in increased uplift of the land. The analysis of the section showed the regressive type of sedimentation. The layers of conglomerates and sandstones, underlying Sputnik Horizon, are represented by sea facies, which were formed due to sharp tectonic movements that favoured the accumulation of coarse sediments. The latter were changed by the deposits of the freshened lagoon (Sputnik formation) formed under the conditions of calm tectonic regime and peneplanation of the washout area. The superposed deposits of the Kiparisovka formation are represented by the continental series with coal (Ladinian age on our data). Repeated deposition of the marine deposits happened also occured during Early Kiparisovka time. At the end of Ladinian and by the beginning of Carnian, the continental regime was completely set, pronounced by the accumulation of thick series of lagoon-lake formations of the Upper part of the Kiparisovka formation occupying a tremendous territory of Suputinka and neighbouring Suifun troughs.

3.3. Late Triassic

The sedimentation conditions at the very beginning of Late Triassic epoch were distinctly changed. The elevations at the end of Ladinian and beginning of Carnian resulted in the draining of the territory, which before was occupied by the sea. The sea retreated to the south-west towards Tethys. The territory of South Primorye turned into the coastal-plain area that favoured the formation of coal-bearing layers of the Sadgorod formation. The presence of the tuffogen rock interbeds in the formation indicates that in the south of Far East, volcanism was active.

The territory of South Primorye in Carnian located in the field of warm damp climate favoured the growth of ferns, equisanda and conifers which produced the material for peat accumulation and coal formation in Sadgorod formation.

Norian was marked by new sea transgression from Boreal basin through the north Sikhote-Alin along the Daubikhe trough. The sea deposits of the Peschanka formation are represented by terrigeneous sequence: sandstones, siltstones, argillites, and tuffogene rock (tuff breccias, tuff sandstones, and tuff shales) testifying to the continuation of volcanic activity, which began in Carnian time. Early Norian sea was shallow-water (with islands), that is indicate by the fragmental composition of sediments. Fauna composition shows its similarity with Norian fauna of the north-east Siberia, that has no any common features with the fossil fauna of Mediterranean type.

In Middle Norian, the retreat of the sea from this territory took place again. On the newly-formed coastal plain, formation of coal-bearing deposits of Amba formation resumed.

At the beginning of Late Norian, due to the subsidence of the land, the water of Boreal sea penetrated again to South Primorye from the north. Vast sea transgression extended and deposited sediments with monotonous Monotis fauna. Late Norian sea basin was shallow water. Monotony of the fauna species composition by enormous number of individuals is conditioned rather by low-temperature regime of the sea. The presence of tuffogene rocks in the Perevozninskian Horizon indicates the continuing volcanic activity.

At the end of Late Triassic epoch, the sea shallowed significantly and then left Suputinka depression, where apparently the favourable conditions for the accumulation of Rhaetian-Liasic continental deposits were created.

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EARLY TRIASSIC CONODONT BIOFACIES OF PRIMORYE

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Abstract

Conodont assemblages of various facies of the Tobisin Horizon (Lower Olenekian) of Primorye differ in composition and size at the generic and species level. In the coastal inner-shelf facies (Russian Island) the *Parachirognathus* biofacies was recognized, in the outer-shelf facies (recent Ussuri Gulf coast, Artemovka and Kamenushka River systems) *Neogondolella-Smithodus* occur, and the oceanic facies (the Taukha terrane in the Dalnegorsk region) is characterized by *Smithodus-Neospathodus.*

1. Introduction

Detailed biostratigraphic study of conodonts in Lower Triassic deposits of North America (Clark et al., 1979), Australia (McTavish, 1973), Japan (Koike, 1979), South Primorye (Buryi, 1979), West Pakistan (Sweet, 1970), Svalbard and Nepal (Hatleberg and Clark, 1984) showed the dependence of conodont assemblages upon the lithofacies. In western North America certain conodont assemblages were found in different areas of the marine basin. *Neogondolella milleri* (Müller) and *Smithodus discreta* (Müller) characterize the outer-shelf facies of the Nevada Basin (Müller, 1956). *Parachirognathus* and *Furnishius* (Clark, 1959; Clark and Rosser, 1976) are common within coeval shallow deposits in Utah. These coeval conodont assemblages, which differ by prevalence of various genera and species and depend on the enclosing lithofacies define what is called biofacies (Clark and Carr, 1984; Barskov, 1985).

In their model D. Clark and T. Carr arranged all Lower Triassic sediment types as a straight line - a scale of the environmental gradients the final points of which are continental facies on the one end and deep-sea basin facies on the other end. Each conodont biofacies corresponds to a different environments. Three biofacies were distinguished for the Early Olenekian (Smithian) time: *Neogondolella* for the open waters, *Furnishius-Neospathodus* for the outer shelf, and *Parachirognathus* for the inner shallow shelf. It is known that most Lower Triassic conodonts occur within one or two lithofacies, i.e. there are significant variations of the lateral distribution of species. Thus, in North America and Nepal sections the conodonts of the basin facies occur also in the outer shelf. Based on this we can make biostratigraphic correlation between the deposits with different facies. However, at present such correlation are difficult due to the fact that the biofacies criteria for most Lower Triassic conodonts are not available. The facies character of the conodont distribution within the deposits of the Tobisin Horizon (Lower Olenekian) (Burij et al., 1976) occurring in Primorye: i.e. in the south near Vladivostok and in the east in Dalnegorsk (Fig. 1) was studied.

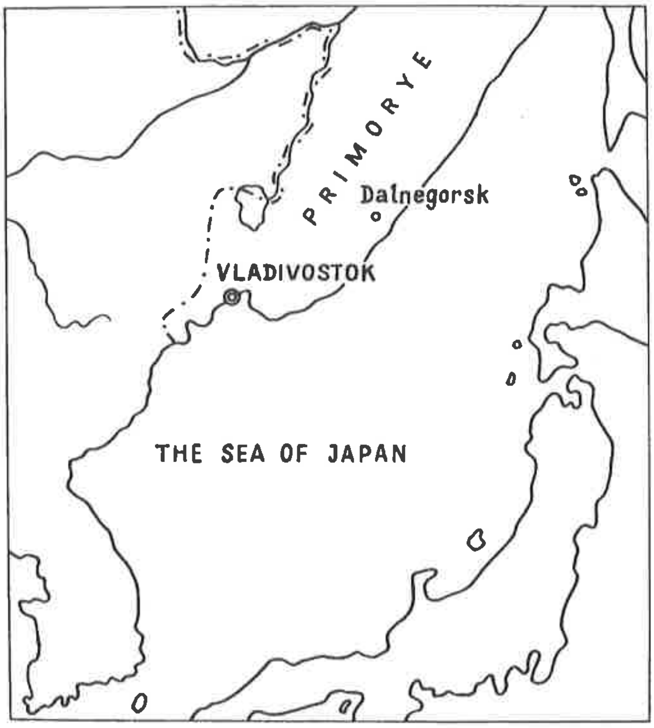


Fig. 1. Sketch map showing the conodont distribution in Primorye area.

2. Stratigraphy

This paper is based on the stratigraphic scheme of the Lower Triassic subdivision of South Primorye, compiled by I.V. Burij, N.K. Zharnikova, G.I. Buryi (1976) and G.I. Buryi (1979). According to this scheme the Lower Triassic deposits of South Primorye are divided into the Induan and Olenekian stages. Upper Induan deposits consist of the Lazurnian Horizon, corresponding to the *Gyronites subdharmus* ammonoid Zone. The Olenekian is divided into two horizons: Tobisin and Chernyshev corresponding each to two ammonoid zones. The lower or Tobizin Horizon is defined by the *Arctoceras tuberculatum* and *Anasibirites nevolini* Zones and the upper part or Chernyshev Horizon includes the *Tirolites cassianus* and *Columbites parisianus* Zones. The sections of Russian Island the Tobizin and Chernyshev Horizons are separated by intra-formation conglomerates, that consist of large fragments of red granites, and cover the top of the *Anasibirites nevolini* Zone. The lower boundary of the Tobizin Horizon corresponds to the Induan and Olenekian boundary. Above the Chernyshev Horizon follow Anisian deposits (Table 1).

Stage	Horizon	Zone (Bed)		
		Burij, Zharnikova, Buryi, 1976; Buryi, 1979	Zakharov, 1987	
Olenekian	Chernyshev	Columbites parisianus	Subcolumbites multiformis	
			Neocolumbites insignis	
		Tirolites cassianus	Tirolites-Amphistephanites	Tirolites ussuriensis Beds
				Bajarunia dagysi Beds
	Tobizin	Anasibirites nevolini	Anasibirites nevolini	
		Arctoceras tuberculatum	Hedenstroemia bosphorensis	
Induan	Lazurnian	Gyronites subdharmus	Gyronites subdharmus	
			Glyptophiceras ussuriense Beds	

Table 1. Stratigraphic scheme of South Primorye Lower Triassic deposits.

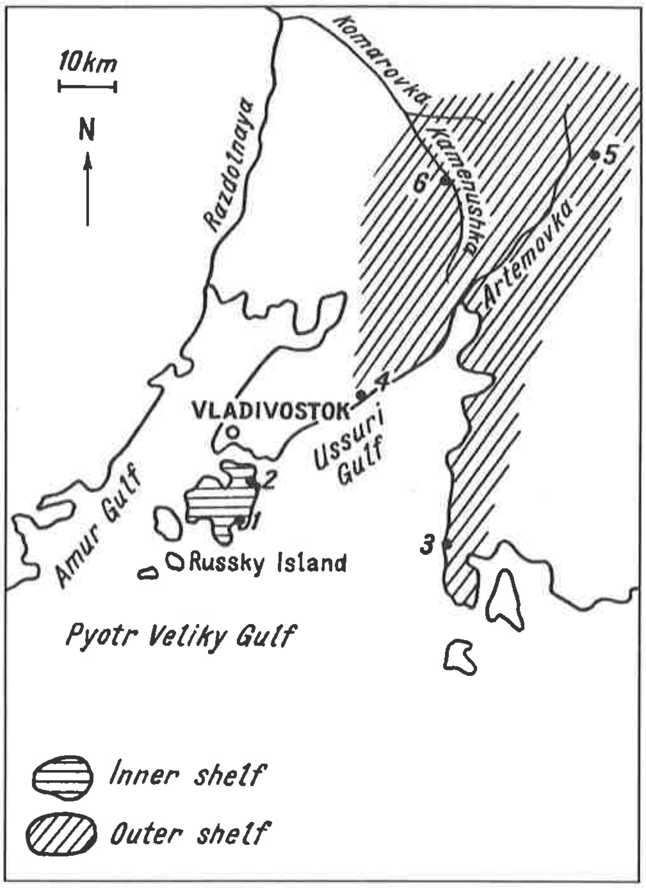


Fig. 2. The supposed distribution of facies in the Primorye area during Early Olenekian time. Lower Triassic sections: (1) location between the Tobizin Cape and Chernyshev Bay, (2) location between Ayax and Paris Bays (Russian Island), (3) eastern coast of Ussuri Gulf, (4) western coast of Ussuri Gulf, (5) Artemovka River, (6) Kamenushka River.

According to I.V. Burij and N.K. Zharnikova (1989), the Lower Triassic deposits of South Primorye belong to a rather vast inner sea basin - with numerous gulfs and islands, its coastal line resembling the recent Pyotr Veliky Gulf. This basin was formed by a transgression, prograding from South China from south-west to north-east at the beginning of Induan age. The Lower Triassic basal conglomerates contain fragments of Pre-Triassic granites and Upper Permian sediments. These conglomerates form a wedge decreasing in thickness from the south-west to the north-east.

The Early Olenekian Tobizin Horizon of South Primorye consists of a coastal shallow inner-shelf (Russian Island) and a deeper outer-shelf (recent coast of Ussuri Gulf, Artemovka and Kamenushka River systems) (Fig. 2). Very shoaly tidal environments with high energy characterizes the sediments in the immediate proximity of the granitic islands. The coastal-sea facies is represented by coarse- and middle-grained sandstone with calcareous cement, coquina lenses of broken bivalve shells, rare remains of ammonoids, gastropods, and few conodonts. Along the Ussuri Gulf coast and Artemovka and Kamenushka River system deeper water, outer-shelf conditions with quiet sedimentation and low water energy prevailed. Muds and sands contain abundant remains of ammonoids, bivalves, gastropods, and conodonts were deposited.

2.1. Conodonts of inner-shelf facies

Sediments of the coastal-shallow inner-shelf facies of the Tobizin Horizon outcrop on the south-east coast of Russian Island between Tobizin Cape and Chernyshev Bay and on its north-east coast, between Ayax and Paris Bay (Zakharov, 1968; Buryi, 1979). Quantitative characteristics and data on stratigraphic distribution of conodonts of inner-shelf facies of the Tobizin Horizon are given in Tables 2 and 3.

At Tobizin Cape (Fig. 3a), the 25.5 m thick deposits of *Arctoceras tuberculatum* Zone occur, overlying conformably lithologically similar sandstone of the *Gyronites subdharmus* Zone (Induan). They are characterized in layer 1 by the following ammonoid assemblage: *Arctoceras tuberculatum* (Smith), *Proptychites (Discoproptychites) septentrionalis* Dien., etc. At 10 m above base(layer 4) and 20 m above base(layer 6) of the *Arctoceras tuberculatum* Zone the conodont *Parachirognathus symmetrica* (Staesche) was found (sample 4009, 4038). Conodonts from deposits of the *Anasibirites nevolini* Zone (60 m thick) are more diverse. In layer 10 containing *Meekoceras* cf. *boreale* Dien., *Owenites koeneni* Hyatt et Smith, and *Paranannites suboviformis* Kipar., they consist of *Enantiognathus ziegleri* (Diebel), *Furnishius triserratus* Clark (sample 4039), and in layer 12 - *Hadrodontina symmetrica* (Staesche) and *Furnishius triserratus* Clark (sample 4040).

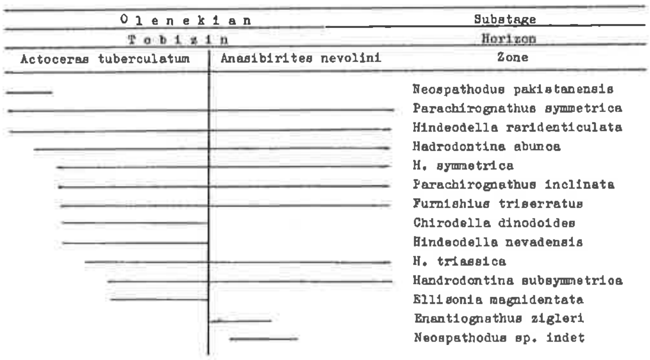
In the upper layers of the section containing *Meekoceras gracilitatis* White and *Anasibirites nevolini* Burij et Zharn., *Hadrodontina symmetrica* (Staesche), *Furnishius triserratus* Clark, *Parachirognathus symmetrica* (Staesche), and *Hindeodella raridenticulata* Müller (sample 4016) were found.

Table 2. Quantitative characteristic (number of specimens) of conodonts of inner-shelf facies of the Tobizin Horizon.

N of sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14
South-eastern part (between Tobizin Cape and Chernyshev Bay														
4016				4	7			4					10	
4040				3	30									
4039		1		2										
4038													2	
4009													3	
North-eastern part (between Ayax and Paris Bays)														
4021				1	1	2	1	3					2	2
4048										1		2		
4047	3		1	16	5	8	4	8	2	3			14	13
4024	1			2	2					1			7	
4022	1			3	1	2		3	1				10	7
4023						2							4	
4046								1					1	
4045											1			

Note: 1 - *Chirodella dinodoides*. 2 - *Enantiognathus zigleri*. 3 - *Ellisonia magnidentata*. 4 - *Furnishius triserratus*. 5 - *Hadrodontina symmetrica*. 6 - *H. adunca*. 7 - *H. subsymmetrica*. 8 - *Hindeodella raridenticulata*. 9 - *H. nevadensis*. 10 - *H. triassica*. 11 - *Neospathodus pakistanensis*. 12 - *N.* sp. indet. 13 - *Parachirognathus symmetrica*. 14 - *P. inclinata*.

Table 3. Stratigraphic distribution of conodonts of the inner-shelf facies from the Tobizin Horizon.



On the north-eastern coast of Russian Island between Ayax and Paris Bay 67 m thick similar sediments occur (Fig. 3b). In layer 1 of greenish-grey fine-grained sandstone with rare remains of *Gyronites* sp. indet. aff. *planisimus* Koken et Spath, isolated *Neospathodus pakistanensis* Sweet and indeterminable fragments of bar-like conodonts were recognized (sample 4045). Above them in the calcareous interbeds and lens-like layers 2 and 3, containing abundant *Owenites koeneni* Hyath et Smith, *Arctoceras tuberculatum* (Smith), *?Flemingites flemingianus* (Koninck), *Prosphingites ovalis* Kipar., bivalves and gastropods, there occur fairly abundant *Parachirognathus symmetrica* (Staesche), *P. inclinata* Staesche, *Hadrodontina adunca* Staesche, *H. symmetrica* (Staesche), *H. subsymmetrica* (Müller), *Furnishius triserratus* Clark, *Chirodella dinodoides* (Tatge), *Hindeodella nevadensis* Müller, *H. raridenticulata* Müller, *H. triassica* Müller (samples 4046, 4023, 4022, 4024, 4047). In the *Anisibirites nevolini* Zone rare remains of *Neospathodus* sp. indet., *Hindeodella triassica* Müller (layer 4, sample 4048), *Parachirognathus symmetrica* (Staesche), *P. inclinata* (Staesche), *Hindeodella raridenticulata* Müller, *Hadrodontina adunca* Staesche, *H. symmetrica* (Staesche), *H. subsymmetrica* (Müller) and *Furnishius triserrathus* Clark (sample 4021) were found.

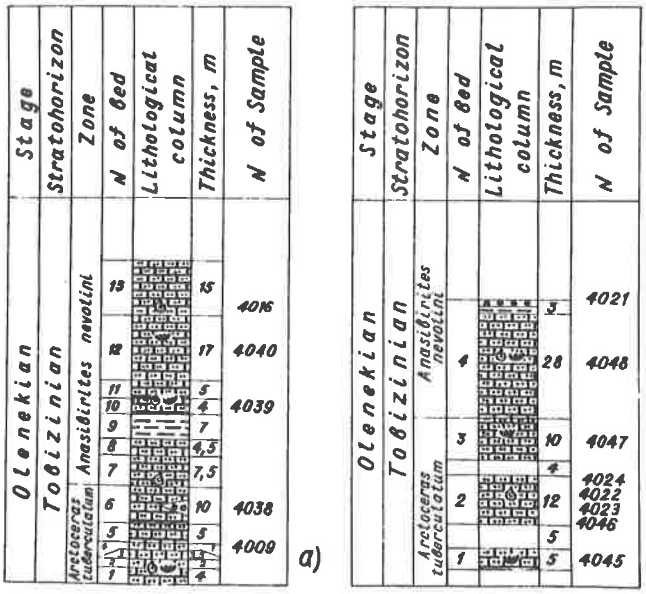


Fig. 3. Sections of coastal inner-shelf facies of the Tobizin Horizon on Russian Island: a - between the Tobizin Cape and Chernyshev Bay; b - between Ayax and Paris Bays. 1 - conglomerates; 2 - calcareous sandstones; 3 - siltstones; 4 - ammonoid remains; 5 - conodonts.

2.2. Conodonts of outer-shelf facies

The deeper outer-shelf facies of the Tobizin Horizon occur in the sections of the eastern and western coasts of Ussuri Gulf and in the Artemovka and Kamenushka River systems (Zakharov, 1968; Buryi, 1979).

On the eastern coast of the Ussuri Gulf near Golyi Cape (Com-Pikho-Sakho) (Fig. 4a) Induan sandstone containing *Gyronites subdharmus* Kipar. are overlain by the dark-gray siltstones with interbeds of calcareous sandstone, and carbonate concretions, yielding the ammonoids of the *Artoceras tuberculatum* Zone (*Pseudosageceras longilobatum* Kipar., *Dieneroceras chaoi* Kipar., *Anaxenaspis orientalis* (Diener), *Arctoceras* cf. *tuberculatum* (Smith.), *Owenites koeneni* Hyatt et Smith, *Nannites simplex* (Chao), etc.), and conodonts (*Neospathodus zharnikovae* Buryi, *Furnishius triserratus* Clark, *Hadrodontina subsymmetrica* (Müller), *Ellisonia triassica* Müller, *Ellisonia triassica* Müller, *Hindeodella nevadensis* Müller) - layer I, samples 4059, 4060 (Tables 4

Table 4. Quantitative characteristic of conodonts of outer-shelf facies of the Tobizin Horizon (number of specimens).

N of sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Eastern coast of Ussuri Gulf (Golyi Cape)																								
4061				1		1							1											
4063	2	1	1			3			9		1	2		5					3				8	
4060						2																		
4059		2			1	6			8		2	4							5					
Left bank of Artemovka River																								
4031	24					3	1	11	27	1	11		2	4				2			31		1	
4032	6					15			8		6	10	6	7	2			3			1		1	
Pereval'nyi Spring in Kamenushka River head																								
4035	9			4	3	170	30	13	36	15	24	36	7	19		1	4				22		4	1
4033	1					8		2									2				2	1	1	
4034				1		5			2			1		3	3									

Note: 1 - *Chirodella dinodoides.* 2 - *Ellisonia triassica.* 3 - *El. nevadensis.* 4 - *El. magnidentata.* 5 - *El. meissneri.* 6 - *Furnishius triserratus.* 7 - *Hadrodontina symmetrica.* 8 - *H. abunca.* 9 - *H. subsymmetrica.* 10 - *Hindeodella raridenticulata.* 11 - *H. nevadensis.* 12 - *H. triassica.* 13 - *H. budurovi.* 14 - *Smithodus discreta.* 15 - *S. longtusculus.* 16 - *S. conservatica.* 17 - *Neospathodus cristsgalli.* 18 - *N. waageni.* 19 - *N. zharnikovae.* 20 - *N. dieneri.* 21 - *Neogondolella milleri.* 22 - *Platyvillosus* aff. *gardinae.* 23 - *Parachirognathus symmetrica.* 24 - *P. inclinata.*

and 5). This sequence may be compared with the deposits outcropped along the railway between the Dunai and Yuzhnorechenskaya (Shimeuza) Stations, where *Xenoceltites spitsbergensis* Spath, *Owenites koeneni* Hyatt et Smith, *Anaxenaspis orientalis* (Diener), etc. were found together with conodonts *Smithodus discreta* (Müller), *Neospathodus zharnikovae* Buryi, *Furnishius triserratus* (Clark), *Parachirognathus symmetrica* (Staesche),

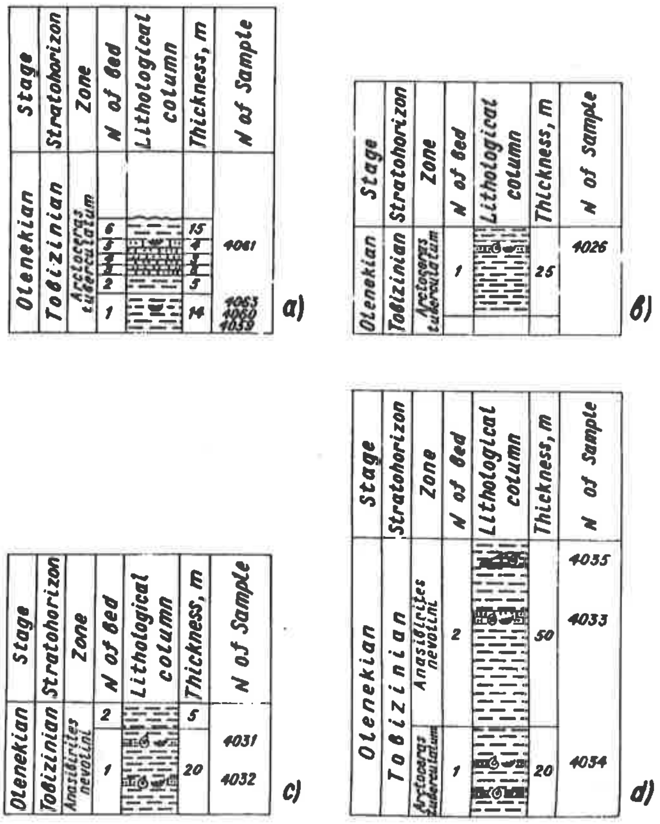


Fig. 4. Sections of outer-shelf facies of the Tobizin Horizon on the eastern (a) and western (b) coasts of Ussuri Gulf, in Artemovka (c) and Kamenushka (d) River systems. Symbols see in Fig. 3.

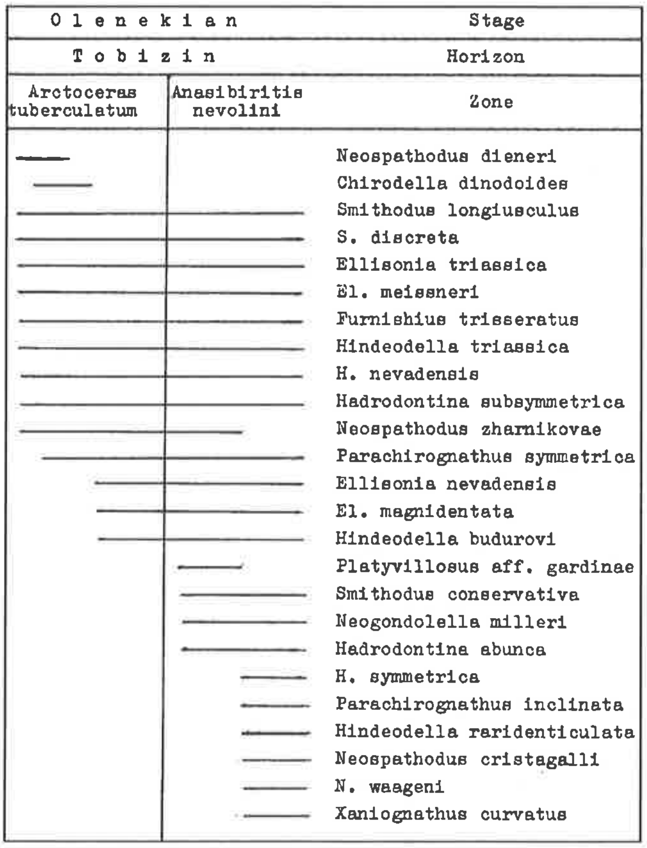


Table 5. Stratigraphic distribution of conodonts in outer-shelf facies of the Tobizin Horizon.

Hadrodontina subsymmetrica (Müller), *Hindeodella triassica* Müller, *H. nevadensis* Müller, *Chirodella dinodoides* (Tatge), *Ellisonia triassica* (Müller), *El. nevadensis* Müller (sample 4063). Above the siltstones (layers 1-2, 19 m thick) at the Golyi Cape follow fine-grained sandstone (layers 3-5, 10 m thick) rest, in which *Furnishius triserratus* Clark, *Hindeodella budurovi* Buryi, and *Ellisonia magnidentata* (Tatge) occur together with *?Xenocelites spitsbergensis* Spath (sample 4061).

On the west coast of Ussuri Gulf about 3 km to the south of the Seryi Cape *Neospathodus dieneri* Sweet (sample 4026) was found in siltstones 25 m thick (Fig. 4b) attributed to the *Arctoceras tuberculatum* Zone.

On the left bank of the Artemovka River between Kharitonovka and Novo-Khatunichi, a packet of siltstones 20 m thick (Fig. 4c) abundant ammonoids of the *Anasibirites nevolini* Zone occur: *Meekoceras gracilitatis* White, *Owenites koeneni* Hyatt et Smith, *Arctoprionites tyrrely* Spath, *A. nodosus* (Freb.), *Hemiprionites omatus* (Mathews), *H. utahensis* (Mathews), *H. garwoodi* (Spath), *A. nevolini* Burij et Zharn., *Wasatchites orientalis* Spath, etc. with the conodonts *Neogondolella milleri* (Müller), *Neospathodus waageni* Sweet, *Smithodus discreta* (Müller), *Furnishius triserratus* Clark, *Hindeodella nevadensis* Müller, *Hadrodontina adunca* Staesche, *H. symmetrica* (Staesche), *Ellisonia triassica* Müller (sample 4031). Along the strike of the same packet in the Yakovlev Pad' near Bezymyannyi Spring, numerous *Neogondolella milleri* (Müller), *Smithodus discreta* (Müller), *S. longiusculus* (Buryi), *Furnishius triserratus* Clark, *Ellisonia triassica* Müller, *Parachirognathus symmetrica* (Staesche), *Hadrodontina subsymmetrica* (Müller), *Hindeodella budurovi* Buryi, *H. triassica* Müller, *H. nevadensis* Müller (sample 4032) occur together with ammonoids (*Dieneroceras shtempeli* Burij, *Owenites* cf. *egrediens* Welter, *Anaptychus similiconoideus* Korob. et Zharn.) and bivalve remains.

The most complete section of outer-shelf facies of the Tobizin Horizon occurs near Perevalnyi Spring at Kamenushka River head (Fig. 4d). Overlying the Induan 20 m thick siltstones, are put to the *Arctoceras tuberculatum* Zone, yielding *Furnishius triserratus* Clark, *Smithodus discreta* (Müller), *S. longiusculus* (Buryi), *Hadrodontina subsymmetrica* (Müller) and *Hindeodella triassica* Müller (sample 4034). The overlying 50 m thick siltstones put to the *Anasibirites nevolini* Zone yield in their lower part, in a lens of calcareous sandstone, *Anasibirites nevolini* Burij et Zharn., *Platyvillosus* aff. *gardenae* (Staesche), *Neogondolella milleri* (Müller), *Smithodus conservativa* (Müller), *Furnishius triserratus* Clark, *Ellisonia triassica* Müller, *Parachirognathus symmetrica* (Staesche), *Hadrodontina adunca* Staesche (sample 4033). In the upper part of this sequence numerous *Neogondolella milleri* (Müller), *Smithodus discreta* (Müller), *S. conservativa* (Müller), *Neospathodus cristagalli* (Huckriede), *Furnishius triserratus* Clark, *Ellisonia triassica* Müller, *E. meissneri* (Tatge), *E. magnidentata* (Tatge), *E. nevadensis* Müller, *Hindeodella triassica* Müller, *H. nevadensis* Müller, *H. raridenticulata* Müller, *H. budurovi* Buryi, *Parachirognathus symmetrica* (Staesche), *P. inclinata* Staesche, *Hadrodontina adunca* Staesche, *H. subsymmetrica* (Müller), *H. symmetrica* (Staesche), *Xaniognathus curvatus* Sweet were found within the lens of cephalopod coquina containing *Meekoceras subcristatum* Kipar., *M. boreale* Diener, *Proptychites robinsoni* Kipar., *Nannites sinuosus* Kipar (sample 4035).

2.3. Conodonts of the oceanic facies

In east Primorye (Dalnegorsk, Rudnaya River) conodonts from cherts of the Gorbusha Suite formerly referred to the Jurassic are most probably coeval to the Tobizin Horizon of South Primorye (Buryi, 1984, 1985, 1989; Burij et al., 1986). The siliceous deposits are interpreted as an oceanic facies of Triassic a proto-Pacific paleobasin.

The Gorbusha Suite is a terrane accreted to the Asia continental margin (Khanchuk et al., 1988) consisting of often repeated slices of Triassic cherts, Jurassic clay cherts and siltstones as well as Lower Cretaceous sandstone. The Gorbusha Suite along the banks of the Rudnaya River (Dalnegorsk) (Volokhin et al., 1989) (Fig. 5) consists in its lower part Upper Jurassic - Lower Berriasian? clays and sandstones separated from the upper part of the Gorbusha Suite by a dike of titanium-augite-plagioclase porphyrites, along a sinistral wrench-fault. In the centre of a near-rupture anticlinal fold, clays and olive-green cherts (layer 1.9 m thick) and red clay jasper with subordinate (from 1:3 to 1:20, average 1:10) layers and lenses of grey cherts beneath. The clay cherts and jaspers are 3-20 cm thick, cherts -0.5-2 cm, swelling up to 3 cm. The red rocks are characterized by thin discordant folding, due to a system of frequent gliding surfaces parallel to the axial surface of the anticline, showing almost vertical striation. Red clay jaspers of layer 1, 2.7 m thick (Table 6) yield *Neospathodus* sp. (sample P-168), *Smithodus* sp. juv. aff. *discreta* (Müller) (sample P-167) at the bottom as well as of the packet, *N.* cf. *waageni* Sweet (sample P-169), *N. homeri* (Bender), *N.* aff. *triangularis* (Bender) (sample P-166) above. From the middle part of the sequence *N.* aff. *triangularis* (Bender), *N.* aff. *homeri* (Bender) (sample P-164), *N. homeri* (Bender), *N. triangularis* (Bender), *Smithodus clarki* Buryi (samples P-240, P-239, P-242), were recovered, and in the upper part *N.* cf.*zaksi* Buryi, *Oncodella obuti* Buryi (sample P-170) occurred. The overlaying phtanitic unit contains Anisian conodonts (layer 2). The Early Olenekian conodonts assemblage found in the lower part is composed

Gorbusha											Suite
Olenekian											Stage
1									2		Number of bed
9									3		Thickness (m)
N. waageni			N. homeri								Conodont zone
168	167	169	166	164	240	239	242	170	163	162	Number of sample
1											Neospathodus sp.
	1										Smithodus sp. juv. aff. discreta
		1									Neospathodus cf. waageni
			4	2					2		N. aff. triangularis
			1		4	1	15				N. homeri
				1							N. aff. homeri
					8		4				N. triangularis
					10						Smithodus clarki
								1			Neospathodus cf. zaksi
								2			Oncodella obuti
										2	Neospathodus dieneri

Table 6. Stratigraphic distribution of conodonts in oceanic facies of Dalnegorsk region. Figures show the number of conodonts in a corresponding sample.

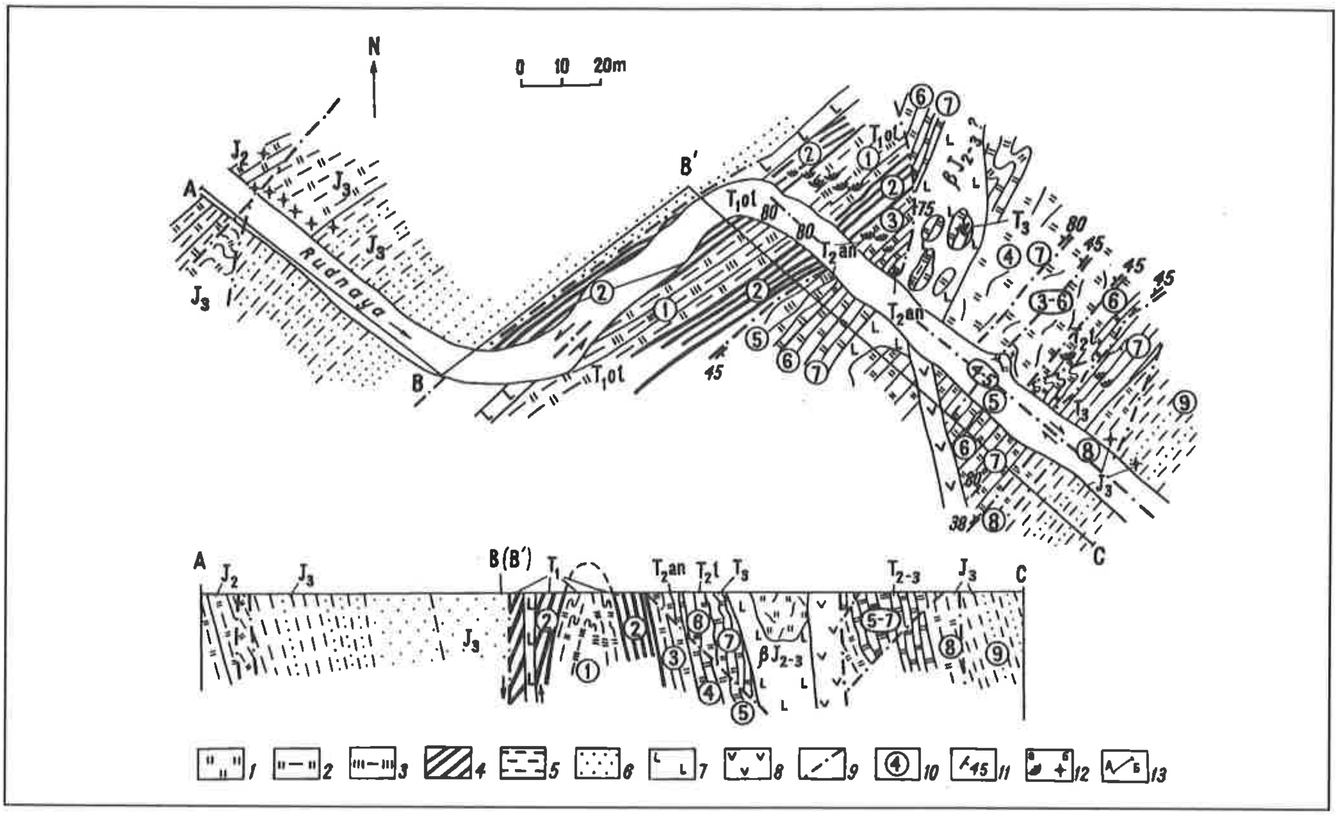


Fig. 5. Geological map and section of the terrane in Dalnegorsk (compiler Y. G. Volokhin). 1 - cherts. 2 - clay cherts. 3 - clay jaspers. 4 - phtanitic packet. 5 - siltstones. 6 - sandstones. 7 - basalts. 8 - andesites. 9 - tectonic fractures. 10 - number of layers. 11 - occurrences. 12 - microfauna: a - conodonts, b - radiolarians. 13 - section line.

of rare and very small specimens that are probably coeval with the lower Olenekian *Anasiberites nevolini* ammonite Zone of the Tobizin Horizon of South Primorye.

2.4. Early Olenekian conodont biofacies of Primorye

The Early Olenekian conodont assemblages of the Tobizin Horizon which differ by genus and species composition, are indicative for different conodont biofacies.

In the inner-shelf facies the *Parachirognathus* conodont biofacies prevail represented by 12 species of rare bar-like *Parachirognathus, Furnishius, Hadrodontina, Hindeodella* and other (Table 2, 3). Relatively abundant and characteristic of the whole Tobizin time are *Parachirognathus symmetrica, Hadrodontina symmetrica* and *Furnishius triserratus.* The *Arctoceras tuberculatum* Zone yields *Neospathodus pakistanensis, Hindeodella nevadensis, Chirodella dinodoides* and *Ellisonia magnidentata.* The *Anasibirites nevolini* Zone is characterized by *Enantiognathus ziegleri* and *Neospathodus sp.*

In the outer-shelf facies the *Neogondolella-Smithodus* biofacies prevails by the abundance of *Neogondolella milleri* (Müller), *Smithodus discreta* (Müller), *S. longiusculus* (Buryi), and *S. conservativa* (Müller). The rich conodont assemblage of this biofacies includes 25 species (Table 3, 4). Next to ellisoniids the genera *Neospathodus, Smithodus, Neogondolella* and *Platyvillosus* occurr.

Most abundant are *Furnishius triserratus* Clark (up to 170 specimens in a sample) and bar-like *Ellisonia triassica* Müller, *Hadrodontina subsymmetrica* (Müller), *Hindeodella nevadensis* Müller, *H. triassica* Müller. Rather abundant are *Neogondolella milleri* (Müller), *Smithodus discreta* (Müller), *S. longiusculus* (Buryi) occur throughout the Tobizin time.

At the time corresponding to the *Arctoceras tuberculatum* Zone, *Neospathodus dieneri* Sweet and *Chirodella dinodoides* (Tatge) appears, whereas *Smithodus conservativa* (Müller), *Neospathodus cristagalli* (Huckride), *N. waageni* Sweet, *Neogondolella milleri* (Müller), *Platyvillosus* aff. *gardinae* Staesche, *Hadrodontina adunca* Staesche, *Hindeodella raridenticulata* (Müller) characterize the *Anasibirites nevolini* Zone. The early Triassic coastal-shallow water inner-shelf facies of South Primorye is composed of the predominantly bar-like forms of the *Parachirognathus* biofacies. In this assemblage *Parachirognathus symmetrica* (Staesche), *Hadrodontina symmetrica* (Staesche), and *Furnishius triserratus* Clark are most characteristic. Isolated *Neospathodus* were found.

In the outer-shelf facies, the *Neogondolella-Smithodus* biofacies - *Neogondolella milleri* (Müller), *Smithodus discreta* (Müller), *S. longiusculus* (Buryi), *S. conservativa* (Müller) prevail over conodonts of the first biofacies.

In an earlier study of conodont paleoecology of the Tobizin Horizon, a *Neospathodus* biofacies, was proposed for the outer-shelf facies (Buryi, 1988). However, *Neospathodus discreta* (Müller), *N. conservativa* (Müller) and *N. longiusculus* Buryi, which are as abundant in this biofacies as *Neogondolella milleri* (Müller) are now referred to the genus *Smithodus* (Budurov et al., 1988), which demands the second biofacies to be renamed *Neogondolella-Smithodus*.

Bar-like conodonts of the more coastal inner-shelf biofacies co-exist within the fauna of the more deep-sea environment of the outer-shelf biofacies. But only rare isolated conodonts of the outer-shelf biofacies were found in the more coastal environments. Such factors as shallow basin, proximity to the tidal zone, and high water energy seemed to be an ecological barrier to the setting of most conodonts. Higher diversify of genera and species are seen in the second biofacies. This testifies to that normal-sea environments of the lower sublitoral zone were optimal to them. Only few inner-shelf species of bar-like conodonts, that could live in more extreme coastal environments of the upper sublitoral zone are found in the outer-shelf biofacies, their morphology being changed adaptively. For example, *Hadrodontina subsymmetrica* (Müller) of the outer-shelf facies are small with long and thin teeth and rudimentary processes and denticles. In the inner-shelf facies these conodonts are larger and more massive, the main tooth is shorter, frontal and posterior processes and denticles on them are thicker, and basal attaching area is larger (Buryi, 1979).

The third Early Triassic (*Smithodus-Neospathodus*) biofacies that defines the oceanic basin facies is poorly represented in the Tobizin Horizon. However, conodonts defining the oceanic facies are more abundant within the Upper Olenekian (upper part of layer I and lower part of layer 2) at Dalnegorsk are remarkably only very small blade-like conodonts of *Smithodus* and *Neospathodus*. Bar-like conodonts also occur, but due to their extreme fragility and small sizes they were practically not preserved. Not a single specimen of platform conodonts was found in this biofacies. One may suppose that only very small conodonts represented by blade-like and bar-like elements could occur in the pelagic environments of the third biofacies.

3. Conclusions

1. In Early Olenekian (Tobizinian) time, there were a shallow inner-shelf facies (Russian Island) and a deeper outer-shelf facies (recent coast of Ussuri Gulf, Artemovka and Kamenushka River systems) in South Primorye.
2. Coeval cherts of Taucha terrane in the Dalnegorsk area belonged most likely to the oceanic facies.
3. Inner-shelf facies is characterized by the impoverished conodont assemblage - *Parachirognathus* biofacies. Abundant and very divers conodont assemblage - *Neogondolella-Smithodus* - was recognized in the outer-shelf facies. The third biofacies *Smithodus-Neospathodus* represented by solely blade-like and poorly-preserved bar-like elements characterising the oceanic basin facies.

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Plate I

Conodonts of the inner-shelf facies of South Primorye

Fig. 1, 2, 3, 4. *Parachirognathus symmetrica* (Staesche): 1, 2 -461/51,N 4016; x 50, outer and inner lateral views; Russian Island, location between the Tobizin Cape and Chernyshev Bay, Olenekian, *Anasibirites nevolini* Zone, 3,4 - 461/52, N 4016; x 50, outer and inner lateral sides, the same location.

Fig. 5, 6, 7, 8. *Hadrodontina symmetrica* (Staesche): 5, 6 - 461/38, N 4016; x 50, outer and inner lateral sides; Russian Island, the same location. 7, 8 - 461/40, N 4016, x 50, outer and inner lateral sides, the same location.

Fig. 9. *Neospathodus pakistanensis* Sweet. 461/19, N 4037; x 50, lateral side; Russian Island, location between the Tobizin Cape and Chernyshev Bay. Induan, uppermost beds of the *Gyronites subdharmus* Zone.

Fig. 10. *Furnishius triserratus* Clark. 461/150, N 4047, x 60, lateral side; Russian Island location between Ayax and Paris Bays; Olenekian, *Arctoceras tuberculatum* Zone.

Fig. 11. *Hindeodella raridenticulata* Müller. 461/47, N 4021;x 50, lateral side; Russian Island, location between Ayax and Paris Bays; Olenekian, *Anasibirites nevolini* Zone.

Fig. 12. *Hadrodontina adunca* Staesche. 461/101, N 4022; x 50, outer lateral side; Russian Island location between Ayax and Paris Bays; Olenekian, *Arctoceras tuberculatum* Zone. Conodonts of the outer-shelf facies of South Primorye.

Fig. 13, 14, 15, 16, 17. *Neogondolella milleri* (Müller): 13, 14, 15 - 461/13, N 4031; x 50, upper and lower and lateral views. Artemovka River; Olenekian, *Anasibirites nevolini* Zone 16, 17 - 461/12, N 4031; x 50, upper and lower views; the same location.

Fig. 18. *Smithodus conservativa* (Müller). 461/18, N 4035; x 30, lateral view; Kamenushka River; Olenekian, *Anasibirites nevolini* Zone.

Fig. 19, 20, 21, 22. *Smithodus discreta* (Müller): 19-461/25, N 4035; x 50, lateral view; Artemovka River; Olenekian, *Anasibirites nevolini* Zone. 20 - 461/26, N 4035, x 50, lateral view; the same localition. 21 - 461/27, N 4035, x 50, lateral view; the same location. 22 - 461/28, N 4035; x 50, lateral view; the same location.

Fig. 23. *Hindeodella nevadensis* Müller. 461/62, N 4032; x 50, lateral view; Artemovka River, Olenekian, *Anasibirites nevolini* Zone.

Plate II

Conodonts of the outer-shelf facies of South Primorye:

Fig. 1, 2. *Smithodus longiusculus* Buryi, holotype: 1-461/69, N 4034; x 70, 2 - x 150; lateral view; Kamenushka River; Olenekian *Anasibirites nevolini* Zone.

Fig. 3. *Neospathodus zharnikovae* Buryi, holotype 461/73, N 4032; x 150, lower view; Artemovka River; Olenekian *Anasibirites nevolini* Zone.

Conodonts of the oceanic facies of the Dalnegorsk region (Taukha terrane):

Fig. 4. *Smithodus clarki* Buryi 2B/24, N P-240, juvenile form x 380, lateral view; Rudnaya River; Olenekian.

Fig. 5. *Cratognathodus* sp. 2B/22, N P-170, x 400, lateral view x 400; Rudnaya River; Olenekian.

Fig. 6. *Neospathodus* cf. triangularis (Bender). 2B/14, N P-240, x 500, lateral view; Rudnaya River; Olenekian.

Fig. 7. *Neospathodus* cf. waageni Sweet. 2B/13, N P-169, x 400, lateral view; Rudnaya River; Olenekian.

Fig. 8. *Neospathodus* sp. 2B/42, N P-168, x 400, lateral view; Rudnaya River; Olenekian.

Fig. 9. *Neospathodus dieneri* Sweet. 2B/12, N P-162, x 160, lateral view; Rudnaya River, Olenekian.

Fig. 10. *Oncodella obuti* Buryi. 2B/21, N P-170, x 400, lateral view, Rudnaya River.

Plate I

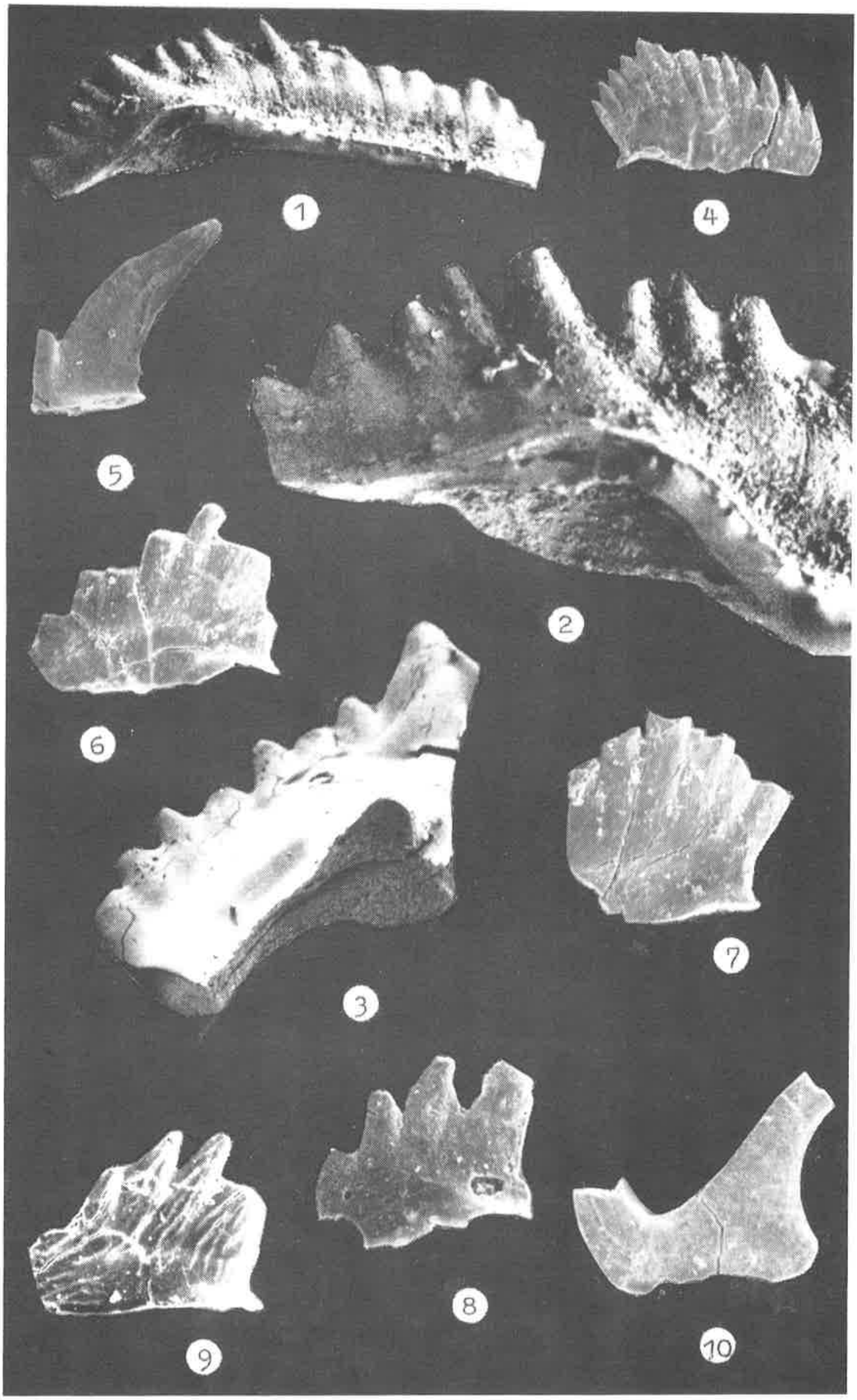
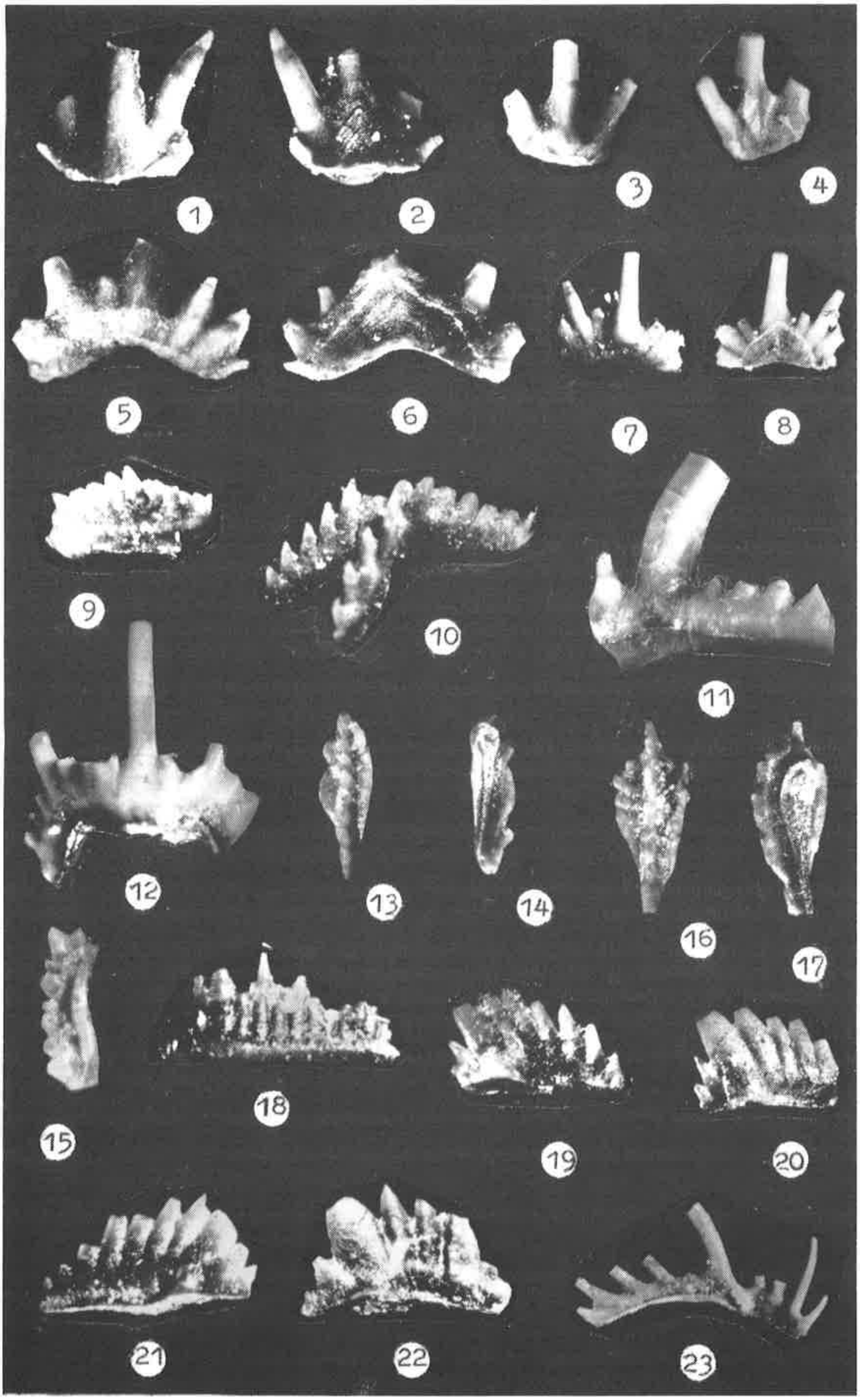


Plate II



TRIASSIC CONODONT BIOSTRATIGRAPHY OF THE SIKHOTE-ALIN

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Abstract

Over 700 samples were collected from complete series of biogenic limestones and cherts of the Rudnaya River basin (Dalnegorsk region), the Ussuri River right bank sections (Chuguevka region), as well as from the sections in the Gur, and Bikin River basins, and 343 samples yielded conodonts. More than one thousand conodont elements were identifid. Conodonts from the Dalnegorsk region provide the basis for the biostratigraphic zonation of the Triassic of the Sikhote-Alin. Twelve conodont zones were distinguished, and represent the Olenekian to Rhaetian interval (1 - *Neospathodus waageni,* 2 - *N. homeri* - Olenekian; 3 - *N. timorensis* - Aegean, Bithynian and Lower Pelsonian; 4 - *N. kockeli* - Upper Pelsonian; 5 - *Paragondolella excelsa* - Illyrian, Fassanian and Lower Langobardian; 6 - *P. foliata* - Upper Langobardian; 7 - *P. polygnathiformis* - Cordevolian, Julian and Lower Tuvalian; 8 - *Metapolygnathus nodosus* - Middle and Upper Tuvalian; 9 - *Epigondolella abneptis* - Lacian; 10 - *E. postera* - Alaunian; 11 - *E. bidentata* - Sevatian; 12 - *Misikella posthernsteini* - Rhaetian). Strong analogy to the Zones observed in Nevada, Pakistan, Poland, Austria, Yugoslavia, and Bulgaria exists. The zone's limits were defined according to the first occurrence of species replacing successively each other in the line *Neospathodus - Paragondolella - Metapolygnathus - Epigondolella - Misikella.* The reconstructed section of Sikhote-Alin may represent one of the most complete Triassic conodont sequences worldwide. The Triassic conodont fauna of Sikhote-Alin are similar to the conodont assemblages of Japan.

1. Introduction

Sikhote-Alin is an area of folding, dislocations with a break in continuity, and block tectonics. It is characterized by lithological diversity of the rocks.

The Triassic predominantly thick terrigeneous, cherty-terrigeneous and terrigeneous-carbonaceous-cherty deposits with thick reef buildups yield the bivalve molluscs (*Eumonotis scutiformis* Kipar. and other) in sandstones and silstones, and foraminifers, bryozoans, corals, gastropods, and algae in limestones.

From these organic remains, the age of the deposits was determined as Lower, Middle, and Upper Triassic (Burij, 1973). Cherty and volcanogenic-cherty rocks, developed on the large area of the Sikhote-Alin, seemed to be almost devoid of organic remains, except microfauna.

For a long time, these rocks were considered Paleozoic, however in 1938, V.P. Miknovich concluded that a part of cherty series of Sikhote-Alin might be Mesozoic, and Triassic as well. A.I. Zhamoida (1972), in his study of Mesozoic radiolarians of the Far East, suggested a restricted distribution of Triassic chert series in the Sikhote-Alin-Rudnaya, Zerkalnaya, Dalnyaya, Anyuj, Dzhaur, and Khor River basins. He attributed the radiolarians in the these cherty deposits to the Upper Triassic.

The first findings of Triassic conodonts in 1971 showed their common occurrence in both limestones and cherts of Sikhote-Alin (Zharnikova and Buryi, 1973; Buryi, 1984, 1985).

In 1978-1988, the author dated many cherty and volcanogenic - cherty sequences of the Sikhote-Alin as Triassic with the aid of conodonts. They were recognized in the Dalnegorsk and Chuguevka regions (Rudnaya and Ussuri Rivers) in Primorye and in the South Khabarovsk territory (Gur, Dzhaur, and Bikin Rivers). Before, these sediments were believed to be Paleozoic, (Malyanovka, Samarka, and Sebuchar Suites) and Jurassic (Gorbusha Suite). Triassic rocks are represented by cherts, volcanogenic-siliceous sediments, phtanite, and biogenic, including reef, limestones.

The stratigraphy of the biogenic limestones, as well as the fossils (bivalves and corals) of the Dalnegorsk region were studied by L.D. Kiparisova (1972), I.V. Burij and N.K. Zharnikova (1981, 1987), E.V. Krasnov et al., (1975) and T.A. Punina (1989). Triassic conodonts and radiolarians were investigated by S.V. Rybalka (1987), A.A. Dagys and al. (1984), N.Y. Bragin (1991), M.V. Pyatakova, V.S. Rudenko as well as by L.M. Oleinik. Lithology of cherts and geology of the Sikhote-Alin were studied by V.A. Krassilov and V.P. Parnjakov (1984), Y.G. Volokhin (1985), A.N. Filippov (1985), A.I. Khanchuk (1992) and others.

These studies showed that the Triassic deposits of the Sikhote-Alin belong to different terranes (Fig. 1) (Khanchuk, 1992). The present paper describes the biostratigraphic and evolutionary relationships of Triassic conodont fauna of the Sikhote-Alin.

This paper is based on the materials of my monograph (in Russian) «Triassic Conodonts and Stratigraphy of Sikhote-Alin» (Buryi, 1989).

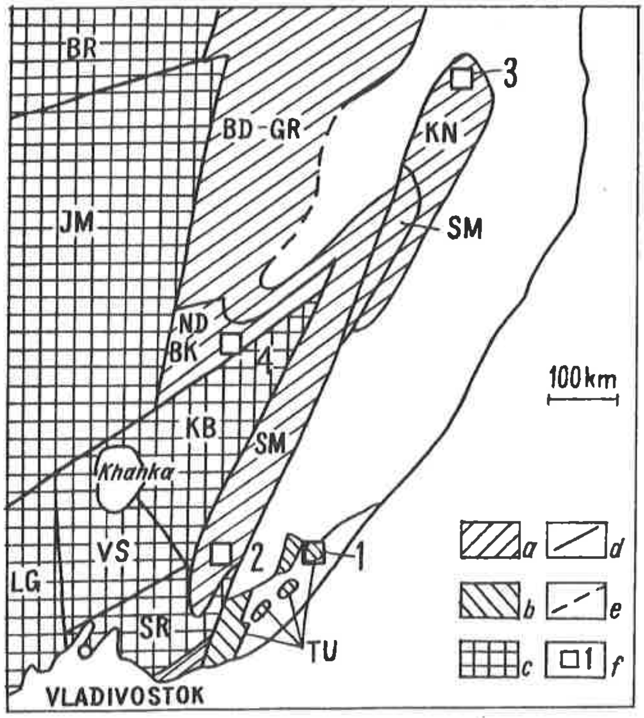

Fig. 1. A scheme of the location of the Triassic rock blocks in Sikhote-Alin (the major tectonostratigraphic terranes of Sikhote-Alin redrawn from A.I. Khanchuk, 1992).
BR - Burea terrane Jm - Jiamusi terrane, BD - GR - Badzhal - Gorinsky terrane, ND - BK - Nadankhada - Bikin terrane, KN - Khungary terrane, Sm - Samarka terrane, KB - Kabarga terrane, LG - Laoelin - Grodekovo terrane, VS - Voznesenka terrane, SR - Sergeevka terrane, TU -Taukha terrane.
The age of the matrix: a - Middle Jurassic - Early Cretaceous (Berriasian), b - Early Cretaceous, c - Permian - Triassic.
1 - Dalnegorsk region, 2 - Chuguevka region, 3 - Gur River basin, 4 - Bikin River basin.

2. Stratigraphy

2.1. Taukha terrane (Dalnegorsk region)

Conodonts were found in cherts and biogenic limestones of the Taukha terrane (Dalnegorsk region) (Fig. 1).

The Taukha terrane is an Early Cretaceous accretionary wedge (Khanchuk, 1992) consisting of turbidites and olistostrome dated by macrofossils and plant remains as Valanginian to Barremian with allochthonous enclosures of Triassic pelagic cherts and large blocks of reef limestones - fragments of paleoguyot caps.

The large (up to 500 m thick) massifs of biogenic limestones - Sakharnaya Golova, Bolnichny, Kamennye Vorota, Partizansky, Verkhny are located in the middle course of the Rudnaya River (Fig. 2). In limestones of these reef massifs similar conodont associations were found (Tables 1-3). In the lowermost parts of the limestones, Early Carnian *Paragondolella* cf. *polygnathiformis* (Budurov et Stefanov) (Bolnichny reef massif), Late Carnian *Metapolygnathus nodosus* (Hayashi), *M. vialovi* (Buryi) (Verkhny reef massif), and *M. primitia* Mosher (Sakharnaya Golova) occur. Above, Early Norian (Lacian) *Epigondolells abneptis* (Huckriede), *Paragondolella hallstatensis* Mossier (Sakharnaya Golova, Verkhny), *Ancyrogondolella triangularis* Budurov, *M. linguiformis* Hayashi (Kamennye Vorota) were found, and in the Alaunian *Epigondolella postera* (Kozur et Mostler), *E. multidentata* Mosher and *P. steinbergensis* Mosher are present. In the uppermost part of the massifs Late Norian (Sevatian), *E. bidentata* Mosher and *P. steinbergensis* Mosher were found

In cherts of the Rudnaya River rock scarps, conodonts ranging from Olenekian *Neospathodus* cf. *waageni* Sweet to Anisian, *Neospathodus kockeli* (Tatge) were found

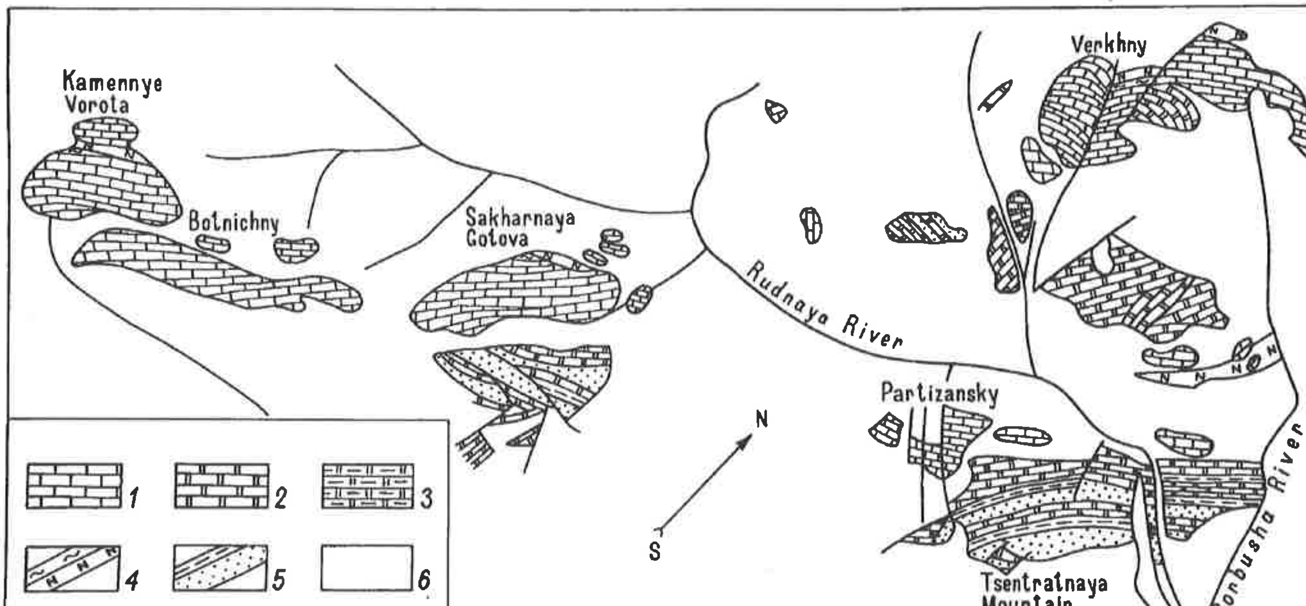

Fig. 2. The scheme of the location of biogenic limestone massifs (1,4) and plates of Gorbusha Suite rocks (2, 3, 5) in Dalnegorsk region. 1 - Triassic biogenic limestones, 2 - Triassic cherts, 3 - Triassic and Jurassic clay cherts, 4 - Triassic basaltoids and silty marls, 5 - Jurassic siltstones and Early Cretaceous sandstones, 6 - Early Cretaceous coarse - fragmental and predominantly Cretaceous volcanogene and terrigeneous deposits.

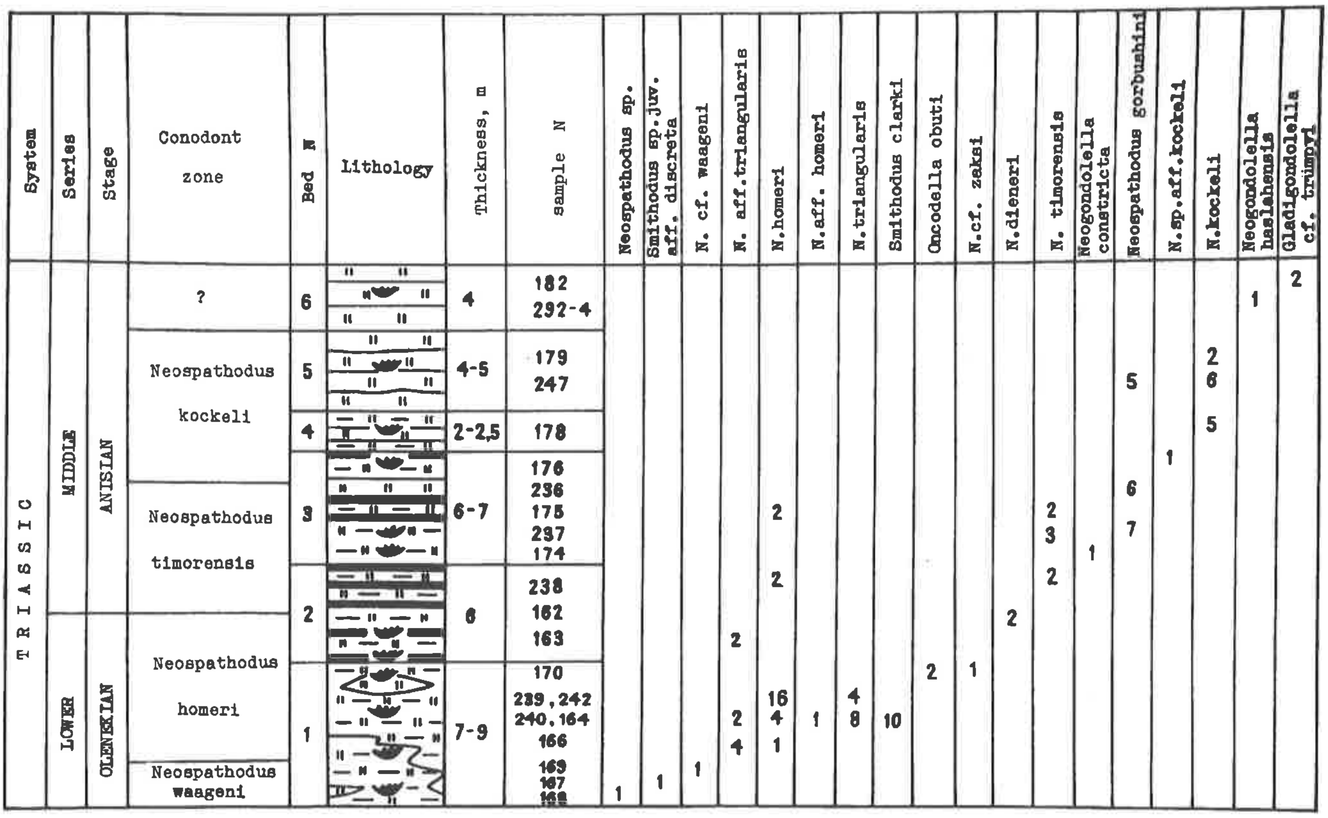

Fig. 3. Stratigraphic distribution of conodonts in Triassic cherts of right and left banks of the Rudnaya River in Dalnegorsk Town (Taukha terrane). Figures show the number of conodonts in a corresponding sample (designation as in Fig. 2).

(Fig. 3). Conodonts with a range-chart from Anisian *Neospathodus kockeli* (Tatge) to Rhaetian *Misikella posthernsteini* Kozur et Mock were found in cherts of the Tsentralnaya Mountain quarry (Fig. 4).

Common conodont species of both limestones and cherts suggest a common paleoceanic association existed, before accretion to the Asian continental margin. In this basin, cherts accumulated, since Olenekian time to which, volcanic activity was added since Middle Triassic. Triassic reef massifs are determined as a paleoguyot «caps».

2.2. The Samarka terrane (Chuguevka region)

The Samarka terrane consists of a Middle-Late Jurassic and locally Late Jurassic - Early Cretaceous subduction-accretionary wedge. Its turbidite-olistostrome matrix includes allochthonous Middle to Late Triassic cherts (Khanchuk, 1992).

In 1989 Y.G. Volokhin together with the author, A.N. Filippov and V.S. Rudenko (Volokhin et al., 1990) restored the section of the Middle and Upper Triassic cherts of the Ussuri River basin in 2 localities: 1) north - east outskirts of Uborka, 2) along the road Uborka - Koksharovka (Ogorodnaya River mouth) (Buryi, 1989, Fig. 8-10).

Along the right bank of the Ussuri River (Fig. 5) a 66-72 m thick Anisian - Rhaetian cherty series yield Anisian *Neospathodus kockeli* (Tatge), Ladinian *Paragondolella excelsa* Mossier, *Neogondolella haslachensis* (Tatge), Early Carnian *Paragondolella polygnathiformis* (Budurov, Stefanov), Upper Carnian - Early Norian *Metapolygnathus vialovi* Buryi and *Epigondolella abneptis* (Huckriede), Middle-Late Norian *Epigondolella multidentata* Mosher and Late Carnian-Norian radiolarian *Napora robusta*. In the upper part of the section, Upper Norian, *Misikella hernsteini* (Mosher) and Rhaetian *M. posthernsteini* Kozur et Mock are present, accompanied by Late Triassic *Spongosaturnalis quadriradiatus* and Late Norian - Early Jurassic *Siringocapsa* sp.

2.3. Khungary terrane (accretionary wedge)

The Khungary terrane is located in the north of Sikhote-Alin (Fig. 1). The stratotype section of Triassic deposits of the Khungary terrane occurs on the right slope of the Gur River, below the - Dyukali Creek near the Kakdyamu Rocks (Buryi, 1989, Fig. 11, 13). This carbonaceous - cherty section was investigated in 1987 by Y.G. Volokhin together with A.N. Filippov, E.V. Mikhailik, and the author (Volokhin et al., 1987).

The section is composed of a single 385-425 m thick macrocyclite gradually connecting four series of platy cherts and three essentially carbonaceous series.

In the lower cherty series (52-71 m) (Fig. 6), Late Anisian - Early Ladinian *Neogondolella constricta* (Mosher, Clark), Ladinian - Early Carnian *Gladigondolella* cf. *tethydis* (Huckriede), Late Ladinian *Paragondolella foliata* Budurov, *Sephardiella* cf. *mungoensis* (Diebel) were found successively. In the second series of the section (limestone 7-8.5 m thick), conodonts were not found. In the third series (cherty, 75 m thick) Early Carnian *Paragondolella polygnathiformis* (Budurov, Stefanov) were present. The fourth series is composed of limestones with interbeds, lenses, and nodules of cherts 78 m thick. The lower limestones of the fourth series yield Upper Carnian

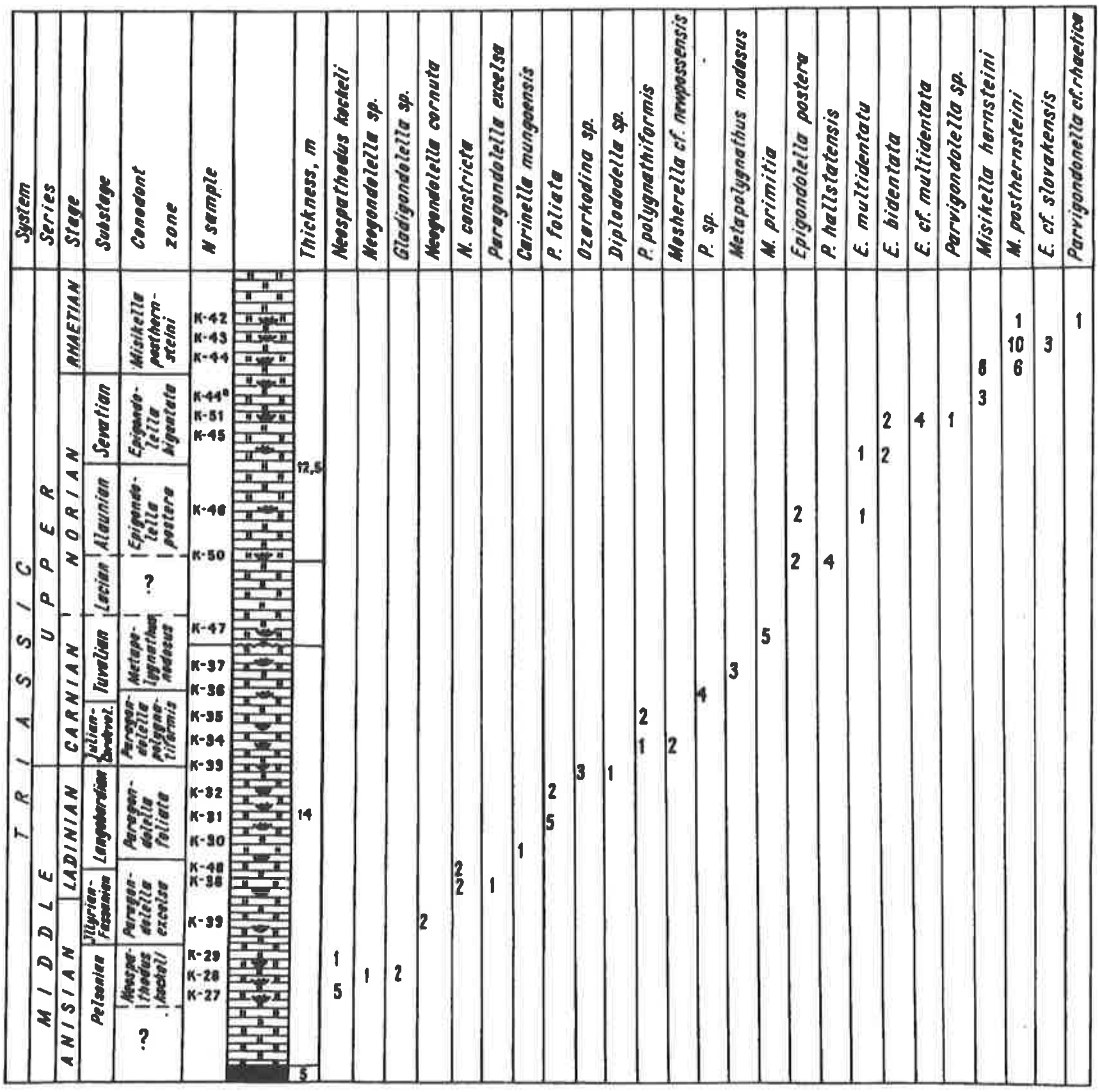

Fig. 4. Stratigraphic distribution of conodonts in Triassic cherts of the Tsentralnaya Mountain quarry in Dalnegorsk Town (Taukha terrane). Figures show the number of conodonts in a corresponding sample (designation as in Fig. 2).

Metapolygnathus vialovi Buryi, *M. nodosus* Hayashi and *M.* aff. *permicus* (Hayashi). In limestones of the upper part, Early Norian *Epigondolella abneptis* (Huckriede) were found. In the fifth series of 20-25 m thick lens-like bedded cherts conodonts were not found. In the sixth series, composed of limestones with interbeds, lenses, and nodules of cherts 102-113 m thick, *Metapolygnathus vialovi* Buryi and *M. spatulatus* (Hayashi) juv.form were observed in the lower part, and above, Early Norian *Paragondolella hallstatensis* Mosher and *Epigondolella abneptis* (Huckriede) occur. In the upper layers of the sixth series, apparently Middle Norian *Epigondolella* aff. *postera* (Kozur et Mostler) was found. In the seventh series of the platy cherts completed the section, strongly modified conodonts, possibly, of the genus *Epigondolella*, were found.

2.4. Nadankhada - Bikin terrane

This terrane is similar to the Samarka one. Triassic deposits are represented by individual blocks, predominantly bedded cherts and sometimes cherts in association with micritic limestone.

In 1985, A.N. Filippov (1985) studied the Bikin member of the terrane, in 200 km wide belt extending from the Strelnikov Ridge in the south-west to the right bank of the Khor River middle course in the north-east. In 20 localities cherts contained conodonts ranging from Early Triassic *Neospathodus* cf. *homeri* Sweet, *N. zharnikovae* Buryi, *Hindeodella* sp. (Lesnaya River right bank), to Anisian *Neogondolella pridaensis* Nikora, Kozur et Mostler, *N. constricta* (Mosher et Clark) and *Neospathodus kockeli* (Tatge) (left bank of the Kamenushka Creek). In cherts on the right bank of the Mokhovoi Creek, near the inflow of the Ulitka River, Anisian - Ladinian *Neogondolella cornuta* Budurov et Stefanov and *Paragondolella* cf. *excelsa* (Mosher.) occur. In the quarry on the north outskirts of Bikin and on the watershed of the Pryamaya and Birushka River valley Early Carnian *Epigondolella* cf. *tadpole* Hayashi and *Paragondolella* cf. *polygnathiformis* (Budurov et Stefanov) were found. In lens-like limestone interlayer, within the chert block located between the Pravaya Predgorka River and the Ludannyi Creek, Late Carnian -

Sample N°	Conodonts: *Metapolygnathus primitia*	*Paragondolella hallstattensis*	*Epigondolella abneptis*	*Paragondolella steinbergensis*	*Epigondolella postera*	*Epigondolella multidentata*	*Epigondolella bidentata*	Conodont zone	Substage	Stage
99/43	—	—	—	—	—	—	2	*Epigondolella bidentata*	Sevatian	Norian
99/78	—	—	—	—	1	—	1			
99/79	—	—	—	4	—	—	—	*Epigondolella postera*	Alaunian	
99/80[a]	—	—	—	3	1	—	—			
99/39	—	—	—	—	6	—	—			
99/38	—	—	—	—	2	4	—			
99/44	—	—	—	—	—	5	—			
99/68	—	—	—	—	4	—	—			
220	—	—	—	—	9	—	—			
224	—	—	—	—	17	9	—			
16	—	—	—	—	30	—	—			
15, 67	—	—	—	—	100	—	—			
13, 32	—	—	—	—	30	—	—			
12	—	—	—	8	30	—	—			
11	—	—	—	7	17	—	—			
10	—	—	—	—	12	—	—			
3	—	—	—	—	—	—	—	*Epigondolella abneptis*	Lacian	
29	—	—	1	—	—	—	—			
99/36	3	2	—	—	—	—	—			
99/87	100*	—	—	—	—	—	—	*Metapolygnathus nodosus*	Upper-Tuvalian	Carnian

Table 1. Stratigraphic distribution of conodonts in the reef massif Sakharnaya Golova.
* Figures show the number of conodonts in a corresponding sample.

Early Norian *Epigondolella abneptis* (Huckriede) were found. In the Mokhovoi Creek head, Late Norian *Misikella hernsteini* (Mostler) were found in cherts of Nadankhada - Bikin terrane. According to A. N. Filippov data the reconstructed thickness of such a composite section reaches 400 m.

3. Conodont Zonation

The Sikhote-Alin fauna yield 30 species of Triassic platform and blade - like conodonts belonging to 9 genera. Bar-like conodonts, juvenile forms and badly preserved specimens, were not described monographically.

The stratigraphic distribution of the Sikhote-Alin conodonts ascertains the existence of a continuous sequence of Olenekian to Late Rhaetian (Fig. 7). The most complete sequence (12 conodont zones) is observed in the Triassic sediments of the Taukha terrane (Dalnegorsk region). All the conodont zones were distinguished in deep-sea facies - cherts of Dalnegorsk region, however, zones 8 to 10 are better characterized by the conodonts from the limestones of paleoguyots. It was the base for the biostratigraphic division of Sikhote-Alin. These zones are also found in cherty outcrops in the Chuguevka region on the Ussuri River right bank (Samarka terrane) and in the cherty and carbonaceous - cherty sequences in the Gur, and Bikin River basins (Khungary and Nadankhada - Bikin terranes). The Zones were determined according to the first occurrence of species replacing successively each other in the lineage of *Neospathodus - Paragondolella - Metapolygnathus - Epigondolella - Misikella.*

3.1. Olenekian Stage

(1) Neospathodus waageni Zone

The oldest Sikhote-Alin conodonts occurred in red clay jaspers with subordinate layers and lenses of grey cherts 2.7 m thick (lower part of layer 1) along the Rudnaya River in Dalnegorsk (Taukha terrane). The assemblage includes *Neospathodus* sp. (sample P-168), *Smithodus* sp. juv. aff. *discreta* (sample P-167), *N.* cf. *waageni* (sample P-169), similar to conodonts of the 4th complex of South Primorye (Buryi, 1979), defining the lower part of the Olenekian.

(2) Neospathodus homeri Zone

The Zone was established in the same section. The lower boundary of the Zone fixed by the disappearance of *N.* cf. *waageni* and appearance of *N. homeri* in the continuation of layer 1 represented by clay olive-green cherts 6.3 m thick with *N. homeri, N.* aff. *homeri, N. triangularis, N.* aff. *triangularis* and *Smithodus clarki* (samples P-166, P-164, P-240, P-239, P-242), *N.* cf. *zaksi, Oncodella obuti* (sample P-170). Phtanite packet (lower part of layer 2): clay cherts with interlayers of light-grey greenish cherts and black and clay phtanites 3 m thick with *N.* cf. *triangularis* (sample P-163) and *N. dieneri* (sample P-162). The total thickness of the deposits in the Zone is 9.3 m. *Neospathodus* cf. *homeri, N. zharnikovae* and *Hindeodella* sp. were also found in the Bikin River basin (Nadankhada - Bikin terrane). This assemblage define the upper part of the Olenekian.

3.2. Anisian Stage

(3) Neospathodus timorensis Zone

The conodont Zone of *Neospathodus timorensis* occurs in cherts along the Rudnaya River. The lower boundary of the Zone is fixed by the appearance of *N. timorensis* in the upper 3 m of layer 2 of the phtanite packet together with *N. homeri* (sample P-238) and in layer 3 represented by clay cherts with *Neogondolella constricta* (sample P-174), *N. timorensis, N. gorbushini* (sample P - 237), *N. homeri* and *N. timorensis* (sample P-175), *N. gorbushini* (sample P-236). The total thickness of the Zone is 10 m. This zone defines the Aegean and Bithynian and lower Pelsonian.

(4) Neospathodus kockeli Zone

The Zone occur in cherts along the Rudnaya River. The lower boundary of the Zone coincides with the appearance of *N.* sp. aff. *kockeli* (sample P-176, layer 3 and first *N. kockeli* in the bottom of layer 4 (sample P-178). The volume of the Zone defined by the stratigraphic interval of the species-index distribution samples P-176, P-178, P-247, P-179). Together with it in the type section *N. gorbushini* were found, and in Tsentralnaya Mountain *Gladigondolella* sp. and *Neogondolella* sp. were found (sample K-27, K-28,

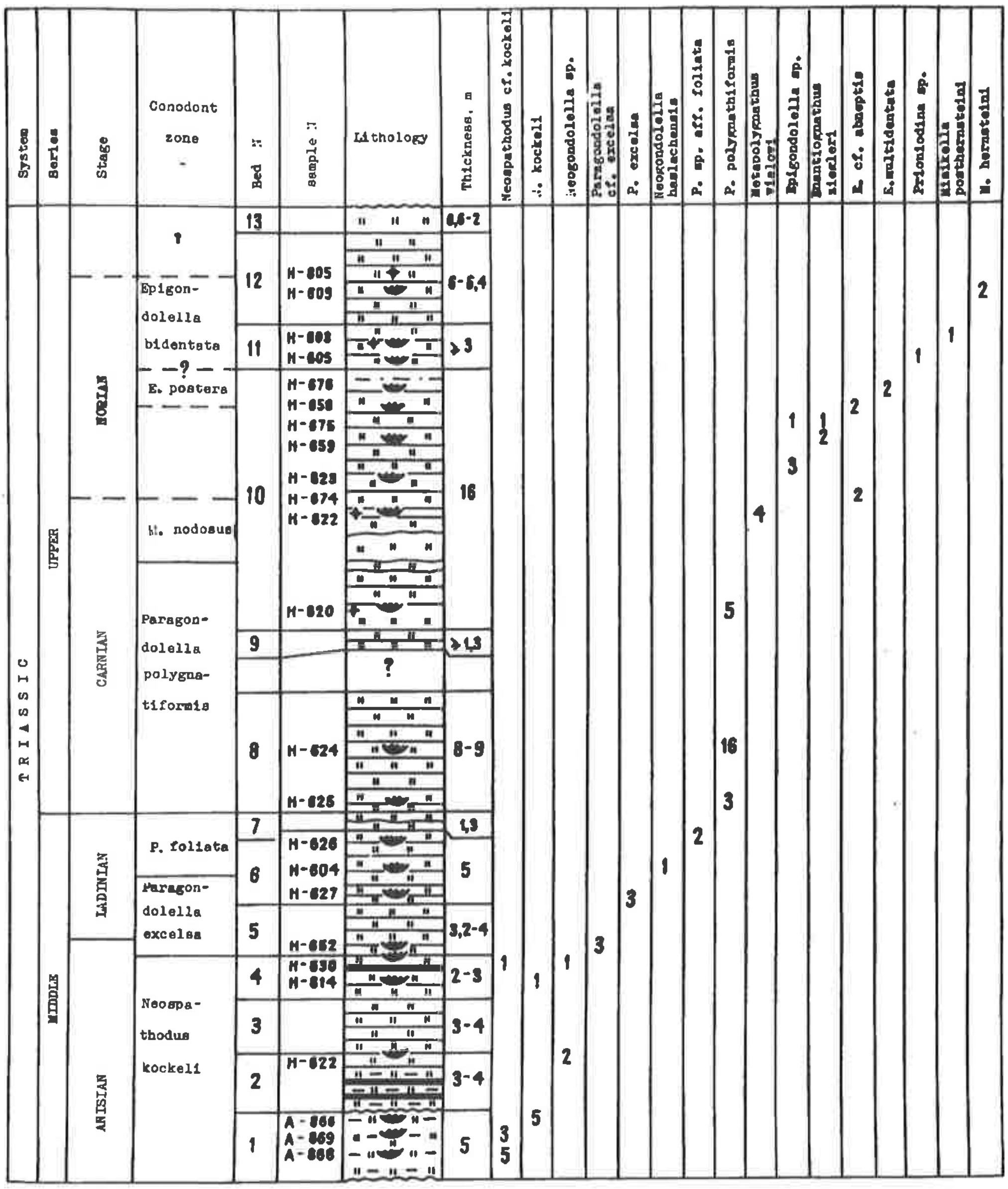

Fig. 5. Stratigraphic distribution of conodonts in Triassic cherts of the Ussuri River right bank (Chuguevka region, Samarka terrane). Figures show the number of conodonts in a corresponding sample (designation as in Fig. 2).

K-29). The deposits of the Zone are common in the Sikhote-Alin. They occur in Samarka terrane in the Ussuri River basin (layer 1, sample A-866, layer 4, sample H-814) and in Nadankhada-Bikin terrane in the Bikin River basin. This assemblage defines the Upper Pelsonian.

(5) Paragondolella excelsa Zone

The Zone occurs in cherts of Tsentralnaya Mountain (Fig. 4). The lower boundary of the Zone is fixed by the change of layers with *Neospathodus kockeli* (sample K-29) for cherts with *Neogondolella cornuta* (samle K-39). Above, *Paragondolella excelsa* and *Neogondolella constricta* were found (samples K-38, K-48). The thickness of the Zone is about 3 m. This Zone is observed also in Samarka terrane in the Ussuri River basin (layers 5 and 6, lower part samples H-652, H-627), and in Khungary terrane in the Gur River basin (layer 1, sample D-209). It defines the Illyrian, Fassanian and lower Langobardian.

3.3. Ladinian

(6) Paragondolella foliata Zone

In cherts, outcropped in the Tsentralnaya Mountain quarry, above the *Paragondolella excelsa* Zone, the*Sephardiella mungoensis* (sample K-30) and *Paragondolella foliata* (samples K-31, K-32) were found. The thickness of the Zone is 3.2 m. In the Khungary terrane, the layers with *Paragondolella foliata, Gladigondolella* cf. *tethydis* (sample D-217), *Sephardiella* cf. *mungoensis* and *P. foliata* (sample D-219, layers 3, 4) correspond to the stratigraphic interval of this Zone. *Sephardiella mungoensis* occurs also in the lower layers of Verkhny reef massif in the Dalnegorsk region. The conodont assemblage of the *Paragondolella foliata* Zone includes also *P.* sp.*foliata* and *Neogondolella haslachensis* (sample H-604, H-626, upper part of layer 6) from cherts of the Ussuri River basin. This Zone characterizes the Upper Langobardian.

Sample N°	Conodonts								Conodont zone	Substage	Stage
	Metapolygnathus nodosus	*Metapolygnathus primitia*	*Metapolygnathus vialovi*	*Epigondolella abneptis*	*Epigondolella postera*	*Paragondolella sp. indet*	*Paragondolella steinbergensis*	*Epigondolella bidentata*			
36							1	1	*Epigondolella bidentata*	Sevatian	Norian
159							2				
31					2	1					
30					6				*Epigondolella postera*	Alaunian	
32					1						
38				2					*Epigondolella abneptis*	Lacian	
39				2							
40				9							
17				5							
16				10							
28				6							
15				2							
10				3							
11			3						*Metapolygnathus nodosus*	Upper-Tuvalian	Carnian
20			2								
25		4									
104	3 *										
24	3										
102	1										
101	5										

Table 2. Stratigraphic distribution of conodonts in the reef massif Verkhny (Borehole 2400).
* Figures show the number of conodonts in a corresponding sample.

Sample N°	Conodonts							Conodont zone	Substage	Stage
	Metapolygnathus primitia	*Epigondolella abneptis*	*Ancyrogondolella triangularis*	*Metapolygnathus linguiformis*	*Epigondolella sp. aff. postera*	*Epigondolella multidentata*	*Epigondolella bidentata*			
99/185							1	*Epigondolella postera*	Alaunian	Norian
99/184	3	6		1	1	1		*Epigondolella abneptis*	Lacian	
99/183 a						8				
99/183			2							
99/181		10								
99/181	1							*Metapolygnathus nodosus*	Tuvalian	Carnian

Table 3. Stratigraphic distribution of conodonts in the reef massif Kamennye Vorota.
* Figures show the number of conodonts in a corresponding sample.

3.4. Carnian

(7) Paragondolella polygnathiformis Zone

In cherts of the Tsentralnaya Mountain quarry a conodont assemblage of *Paragondolella polygnathiformis* Zone includes *Mosherella* cf. *newpassensis* (K-34). The species-index is traced upwards for 1 m (sample K-35) and changed by *Paragondolella* sp. (sample K-36). The Zone is distinguished also in the Samarka terrane (samples H-625, H-624, H-820, layer 8, lower part of layer 10) in Khungary terrane (sample D-228, layer 9) and in Nadankhada - Bikin terrane. The Zone defines the Cordevolian, Julian, and lower part of the Tuvalian.

(8) Metapolygnathus nodosus Zone

In the limestone of the Verkhny reef massif *Metapolygnathus nodosus* (samples 101, 102, 24, 104, 25), *M. primitia* (sample 25), and *M. vialovi* (samples 20, 11) appear in the Borehole 2400. The same assemblage is found ine the reef massifs of Sakharnaya Golova (sample 99/87) and Kamennye Vorota (sample 99/181). It is also observed in cherts of the Tsentralnaya Mountain quarry (samples K-37, K-47) of the Dalnegorsk region, the Ussuri River basin (sample H-822, lower part of the layer 10), and the Gur River basin (samples D-109, D-245, D-238, layers, 14, 16, 17).This Zone defines the middle and upper Tuvalian.

3.5. Norian

Two Norian conodont Zones (lower and middle) as the previous Upper Carnian one, are well defined in the limestones of the Verkhny reef massif (Borehole 2400).

(9) Epigondolella abneptis Zone

Its lower boundary coincides with the appearance of *Epigondolella abneptis* (sample 10), that ranges upwards in the section of the borehole (samples 15, 28, 16, 17, 40, 39 38). The assemblage of the Zone includes also *Paragondolella hallstatensis, M. primitia* (sample 99/36, Sakharnaya Golova reef massif), *Ancyrogondolella triangularis, M. linguiformis, M. vialovi, M. primitia* (sample 99/184, Kamennye Vorota reef massif). The Zone occurs also in a cherts of the Ussuri River basin (sample H-674, H-823, H-675, H-658, layer 10, middle part, Gur River basin (samples D-247, D-117, D-285, D-284, D-283, layers 18, 23, 25, 26). This Zone defines the Lacian.

(10) Epigondolella postera Zone

Its lower boundary is fixed by the appearance of *E. postera* (sample 32, Borehole 2400, Verkhny reef massif). The species-index is traced up section (samples 30, 31) together with *Paragondolella* sp. indet. In the limestones of the Sakharnaya Golova reef massif, the members of the zonal association are *P. steinbergensis*. (99/11, 99/12, 99/80a, 99/79) and *E. multidentata* (99/224, 99/44, 99/38), and Kamennye Vorota reef massif contains *E.* cf. *multidentata* (sample 99/185). The Zone occurs in cherts of the Tsentralnaya Mountain quarry (samples K-50, K-46), the Ussuri River basin (sample H-676, upper part of the layer 10), the Gur River basin (sample D-271, layer 27). This Zone characterizes the Alaunian.

(11) Epigondolella bidentata Zone

In cherts of the Tsentralnaya Mountain quarry, the lower boundary of the Zone coincides with the first appearance of *Epigondolella bidentata* together with *E. multidentata* (sample K-45). The assemblage of the Zone contains also *Parvigondolella* sp., *E.* cf. *multidentata* (sample K-51) and in the upper part of the Zone, *Misikella hernsteini* occurs (sample K-44a). The thickness of the Zone is 3.2 m. The Zone was also recognized in the limestones of Sakharnaya

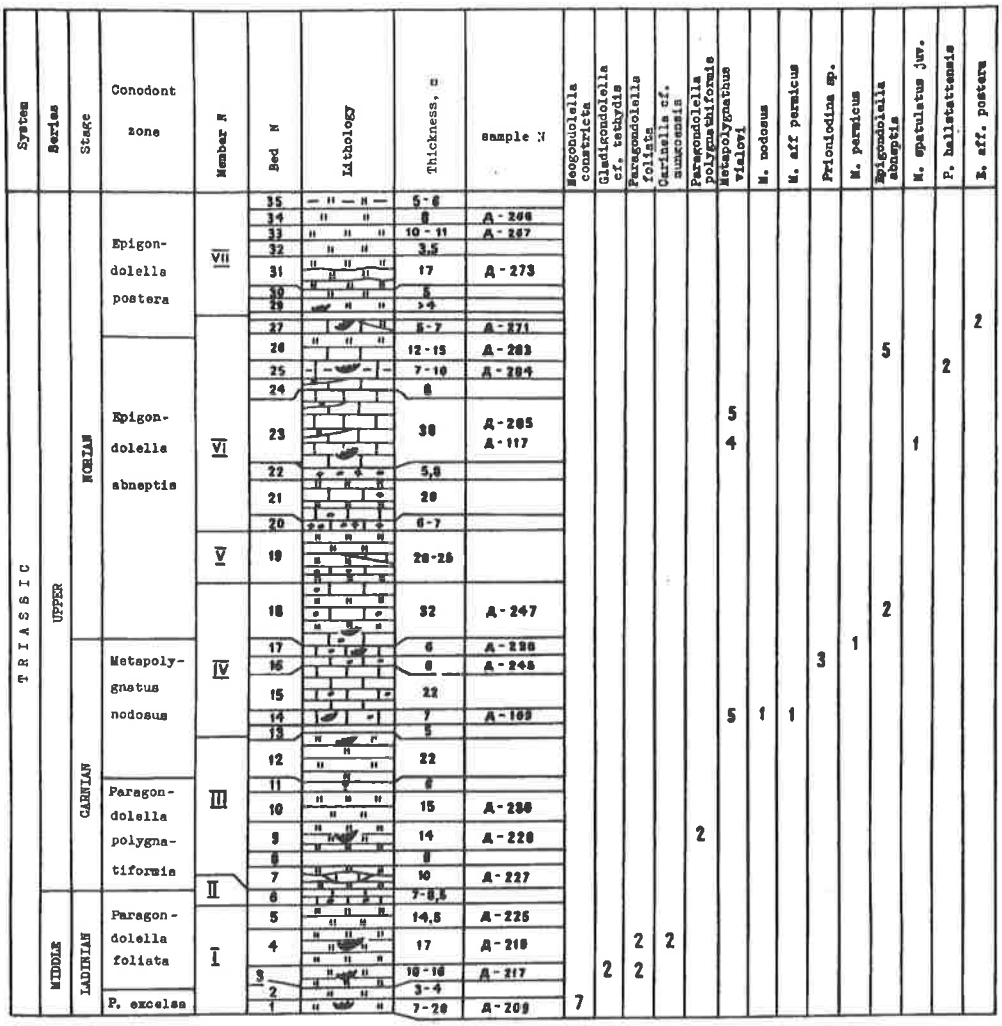

Fig. 6. Stratigraphic distribution of the conodonts in Triassic carbonaceous-cherty series of the right slope of the Gur River valley (Khungary terrane). Figures show the number of conodonts in a corresponding sample (designation as in Fig. 2).

Golova (samples 99/78, 99/43) and Verkhny (sample 159,36) reef massifs. This Zone defines in the Sevatian.

3.6. Rhaetian

(12) Misikella posthernsteini Zone

The Zone was established in the cherts of the Tsentralnaya Mountain quarry. The lower boundary of the Zone is the first appearance of *Misikella posthernsteini* together with *M. hernsteini* (sample K-44). The species-index is traced all over the section of the Zone deposits (samples K-43, K-42). In the upper part it is observed together with *E.* cf. *slovakensis* and *Parvigondolella* cf. *rhaetica*. The thickness of the lithologic unit of this Zone is 3.4 m. The upper boundary is fixed conditionally at the top of the layers with *M. posthernsteini*. The Zone was also established in the Ussuri River basin (samples H-803, H-609, layers 11 and 12).

4. Correlation

Triassic conodont fauna of the Sikhote-Alin correspond to those of North America, Asia and West Europe (Buryi, 1989). They have the closest similarity with the conodont assemblages of Japan (Koike, 1979, 1981). Japanese Triassic conodont scale encloses the same stratigraphic interval as Sikhote-Alin one does - from Olenekian to Rhaetian. However, the Japanese scale is summarized, it is composed of the conodont assemblages characteristic of shallow-water carbonate facies (Taho and Kamura Limestones), as well as deep-seated siliceous shales and cherts (in Oze, Nichiharn district, Kanoashi-gun, Shimane Prefecture). At the same time, all Triassic conodont Zones of the Sikhote-Alin were recognized in deep-sea facies - cherts of Dalnegorsk region, although, Zones 8 to 10 are better characterized by conodonts from limestones of the Dalnegorsk paleoguyots.

The most ancient Early Triassic Japanese conodont assemblages *N. conservativa - N. dieneri* (from limestones) was not found in the deep-sea facies of the Sikhote-Alin. It correlates best of all with the 4th conodont assemblage of South Primorye (Buryi, 1979). Zone *N. waageni* corresponds to it in the Sikhote-Alin. Other zonal assemblages of Japan and the Sikhote-Alin correspond in general to each other (excepti the *bulgarica* and *mungoensis* Zones), but some of them differ in the stratigraphic volume.

Triassic sections of Japan and the Sikhote-Alin belong to the Asian conodont province according to H. Kozur (1980) classification or to the Tethys-Pacific province

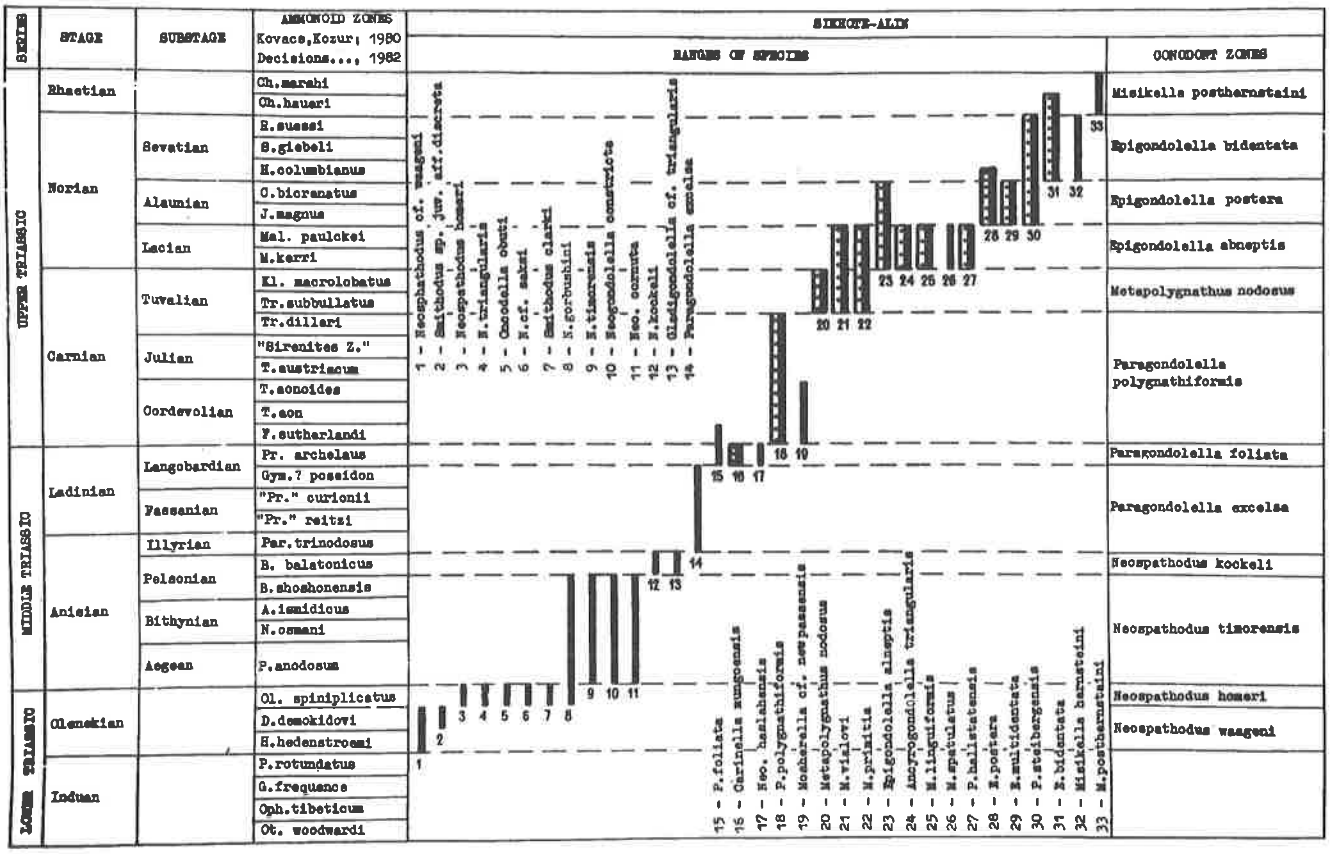

Fig. 7. Ranges of Triassic conodont species and Zones in the Sikhote-Alin.

according to K. Budurov, V. Gupta, M. Sudar, and G.I. Buryi (1983). The comparison of the Triassic conodont zonal scales of Japan and the Sikhote-Alin with the standard scale of the Tethys-Pacific province shows that they coincide since Late Ladinian, but are less comparable in the upper part of the Lower Triassic, and even much less comparable in the Middle Triassic. The Conodont standard, as proposed by H. Kozur (1980) for the Asian conodont province is practically not comparable with regional zonal scales of Japan and the Sikhote-Alin at this stage of study. H. Kozur has distinguished 26 very fractional conodont zones for the Middle and Upper Triassic, including *pseudolonga, transita, truempyi, hungaricus, diebeli, noah, carpathica*, and *andrusovi* Zones, species of which have not been described from the Far East regions up to date, but are very common in the Austro-Alpine and Dinaric provinces of West Europe.

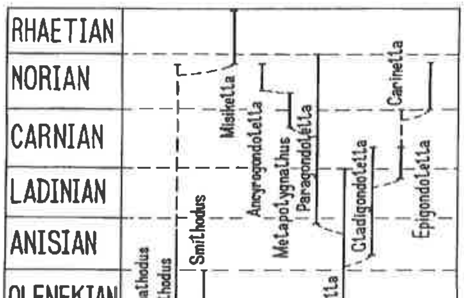

Fig. 8. Succession of the development of blade-like and platform conodont genera of the Sikhote-Alin.

5. Evolution

The most important investigations on the Triassic conodont evolution are published by L. Mosher (1968), W. Sweet (1970) and K. Budurov (1976). K. Budurov have studed the microstructure of the Middle and Late Triassic platform conodonts and determined their most changeable morphological features (eight types of biostructure of basal field and pit, structure of platform edges, structure of denticles of carina) and revealed the main phylogenetic lines of Triasiic platform conodonts. I observed well these phylogenetic lines on the example of conodonts of the Sikhote-Alin, and owing to that a certain succession of the development of blade-like and platform conodont genera of this region had been determined (Fig. 8).

W. Sweet (1970), when studying the Late Permian - Early Triassic conodonts of West Pakistan, recognized that the first Triassic blade-like genus was *Anchignathodus*, that came from Paleozoic, and *Neospathodus* developed during the Induan Stage. According to K. Budurov, G. Buryi and M. Sudar (1988), *Neospathodus* genus appears in the Olenekian Stage with well developed posterior blade behind the main denticle and such conodonts were attributed to the genus *Smithodus*. On my opinion, the development of Triassic blade-like conodonts came to an end in Upper Norian and Rhaetian with the appearance of *Misikella*.

All Triassic platform conodonts originated from *Neogondolella*. The basal plate of Early Triassic *Neogondolella* extends outwards, and the loop is poorly developed or absent. Through the evolution the pit becomes deeper, its margins project outward, and from behind the well-defined rounded loop forms. This process characterized Middle Triassic *Neogondolella*. Further evolution of the process results in the formation of conodonts with wide rounded, or right-angled on the back end, basal field, narrow conic loop and wide pit. L. Mosher (1968) has distinguished the conodonts with such morphological characters as *Paragondolella* has. At the end of Ladinian, the gradual furcation of the wide right-angled back end of the basal field of *Paragongolella polygnathiformis* (Budurov et Stefanov) is observed. It begins to take on the triangular shape characterizing, *Metapolygnathus*. Further much stronger furcation of the basal field resulted in the formation of *Ancyrogondolella* in Norian time (Budurov, 1976).

In parallel with phylogenetic line *Neogondolella - Paragondolella - Metapolygnathus - Ancyrogondolella*, a new phylogenetic branch *Neogondolella - Gladigondolella - Serphardiella- Epigondolella* appears at the beginning of Middle Triassic. In it, *Neogondolella* develops not towards the extension and furcation of the basal field back end, but in contrast, the basal field takes on the lancet shape, its back end becomes sharp, and the basal pit shifts first to the back one third (*Gladigondolella*) and then to the centre of conodont (*Sephardiella*). Middle Triassic *Sephardiella* appeared to be the ancestral forms of Late Triassic *Epigondolella*. L. Mosher has defined *Epigondolella* for the conodonts with narrow basal field of elliptical shape, pointed loop and elliptical pit located in the back one third.

Thus, all platform conodonts developed from the same root - *Neogondolella*, however, in different ways. In the first case the basal field extended and bifurcated, and in the second case it became sharp.

The conodont collection, discussed in this paper, contains many representatives of *Metapolygnathus* and *Epigondolella*. The author studied in detail the systematic of the species, belonging to these genera, and made more distinct determination of *Epigondolella abneptis* (Huckriede), attributing to this species only the conodonts with narrow elliptical basal field, painted loop, and elliptical pit located in the back one third. Conodonts similar to *Epigondolella abneptis* (Huckriede) in the character of the upper surface structure, but having furcate triangular basal field typical of *Metapolygnathus*, were attributed to the new species *Metapolygnathus vialovi* Buryi.

Upper Triassic platform conodont of *Epigondolella* and *Metapolygnathus* are similar in shape and platform outline, and denticle and nodule disposition. This explains the difficulties in their determination. According to S. Kovács and H. Kozur (Kovács and Kozur, 1980), the diversity of Late Triassic conodonts is represented by *Metapolygnathus* into the synonymy of which they put *Ancyrogondolella, Epigondolella*, and *Sephardiella*. K. Budurov (1976) using scanning microscope, established that *Epigondolella* and *Metapolygnathus* differ in the shape of the basal field and the loop structure. *Epigondolella* has elliptical or lanceolate basal field with pointed loop, and *Metapolygnathus* have the basal field widened on the back end with the loop bifurcated into two parts. The same features were observed in generic diagnoses of *Epigondolella* and *Metapolygnathus*.

Sh. Hayashi (1968) noted that the «back end of *Metapolygnathus* was always right-angled and often bifurcate». Type species *M. communisti* has right-angled and slightly bifurcated loop. L. Mosher (1968) did not describe the structure of the basal field in the generic diagnosis of *Epigondolella*. R. Huckriede (1958), when describing the type species *E. abneptis*, did not dwell on the structure of the basal field either. He only indicated, that the «aboral (lower) side is typically *Gondolella*- like, and from the basal pit to the backs end a fissure stretches». Apparently, it was meant that the basal field of *E. abneptis* has the stretched pointed back end. The holotype of this species has no picture of the lower surface. R. Huckried did not attach importance to the structure of the basal field and, judging by the image, attributed to *E. abneptis* both conodonts with acute-angled and bifurcated loops. As a result, the representatives of two genera - *Epigondolella* and *Metapolygnathus* - were united under the name *E. abneptis*. However, after K. Budurov's revision of Triassic conodonts, we attribute to *Epigondolella abneptis* (Huckriede) only conodonts with lanceolate basal field and acute-angled loop (Table 2, Fig. 12-15) and conodonts similar to them, but with bifurcate loop - to *Metapolygnathus primitia* (Mosher), *M. linguiformis* Hayashi, and other.

In our collection, numerous *Metapolygnathus vialovi* Buryi are characterized by rather wide rounded or rigth-angled-rounded platform, slightly narrowed at the lateral sides at one third of the distance from the front end and gradually widening to the back one. Large sharp denticles are developed on the front half of the platform (Table 2, Fig. 1-3, 6-11).

K. Budurov attributed the analogous conodonts to *M. linguiformis* Hayashi (Catalov and Budurov, 1978), S. Kovács and H. Kozur - to *M. abneptis* (Kovács and Kozur, 1980) and Yu. Isozaki and I. Matsuda - to *Epigondolella abneptis* (Isozaki and Matsuda, 1982). However, all these conodonts have the bifurcate loop on the lower surface and may not be attributed to *Epigondolella* by the causes discussed above. They are also not like *Metapolygnathus linguiformis* Hayashi, as the platform of the latter is not wide, it gradually narrows from the back rigth-angled end to the front one, and has shallow hollows on the lateral sides near the back end (Table 2, Fig. 4, 5). Thus, these conodont must be attributed to *Metapolygnathus*. At the same time, they differ from all known species of this genera: from *M. nodosus* Hayashi (Table I, Fig. 21, Table 2, Fig. 19) - in the widened back end and much more bifurcated loop on the lower surface; from *M. spatulatus* (Hayashi) - in much longer platform. The fissure on the lateral sides of *M. permicus* (Hayashi) occurs on the back and not on the front one third part of more narrow platform.

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Plate I

Fig. 1,2. *Neospathodus timorensis* (Nogami), 2B/1B, No P-175, lateral view, Rudnaya River; *N. timorensis* Zone, 1 - x 600, 2 - x 350.

Fig. 3-5. *Neospathodus gorbushini* Buryi, Rudnaya River, Anisian, *N. timorensis* Zone, 3 - 2B/11, N P-236, holotype, lateral view, x 400, 4 - 2B/25, N P-236, lateral view, x 350; 5 - 2B/26 - lateral view of the juvenile form, x 400.

Fig. 6,7. *Neospathodus homeri* (Bender), 2B/15, N P-242, lateral view, Rudnaya River, Olenekian, *N. homeri* Zone, 6 - x 350, 7 - x 600.

Fig. 8. *Misikella posthernsteini* Kozur et Mock, 2B/41, No K-44, lateral view, x 450; Tsentralnaya Mountain quarry, Rhaetian, *M. posthernsteini* Zone.

Fig. 9. *Neospathodus triangularis* (Bender), 2B/39, No P-242, lateral view, x 240; Rudnaya River, Olenekian, *N. homeri* Zone.

Fig. 10. *Misikella hernsteini* (Mostler), 2B/37, No P-251, lateral view, x 450; Rudnaya River basin, Norian, *Epigondolella bidentata* Zone.

Fig. 11. *Paragondolella foliata* Budurov, 2B/34, No D-217, upper-lateral view, x 300; Gur River, Ladinian, *P. foliata* Zone.

Fig. 12. *Paragondolella polygnathiformis* (Budurov et Stefanov), 2B/42, No K-35, upper-lateral view, x 150; Tsentralnaya Mountain quarry, Carnian, *P. polygnathiformis* Zone.

Fig. 13, 14, *Paragondolella excelsa* Mosher, 2B-31, No H-627, Upper-lateral view; Ussuri River right bank, upper Anisian - Lower Ladinian, *P. excelsa* Zone; 13 - x 160, 14 - x 250.

Fig. 15. *Neogondolella constricta* (Mosher et Clark), 2B/18, No P-174, lateral view, x 250; Rudnaya River, Anisian, *Neospathodus timorensis* Zone.

Fig. 16. *Neogondolella haslachensis* (Tatge), 2B/28, No H-604, upper view, x 400; Ussuri River right bank, Ladinian, *Paragondolella foliata* Zone.

Fig. 17, 18. *Neospathodus kockeli* (Tatge), Rudnaya River, Anisian, *N. kockeli* Zone: 17 - 2B/17, No P-178, lateral view of the juvenile form, x 500; 18 - 2B/10, No P-178, lateral view, x 300.

Fig. 19, 20. *Paragondolella polygnathiformis* (Budurov et Stefanov), 2B/33, No K-34, lateral view, Tsentralnaya Mountain quarry, Carnian, *P. polygnathiformis* Zone, 19 - x 150, 20 - x 300.

Fig. 21. *Metapolygnathus nodosus* (Hayashi), 1B/23, No 101, upper view, x 150; reef massif Verkhny, Hole 2400, Carnian, *M. nodosus* Zone.

Plate I

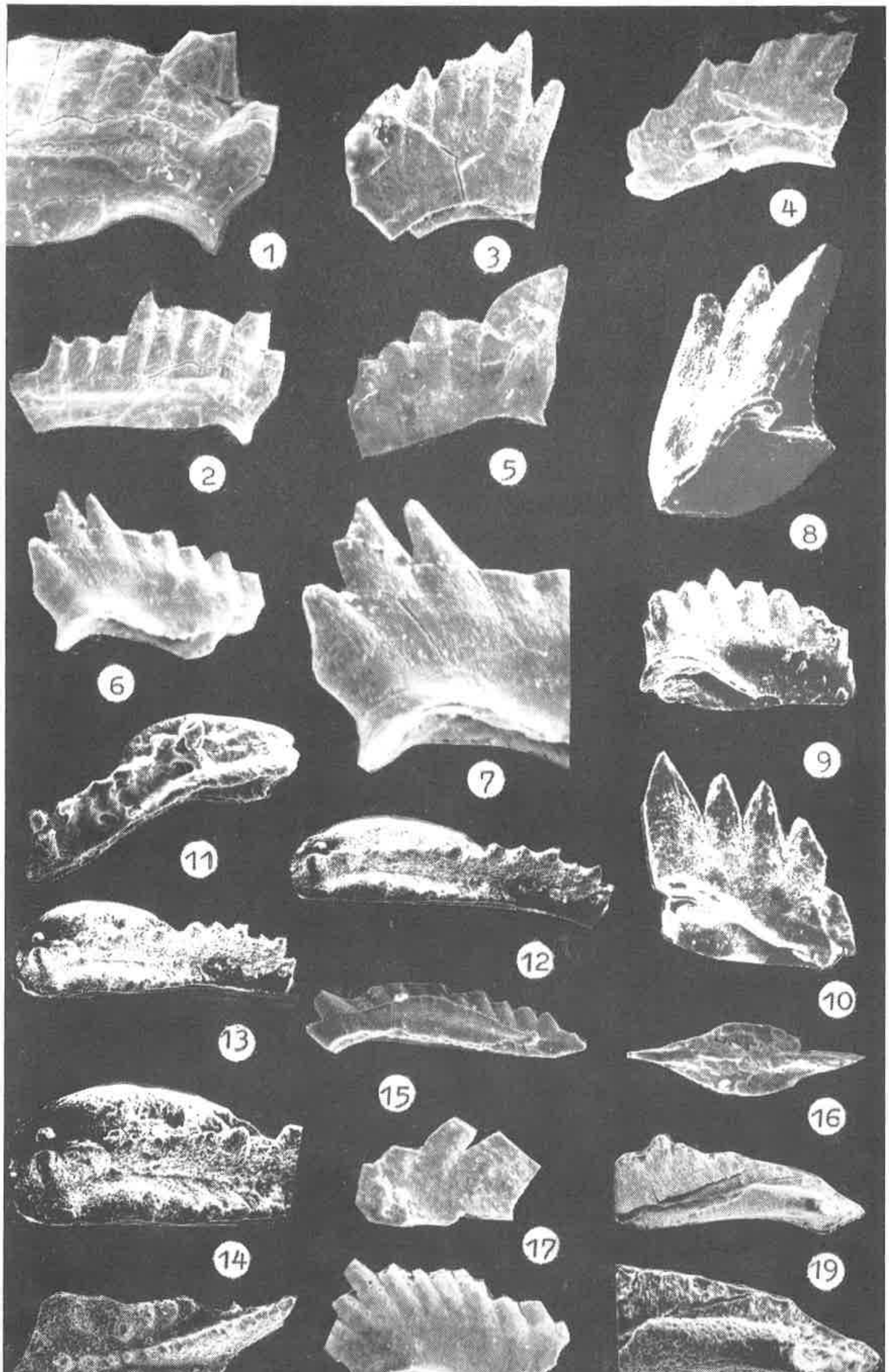


Plate II

Fig. 1-3. *Metapolygnathus vialovi* Buryi, holotype, 1B/15, No 99/183a, upper view; reef massif Kamennye Vorota, Norian, *Epigondolella abneptis* Zone. 1 - x 180. 2 - x 450, 3 - x 610.

Fig. 4,5. *Metapolygnathus linguiformis* Hayashi, 1B/7, No 99/184, x 330; the same location. 4 - upper view, 5 - lower view.

Fig. 6-11. *Metapolygnathus vialovi* Buryi, 6-8 -1B/10. No 99/183a, upper view; the same location. 6 - x 190, 7 - x 460, 8 - x 1000. 9-11 - 1B/11, No 99/169, lower view; reef massif Verkhny, Carnian, *M. nodosus* Zone. 9 - x 320, 1O- x 550, 11 - x 1300.

Fig. 12-15. *Epigondolella abneptis* (Huckriede) 12 - 1B/1, No 99/181b, upper view, x 380; reef massif Kamennye Vorota, Norian, *E. abneptis* Zone. 13- 1B/3, No 99/181b, upper view of the juvenile form, x 500; the same location. 14 - 1B/2, No 99/181b, lower view, x 300: the same location; 15 - 1B/13, No C -261/1, lower view, x 360; Gur River bassin, Norian, *E. abneptis* Zone.

Fig. 16, 17. *Ancyrogondolella triangularis* Budurov, 1B/8, No 99/183, the same location; 15 - lower view, x 180, 16 - upper view, x 180.

Fig. 18. *Sephardiella mungoensis* (Diebel), 1B/6, No 99/157, lateral view, x 180; reef massif Verkhny, Ladinian, *Paragondolella foliata* Zone.

Fig. 19. *Metapolygnathus nodosus* (Hayashi), 1B/14, No D -109, upper view, x 200, Gur River, Carnian, *M. nodosus* Zone.

Plate III

Fig. 1-3. *Metapolygnathus primitia* (Mosher), x 60, 1 - 461/203, No 99/87, upper view, reef massif Sakharnaya Golova, Carnian, M. nodosus zone; 2 - 461/204, No 99/87, upper view, the same location and age; 3 - 461/205, N 99/36, lateral view, the same location, Norian, *Epigondolella abneptis* Zone.

Fig. 4-6. *Epigondolella multidentata* Moscher, x 60, 4 - 461/206, No 99/50, lateral view, reef massif Bolnichny, Norian, *E. postera* Zone; 5 - 461/207, No 99/44, upper view, reef massif Sakharnaya Golova, Norian, *E. postera* Zone; 6 - 461/207, No 99/44, lateral view, the same location.

Fig. 7. *Enantiognathus ziegleri* (Diebel), 461/220, No 99/32, lateral view, x 60; reef massif Sakharnaya Golova, Norian, *E. postera* Zone.

Fig. 8-12. *Eigondolella postera* (Kozur et Mostler), x 60, reef massif Sakharnaya Golova, Norian, *E. postera* Zone: 8 - 461/208, No 99/32, lateral view of the juvenile form; 9 - 461/210, No 99/32, upper view; 10 - 461/210, No 99/32, lateral view; 11 - 461/209, No 99/39, lateral view; 12 - 461/209, No 99/39, upper view.

Fig. 13,14. *Paragondolella hallstatensis* Mosher, x 60, reef massif Sakharnaya Golova, Norian, *Epigondolella abneptis* Zone: 13 - 461/218, No 99/36, upper view; 14 - 461/218, No 99/36, lower view.

Fig. 15-17. *Epigondolella bidentata* Mosher, x 60, reef massif Sakharnaya Golova, Norian, *E. bidentata* Zone: 15 - 461/212, No 99/78, upper view; 16 - 461/221, No 99/78, upper view of the juvenile form; 17 - 461/211, No 99/78, lower view.

Fig. 18-21. *Paragondolella steinbergensis* Mosher: 18 - 1B/27, No 36, upper view, x 300; reef massif Verkhny, Hole 2400, Norian, *Epigondolella bidentata* Zone; 19 - 461/217, No 99/80a, x 60, lower view; reef massif Sakharnaya Golova, Norian, *Epigondolella postera* Zone; 20 - 461/216, No 99/79, x 60, lateral view; the same location; 21 - 461/215, No 99/79, x 60, lateral view of the juvenile form; the same location.

Fig. 22. *Epigondolella* aff. *postera* (Kozur et Mostler), 1B/4, No 99/184, upper view, x 400; reef massif Kamennye Vorota, Norian, *E. abneptis* Zone.

Fig. 23. *Epigondolella abneptis* (Huckriede), 1B/29, No 99/184, lower view, x 300; the same location.

Fig. 24. *Epigondolella postera* (Kozur et Mostler), 1B/28, No 99/32, lower view, x 280; reef massif Sakharnaya Golova, Norian, *E. postera* Zone.

Fig. 25. *Paragondolella hallstatensis* Mosher, 1B/26, No C-262/17, lower-lateral view, x 150; Gur River basin, *Epigondolella abneptis* Zone.

Fig. 26-28. *Ancyrogondolella triangularis* Budurov, juvenile form; reef massif Verkhny, Norian, *Epigondolella abneptis* Zone: 26 - 1B/9, No 99/133, lower view, x 260; 27 - 1B/9, No 99/133, lower view, x 500; 28 - 1B/9, No 99/133, upper view, x 270.

Fig. 29, 30. *Smithodus clarki* Buryi, holotype, lateral view; Rudnaya River, Olenekian, *Neospathodus homeri* Zone: 29 - 2B/38, No P-240, x 500; 30 - 2B/38, No P-240, x 300.

Plate II

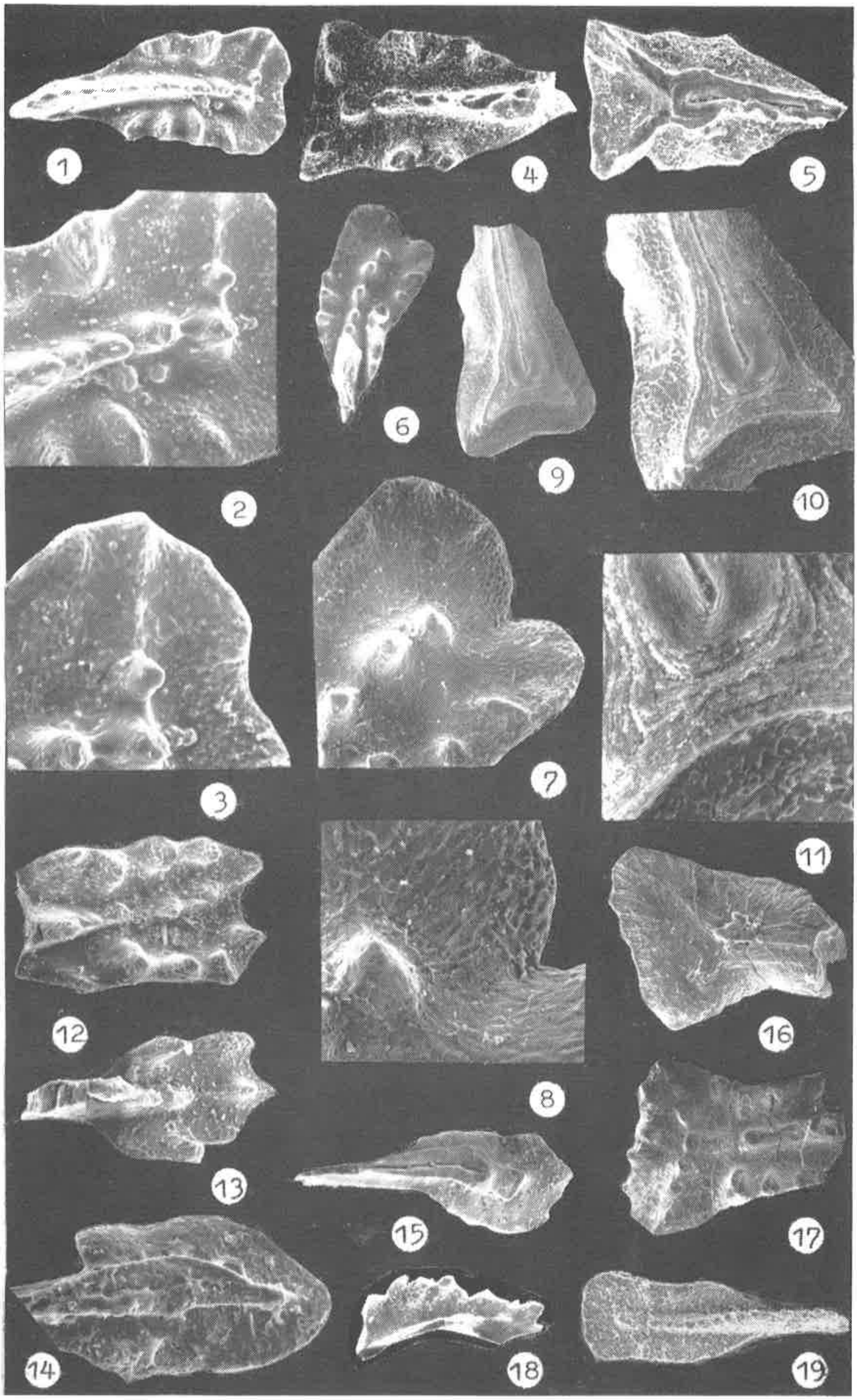
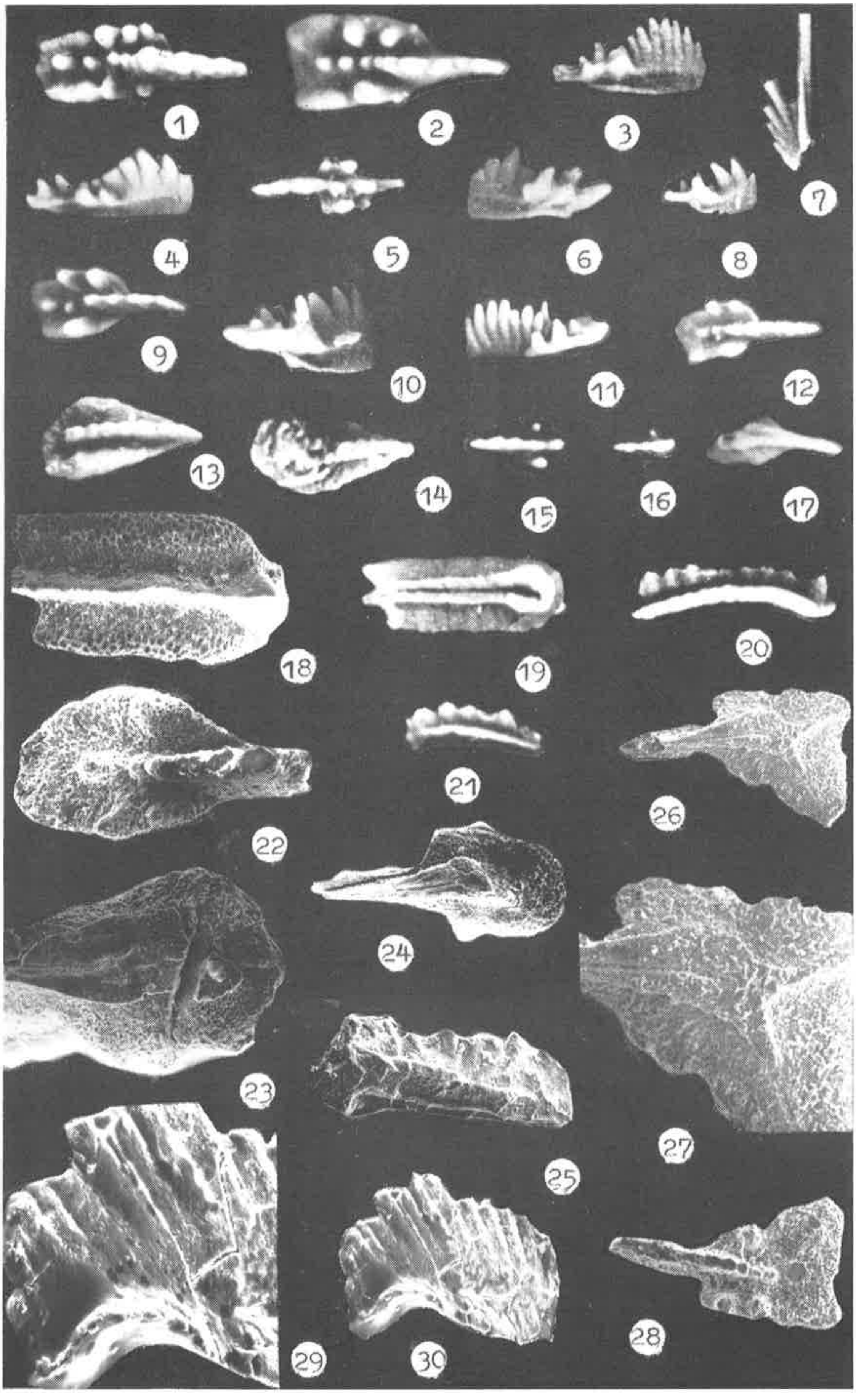


Plate III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OSTRACODES OF THE CHANDALAZ HORIZON (UPPER PERMIAN) OF SOUTH PRIMORYE

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Abstract

This paper contains the first data on marine Permian ostracodes of Primorye territory (Russian Far East). Some new taxa (*Chamishaella maichensis* n. sp., *Shishaella? ussurienses* n. sp., *Vanganardia koczyrkeviczi* n. gen. et sp., *V. maichensis* n. gen. et sp., *Lanczichebairdia koczyrkeviczi* n. gen. et sp., *Arcibairdia bogdani* n. gen. et sp., *Bairdia imposita* n. sp., and *Orthobairdia vanganensis* n. sp.) are described.

1. Introduction

The collection of Permian ostracodes from the Primorye region has been received from Dr. Bogdan V. Koczyrkevicz who discovered them incidentally during his investigations of brachiopods from Upper Chandalaz limestones (Middle Midian) cropping out in the valleys of the Maiche River (Vangan and Golubinaya Mounts and the village of Sudoverf) and the Lanczishe River, about 50 and 20 km (respectively) north-east of Vladivostok. According to B.V. Koczyrkevicz, the ostracodes have been found in the upper part of the Chandalaz Horizon that corresponds to the *Metadoliolina lepida* Zone (Kotlyar, Zakharov, Koczyrkevicz et al., 1983).

In the Far East of Asia, marine Permian ostracodes have been known in north-east Japan (Ishizaki, 1964, 1967). The collection from South Primorye is rather poor. It contains 14 genera and 29 species among which there are three new genera (*Vanganardia, Lanczichebairdia*, and *Arcibairdia*) and seven new species. The number of specimens is few. Nevertheless, in spite of their scarcity, the given data are important as a first report on the Late Permian ostracode fauna from the Primorye area.

As shown in Table 1, the Chandalaz complex contains representatives of *Chamishaella* - (one species); *Shishaella* - (four species), *Bairdiacea* (19 species), *Microcheilinella* (one species) and *Myodocopa* (*Cypridella* - two species). The bairdiaceans constitute the most important group. Of special interest is the presence of such peculiar forms as *Petasobairdia, Abrobairdia?, Vanganardia*, and *Lanczichebairdia.* This indicates a definite similarity to the Tethyan ostracode fauna from Upper Permian limestones at Nantong, Jiangsu and at Mianyang, Hubei (South China), which was described in the important paper by Chen De-kiong and Shi Cong-guang (1982).

It should be noted that the Late Permian ostracodes of Primorye need special detailed investigations. The collection is stored under the BPI 1120 in the Institute of Biology and Pedology (BPI), Far East Branch, Russian Academy of Sciences, Vladivostok.

2. Systematics

All of the taxa described below are from South Primorye (Maiche and Lancziche Rivers) and their geologic range is Late Permian (Middle Midian, Chandalaz Horizon).

Superfamily PARAPARCHITACEA Scott, 1959
Family PARAPARCHITIDAE Scott, 1959
Genus *Chamishaella* Sohn, 1971
Chamishaella maichensis n. sp.
Pl. I, fig. 5-9

Name. After the Maiche River.

Holotype - Left valve, BPI 1120/1; South Primorye, Maiche, Sudoverf; Upper Permian, Midian, Chandalaz Horizon.

Material. Four left valves.

Description. Valves large, thick-shelled. In lateral view subellipsoidal or subcircular, anterior and posterior margins broadly rounded, the anterior somewhat higher, dorsal margin straight, ventral evenly rounded. In dorsal view moderately convex. Surface smooth.

Dimensions in mm: holotype BPI 1120/1, left valve, L=2200, H=1525, W=700; BPI 1120/41, left valve, L=2350, H=1725, W=7500; BPI 1120/37, left valve, L=1800, H=1375, W=625.

Remarks. Resembles some adult representatives of *Chamishaella brosgei* Sohn from the Mississippian of Alaska (Sohn, 1971, Pl. 6, fig. 29, 31).

Occurrence. South Primorye, Maiche.

Genus *Shishaella* Sohn, 1971
Shishaella? ussuriensis n. sp.
Pl.I, fig. 12-14

Name. After Ussuri Bay into which the Maiche River discharges.

Table 1. List of ostracode species from Chandalaz limestone (Midian).

No	Species	Maiche (=Artemovka) River	Lancziche (=Bogataja) River
1.	*Aurikirkbya* sp.	+	
2.	*Cyathus* aff. *caperatus* (Guan)	+	
3.	*Chamishaella maichensis* n. sp.	+	
4.	*Shishaella* aff. *geisi* Sohn	-	+
5.	*Shishaella? ussuriensis* n. sp.	+	
6.	*Shishaella?* sp. A	+	
7.	*Shishaella?* sp.	+	
8.	*Petasobairdia bicornuta* Chen	+	
9.	*Petasobairdia* sp.	+	
10.	*Vanganardia koczyrkeviczi* n. sp.	+	
11.	*V. maichenses* n. sp.	+	+
12.	*Lanczichebairdia koczyrkeviczi* n. sp.	+	+
13.	*Lanczichebairdia* sp.	+	
14.	*Abrobairdia?* sp.	+	
15.	*Bairdia* aff. *hassi* Sohn	+	
16.	*B.* aff. *pecosensis* Delo	+	
17.	*B.* cf. *radlerae* Kellett	+	
18.	*B. imposita* n. sp.	+	+
19.	*Bairdia* sp.	+	
20.	*Orthobairdia vanganensis* n. sp.	+	
21.	*O.* aff. *cestriensis* (Ulrich)	+	
22.	*Orthobairdia* sp.	+	
23.	*Arcibardia bogdani* n. sp.	-	+
24.	*Bairdiacypris* cf. *shangxingensis* Shi	+	
25.	*Bairdiacypris* sp. A	+	
26.	*Bairdiacypris* sp.	+	
27.	*Microcheilinella?* sp.	+	
28.	*Cypridella* sp. A	+	
29.	*Cypridella* sp. B	+	

Holotype - Right valve, BPI 1120/47; South Primorye, Maiche, Golubinaja Mount; Upper Permian, Midian, Chandalaz Horizon.

Material. Four right valves.

Description. Valves large, in lateral view elongate-ovate, both ends broadly rounded, the anterior is higher than the posterior; near the dorsal margin there is a swelling. In dorsal view slightly convex. Surface smooth.

Dimensions in mm: holotype, BPI 1120/47, right valve, L=2250, H=1750; BPI 1120/51, right valve, L>2200, H=1700; BPI 1120/49-2, L=1975, H=1700.

Remarks. This species is referred to *Shishaella* with some doubt.

Occurrence. South Primorye, Maiche.

Superfamily BAIRDIACEA Sars, 1887
Family Bairdiidae Sars, 1887
Genus *Vanganardia* n. gen.

Name. After Vangan Mount.

Type species - *Vanganardia koczyrkeviczi* n. sp.

Diagnosis. Bairdiidae with flat venter and ventrolateral ridge. Dorsal margin strongly arched. Both ends are beak-like. In dorsal view sides convex, ends acute. Surface smooth.

Species: The type-species (left valves) and *V. maichensis* n. sp.

Remarks. In lateral outline this genus is similar to *Ceratobaidia* Sohn, but differs in the absence of dorsal spines or knobs and less expressed ventro-lateral ridges. The ostracodes *Ceratobairdia? ambigua* Ishizaki from the Permian of north-east Japan, Kitakami massif (Ishizaki, 1964) may be also referred to *Vanganardia*.

Occurrence. Upper Permian, South Primorye.

Vanganardia koczyrkeviczi n. sp.
Pl. II, fig. 8-10

Name. In honour of Bogdan V. Koczyrkevicz, a paleontologist who studied Permian brachiopods and from whom the ostracode material has been received.

Holotype - left valve, BPI 1120/24; South Primorye, Maiche, Vangan Mount; Upper Permian, Midian, Chandalaz Horizon.

Material. The holotype.

Description. A large left valve. In lateral view subrhomboid; both ends are beak-like, the anterior is higher; dorsal margin strongly arched, dorso-anterior and dorso-posterior margins concave; ventral margin slightly convex. In dorsal view sides convex, ends acute. The ventral part is flattened and bears a narrow ventro-lateral ridge that extends along the middle of the venter and does not reach the ends. Surface smooth.

Dimensions in mm: holotype, BPI 1120/24, left valve, L=1985, H=1200, W=500.

Remarks. Differs from *V. maichensis* n.sp. by a more elongated anterior part.

Occurrence. South Primorye, Maiche.

Vanganardia maichensis n. sp.
Pl. II, fig. 11-15; pl. III, fig. 16

Name. After the Maiche River.

Holotype - Left valve, BPI 1120/14; South Primorye, Maiche, Sudoverf; Upper Permian, Midian, Chandalaz Horizon.

Material. Three left valves (two from the village of Sudoverf, and one from Lancziche River).

Description. Large left valves. In lateral view subrhomboid, both ends beak-like, dorsal margin strongly arched, dorso-anterior and dorso-posterior margins slightly concave, ventral margin straight to slightly convex. In dorsal aspect sides convex. The ventral part is flattened and bears a narrow ventro-lateral ridge. Surface smooth.

Dimensions in mm: holotype, BPI 1120/14, left valve, L=1600, H=1125, W=375;BPI 1120/16, left valve, L=1575, H=1050, W=375; BPI 1120/43, left valve, L=1725, H=1100 (specimen lost).

Remarks. Differs from *V. koczyrkeviczi* n. sp. by having a shorter dorso-anterior margin.

Occurrence. South Primorye, Maiche and Lancziche Rivers.

Genus *Lanczichebairdia* n. gen.

Name. After the Lancziche River at the Murav'ev - Amursky Peninsula.

Type species - *Lanczichebairdia koczyrkeviczi* n. sp.

Diagnosis. Large elongated bairdiid with little knobs on the cardinal angles of the left valve dorsum.

Species: The type species.

Occurrence. Upper Permian, South Primorye.

Lanczichebairdia koczyrkeviczi n. sp.
Pl. III, fig. 1-4

Name. In honour of Bogdan V. Koczyrkevicz.

Holotype - Carapace, BPI 1120/5; South Primorye, Lancziche; Upper Permian, Midian, Chandalaz Horizon.

Material. One carapace and one left valve.

Description. A large bairdiid, in lateral view elongate, both ends beak-like, the anterior is higher than the posterior; dorsal margin is about one third of the length and slightly convex with little knobs on each cardinal angle of left valve; ventral margin is nearly straight and parallel to the dorsum. In dorsal aspect convex, ends acute. Surface smooth.

Dimensions in mm: holotype, BPI 1120/5, carapace, L=1775, H=1050, W=825; BPI 1120/26, left valve, L=1600, H=1000.

Occurrence. South Primorye, Lancziche and Maiche Rivers.

Genus *Arcibairdia* n. gen.

Name. From Latin arca, meaning case (with reference to case-like appearance).

Type species - *Arcibairdia bogdani* n. sp.

Description. A large long bairdiid of case-like appearance; in lateral view anterior rounded, posterior pointed; dorsal margin slightly convex, ventral margin slightly concave, both parallel to each other. In dorsal view hexagonal, lateral sides nearly parallel, ends acute, the anterior blunting. Surface smooth; on each valve two indistinct vertical ridges rested against the cardinal angles, the posterior is rather a bend.

Species. The type species.

Remarks. In lateral outline this genus is similar to Bairdia McCoy, but differs as a more elongated.

Occurrence. Upper Permian, South Primorye.

Arcibairdia bogdani n. sp.
Pl. IV, fig. 14-17

Name. In honour of Bogdan V. Koczyrkevicz.

Holotype - Carapace, BPI 1120/10 (in the anterodorsal part damaged); South Primorye, Lancziche; Upper Permian, Midian, Chandalaz Horizon.

Material. The holotype.

Description. As for the genus.

Dimensions in mm: holotype, BPI 1120/10, carapace, L=1825, H=925, W=750.

Occurrence. South Primorye, Lancziche.

Genus *Bairdia* McCoy, 1844
Bairdia imposita n. sp.
Pl. V, fig. 1-6

Name. From Latin *impositus*, meaning superimposed (with reference to the lateral thickening).

Holotype - Carapace, BPI 1120/17; South Primorye, Maiche, Sudoverf; Upper Permian, Midian, Chandalaz Horizon.

Material. Two carapaces.

Description. Medium-sized inflated bairdiid carapaces. In lateral view subtriangular, anterior margin broadly rounded, posterior pointed; dorsal margin convex, ventral nearly straight. In dorsal view subrhomboid. In the middle part of the both valve (or on one of them) a wide superimposed thickening stretches in dorsoventral direction. Surface smooth, except the thickening which is rugged.

Dimensions in mm: holotype, BPI 1120/17, carapace, L=900, H=600, W=575; BPI 1120/8, carapace, L=950, H=650, W=600.

Occurrence. South Primorye, Maiche and Lancziche Rivers.

Genus *Orthobairdia* Sohn, 1960
Orthobairdia vanganensis n. sp.
Pl. IV, fig. 8-10

Name. After Vangan Mount.

Holotype - Carapace, BPI 1120/31; South Primorye, Maiche, Vangan Mount; Upper Permian, Midian, Chandalaz Horizon.

Material. The holotype.

Description. Carapace large, in lateral view subrectangular, anterior margin broadly rounded, higher than the posterior; dorsal margin straight in the middle part, ventral margin straight and parallel to the dorsal. In dorsal view compressed, slightly convex; ends acute. Surface smooth.

Dimensions in mm: holotype, BPI 1120/31, carapace, L=1535, H=850, W=575.

Remarks. Differs from *Orthobairdia cestriensis* (Ulrich) (see Sohn, 1960, pl. 3, fig. 24, 25) by having higher anterior and posterior margins in lateral view and less parallel sides in dorsal view.

Occurrence. South Primorye, Maiche.

Acknowledgements

The author is thankful to reviewers of this paper Prof. Y. Zakharov and Dr. S. Crasquin.

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All of the illustrated specimens (Plates I-V) are from South Primorye and their geological range is Late Permian (Middle Midian, Chandalaz Horizon)

Plate I

Fig. 1. *Aurikirkbya* sp. LV, lateral view, BPI 1120/46, L=1750, H=875, x 35; Maiche, Vangan Mount.

Fig. 2-4. *Cyathus* aff. *caperatus* (Guan). C, BPI 1120/55, L=500, H= 275, W=300: 2 - right lateral view, x 62, 3 - dorsal, x 62, 4 - ventral, x 54; Maiche, Vangan Mount.

Fig. 5-9. *Chamishaella maichensis* n. sp.: 5, 6 - holotype LV, BPI 1120/1, L=2200, H=1525, W=700, 5 - lateral view, x 24, 6 - dorsal, x 23; 7, 8 - LV, BPI 1120/41, L=2350, H=1725, W=750, 7 - lateral view, x 17, 8 - ventral, x 23; 9 - LV, BPI 1120/37, L=1800, H=1375, W=625, dorsal, x 23; Maiche, Sudoverf.

Fig. 10-11. *Shishaella* aff. *geisi* Sohn. C, BPI 1120/7, L=975, H=725, W=500: 10 - right lateral view, x 53, 11 - dorsal, x 51; Lancziche.

Fig. 12-14. *Shishaella? ussuriensis* n. sp.: 12 - holotype RV, BPI 1120/47, L=2250, H=1750, lateral view, x 21; 13 - RV, BPI 1120/51, L>2200, H=1700, lateral view, x 21; 14 - RV, BPI 1120/49-2, L=1975, H=1700, lateral view, x 21; Maiche (12 - Golubinaja Mount; 13, 14 - Sudoverf).

Fig. 15. *Shishaella?* sp. A. RV, BPI 1120/50, L=2975, H=2250, lateral view, x 21; the contour of the adductor muscle scar, mandibular and frontal stigmata are seen; Maiche, Sudoverf.

Fig. 16. *Shishaella?* sp. B. Steinkern, left lateral view, BPI 1120/56, L=2575, H=1985, x 20; Maiche, Sudoverf.

Abbreviations: C = carapace, RV = right valve, LV = left valve.
Measurements (in mm): L = length, H = hight, W = width.

Plate II

Fig. 1-5. *Petasobairdia bicornuta* Chen: 1-4 - C, BPI 1120/12-1, L=1075, H=725, W=550, 1 - right lateral view, x 48, 2 - left lateral view, x 41, 3 - dorsal, x 46, 4 -ventral, x 42; 5 - LV, BPI 1120/12-2, lateral view, x 46; Mache, Golubinaja Mount.

Fig. 6, 7. *Petasobairdia* sp. LV, BPI 1120/67, L=1000, H=550: 6 - left lateral view, x 54, 7 - ventral, x 56; Maiche, Vangan Mount.

Fig. 8-10. *Vanganardia koczyrkeviczi* n. sp. Holotype LV, BPI 1120/24, L=1985, H=1200, W=500, 8 - lateral view, x 39, 9 - dorsal, x 32, 10 - ventral, x 29; Maiche, Vangan Mount.

Fig. 11-15. *Vanganardia maichensis* n. sp.: 11-14 - holotype LV, BPI 1120/14, L=1600, H=1125, W=375, 11 - lateral view, x 40, 12 - dorsal, x 31, 13 - ventral, x 31, 14 - posterior view, x 33; Maiche, Sudoverf; 15 - LV, BPI 1120/16, L=1575, H=1050, W=375, lateral view, x 40; Lancziche.

Plate III

Fig. 1-4. *Lanczichebairdia koczyrkeviczi* n. sp.: 1, 2 - holotype C, BPI 1120/5, L=1775, H=1050, W=825, 1 - right lateral view, x 41, 2 - dorsal, x 31; Lancziche; 3, 4 - LV, BPI 1120/26, L=1600, H=1000, 3 - lateral view, x 31, 4 - dorsal, x 31; Maiche, Vangan Mount.

Fig. 5, 6. *Lanczichebairdia?* sp. Upper half of C, BPI, 1120/62,L=1260: 5 - right lateral view, x 37, 6 - dorsal, x 33; Maiche, Sudoverf.

Fig. 7-10. *Abrobairdia?* sp. C (damaged), BPI 1120/61, L=1650, H=1050, W=950: 7 - right lateral view, x 36, 8 - left lateral view, x 32, 9 - dorsal, x 30, 10 - ventral, x 30; Maiche, Sudoverf.

Fig. 11,12. *Bairdia* aff. *hassi* Sohn. C, BPI, 1120/2, L=1225, H=750,W=560: 11 - right lateral view, x 42, 12 - dorsal, x 51; Maiche, Sudoverf.

Fig. 13-15. *Bairdia* sp. C juv., BPI 1120/34, L=650, H=430, W=310: 13-right lateral view, x 48, 14 - dorsal, x 52, 15 - ventral, x 52; Maiche, Golubinaja Mount.

Fig. 16. *Vanganardia maichensis* n. sp. LV, BPI, 1120/43, L=1725, H=1100, lateral view, x 38; Maiche, Sudoverf.

Plate IV

Fig. 1-3. *Bairdia* aff. *pecosensis* Delo. C, BPI 1120/28, L=950, H=600, W=530: 1 - right lateral view, x 49, 2 - dorsal, x 47, 3 -ventral, x 47; Maiche, Vangan Mount.

Fig. 4,5. *Bairdia* aff. *radlerae* Kellett. C (anterior and posterior damaged), BPI 1120/68, L->1325, H=800, W=620: 4 - right lateral view, x 32, 5 - dorsal, x 30; Maiche, Vangan Mount.

Fig. 6,7. *Orthobairdia* aff. *cestriensis* (Ulrich). C, BPI 1120/53, L=725, H=400, W=325: 6 - right lateral view, x 74, 7 - dorsal,x 62; Maiche, Vangan Mount.

Fig. 8-10. *Orthobairdia vanganensis* n. sp. Holotype C, BPI 1120/31,L=1535, H=850, W=575: 8 - right lateral view, x 36, 9 - dorsal, x 34, 10- ventral, x 32; Maiche, Vangan Mount.

Fig. 11-13. *Orthobairdia?* sp. C (anterior damaged), BPI 1120/30, L->1275, H=800, W=525: 11 - right lateral view, x 39, 12 - dorsal, x 49, 13 - posterior view, x 33; Maiche, Vangan Mount.

Fig. 14-17. *Arcibairdia bogdani* n.sp. Holotype, C (damaged in anterodorsal part) BPI 1120/10, L=1825, H=925, W=750: 14 - right lateral view, x 31, 15 - left lateral view, x 31, 16 - dorsal, x 31, 17 - ventral, x 31; Lancziche.

Plate V

Fig. 1-6. *Bairdia imposita* n. sp.: 1-3 - holotype, C, BPI 1120/17, L=900, H=600, W=575, 1 - right lateral view, x 54, 2 - left lateral view, x 54, 3 - dorsal, x 51, Maiche, Sudoverf; 4-6, C,BPI 1120/8, L=950, H=650, W=600: 4 - right lateral view, x 54, 5 -left lateral view, x 54, 6 - dorsal, x 51; Lancziche.

Fig. 7,8. *Bairdiacypris* cf. *shangxingensis* Shi. C (dorsal part of LV damaged), BPI 1120/44, L=1275, H=580, W=500: 7 - right lateral view, x 29, 8 - ventral, x 31; Maiche, Sudoverf.

Fig. 9,10. *Bairdiacypris* sp. A. C (posterior damaged), BPI 1120/66-1, l -> 1250, H=675, W=425: 9 - right lateral view, x 30,10 - dorsal, x 32; Maiche, Vangan Mount.

Fig. 11, 12. *Bairdiocypris* sp. C juv., BPI 1120/66-2, L=575, H=28O,W=180: 11-right lateral view, x 57, 12 - dorsal, x 50; Maiche, Vangan Mount.

Fig. 13,14. *Microcheilinella?* sp. C, BPI 1120/20, L=700, H=462, W=475: 13-right lateral view, x 60, 14 - dorsal, x 51; Maiche, Golubinaja Mount.

Fig. 15, 16. *Cypridella* sp. A. LV, BPI 1120/35, L=1750, H=1250: 15 -lateral view, x 38, 16 -dorsal, x 35; Maiche, Sudoferf.

Fig. 17. *Cypridella* sp. B. A fragment, BPI 1120/36, lateral view, x 47; Maiche, Sudoverf.

Plate I

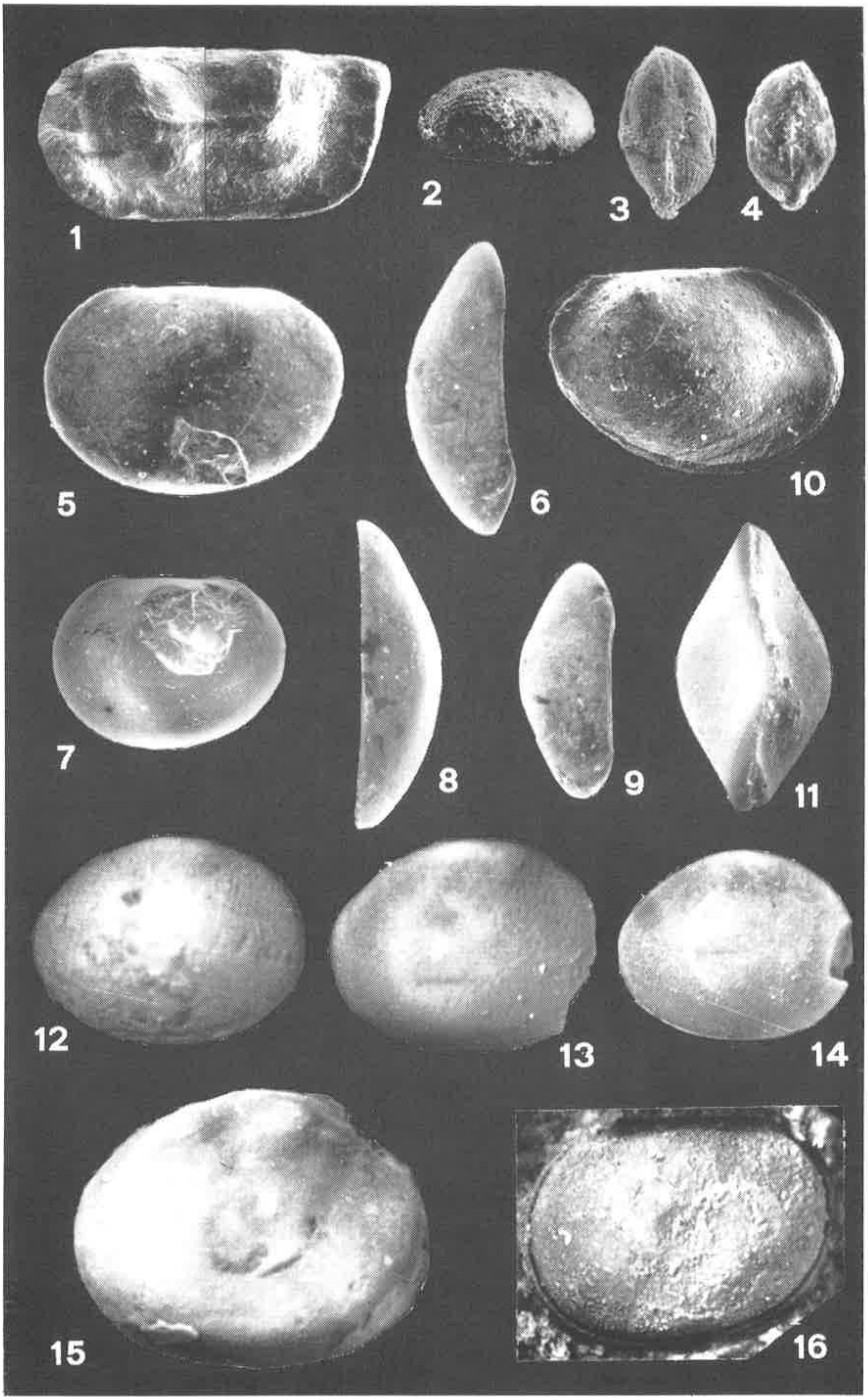
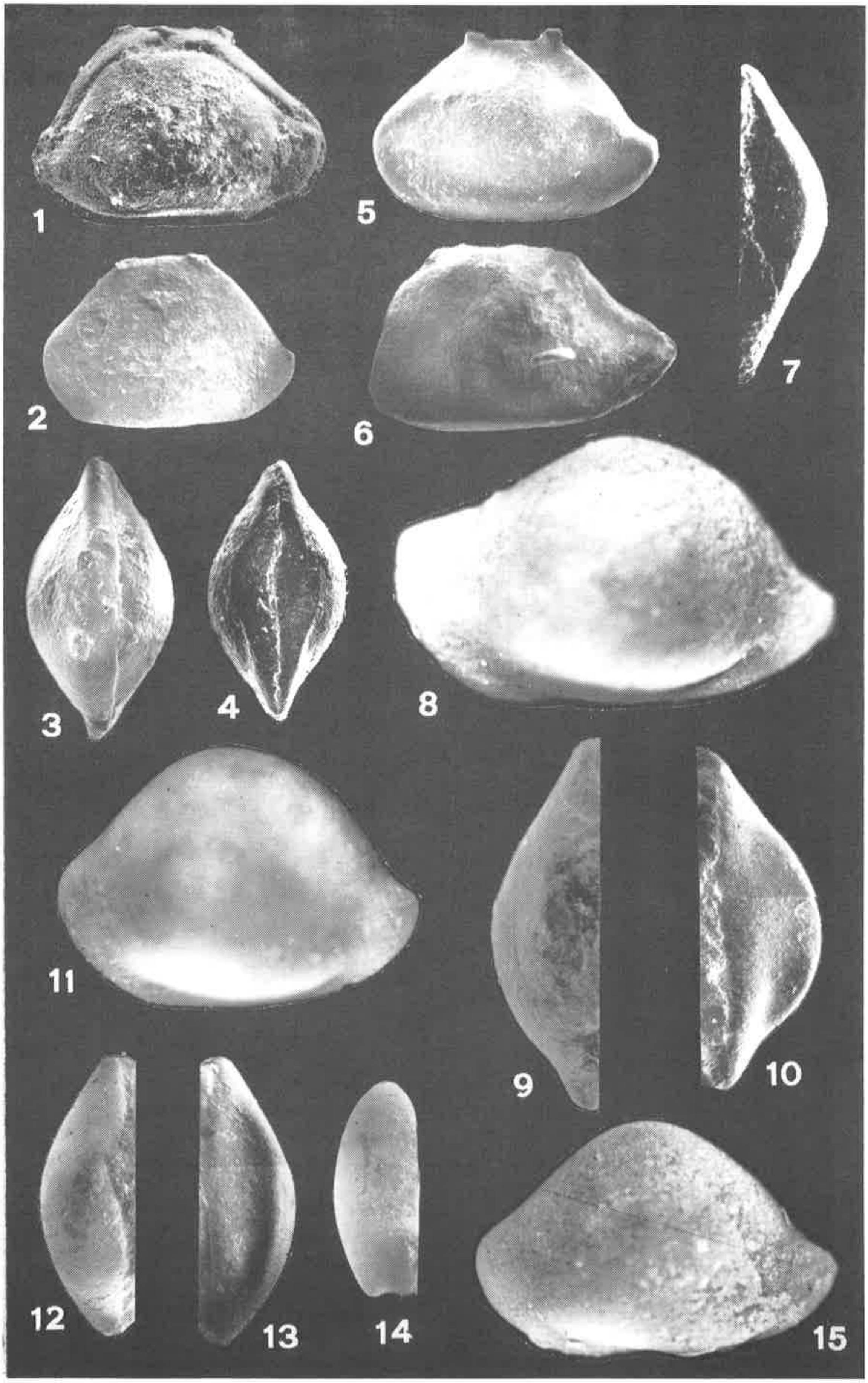


Plate II



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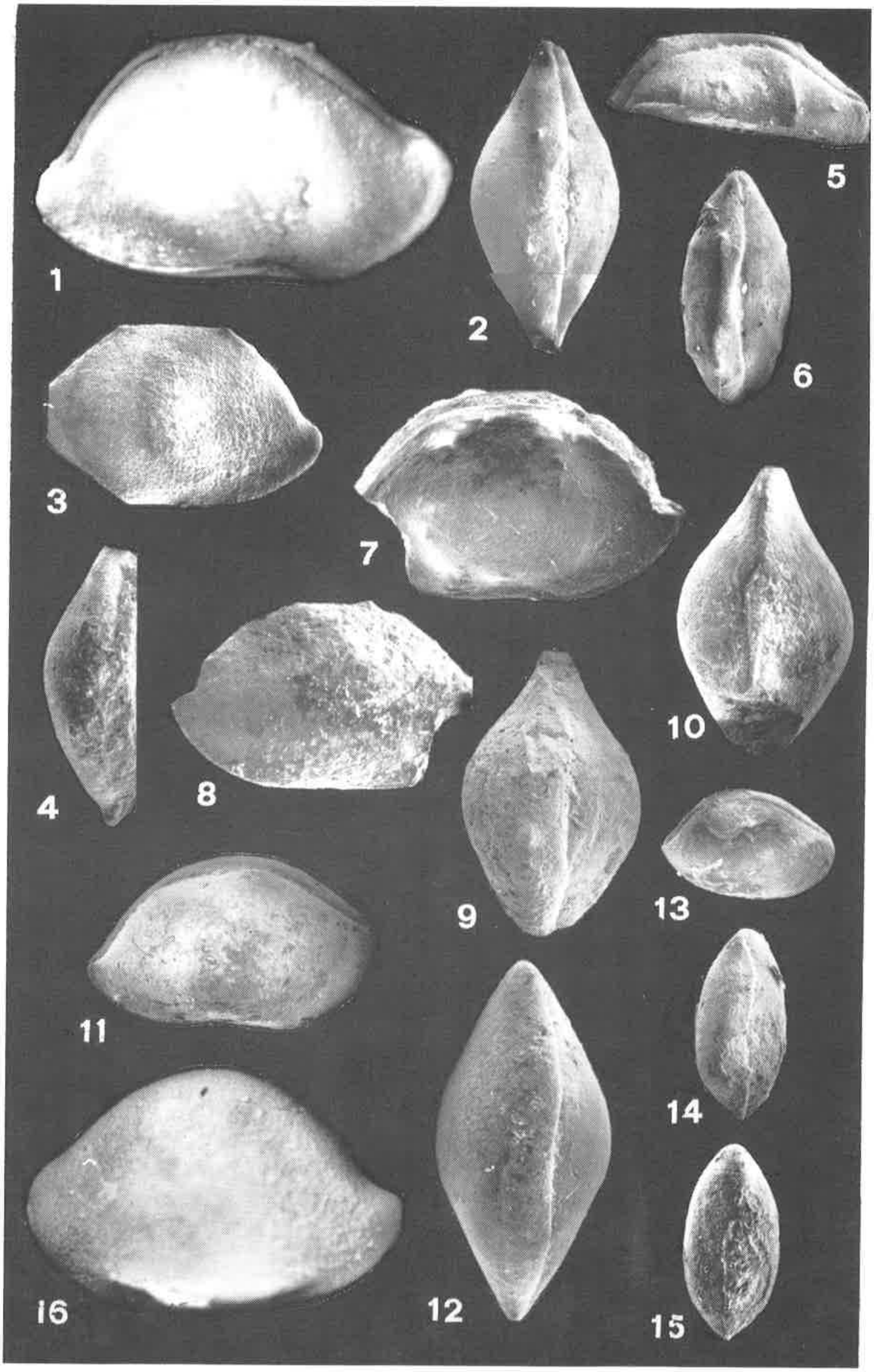

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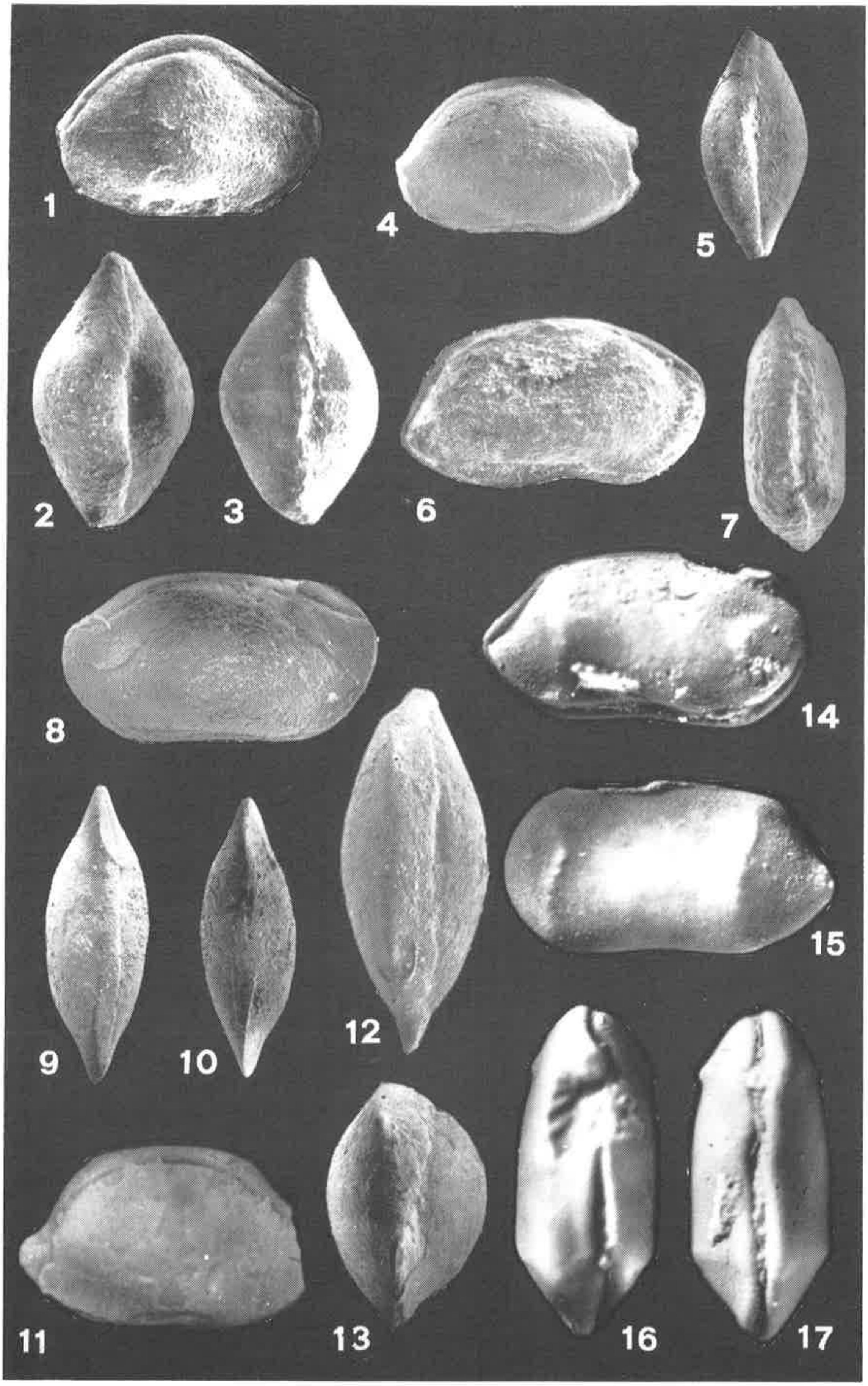
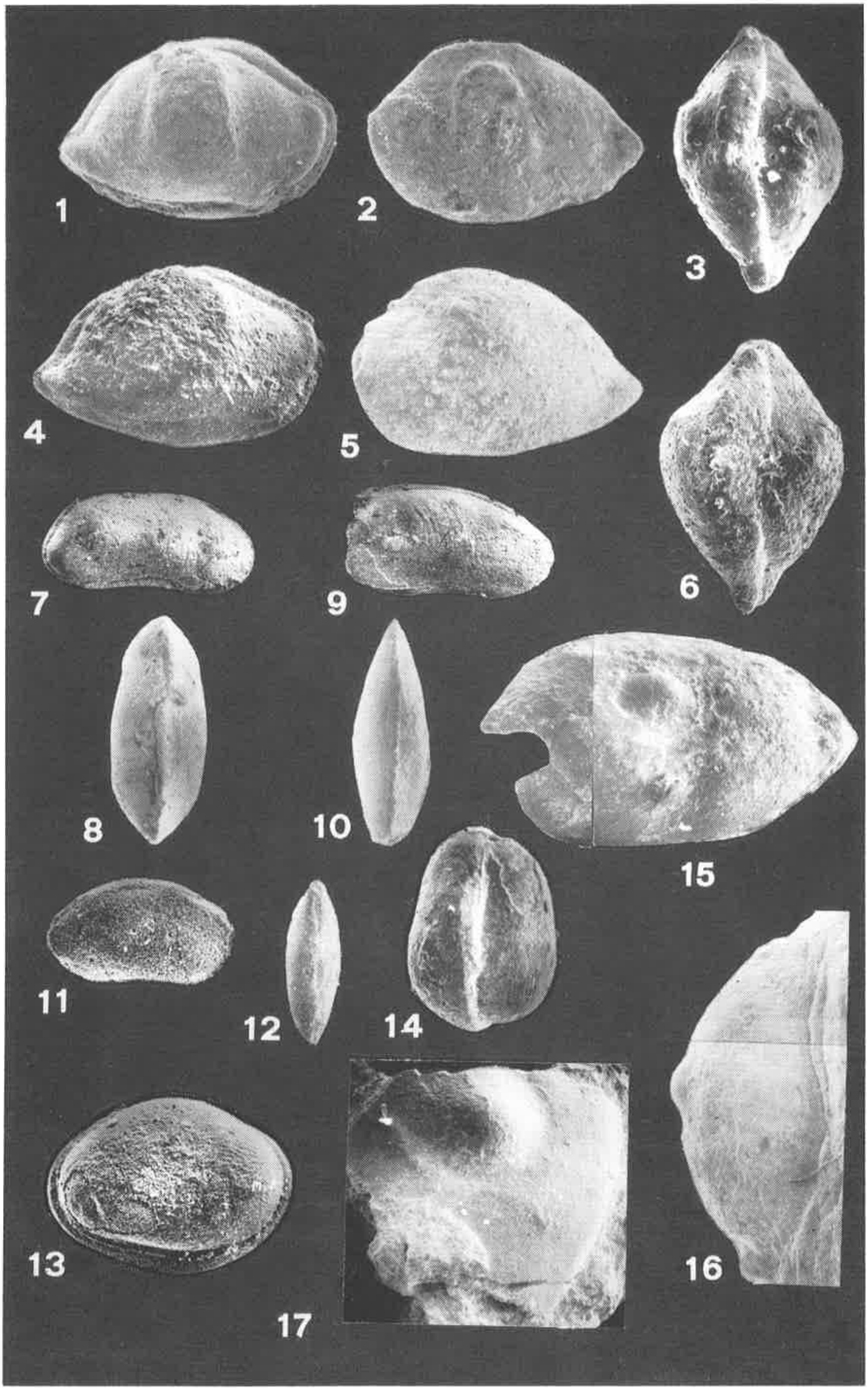


Plate V



BIOSTRATIGRAPHY OF PERMIAN DEPOSITS OF SIKHOTE-ALIN BASED ON RADIOLARIANS

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Abstract

This report presents new data on Permian *Albaillellaria* (Radiolaria) of Sikhote-Alin (Primorye region). Eleven Permian radiolarian zones have been established in the bedded chert and terrigenous deposits of Sikhote-Alin. This zones are recognized mainly on the characteristic species of *Albaillellaria,* and its distribution and domination. Radiolarians zones of Sikhote-Alin are correlated with those of Japan, North America and other regions.

1. Introduction

The upper Paleozoic stratigraphy of Sikhote-Alin was worked out from data on foraminifers (for limestones, more rarely for terrigenous rocks), on radiolarians (for bedded chert and more rarely for terrigenous rocks), and conodonts (for limestones and bedded chert) (Nikitina, 1974; Nazarov et al., 1978; Belyansky et al., 1989, 1990; Panasenko et al., 1990; Rudenko, 1991, 1994; Nikitina et al., 1992; Rudenko et al., 1992; Panasenko and Rudenko, 1995).

Radiolaria is a group of microfossils frequently preserved in siliceous and terrigenous Paleozoic and Mesozoic deposits of Sikhote-Alin. Permian radiolarians were found in bedded chert and terrigenous deposits (mudstones and carbonate-phosphate nodules) of Sikhote-Alin. Over 1000 radiolarian-bearing samples were collected from different lithological types of rocks in Sikhote-Alin.

Bedded cherts with radiolarians were found in the Samarka and Taukha terranes (Fig. 1, 2). Because the Permian bedded chert and part of the mudstones of this terranes are usually strongly deformed and occur as olistolithes within the Mesozoic olistostrome, a complete section covering the whole of the Permian has not been found yet. The thickness of the fragments of bedded chert is from one meter to several tens of meters. The age of radiolarian associations in bedded chert is confirmed by conodonts (Rybalka, 1987, 1990; Nikitina et al., 1992; Rudenko et al., 1992). Samples from bedded chert were collected bed by bed (Loc. 16a).

Terrigenous deposits with Late Permian radiolarians in Sikhote-Alin were found both in normal position (Fig. 1, 2: Loc. 13, 14, 22, 23, 24, 25), and in the olistolites (Loc. 5, 9, 10). The age of Late Permian radiolarian assemblages from terrigenous deposits of this terrane is confirmed by foraminifers, bryozoans, brachiopods, and plant fossils (Kiseleva and Rudenko, 1984; Belyansky et al., 1984).

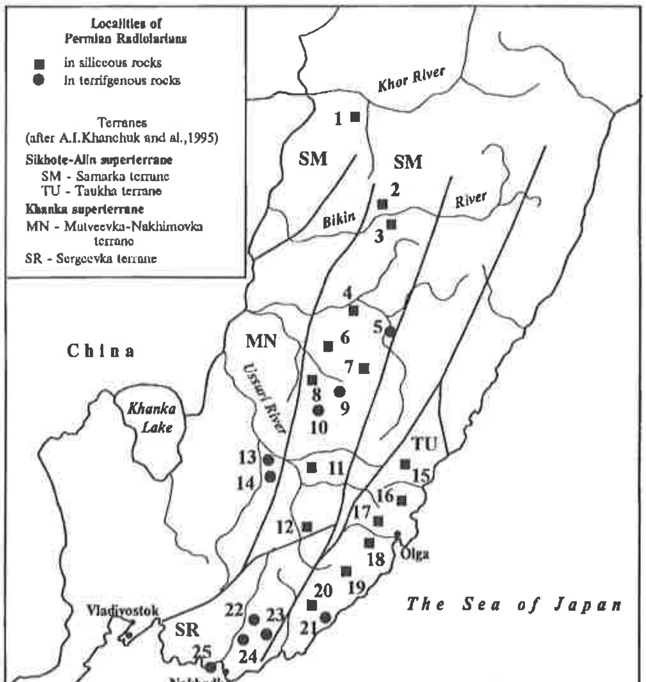

Fig.1. Localities of Permian radiolarians of Sikhote-Aline: 1 - Lyamfana Creek, 2 - Amba Mountain, 3 - Kornevoy Creek, 4 - Roshchino Village, 5 - Dalny Kut Village, 6 - Gornaya River, 7 - Orekhovka River, 8 - Pozhiga Village, 9 - Otkosnaya River, 10 - Pozhiga - Lesogorje Pass, 11 - Ogorodnaya River, 12 -Brejevka Village, 13 - Yablonovka Village, 14 - Roslavka Village, 15 - Komsomolskaya Mountain, 16 - Pantovy Creek, 17 - Fudinov Kamen' Mountain, 18 - Skalistaya Brook, 19 - Shcherbakovka Village, 20 - Pad Korejskaya, 21 - Chernaya River, 22 - Ikryanka River, 23 - Yastrebovka Village, 24 - Oryel Mountain, 25 - Sredny Cape.

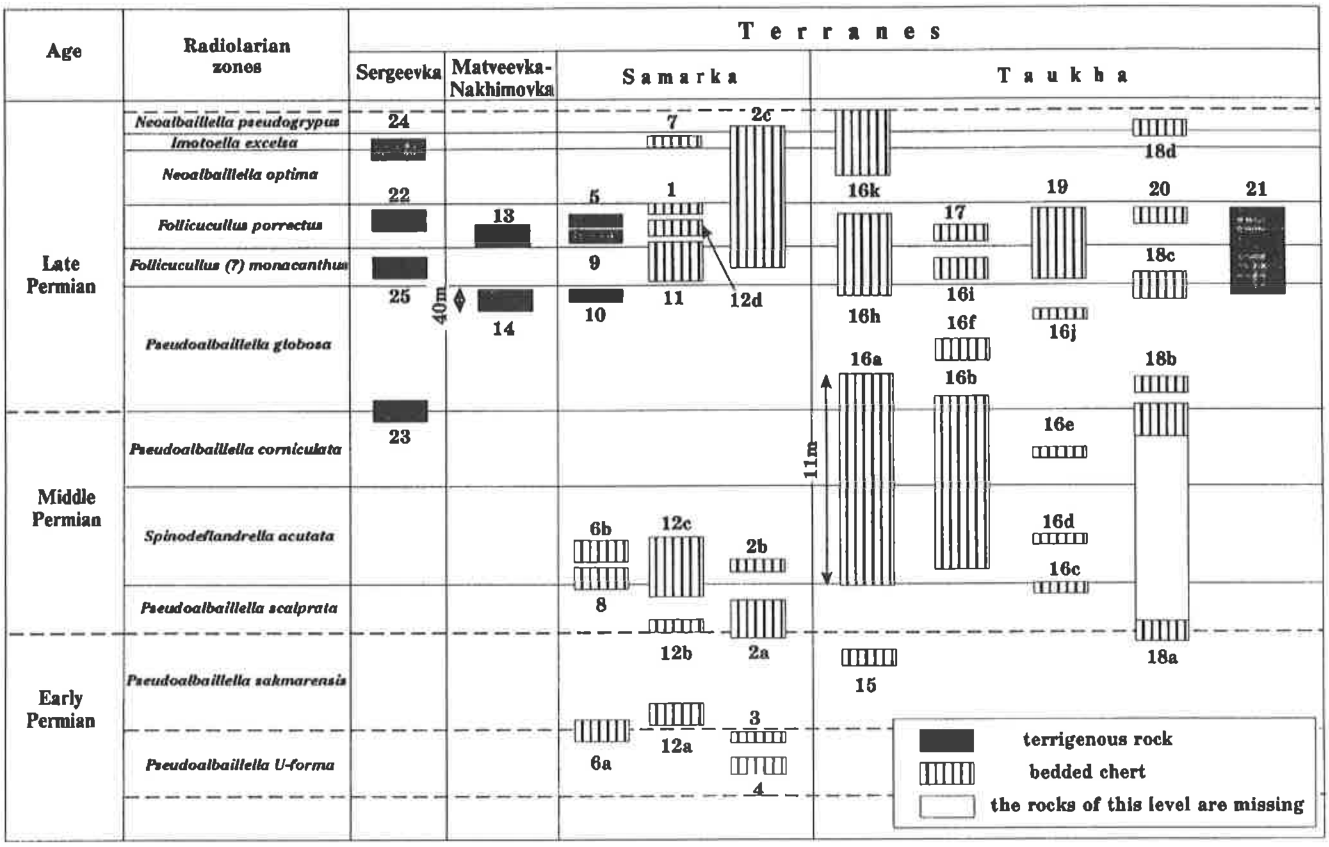

Fig. 2. Distribution of Permian deposits with radiolarian. Designation of the localities as in Fig. 1. Vertical scale for terrigenous rocks and bedded chert are different (see sections 14 and 16a).

Eleven Permian radiolarian zones have been discriminated in the bedded chert and terrigenous deposits of Sikhote-Alin. These zones are recognized mainly on the characteristic species of *Albaillellaria,* and its distribution (Fig. 3) and domination. Two localities - bedded chert near Roshchino Village (Loc. 4), and carbonate-phosphate nodules near Yastrebovka Village (Loc. 23) - contained only stauroxon radiolarians. Radiolarian zones of Sikhote-Alin are correlated with those of Japan, North America and other regions (Fig. 4).

Microfossils were extracted by using HF solution (from 1-2% to 10%). For detailed study we used a stereoscopic binocular microscope and SEM.

2. Radiolarian Zonation

(1). Pseudoalbaillella U-forma Zone.

Composition of radiolarian assemblage. This zone is characterised by an assemblage of *Ps. U-forma* Holdsworth et Jones, *Ps. annulata* Ishiga, *Ps. elegans* Ishiga et Imoto, *Ps.* cf. *lomentaria* Ishiga et Imoto and *Ps.* sp. aff.*Ps. scalprata* Holdsworth et Jones. Concerning the characteristic species, radiolarian contents in this zone are different from each other between localities of Sikhote-Alin. Only stauraxonian radiolarians are presence in the chert of Roshchino Village (Loc. 4).

Range and distribution. Lower Permian (middle part Wolfcampian) bedded chert of Japan (Ishiga and Imoto, 1980; Ishiga et al., 1984; Ishiga, 1986; Sashida, 1995). Lower Permian (Virgil-Wolfcamp) chert of North America (Murchey and Jones, 1992; Harms and Murchey, 1992). Lower Permian (Wolfcampian and Leonardian) chert in Alaska (Holdsworth and Jones, 1980).

Occurence. Sikhote-Aline, bedded chert in Samarka terrane: Kornevoy Creek (Loc. 3), Gornaya River (Loc. 6a), and probably Roshchino Village (Loc. 4).

Remarks. The presence of *Ps. elegans* together with *Ps. U-forma* allows correlation of this zone to the *Ps. U-forma* m.II A-zone (Ishiga, 1986) and partly to Assemblage Zone B of Japan (Sashida, 1995). *Ps. U-forma* zone is the oldest zone recognized in Sikhote-Alin.

(2). Pseudoalbaillella sakmarensis Zone.

Composition of radiolarian assemblage. The diagnostic and dominant species of this zone is *Ps. sakmarensis* (Kozur). *Ps.* sp. aff. *Ps. scalprata* Holdsworth et Jones, and *Ps.* cf. *lomentaria* occur in this zone. *Ps. scalprata* occurs in the upper part of this zone.

Range and distribution. Lower Permian (Sakmarian, Wolfcampian) bedded chert in the Tamba-Mino Belt of Japan (Ishiga and Imoto, 1980; Ishiga et al., 1984; Ishiga, 1986). Lower Permian (Wolfcampian) chert of Silvester allochthon, Canadian Cordillera (Harms and Murchey, 1992). Probably, chert of northern Tailand (Sashida et al., 1993).

Occurence. Sikhote-Aline, bedded chert in Taukha terrane: Komsomolskaya Mountain (Loc. 15) and Skalistaya Brook (Loc. 18a); and bedded chert in Samarka terrane: Amba Mountain (Loc. 2a), Gornaya River (Loc. 6a), and Breevka Village (Loc. 12a).

Remarks. This zone corresponds to the *Ps. lomentaria* Range-zone in Japan (Ishiga, 1986, 1990).

(3). Pseudoalbaillella scalprata Zone.

Composition of radiolarian assemblage. The diagnostic and dominant species of this zone is *Ps. scalprata* Holdsworth et Jones. *Ps. sakmarensis* Kozur, *Ps. rhombothoracata* Ishiga et Imoto occur in this zone. In the upper part of this zone *Ps. elongata* Ishiga et Imoto occurs.

Range and distribution. Lower Permian (Latest Wolfcampian) bedded chert in the Tamba-Mino Belt of Japan (Ishiga and Imoto, 1980; Ishiga et al., 1982c; Ishiga, 1986, 1990; Ishiga and Suzuki, 1984). Leonardian bedded chert of North America (Holdsworth and Jones, 1980; Harms and Murchey, 1992; Murchey and Jones, 1983, 1994). Lower Permian (Maokoun) chert of Kufeng Formation of China (Wang, 1993a, b). Possibily, chert of northern Tailand (Sashida et al., 1993).

Occurence. Sikhote-Aline, bedded chert in Taukha terrane: Pantovy Creek (16a, 16c) and Skalistaya Brook (Loc. 18a); and bedded chert in Samarka terrane: Amba Mountain (Loc. 2a), Pozhiga Village (Loc. 8), and Brejevka Village (Loc. 12b, 12c).

Remarks. *Ps. scalprata* zone is correlated with the upper part of the *Ps. lomentaria* Range-zone and most of the *Ps. scalprata* m. *rhombothoracata* A-zone in Japan (Ishiga, 1986, 1990). The conodonts *Sweetognathus whitei* (Rodes), *Gondolella inornatus*, *G.gujioensis*, *Neogondolella bisseli*, *Hindeodus typicalis*, and *Mesogondolella idahoensis* occur in the bedded chert of Pantovy Creek (Loc. 16, definition by S.V. Rybalka). The top of this zone nearly corresponds to the first occurrence of *Spinodeflandrella* species.

(4). Spinodeflandrella acutata Zone.

Composition of radiolarian assemblage. The species characteristic and dominant in this zone is *Spinodeflandrella acutata* Rudenko. *S. sinuata* Ishiga et Watase, *S. bicornuta* Rudenko et Panasenko and *Albaillella asymmetrica* Ishiga et Imoto occur in this zone. In the lower part of this zone, *Ps. rhombothoracata* Ishiga et Imoto, *S. obtusa* Rudenko and *Ps. elegans* Ishiga et Imoto occur, while in the upper part *Ps.* sp. *D* (in Ishiga et al., 1982c) and *Ps.* sp. *C* (in Ishiga et al., 1982c) occur.

Range and distribution. Lower Permian (Leonardian) bedded chert of Japan (Ishiga et al., 1982b, c; Ishiga and Suzuki, 1984; Ishiga et al., 1986; Ishiga, 1986, 1990). Lower Permian bedded chert of Koryak Upland (Rudenko, 1991; Vishnevskaya, 1994). Lower Permian (Leonardian) chert of North America (Murchey and Jones, 1992).

Occurence. Sikhote-Alin, bedded chert in Samarka terrane: Amba Mountain (Loc. 2b), Gornaya River (Loc. 6b), Pozhiga Village (Loc. 8), Brejevka Village (Loc. 12c); bedded chert in Taukha terrane: Pantovy Creek (Loc. 16a, 16b, 16d).

Remarks. *S. sinuata* is a very rare species in the bedded chert of Sikhote-Alin. The top of this zone corresponds to the first appearance of *Ps. corniculata* Rudenko and latest

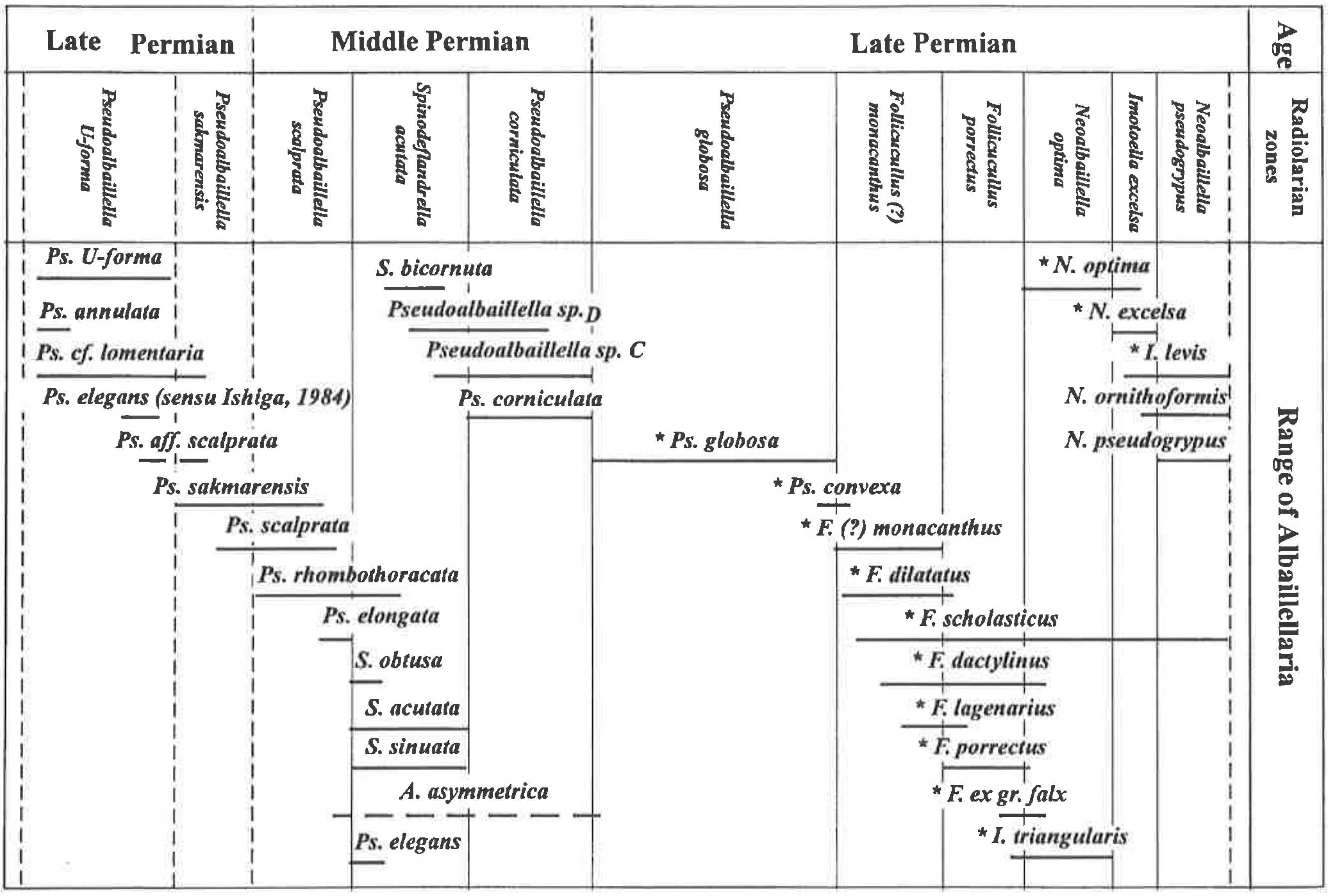

Fig. 3. Stratigraphic range of the important species of Permian *Albaillellaria* in Sikhote-Aline. Asterisk indicate the species found in both terrigenous rocks and bedded chert.

Sikhote-Aline (Rudenko, Panasenko, this report)		Japan (Ishiga, 1986, 1990)		North America (Murchey, Holdswoth, Jones, 1983)		Tethyan and Circum-Pacific (Kozur, 1993, 1994)	
	N. pseudogrypus		*N. ornithoformis* A-zone			Chang-xingian	*N. grypa* Zone
	Imotoella excelsa	Late Permian		Ochoa	*N. optima*	Dzhul-fian	*N. ornithoformis* Zone
	N. optima		*N. optima* A-zone				*F. ventricosus* - *Ish. scholasticus* A. Zone
Late Permian	*F. porrectus*		*F. scholasticus* A-zone	Guadalupian	*F. scholasticus*	Capi-tanian	*F. sharveti* - *F. porrectus* A. Zone
	F.(?) monacanthus		*F. monacanthus* R-zone				*F. monacanthus* Zone
	Ps. globosa	Middle Permian	*Ps. globosa* A-zone		*Ps. fusiformis*	Wordian	*Paraf. fusiformis* - *Paraf. globosus* A. Zone
	Ps. corniculata		*Ps. longtanansis* A-zone			Roadian	*Paraf. longtanensis* Zone
Middle Permian	*Spinodeflandrella acutata*		*A. sinuata* R-zone	Leonardian			*S. foremanae* - *Paraf. cornelli* A. Zone
	Ps. scalprata		*Ps. scalprata* m. *rhombothoracata* A-zone		*Ps. aff. rhombothoracata* - *Ps. aff. sakmarensis*	Leonar-dian	*Ps. rhombothoracata* Zone
					Ps. scalprata		*Paraf. ornatus* Zone
Early Permian	*Ps. sakmarensis*	Early Permian	*Ps. lomentaria* R-zone	Wolfcampian		Artin-skian	*Paraf. lomentaria* A. Zone
	Ps. U-forma		*Ps. U-forma* m. *II* A-zone		*Ps.* sp. *B* - *Ps. elegans*	Sakma-rian	*Ps. (Kiticonus) elegans* Zone
			Ps. U-forma m. *I* A-zone		*Ps. U-forma* - *Ps. elegans*	Asselian	*Curvalbaillella U-forma* A. Zone
			Ps. bulbosa A-zone				
Carboni-ferous		Late Carboni-ferous	*Ps. nodosa* A-zone			Upper Gzhelian (Carbon)	*Curvalbaillella bulbosa* Zone

Fig. 4. Correlation of the Upper Paleozoic Radiolarian zones.

representatives of *Spinodeflandrella*. This zone corresponds to the *S. sinuata* range-zone in Japan (Ishiga, 1986, 1990). Possibly, this zone in the bedded chert corresponds to the assemblage with *Albaillella foremanae* and *Pseudoalbaillella cona* (Cornell and Simpson, 1985) and the *Spinodeflandrella foremanae - Parafollicucullus cornelli* assemblage zone (Kozur, 1993, 1994) from the Bone Spring Limestone of the Delaware Basin of West Texas.

(5). Pseudoalbaillella corniculata Zone.

Composition of radiolarian assemblage. The diagnostic and dominant species of this zone is *Ps. corniculata* Rudenko. *Ps.* sp. *D* (in Ishiga et al., 1982c), *Ps.* sp. *C* (in Ishida et al., 1982c) and *Albaillella asymmetrica* Ishiga et Imoto occur in this zone. Concerning the characteristic species, radiolarian content of this zone differs between terrigenous deposits and bedded chert in Sikhote-Alin. The carbonate-phosphate nodules from mudstones sequences near Yastrebovka Village contain only stauraxon radiolarian.

Range and distribution. Lower Permian (Late Leonardian) mudstone and bedded chert of Japan (Ishiga and al., 1982b, c; Ishiga and al., 1986; Ishiga, 1986). Probably, Lower Permian (Leonardian) chert of North America (Murchey and Jones, 1992). Lower Permian (Maokoun) chert of Kufeng Formation of China (Wang, 1993a).

Occurence. Sikhote-Alin, bedded chert in Taukha terrane: Pantovy Creek (Loc. 16a, 16b, 16e), Skalistaya Brook (Loc. 18a). Probably, terrigenous deposits in Sergeevka terrane: Yastrebovka Village (Loc. 23).

Remarks. This zone is set up above the *Sp. acutata* Zone in the bedded chert of Pantovy Creek, based on the age of the overlying and the underlying zones. The conodonts *Mesogondolella idachoensis*, and *M. serrata* were found from bedded chert in Pantovy Creek (Loc. 16a, definition by S.V. Rybalka). This zone corresponds to the *Ps. longtanensis* (*Ps.* sp. *C*) assemblage-zone in Japan (Ishiga, 1986, 1990). This zone has some similarity with the radiolarian fauna with *Ps. longtanensis* from the Kufeng Formation, Nanjing, which is correlated with the Maokouan (Sheng and Wang, 1985).

(6). Pseudoalbaillella globosa Zone.

Composition of radiolarian assemblage. The index-species of this zone is *Ps. globosa* Ishiga et Imoto. In the upper part of this zone *Ps. convexa* Rudenko et Panasenko occurs. In the uppermost part of the terrigenous deposits in Pozhiga-Lesogorje Pass (Loc. 10) and Roslavka Village (Loc. 14) many new species of *Albaillellaria* (Rudenko, unpubl. data) were found. Concerning the characteristic species, radiolarian content in the upper part of this zone differs between terrigenous deposits and bedded chert in Sikhote-Alin. The carbonate-phosphate nodules from mudstones sequences near Yastrebovka Village contain only stauraxon radiolarian.

Range and distribution. Late Leonardian to Guadalupian mudstone and bedded chert of Japan (Ishiga and al., 1982b, c; Ishiga and al., 1986). Latest Leonardian chert of

North America (Murchey and Jones, 1992, 1994; Harms and Murchey, 1992). Latest Leonardian Bone Spring Limestone of Texas (Murchey et al., 1983). Probably, chert of Gufeng Formation in China (Wang, 1995).

Occurence. Sikhote-Alin, bedded chert in Taukha terrane: Pantovy Creek (Loc. 16a, 16b, 16f, 16j, 16h), Skalistaya Brook (Loc. 18a, 18b, 18c). Mudstones in Taukha terrane: Chernaya River (Loc. 21); mudstones in Samarka terrane: Pozhiga-Lesogorje Pass (Loc. 10); and terrigenous deposits in Sergeevka terrane: Yastrebovka Village (Loc. 23). Probably, mudstones near Roslavka Village (Loc. 14).

Remarks. This zone is equivalent to the *Ps. globosa* assemblage-zone in Japan (Ishiga, 1986, 1990). The top of this zone is defined by the first occurence of *F.*(?) *monacanthus* Ishiga et Imoto. Concerning the characteristic species, radiolarian content of this zone differs between terrigenous deposits and bedded chert in Sikhote-Alin.

(7). Follicucullus (?) monacanthus Zone.

Composition of radiolarian assemblage. The diagnostic species of this zone is *F.* (?) *monacanthus* Ishiga et Imoto. *F. dilatatus* Rudenko, *F. scholasticus* Ormiston et Babcock, *F. dactylinus* Rudenko et Panasenko, and *F. lagenarius* Rudenko occur in this zone. In the lower part of this zone, *Pseudoalbaillella convexa* Rudenko et Panasenko occurs.

Range and distribution. Late Leonardian or Early Guadalupian bedded chert and mudstone of Japan (Ishiga et al., 1982b,c; Ishiga et al., 1986; Ishiga, 1986, 1990). Leonardian to Early Guadalupian chert of North America (Murchey and Jones, 1992, 1994). Chert of nothern Tailand (Sashida et al., 1993). Chert of Gufeng Formation in China (Wang, 1995).

Occurence. Sikhote-Alin, bedded chert in Samarka terrane: Amba Mountain (Loc. 2c), Ogorodnaya River (Loc. 11); bedded chert in Taukha terrane: Pantovy Creek (Loc. 16h, 16i), Skalistaya Brook (Loc. 18c), Shcherbakovka Village (Loc. 19). Terrigenous deposits in Taukha terrane: Chernaya River (Loc. 21), and mudstones in Sergeevka terrane: Sredny Cape (Loc. 25).

Remarks. This zone is equivalent to the *F. monacanthus* Range-zone in Japan (Ishiga, 1986, 1990). The top of this zone is defined by the first occurence of *F. porrectus*.

(8). Follicucullus porrectus Zone.

Composition of radiolarian assemblage. The diagnostic and dominant radiolarian of this zone is *F. porrectus* Rudenko. *F. scholasticus* Ormiston et Babcock, and *F. dactylinus* Rudenko et Panasenko occur in this zone. In the lower part of this zone *F. dilatatus* Rudenko and *F. lagenarius* Rudenko occur, while in upper part *F.* ex gr. *falx* Caridroit et De Wever occurs.

Range and distribution. Late Permian (*Lepidolina kumaensis* Zone) bedded chert and mudstone in Japan (Ishiga and Imoto, 1980; Ishiga et al., 1982b, c; Ishiga, 1986, 1990; Ishiga et al., 1986). Guadalupian chert of North America (Ormiston and Babcock, 1979; Murchey and Jones, 1983; 1994). Probably, chert of Kufeng Formation and chert with Follicucullus assemblages from Yunnan of China (Wang, 1993b; Feng and Lin, 1993). Possibily Permian chert (Upper Kazanian to Lower Tatarian) chert of New Zealand (Caridroit and Ferriere, 1988). Chert from Busuanga Islands (Cheng, 1989; Tumanda et al., 1990).

Occurence. Sikhote-Alin, bedded chert in Samarka terrane: Lyamfana Creek (Loc. 1), Amba Mountain (Loc. 2c), Ogorodnaya River (Loc. 11), Brejevka Village (12d), bedded chert in Taukha terrane: Pantovy Creek (Loc. 16h), Fudinov Kamen Mountain (Loc. 17), Shcherbakovka Village (Loc. 19), Pad Korejskaya (Loc. 20). Mudstones in Samarka terrane: Dalny Kut Village (Loc. 5) (Belyannsky and al., 1984), and Otkosnaya River (Loc. 9). Terrigenous deposits in Taukha terrane: Chernaya River (Loc. 21). Spongolites in Sergeevka terrane: Ikryanka River (Loc. 22). Mudstones near Yablonovka Village (Loc. 13) (Kiseleva and Rudenko, 1984).

Remarks. This zone corresponds to the *F. scholasticus* assemblage-zone in Japan (Ishiga, 1986, 1990). The top of this zone is defined by the first occurence of *Neoalbaillella optima* Takemura et Nakaseko.

(9). Neoalbaillella optima Zone.

Composition of radiolarian assemblage. The diagnostic radiolarian of this zone is *N. optima* Ishiga et Imoto. *Imotoella triangularis* (Ishiga, Kito et Imoto) and *F. scholasticus* occur in this zone. In addition, *F. dactylinus* and *F.* ex gr. *falx* occur in the lower part of this zone.

Range and distribution. Late Permian (Dzhulfian) bedded chert of Japan (Ishiga and al., 1982a, b, c). Probably, Guadalupian or younger chert of North America (Murchey and Jones, 1992). Late Longtan chert from Yunnan of China (Feng and Lin, 1993). Chert from Busuanga Islands (Cheng, 1989; Tumanda et al., 1990).

Occurence. Sikhote-Alin, bedded chert in Samarka terrane: Amba Mountain (Loc. 2c); bedded chert in Taukha terrane: Pantovy Creek (Loc. 16k). Terrigenous deposits in Sergeevka terrane: Oryel Mountain (Loc. 24).

Remarks. This zone corresponds to most of the *N. optima* assemblage-zone in Japan (Ishiga, 1986, 1990). The top of this zone is defined by the first occurrence of *Imotoella excelsa* (Ishiga, Kito et Imoto).

(10). Imotoella excelsa Zone.

Composition of radiolarian assemblage. The diagnostic species of this zone is *I. excelsa* (Ishiga, Kito et Imoto). *N. optima*, *Imotoella levis* (Ishiga, Kito et Imoto), and *N. ornithoformis* Takemura et Nakaseko occur in this zone.

Range and distribution. Bedded chert of Japan, as part of *N. optima* and *N. ornithoformis* zones (Ishiga, 1986, 1990). Probably, chert of North America (Noble and Renne, 1990; Murchey and Jones, 1994; Blome and Reed, 1995), and chert of New Zeland (Caridroit et Ferriere, 1988). Chert from Busuanga Islands (Cheng, 1989; Tumanda et al., 1990).

Occurence. Sikhote-Alin, bedded chert in Samarka terrane: Amba Mountain (Loc. 2c), and Orekhovka River (Loc. 7); bedded chert in Taukha terrane: Pantovy Creek (Loc. 16k), and Skalistaya Brook (Loc. 18d). Mudstones in Sergeevka terrane: Oryel Mountain (Loc. 24).

Remarks. The diagnostic species has a short interval of stratigraphical distribution and is a good age marker. This zone corresponds to the uppermost part of the *N. optima* Assemblage-zone and lowermost part of *N. ornithoformis* A-zone in Japan (Ishiga, 1986, 1990). The top of this zone is defined by he first occurence of *Neoalbaillella pseudogrypus* Sashida et Tonishi.

(11). Neoalbaillella pseudogrypus Zone.

Composition of radiolarian assemblage. The diagnostic species of this zone is *Neoalbaillella pseudogrypus* Sashida et Tonishi. *Imotoella levis* (Ishiga, Kito et Imoto), *N. ornithoformis* and *Follicucullus scholasticus* are present in this zone.

Range and distribution. Upper Permian (probably upper part of the Upper Permian) bedded chert of the Tamba-Mino Belt in Japan (Ishiga et al., 1982a, b; Ishiga, 1986, 1990). Probably, chert of North America (Murchey and Jones, 1994; Blome and Reed, 1995). Early Changxing chert from Yunnan of China (Feng and Lin, 1993).

Occurence. Sikhote-Alin, bedded chert in Samarka terrane: Amba Mountain (Loc. 2c), and bedded chert in Taukha terrane: Pantovy Creek (Loc. 16k), and Skalistaya Brook (Loc. 18d).

Remarks. Probably, this zone corresponds to the upper part of *N. ornithoformis* Assemblage-zone in Japan (Ishiga, 1986, 1990).

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Plate I

Permian radiolarians of Sikhote-Aline
(marker A = 100 micrometers: Fig. 1-10; marker B =10 micrometers: Fig. 11).

Fig. 1. *Pseudoalbaillella annulata* Ishiga. Bedded chert, *Ps. U-forma* Zone, Gornaya River (Loc. 6a, sm.42c-87).

Fig. 2. *Pseudoalbaillella* cf. *lomentaria* Ishiga et Imoto. Bedded chert, Ps. U-forma Zone, Gornaya River (Loc. 6a, sm.42c-87).

Fig. 3. *Pseudoalbaillella sakmarensis* (Kozur). Bedded chert, *Ps. scalprata* Zone, Amba Mountain (Loc. 2a, sm. 37-60).

Fig. 4. *Pseudoalbaillella sakmarensis* (Kozur). Bedded chert, *Ps. sakmarensis* Zone, Komsomolskaya Mountain (Loc. 15, sm. 1302).

Fig. 5. *Pseudoalbaillella rhombothoracata* Ishiga et Imoto. Bedded chert, *Ps. scalprata* Zone, Amba Mountain (Loc. 2a, sm. 37-37).

Fig. 6. *Pseudoalbaillella scalprata* Holdsworth et Jones. Bedded chert, *Ps. scalprata* Zone, Pantovy Creek (Loc. 16a, sm. 25-200).

Fig. 7. *Pseudoalbaillella elegans* Ishiga et Imoto. Bedded chert, *S. acutata* Zone, Amba Mountain (Loc. 2b, sm. 267-7).

Fig. 8. *Albaillella asymmetrica* Ishiga et Imoto. Bedded chert, *S. acutata* Zone, Pantovy Creek (Loc. 16a, sm. 25-108).

Fig. 9. *Spinodeflandrella acutata* Rudenko et Panasenko. Bedded chert, *S. acutata* Zone, Pantovy Creek (Loc. 16a, sm. 249-5).

Fig. 10, 11. *Spinodeflandrella bicornuta* Rudenko et Panasenko. Bedded chert, *S. acutata* Zone, Breyevka Village (Loc. 12a, sm. 477-3).

Plate II

Permian radiolarians of Sikhote-Aline
(marker = 100 micrometers: all Fig.)

Fig. 1. *Pseudoalbaillella* sp. C (in Ishiga, Kito et Imoto, 1982). Bedded chert, *S. acutata* Zone, Pantovy Creek (Loc. 16a, sm. 25-139).

Fig. 2. *Pseudoalbaillella* sp. D (in Ishiga, Kito et Imoto, 1982). Bedded chert, *Ps. corniculata* Zone, Pantovy Creek (Loc. 16a, sm. 25-41).

Fig. 3. *Pseudoalbaillella corniculata* Rudenko et Panasenko. Bedded chert, *Ps. corniculata* Zone, Pantovy Creek (Loc. 16b, sm. 29-1).

Fig. 4. *Pseudoalbaillella corniculata* Rudenko et Panasenko. Bedded chert, *Ps. globosa* Zone, Pantovy Creek (Loc. 16a, sm. 25-24).

Fig. 5. *Pseudoalbaillella globosa* Ishiga et Imoto. Tuffaceous mudstones, *Ps. globosa* Zone, Roslavka Village (Loc. 14, sm. 14-16).

Fig. 6. *Pseudoalbaillella globosa* Ishiga et Imoto. Bedded chert, *Ps. globosa* Zone, Pantovy Creek (Loc. 16f, sm. 27-3).

Fig. 7. *Follicucullus (?) monacanthus* Ishiga et Imoto. Bedded chert, *F. (?) monacanthus* Zone, Pantovy Creek (Loc. 16h, sm. 25-210).

Fig. 8. *Follicucullus (?) monacanthus* Ishiga et Imoto. Bedded chert, *F. (?) monacanthus* Zone, Ogorodnaya River (Loc. 11, sm. 861-9).

Plate I

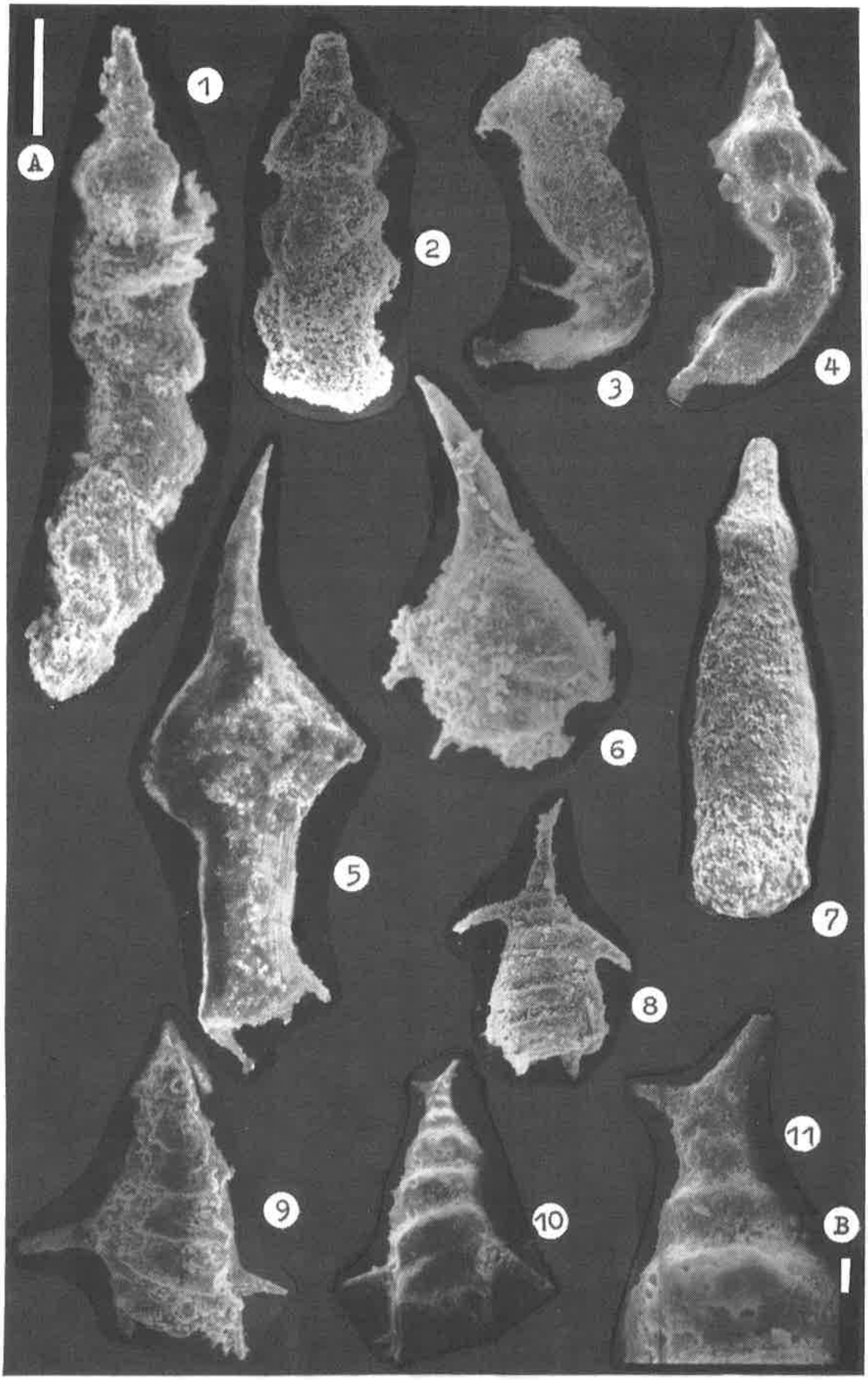


Plate II

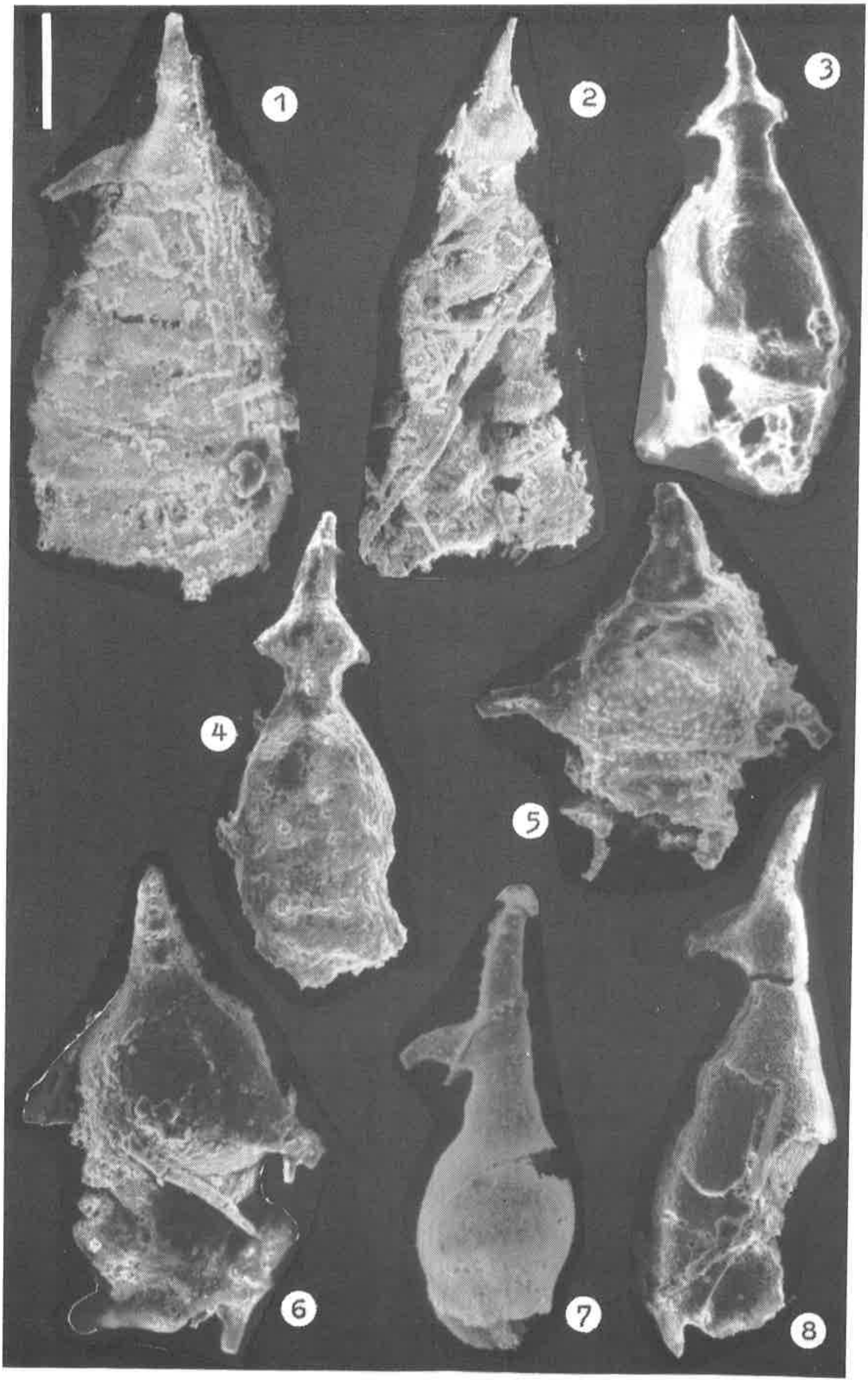


Plate III

Permian radiolarians of Sikhote-Aline
(marker = 100 micrometers: A - Fig. 1-11 and 15, B - Fig. 12, C - Fig. 13, D - Fig. 14).

Fig. 1. *Follicucullus scholasticus* Ormiston et Babcock. Bedded chert, *F.(?) monacanthus* Zone, Ogorodnaya River (Loc. 11, sm. 861-10).

Fig. 2. *Follicucullus scholasticus* Ormiston et Babcock. Bedded chert, *F. porrectus* Zone, Pantovy Creek (Loc. 16h, sm. 25-227).

Fig. 3. *Follicucullus dilatatus* Rudenko. Bedded chert, *F.(?) monacanthus* Zone, Ogorodnaya River (Loc. 11, sm. 861-9).

Fig. 4. *Follicucullus lagenarius* Rudenko. Bedded chert, *F.(?) monacanthus* Zone, Pantovy Creek (Loc. 16i, sm. 503-9).

Fig. 5. *Follicucullus porrectus* Rudenko. Bedded chert, *F. porrectus* Zone, Pantovy Creek (Loc. 16h, sm. 25-221).

Fig. 6, 7. *Follicucullus dactylinus* Rudenko et Panasenko. Bedded chert, *F. porrectus* Zone, Pantovy Creek (Loc. 16i, sm. 503-11).

Fig. 8. *Imotoella triangularis* (Ishiga, Kito et Imoto). Mudstones, *I. excelsa* Zone, Oryel Mountain (Loc. 24, sm. 6-16).

Fig. 9. *Imotoella excelsa* (Ishiga, Kito et Imoto). Mudstones, *I. excelsa* Zone, Oryel Mountain (Loc. 24, sm. 6-16).

Fig. 10. *Follicucullus* ex gr. *falx* Caridroit et De Wever. Bedded chert, *F. porrectus* Zone, Lyamfana Creek (Loc. 1, sm. L-395).

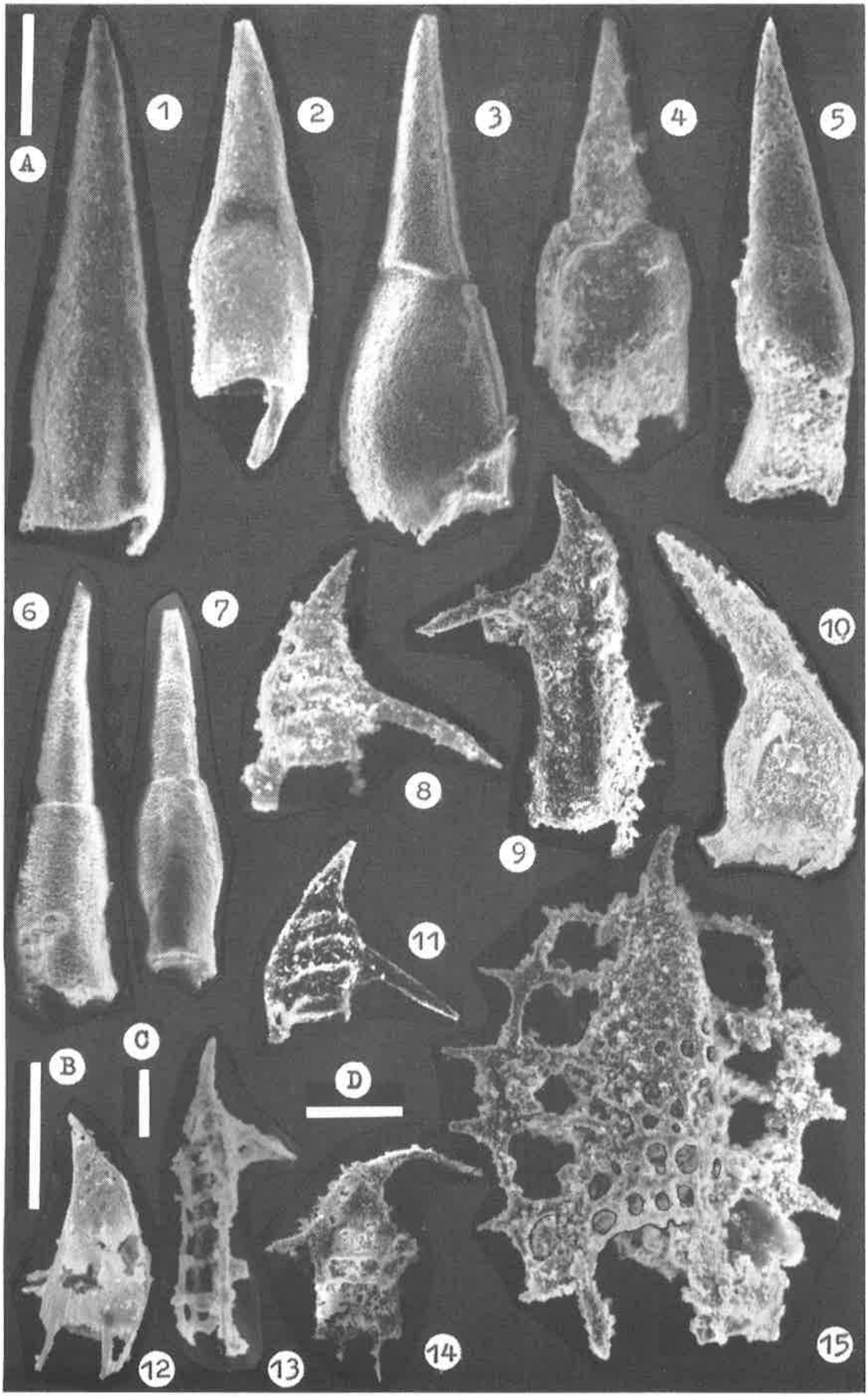
Fig. 11. *Imotoella levis* (Ishiga, Kito et Imoto). Bedded chert, *I. excelsa* Zone, Orekhovka River (Loc. 7, sm. D-156).

Fig. 12. *Imotoella levis* (Ishiga, Kito et Imoto). Bedded chert, *N. pseudogrypus* Zone, Skalistaya Brook (Loc. 18e, sm. 703-34).

Fig. 13. *Neoalbaillella ornithoformis* Takemura et Nakaseko. Bedded chert, *N. pseudogrypus* Zone, Skalistaya Brook (Loc. 18e, sm. 703-34).

Fig. 14. *Neoalbaillella pseudogrypus* Sashida et Tonishi. Bedded chert, *N. pseudogrypus* Zone, Pantovy Creek (Loc. 16k, sm. 64-13).

Plate III



UPPER PLIENSBACHIAN RADIOLARIA FROM THE SOUTH PRIMORYE (RUSSIAN FAR EAST)

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Abstract

Radiolaria are used to distinguish an informal Canutus idomitus Zone for Jurassic strata of the late Pliensbachian age from the Okrainka Formation, South Sikhote-Alin, Russian Far East. The radiolarian assemblages were found in close association with ammonite suites, providing the biostratigraphic control. Upper Pliensbachian Radiolaria from the South Sikhote-Alin are compared with other Lower Jurassic assemblages from the circum-Pacific region.

1. Introduction

The study is restricted to the Okrainka Formation, which outcrops in South Sikhote-Alin, Primorye, Russian Far East (Fig. 1). The purpose of this study is to contribute to the developing local zonation of the Jurassic on the basis of radiolarians.

The present paper focuses on the description of the upper Pliensbachian Radiolaria from the lowermost part of the Okrainka Formation. Radiolarian assemblages are dated by using closely associated suites of ammonites.

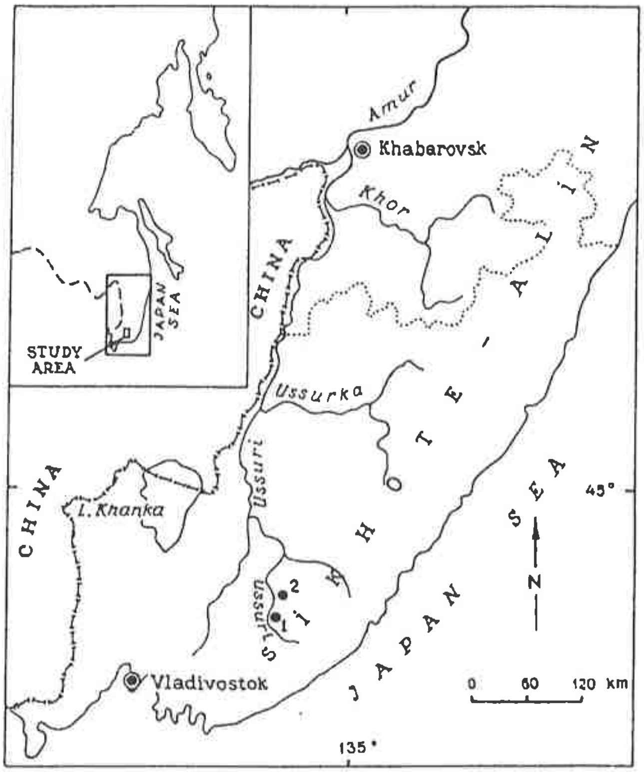

Fig. 1. Location map of Primorye. Localities: 1-Basin of the Poperechka River, 2-Basin of the Izvilinca River.

Ammonites were collected due to previous and present biostratigraphic investigation of the Jurassic sequences. According to Sey and Kalachova (1980) upper Pliensbachian ammonites are referred to Northwest European ammonite zones and compared provisionally to North American ammonite sequences.

Middle and Upper Jurassic Radiolaria from the South Sikhote-Alin will be discussed in other reports.

2. Material and Methods

The Okrainka Formation consists of monotonous thin-bedded dark grey and black siltstone, mudstone and shale succession with interbeds of basalt and occasional limestone. This Formation is covered unconformably by Upper Jurassic strata of the Pogskaya Formation. The contacts with underlying Upper Triassic strata has been obscured by faulting or cannot be seen.

The two localities were examined in the area of the Ussuri River: (1) in the basin of the Poperechka River and (2) in the basin of the Izvilinka River (Text-fig.3).

1. Basin of the Poperechka River. Seven radiolarian samples were collected at this locality. Four of them (samples 340, 340/1, 63c/5, 63c/6) contain ammonites. These ammonites were identified by I.V. Konovalova («Primorgeologiya», personal communication) as «*Dactylioceras*» *polymorphum* Fucini and *Amaltheus* cf. *algovianum* (Oppel). According to Konovalova these species are indicative of the *Amaltheus stokesi* Zone. Three other samples (339/21, 339/23, 63c/10) were collected from overlying tuffaceous siltstone.

2. Basin of the Isvilinka River. At this locality 16 m of grey and black siltstone are exposed. Contacts with underlying and overlying layers cannot be seen. A number of samples (35c/6, 38c/3, 7, 9, 10, 11, 13, 14, 15, 18, 20, 21) contain radiolarians. Ammonites from this section were identified by I.I. Sey and E.D. Kalachova (1980) as *Amaltheus stokesi* (Sowerby), *A.* sp. indet. *Arieticeras japonicum* Matsumoto, *A.* sp. aff. *algovianum* (Oppel), *Fontanelliceras* cf. *fontanellence* (Gemmellaro),

«*Dactylioceras*» *polymorphum* Fucini, «*D*». *simplexs* Fucini, *Protogrammoceras* cf. *sirotinum* (Bettoni), *Paltarpites* sp. indet. According to Sey and Kalachova these forms are indicative of the upper Pliensbachian *Amaltheus stokesi* Zone, the *Amaltheus margaritatus* Zone and perhaps, the *Paltarpites spinatum* Zone.

Radiolarians were extracted from siltstone, mudstone and tuffaceous cherts by means of 1-2 % hydrofluoric acid. The scanning electron microscope in conjaction with light microscope were used for determination of these radiolarian faunas.

Radiolarian assemblages from these two localities show only minor differences in composition (see Text-fig. 3).

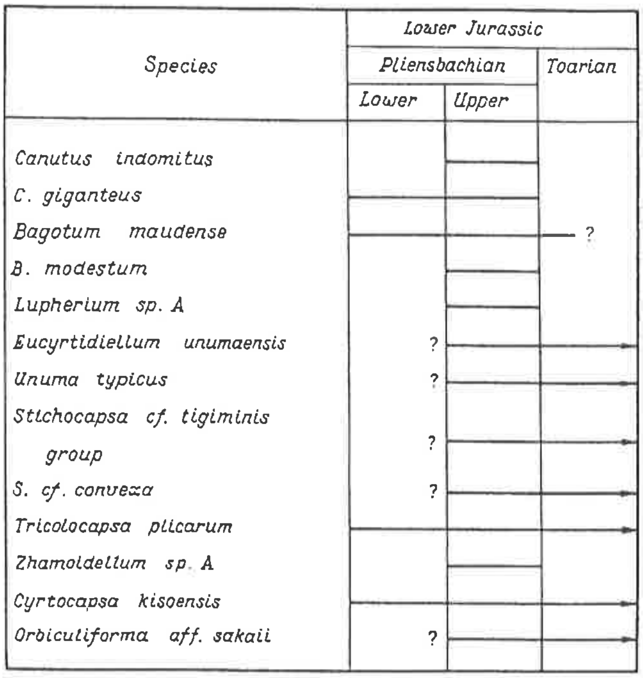

Fig. 2. Stratigraphic section of the upper Pliensbachian strata of the Okrainka Formation in the basins (1) of the Poperechka River and (2) Izvilinka River with position of radiolarian samples and ammonoides.

3. Results

From the material presently available, local informal radiolarian *Canutus indomitus* Zone has been proposed within the lowermost part of the Okrainka Formation. *Canutus indomitus* Pessagno and Whalen has been chosen as index-species of this Zone, because it is the short-ranged distinctive species, which is presented in variety of rock type. Other characteristic forms are: *C. giganteus* Pessagno and Whalen, *Bagotum maudense* Pessagno and Whalen, *B. modestum* Pessagno and Whalen, *Lupherium* sp. A (in Pessagno and Whalen, 1982), *Droltus* sp. indet., *Katroma* sp. indet., *Eucyrtidiellum* sp. cf. *E. unumaensis* Yao, *Stichocapsa* sp. cf. *S. tegimiminis* group Yao, *St.* sp. aff. *St. convexa* Yao, *Unuma typicus* Ichikava and Yao, *Tricolocapsa* sp. cf. *T. plicarum*, *Zhamoidellum* sp. A , *Cyrtocapsa kisoensis* Yao. *Stylocapsa* sp. indet, *Orbiculiforma* sp. cf. *O. trispinula* Carter, *O.* sp. cf. *O. kwunaensis* Carter, *Tripocyclia* sp.indet., *Tetratrabs* sp. indet., *Praeconocaryomma* sp. cf. *P. whiteavesi* Carter. A number of other species have not been dealt with in this paper because they are represented by only several indifferently preserved speciments.

The base of this Zone is defined by the lowest occurrence *Canutus indomitus* and *Bagotum modestum.* The top is marked by the final appearance of the index-species, *Canutus giganteus*, *Bagotum modestum* and *B. maudense*, none of which is presently known to range above the upper Pliensbachian.

The age of the *Canutus indomitus* Zone is based on associated ammonites and, to a lesser degree, on comparison with other radiolarian assemblages from the western North America (Pessagno and Whalen, 1982; Carter et al., 1988; Tipper et al., 1991).

The geologic range of the *Canutus indomitus* Zone is the upper Pliensbschian.

Based on species composition and stratigraphic position, the *Canutus indomitus* Zone can be correlated with some Lower Jurassic radiolarian zones proposed for the circum-Pacific region. For example, it can be correlated with the Zone 1 proposed by Carter et al., (1988) for the upper Pliensbachian strata in the Queen Charlotte Islands and, partly with the Subzone 01A of the Zone 01 proposed by Pessagno et al.(1987) for the North America.

The correlation with the Lower Jurassic Assemblage-zones of Japan (Matsuoka and Yao, 1986; Hori, 1990; Matsuoka et al., 1994, ets.) is very difficult due to the scarcity of the age-diagnostic species common to both areas. However, the *Canutus indomitus* Zone may be correlated with upper part of the Subzone III and with Subzone IV of the *Parahsuum simplum* Assemblage-zone in SW Japan (Hori, 1990; Matsuoka et al., 1994). This correlation based on a comparison on the genus level.

Only *Bagotum modestum* is common species for both the *Canutus indomitus* Zone and the Radiolarian Beds R:3 proposed by Tikhomirova (1988) for the Pliensbachian (?) strata in the Russian Far East. The *Canutus indomitus* Zone, therefore, is partly correlative to the upper part of the R:3.

4. Conclusions

The informal local *Canutus indomitus* Zone has been proposed for upper Pliensbachian strata in the South Sikhote-Alin, Russian Far East. The age of this Zone is well controlled by co-occurence with isochronal ammonite suites. This Zone is correlative to the other Lower Jurassic radiolarian zones and Radiolarian Beds proposed for the circum-Pacific region.

Although the *Canutus indomitus* Zone apply only to South Sikhote-Alin at present, it is possible that further investigation well prove this Zone to be of more regional value.

Acknowledgements

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Plate I

Scanning electron micrographs of upper Pliensbachian Radiolaria from the lowermost part of the Okrainka Formation, South Sikhote-Alin, Russian Far East.

Fig. 1, 2, 3. *Canutus indomitus* Pessagno and Whalen, 1,2,3-339/21, 1,2-x250, 3-x350

Fig. 4. *Bagotum modestum* Pessagno and Whalen, 339/23, x230

Fig. 5. *Canutus giganteus* Pessagno and Whalen, 339/23, x240

Fig. 6. *Bagotum maudens*e Pessagno and Whalen, 36c/5, x350

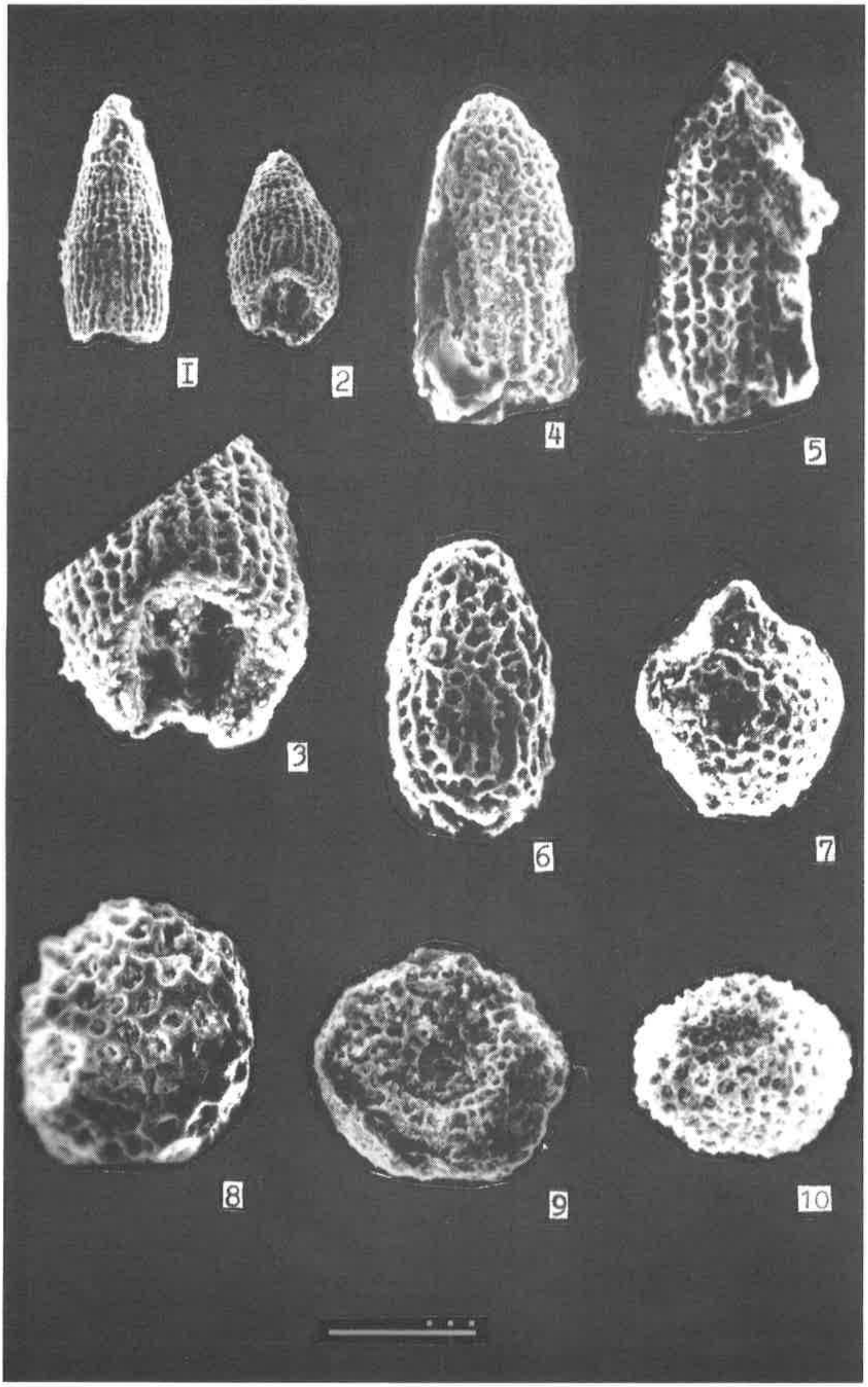
Fig. 7. *Zhamoidellum* sp. A, 35c/6, x240

Fig. 8. *Praeconocaryomma* sp. cf. *P. whiteavesi* Carter, 340; 8- x350, 13- x250

Fig. 9. *Orbiculiforma* sp. cf. *O. trispinula* Carter 339/23, x250

Fig. 10. *Spumellarien* gen. and sp. indet., 340, x240.

Plate I



LATE PALEOZOIC FLORA OF SOUTH PRIMORYE AND SOME PROBLEMS OF PHYTOGEOGRAPHY

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Abstract

The Devonian, Early Carboniferous and Permian associations of flora in Primorsky region are discussed in the article. Two major stages of the Late Paleozoic flora development are distinguished: Pro-Pteridophytic - Pteridophytic one (D_2 - C_1) and Cordaitantic one (P_1 - P_2). Two new species *Prynadaeopteris smirnovii* and *Comia pospeloviensis* are described.

1. Introduction

Three associations of different age are in the composition of the Late Paleozoic (first stage) flora in Primorye region. The assemblages existed in (1) Early? - Middle (beginning) Devonian, (2) in Middle Devonian (possibly, at the beginning of Late Devonian also), (3) in Late Devonian - beginning of Early Carboniferous (Tournasian). Information on the Early Devonian flora of Primorye is very scrappy. According to L. A. Izosov and A. P. Nikitina (1986), the possibility of its presence is shown by the finding of *Sawdonia* cf. *ornata* (Dawson) Hueber, *Taeniocrada decheniana* (Goeppert) Krausel et Weyland, and *Drepanophycus* sp.in rhyolites and their tuffs in the Ilistaya River basin.

In the early Middle Devonian (Eifelian - Early Givetian), the flora of Primorye is the most representative. Its composition is characterized by the plant remains reported (Zimina, 1989a, 1991) from the Peishula River left side and the Village of Shevelevka area, where the lower and middle members of Lyutorga Formation crop out. This association is represented by the species *Taeniocrada decheniana* f. *tipica* (Goeppert) Krausel et Weyland, *Psilophyton ?* sp., *Brandenbergia* cf.*meinertii* Mustafa, *Salairia* sp. aff. S.*fruticulosa* Zakharova, *Ilemorophyton ? ussuriensis* Zimina, *Platyphyllum* sp.

The close relationship of the Paleozoic flora in Primorye to the coeval flora of West Siberia, is supported by the presence of forms similar to some endemic genera of West Siberia (*Salairia* and *Ilemorophyton).* The occurrence of West-European floristic elements, similar to *Brandenbergia meinertii* Mustafa reported from the Middle Devonian of Germany (Mustafa, 1975) is important.

I have described and determined the following species from the Middle Devonian association occurring in the higher parts of the section of the Lyutorga Formation (Peishula River left side, the Village of Flegentovo area, and Artemovka River right side and mouth): *Taeniocrada* sp., *Barrandeinopsis beliakovii* Kryshtofovich, *Drepanophycus* cf. *spinaeformis* Goeppert, *Cyclostigma?* sp., *Lepidodendropsis orientalis* Zimina, *Ursodendron? radczenkoi* Zimina, *Pseudosporochnus* cf. *nodosus* Leclercq et Banks, *Protopteridium?* cf. *devonicum* Li and Hsu.

The list of species shows that in the composition of the association, lycopsids are important. It is characteristic of the Middle - lower Upper Devonian of the Spitsbergen, Central Kazakhstan, North Africa, and South China.

The presence of remains defined as *Pseudosporochnus* cf. *nodosus* Leclercq and Banks as well as imprints of spore-cases similar to those of *Protopteridium devonicum* Li and Hsu from the Middle Devonian of South China, could indicate warmer climate flora this age for Primorye .

However, the presence of *Barrandeinopsis beliakovii* Kryshtofovich, reported before from the Givetian of the Sayano-Altai Mountain area, testifies that the elements of coeval flora of West Siberia are preserved as before in flora of Primorye.

The age of the youngest floristic association of this stage is determined as Late Devonian - beginning of Early Carboniferous or Early Carboniferous (Tournaisia, Zimina, 1989a, 1991). I have reported it from the Shevelevka Member in the Village of Shevelevka area. In its composition there are *Barinophyton* sp., *Uralia artemovskiensis* Zimina, *Cyclostigma primorskiense* Zimina, *Pseudolepidodendron igrischense* (A.R. Ananiev) V.A. Ananiev, *Stigmaria angaridense* Zimina, *Lepidostrobus ?* sp., *Taeniocrada* (al. *Orestovia*) sp.

This flora of Primorye preserves features of coeval West Siberian ones. It is indicated by the presence of *Pseudolepidodendron igrischense* (A.R. Ananiev) V.A. Ananiev reported first from the Tournaisian of the North-Minusinsk depression (A.P. Ananiev, 1955, 1959; V.A. Ananiev, 1979). Together with the indicated Angaran species in this association there are lycopods similar to West European genus *Cyclostigma* (Schweitzer, 1969; Schweitzer and Cai, 1987).

I must emphasise that is the presence of spore-bearing runners, resembling in outer morphology the strobiles of Late Devonian and Early Carboniferous lycopods of Euroamerican ones, is a special feature of the South-Primorye flora, manifested more strongly than in the central regions, due to its location on the margin of Angara.

Late Paleozoic flora of the second stage is broadly represented in West Primorye and in the south and southeast the Khanka massif. The Permian flora from the South Primorye Zone is better studied and largely described (Zimina, 1967 a,b, 1969b, 1977, 1982, 1989b; Burago, 1976, 1986, et al.) (Pl. I-X). More often, five age floristic associations are distinguished here: (1) Dunai, (2) Lower Pospelov (Abrek), (3) Upper Pospelov (Mingorodok), (4) Vladivostok-Chandalaz (Barabash), and (5) Lyudyanza.

The Dunai Peninsula floristic association, according to the assumed stratification of the same-named formation, is divided into two subassociations: Lower Dunai and Upper Dunai.

The Lower Dunai subassociation includes flora of the Dunai Peninsula (Konyushkov Bay coast and Obruchev Cape region). It contains the following species: *Angaropteridium buconicum* Tschirkova, *Glossopteropsis?* sp., *Rufloria sp. aff. R.theodorii* (Tschirkova et Zalessky) S. Meyen, *R.* aff. *mirabilis* S. Meyen, *R. derzavinii* (Neuburg) S. Meyen, *Crassinervia angusta* Gorelova.

Upper Dunai subassociations includes flora of the Dunai Peninsula (Osipov and Obruchev Capes) and Putyatin Island (to the south of the Felkerzam Cape): *Sphenophyllum osipoviense* Zimina, *Paracalamites? deliquescens* (Goeppert) Radczenko, *Phyllotheca* cf. *turnaensis* Gorelova, *Prynadaeopteris tunguscana* (Schmalhausen) Radczenko, *Cordaites hypoglossus* (Neuburg) S. Meyen, *Rufloria* aff. *theodorii* (Tschirkova et Zalessky) S. Meyen, *R. derzavinii* (Neuburg) S. Meyen, *R.* aff. *recta* (Neuburg) S. Meyen, *Cordaicladus?* sp., *Crassinervia tunguscana* Schvedov, *Nephropsis integerrima* (Schmalhausen) Zalessky, *N.* cf. *semiorbicularis* Neuburg.

The age of Dunai association is Early Permian as a whole. Its flora may be compared with that from the upper part of Promezhutochnaya and Ishanovskaya Formations of Kuzbass (or their stratigraphic analogues in other regions of North Asia).

Lower Pospelov (Abrek) association includes flora of the same-named formation in Russian Island, and sandy-shale sequence in the Artemovka River lower reaches. It contains *Sphenophyllum osipoviense* Zimina, *S. meyenii* Zimina, *Paracalamites decoratus* (Eichwald) Zalessky, *P. frigidus* Neuburg, *Annularia tenuifolia* Neuburg, *Annulina neuburgiana* (Radczenko) Neuburg, *A.* aff. *neuburgiana* (Radczenko) Neuburg, *Koretrophyllites prostratus* (Chachlov) Radczenko, *Tschernovia kuznetskiana* Neuburg, *Prynadaeopteris tunguscana* (Schmalhausen) Radczenko. *P. smirnovii* n. sp., *Zamiopteris glossopteroides* Schmalhausen, *Z. subglossopteroides* Zimina, *Cordaites primorskiensis* Zimina, *Rufloria derzavinii* (Neuburg) S. Meyen, *R.* aff. *recta* (Neuburg) S. Meyen, *R. ussurica* Zimina, *Crassinervia tunguscana* Schvedov, *C. grammii* Zimina, *C.? neuburgiana* Zimina, *Nephropsis (Sulcinephropsis) asiatica* Zimina, *N. (Sulcinephropsis) lampadiformis* (Gorelova) Zimina, *Vojnovskya elengans* Zimina, *V. pacifica* Zimina, *Gaussia scutellata* Neuburg, *Mengrammia mirabilis* Zimina, *Samaropsis ampulliformis* Neuburg, *S. elegans* (Dombrovskaya, in coll.) Neuburg, *S. subelegans* Neuburg, *S. skokii* Neuburg, S.*(?) polymorpha* Neuburg, *S.* aff. *prokopievskiensis* Suchov, *Cordaicarpus tschemulakiensis* Suchov, *Sylvella alata* Zalessky.

The majority of species from floristic association of South Primorye characterized the upper half (Kemerovo and Usyatskian Formations) of the Upper Balakhon member of the Kuzbass and Vorkuta Formations of the Pechora basin.

As the question of the boundary position of Permian divisions is debatable, some workers (Neuburg, 1965) consider the age of this part of the section Early Permian, other workers (Meyen, 1970b) define it as the end of Early - beginning of Late (Ufimian) Permian.

Upper Pospelov floristic association is known from the localities of Tikhaya Bay and Mingorodok.

In the composition of the flora from second locality the following species were recognized: *Paracalamites decoratus* (Eichwald) Zalessky, *Paracalamites ?* sp., *Koretrophyllites tenuis* Gorelova, *Sphenopteris grabaui* Halle, *S. nystroemii* Halle, *Prynadaeopteris anthriscifolia* (Goeppert) Radczenko, *Pecopteris micropinnata* Fefilova, *Callipteris sahnii* Zalessky, *Odontopteris ?* sp., *Glossopteris* cf. *orientalis* Zimina, *G.* cf. *indica* Schimper, *G.* cf. *tunguscana* (Neuburg) Zimina, *Glossopteris* sp., *Gangamopteris* (al. *Glossopteris*) sp., *Gangamopteris ?* sp. A, *Gangamopteris ?* sp. B, *Psygmophyllum* cf. *expansum* Brongniart, *Permophyllum ?* sp., *Comia pospeloviensis* n. sp., *Cordaites buragoi* Zimina, *Cordaites?* sp., *Rufloria ensiformis* (Zalessky) S. Meyen, *Rufloria* sp. A, *Crassinervia* cf. *neuburgiana* Zimina, *Crassinervia* (al. *Rufloria*) *spp*., *Sylvella alata* Zalessky.

In this assemblage, together with the forms known from Lower Pospelov association (*Paracalamites decoratus* (Eichwald) Zalessky, *Crassinervia neuburgiana* Zimina, *Sylvella alata* Zalessky and others), a significant number of Late Permian forms appear, some of which (*Callipteris sahnii* Zalessky, *Cordaites buragoi* Zimina) are preserved also in the younger Vladivostok (Barabash) assemblage. Characteristic of this flora is the first appearance of Cathaysian and Gondwanan forms. Among the latter are the representatives of *Glossopteris* and, apparently, *Gangamopteris* genera. Because of the presence of *Comia* noted in Kuzbass since the origin of the Kuznetsk Formation, as well as *Glossopteris tunguscana* (Neuburg) Zimina, characteristic of the Il'inskian Formation of Kuzbass and the Pelyatkinskian Formation of Tungus basin, the age of the Upper Pospelov association is defined as the beginning of Late Permian (Zimina, 1969a, 1977).

Common features of the systematic composition of the Upper Pospelov assemblage are observed in the flora of the Artemovka River basin, found in the deposits outcropping in the hollows of the earth road (to the south of the Village of Shevelevka). The characteristics of this flora with the description of some species was given in my works (Zimina, 1967a, 1976, 1977, 1983, 1984, 1989b) so only a brief list of species is cited below (the pictures of some of them are shown in the Plates): *Annularia ? lanceolata* (Radczenko), *Lobatannularia sinensis* (Halle) Halle, *Koretrophyllites* aff. *tenuis* Radczenko, *Sphenopteris* aff. *dymovii* (Radczenko) Zimina, *Prynadaeopteris anthriscifolia* (Goeppert) Radczenko, *Pecopteris oviformis* Radczenko, *P.* (Asterotheca) *norinii* Halle, *P. (Asterotheca) orientalis* (Schenk) Potonie, *Pecopteris* sp., *Odontopteris* aff. *rossica* Zalessky, *Glossopteris orientalis* Zimina, *G.* cf. *retifera* Feistmantel, *Glossopteris* sp., *Gangamopteris* aff. *cyclopteroides* Feistmantel, *G. pacifica* Zimina, *G. ussuriensis* Zimina, *Palaeovittaria* sp., *Angaropteridium tyrganicum* Zalessky, *Comia laceratifolia* (Halle) Zimina, *Taeniopteris* cf. *taiyanensis* Halle, *Rhipidopsis baieroides* Kawasaki et Kon'no, *Ginkgophyton?* sp., *Paraburiadia mennerii* Zimina, *Cordaites latifolius* (Neuburg) S. Meyen, *Rufloria* sp., *Cardiocarpus* cf. *krapivinoensis* Suchov, *Samaropsis ?* aff. *neuburgii* Suchov f. *bungurica* Suchov, *Bardocarpus* *discretus* (Neuburg) Neuburg, *Prymocarpus lampadiformis* Zimina, *P. reniformis* Zimina.

This assemblage, like that described above, contains Carboniferous-like forms (*Cardiocarpus krapivinoensis* Suchov) and Early Permian (*Sphenopteris dymovii* (Radczenko) Zimina and *Angaropteridium tyrganicum* Zalessky) to Late Permian ones. This flora contains also Cathaysian and Gondwana elements. The latter are represented by *Glossopteris, Gangamopteris*, and *Palaeovittaria*. In addition, the conifers of the genus *Paraburiadia* with isolated seed rudiments (Zimina, 1983) like those of Gondwana genera *Buriadia* (Pant and Nautiyal, 1967) and *Walkomiella* (Surange and Singh, 1953), were found. The flora of the Village of Shevelevka region is comparable with the flora of Upper Pospelov association in the features described above.

The Late Permian flora of the Vladivostok and Chandalaz Horizons is often considered as flora of two assemblages (Vladivostok and Sitsa). Geological data show that the layers characterized by the first floristic association occur immediately beneath the deposits of the *Monodiexodina sutchanicaa* Zone (the second association is not related to the foraminifer zones) (Burago et al., 1974). As the question of different age of the floristic associations of Primorye, mentioned above, remains unsolved, this flora is often named Vladivostok-Chandalaz (or Barabash). Below are recognized two assemblages: (1) Pervaya Rechka River (Snegovaya) and (2) Shevelevka Village. The locality in the Pervaya Rechka River is confined to the stratotype of the Vladivostok Formation (Burago, 1990). The following species were recognized and described from this locality: *Lobatannularia lingulata* (Halle) Kawasaki, *Callipteris ivancevia* Gorelova, *Comia* aff. *dentata* Radczenko, *Comia* sp. A, *Compsopteris tschirkovae* Zalessky, *Iniopteris ? sibirica* Zalessky, *Mengrammia ? nitida* Zimina, *Rufloria derzavinii* (Neuburg) S. Meyen, *Crassinervia* aff. *pentagonata* Gorelova, *Nephropsis (Sulcinephropsis)* cf. *asiatica* Zimina.

Together with plants, fish remains were found, attributed by D. V. Obruchev to *Elonichthys* sp.

The Vladivostok association differs from the more ancient Upper Pospelov one in the absence of Gondwana elements, however, the Cathaysian ones are observed. Like Upper Pospelov assemblage, this one contains Early Permian forms known from Lower Pospelov assemblage (*Rufloria derzavinii* (Neuburg) S. Meyen, *Nephropsis (Sulcinephropsis) asiatica* Zimina). However, in Vladivostok association, the main species are those characteristic of the upper horizons of the Kuznetsk and total Il'inskian Formations in Kuzbass (*Callipteris ivancevia* Gorelova, *Compsopteris tshirkovae* Zalessky, *Crassinervia pentagonata* Gorelova), and isolated Erunakovskian forms exist also (*Comia dentata* Radczenko, *Iniopteris sibirica* Zalessky). The deposits enclosing this flora are dated as the lower part of the Late Permian from the brachiopod fauna determined by G.V. Kotlyar, B.V. Koczyrkevcz and I.P. Chernysh (Burago, 1990).

In the association of the Shevelevka Village (hollows of the road Vladivostok - Artem) I have determined the species: *Calamites ?* sp., *Lobatannularia ensifolia* (Halle) Halle, *Prynadaeopteris anthriscifolia* (Goeppert) Radczenko, *Callipteris sahnii* Zalessky, *Comia* aff. *dentifolia* Rasskazova, *Palaeovittaria ?* sp., *Psygmophyllum demetrianum* (Zalessky) Burago, *Protoblechnum* sp. A, *Dicranophyllum* cf.*sylvense* Zalessky, *Rhipidopsis baieroides* Kawasaki et Kon'no, *R.* cf. *imaizumii* Kon'no. In the florae composition of this part of the section, V. I. Burago (1976, 1977, 1986) described the following species: *Pecopteris andersonii* Halle, *P. jabei* Kawasaki, *Protoblechnum imaizumii* Kon'no, *Sphenozamites permicus* Burago, *Rhipidopsis* aff. *palmata* Zalessky and *Ginkgophyton giganteum* Burago.

The assemblage, described above, differs from that of Pervaya Rechka River (Snegovaya) in more diverse composition of Cathaysian plants. It includes *Lobatannularia ensifolia* (Halle) Halle, *Pecopteris andersonii* Halle, *P. arcuata* Halle, *Protoblechnum imaizumii* Kon'no, *Rhipidopsis baieroides* Kawasaki et Kon'no and *Rh.* cf. *imaizumii* Kon'no. The three last species were known before from the flora of Kaishantun. According to E. Kon'no (1968) this flora originated from the upper part of Tuman formation comparable with *Jabeina* Zone, Kitakami region, Japan, on the basis of marine fauna. In Ginkgophyte composition, the association of the Shevelevka Village is also similar to the Barabash flora of West Primorye (the Fadeevka Village), from which the typical Cathaysian *Gigantopteris nicotianaefolia* Schenk was first described by A.N. Kryshtofovich (1939). The flora of the Fadeevka Village occurs immediately under deposits with foraminifers, bryozoans, and brachiopods of Midian age.

Thus, the difference in the composition of the associations from the Shevelevka Village and Pervaya Rechka River is possibly the result of facies peculiarities, and not different age (the age of the first assemblage is sometimes assumed as the youngest one attributed to the lower part of the Chandalaz Formation) (Burago, 1986).

In the collection of the Village of Shevelevka, the plant remains are represented by well preserved leaves and fronds of plants, buried in quiet environments and near the places of their growth. In the Pervaya Rechka River, the plant remains were found in cherty siltstones alternating with volcanogene-sedimentary rocks. The fact, that the plants were significantly transferred before the burial, is evidenced by their fragmentary state poor preservation, and occurrence with fish remains.

The analysis of the Permian flora discussed above, shows the flora of South Primorye to be typically Angaran during Early Permian (endemic elements in it are observed only on the species level), but in Late Permian (Late Pospelov, Vladivostok and Chandalaz time) the flora of South Primorye, having , apparently, Angaran appearance as a whole, is characterized by more complicated composition. This is conditioned on the one hand by more strongly pronounced autonomy in the development (endemism is observed on both the species and generic levels), on the other hand by the influence of Cathaysian (Kryshtofofich, 1939) and Gondwana (Zimina, 1970) florae. Latitudinal relations with florae of the west parts of Angara (Pechora River basin, Ural, and Russian Platform) also played a significant role in the formation of South Far East flora at the Early Permian - Late Permian boundary time. Below this problem is considered in detail.

At the early stage of investigations (Zimina, 1967b, 1976, 1977) I noted that more ancient Early Permian (Early Dunai) flora of Primorye was most similar in its composition to the coeval flora of the central part of Angara. In Late Dunai and Early Pospelov (Abrek) time, the elements of the marginal parts (Pechora River basin, Kara-Maraz Mountains) appeared in it. This fact allowed me to conclude, that the Pechora province and Ural-

Kazakhstan realm distinguished by S.V. Meyen (1970a,b) as well as West Taimyr and Tungus basin were at the end of Early Permian within the specific phytogeographic belt (Superprovince) extending eastwards to the South Primorye. Later on, it was called Vneshneangarsk Belt (Zimina, 1989). Within the Belt, the typical *Vojnovskyales* flora is developed which, however, differs from that of the central and north-east parts of the Angara Kingdom in more species diversity Angara elements and existence of such Euroamerican elements as *Sphenophyllum*. The existence of this Belt, gravitating to the Angara margin, is indicated by the presence in Upper Dunai, Lower Pospelov, and Abrek Formations of Primorye, of the following species: *Paracalamites decoratus* (Eichwald) Zalessky, *Annulina neuburgiana* (Radczenko) Neuburg, *Cordaites hypoglossus* (Neuburg) S. Meyen, *Rufloria* aff. *recta* (Neuburg) S. Meyen, *Nephropsis (Sulcinephropsis) lampadiformis* (Gorelova) Zimina, *N.* cf. *semiorbicularis* Neuburg, *Samaropsis skokii* Neuburg, *Sylvella alata* Zalessky and others, known from Vorkuta Formation of the Pechora basin or Lower Balachon Formation of Kuzbass. The most important is the finding of the representatives of the *Vojnovskya* (Zimina, 1967b): *V. elegans* Zimina and *V. pacifica* Zimina, of which the latter is very close in outside morphology to *V. paradoxa* Neuburg from Vorkuta Formation of the Pechora basin. The latitudinal floristic relations in Early Permian are also indicated by the presence in the South Primorye of plant leaves described as *Nephropsis (Sulcinephropsis) asiatica* Zimina, resembling the leaves of *N. sigalovii* Sixtel from Lower Permian deposits of Kara-Mazar.

The problem of the outer boundary of the proposed Vneshneangarsk Belt is not yet solved for certain. Following S.V. Meyen (1980) the areas characterized during Permian by Euroamerican and Cathaysian flora, but with Angaran elements, may be combined into a Subangara area. It includes East-European and Ural-Kazakhstan areas as well as Central Asia, Afghanistan, Nan-Shan and (conditionally) Kamchatka. Thus, Ural-Kazakhstan area (Meyen, 1970b; Chaloner and Meyen, 1973) is proved to be included in both belts. In my opinion, it is explained by the fact, that the boundary of Vneshneangarsk Belt at the end of Early Permian passed through the Ural-Kazakhstan area. This is suggested from the data on the flora of Balkhash region, given by K.Z. Sal'menova (1982, 1988). In this region, since the beginning of Early Permian (Koldarian time), together with Angara forms, the Euroamerian ones were also important (i.e. flora was close to Subangara one). In later (Kyzylkinian time), it had the outer features similar to those of Angara flora. This is indicated by the elements of Vorkuta flora of Pechora basin and coeval flora of South Primorye.

To the east, the boundary of the Vneshneangarsk Belt and Sub-Angara area, apparently, was inside Mongolia and North-East China (Huang, 1983). In the very east it approximately corresponds to the frontier between Primorye and north-east parts of China and North Korea.

In Late Permian (Late Pospelov and Vladivostok-Chandalaz time), the similarity of the South-Primorye flora with the florae of marginal parts of Angara Realm, as well as Amerosinian one, was, apparently, much greater. It is suggested from the fact, that, for example, in South Primorye, like the Pechora basin, one can see the same diversity of fern and pteridospermals and presence of common species among *Psygmophyllum*, *Rhipidopsis*, and other. The similarity of the Late Permian flora of South Primorye with that of Urals and the east part of the Russian Platform, is indicated by the presence of the plant remains similar to *Paracalamites decoratus* (Eichwald) Zalessky, *Dicranophyllum silvense* Zalessky, *Odontopteris rossica* Zalessky, *Protoblechnum* sp. and *Permophyllum* sp., V.I. Burago (1976) proved the presence in South Primorye of a representative of *Phylladoderma*, widely developed in the Pechora basin and Russian Platform (Meyen and Goman'kov, 1971). Since the beginning of Late Permian, the area of Vneshneangarsk phytogeographic Belt in the north-west Angara was somewhat reduced. Its inner boundary appeared to be inside the Siberian province. At least, the Tungus basin could not be included in it. It is suggested because of the absence of typical elements for the Vneshneangarsk Belt the Late Permian genera, such as *Comia, Rhipidopsis, Ginkgoides, Tomia*, and extreme rarity of *Callipteris* (Gorelova, Meyen and Suchov, 1978).

In the very east, the outer boundary of the Vneshneangarsk Belt was possibly in Primorye territory.

2. Systematics

Class POLYPODIOPSIDA Meyen, 1987
Genus *Prynadaeopteris* Radczenko, 1955
Prynadaeopteris smirnovii n. sp.
Pl. II, fig. 1-3

The name of the species is in memory of the Prof. A.M. Smirnov.

Holotype - DVGI 403/2030; South Primorye, Russian Island, 800 m to the south-west of Novosilsky Cape; Lower Permian-base of the Late Permian, lower Pospelov Formation (Formation).

Description. Fronds are not less than tri-pinnate. Pinnae of penultimate order are wide, extended, and almost triangular. The width is about 150 mm. Rachis is straight or slightly curved with narrow margin, and weakly domed on the lower side. Pinnae of the last order are approximate by pairs or alternate and linear-lanceolate to almost triangular. They are declining to the rachis at an angle of 60-90°, their margins overlapping each other. Rachis of the pinnae of the last order are straight or slightly curved and weakly sinuate in the upper part. They are thin enough, but domed and widely winged. Their width in the middle of the pinna is about 0.5 mm and base is 0.7 mm. The pinnules are large enough. Their length may be up to 27 mm. There are 7-8 pairs of such pinnules on each pinna. They are approximate by pairs or alternate and declined to the rachis at an angle of 60-70°. Outline of the pinnules is lengthened-ovate to lanceolate. At the base they are somewhat choked. On each side the pinnule is usually dissected into 3 to 4 lobes with rounded tips directed obliquely forward. Developed pinnules have margin of the lobe slightly sinuate.

The midrib is distinct with striate surface. It is sinuate, somewhat thickened at the base and thinned towards the top, where it is traced to the margin.

Four to five pairs of lateral ribs branch from the midrib at an angle of 30-60 and separate sympodially three to five times. Each branch in its turn separates into boughs like fork.

Spore-bearing pinnules do not differ from sterile ones. Sorus are confined to the lateral ribs gravitating to the marginal part of a pinnule. It should be mentioned, that the number of sorus as well as the number of spore-cases appears to depend directly on the extend of the pinnule development. The most accumulations of sorus are on the pinnules occurring at the base of pinna. Sorus here seemingly overlap each other. This is especially well seen on the slide made by the method of Walton-Eshby. The number of spore-cases on such pinnules, apparently, exceeded, nine. Closer to the pinna (or pinnule) tip, the sorus may consist of less number of spore-cases or even a single specimen. Sorus are often rounded, some of them have a small projection in the centre.

Spore-cases are sphere-like and oval-sphere-like, sometimes narrowed at the place of insertion, and 0.1-0.2 mm in diametre. The walls of spore-cases are composed of polygonal, longitudinally elongated cells. On one of the spore-cases we can see the longitudinal thickening, along which the rupture of its wall apparently took place.

Comparison. The species of South Primorye resembles *Prynadaeopteris maneichensis* (Zalessky) Radczenko and *P. irregularis* Radczenko from the upper part of Balakhon Formation, Kuzbass (Radczenko, 1956) in pinnule nature, their venation, as well as in shape and arrangement of sorus. It differs from both species in a greater angle of the tilt of the last order pinnae and the pinnules and more approximate position of both. In addition, it differ from the first of the mentioned species in more rounded margins of lobes and less number of spore - cases in sorus, and by contrast from the second one it differs in larger number of them. The new species differs from fern from the north Urals Depression, described as *P. venusta* Radczenko (Fefilova, 1973), in shorter pinnules and greater number of spore-cases in sorus.

Distribution. Lower Permian - the lower part of the Late Permian, South Primorye.

Material. Numerous imprints of sterile pinnae and one fertile pinna were found in dark-gray coaly siltstone of the lower Pospelov Formation in Russian Island (800 m to the south-west of Novosilsky Cape).

Division PINOPHYTA Meyen, 1987
Order PTERIDOSPERMLES Meyen, 1987
Genus *Comia* Zalessky, 1934
Comia pospeloviensis n. sp.
Pl. IV, fig. 7-9

The name of the species is from the Pospelov Cape.

Holotype - DVGI 403/1516; South Primorye, Murav'ev-Amursky Peninsula, interstream of the Pervaya Rechka and Ob'yasneniya Rivers (Minnyi Gorodok); the lower part of the Late Permian, upper Pospelov Formation.

Description. Simplipinnate frond, 80 mm wide, more than 120 mm long. Rachis is about 2.5 mm thick and in the places of pinnule insertion is slightly thickened. Pinnules, arranged on the rachis at an angle of about 45, are medium-sized. They are opposite to each other, closely spaced, sometimes overlapping each other. Outline of the pinnules is linear or linear-lanceolate. Their margins are wave, nearer to the tip-slightly wave, and lower margins of the pinnules decurrent onto the rachis. The midrib is rather thin and extends up to the tip of the pinnule. The midrib is irregular in thickness. In the places of thickening at equal intervals, the additional ribs branch. The latter first decurrent and then decline towards the pinnule margin. The additional ribs dichotomate one or two times forming a flabellate bunch.

Comparison. The species from South Primorye resembles in the pinnule nature some specimens reported from the Pechora River as *Comia pereborensis* Zalessky (Fefilova, 1973) and differs in opposite pinnules, presence of thickening on the rachis and midrib.

Distribution. Lower part of the Late Permian; South Primorye.

Material. Two imprints (one with a counter part) were found in the bed of dark-gray siltstone within the upper Pospelov Formation on the interstream of the Pervaya Rechka and Ob'yasneniya Rivers (Minnyi Gorodok).

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Plate I

Fig. 1, 2. *Paracalamites decoratus* (Eichwald) Zalessky: 1 - DVGI 403/2091, x 1; 2 - DVGI 403/2612-1; Russian Island, Novosilsky Cape area; upper Lower Permian - lower Late Permian - lower Pospelov Formation.

Fig. 3. *Paracalamites frigidus* Neuburg, DVGI 403/2140, x 1. The same locality.

Fig. 4. *Paracalamites? deliquescens* (Goeppert) Radczenko, DVGI 403/545, x 1. Dunai Peninsula, Bezymyannaya Bay; lower Permian, upper Dunai Formation.

Fig. 5. *Phyllotheca* cf. *turnaensis* Gorelova, DVGI 403/2613, x 1. Dunai Peninsula, Osipov Cape area; lower Permian, upper Dunai Formation.

Fig. 6. *Annularia tenuifolia* Neuburg, DVGI 403/1215, x 2. Dunai Peninsula; upper Early Permian - lower Late Permian, Abrek Formation.

Fig. 7, 8. *Annulina neuburgiana* (Radczenko) Neuburg: 7 - DVGI 403/2012, x 1; 8 - DVGI 403/1208, x 1. Russian Island, Novosilsky Cape area; upper Lower Permian - lower Upper Permian - lower Pospelov Formation.

Fig. 9, 10. *Annulina* aff. *neuburgiana* (Radczenko) Neuburg: 9 - DVGI 403/2614, x 2; Dunai Peninsula, late Early Permian - early Late Permian, Abrek Formation; 10 - DVGI 403/149, Putiatin Island; late Early Permian - lower Late Permian, Abrek Formation.

Plate II

Fig. 1-3. *Prynadaeopteris smirnovii* n. sp.: 1 - DVGI 403/2030 (holotype): 1a - frond fragment, x 1, 1b - pinnule fragment with sorus, x 25, 1c - pinnule fragment with spore-cases, x 25; 1d - sorus , x 25; 1e - the same sorus, x 50. Russian Island, Novosilsky Cape area; upper Lower Permian - lower Upper Permian, Pospelov Formation; 3 - DVGI 403/2181: 3a - x 1, 3b - x 3. The same locality.

Plate III

Fig. 1. *Prynadaeopteris* aff. *tunguscana* (Schmalhausen) Radczenko, BPI 403/2617, x 1. Dunai Peninsula, to the west of the Abrek Cape; upper Lower Permian - lower Upper Permian, Abrek Formation.

Fig. 2. *Vojnovskya pacifica* Zimina, DVGI 403/8, x 1; the same locality.

Fig. 3. *Rufloria ussurica* Zimina, DVGI 403/82, x 1. Dunai Peninsula, Osipov Cape area; upper Lower Permian - lower Upper Permian, Abrek Formation.

Fig. 4. *Zamiopteris?* sp. A, DVGI 402/115, x 1. Western Primorye, Komissarovka River; upper Lower Permian -lower Upper Permian, Reshetnikovo Formation.

Fig, 5. *Crassinervia? neuburgiana* Zimina, DVGI 403/2220, x 1. Russian Island, Novosilsky Cape area; late Early Permian - lower Late Permian, Pospelov Formation.

Fig. 6. *Krylovia* sp. A and *Samaropsis* sp. A, DVGI 403/2615, x 2. The same locality.

Fig. 7, 8. *Samaropsis ampuliformis* Neuburg : 7 - DVGI 402/114, x 2. Western Primorye, Komissarovka River; upper Lower Permian - lower Upper Permian, Reshetnikovo Formation; 8 - DVGI 4031/2053, x 2. Russian Island, Novosilsky Cape area, late Early Permian - lower Late Permian - lower Pospelov Formation.

Fig. 9. *Samaropsis* aff.*punctulata* Neuburg, DVGI 403/2616, x 2. Russian Island, Novosilsky Cape area; upper Lower Permian - lower Upper Permian - lower Pospelov Formation.

Fig. 10. *Samaropsis skokii* Neuburg, DVGI 403/1072, x 2. Dunai Peninsula, Sredny Cape area; late Early Permian - lower Late Permian, Abrek Formation.

Fig. 11, 12. *Samaropsis subelegans* Neuburg: 11 - DVGI 403/2618, x 2; 12 - DVGI 403/1688, x4. The same locality.

Fig. 13. *Samaropsis? polymorpha* Neuburg, DVGI 403/4226-A, x 20. Dunai Peninsula, Sredny Cape area; upper Lower Permian - lower Upper Permian, Abrek Formation.

Plate IV

Fig. 1. *Paracalamites?* sp., DVGI 403/1439: !a - x 1, !b - x 2. Murav'ev Amursky Peninsula, Minnyi Gorodok; lower Upper Permian, upper Pospelov Formation.

Fig. 2. *Paracalamites decoratus* (Eichwald) Zalessky, DVGI 403/2587, x 1. The same locality.

Fig. 3. *Koretrophyllites tenuis* Gorelova, DVGI 403/1424. The same locality.

Fig. 4. *Callipteris sahnii* Zalessky, DVGI 403/2609, x1. The same locality.

Fig. 5. *Odontopteris?* sp., DVGI 403/1430: 5a - x 1; 5b - x 2. The same locality.

Fig. 6. *Annularia? batschatensis* (Chachlov) Radczenko, DVGI 403/2610, x 1. The same locality.

Fig. 7-9. *Comia pospeloviensis* n. sp.: 7 - the frond, DVGI 403/1516, x 1; 8 - frond fragment, DVGI 403/2582, x 1.5; 9 - pinnale, DVGI 403/1368: 8a - x 1, 9b - x 3. The same locality.

Fig. 10. *Comia* sp., DVGI 403/1491, x 1. The same locality.

Plate V

Fig. 1. *Glossopteris?* sp., DVGI 403/1355-1, x 1. Murav'ev Amursky Peninsula, Minnyi Gorodok; lower Upper Permian, upper Pospelov Formation.

Fig. 2. *Glossopteris* cf. *orientalis* Zimina, DVGI 403/1506, x1.5. The same locality.

Fig. 3. *Glossopteris* cf. *indica* Schimper, DVGI 403/2573, x 2, The same locality.

Fig. 4. *Gangamopteris* (al. *Glossopteris*) sp., DVGI 403/1308, x 2. The same locality.

Fig. 5. *Gangamopteris?* sp.A, DVGI 403/1312, x 2. The same locality.

Fig. 6. *Gangamopteris?* sp. B, DVGI 403/1513: 6a - x 1, 6b - x 2. The same locality.

Fig. 7. *Psygmophyllum* cf.*expansum* Brongniart (a) and *Cordaites?* sp.(b), DVGI 403/1516, x 1. The same locality.

Fig. 8. *Cordaicarpus?* sp., DVGI 403/135, x 5. The same locality.

Plate VI

Fig. 1, 2. *Rufloria ensiformis* (Zalessky) S. Meyen: 1 - DVGI 403/1517, x 1; 2 - DVGI 403/476, x 1. Murav'ev-Amursky Peninsula, Minnyi Gorodok; lower Upper Permian, upper Pospelov Formation.

Fig. 3. *Cordaites buragoi* Zimina, DVGI 403/1385, x 1. The same locality.

Fig. 4, 5. *Cordaites* sp. A: 4 - DVGI 403/1516, x 1; 5 - DVGI 03/1334, x 1. The same locality.

Fig. 6. *Permophyllum?* sp., DVGI 403/1386, x 1. The same locality.

Fig. 7. *Rufloria* sp., base of the leaf, DVGI 403/2611, x 1. The same locality.

Fig 8. *Crassinervia* (al. *Rufloria*) sp. A, DVGI 403/2599-8, x 2. The same locality.

Fig. 9. *Crassinervia* (al. *Rufloria*) sp. B, DVGI 403/1325, x 1. The same locality.

Fig. 10. *Crassinervia* (al. *Rufloria*) sp. C, DVGI 403/1325-8, x 2. The same locality.

Fig. 11. *Rufloria?* sp., DVGI 403/258, x 1. The same locality.

Plate VII

Fig. 1. *Glossopteris* sp., DVGI 405/200, x 1. Murav'ev-Amursky Peninsula, to south of the Village of Shevelevka; lower Upper Permian, upper Pospelov Formation.

Fig. 2, 3. *Glossopteris orientalis* Zimina: 2 - leaf fragment (narrowing part), DVGI 405/11: 2a - x 1, 2b x 2; 3 - leaf fragment with lobe edge, DVGI 405/201, x 2. The same locality.

Fig. 4. *Glossopteris?* cf. *retifera* Feistmantel, DVGI, 405/14, x 3. The same locality.

Fig. 5, 6. *Odontopteris* aff. *rossica* Zalessky: 5 - DVGI 405/106, x 1.5; 6 DVGI 405/104, x 1.5. The same locality.

Fig. 7. *Comia laceratifolia* (Halle) Zimina, DVGI 405/306, x 1.5. The same locality.

Plate VIII

Fig. 1. *Lobatannularia lingulata* (Halle) Kawasaki, DVGI 403/2626, x 1. Murav'ev-Amursky Peninsula, Pervaya Rechka River (Snegovaya), Upper Permian, upper Vladivostok Formation.

Fig. 2. *Callipteris ivancevia* Gorelova, DVGI 403/2627, x 1. The same locality.

Fig. 3. *Comia* aff. *dentata* Radczenko, DVGI 403/2628, x 1.5. The same locality.

Fig. 4, 5. *Comia* sp. A: 4 - pinnule (middle part), DVGI 403/2624, x 1.5; 5 - pinnule (apex with two seedbuds?), DVGI 403/2625, x 1.2. The same locality.

Fig. 6. *Rufloria derzavinii* (Neuburg) S. Meyen, DVGI 403/24, x 1. The same locality.

Fig. 7, 8. *Compsopteris tschirkovae* Zalessky: 7 - DVGI 403/2629, x 1; 8 - DVGI 403/2629, x 1. The same locality.

Fig. 9. *Comia?* sp., DVGI 403/2630, x 1. The same locality.

Fig. 10. *Iniopteris? sibirica* Zalessky, DVGI 403/2631, x 1. The same locality.

Fig. 11. *Crassinervia* aff. *pentagonata* Gorelova, DVGI 403/2439, x 2.

Fig. 12. *Neuropteridium? kaishanense* Kon'no, DVGI 403/2632, x 1. The same locality.

Fig. 13-16. *Elonichtis* sp. (fish remains associated with plant fossils). The same locality.

Plate IX

Fig. 1, 2. *Calamites?* sp.: 1 - DVGI 403/2620a, x 2; 2 - DVGI 403/2620-B, x 1. Murav'ev-Amursky Peninsula, Shevelevka Village; Upper Permian, Chandalaz Formation.

Fig. 3. *Dicranophyllum* cf. *silvense* Zalessky, DVGI 403/2621, x 1. The same locality.

Fig. 4. *Protoblechnum* sp. A, DVGI 407/437, x 1. The station of Krasnoarmeisky; Late Permian, Chandalaz Formation.

Fig. 5. *Palaeovittaria* sp. A, DVGI 403/2622, x 1. The same locality.

Fig. 6. *Bardocarpus? ussuriensis* Zimina, DVGI 403/2608, x 1. Nakhodka; Late Permian, Chandalaz Formation.

Fig. 7. *Prymocarpus lampadiformis* Zimina, DVGI 405/139 (holotype), x 1.2. Murav'ev-Amursky Peninsula, southern of the Village of Shevelevka; lower Upper Permian, upper Pospelov Formation.

Fig. 8. *Paraburiadia mennerii* Zimina, DVGI 405/25 (holotype), x 1. The same locality.

Fig. 9. *Bardocarpus discretus* (Neuburg) Neuburg, DVGI 405/133, x 1. The same locality.

Fig. 10. *Todites* sp., DVGI 403/2623, x 5, Western Primorye, Medvezhyi Log; Late Permian, Barabash Formation.

Plate X

Fig. 1. *Psygmophyllum demetrianum* (Zalessky) Burago (a), *Callipteris sahnii* Zalessky (b), DVGI 408/168-A, x 1. Murav'ev-Amursky Peninsula, Shevelevka Village; Upper Permian, Chandalaz Formation.

Plate I

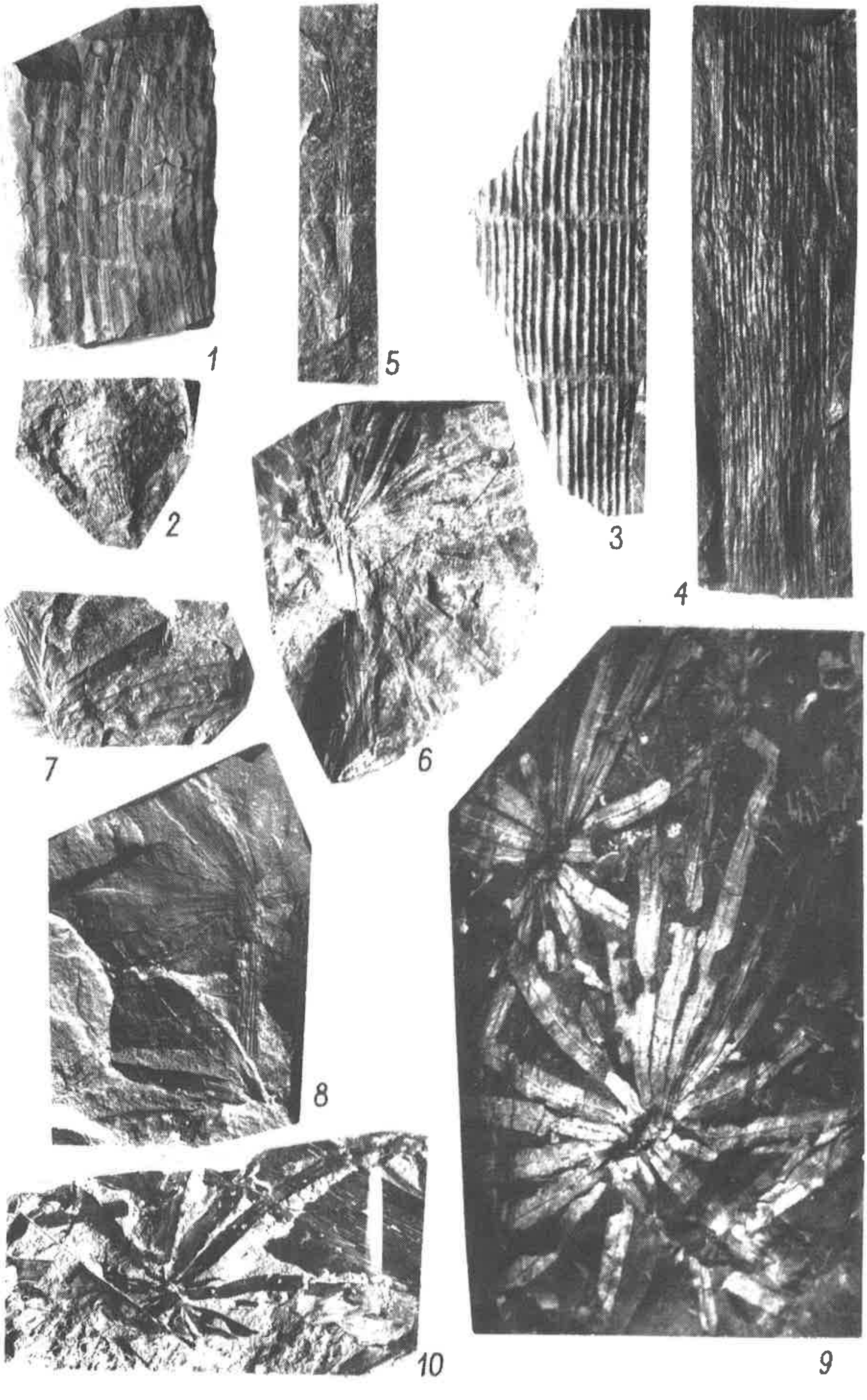


Plate II

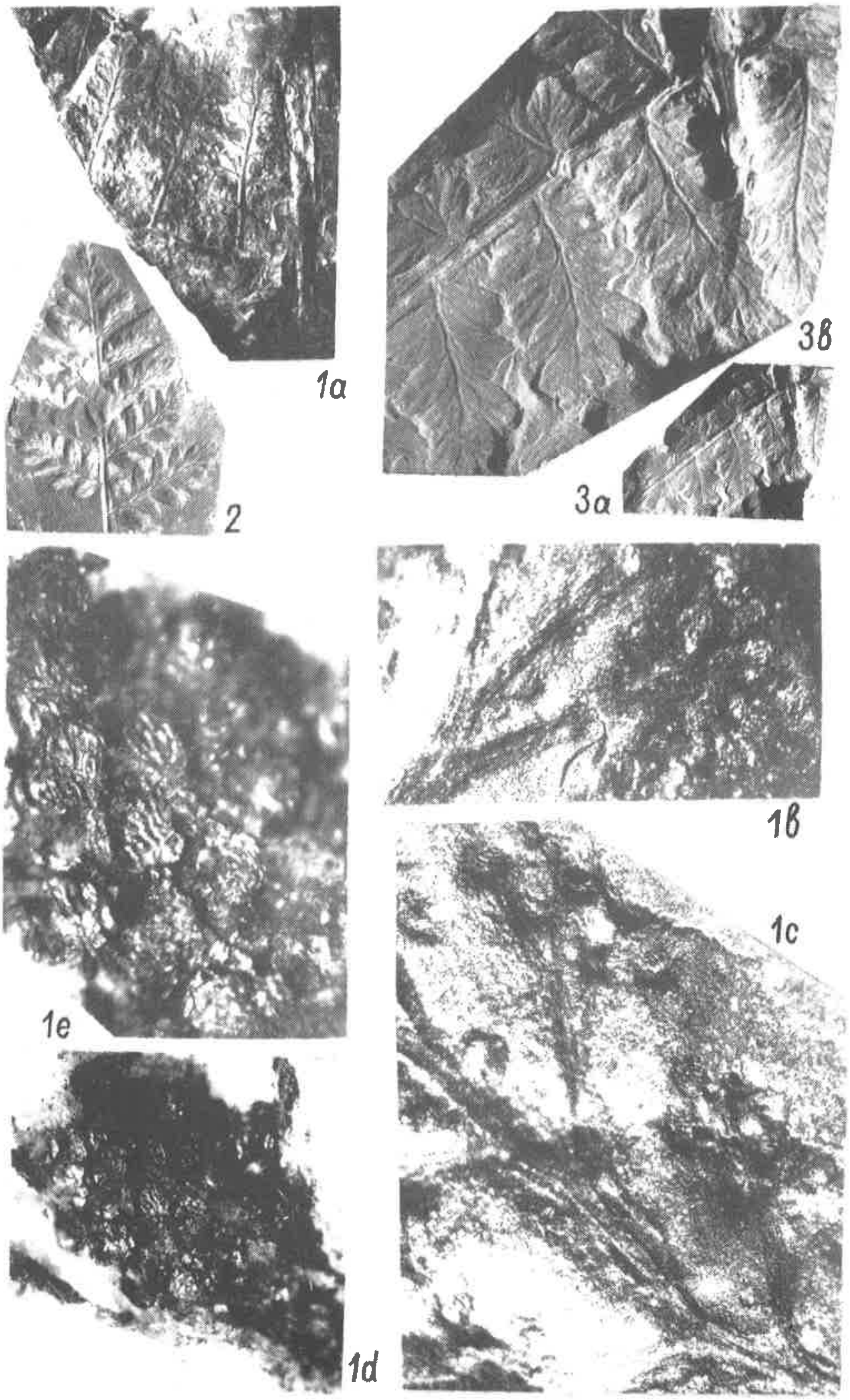
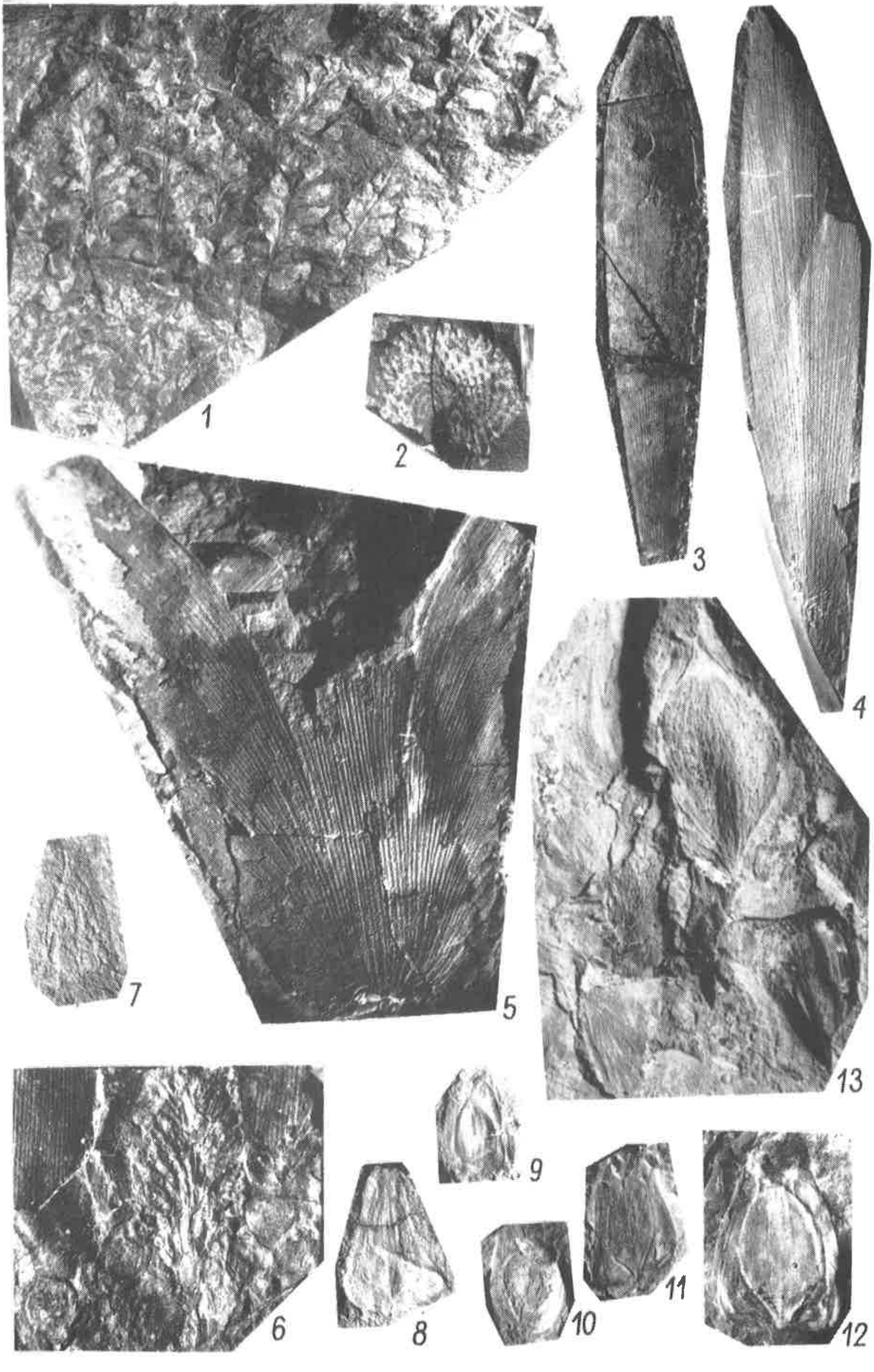


Plate III



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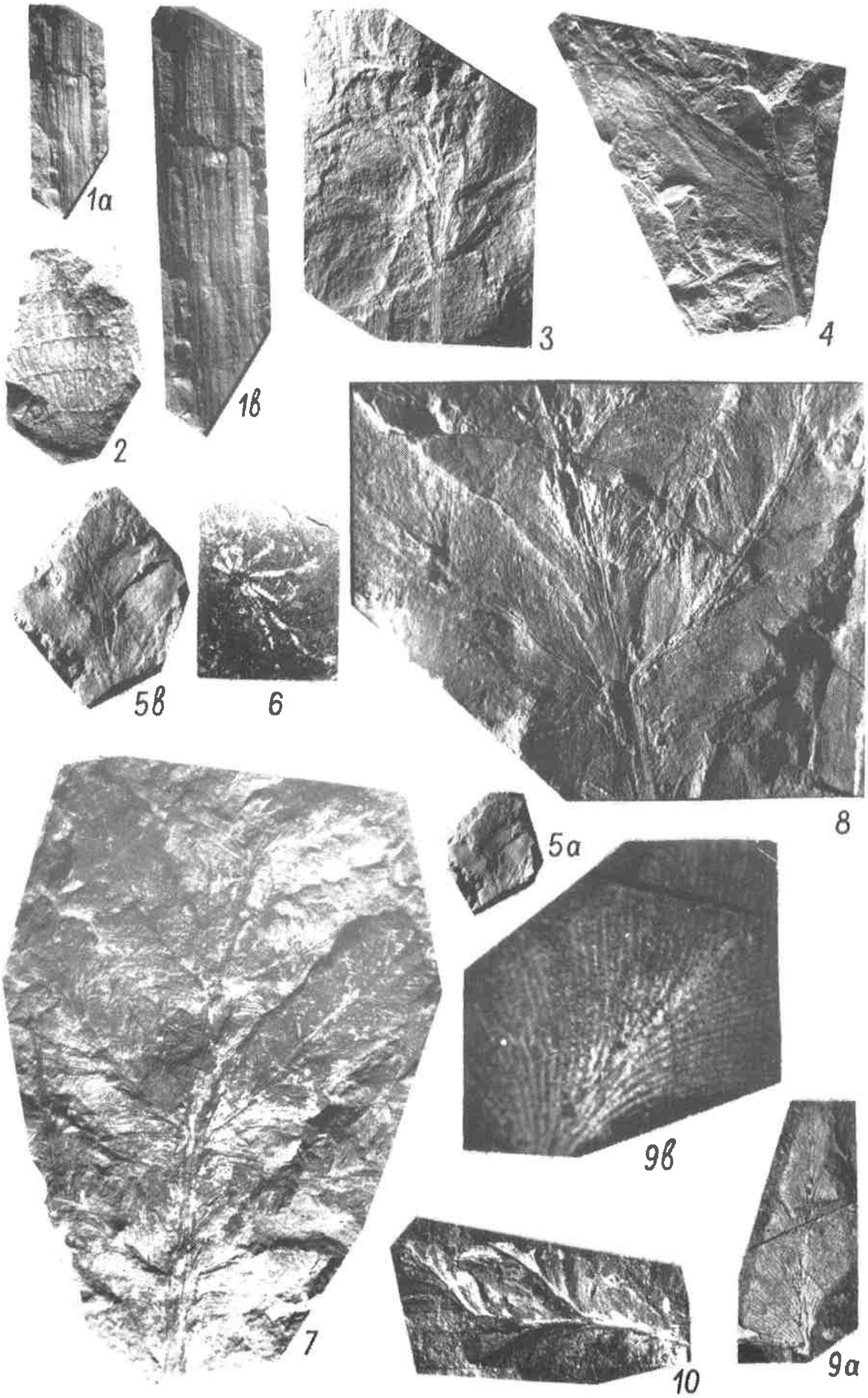
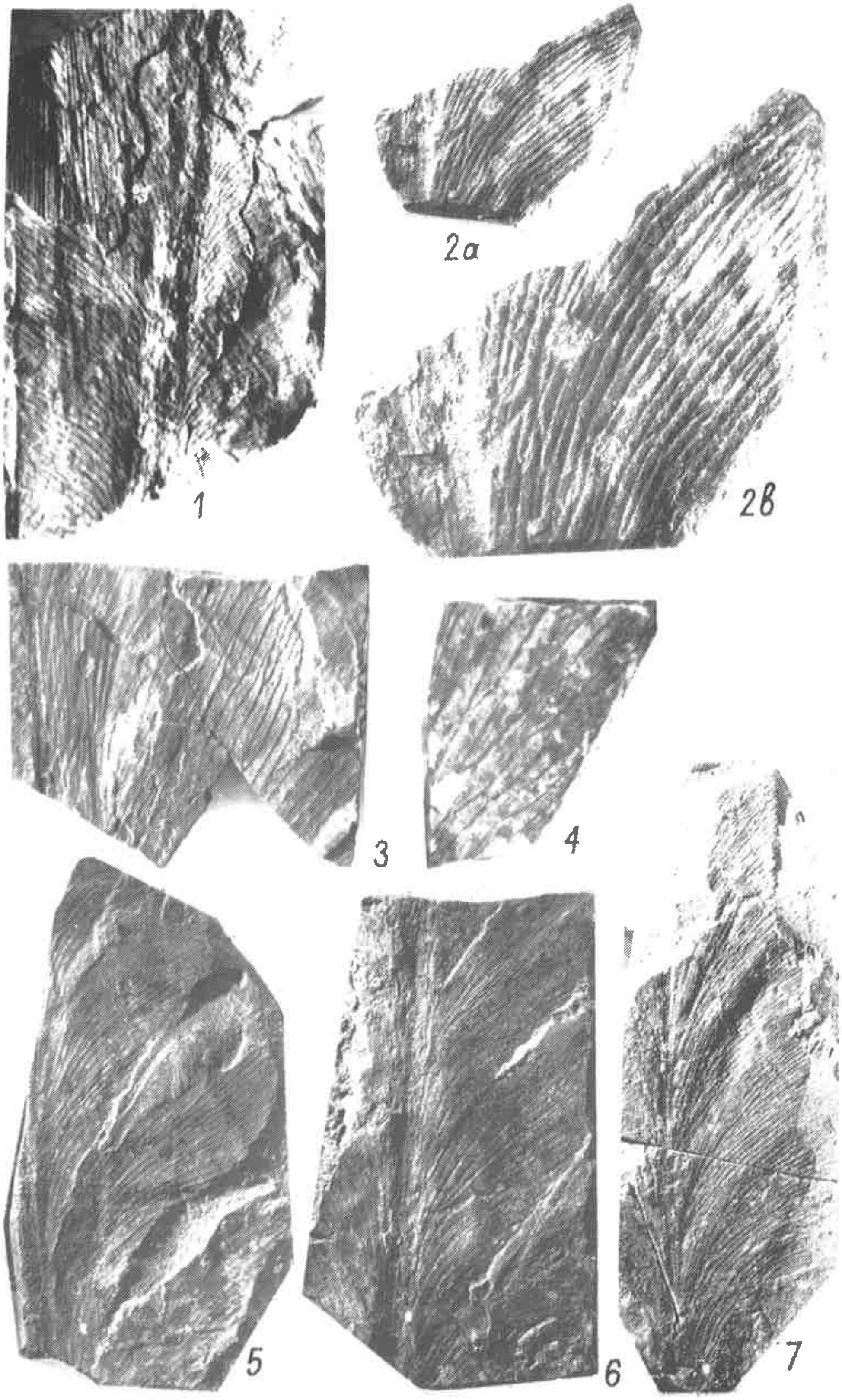


Plate V

Plate VI

Plate VII



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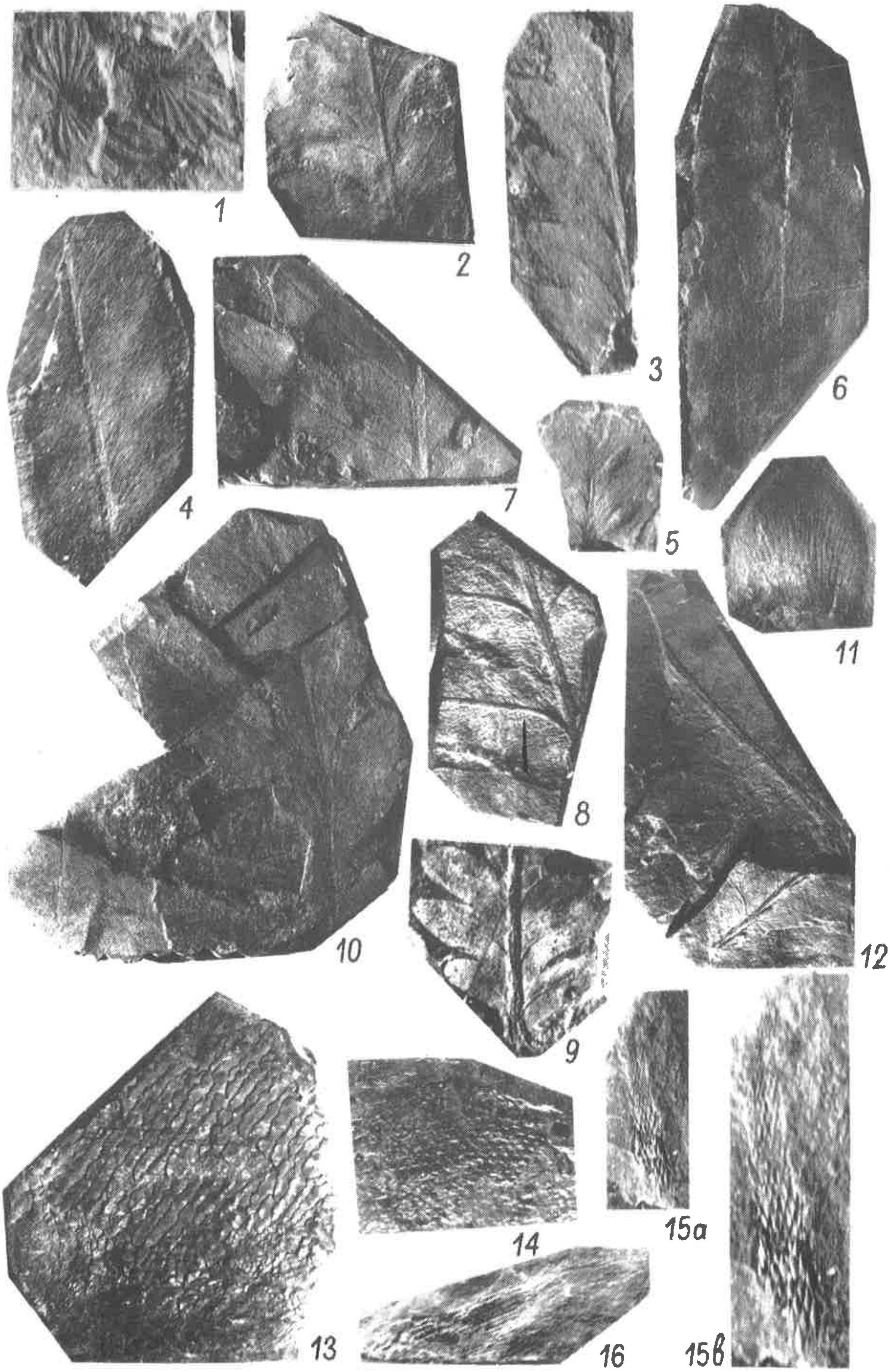


Plate IX

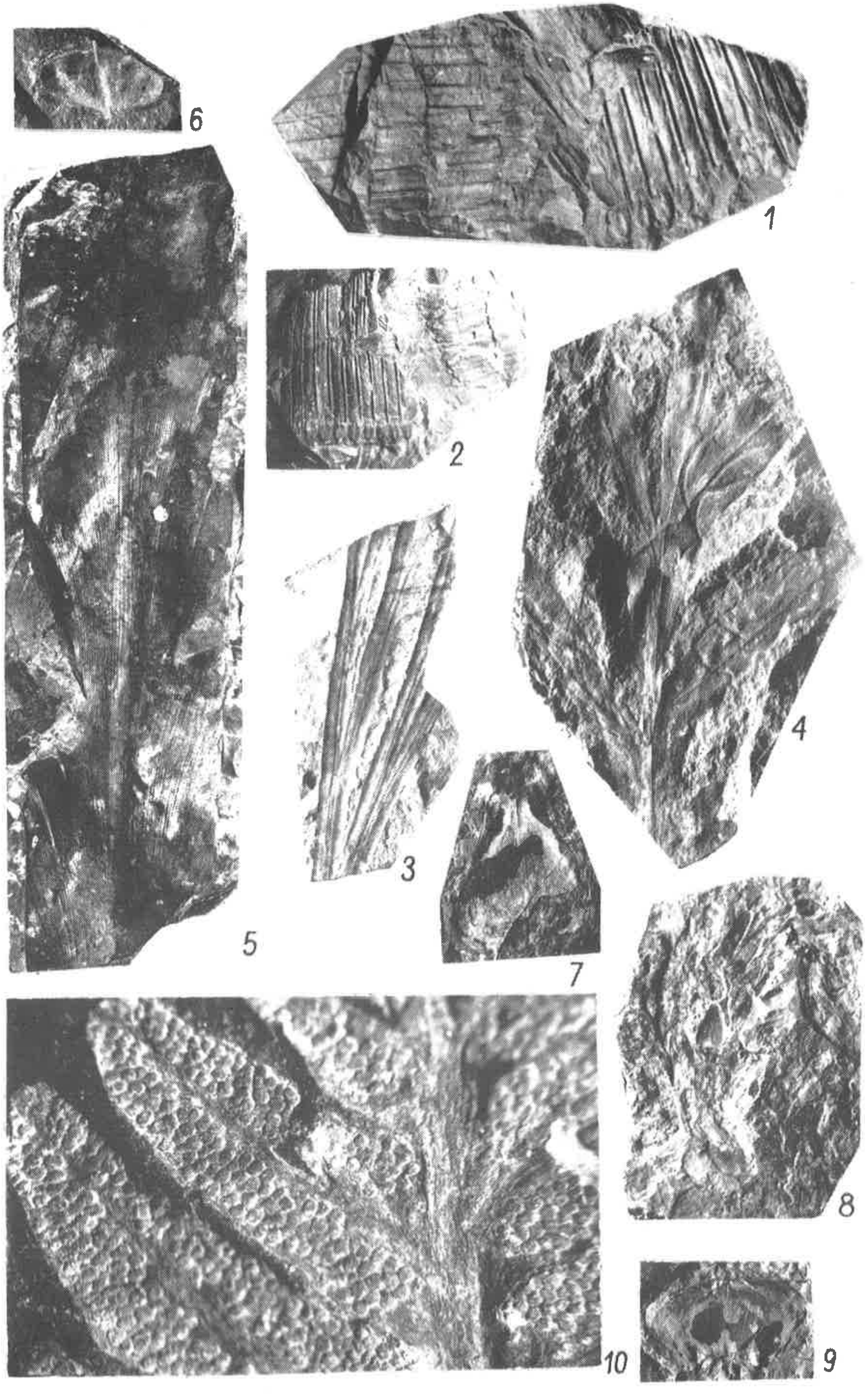
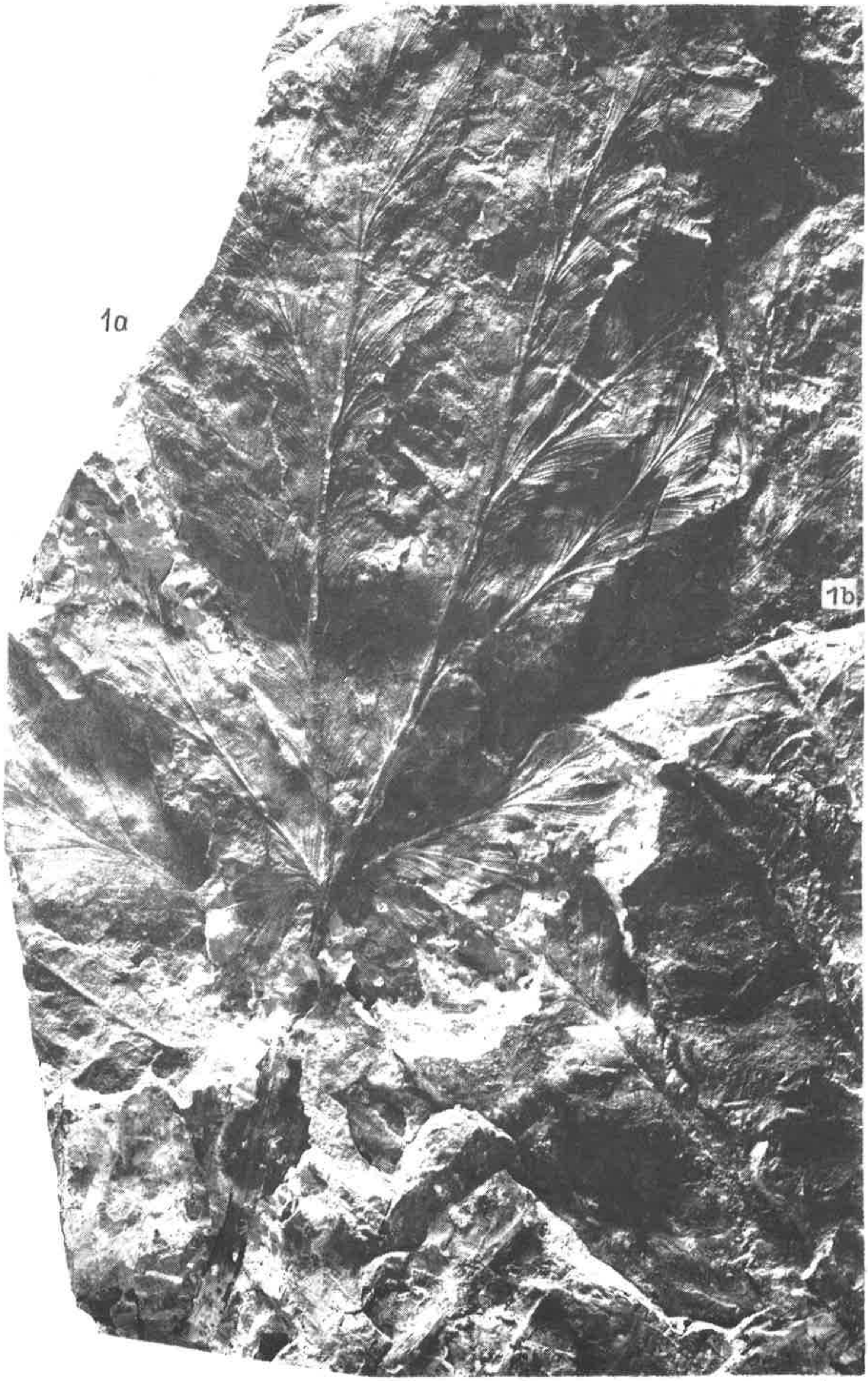


Plate X



LATE TRIASSIC FLORAS IN THE PRIMORYE REGION, RUSSIA

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Abstract

In the Primorye Region, the age of the Triassic plant-bearing deposits is determined by under - and overlying marine layers. The Carnian flora of Primorye is characterized by abundant *Neocalamites, Cladophlebis, Czekanowskia, Phoenicopsis, Pityophyllum, Podozamites, Taeniopteris*, and few ferns *Dipteridaceae* (only *Clathropteris* and *Hausmannia*). The Norian flora of Primorye is characterized by a dominance of *Dipteridaceae* (*Clathropteris, Dictyophyllum*, and *Camptopteris*), *Pterophyllum*, significant numbers of *Todites, Sphenobaiera, Baiera, Ginkgoites*, and *Podozamites*, and few *Thinnfeldia, Imania*, and *Tudovakia.*

In Primorye, major Upper Triassic nonmarine and near-shore deposits with fossil plants are known in the south and southwest, predominantly in the basin of the Razdolnaya River, at the western coast of the Amur Gulf, in the basins of the Barabashevka and Philippovka Rivers, and in the northern Murav'ev-Amursky Peninsula (Fig. 1). In the rest of Primorye they occur sporadically.

1. Southern Primorye

The most complete Upper Triassic sections occur in southern Primorye, where non marine deposits with fossil plants are underlain and overlain by marine deposits with bivalves. We distinguish a Carnian and a Norian flora. The Late Triassic flora of Primorye is known from literature as Mongugai. It was studied by A.N. Kryshtofovich (Kryshtofovich, 1910, 1921, 1923; Kryshtofovich and Prinada, 1932), I.N. Srebrodolskaja (Srebrodolskaja, 1958, 1960, 1961, 1964, 1968a, b, 1980; Shorokhova and Srebrodolskaja, 1979), S.A. Shorokhova (Shorokhova, 1971, 1975a, b, 1977) and V.A. Krassilov (Krassilov, Shorokhova, 1970).

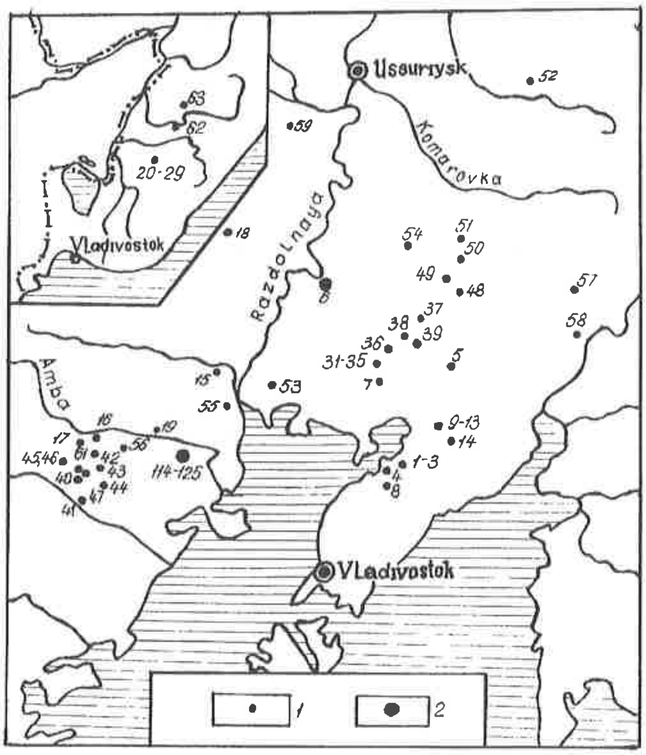

Fig. 1. The main localities of the Upper Triassic floras in South Primorye.

1 - The Carnian flora, 2 - The Norian flora.

In southern Primorye, in the basins of the Sirenevka and Razdolnaya Rivers, a bed of quartz sandstone, 20 to 150 m thick, forms at the base of the Carnian. It conformably overlies Ladinian marine deposits with *Daonella moussoni* (Merian). In the quartz sandstone bed, fossil plants include *Cladophlebis* sp., *Otozamites* sp., *Pseudoctenis mongugaica* Pryn., *Taeniopteris stenophylla* Krysht., *T. paraspathulata* Srebrod., T. lanceolata Oishi, *Baierella* sp., *Podozamites* ex gr. *lanceolatus* (L. et H.) Braun, *P. kiparisovkensis* Srebrod. et Shor., and *Cycadocarpidium erdmanni* Nath.

The overlying sequence consists of a well stratified alternation of green-grey fine-grained sandstone and siltstone, with oblique thin bedding and slab jointing. At the base of the sequence, there is an approximately 30 m thick coal-bearing series with the fossil plants *Neocalamites hoerensis* (Schimp.) Halle, *Equisetites* sp., *Clathropteris* sp., *Cladophlebis* sp., *Taeniopteris stenophylla* Krysht., *T. lanceolata* Oishi, *Glossophyllum(?)* sp., *Podozamites* ex gr. *lanceolatus* (L. et H.) Braun and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath.

Except for plant detritus and poorly preserved stems of *Equisetites*, no identifiable plants were observed above the coal bearing beds. The thickness of the sequence is up to 600 m.

A bed of quartz sandstone and a sequence of platy sandstone and siltstone were described by I.V. Burij (1959) as the Kiparisovka River formation.

The Sadgorod formation (suite) is distinguished up the sequence. It is very common in the basins of the Bogataya, Peschanka, Perevoznaya, Komarovka, and Knevichanka Rivers. It rests conformably over the sequence of platy sandstone and siltstone, or overlies older deposits. The formation consists of coal-bearing strata with the fossil plants: *Thallites* sp., *Neocalamites hoerensis* (Schimp.) Halle, *Equisetites* sp., *Cladophlebis* cf. *gigantea* Oishi, *Cladophlebis nebbensis* (Brongn.) Nath., *Pseudoctenis mongugaica* Pryn., *Taeniopteris stenophylla* Krysht., *T. paraspathulata* Srebrod., Taeniopteris *(?)* sp., *Parajacutiella mongugaica* (Srebrod.) Srebrod., *Baiera minuta* Nath., *Glossophyllum(?)* sp., *Czekanowskia* sp., *Podozamites* ex gr. *lanceolatus* (L. et H.) Braun, *P.* ex gr. *schenkii* Heer, *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., *Carpolithes heeri* Tur.-Ket., *C. mongugaicus* Srebrod. The thickness of the formation is up to 700 m.

Non marine deposits of the Sadgorod formation in the southern Primorye are overlain conformably by marine deposits of the Norian Peschanka formation with the bivalves *Oxytoma zitteli* (Tell.), *O. mojsisovicsi* Tell., *Tosapecten suzukii* (Kob.), *Otapiria ussuriensis* (Vor.), *Eomonotis scutiformis* (Tell.) and *E. scutiformis* var. *typica* Kipar. The thickness of the Peschanka formation is 400 to 520 m.

Non marine Norian deposits are represented by the Amba River formation (suite). The stratotype is on the right side of the Amba River, near its mouth. Coal-bearing deposits with fossil plants, 300 m thick, overlie the Peschanka formation and underlie the Perevoznaya River formation with the bivalve *Monotis ochotica* (Keys.).

In the middle and lower parts of the stratotype section of the Amba River formation, 15 cyclothems, 4 to 34 m thick, are distinguished, with abundant plant remains predominantly in the upper fine-grained or coal-bearing members. The upper part of the section essentially consists of inequigranular poorly-rhythmical tuffaceous sandstone. Coal beds are very scarce, plant fossils principally consist of charred stems, fine detritus, and leave fragments.

Fossil plants of the stratotype of the Amba River formation include *Neocalamites hoerensis* (Schimp.) Halle, *Equisetites* sp., *Todites pseudoraciborskii* (Srebrod) Shor., *Clathropteris meniscioides* Brongn., *Dictyophyllum nathorstii* Zeill., *Dictyophyllum* sp., *Cladophlebis macrophylla* Shor., *Thinnfeldia ambabiraensis* Srebrod., *Imania heterophylla* Krassil. et Shor., *Pterophyllum ambabiraensis* (Srebrod.) Shor., *P. marginatum* Unger, *P.* aff. *nathorstii* Schenk., *P. innae* Shor., *Taeniopteris ambabiraensis* Srebrod., *T. stenophylla* Krysht., *Baiera* cf. *minuta* Nath., *Baiera* sp., *Sphenobaiera* cf. *paucipartita* (Nath.) Florin, *Podozamites* ex gr. *lanceolatus* (L. et H.) Braun, *P.* cf. *distans* (Presl) Braun, *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., *Swedenborgia* sp. and *Conites ambabiraensis* Srebrod.

In a railroad cut near the village of Razdolnoe, *Equisetites* sp., *Clathropteris menisciodes* Brongn., *Dictyophyllum kryshtofovichii* Srebrod., *Camptopteris spiralis* Nath., *Todites* cf. *ussuriensis* Shor., *Taeniopteris stenophylla* Krysht., *Glossophyllum* cf. *florinii* Krausel, *Podozamites distans* (Presl) Braun, *Cycadocarpidium erdmannii* Nath. and *Drepanolepis squamulosa* Srebrod. were observed in greenish-grey fine-grained sandstone of the upper part of the section. Non marine deposits are overlain by sandstone with *Monotis ochotica* (Keys.).

2. South-Western Primorye

All over the south-western Primorye (the basins of the Barabashevka, Filippovka, and Amba Rivers), except for a narrow band along the western coast of the Amur Gulf and the right bank of the Razdolnaya River, Upper Triassic deposits are exclusively non marine deposits of the platy sandstone and siltstone sequence and the Sadgorod formation. Conglomerate beds, 100 m thick, eroded and resting with angular unconformity on Upper Permian extrusives, were observed at the base. The 500 m thick Sadgorod formation, consists there of coal-bearing deposits with fossil plants, which are abundant throughout the section of the formation. Fossil plants include *Neocalamites hoerensis* (Schimp.) Halle, *Equisetites* sp., *Todites giganteus* (Oishi) Shor., *Cladophlebis nebbensis* Brongn., *Clathropteris meniscioides* Brongn, *Hausmannia ussuriensis* Krysht., *Cladophlebis nebbensis* (Brongn.) Nath., *Pseudoctenis mongugaica* Pryn., *Taeniopteris stenophylla* Krysht., *T. paraspathulata* Srebrod., *Baiera minuta* Nath., *Glossophyllum(?)* sp., *Baierella* sp., *Phoenicopsis angustifolia* Heer, *Podozamites* ex gr. *lanceolatus* (L. et H) Braun, *P.* ex. gr. *schenkii* (Heer) Nath., *Podozamites* sp. nov., *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath. and *Carpolithes mongugaicus* Srebrod.

3. Northern Primorye

In the northern Primorye, the most complete Upper Triassic section, consisting of marine and near-shore sediments, occurs at the right side of the Malinovka River (the basin of the Bolshaya Ussurka River), across the village of Malinovo. There, the section consists of a 30 m thick sequence of sandstone and siltstone (similar to the Peschanka formation) with the bivalves *Eomonotis pinensis* (West.), *E. scutiformis* var. *typica* Kipar. and *Palaeopharus buriji* Kipar., the 116 m thick Amba River formation, a 350 m thick sandstone and siltstone sequence with bivalves *Monotis ochotica* (Keys.), and a 350 m thick sequence of conglomerate, sandstone, and siltstone (without fossils).

The Amba River formation consists of inaquigranular sandstone, siltstone, and coaly argillite with scarce thin beds of coal. The lithology does not differ much from that of the underlying marine deposits. The boundary is defined at the coaly argillite beds. Seven cyclothems are distinguished. Lithology, rhythmic pattern, bedding, and joint burial of land plants and marine bivalves suggest a near-shore environment. Fossil plants of the Amba River formation at the Malinovka River include *Thallites* sp., *Todites ussuriensis* Shor., *Clathropteris menisciodes* Brongn., *Dictiophyllum kryshtofovichii* Srebrod., *Camptopteris japonica* (Yok.) Konno, *Cladophlebis pseudodelicutula* Oishi, *Acrostichopteris (?) rara* Shor., *Thinnfeldia ambabiraensis* Srebrod., *Imania heterophylla* Krassil. et Shor., *Tudovakia papillosa* Shor. et Krassil., *Pterophyllum nathorstii* Schenk, *P.* cf. *pinnatifidum* Harris, *Pterophyllum* sp., *Ctenis* sp., *Taeniopteris stenophylla* Krysht., *T.paraspathulata* Srebrod., *T.* cf. *ambabiraensis* Srebrod., *T. linearis* Mi et Sun C., *Taeniopteris (?) sp. nov.*, *Baiera minuta* Nath., *Podozamites* ex gr. *lanceolatus* (L. et H.) Braun, *P. angustifolius* (Eichw.) Heer, *Cycadocarpidum erdmannii* Nath., *Elatocladus sp. nov. and Carpolithes minor* Pryn.

Similar Upper Triassic sections occur northward of the Malinovka River, in the basins of the Ul'yanovka and Olon Rivers.

4. Discussion

The Carnian and Middle Norian are clearly distinguished in the development of the flora. The Carnian stage is characterised by abundant *Neocalamites*, common *Phoenicopsis* and *Pityophyllum*, and subordinate *Bennettitales* (*Otozamites* exclusively at the early stage) and *Dipteridaceous* ferns (only *Clathropteris* and *Nausmannia*). During the early Carnian non peat-forming assemblage of *Podozamites, Baierella*, and *Otozamites* predominated among plants. During the early stage of the accumulation of lacustrine deposits of platy sandstone and siltstone, it was replaced peat-forming assemblage of swampy *Podozamites, Taeniopteris*, and *Todites* with coastal brushwood *Equisetales* and locally abundant *Phoenicopsis*, *Pityophyllum*, and *Czekanowskia*. It was the dominant assemblage in the southern and south-western Primorye during the Carnian.

A considerable change in the composition of taxa occurred during the Norian. Only seven species (*Neocalamites hoerensis*, *Clathropteris meniscioides*, *Taeniopteris stenophylla, T. paraspathulata, Baiera minuta, Podozamites* ex gr. *lanceolatus*, and *Pityophyllum* ex gr. *nordenskioldii*) passed on to the Norian flora. *Phoenicopsis* and *Pityophyllum* became subordinate, giving way to *Sphenobaiera. Czekanowskia* disappeared, and the number of *Pterophyllum* species increased. The family *Dipteridaceae*, represented by the genera *Clathropteris*, *Dictyophyllum*, and *Camptopteris* attained the greatest specific variety among ferns. The pteridosperms *Thinnfeldia, Imania*, and *Tudovakia* first appeared. Although articulates were very common during the Carnian (*Neocalamites)*, from the Norian only small forms (*Equisetites)* are known. New species of *Todites, Baiera*, and *Podozamites* appeared and they show a greater variation.

The analysis of successively changing taphocoenoses of the Amba River formation stratotype suggests that the *Podozamites-Sphenobaiera* assemblage was principal in the southern Primorye flood plain forests during Norian times. Peat-forming assemblages with *Taeniopteris* and *Pterophyllum*, and non peat-forming *Pterophyllum* are distinguished. During the deposition of the lower part of the section, peat-forming communities inhabiting swampy flood plains dominated the flora of the Amba River formation. Later, plant community changed, with mesophytic elements being predominant. No peat deposition occurred in the upper section, in which mesophytic elements of the central flood plain and slopes predominate. The change in floral composition is presumably related to the reduction of lowland areas as a result of transgression.

The comparison of the Late Triassic floras of Primorye, with coeval northern hemisphere floras shows that the Carnian flora of Primorye differs considerably from that of the German Basin and other areas of Europe. It is most similar to the Late Triassic flora of the eastern slope of the Urals. The Norian flora of Primorye differs from that of the eastern Urals by the abundant of *Dipteridaceous* ferns and *Bennettitalis*, which makes it similar to the Rhaeto-Liassic flora of eastern Europe and Greenland. Some species of the Norian flora of Primorye formed part of the zonal Rhaetian complex of the European *Lepidopteris* Zone.

Among the Late Triassic flora of south-eastern Asia, the Carnian-Early Norian flora of the Mine Group, Yamaguti area, Japan, is most similar to the Carnian flora of Primorye (many common and similar species). The differences are restricted to a greater variety of *Dipteridaceous* ferns in the Carnian. The Norian flora of the Nariva Group (Oishi, 1932a,b, 1940; Konno, 1968) differs from the flora of the coeval Amba River formation by its greater generic and specific variety of ferns and Cycadales. The flora of the Nariva Group includes species, typical for the Carnian, Norian, and Early Jurassic floras of Primorye.

The Norian flora of Primorye is most similar to the coeval flora of the Tianqiaoling District of eastern Jilin, China (Sun Ge, 1981, 1990). The majority of species are common or similar.

The analysis of paleofloristic relations suggests that the Carnian flora of Primorye is similar to the temperate floras of the Siberian paleofloristic area, and the Norian floras of tropical-subtropical Europe and south-eastern Asia (flora *Dictyophyllum-Clathropteris*). The paleoecological analysis of the Late Triassic flora of Primorye allowed us to infer the climatic cycle with the most favourable conditions during Norian time and less favourable conditions during Carnian times.

Acknowledgements

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Plate I

The Carnian flora of South Primorye

Fig. 1. *Todites giganteus* (Oishi) Shorokhova: DVGTU, 30/1; Filippovka (Mongugai) River (loc. 30); Sadgorod Formation.

Fig. 2, 3. *Otozamites* sp.: 2 - CNIGR Mus. 7/10264, 3 - 8/10264; Kiparisovka River (loc.31) Kiparisovka River Formation.

Fig. 4. *Pseudoctenis mongugaica* Prynada: DVGTU, 47/2; Filippovka River (loc. 47); Sadgorod Formation.

Fig. 5, 6. *Taeniopteris paraspathulata* Srebrod.: DVGTU, 5-4/7, 6-4/8; Bogataya River (loc. 4); Sadgorod Formation.

Fig. 7. *Taeniopteris stenophylla* Kryshtofovich: DVGTU, 47/7; Filippovka (Mongugai) River (loc. 47); Sadgorod Formation.

Fig. 8-9.*Taeniopteris lanceolata* Oishi: CNIGR Mus., 8-17/10264, 9-18/10264; Kiparisovka River (loc. 31); Kiparisovka River Formation.

Fig. 10. *Taeniopteris (?)* sp.: DVGTU, 36/2; Knevithanka River (loc. 36); Sadgorod Formation.

Fig. 11. *Baierella* sp.: CNIGR Mus., 20/10264; Kiparisovka River (loc. 31); Kiparisovka River Formation.

Fig. 12. *Czekanowskia* sp.: DVGTU, 51/1; Perevoznaya River (loc. 51); Sadgorod Formation.

Fig. 13. *Phoenicopsis angustifolia* Heer: DVGTU, 17/10; Filippovka (Mongugai) River (loc. 17); Sadgorod Formation.

Plate II

The Carnian flora of South Primorye

Fig. 1. *Podozamites* ex gr. *schenkii* Heer: CNIGR Mus., 21/11698; Filippovka (Mongugai) River (loc. 40); Sadgorod Formation.

Fig. 2-7. *Podozamites kiparisovkensis* Srebrodolskaja et Shorokhova: CNIGR Mus., 2-26/10264, 3 - 25/10264, 4 - 32/10264,5 -29/10264, 6 - 18/10264, 7 - 30/10264; Kiparisovka River (loc. 31); Kiparisovka River Formation.

Plate III

The Norian flora of Primorye

Fig. 1. *Clathropteris meniscioides* Brongniart: DVGTU, 117/4; Amba River (loc. 117); Amba River Formation.

Fig. 2-3. *Dictyophyllum kryshtofovichii* Srebrodolskaja : DVGTU, 2-6/95, 3-6/96; Razdolnaya River (loc. 6); Amba River Formation.

Fig. 4-6. *Camptopteris spiralis* Nathorst: DVGTU, 4-6/125, 5-6/124, 6-121; Razdolnaya River (loc. 6); Amba River Formation.

Fig. 7. *Camptopteris japonica* (Yokoyama) Konno: DVGTU, 7-22/236; Malinovka River (loc. 22); Amba River Formation.

Fig. 8. *Todites pseudoraciborskii* (Srebrodolskaja) Shorokhova: DVGTU, 118/71; Amba River (loc. 118); Amba River Formation.

Fig. 9-10. *Thinnfeldia ambabiraensis* Srebrodolskaja : CNIGR Mus., 9-16/11698, 10-13/11698; Amba River (loc. 119); Amba River Formation.

Fig. 11-12. *Tudovakia papillosa* Shorokhova et Krassilov: BPI, 11-22/326, 12-22/380; Malinovka River (loc. 22); Amba River Formation.

Plate IV

The Norian flora of Primorye

Fig. 1-8. *Imania heterophyllaa* Krassilov et Shorokhova: BPI, 1-22/277, 2 - 22/267, 3-22/304, 4-22/272, 5-22/374, 6-22/327, 7-22/326, 8-22/332; Malinovka River (loc. 22); Amba River Formation.

Fig. 9-10. *Pterophyllum nathorstii* Schenk: DVGTU, 9-121/16, 10-121/13; Amba River (loc. 121); Amba River Formation.

Fig. 11. *Pterophyllum ambabiraensis* (Srebrodolskaja) Shorokhova: DVGTU, 119/24; Amba River (loc. 119); Amba River Formation.

Fig. 12. *Pterophyllum innae* Shorokhova: DVGTU, 119/5; Amba River (loc. 119); Amba River Formation.

Fig. 13-14. *Pterophyllum* cf. *pinnatifidum* Harris: DVGTU, 13-20/174,14-20/177; Malinovka River (loc. 20); Amba River Formation.

Plate V

The Norian flora of Primorye

Fig. 1-2. *Pterophyllum marginatum* Unger: DVGTU, 1-118/32, 2-118/30; Amba River (loc. 118); Amba River Formation.

Fig. 3-4. *Taeniopteris ambabiraensis* Srebrodolskaja: DVGTU, 3-116/1, 4-119/3; Amba River (loc. 116, 119); Amba River Formation.

Fig. 5-6. *Taeniopteris linearis* Mi et Sun C.: DVGTU, 5-22/378, 6-22/345; Malinovka River (loc. 22); Amba River Formation.

Fig. 7. *Taeniopteris stenophylla* Kryshtofovich: DVGTU, 22/363; Malinovka River (loc. 22); Amba River Formation.

Fig. 8-9. *Taeniopteris(?)* sp. nov.: DVGTU, 8-22/310, 9-22/312; Malinovka River (loc. 22); Amba River Formation.

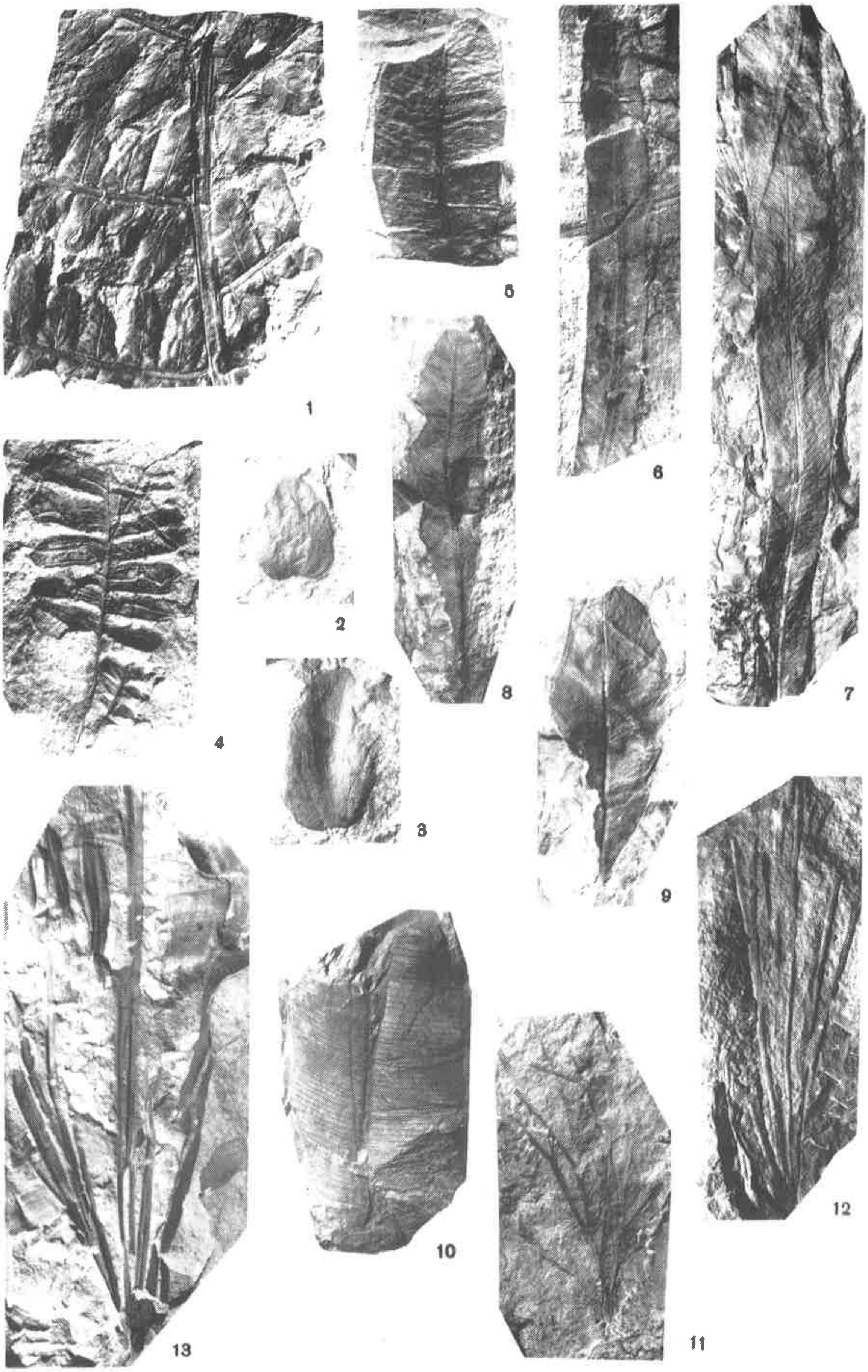
Fig. 10-11. *Acrostichopteris(?)* rara Shorokhova: CNIGR Mus., 10-9/11698, 11-10/11698; Malinovka River (loc. 22); Amba River Formation.

Fig. 12-13. *Sphenobaiera* cf. *paucipartita* (Nathorst) Florin: DVGTU, 11-119/17, 12-119/16; Amba River (loc. 119); Amba River Formation.

Fig. 14-15. *Baiera minuta* Nathorst: DVGTU, 14-20/143, 15-20/144; Malinovka River (loc. 20); Amba River Formation.

Fig. 16. *Cycadocarpidium erdmannii* Nathorst: DVGTU, 20/413; Malinovka River (loc. 20); Amba River Formation.

Plate I



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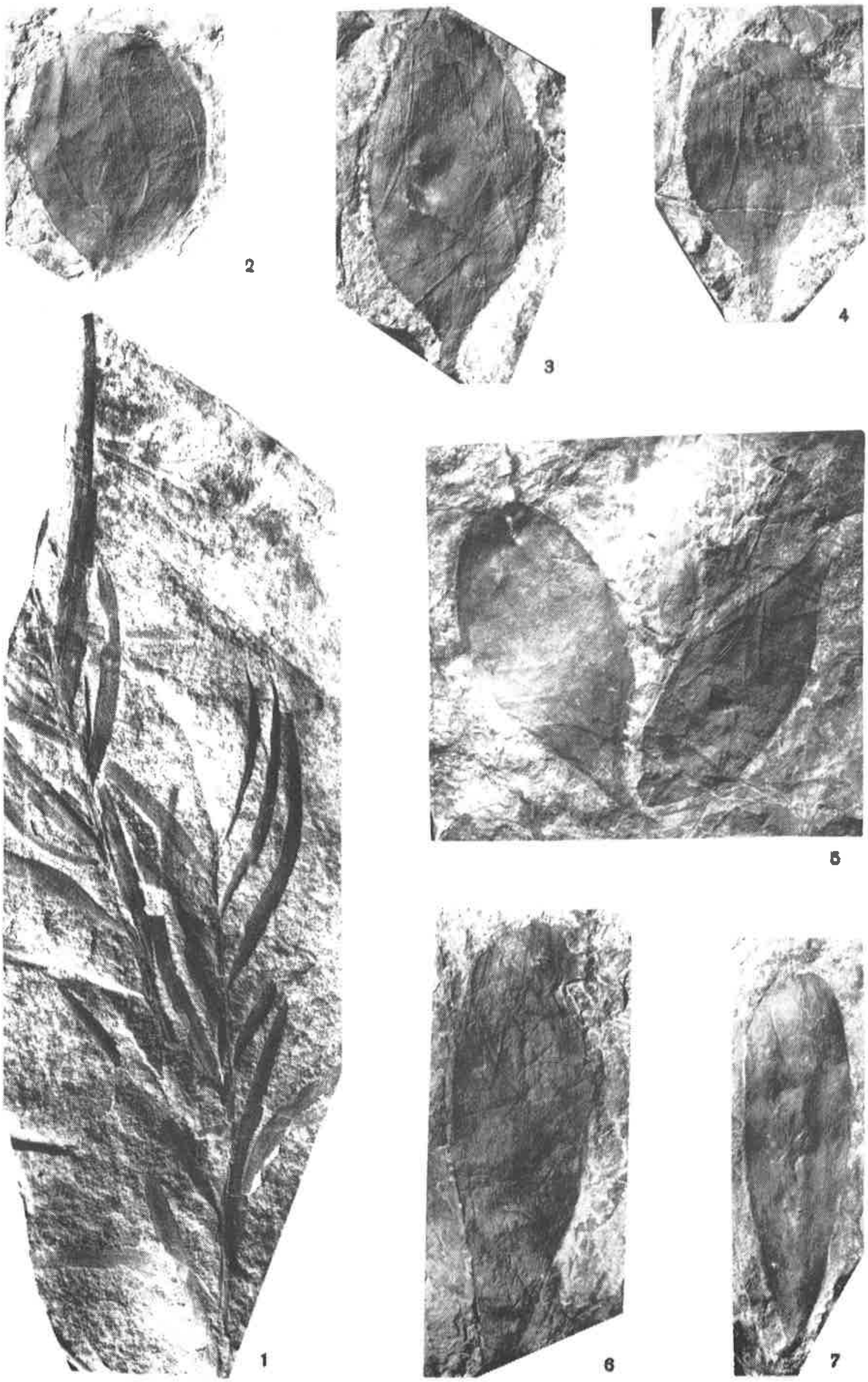

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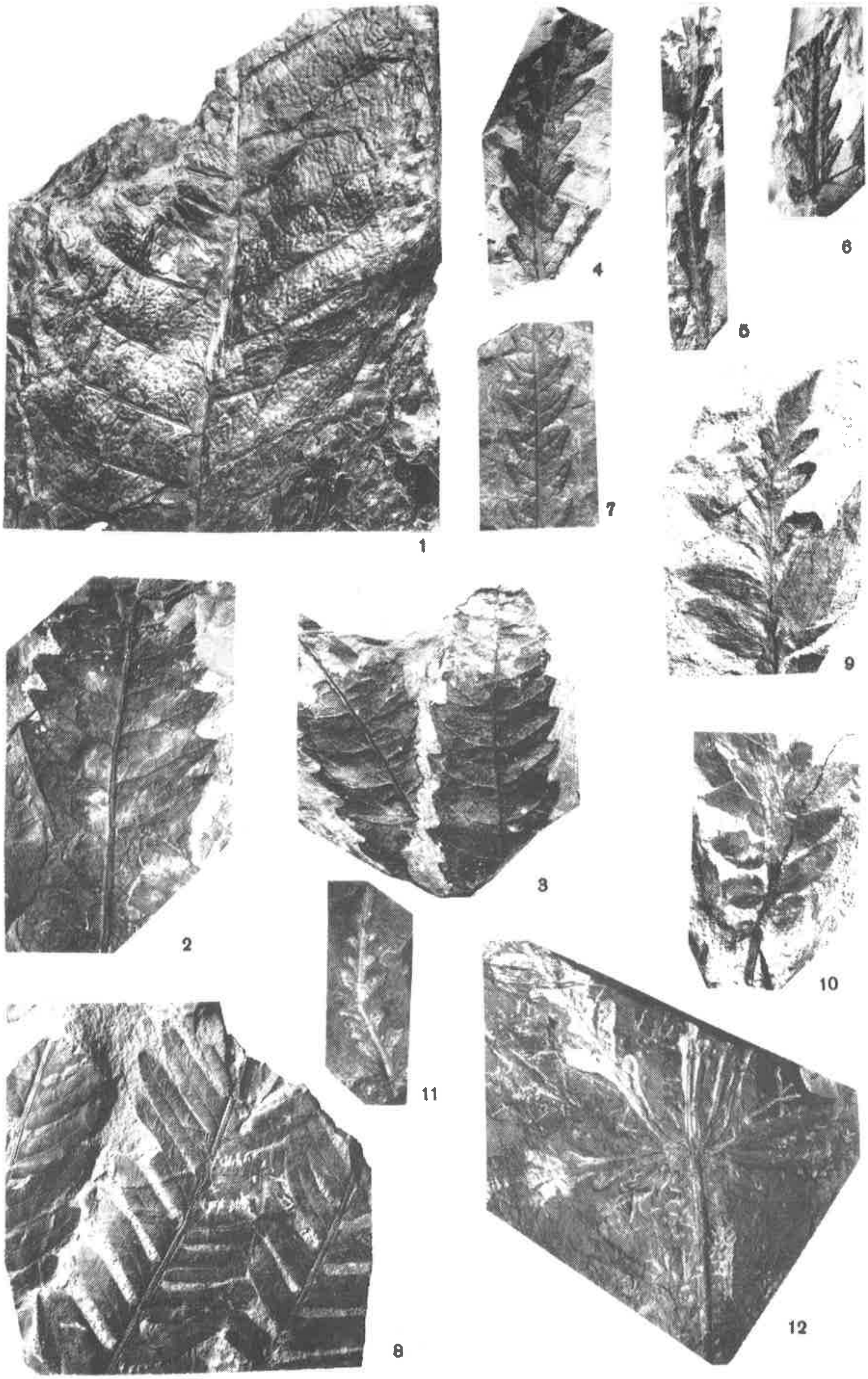

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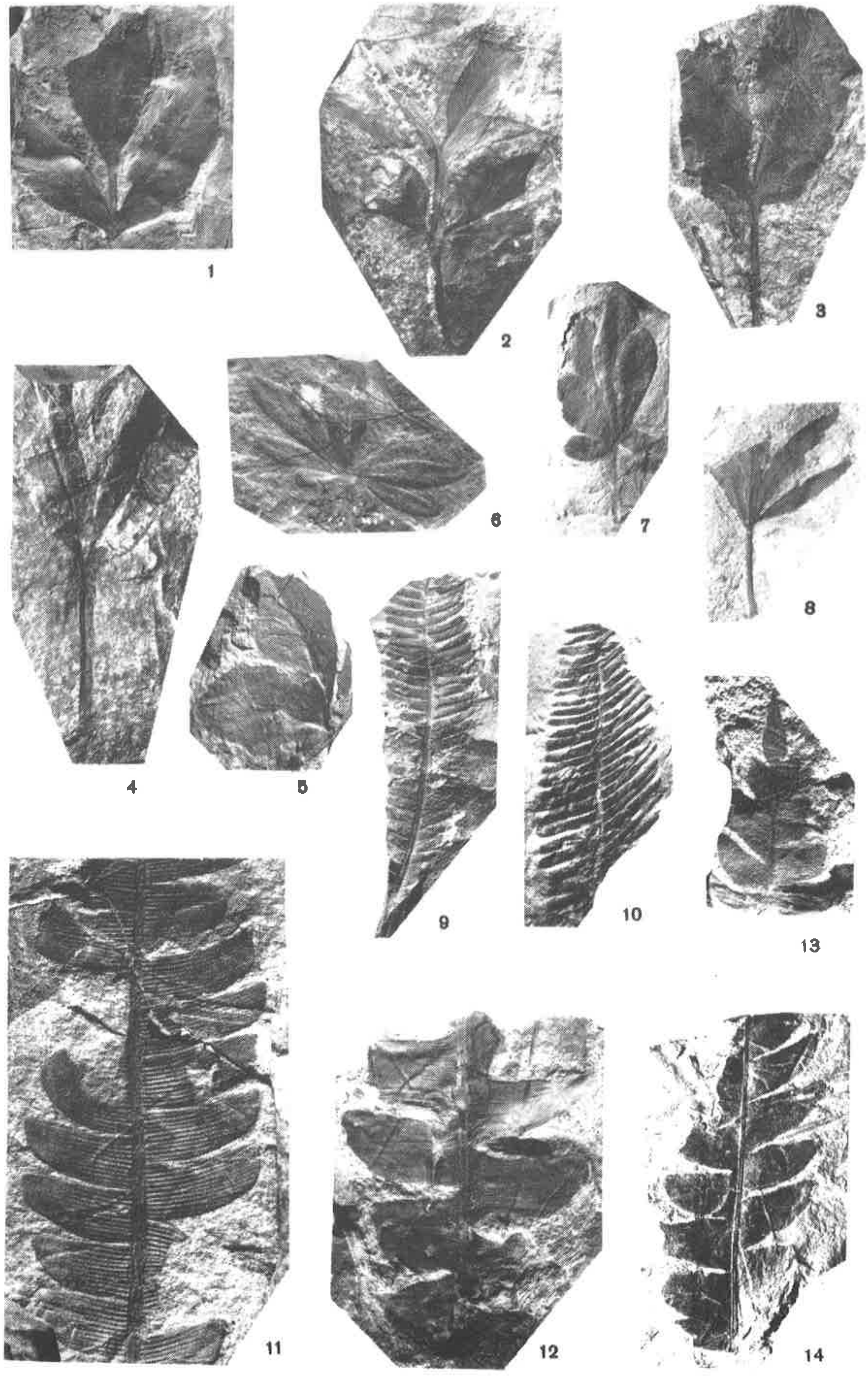

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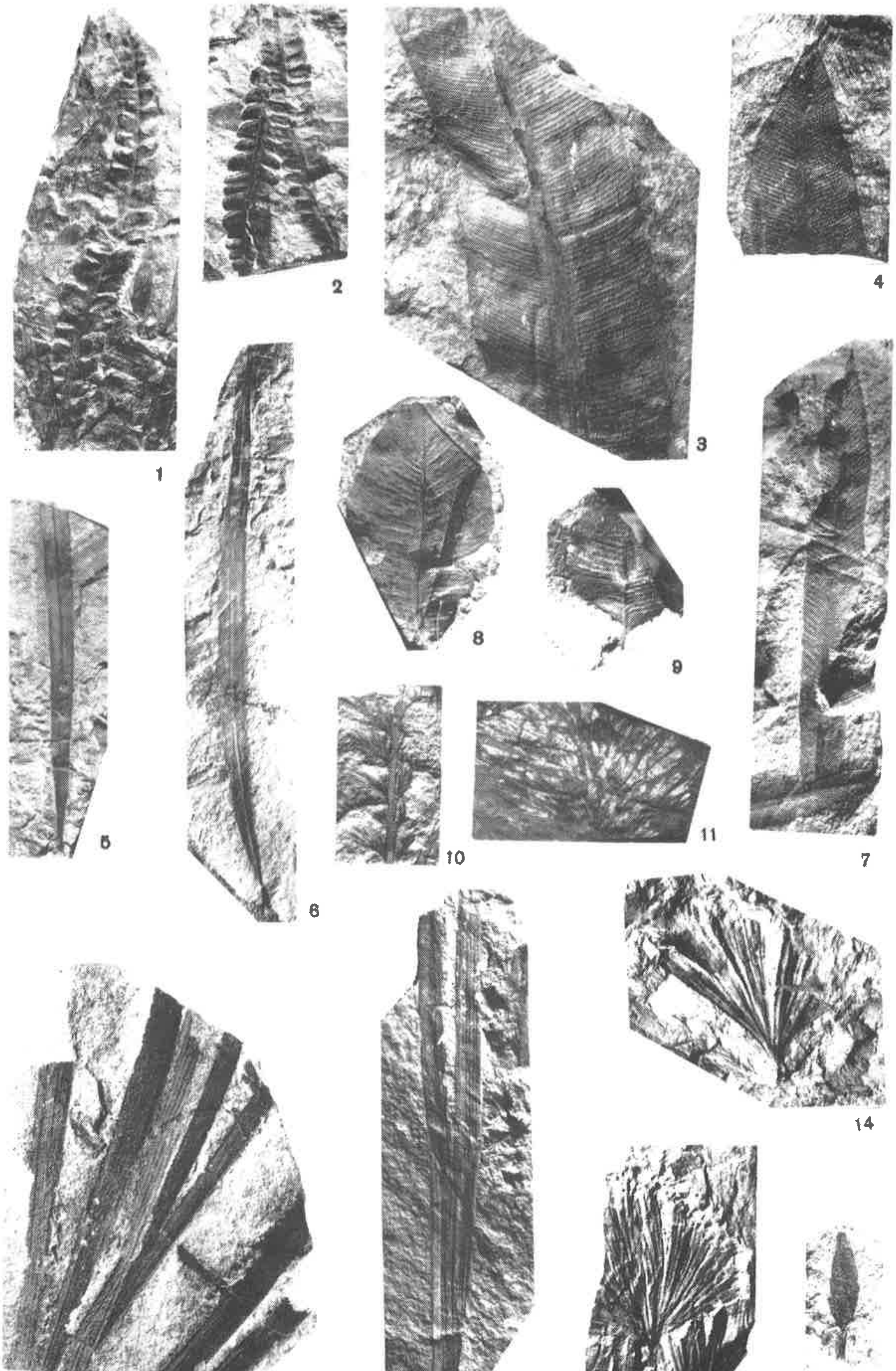

AMMONOID EVOLUTION AND THE PROBLEM OF THE STAGE AND SUBSTAGE DIVISION OF THE LOWER TRIASSIC

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Abstract

The most popular stage scheme of the Lower Triassic proposed by L.D. Kiparisova and Y.N. Popov may be significantly improved by division of the uppermost stage into two fundamentally different substages. The binomial composition of the Lower Triassic, with a single substage (stage) in the lower member, but with two sharply pronounced substages within the uppermost one, reflects more or less satisfactorily the triphasic character of evolution of the Early Triassic biota.

1. Introduction

There are many problems of stage and substage division of the Lower Triassic and therefore a lot of suggestions have been made regarding this (Mojsisovics,1882; Mojsisovics et al., 1895; Lapparent, 1900, Ichikawa, 1950, 1956; Kiparisova and Popov, 1956, 1964; Arkell et al., 1957; Mutch and Waterhouse, 1965; Tozer, 1965, 1978; Vavilov and Lozovsky, 1970; Zakharov, 1973, 1974, 1978a,b, 1987, 1992; Kozur, 1973; Guex, 1978; Rostovcev and Dagys, 1984). Because marine Triassic biostratigraphy is based on data on ammonoids it is logical to use some materials on general evolution of these animals for the solution of the problem.

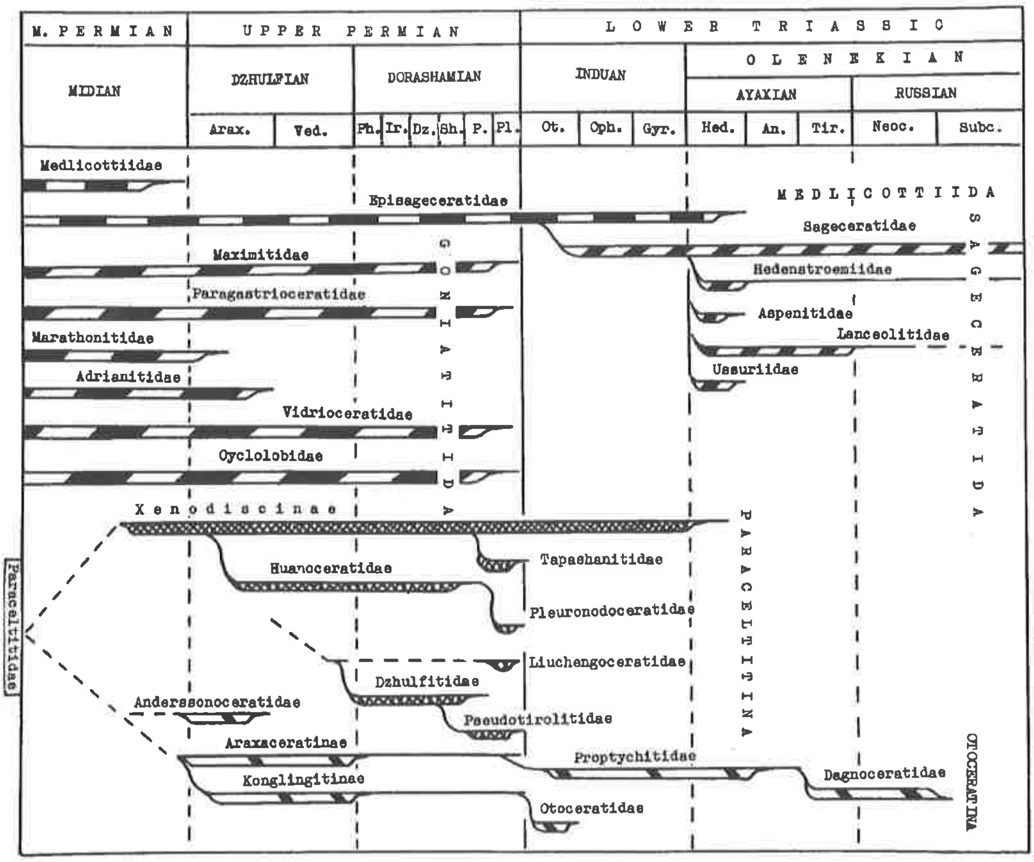

Fig. 1. Four main ammonoid stocks - *Medlicottiida, Sageceratida, Goniatitida, Ceratitida* (Paraceltitina, Otoceratina) near by Permo-Triassic boundary.

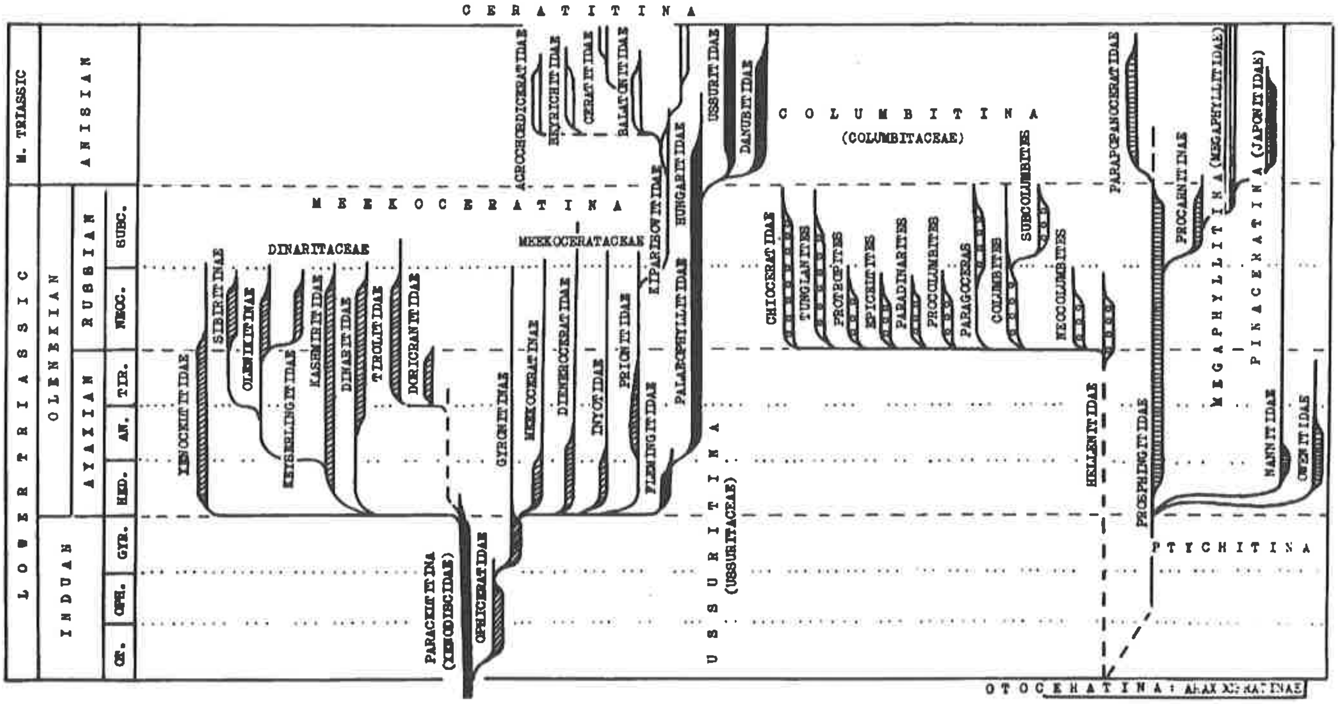

Fig. 2. Eight main ceratitoid stocks (*Meekoceratina, Ceratitina, Ussuritina, Columbitina, Ptychitina, Megaphyllitina*, and *Pinacoceratina*) existing during early Triassic and Anisian time.

2. Evolution

At the very end of the Permian a such large ammonoid stock, as *Goniatitida*, was eliminated (Fig. 1). In the evolution of the Early Triassic ammonoids, three major phases (stages) can be recognized (Fig. 2).

During the first phase (early Early Triassic), the oldest representatives of three typical Mesozoic taxa - (1) *Nannitaceae* (*?Anotoceras* and *Dunedinites*), (2) *Meekocerataceae* (*Ophiceratidae* and *Meekoceratidae*) and (3) *Proptychitaceae* (*Proptychitidae* and *Paranoritidae*) superfamilies were formed. The beginning of the phase seems to be determined by the first emergence of Otoceratidae.

The second phase (middle Early Triassic) can be characterized by the appearance and development of the *Aspenitidae, Lanceolitidae, Hedenstroemiidae, Ussuritidae, Xenoceltitidae, Sibiritidae* (*Palaeokasachstanites, Parastephanites, Stephanites,* and *Amphistephanites*), *Kashmiritidae, Tirolitidae, Dinaritidae* (*Tchernyschevites*), *Meekoceratinae, Dieneroceratidae, Inyoitidae, Prionitidae, Flemingitidae* and *Palaeophyllitidae* (*Anaxenaspis* and *Burijites*), *Nannitidae* (*Nannites, Paranannites* and *Melagathiceras*), *Owenitidae* and some representatives of the *Prosphingitidae* (*Prosphingitoides*).

In the third phase (late Early Triassic) we observe the appearance and development of the *Keyserlingitidae* (*Keyserlingites, Olenekoceras*), *Columbitidae* (*Neocolumbites, Columbites, Subcolumbites, Paragoceras, Procolumbites, Paradinarites, Epiceltites, Protropites, Tunglanites*), *Chioceratidae*, and some representatives of the *Hedenstroemiidae* (*Metahedenstroemia* and *Beatites*), *Sibiritidae* (*Olenikites, Subolenekites, Parasibirites*, and *Sibirites*), *Tirolitidae* (*Carniolites, Hololobus, Bittnerites, ?Tirolitoides* and *Diaplococeras*), *Meekoceratidae* (*Nordophiceras, Arctotirolites, Svalbardiceras, Arctomeekoceras* and *Boreomeekoceras*), Kashmiritidae (*Mangyshlakites*), *Prosphingitidae* (*Prosphingites* and *Zhitkovites* n. gen.), *Nannitidae* (*Isculitoides*), *Palaeophyllitidae* (*Leiophyllites, Palaeophyllites, Eophyllites*, and *Schizophylltes*), *Hungaritidae* (*Dalmatites*), and *Noritidae* (*Subalbanites*).

The idea of three major phases in the evolution of the Early Triassic fauna seems to be confirmed by some data on the vertebrates (Lozovsky, 1969) and conodonts (Kozur, 1972).

Two additional conclusions can be also made regarding the Early Triassic ammonoid successions:

(1) The Phase 1/Phase 2 boundary time is characterized by the most sharp increase in taxonomic diversity both at the generic and familial levels.

(2) Somewhat more essential distinctions between ammonoid associations of phases 1 and 2 (not less 66-67%) than the associations of the phases 2 and 3 (only about 57%) take place. Representative calculation was made on the family level with the registration of the quantity of genera (Zakharov, 1978 a,b). This is illustrated also by Fig. 2 based on data predominatingly at the family level.

Judging from these facts, I favour the assumption now that three phases in ammonoid evolution correspond to three major stratigraphical units, having, apparently, a different rank. The base of the Zone of *Flemingites flemingianus* in the Salt Range and its equivalents in the Far East, North Siberia (*Hedenstroemia hedenstroemi* Zone) and North America (*Meekoceras gracilitatis* Zone) appears to be the boundary of the two largest units (stages) of the Lower Triassic - Induan and Olenekian in L. D. Kiparisova and Y. N. Popov's (1956, 1964) sense. The most popular scheme of the Lower Triassic proposed by these workers may be significantly improved by division of the uppermost stage (Olenekian) into two fundamentally different substages; at least for the Tethys, the Ayaxian and Russian are proposed. These units originally recommended to be of stage rank (Zakharov, 1978 a,b) are typified by the sections located in Ussuri province (South Primorye, Russian Island). Here one can observe essentially more diverse late

Early Triassic ammonoid faunas as compared with the Himalayan province.

The equivalents of same late Early Triassic ammonoid associations (*Bajarunia dagysi*, *Tirolites ussuriensis* and *Subcolumbites multiformis*) have not been recognized in Arctic Canada (the latter seems to be also lacking in Arctic Siberia), therefore the Smithian and the Spathian cannot be, apparently, recommended as the valuable substages of the Olenekian for the Boreal realm. The Induan stage seems to lack any real substages because of a sharp reduction in taxonomic diversity of invertebrates during Early Triassic time (apparently, only the zonal members can be adequately recognized here).

The binomial composition of the Lower Triassic, with a single substage (stage) in the lower member, but with two sharply pronounced substages within the uppermost one, reflects more or less satisfactorily the triphasic character of evolution of the Early Triassic biota.

3. Discussion

Vladivostok was found at Murav'ev Amursky Peninsula in 1860 as a military outpost and needed some geological investigations.The first geological studies there were made by V. P. Margaritov, a graduate from the St.Petersburg University, arriving in Vladivostok in 1880 as a teacher of math, he turned into an active member of the Society for the investigation of the Amur region, a head of several ethnographic and geological field trips resulted in surprising discoveries. For example, on the western coast of the Ussuri Gulf, near the Shamara Bay (now Lazurnaya)

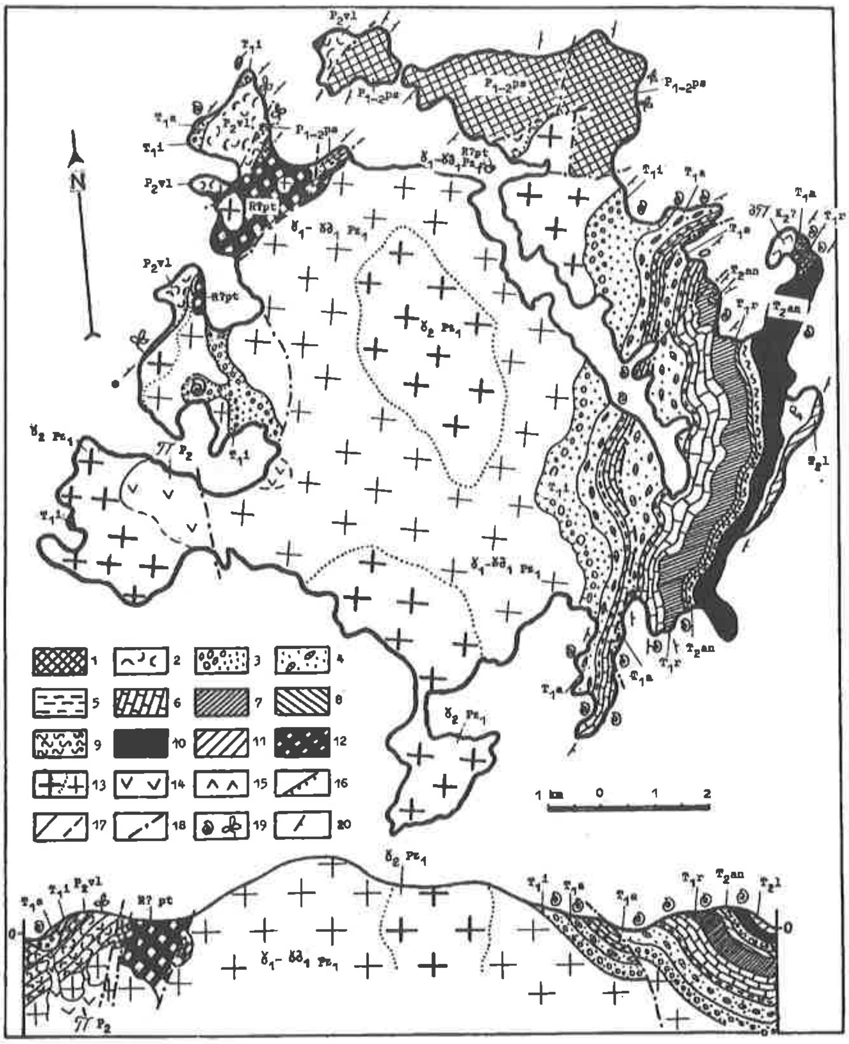

Fig. 3. Geological map of the type region of the Ayaxian and Russian (Russian Island), showing distribution of Permian and Triassic sediments.

1 - Bolorian - Kubergandinian (Pospelov Fm.), 2 - Murgabian - Lower Midian (Vladivostok Fm.), 3 - Induan (Lazurnian Horizon), 4 - Lower Ayaxian, *Hedenstroemia bosphorensis* Zone, 5 - Middle Ayaxian, *Anasibirites nevolini* Zone, 6 - Upper Ayaxian, Tirolites-*Amphistephanites* Zone, 7 - Lower Russian, *Neocolumbites insignis* Zone, 8 - Upper Russian, *Subcolumbites multiformis* Zone, 9 - Lower Anisian, *Ussuriphyllites amurensis* and *Leiophyllites pradyumna* Zones, 10 - Upper Anisian, 11 - Upper Ladinian, Bogataya River Sandstone Mb. («Ussurites» beds), 12 - large xenolith (Precambrian? Putyatin Fm.) in early Paleozoic granitoids, 13 - early Paleozoic granitoids (heavy cross - granite and granite porphyr, other - granodiorite, 14 - late Permian andesite, 15 - Cretaceous felsite porphyr, 16 - erosion boundary, 17 - normal stratigraphic boundary (confident or conditional), 18 - tectonic boundary, 19 - fossils, 20 - element of deposition.

he discovered, due to his curiosity, some fossils, ammonoids. V. P. Margaritov's collection fell into the hands of the President of the Russian Academy of Sciences, A. P. Karpinsky, a recognized expert in Late Paleozoic ammonoids, who distinguished Triassic ceratitid ammonoids among them.

America and some other regions were at their initial stage. Following K. Diener, the sections of Triassic marine deposits in the western coast of the Ussuri Gulf and Russian Island were treated as classical (since that time, no publications on Early Triassic rocks could do without the comparison with that area).

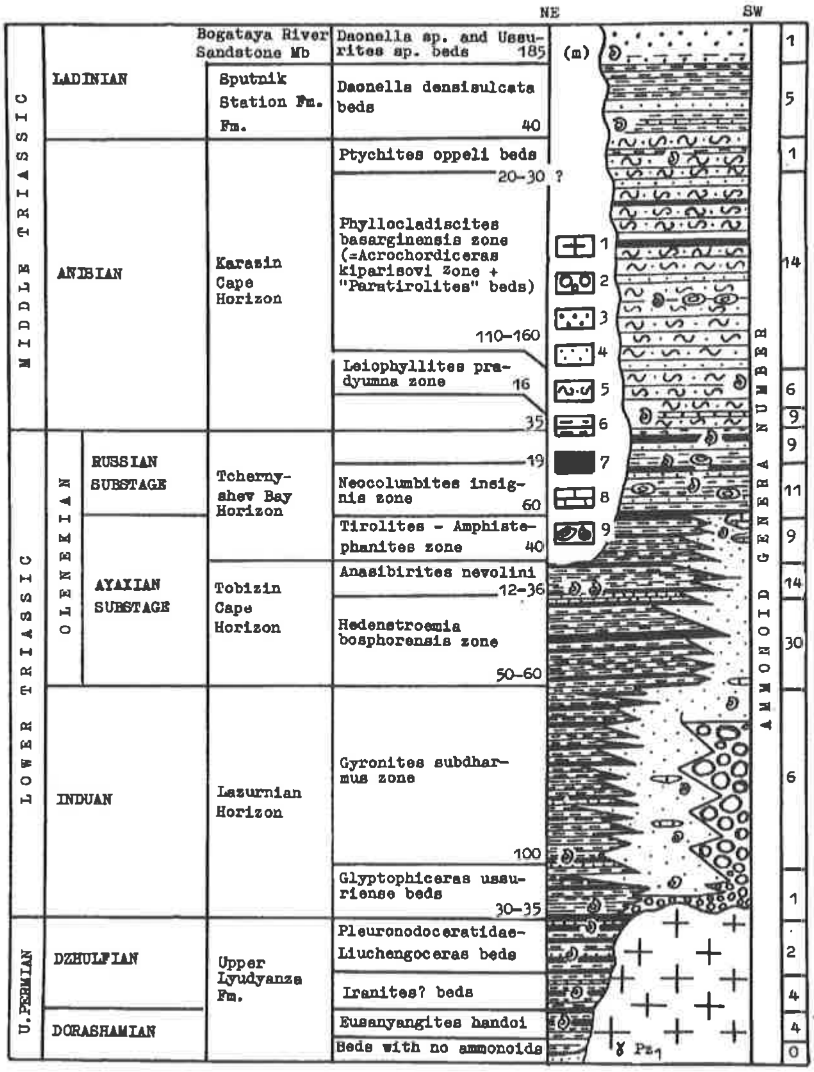

Fig. 4. Lithostratigraphy and subdivisions of the Lower and Middle Triassic in South Primorye (from SW to NE: Russian Island, Amur and Ussuri bays, Artemovka River correspondingly).

Later, Triassic marine deposits in the environs of Vladivostok were studied by D.L. Ivanov, the chief of a geological team making reconnaissance work for the construction of the Trans-Siberian railroad. He also collected mollusc remains in the area of the Shamara Bay and for the first time collected ammonoids and bivalves on Russian Island. On the initiative of A. P. Karpinsky, a representative collection of D. L. Ivanov was forwarded to Austrian palaeontologist K. Diener, who studied it simultaneously with a more abundant set he collected from Lower Triassic rocks of Himalayas. He identified the majority of studied cephalopods from southern Primorye (20 species of 14 genera) as Early Triassic (Diener, 1895). K. Diener attached great importance to the discoveries of Triassic marine deposits in the western Pacific, because, that time, the Himalayas, Alps, and Arctic Siberia were the only well known areas for the occurrences of Early Triassic ammonoids. The studies of Triassic ammonoids in North

The role of Lower and Middle Triassic rocks in the southern Primorye increased after publications of a monograph by L. D. Kiparisova (1961, 1972) and some later works.

4. Stratotypes

As was mentioned above, the stratotype region of the Ayaxian and Russian substages is the Russian Island. An anticline with the core, consisting of dominant Early Paleozoic biotite-hornblende granitoids with large xenoliths of presumably Precambrian micaceous schists, is clearly seen on Russian Island. It is the basement of the sedimentary and volcano-sedimentary cover in the island area neighbouring Vladivostok. The south-eastern limb of the fold (Ayax, Paris and Tchernyschev bays, Akhlestyshev Cape) consists of exclusively Lower and Middle Triassic deposits (Fig. 3); and north-western one (Philippovsky and Rynda bays, Babkin Peninsula) largely of Permian and less of lower Lower Triassic sequences.

Volcanic activity in the area under discussion practically did not cease during the Middle and Late Permian. In the Late Kubergandinian, intermediate tuffs were accumulated (the upper part of the Pospelov Formation, Middle Permian). Lava of dominantly intermediate composition erupted during Murgabian time (lower Vladivostok Formation, Middle Permian). Acid magmatism started since early Midian time (a large part of the Vladivostok Formation). In contrast, no more or less visible signs of volcanism were observed in the Lower and significant part of the Middle Triassic of South Primorye. Volcanic activity was presumably resumed there only in the Late Triassic (Norian, Monotis ochotica Beds, Murav'ev-Amursky Peninsula).

The upper Vladivostok Formation and some overlying Middle and Upper Permian rocks were eroded on Russian Island. The Upper Triassic is also absent there.

4.1. Type of the Ayaxian Substage

Statotype of the Ayaxian (Lower Olenekian), the middle part of the Lower Triassic, is located in the north-eastern part of the Russian Island between Ayax Bay and western part of Paris Bay. Three zones are recognized within these sequences:

(1) *Hedenstroemia bosphorenses*, (2) *Anasibirites nevolini*, and (3) *Tirolites-Amphistephanites* (Fig. 4).

The lower one, *Hedenstroemia bosphorensis* Zone, exposed between Ayax Bay and Balka Cape, is composed of sandstone with numerous thin lenses of sandy limestone-

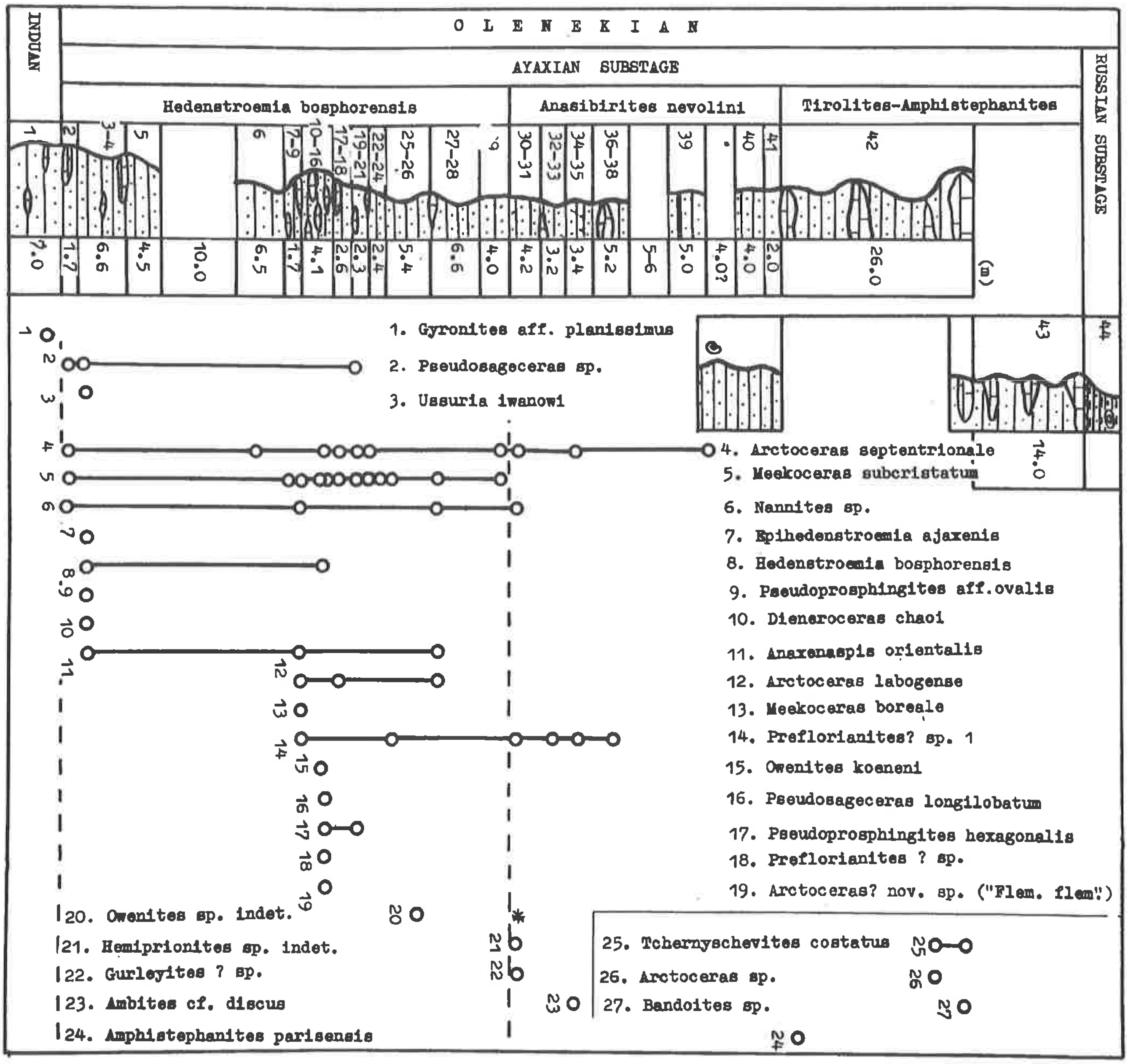

Fig. 5. The type section of the Ayaxian, Lower Olenekian (north-eastern part of Russian Island, Ayax Bay) with vertical ranges of ammonoid species. Ammonoid association of the *Anasibirites nevolini* Zone seems to be incomplete (see the sign *). But at the same level of the neighborn section (Tobizin Cape, 10 km S), *Anasibirites nevolini* Burij et Zharn., *Anasibirites* sp., *Wasatchites sikhotealinensis* Zakh. and *Parahedenstroemia conspicienda* Zakh., associated with *Arctoceras septentrionale* (Diener) and *Meekoceras subcristatum* Kipar., were recognized. Designation as in Fig. 4.

coquina rarely interlayered with siltstone (Fig. 5). Outcrops are up to 38 m thick.

The *Anasibirites nevolini* Zone exposed within the Russian Island on the northern coast of the Paris Bay, Zhitkov Cape and Tobizin Peninsula is mainly fine-grained sandstone with rare lenses of sandy limestone and interbeds of siltstone, 16.8 m thick. The sequence of the *Hedenstroemia bosphorensis* and *Anasibirites nevolini* Zones very similar in facies is named the Tobizin Formation (Suite), with its type at Tobizin Peninsula. It corresponds to the Tobizin Cape Horizon in I.V. Burij's sense. Underlying sediments, represented by the *Glyptophiceras ussuriense* Beds and the *Gyronites subdharmus* Zone, may be named the Lazurnaya Bay Formation (Suite). It is also corresponds to one of the horizons (Lazurnian Horizon) offered by I.V. Burij (Burij, Zharnikova and Buryi, 1976).

The *Tirolites-Amphistephanites* Zone exposed on the northern coast of Paris Bay, Zhitkov and Tobizin peninsulas, and Schmidt Cape, is mostly sandstone with numerous, relatively thick (up to 1 m) lenses of sandy limestone-coquina, and rare limestone. The deposits are about 40 m thick taking into account a repeated section to the east of Balka Cape and Tobizin Peninsula due to a fault. I name the sequences as Schmidt Formation (Suite), with its stratotype at Schmidt Cape. The Schmidt Suite (*Tirolites-Amphistephanites* Zone) is customarily divided into two members, in stratotype section: (1) Bajarunia dagysi Beds (about 15 m thick) and (2) *Tirolites ussuriensis* Beds (about 25 m).

In descending order, the sequence of the Ayaxian Substage in the stratotype section (between Ayax and Paris bays) is:

Schmidt Formation (Suite)
Tirolites-Amphistephanites Zone

43. Greyish-green sandstone with lenses of sandy limestone-coquina 14.0 m

42. Greyish-green sandstone with relatively thick lenses of sandy limestone-coquina and white limestone 26.0 m

Fossils: ammonoids (*Amphistephanites parisensis* (Zakh.), *Tchernyschevites costatus* Zakh., *Arctoceras* sp., *Bandoites* sp.), «nautiloids» (*Trematoceras* sp.), brachiopods *Spiriferina* aff. *mansfieldi* Girty), bivalves (*Neoschizodus laevigatus* (Zieten) (Zakharov, 1968, 1978a,b) and conodonts (*Neogondolella jubata, Neospathodus triangularis, Enantiognathus ziegleri, Hindeodella triassica* (Buryi, 1979), *Pachycladina symmetrica*, and *Furnishius triserratus* (Zakharov and Rybalka, 1987).

Tobizin Formation (Suite)
Anasibirites nevolini Zone

41. Grey sandstone with shale debris 2.0 m

40. Greyish-green sandstone with lenses of calcareous sandstone 4.0 m

Fossils: bivalves and conodonts *(Parachirognathus symmetrica, P. inclinata, Hindeodella rarimetrica, H. subsymmetrica, Furnishius triserratus)* (Buryi, 1979).

39. Grey sandstone, intercalated with thin-bedded (1-10 cm) mudstone 5.0 m

38. Greyish-green sandstone 0.5 m

37. Grey sandy limestone with shale debris 3.5 m

Fossils: ammonoids (*Preflorianites?* sp.1) and bivalves (*Neoschizodus* sp.) (Zakharov, 1978a,b).

36. Grey calcareous sandstone 1.2 m

35. Greyish-green sandstone 3.0 m

34. Grey calcareous sandstone 0.35 m

Fossils: ammonoids (*Preflorianites ?* sp.1, *Arctoceras septentrionale* (Dien.), *Ambites* cf. *discus* (Waagen) (Zakharov, 1968), brachiopods (*Lingula borealis* Bittner), and bivalves (*Neoschizodus laevigatus* (Zieten) (Kiparisova, 1938). Some conodonts (*Neospathodus* sp.ind., *Hindeodella triassica*) (Buryi, 1979) were, apparently, found there also.

33. Greyish-green sandstone 3.0 m

32. Grey calcareous sandstone 0.2 m

Fossils: ammonoids (*Preflorianites ?* sp.1), brachiopods (*Lingula* sp.) and bivalves.

31. Greyish-green sandstone 4.0 m

30. Grey sandstone 0.15 m

Fossils: ammonoids (*Arctoceras septentrionale* (Diener), *Nannites* sp. indet., *Preflorianites?* sp.1, *Hemiprionites* sp. indet., *Gurleyites ?* sp.), brachiopods (*Lingula borealis* Bittner), and bivalves (*Neoschizodus laevigatus* (Zieten).

In the south-eastern part of Russian Island (7 km S from stratotype) and especially at the Artemovka River basin, the *Anasibirites nevolini* Zone is characterized by a significantly more representative ammonoid association.

Hedenstroemia bosphorensis Zone

29. Grey calcareous sandstone with thin lenses of limestone 4.0 m

Fossils: ammonoids (*Arctoceras septentrionale* (Diener), *Meekoceras subcristatum* Kipar.), bivalves (*Pectinidae*) (Diener, 1895; Kiparisova, 1961; Zakharov, 1968), and conodonts (*Furnishius triserratus, Hadrodontina adunca, H. symmetrica, H. subsimmetrica, Parachirognathus symmetrica, P. inclinata, Hindeodella triassuca, H. nevadensis, H. raridenticulata, Chirodella dinoides, Elisonia magnidentata*) (Buryi, 1979).

28. Greyish-green sandstone 6.0 m

27. Greyish-green sandstone with numerous lenses of sandy limestone-coquina 0.6 m

Fossils: ammonoids (*Arctoceras labogense* Zharn., *Nannites* sp. indet., *Owenites* sp. indet., *Meekoceras subcristatum* Kipar., *Anaxenaspis orientalis* Kipar.), brachiopods (*Lingula* sp.), bivalves (*Entolium microtis* Witt.) (Kiparisova, 1961; Zakharov, 1967; Burij, Zharnikova and Buryi, 1976) and conodonts (*Furnishius triserratus, Parachirognathus symmetrica, P. inclinata, Chirodella dinodoides, Hadrodentina adunca, H. symmetrica, H. subsymmetrica, Hindeodella nevadensis, H.raridenticulata, H. triassica*) (Buryi, 1979).

26. Greyish-green sandstone 5.0 m

25. Grey calcareous sandstone and sandy limestone 0.4.m

Fossils: ammonoids (*Arctoceras labogense* Zharn., *Meekoceras subcristatum* Kipar., *Preflorianites?* sp.1), «nautiloides» (*Trematoceras* sp. indet.), brachiopods (*Lingula* sp.), bivalves (*Leptochondria minima* (Kipar.), and ostracodes (*Bairdia* sp.).

24. Greyish-green sandstone 1.3 m

23. Grey calcareous sandstone with thin lenses (1.O - 2.5 cm thick) of sandy limestone 0.13 m

Fossils: ammonoids (*Meekoceras subcristatum* Kipar.).

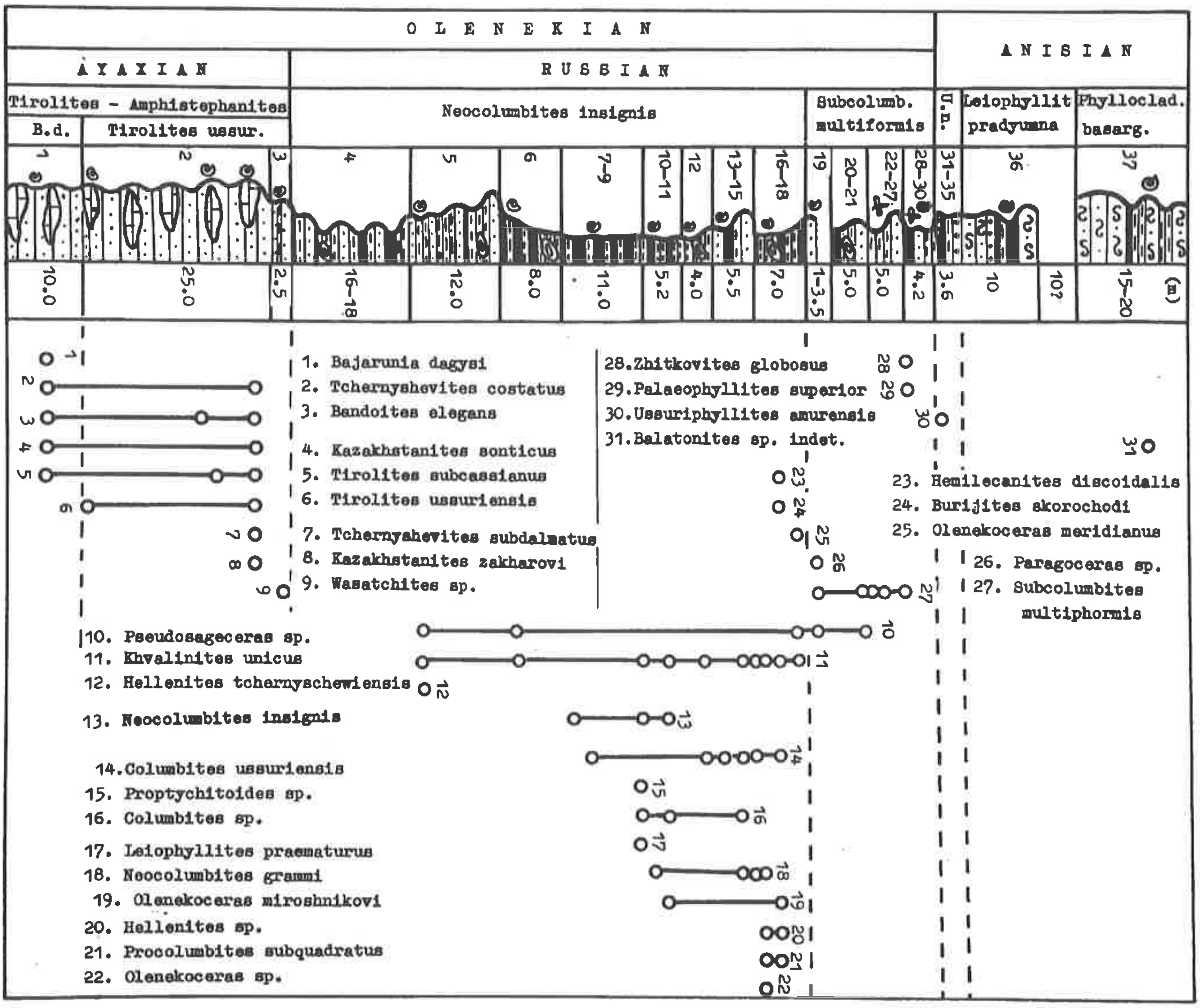

Fig. 6. The type section of the Russian, Upper Olenekian southeastern part of Russian Island, Tchernyschev Bay), with vertical ranges of ammonoids species. Designation as in Fig. 4.

22. Greyish-green sandstone 1.0 m

21. Grey calcareous sandstone 0.07 m

Fossils: ammonoids (*Arctoceras septentrionale* (Diener), *Meekoceras subcristatum* Kipar.) and bivalves (*Entolium microtis* Witt.).

20. Greyish-green sandstone 0.7 m

19. Grey sandy limestone 0.5 m

Fossils: ammonoids (*Pseudosageceras* sp., *Arctoceras septentrionale* (Diener) (dominant), *Prosphingitoides hexagonalis* (Zakh.), *Meekoceras subcristatum* Kipar.), brachiopods (*Lingula* sp.), bivalves (*Entolium microtis* Witt., *Leptochondria minima* (Kipar.), *Neoschizodus laevigatus* (Zieten), *Anodontophora fassaensis* Wissman), gastropods (Zakharov, 1978a,b), and conodonts (*Parachirognathus symmetrica, Hadrodontina adunca*) (Buryi, 1979).

18. Greyish-green sandstone 2.4 m

17. Grey sandy limestone about 15.0 m

Fossils: ammonoids (*Arctoceras septentrionale* (Diener) and *Meekoceras subcristatum* Kipar.).

16. Grey calcareous sandstone 0.2 m

15. Grey sandy limestone 0.2 m

Fossils ammonoids (*Pseudosageceras longilobatum* Kipar., *Hedenstroemia bosphorensis* Zakh., *Arctoceras* sp., *Prosphingitoides hexagonalis* (Zakh.), *Meekoceras subcristatum* Kipar. (dominant), *Preflorianites?* sp. (Zakharov, 1968, 1978) and conodonts (*Parachirognathus symmetrica* and *Hindeodella raridenticulata*) (Buryi, 1979).

14. Grey calcareous sandstone 0.25 m

13. Grey sandy limestone-coquina 0.15 m

Fossils: ammonoids (*Meekoceras subcristatum* Kipar. (dominant) and *Owenites koeneni* Hyatt et Smith.

12. Greyish-green sandstone with thin lenses of sandy limestone 1.5 m

11. Grey sandy limestone-coquina 0.30 m

Fossils: *Meekoceras subcristatum* Kipar. (dominant).

10. Greyish-green sandstone 1.5 m

9. Grey sandy limestone-coquina 0.25 m

Fossils: ammonoids (*Arctoceras labogense* (Zharn.), *Nannites ?* sp., *Meekoceras subcristatum* Kipar. (dominant), *M. boreale* Diener, *Preflorianites ?* sp.1, and *Anaxenaspis* *orientalis* (Diener), brachiopods (*Lingula* sp.), bivalves (*Entolium microtis* Witt., *Leptochondria minima* Kipar., etc.) and gastropods.

8. Greyish-green sandstone 1.2 m

7. Grey sandy limestone-coquina 0.25 m

Fossils: ammonoids (*Meekoceras subcristatum* Kipar.), «nautiloids» (*Trematoceras* sp.), brachiopods (*Lingula* sp.) and bivalves.

6. Greyish-green sandstone intercalated with Grey calcareous sandstone 6.5 m

Fossils: ammonoids (*Arctoceras* sp. indet.), bivalves.

Turf-clad interval 10.0 m

5. Greyish-green sandstone with calcareous nodules 4.5 m

4. Grey sandy limestone-coquina 0.25 m

Fossils: ammonoids (*Pseudosageceras* sp. indet., *Epihedenstroemia ajaxensis* Zakh., *Hedenstroemia bosphorensis* (Zakh.), *Ussuria iwanowi* Diener, *Prosphingitoides* aff. *ovalis* (Kipar.), *Dieneroceras chaoi* Kipar., *Anaxenaspis orientalis* Kipar.), brachiopods (*Lingula* sp.), and bivalves (*Eumorphotis multiphormis* Bitner, *Entolium microtis* (Witt.), and *Leptochondria minima* (Kipar.).

3. Greyish-green sandstone with thin lenses of sandy limestone and calcareous nodules 6.3 m

Fossils: rare ammonoid and small bivalves

2. Greyish-green sandstone with lenses of sandy limestone-coquina 1.7 m

Fossils: ammonoids (*Arctoceras septentrionale* (Diener), *Meekoceras subcristatum* Kipar. (dominant), *Pseudosageceras* sp. and *Nannites* sp.), and bivalves (*Entolium microtis* (Witt.) and *Leptochondria minima* (Kipar.).

Lazurnaya Bay Formation (Suite)
Gyronites subdharmus Zone
Induan-Olenekian intermediate Beds

1. Greyish-green sandstone with thin lenses and small nodules of marls 7.0 m

Fossils: ammonoids (*Gyronites* aff. *planissimus* Spath) and bivalves (Zakharov, 1978), G.I. Buryi believes that the conodont *Neospathodus pakistanensis* Sweet was found in association with *Gyronites*.

Underlying sediments (Induan) are composed of conglomerate and minor sandstone in the section.

4.2. Type of the Russian Substage

Stratotype of the Russian Substage (Upper Olenekian) is situated in the north-western coast of Tchernyschev Bay in the south-eastern part of Russian Island (Fig. 6). The lower member of the Russian Substage (*Neocolumbites insignis* Zone), about 60 m thick, is characterized by the dominance of mudstone and siltstone with numerous calcareous-marly nodules, which contain thin, irregular beds of sandstone. The uppermost part of the Russian is siltstone with nodules and lenses of calcareous-marly rocks.

The sequence of these two zones I name Zhitkov Formation (Suite), with the type at Zhitkov Cape. It corresponds to the upper part of the Tchernyschev Horizon in I.V. Burij's sense. Overlying Anisian sediments may be named Karazin Suite (Formation), with the type at Karazin Cape. It corresponds to the Karazin Horizon in I.V. Burij's sense.

In descending order, the sequence of the Russian Substage in its stratotype section (Tchernyschev Bay) is:

Karazin Formation (Suite), Anisian (part)

31. Dark grey sandy siltstone with lens-like bed of light-grey loose sandstone and lenses of calcareous-marly rocks 0.15 m

Fossils: ammonoid *Ussuriphyllites amurensis* (Kipar.).

Zhitkov Formation (Suite), Russian
Subcolumbites multiphormis Zone

30. Grey, thin-bedded sandy siltstone, intercalated with black mudstone, rarely grey sandstone 0.8 m

29. Grey sandstone 0.17 m

28. Grey, thin-bedded sandy siltstone, intercalated with mudstone and calcareous and spotted sandstone 3.2 m

Fossils: small bivalves.

27. Dark grey sandy siltstone, calcareous sandstone and mudstone with calcareous-marly nodules and lenses of grey limestones 1.4 m

Fossils: ammonoids (*Zhitkovites globosus* (Kipar.), *Subcolumbites multiformis* Kipar. (dominant), and *Palaeophyllites superior* Zakh.) and bivalves.

26. Dark grey, thin-bedded sandy siltstone and mudstone, rarely calcareous sandstone 1.3 m

25. Grey calcareous sandstone, intercalated with thin bedded sandy siltstone 0.7 m

Fossils: *Cladophlebis gracilis* Sze (V. I. Burago's determination).

24. Greyish-green siltstone with calcareous-marly nodules 1.5 m

Fossils: ammonoids (*Pseudosageceras* sp., *Paragoceras gracilis* (Kipar.), *Subcolumbites multiphormis* Kipar.), nautiloids (*Phaedrysmocheilus* sp.) and bivalves.

23. Greyish-green sandy siltstone with calcareous-marly nodules 1.0 m

Fossils: ammonoids (*Subcolumbites multiformis* Kipar.) and bivalves.

21. Greyish-green spotted sandy siltstone with calcareous-marly lenses intercalated with grey calcareous sandstone 0.8 m

20. Black mudstone with calcareous nodules and lenses intercalated with greyish-green calcareous siltstone and grey sandstone 4.2 m

Fossil: ammonoids (*Pseudosageseras* sp., *Paragoceras* sp., and *Subcolumbites multiformis* Kipar.), nautiloids (*Phaedrysmocheilus* sp.), and bivalves.

Turf-clad interval 1-3 m

19. Grey calcareous sandstone 0.2-0.5 m

Fossils: ammonoids (*Pseudosageceras* sp., *Paragoceras* sp., *Subcolumbites multiformis* Kipar.) and nautiloids (*Phaedrysmocheilus* sp.).

Neocolumbites insignis Zone

18. Dark grey siltstone and mudstone with marly nodules and lenses intercalated with calcareous sandstone 3.0 m

Fossils: ammonoids (*Pseudosageceras* sp., *Khvalinites unicus* (Kipar.) and *Olenekoceras meridianus* (Zakh.).

17. Dark grey siltstone and mudstone with calcareous -

marly nodules, lenses of sandy limestone and rare interbeds of calcareous sandstone 2.5 m

Fossils: ammonoids (*Khvalinites unicus* (Kipar.), *Hellenites inopinatus* Kipar., *Columbites ussuriensis* Burij et Zharn., *Procolumbites subquadratum* Burij et Zharn., *Olenekoceras microshnikovi* (Burij et Zharn.), nautiloides (*Phaedrysmocheillus russkiensis* (Zakh.) and bivalves (*Palaeoneilo prynadai* Kipar., *Pteria ussurica* (Bittn.), *Gervillia exporrecta* Leps., *Entolium* sp., *Anodontophora fassaensis* Wissm.) and plant remains (*Pleuromeia obrutschewii* Elias).

16. Black siltstone and mudstone intercalated with grey calcareous sandstone and sandy limestone 1.5 m

Fossils: ammonoids (*Khvalinites unicus* (Kipar.), *Hellenites* sp., *Neocolumbites grammi* Zakh., *Procolumbites subquadratus* Burij et Zharn., and *Olenekoceras* sp.), nautiloids (*Phaedrysmocheilus* sp.), and bivalves (*Leda, Pteria, Gervillia*, etc.) and gastropods.

15. Grey calcareous sandstone with lenses of grey sandy limestone 1.5 m

Fossils: ammonoids (*Columbites ussuriensis* Burij et Zarn. (dominant), *Neocolumbites grammi* Zakh., *Olenekoceras miroshnikovi* Burij et Zharn.), nautiloids (*Phaedrysmocheilus russkiensis* (Zakh.) and bivalves (*Gervillia exporrecta* Leps., *Neoschizodus laevigatus* (Ziet.).

14. Black siltstone and mudstone with lenses of sandy limestone-coquina intercalated with grey calcareous sandstone 1.5 m

Fossils: ammonoids (*Khvalynites unicus* (Kipar.), *Neocolumbites grammi* Zakh., *Columbites ussuriensis* Burij et Zharn., *C.* cf. *parisianus* Hyatt et Smith), nautiloids (*Phaedrysmocheilus russkiensis* (Zakh.) and plant remains (*Pleuromeia obrutschewii* Elias).

13. Dark grey siltstone and fine sandstone with lenses of sandy limestone and rare nodules intercalated with grey calcareous sandstone 2.5 m

Fossils: ammonoids (*Columbites ussuriensis* Burij et Zharn.).

12. Dark grey siltstone and fine sandstone with nodules intercalated with grey sandstone 4.0 m

Fossils: ammonoids (*Khvalynites unicus* (Kipar.), *Columbites ussuriensis* Burij et Zharn.), nautiloids (*Phaedrysmocheilus ussuriense* Kipar.), bivalves, labyrinthodonts (*Aphanerama* or *Gonioglyptus*), and plant remains (*Pleuromeia obrutschewii* Elias) (Kiparisova, 1961; Zakharov, 1968, 1978a,b; Shishkin, 1964; Krassilov and Zakharov, 1975; Burij, Zharnikova and Buryi, 1976).

11. Dark siltstone and mudstone with calcareous-marly nodules and lenses, intercalated with thin-bedded sandstone 5.0 m

Fossils: ammonoids (*Khvalynites unicus* (Kipar.), *Neocolumbites insignis* Zakh. (dominant), *Columbites* sp.), bivalves (*Gervillia exporrecta* Leps.), gastropods and plant remains.

10. Grey calcareous sandstone 0.2 m

Fossils: ammonoids (*Neocolumbites grammi* Zakh.).

9. Black siltstone and mudstone with numerous nodules 1.0 m

Fossils: ammonoids (*Proptychitoides* sp., *Khvalynites unicus* (Kipar.), *Neocolumbites insignis* Zakh.(dominant), *Columbites* sp. indet., and *Leiophyllites praematurus* Kipar.), plant detritus.

8. Black siltstone and mudstone with calcareous-marly nodules 9.0 m

Fossils: bivalve *Gervillia* . sp.

7. Dark grey siltstone and mudstone with calcareous-marly nodules 9.0 m

Fossils: ammonoids (*Neocolumbites insignis* Zakh. and *Columbites ussuriensis* Burij et Zharn.).

6. Black siltstone and mudstone with numerous calcareous-marly nodules 8.0 m

Fossils: ammonoids (*Pseudosageceras* sp., *Khvalynites unicus* (Kipar.) (dominant) and *Columbites ussuriensis* Burij et Zharn.).

5. Dark grey fine sandstone, intercalated with black siltstone, grey sandstone and sandy limestone 12.0 m

Fossils: ammonoids (*Pseudosageceras* sp., *Khvalynites unicus* (Kipar.), *Hellenites tchernyschewiensis* Zakh.), spiriferid brachiopods, bivalves and gastropods.

4. Black siltstone and mudstone, with minor sandstone 16-18 m

Tirolites-Amphistephanites Zone
Tirolites ussuriensis Beds

3. Grey, calcareous sandstone with mudstone debris and black, thin-bedded siltstone 2.5 m

Fossils: ammonoids (*Wasatchites* sp., *Preflorianites ?* sp., etc.).

2. Greyish-green sandstone with numerous relatively thick (up to 1 m) lenses of sandy limestone-coquina, rarely, white limestone, yielding numerous brachiopods 25.0 m

Fossils: ammonoids (*Tchernyschevites costatus* Zakh., *T. subdalmatus* (Zharn.) *Bandoites elegans* Zakh. *Kazakhstanites sonticus* (Zakh.), *K. zakharovi* Zharn., *Tirolites subcassianus* Zakh., and *T. ussuriensis* Zharn.), bivalves (large *Eumorphotis iwanowi* Bittn., etc.).

Bajarunia dagysi Beds (part)

1. Greyish-green sandstone with thick lenses of sandy limestone-coquina 10 m

Fossils: ammonoids (*Bajarunia dagysi* Zakh., *Tchernyschevites costatus* Zakh., *Bandoites elegans* Zakh.) and bivalves.

5. Discussion

L.F. Spath (1934) considered the *Tirolites* Beds (Alps, etc.) and *Columbites* Beds (Idaho) to be closely connected. He offered a special subdivision (Columbitan) consisting of two of these beds. Many recent authors believe the *Tirolites* Beds underlying the Columbites Beds to be the lower portion of the Upper Olenekian. Some *Tirolites* species, indeed, are known in association with *Columbites*. This take place within the *Neocolumbites insignis* Zone in the Primorye region (Zakharov and Rybalka, 1987), Alps (Krystyn, 1974) and Mangyshlak (Shevyrev, 1968; Zakharov and Sokarev, 1991).

Results of this study in the Primorye region lead to the conclusion that it is undesirable to consider the *Tirolites-Amphistephanites*, *Neocolumbites insignis* and *Subcolumbites multiformis* Zones to be within the same substage of the Olenekian for several reasons:

(1) No typical Late Olenekian genera (*Hellenites, Khvalinites, Svalbardiceras, Neocolumbites, Columbites, Procolumbites, Subcolumbites, Prenkites, Olenekoceras,*

Zhitkovites, etc.), which are common for the *Neocolumbites insignis* or *Subcolumbites multiformis* zones, are known in the underlying *Tirolites-Amphistephanites* Zone. (2) On the contrary, few representatives of *Wasatchites* (Plate 1) (Tchernyschev Bay) and *Arctoceras* (Paris Bay) were recognized in this level. The first genus is common in the *Anasibirites nevolini* Zone, the second one is characteristic in both the *Hedenstroemia bosphorensis* and the *Anasibirites nevolini* Zones (Ayaxian Substage). Besides, lithofacies of the Zone of *Tirolites-Amphistephanites* in the stratotype region are more similar to those of the Zones of *Hedenstroemia bosphorensis* and *Anasibirites nevolini*.

Therefore, the *Tirolites-Amphistephanites* Zone and its equivalents (including, apparently, *Tirolites cassianus* Zone) are believed to be late Early Olenekian (late Ayaxian).

Another problem for some authors is whether the *Keyserlingites subrobustus* Beds in Arctic Siberia and Canada should be late Olenekian or early Anisian in age. The *Keyserlingites subrobustus* Beds in Arctic Siberia (Olenek River, stratotype region of the Olenekian Stage) represent the significant part (220 m thick) of the Olenekian zone of *Olenikites spiniplicatus* (250 m thick). *Keyserlingites subrobustus* (Keys.) is associated there with many species of typical Lower Triassic ammonoid genera: *Nordophiceras, Arctomeekoceras, Boreomeekoceras, Pseudosvalbardiceras, Olenikites, Timoceras, Subolenekites, Sibirites, Olenekoceras* and *Prosphingites* (Zakharov, 1978a,b; Dagys and Ermakova, 1988). These evidences leave no doubt that the *Keyserlingites subrobustus* Beds, the middle and upper parts of the *Olenikites spiniplicatus* Zone in the Boreal realm, are early Triassic in age. Moreover, in accordance with the data on the stratigraphical distribution of some genera (*Olenekoceras, Nordophiceras*) in the Primorye region, the *Keyserlingites subrobustus* Beds in the Boreal realm do not seem to be the uppermost member of the Lower Triassic and must be correlated only with the zone of *Neocolumbites insignis* (lower Russian Substage) (Plates 2, 3). Himalayan *Keyserlingites dieneri* Mojs. (= «*Ceratites subrobustus*») (Diener, 1897) resemble *K. subrobustus* (distinguished only some more denticulation of the suture-line) is believed to be Anisian in age (Wang, 1984). I agree with E.T. Tozer now that «*Durgaites* aff. *dieneri*» from the *Phyllocladiscites basarginensis* Zone (Anisian) of Primorye region (Zakharov, 1968, p. 133, pl. 26, fig. 2, pl. 27, fig. 1) seems to be *Hollandites* or *Acrochordiceras*.

6. Systematics

Suborder PTYCHITINA Hyatt et Smith, 1905
Superfamily PROSPHINGITACEAE Zakharov, 1978a
[nom.transl.hic(ex.PROSPHINGITINAEZakharov, 1978a)]

Two families: PROSPHINGITIDAE Zakharov, 1978a and PARAPOPANOCERATIDAE Tozer, 1971. Lower-Middle (Anisian) Triassic.

Family PROSPHINGITIDAE Zakharov, 1978a
[nom. transl. hic. (ex PROSPHINGITINAE Zakharov, 1978a)]

Nine genera: *Prosphingites* Mojsisovics, 1886; *Anotoceras* Hyatt, 1900; *Chiotites* Renz et Renz, 1948; *Zenoites* Renz et Renz, 1948; *Dunedinites* Tozer, 1963; *Monocanthites* Tozer, 1965; *Popovites* Tozer, 1965; *Prosphingitoides* Shevyrev, 1995 (=? *Pseudoprosphingites* Shevyrev, 1965); *Zhitkovites* Zakharov, n. gen. Lower Triassic.

Genus *Pseudoprosphingites* Zakharov, n. gen.

Name from *Prosphingites* Mojsisovics.

Type species. *Prosphingites ovalis* Kiparisova, 1961; Lower Triassic, Olenekian, Ayaxian Substage, *Hedenstroemia bosphorensis* Zone; South Primorye (Plate 1).

Diagnosis. Generally ellipsoidal form with rounded ventral side. The umbilicus fluctuates from moderately wide to wide. With radial folds and marked constrictions on the outer whorl. The saddles of the suture-line have subparallel walls, the lobes with denticulation at the base rarely - at the lower part of their walls. Suture-line consists of ten lobes (with four ones in early stage of ontogenesis): $(V_1V_1)UU^1$: $U^2I(D^1D^1)$ - $(V_1V_1)UU^1U^3$: $U^2I(D_1D_1)$ - $(V_1V_1)UU^1U^3_{12}$: $U^3_{12}U^3_{12}U^2I(D_1D_1)$.

Species composition: *Pseudoprospingites ovalis* (Kiparisova) (Kiparisova, 1961), *P.* aff. *ovalis* (Kiparisova) (Zakharov, 1968), *P. austini* (Hyatt et Smith) (Hyatt and Smith, 1905), *P.* aff. *austini* (Hyatt et Smith) (Kiparisova, 1961), *P. spathi* (Frebold) (Frebold, 1930), *P. hexagonalis* (Zakharov) (Zakharov, 1968), *P. involutus* (Chao) (Chao, 1959), *P. radians* (Chao) (Chao, 1959), *P. kwangsianus* (Chao) (Chao, 1959), *P. sinensis* (Chao) (Chao, 1959) and *P.? ali* (Arthaber) (Arthaber, 1911), *P.? globularis* (Renz et Renz) (Renz and Renz, 1948), *P.? superglobosus* (Renz et Renz) (Renz and Renz, 1948), *P.? globosus* (Kiparisova) (Kiparisova, 1947).

Remarks. The new genus resembled *Prosphingites* is distinguished by its globose outer whorls, absence of keel, and presence of marked constrictions on the outer whorl and more complicated suture-line, including lobe U^3.

Distribution. Lower Triassic, Ayaxian and, apparently, Russian substages; Primorye, China, California, Nevada, Arctic Canada, Spitsbergen and Albania(?).

Genus *Zhitkovites* Zakharov, n. gen.

Name from Zhitkov Cape on Russian Island (South Primorye).

Type species. *Prospingites insularis* Kiparisova, 1961; Lower Triassic, Russian Substage, *Subcolumbites multiformis* Zone; South Primorye.

Diagnosis. Ellipsoidal or globose form. Umbilicus fluctuates from moderately narrow to wide. Surface with faint radial striae. The saddles of the suture-line are high, phylloid. The lobes with denticulation at the base and at the lower part of their walls. Suture-line consists of 11-12 lobes: $(V_1V_1)UU^1U^3U^5_1U^5_1U^4_1U^4_1U^2I(D_1D_1)$.

Species composition: type species.

Remarks. *Zhitkovites* resembles *Prosphingites* but is distinguished by globose outer whorls, without a tendency for carination of the venter, a significantly more complicated suture-line, including lobes U^4 and U^5. Like *Pseudoprosphingites* but with phylloid saddles of the suture-line, more complicated lobes and absence of the marked constrictions on the outer whorl.

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Plate I

Ammonoids from the Ayaxian Substage of Far East

Fig. 1,2. *Prosphingitoides ovalis* (Kiparisova): 1 -DVGI 385/801, x 1, Artemovka River (South Primorye), *Hedenstroemia bosphorensis* Zone, 2 - DVGI 296/801, x 1, Dunai Peninsula (South Primorye), *Hedenstroemia bosphorensis* Zone.

Fig. 3, 4. *Prosphingitoides hexagonalis* (Zakharov), DVGI 315/801, x 1, eastern Ussuri Gulf (South Primorye), *Hedenstroemia bosphorensis* Zone.

Fig. 5. *Prosphingitoides* aff. *ovalis* (Kiparisova), DVGI 313/801, x 1, Dunai Peninsula, *Hedenstroemia bosphorensis* Zone.

Fig. 6. *Euflemingites prynadai* (Kiparisova), DVGI 925/801, x 1, western Ussuri Gulf, Tri Kamnya Cape (South Primorye), *Hedenstroemia bosphorensis* Zone.

Fig. 7. *Flemingites* n. sp., DVGI 926/801, x 1, Komarovka River basin, Ussuri Park (South Primorye), *Hedenstroemia bosphorensis* Zone (V.A. Stepanov and L.B. Golovneva's collection, 1988).

Fig. 8. *Boreoceras cf. demokidovi* (Popov), DVGI 1/840, x 1, Lower Shevli River, near Lower Elga River, Khabarovsk region, Tuguro-Chimkan. *Bajarunia euomphala* Zone (A.V. Makhinin and E. P. Brudnitskaya's collection, 1979).

Fig. 9. *Wasatchites sichotealinensis* Zakharov, DVGI 183/801, x 1. Russian Island, Tobizin Cape, *Anasibirites nevolini* Zone.

Fig. 10. *Wasatchites* sp., DVGI, 927/801, x 1, Russian Island, Tchernyschev Bay, *Tirolites-Amphistephanites* Zone, *Tirolites ussuriensis* Beds (uppermost part), in association of *Tirolites* cf. *ussuriensis* Zharn. (Burij and Zharnikova's collection, 8/18, 1976).

Plate I

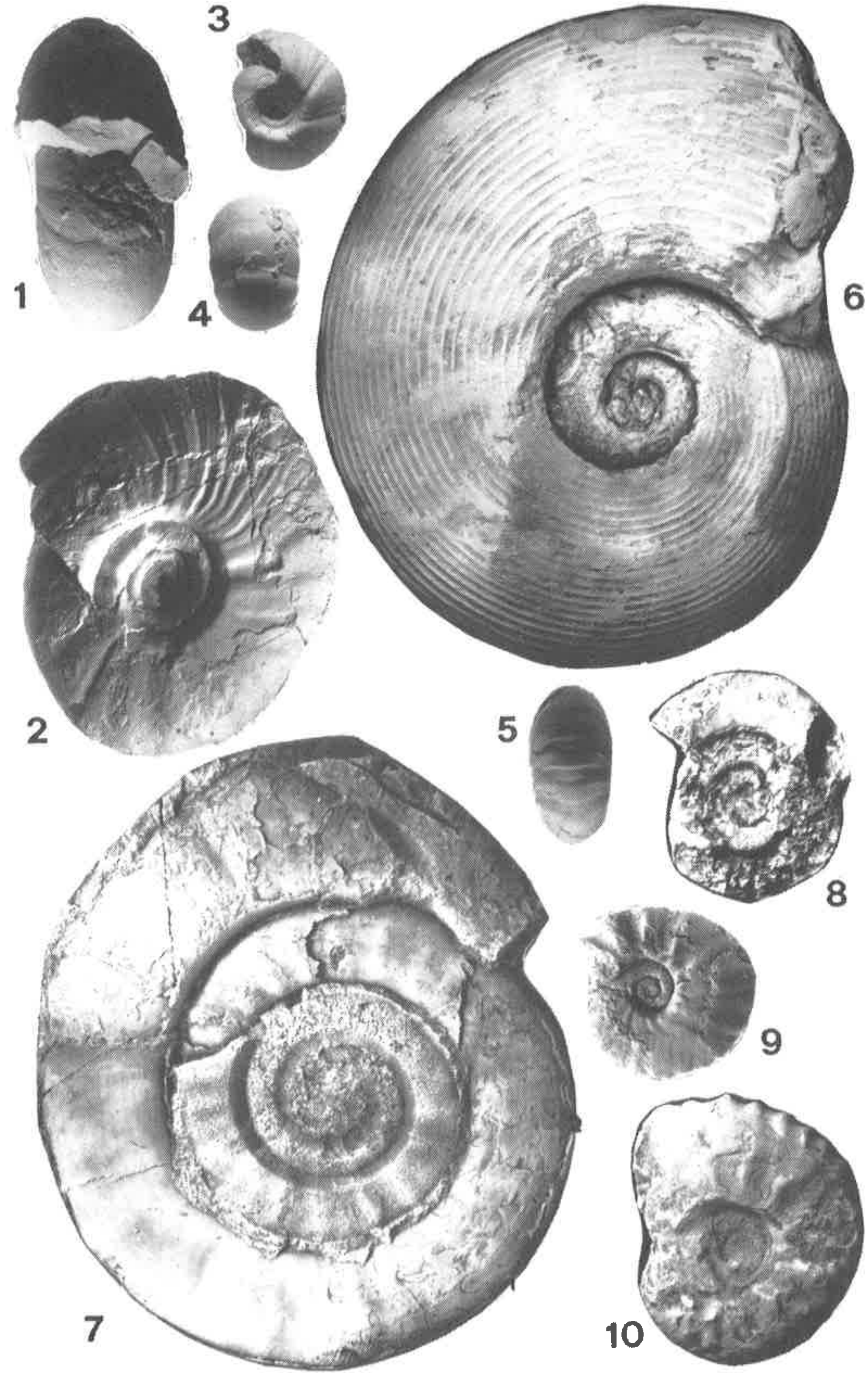


Plate II

Ammonoids from the Russian Substage of Arctic Siberia and South Primorye

Fig. 1. *Olenekoceras middendorffi* (Keyserling), DVGI 681/802, x 1, Olenek River, Mengilyakh Creek (Arctic Siberia), *Olenikites spiniplicatus* Zone.

Fig. 2. *Olenekoceras meridianus* (Zakharov), DVGI 928/801, x 1, Russian Island, Tchernyschev Bay (South Primorye), *Neocolumbites insignis* Zone.

Fig. 3, 4. *Columbites ussurienses* Burij et Zharnikova: 3 - DVGI 464/801, x 1, Russian Island, Tchernyschev Bay, *Neocolumbites insignis* Zone; 4 - DVGI 929/801, x 1, Muravev Amursky Peninsula, Kirov Str. 31 (South Primorye), *Neocolumbites insignis* Zone.

Fig. 5. *Tirolites* cf. *subcassianus* Zakharov (a single specimen Tirolites was found within the Russian Substage in Primorye region), DVGI 493/801, x 1, Russian Island, Zhitkov Cape (South Primorye), *Neocolumbites insignis* Zone.

Fig 6. *Prosphingites czekanowskii* Mojsisovics, DVGI 900/802, x 1, Olenek River, Mengilyakh Creek (Arctic Siberia), *Olenikites spiniplicatus* Zone.

Fig. 7. *Prosphingites* n. sp., DVGI 635/802, x 1, Olenek River, Mengilyakh Creek, *Olenikites spiniplicatus* Zone.

Plate III

Ammonoids from the Russian Substage of Arctic Siberia and Far East

Fig. 1, 5, 6. *Keyserlingites subrobustus* (Mojsisovics): 1 - DVGI 690/802, x 1; 5 - DVGI 694/802, x 1; 6 - DVGI 690/802 x 1; Olenek River, Mengilyakh Creek (Arctic Siberia), *Olenikites spiniplicatus* Zone.

Fig. 2. *Hellenites inopinatus* Kiparisova, DVGI 491/801, x 1, Zhitkov Cape, Russian Island (South Primorye), *Neocolumbites insignis* Zone.

Fig. 3, 4. *Hellenites tchernyschewiensis* Zakharov; 3 - DVGI 929/801, x 1, Rudnevka River basin, Soldatsky Creek. *Neocolumbites insignis* Zone (V. V. Ivanov's collections, 1991); 4 - DVGI 930/801, x 1, Kirov Str. 31 (South Primorye), *Neocolumbites insignis* Zone (V. O. Avchenko's collection).

Fig. 7. *Olenekoceras middendorffi* (Keyserling), DVGI 79/802, x 1; Olenek River, Mengilyakh Creek.

Fig. 8. *Olenekoceras miroshnikovi* (Burij et Zharnikova), DVGI 714/801, x 0.9. Russian Island, Zhitkov Cape (South Primorye), *Neocolumbites insignis* Zone.

Fig. 9. *Arnautoceltites gracilis* (Kiparisova), DVGI 930/801, x 1, Russian Island, Tchernyschev Bay (South Primorye), *Subcolumbites multiphormis* Zone.

Fig. 10. *Subolenekites* sp., DVGI 2/840, x 1, Lower Shevli River, Mudyuyan Creek, Khabarovsk region, Tuguro-Chimkan, *Olenikites spiniplicatus* Zone (A. V. Makhinin and E. P. Brudnitskaya's collection, 1963).

Plate II

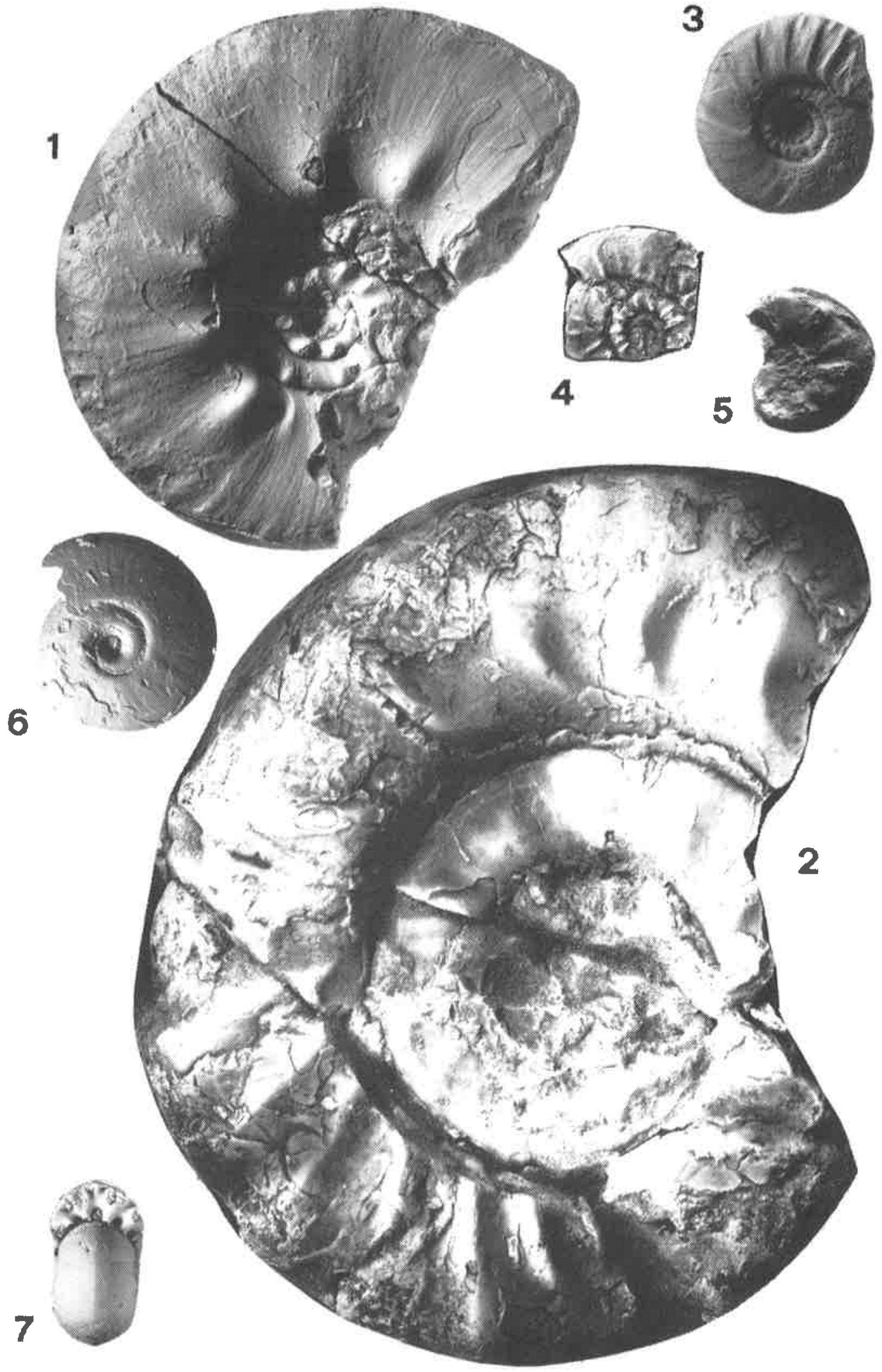
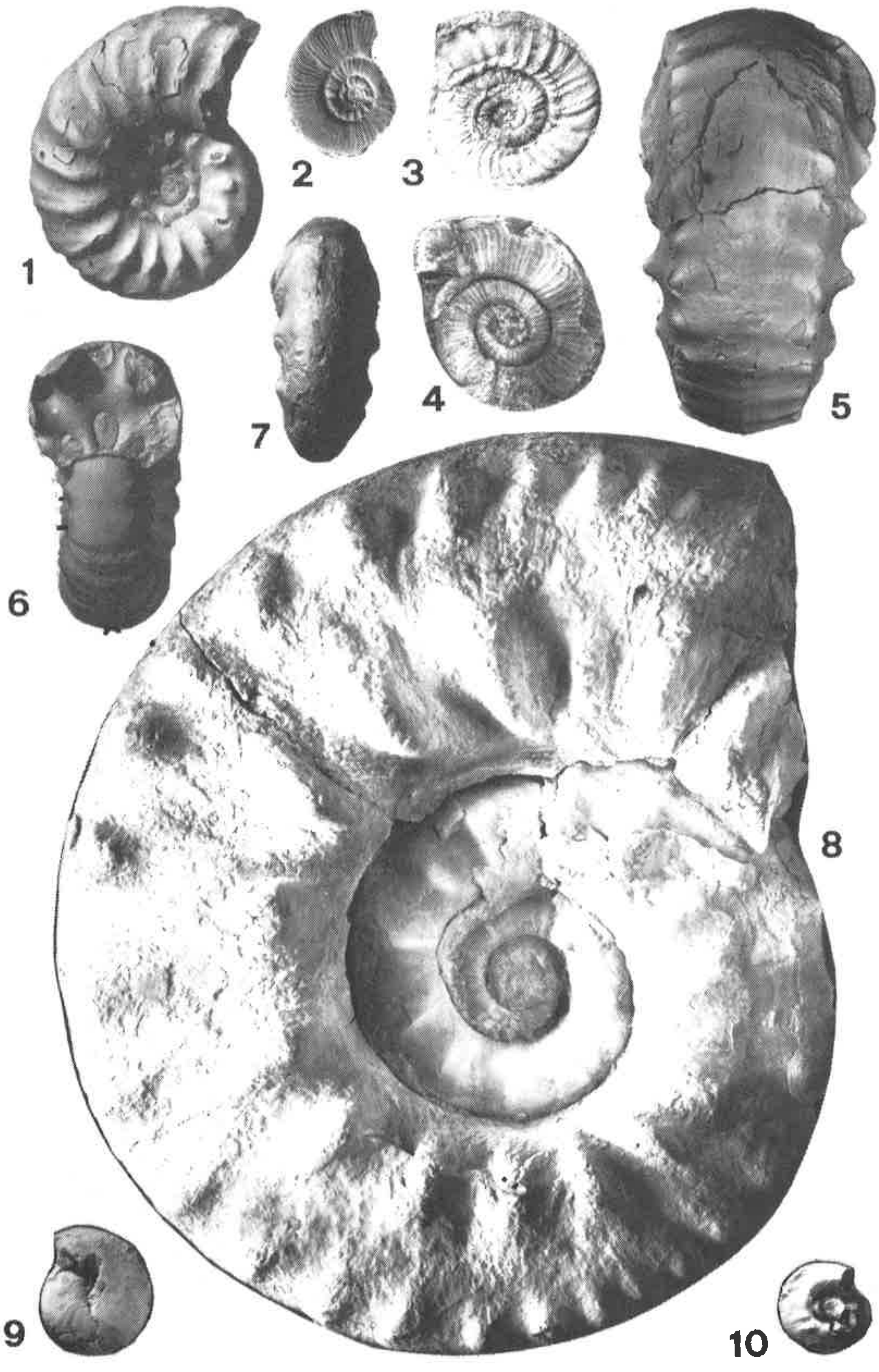


Plate III



CARNIAN AND NORIAN *SIRENITID* AMMONOIDS OF THE NORTH-WESTERN CIRCUM-PACIFIC AND THEIR ROLE IN THE LATE TRIASSIC FAUNAL SUCCESSIONS

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Abstract

Information on distribution of the Late Triassic sirenitid ammonoids and their associations in North East Russia, Trans-Baikal, Khabarovsk and Primorye regions, and Japan, some data on correlation of the Upper Triassic and geographical differentiation of the Triassic ammonoids and bivalves in the Far East are given. *Monotis ochotica* (Keyserling) and some other Norian bivalve and brachiopod species can not be always used, apparently, as indicator of faunistic associations of Boreal type in north-western circum-Pacific.

1. Introduction

Representatives of the *Sirenitidae*, a distinctive group of the Late Triassic ammonoids, are known from the Carnian and Norian terrigenous facies in some regions of north-western circum-Pacific (North East Russia, Trans-Baikal, Khabarovsk and Primorye regions, Japan). Information on sirenitid ammonoids and their associations permits to understand the peculiarities of geographical differentiation of the Late Triassic invertebrates and helps to correlate the sediments of the correspondent age.

2. Biogeography

2.1. North East Russia

The appearance of the sirenitid ammonoids in Boreal basins of the North Western circum-Pacific seems to be in early Carnian (*Neoprotrachyceras seimkanense* Zone). They are represented by three species of the genus *Striatosirenites* and two species of the genus *Neosirenites* (Fig. 1) associated with the *Proarcestes* and *Halobia* (Bytchkov and Polubotko, 1973).

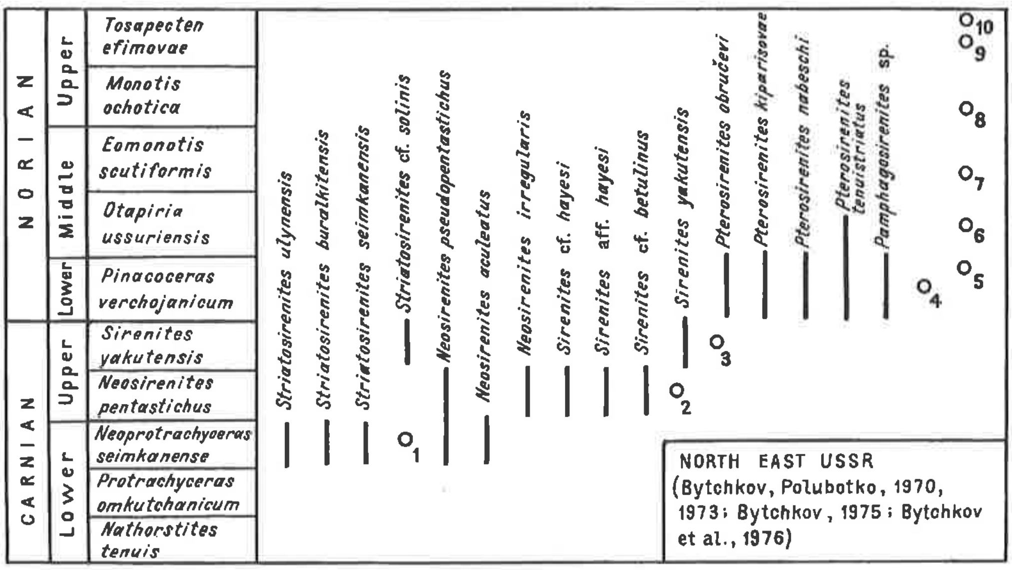

Fig. 1. Distribution of sirenitid ammonoids in the Late Triassic of North East Russia and their associations.

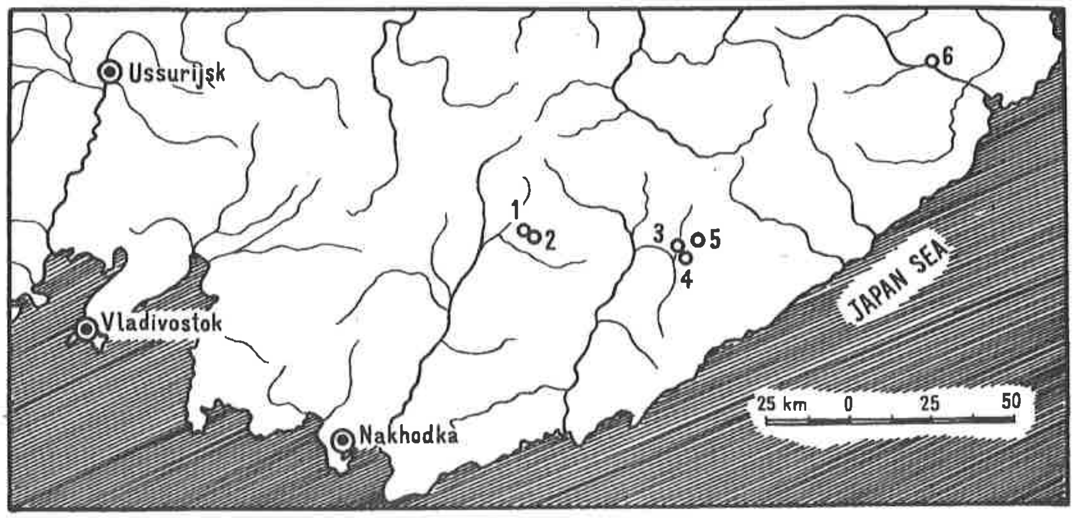

Fig. 2. The main localities of the Late Triassic ammonoids in Primorye region.

1 - Sergeevka River basin (*Trachiceratidae, Pterosirenites kiparisovae* (Zharnikova), *Pterosirenites evolutus* Zakharov et Zharnikova), 2 - Malaya Lazovka River basin (*Cyrtopleuritidae*), 3 - Kievka River, near Tigrovyi Spring (*Arietoceltites* sp.), 6 - Novo-Nikolaevka destrict, Avakumovka River (*Coeloceltites?* sp. indet., *Metasibiritidae?, Megaphyllitidae?, Arcestes* cf. *colonus* Mojsisovics.

The rich sirenitid fauna from the Upper Carnian of North East Russia includes *Striatosirenites* (one species), *Neosirenites* (three species) and *Sirenites* (four species) associated with *Proarcestes*, *Discophyllites* and bivalve *Halobia* (Bytchkov and Polubotko, 1973; Bytchkov, 1975).

Early Norian association in this region consists of three species of *Pterosirenites* (one of which was identified by Y. M. Bytchkov as *Pterosirenites kiparisovae* (Zharnikova), but we have not information on suture-line of this form) and species of *Pamphagosirenites*, *Wangoceras*, *Paratrachyceras*, bivalve *Halobia* and *Oxytoma* (Bytchkov and Polubotko, 1973, 1984; Bytchkov, 1974).

The latest representatives of sirenitid ammonoids *Pterosirenites tenuistriatus* (Popov) is originated in the Middle Norian (*Otapiria ussuriensis* Zone). Ammonoid *Arcestes, Placites* and *Cladiscites* were additionally met in this level.

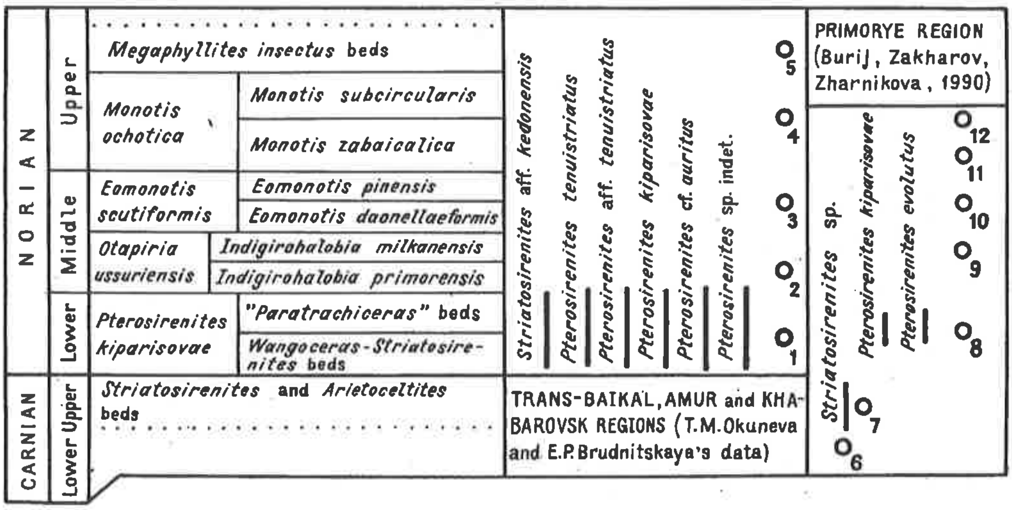

Fig. 3. Distribution of the sirenitid ammonoids in the Late Triassic of south Far East and their associations.

1 - *Paratrachyceras ? ulynense; Wangoceras* sp. indet.; *Hypocladiscites compressus; Placites placoides; Halobia aotii.* 2 - *Arcestes* cf. *seimkanensis; Otapiria ussuriensis.* 3 - *Arcestes biceps; Eomonotis scutiformis; Halobia obruchevi.* 4 - *Arcestes colonus; Paracladiscites* sp. indet.; *Placites subsymmetricus; Monotis ochotica; M. jakutica; M. zabaikalica.* 5 - *Paracladiscites* sp. indet. 6 - *Protrachyceras ?* sp.; *Halobia* sp. 7 - *Neoprotrachyceras ?* sp.; *Striatosirenites* sp.; *Arietoceltites* sp.; *Thisbites ?* sp.; *Monophyllites* sp. 8 - *Trachyceratidae* gen. et sp. indet.; *Paratrachyceras* sp. indet.; *Traskites ?* sp. indet.; *Halobia* sp. 9 - *Megaphyllitidae; Arcestes* cf. *colonus, Coeloceltites ?* sp. indet.; *Metasibiritidae ?; Otapiria ussuriensis; Halobia* aff. *styriaca.* 10 - *Eomonotis scutiformis.* 11 - *Monotis ochotica; M. jakutica.* 12 - *M. ochotica; M. pachypleura.*

The *Eomonotis scutiformis* Zone (upper Middle Norian) is characterized by only ammonoid *Himavatites*, bivalve *Eomonotis* and *Halobia* (Bytchkov and Polubotko, 1970, 1973, 1984). The assemblage of overlying *Monotis ochotica* Zone is represented by *Megaphyllites, Arcestes, Rhabdoceras, Halorites, Rhacophyllites* and *Monotis* (Popov, 1961; Afitsky, 1970).

The main genera of the lower part of the *Tosapecten efimovae* Zone are *Megaphyllites, Placites, Cladiscites, Arcestes, Rhacophyllites* accompanied with some bivalves.

The uppermost part of the Upper Norian is characterized by bivalve *Otapiria*. According to A.I. Afitsky (1985) the Triassic-Jurassic boundary in North East Russia cannot be established on the basis of ammonoid succession judging from the absence of their representatives in the uppermost Norian *Otapiria praecedens* Beds (5-30 m). Only transitional Triassic-Jurassic bivalve form *Otapiria praecedens* Afitsky, *Otapiria pseudooriginalis* (Zakharov), *Lima transversa* Polubotko and some other species are commonly found in this level.

2.2. Trans-Baikal, Amur and Khabarovsk regions

Late Triassic ammonoids including sirenitid ones are sporadically detected from the Carnian and Norian in south of the Far East Russia (Okuneva, 1985; Okuneva and Brudnitskaya's data). All representatives of the Sirenitidae in these regions - *Striatosirenites* (two species), *Pterosirenites* (four-five species), including *Pterosirenites kiparisovae* (Zharnikova) - are known to occur in the Lower Norian, in association with *Paratrachiceras?, Wangoceras, Hypocladiscites, Placites, Discophyllites* and bivalve *Oxytoma* and *Halobia*. Species of *Pterosirenites* were found in Tugur Gulf district (Mamba Bay); representatives of *Striatosirenites* are known from the same locality and Lan River area.

Middle Norian association this region is represented by *Arcestes* and bivalve *Otapiria, Eomonotis* and *Halobia*; Late Norian mollusc fauna includes *Arcestes, Placites, Paracladiscites*, bivalve *Halobia, Eomonotis* and *Monotis*.

2.3. Primorye region

When L.D. Kiparisova (1961) was preparing her book «*Paleontological Grounds of Triassic Sediments in Primorye*», there was no any information on the Late Triassic ammonoids of this region. Owing to N.K. Zharnikova's data (Burij and Zharnikova, 1962) the description of single species of the Late Triassic ammonoids from Primorye region - *Pterosirenites kiparisovae* (Zharnikova) is known. Recently author of this paper and N.K. Zharnikova (Burij, Zakharov and Zharnikova, 1990) have investigated this species additionally as well, as thirteen another ammonoid forms from the Upper Triassic of Primorye (Pl. 1). I should like to give an account of a summary of an available results.

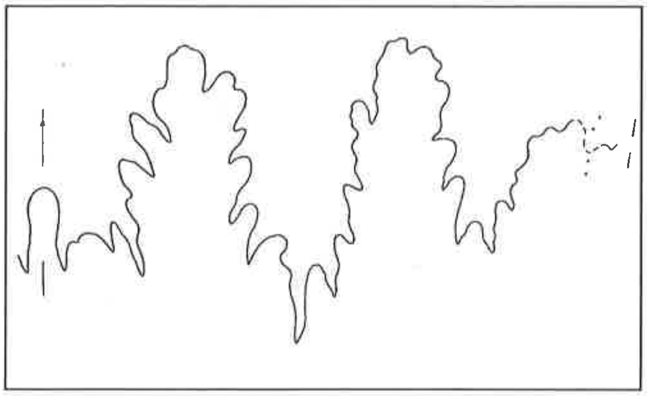

Fig. 4. Suture-line of *Pterosirenites evolutus* Zakharov et Zharnikova from the Lower Norian of Primorye region (Sergeevka River basin, Immalinovsky Spring).

Triassic sediments in Kievka River area (Fig. 2) containing fossils identified as *Protrachiceras?* sp. and *Halobia* spp. are regarded to be early Carnian in age.

The Late Carnian phase of mollusc succession in Primorye region is characterized by the appearance of *Striatosirenites, Neoprotrachiceras?, Thisbites?* (Kievka River area) and *Arietoceltites* (Tchernaya River area) (Fig. 3).

The Lower Norian ammonoids of this region are represented by *Pterosirenites kiparisovae* (Zharnikova) and *Pterosirenites evolutus* Zakharov et Zharnikova (Sergeevka River area) (Fig. 4) associated with bivalve *Halobia* and *Tosapecten*. Apparently with this horizon we must connect the finds of Trachyceratidae in Sergeevka River basin, *Paratrachyceras* sp. indet. and *Traskites?* sp. indet. in Pavlovka River basin.

Unfortunately that we have not trustworthy information on Middle Norian sequence of Primorye region characterized by ammonoids. But some ammonoids that were recognized in blocks within the Jurassic strata of Avakumovka River area are judged to be Middle Norian because they were met together with *Otapiria ussuriensis* (Voronez). They are *Arcestes* cf. *colonus* Mojsisovics, *Coeloceltites?* sp. indet. and *Metasibiritidae?* ammonoid *Cyrtopleuritidae?* which was collected in clay sediments of Malaya Lazovka River area seems to be the same age, too.

The uppermost part of the Middle Norian and the Upper Norian in Primorye region are characterized successively by *Eomonotis scutiformis* (Teller), *Monotis ochotica* (Keyserling), *Monotis zabaikalica* (Kiparisova) and some other bivalves.

2.4. Japan

Only one species of Late Triassic sirenitid ammonoids (*Sirenites* cf. *nanseni* Tozer) was recognized in Japan. It was collected in Carnian sequence of the Nakijin Formation in Okinawa Island devided into three zones: (1) *Sirenites* cf. *nanseni*, (2) *Juvavites* cf. *kelly* (Ishibashi, 1970) and (3) *Sandlingites* aff. *oribasus* (Ishibashi, 1970, 1973, 1975). Sirenitid ammonoids were found only in lower one in association with early Carnian *Paratrachyceras?, Triaskites, Hannaoceras, Leconteiceras, Styrites?, Juvavites* and *Discotropites*. All associated ammonoids are a typical Tethyan.

The Late Carnian ammonoids of two upper zones of Nakijin Formation belong to 21 and 9 genera correspondingly (*Juvavites, Proarcestes, Stenarcestes* and some others).

Norian ammonoid faunae of Sargai Group in Kitakami Massif and Jito Formation in western Shikoku associated with *Monotis ochotica* Keyserling include *Stenarcestes, Placites* and *Arcestes* (Bando, 1964, 1966).

2.5. China

No Late Triassic sirenitid ammonoids are evident from the entire China territory. Carnian ammonoid complex of Lunma region in Tibet consists of 12 genera (Wang and He, 1986). Norian ammonoids of this area accompanied with bivalve *Monotis salinaria* Schlotheim are represented by 25 genera (Wang and He, 1976; Yang, 1986).

Norian consequence of North China yields *Monotis ochotica* Keyserling (Paevskaya, 1985). Ammonoids seem to be missing here.

3. Correlation

We have incomplete information on Carnian ammonoids of Primorye region and adjacent territory now. As was mentioned above, *Protrachyceras?* sp. from Kievka River area seems to be early Carnian (Fig.5).

The new Upper Carnian stratigraphical unit of this region called as *Striatosirenites-Arietoceltites* Beds may be correlated with the *Tropites dilleri, Tropites subbullatus* and *Anatropites* Zones in the Alps (Krystyn et al., 1971; Krystyn, 1980), *Neosirenites pentastichus* and *Sirenites yakutensis* Zones in North East Russia (Dagys et al., 1979), *Sandlingites* aff. *oribasus* Zone in Japan (Ishibashi, 1970) (Fig. 5). The Lower Norian *Pterosirenites kiparisovae* Zone corresponds, apparently, to the Zone of *Pterosirenites tenuistriatus* in North East Russia.

A comparison of the bivalve successions of the Norian strata in various areas of the north-western circum-Pacific shows that those of Japan (Bando, 1964), Primorye region (Kiparisova, 1972; Paevskaya, 1985), Trans-Baikal, Khabarovsk and Amur River regions (Okuneva, 1985) and North East Russia (Dagys et al., 1979) have quite a similar vertical change.

ALPS (Krystyn et al., 1971; Krystyn, 1980 a,б)				NORTH-EAST USSR (Dagys et al., 1979)	TRANS-BAIKAL AMUR AND KHABAROVSK REGION (Okuneva, 1985)	PRIMORYE REGION	JAPAN (Bando, 1964; Ishibashi. 1970, 1973, 1975)
NORIAN	Upper	*Choristoceras marshi*	*Choristoceras marshi*	*Tosapecten efimovae*	?	*Sediments overling the Monotis* beds	?
			Vandaites staerzenbaumi				
		Rhabdoceras suessi	*Sagenites reticulatus*	*Monotis ochotica*	*Monotis ochotica*	*Monotis ochotica*	*Monotis ochotica*
			Sagenites quinquepunctatus				
	Middle	*Halorites macer*		*Eomonotis scutiformis*	*Eomonotis scutiformis*	*Eomonotis scutiformis*	*Eomonotis scutiformis*
		Himavatites hogarti	*H. hogarti*				
			H. watsoni	*Otapiria ussuriensis*	*Otapiria ussuriensis*	*Otapiria ussuriensis*	*Otapiria dubia*
		Cyrtopleurites bicrenatus	—				
	Lower	*Juvavites magnus*	—	*Pinacoceras verchojanicum*	*Pterosirenites tennuistriatus*	*Pterosirenites kiparisovae* beds	?
		Malayites paulckei	Unnamed beds				
			M. paulckei				
			M. lingriensis				
		Guembelites jandianus	*Dimorphites selectus*				
			Dimorphites n. sp.				
CARNIAN	Upper	*Anatropites*	*Gonionotites* cf. *italicus*	*Sirenites yakutensis*	?	?	*Juvavites* cf. *kelly*
			Discotropites plinii			*Striatosirenites and Arietoceltites* beds	*Sandlingites* aff. *oribasus*
		Tropites subbullatus	*Tropites subthiformis*				
			Projuvavites crasseplicatum				
		Tropites dilleri	—	*Neosirenites pentastichus*			*Sirenites* cf. *nanseni*
	Lower	*Austrotrachyceras austriacum*	*Neoprotrachyceras oldipus*	*Neoprotrachyceras seimkanense*		?	
			A. triadicum				
		Trachyceras aonoides	—	*Protrachyceras omkutchanicum*			
		Trachyceras-oan	—	*Nathorstites tenuis*			

Fig. 5. Correlation of the Upper Triassic in Far East.

4. Geographical Differentiation

Now we are far from knowing limits of variation in placing of the boundary between the Tethyan and Boreal realms in the Far East during Late Permian and Triassic time. But it is known that Upper Permian reef limestones and terrigenous sediments in South Primorye contain a typical Tethyan fossils. In the very late of Early Triassic, the Tethyan / Boreal boundary placed, apparently, between Bolshie Churki mountain ridge (northern locality of the Tethyan fauna in the Khabarovsk region) and Dzhagdy mountain ridge (Tugur-Chumkan region, Shevli River, Mudyuyan Creek) near south-eastern outlying districts of the Siberian platform where *Subolenekites* sp. (= «*Olenikites spiniplicatus*»), typical Boreal ammonoid element, was discovered by A.V. Makhinin and E.P. Brudnitskaya in 1963. Find of the fern *Cladophlebis gracilis* Sze (V.I. Burago's determination) in the *Subcolumbites multiphormis* Zone of the Lower Triassic in Russian Island and some paleomagnetic data (Zakharov and Sokarev, 1991) confirm the location of the Primorye in the Tethys (24.2 N) during Early Triassic.

It is known that Primorye and south Khabarovsk regions placed within the same province of the Tethys during Anisian time. A.S. Dagys (1974) has marked also that Carnian brachiopod complexes in Primorye and Japan are characterized by mixed Tethyan and Boreal elements. New data on Carnian ammonoids from terrigenous strata of Primorye region (Burij, Zakharov and Zharnikova, 1990) and some publications on Carnian ones of Japan show that they are definitely Tethyan (from 30 genera of the Carnian ammonoids in Okinawa about 93% are Tethyan; three ammonoid genera from five of the same age in Primorye region are also Tethyan, but two others are cosmopolite).

More difficult is problem of the location of the Tethyan / Boreal boundary during Norian time. In contrary to L.D. Kiparisova (1972), Y.M. Bytchkov, A.S. Dagys (1984), and M. Tamura (1987) I believe that *Monotis ochotica* (Keyserling) and some other Norian bivalve and brachiopod species can not be always used, apparently, as indicator of faunistic associations of Boreal type. This conclusion seems to be at correspondence with such facts:

(1) Dominants of the Middle Norian flora of Amba formation in South Primorye are some *Cylcadophita* and *Dipteriaceae* that in I.A. Dobruskina's (1982) opinion seems to be an indicator of warm climate.

(2) It is worthy of note also that the Norian ammonoids complexes of south Far East Russia and adjacent territory associated with bivalve *Monotis* contain some typical elements of the Tethyan fauna such as *Hypocladiscites* in Khabarovsk region (Bureya-Uda, Manga Bay) and *Stenarcestes* in Kitakami Massif, Japan. Migrant centres of many sirenitid ammonoids have not been determined yet.

Considering the peculiarities of divergence of bivalve *Monotis* no representatives of this genus can be used as an indicator of paleoclimatic zones for certain. The truth is that significant part of *Monotis salinaria* Schlotheim inhabited in low latitudes (Westermann, 1973), *Monotis ochotica* (Keyserling) and some other *Monotis* species are characterized usually the conditions of the warm temperate climate. But in south Far East (south Khabarovsk and Primorye regions, and Japan), the Norian molluscs of terrigenous facies seem to be subtropical.

The Late Triassic fossils (bivalve *Megalodontidae,* corals, ammonoid *Anatropites, Gonionotites, Juvavites*, and conodonts) in carbonate and siliceous rocks of some terranes in Koryak upland (Kenkeren ridge) (Bytchkov and Dagys, 1984; Melnikova and Bytchkov, 1986), Sikhote-Alin (Rybalka, 1987a, b; Punina, 1987; Khanchuk et al., 1988; Buryi, 1984) and Japan (Tairo and Tashiro, 1987) represent, apparently, some elements of tropical communities. Limited thickness, but extensive age interval of siliceous sequences of separate plates in Sikhote-Alin (Rybalka, 1987b; Khanchuk et al., 1988, 1989) and adjacent territories may be indirect argument in favour of oceanic origin of such sediments in the transition zone from the Eurasiatic continent to the Pacific ocean.

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Plate I

Fig. A and B - *Arcestes* cf. *colonus* Mojsisovics, PRIMGEO 63/808, x 1 (collected in the block of the lower Middle Norian among Jurassic sediments, at Novo-Nikolaevka destrict.

Fig. C-E - *Protrachyceras?* sp., DVGI 20/816, DVGI 12/816, DVGI 13/816, x 1 (Lower Carnian?, at Kievka River, near Tigrovyi Spring).

Fig. F - *Neoprotrachyceras?* sp., DVGI 6/816 (Upper Carnian, *Striatosirenites* and *Arietoceltites* Beds, at Kievka River basin, Zverolovnyi Spring).

Fig. G and H - TRACHYCERATIDAE gen. et sp. indet., DVGI 5/816, DVGI 21/816, x 1 (Lower Norian, *Pterosirenites kiparisovae* Beds, at Sergeevka River basin, Immalinovski Spring).

Fig. I - *Striatosirenites* sp., DVGI 7/816, x 1 (Upper Carnian, *Striatosirenites* and *Arietoceltites* Beds, at Kievka River basin, Zverolovnyi Spring).

Fig. J and K - *Pterosirenites evolutus* Zakharov et Zharnikova, holotype DVGI 1/816, DVGI 2/816, x 1 (Lower Norian, *Pterosirenites kiparisovae* Beds, at Sergeevka River basin, Immalinovski Spring).

Fig. L - CYRTOPLEURITIDAE? gen. et sp. indet., DVGI 9/816, x 1 (Middle Norian?, at Malaya Lazovka River basin).

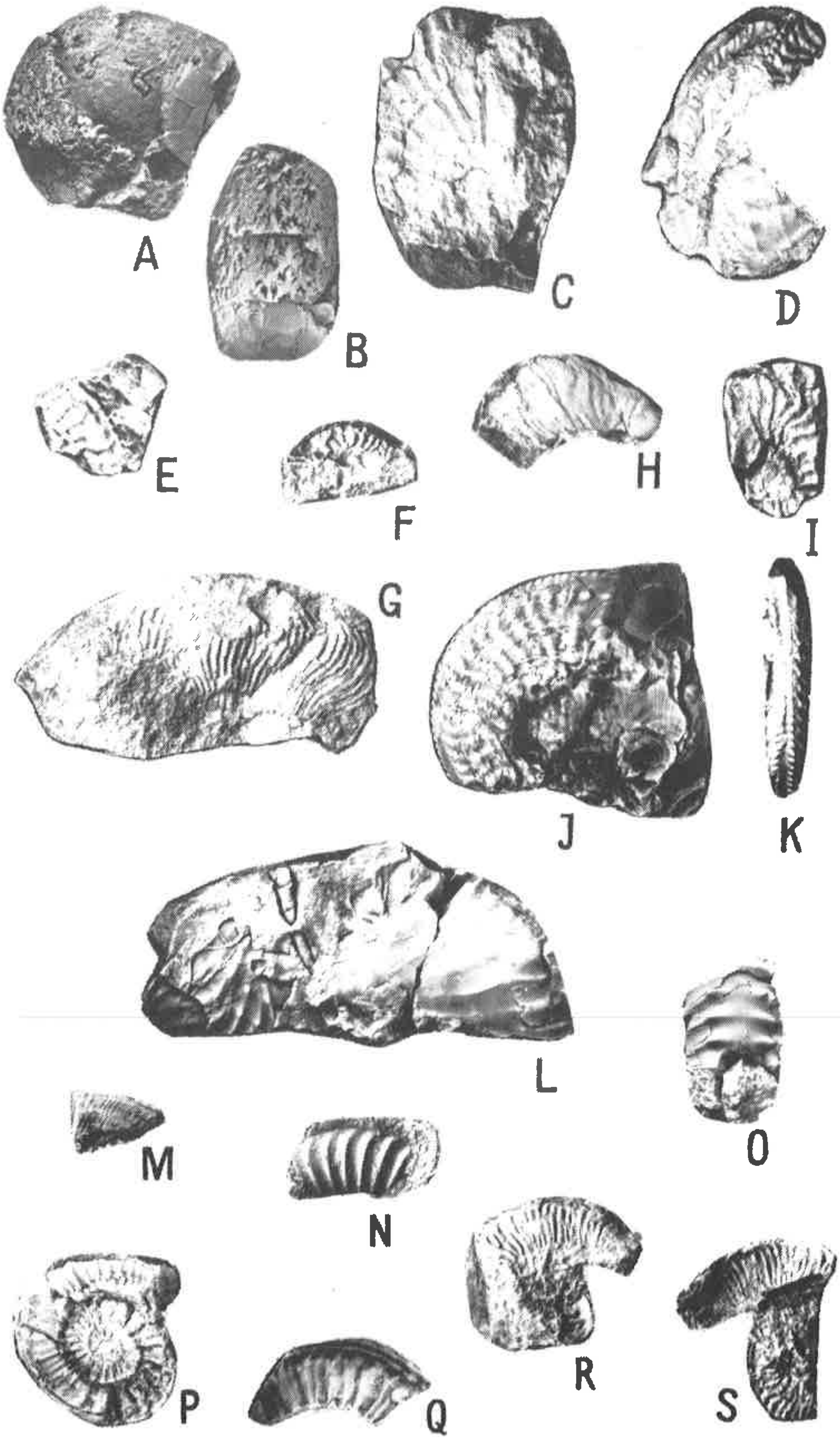
Fig. M - *Coeloceltites?* sp. indet., DVGI 10/816, x 2 (collected in block of lower Middle Norian among Jurassic? sediments, at Novo-Nikolaevka destrict).

Fig. N - METASIBITITIDAE? gen. et sp. indet., DVGI 11/816 (collected in block of lower Middle Norian among Jurassic? sediments, at Novo-Nikolaevka destrict.

Fig. O and P - *Arietoceltites* sp., DVGI 5/816, DVGI 6/816 (Upper Carnian, *Striatosirenites* and *Arietoceltites* Beds, near Chernaya River basin, Chertov Spring).

Fig. Q, R and S - *Thisbites?* sp., DVGI 8/816 (Upper Carnian, *Striatosirenites* and *Arietoceltites* Beds, at Kievka River basin, Zverolovnyi Spring).

Plate I



SPHINCTOZOANS OF PRIMORYE

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Abstract

In Primorye sphinctozoans are known from Upper Permian and Upper Triassic deposits. Upper Permian sphinctozoans have been found in Southern Primorye (Trydnyi Peninsula and Partizanskaya River). They are abundant enough and well preserved. Two assemblages of them have been distinquished: Early Dzhulfian and Late Dzhulfian - ?Early Dorashamian. Their composition and differences are described. Great similarity of Late Permian sphinctozoans of Primorye and South China has been revealed. Late Triassic sphinctozoans are rare in Primorye, they were found only in Sikhote-Alin (Dalnegorsk region).

1. Introduction

On the territory of the present Russia, sphinctozoans are known only in the Far East in Primorye where they were found in Upper Permian and Upper Triassic deposits. Most common and abundant are Upper Permian sphinctozoans in the Trudnyi Peninsula and Partizanskaya River lower reaches. Sphinctozoans, either independently or together with bryozoans, crinoids, algae, and other organisms, are frame-builders in the organogenic constructions among the predominantly terrigenous deposits. Two varieties of sphinctozoan occurrence relative to the layer roof were found: vertical and inclined to a different degree, up to the lateral position, i.e. parallel to the bedding. In my opinion the first variety testifies to the burial of sphinctozoans in the place of their growth. Usually, these are the most strong individuals with thick skeleton and well fastened on substratum. Most of sphinctozoans found here probably ad no organs for fastening, so they were washed off, overturned and so on under the action of even weak streams and water fluctuations. Possibly, this explains the frequent occurrence of sphinctozoans in inclined or lateral position. Good preservation and integrity of their skeletons support the burial of them near the place of their growth. One can often observe joint occurrence of sphinctozoans of both vertical and sharply inclined position.

2. Discussion

Two assemblages of Late Permian sphinctozoans have been distinguished (Boiko, Belyaeva, and Zhuravleva, 1991), the age of which was assumed as Early Dzhulfian and Late Dzhulfian - ?Early Dorashamian, respectively, with some conditionality (Belyaeva and other in this book) due to contradictory data on other groups of organisms (brachiopods, bryozoans and ammonoids). The lower association was found on Sestra and Brat Mountains and in the quarry in Nakhodka (lower part of Nakhodka massif), where sphinctozoans are of secondary importance as frame-builders of bioherms and more rarely bioherm massifs. The association is represented by 25 species of 14 genera (Boiko et al., 1990) including *Sollasia arta* Belyaeva, *?Thaumastocoelia* sp., *Celyphia permica* Belyaeva, *Henricellum* sp. 1, *Follicatena callosa* Belyaeva, *Apocoelia orientalis* Belyaeva, *Colospongia benjamini* (Girty), *?C. composita* Belyaeva, *C. nachodkiensis* Belyaeva, *Colospongia* sp., *C. globosa* Belyaeva, *Amblysiphonella asiatica* Yu, *A. vesiculosa* Koninck, *A. yini* Zhang, *A. oblyquisepta* Zhang, *A. eleganta* Belyaeva, *Amblysiphonella* sp., *Cystothalamia nodulifera* Girty, *Intrasporeocoelia orientalis* Belyaeva, *I. robusta* Belyaeva, *Rhabdactinia columnaria* Yabe et Sugiyama, *Polycystocoelia* cf. *huajaopingensis* Zhang, *?Cystauletes squamilis* Belyaeva, *?C. primoriensis* Belyaeva, *Lichuanospongia primorica* Belyaeva.

In this assemblage, the representatives of *Colospongia, Intrasporeocoelia*, and especially *Amblysiphonella* are abundant. Among the former, *C. benjamini* (Girty) prevail, and among *Amblysiphonella* - *A. asiatica* Yu, *A. vesiculosa* (Koninck) and *A. yini* Zhang. *Intrasporeocoelia orientalis* Belyaeva are common. Other sphinctozoans are represented by either isolated or few specimens. Only in this association the *?Thaumastocoelia* sp., *Henricellum* sp. 1, *Colospongia* sp., *Rhabdactinia columnaria* Yabe et Sugyamea, and *Lichuanospongia primorica* Belyaeva were observed.

The late assemblage was distinguished predominantly in reef facies (Bezymyannaya Mountain, upper part of Nakhodka massif, and other), where sphinctozoans were the main frame-builders. Sphinctozoans with massive thickened walls of the chambers are confined to the reef core often as large colonies. In the back-reef part, where the environments are more calm and predominantly thin-walled elegant individuals and many juvenile forms are observed. This association is represented by 23 species of 14 genera including (Boiko et al., 1991): *Sollasia arta* Belyaeva, *Celyphia permica* Belyaeva, *Henricellum* sp. 2, *Follicatena calosa* Belyaeva, *Apocoelia orientalis* Belyaeva, *Colospongia nachodkiensis* Belyaeva, *C. benjamini* (Girty), *?C. composita* Belyaeva, *C. globosa* Belyaeva, *Amblysiphonella asiatica* Yu, *A. eleganta* Belyaeva, *A.* cf.

Primorye		China	Pamir	Europe	N.Africa	N.America	S.America	Thailand
P_2								
Celyphia Pomel	★			P_2 T_3		T		
Sollasia Steinmann	★	CP_2		T	P_2			P_2
Henricellum Wilckens	▲			T_3		T		
?Thaumastocoelia Steinmann	▲			T_3		T_3		
Follicatena Ott	★	P_2		P_1T_3		T_3		
Apocoelia Rigby	★						P_2	
Colospongia Laube	●	P_2	P_2T_3	T_3	P_2	CPT_3	P_2	
Amblysiphonella Steinmann	●	P_2	C-T_3	PT_3	P_2	P	P_2	
Belyaevaspongia (Sen.-D.)	●							P_2
Intrasporeocoelia Fan et Zhang	●	P_2		P			P_2	
Rhabdactinia Yabe et Sugiyama	●	P_2						
Cystothalamia Girty	●	P_2	P_2	P	P_2	P	P_2	P_2
Polycystocoelia Zhang	▲	P_2	T_3		P_2	T_3	P_2	
Lichuanospongia ˣ) Zhang	★	P_2						
?Cystauletes ˣ) King	★	P_2		P_1	P_2	P_1C		
Imbricatocoelia Rigby et Zhang	▲	P_2						
Preverticillites Parona	●			P	P_2			
T_3								
Sollasia Steinmann	▲	P_2	P_1		P_2			
Celyphia Pomel	▲		T_3	T_3P_2		T		
Parauvanella Sen.-D. et Dist.	★	P		P_1T		P		
Colospongia Laube	★	P_2	P_2T_3	T_3	P_2	CPT_3	P_2	
Uvanella Ott	★	P_2	T_3					
1 - ★ 2 - ▲ 3 - ●								

Fig. 1. Occurrence and abundance of sphinctozoan genera in Primorye region. 1 - most abundant; 2 - abundant; 3 - rare.
ˣ) In contrast to B. Senowbari-Daryan (1990, 1994) the author considers the genera marked to be independent.

regularis Zhang, *A. yini* Zhang, *Belyaevaspongia insolita* (Belyaeva) nom. nov. Senowbari-Daryan, *Intrasporeocoelia robusta* Belyaeva, *Rhabdactinia* cf. *columnaria* Yabe et Sugiyama, *Cystothalamia nodulifera* Girty, *C. crassa* Belyaeva, *Polycystocoelia* cf. *huajaopingensis* Zhang, *?Cystauletes squamilis* Belyaeva, *?C. primoriensis* Belyaeva, *Imbricatocoelia lichatchevi* (Belyaeva), *Preverticillites columnella* Parona.

This assemblage is characterized by numerous *Belyaevaspongia, Preverticillites* and representatives of glomerate genera *Cystothalamia, Polycystocoelia, ?Cystauletes*, and *Imbricatocoelia*. Although *Colospongia* and *Amblysiphonella* are diverse as before, they are less numerous and species, different from those of the previous assemblage, predominant here: *Colospongia nachodkiensis* Belayeva and *Amblysiphonella eleganta* Belyaeva. Only in this assemblage *Henricellum* sp. 2, *Amblysiphonella* cf. *regularis* Zhang., *Belyaevaspongia insolita* (Belyaeva), *Rhabdactinia* cf. *columnaria* Yabe et Sugiyama, *Imbricatocoelia lichatchevi* (Belyaeva) are present.

As it is shown above, the composition of sphinctozoan assemblage of Primorye is diverse enough: 31 species representing 17 genera and seven families. 16 species are not known beyond the region described, that may be a result of specificity of local life-span conditions.

The comparison of Permian sphinctozoan composition of Primorye and other localities of the world showed (Fig. 1) the presence of common genera: in Europe (Aleotti et al., 1986; Senowbari-Daryan, 1990) - 7, in Central Asia (Boiko et al., 1991) - 2, in North America (Rigby, Potter, 1986; Rigby et al., 1988) - 4, in South America (Rigby, 1984) - 5, in North Africa (Senowbari-Daryan, Rigby, 1988) - 7, in South China (Fan et Zhang, 1985; Rigby et al., 1989) - 11; in Thailand (Senowbari-Daryan, Ingavat-Helmcke, 1994) - 4. There are common sphinctozoan species in Primorye and South China (Lichuan reefs, West Hubei). These are *Sollasia arta, Colospongia benjamini, Amblysiphonella yini, A. regularis, A. asiatica, A. obliquisepta, A. vesiculosa, Rhabdactinia columnaria, Rh.* cf. *columnaria, Polycystocoelia huajaopingensis, Imbricatocoelia irregulara* (Fig. 2). Besides, according to the description and image of Chinese sphinctozoans given by Fan and Zhang (1985) and Rigby, Fan and Zhang (1989) they are very similar to ours: *Colospongia salinaria irregularis* - to *?Colospongia composita*. Some of sphinctozoans common with Chinese ones are shown in

Primorye	China	Europe	N. Africa	Thailand
Celyphia permica				
Sollasia arta	+			
Henricellum $sp._1$				
Henricellum $sp._2$				
?Thaumastocoelia sp.				
Follicatena callosa				
Apocoelia orientalis				
Colospongia benjamini	+	+		
C. nachodkiensis				
C. globosa				
?C. composita	+			
Colospongia sp.	+			
Amblysiphonella asiatica	+			
A. eleganta				
A. yini	+			
A. vesiculosa	+	+		
A. cf *.regularis*	+			
A. obliquisepta	+			
Belyaevaspongia insolita				+
Intrasporeocoelia robusta				
I.orientalis				
Rhabdactinia columnaria	+			
Rh. cf. *columnaria*	+			
Cystothalamia crassa				
C. aff. *nodulifera*	+			
Polycystocoelia cf. huaiopimgensis	+	+	+	
Lichuanospongia primorica				
?Cystauletes squamilis				
?Cystauletes primoriensis				
Imbricatocoelia irregulara	+			
Preverticillites columnella		+	+	

Fig. 2. Occurrence of some Permian sphinctozoan species in Primorye and in other localities.

plates 1 and 2. In addition sphinctozoan are common in Primorye and other localities: *Preverticillites columnella* and *Polycystocoelia huajaopingensis* from Tunisia and Sicily, *Belyaevaspongia insolita* from Thailand; *Colospongia benjamini* and *Amblysiphonella vesiculosa* from Sicily.

It should be noted, that Late Permian sphinctozoan assemblages of these regions are similar in both abundance are diversity of the representatives of genera *Amblysiphonella, Intrasporeocoelia, Polycystocoelia, Colospongia* and other. In both regions, most abundant and diverse sphinctozoans are confined to the core facies of the reefs. Flourishing of the latter was at the very end of Late Permian (Fan and Zhang, 1985).

Late Triassic sphinctozoans were found in the reef deposits of Dalnegorsk region. They occur together with corals, sponges, and algae in so called Tetyukha series. They are not numerous here and were found on three stratigraphic levels from corals: Lower Carnian, Middle Norian, and Rhaetian (Punina, 1990). The lower level contains only the representatives of *Sollasia*. Single *Celyphia* are confined to Middle Norian. Most diverse, although not numerous, are Rhaetian sphinctozoans including *Parauvanella* n. sp., *Colospongia* sp., *Colospongia* sp., and *Uvanella* cf. *ducta* Boiko.

In contrast to remarkably diverse systematic composition of Late Permian sphinctozoans, Triassic representatives are rather monotonous and represented by predominantly asiphonate forms, often not porous. Of Late Permian sphinctozoans only the representatives of *Colospongia* are preserved here. By comparison with the coeval sphinctozoans from other regions, one may see the similarity of the Far East representatives with the Central Asian ones (Fig. 1, 2). Four of five sphinctozoans of Primorye are known also in the south-east Pamirs.

Sharp decrease of Primorye sphinctozoans in Triassic as compared to Permian, in systematic and quantitative respect, is most likely to be the reflection of geological reconstructions taking place at the boundary of periods.

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Plate I

Sphinctozoans of Primorye, similar to the South Chinese ones.

Fig. 1. *Colospongia globosa* Belyaeva, 1991. Longitudinal section, x 5, , DVGI 8-B/173-24, Bezymyannaya Mountain, Upper Dzhulfian - ?Lower - Dorashamian.

Fig. 2. *?Colospongia composita* Belyaeva, 1991. Longitudinal section, x 3, DVGI 8-B/157-o, quarry in the Nakhodka environs, Dzhulfian.

Fig. 3, 6. *Amblysiphonella obliquisepta* Zhang, 1983. Quarry in the Nakhodka environs, Dzhulfian:

3 - longitudinal section, x 2, DVGI 8-B/143-a;

6 - longitudinal section, x 2, DVGI 8-B/158-o, quarry in the Nakhodka environs, Dzhulfian.

Fig. 4. *Amblysiphonella yini* Zhang, 1985. Longitudinal section, x 2, DVGI 8-B/157-o-5, quarry in the Nakhodka environs, Dzhulfian.

Fig. 5. *Amblysiphonella* aff. *regularis* Zhang, 1983. Longitudinal section, x 3, DVGI 8-B/143-b, quarry in the Nakhodka environs, Upper Dzhulfian - ?Lower Dorashamian.

Fig. 7. *Amblysiphonella vesiculosa* (Koninck, 1863). Oblique-cross section, x 5, DVGI 8-B/159-b-6, Likhachev Cape, Dzhulfian.

Plate II

Sphinctozoans of Primorye, similar to the South Chinese ones.

Fig. 1. *Lichuanospongia primorica* Belyaeva, 1991. Longitudinal section, x 1, DVGI 8-B/155-g, Brat Mountain, Upper Permian.

Fig. 2. *Rhabdactinia* cf. *columnaria* Yabe et Sugiyama, 1934. Oblique-cross section, x 2, DVGI 8-B/144, quarry in the Nakhodka environs, Upper Dzhulfian - ?Lower Dorashamian.

Fig. 3. *Intrasporeocoelia orientalis* Belyaeva, 1991. Oblique-longitudinal section, x 2, DVGI 8-B/142-6-4, quarry in the Nakhodka environs, Dzhulfian.

Fig. 4. *Polycystocoelia* cf. *huajaopingensis* Zhang, 1983. Oblique-longitudinal section, x 2, DVGI 8-B/174a-11-1, quarry in the Nakhodka environs, Upper Dzhulfian -?Lower Dorashamian.

Fig. 5, 6. *Cystothalamia* aff. *nodulifera* Girty, 1908. x 5, Bezymyannaya Mountain, Upper Dzhulfian - ?Lower Dorashamian.

5 - Oblique-cross section, DVGI 8-B/173-1;

6 - Oblique-longitudinal section, DVGI 8-B/173-35.

Fig. 7. *Rhabdactinia columnaria* Yabe et Sugiyama, 1934. Cross-section, x 3, DVGI 8-B/157-o, quarry in the Nakhodka environs, Dzhulfian.

Plate I

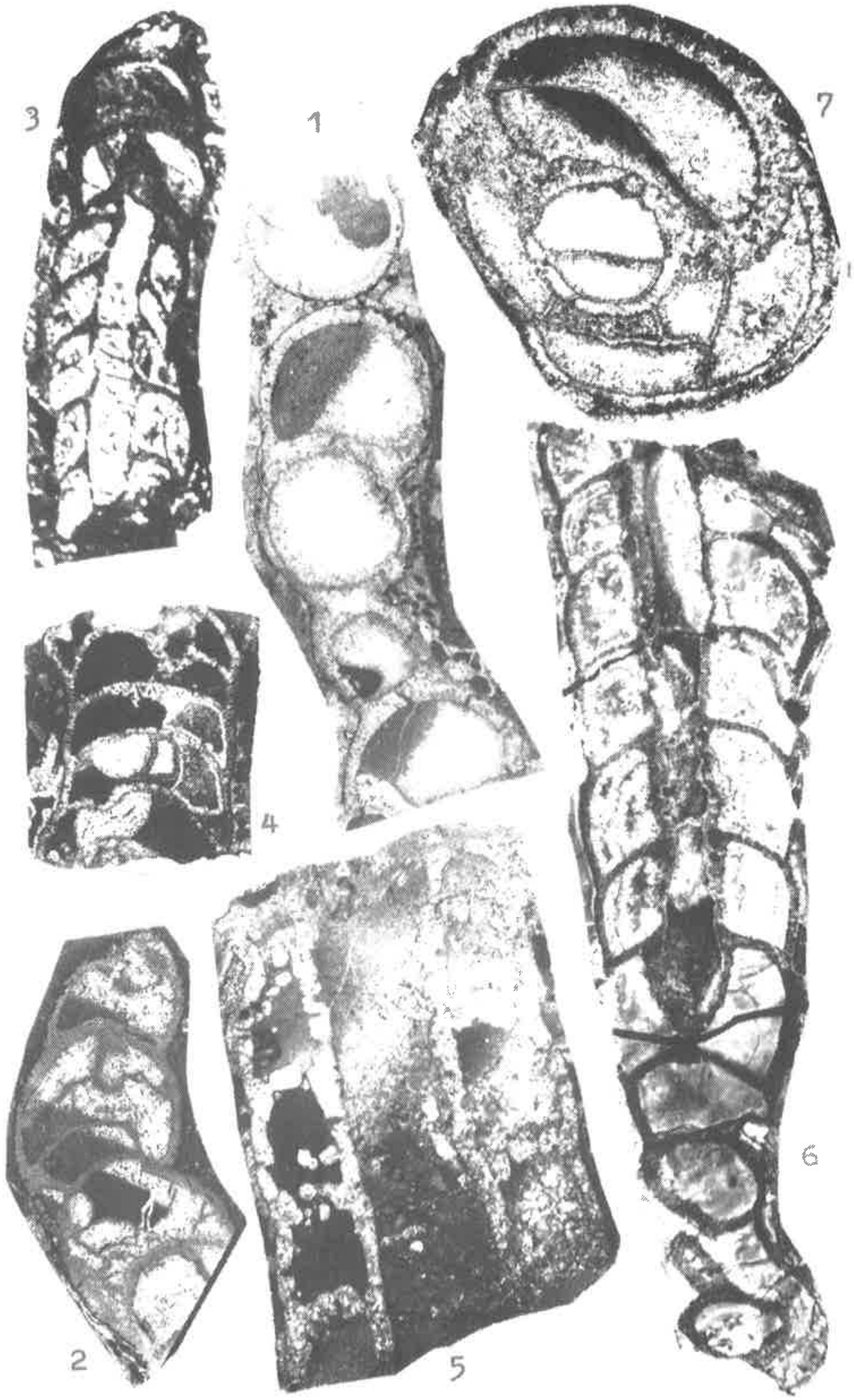

Plate II

STAGES OF LATE PERMIAN BIOGENIC BUILDUPS IN SOUTHERN PRIMORYE

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Abstract

The maximum carbonate accumulation in the South Primorye was apparently during Midian and Dzhulfian. Reef formation having three stages (1. separate bioherms and biostromes, 2. bioherm and biostrome massifs, 3. reefs), began at the end of the Midian and finished at the end of the Dzhulfian, and possibly at the beginning of the Dorashamian.

1. Introduction

Late Permian biogenic buildups in Southern Primorye are mainly known in the Partizansk and Shkotovo regions (Fig. 1). These are the buildups of the Sestra and the Brat Mountains, the massifs of Ekaterinovka (Zolotaya Mountain) and Volchanets Villages, the buildups of the southern part of the Trudnyi Peninsula (from Popov Cape to the Neizvestnaya Bay area), Nakhodka environs, and others. It is difficult to determine the type of biogenic buildups developed in those regions because of unsatisfactory outcrops and undetermined interrelations with enclosing formations, intense secondary alteration of the rocks, and especially became of the scarcity of data on limestone lithology.

Organic remains are very diverse and abundant. Framebuilders in biogenic buildups are crinoids, sphinctozoans, algae, sponges, bryozoans, corals, and hydrozoans, occurring separately or together. Of accompanying organisms, brachiopods, bivalves, and foraminiferans are common, and ammonoids, conodonts, and others are rare. Fusulinids predominate in most banks. Often, bryozoans and algae occur with them.

2. Analysis

The analysis of biogenic communities revealed changes in their composition caused by the evolutionary development of the representatives of different groups of biogenic buildups through Permian time. In this interval, three stages of the formation of organic carbonaceous bodies were distinguished. They were preceded by the stage of bank formation referred to the *Monodiexodina sutchanica, Parafusulina stricta, Neomiselina dutkevitchi* and *Neocrimites kropatchevae* fusulinid and ammonoid regional Zones and bryozoan *Orbinopora perforata* Beds. The shell banks of Sen'kina Shapka Mountain, Ekaterinovka Village, and Sredniy Cape are of different sizes and inhabited with foraminiferans, brachiopods, bryozoans, and rare corals. At this stage, there are more than 70 foraminiferans species of 15 fusulinid genera.

Fusulinids are represented by very large (up to 2 cm) elongated benthic forms with strong skeletons - *Monodiexodina, Parafusulina and Neomisellina* (Nikitina, 1974). Of planktonic (?) forms, *Sichotenella* and *Codonofusiella* are rarely found.

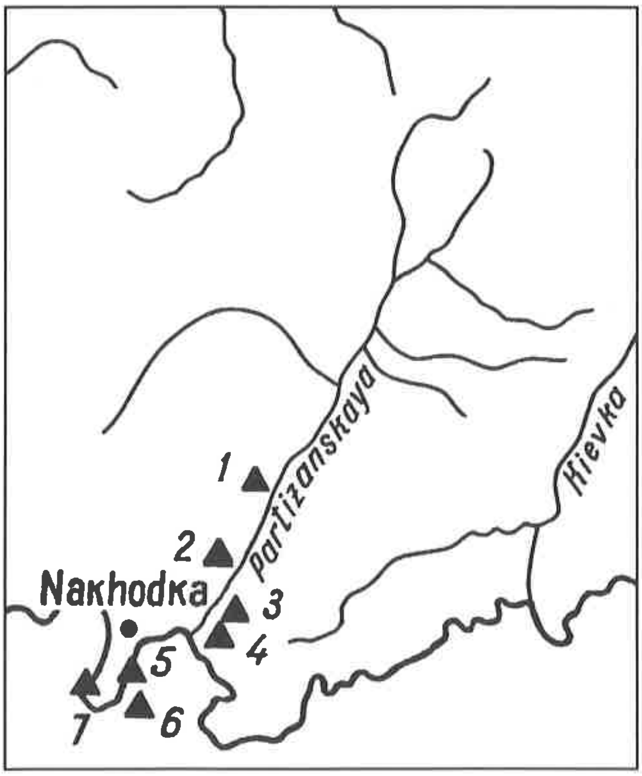

Fig. 1. Localities of biogenic buildups in the Southern Primorye. 1 - Sen'kina Shapka Mountain. 2 - Ekaterinovka Village, Zolotaya Mountain. 3 - Brat. 4 - Sestra Mountain. 5 - Volchanets Village. 6 - Nakhodka. 7 - Popov Cape, Neizvestnaya Bay.

At the time, bryozoans were abundant and very diverse in both systematic composition and colony form. From those layers, more than 80 species of 50 genera are known (Kiseleva, 1982). Large, many-layered overgrowing and massive colonies of *Cystopoda, Trepastomida* and *Cryptostomida* were abundant. The branching colonies of the orders mentioned above, and reticulate *Fenestrida,* existed with them. Bryozoans, algae, brachiopods, crinoids, and their own colonies. The species were represented by abundant specimens. The most characteristic genera are *Fistulipora, Cyclotrypa, Prismopora, Etherella, Epiactinotrypa, Neoeridocampylus, Parastenodiscus, Dyscritellina* and *Orbinopora*. First, in Primorye, the typical Late Permian *Hinganella, Ulrichotrypella, Tavayzopora, Girtypora* and *Hayasakapora* appeared at this time.

The level of the *Neomisellina lepida* fusulinid regional Zone and *Girtypora regula* bryozoan Zone corresponds to the first stage of the development of biogenic buildups. Obviously, at that time, the biogenic buildups of the Brat and Sestra Mountains formed, and the banks of Sen'kina Shapka Mountain continued to accumulate. In addition to the banks, buildups of bioherm and biostrome type appeared. In the banks, fusulinids predominated as before, and were accompanied by brachiopods, bryozoans, crinoids, and rare corals. The frame-builders of bioherms and biostromes were mainly algae and significantly less common bryozoans and corals. On Sen'kina Shapka Mountain, fusulinids of this level are represented by more than 200 species of 30 genera. On Brat and Sestra Mountains, they are buried nest-like, often in the form of lens-like accumulations and represented by a assemblage of somewhat depleted genus and species diversity, where large *Lepidolina, Pseudofusulina, Lantschichites* and forms with rounded shells (*Kahlerina, Pseudokahlerina*, and *Nankinella*) predominate.

The composition of bryozoan assemblage of this level is more poor, than the previous one. Many species continued from earlier levels, but they are represented by smaller colonies and significantly a lesser quantity of specimens. In the assemblage of the first biogenic buildups, there are in all about 35 species belonging to 15 genera. The Beds with *Girtypora regula* are common on Sen'kina Shapka Mountain, near Ekaterinovka Village, and in many other places. The most typical species are *Fistulipora elegantula* Nikiforova, *F. onchonaria* Basslerm, *Fistulina fundata* Morozova, *Distritella russiensis* Morozova, *Paralioclema neospinigerum* (Yang et Lao), *Rhabdomeson crockfordae* Kiseleva., *Girtypora regula* Kiseleva, *G. clara* Kiseleva, *Tavayzopora septata* Kiseleva, etc. The assemblage can readily be traced throughout the Primorye area.

The second stage (the beginning of the Dzhulfian Stage, the level of the lower part of the *Kamurana-Glomotrocholina*) Zone is characterized by the development of bioherms and biostromes, often combined into bioherm massifs, and, at the very beginning, banks. Frame-builders were crinoids, and, to a lesser degree, bryozoans, algae, corals, and sphinctozoans. Of the accompanying organisms at this level we may mention ammonoids, brachiopods, bivalves, gastropods, and foraminiferans. This was the time of the start and initial growth of Nakhodka reef (first a bank and then bioherms) and continuing growth of the buildups of the Sestra and Brat Mountains, Ekaterinovka massif, Volchanets Mountain, and the banks on Sen'kina Shapka Mountain.

Fusulinids at that time were mostly abundant in the banks of Sen'kina Shapka Mountain where they are represented by 33 species of 19 genera. Among them, the most characteristic are the representatives of *Neomisellina* and *Lepidolina (L. kumaensis* and *L. ussurica*). In the Nakhodka reef, fusulinids are very rare (only one fragment of *Lepidolina*, one specimen of *Codonofusiella* and one specimen of *Tchenia* were collected there) and sometimes the «small» foraminiferans *Lasiodiscus, Lasiotrochus, Nodosaria, Tetrataxis*, and *Abadechella* are found. On Sestra Mountain, fusulinids of ten species of eight genera occur, with *Codonofusiella extensa* Skinner et Wilde and others predominating.

Bryozoans of the second level are restricted to the lower part of the Lyudyanza Horizon. In all, there are 40 species and 28 genera, of which 14 species are the same as those from the assemblage of the first level. A new element of the bryozoan fauna is the genus *Arcticopora*, represented by two species typical of the Triassic. The rest, of the genera were common in the Late Paleozoic. *Fistulipora, Streblascopora, Restifenestrella* and *Alternifenestrella* are represented by the most numerous species and specimens. In the Nakhodka reef, there are many net-like fenestrid bryozoans which appeared to be the reef-builders in some areas. The main leading species of the assemblage are *Eridopora inaudita* Kiseleva, *Stenodiscus monilifer* Morozova, *Dyscitella alta* Kiseleva, *Arcticopora innae* (Kiseleva), *A. novella* Kiseleva, *Streblascopora shishovae* Kiseleva, *Kalvarella* n. sp., *Girtyporina crassa* Morozova and *G. asiatica* Kiseleva. This is a group of distinctive species, essentially new in morphological aspect as compared with the bryozoans of the previous level. They occur in the highest levels of the Lyudyanza Horizon (*Colaniella parva* Beds). Among bryozoans of the second level there are many species known from Dzhulfian and Dorashamian deposits of the Trans-Caucasian region and South China.

At the second stage of reef formation, such frame-builders as sphinctozoans (Boiko, Belyaeva and Zhuravleva, 1991) restricted to the bioherms of the lower member of the Nakhodka biogenic buildups and to the reefs of Sestra Mountain, appeared. They are also known at the Ekaterinovka massif (Zolotaya Mountain). The sphinctozoan assemblage of this level is represented by 25 species of 14 genera (Boiko et al., 1991) including *Henricellum* sp., *Celyphia permica* Belyaeva, *?Thaumastocoelia* sp., *Colospongia benjamini* (Girty), *C. globosa* Belyaeva, *C. composita* Belyaeva, *Amblysiphonella asiatica* Ju, *A. yini* Zhang, *A. vesiculosa* (Koninck), *Intrasporeocoelia orientalis* Belyaeva, *Rhabdactinia columnaria* Yabe et Suqiyama, *Lichuanospongia primorica* Belyaeva, etc. Most abundant in this assemblage are representatives of *Colospongia, Intrasporeocoelia* and especially *Amblysiphonella*. Only this assemblage contains *?Thaumastocoelia* sp., *Colospongia composita* Belyaeva, *Intrasporeocoelia orientalis* Belyaeva, *Rhabdactinia columnaria* Yabe et Sugiyama and *Lichuanospongia primorica* Belyaeva.

The third stage or level corresponds to the upper part of the Lyudyanza Horizon-*Kamurana - Glomotrocholina* Beds (upper part). This stage is represented by buildups of reef and bioherm massif type. These are reef facies of Nakhodka massif, Verblyud Rock and, obviously, the upper part of the biogenic buildups of Brat and Zolotaya Mountains. The main frame-builders were sphinctozoans and crinoids, and to a lesser degree, sponges, hydrozoans, bryozoan, algae, and rare corals. Brachiopods, bivalves, more rarely ammonoids, and very rare conodonts and foraminiferans occur with them.

Bryozoans do not differ significantly from bryozoans of the previous level in composition. Extremely abundant are sphinctozoans represented by 23 species of 14 genera, including *Henricellum* sp., *Solassia arta* Belyaeva, *Follicatena callosa* Belyaeva, *Colospongia nachodkiensis* Belyaeva, *Amblysiphonella eleganta* Belyaeva, *A.* cf. *regularis* Zhang, *A. obliquasepta* Zhang, *Belyaevaspongia insolita* (Belyaeva), *Intrasporeocoelia robusta* Belyaeva, *Rhabdactinia* cf. *columnaria* Yabe et Sugiyama, *Cystothalamia crassa* Belyaeva, *C.* aff. *nodulifera* Girty, *?Cystauletes primoriensis* Belyaeva, *Squamaella lichatchevi* Belyaeva, *Preverticillites columnella* Parona, and others. In this assemblage, polybranching *Belyaevaspongia, Preverticillites* and glomerate *Cystothalamia, ?Cystauletes and Squamaella* forms predominate. The representatives of *Colospongia* and *Amblysiphonella*, which are common in the previous assemblage, occur much more rarely, although they are diverse in composition. Only at this level, *Henricellum* sp., *Amblysiphonella* cf. *regularis* Zhang, *Belyaevaspongia insolita* (Belyaeva), *Intrasporeocoelia robusta* Belyaeva and *Squamaella lichatchevi* Belyaeva were found. The generic composition is the core and in the backreef of the Nakhodka reef is similar, but there is some difference in the composition of species. The forms from the core of the reef are larger and have a more massive, thick skeleton. In the back-reef part, the forms are as a rule thin-walled and refined, and many skeletons of juvenile forms are preserved here (Belyaeva, 1987).When comparing the sphinctozoan assemblagees with those known from Permian occurrences of Texas, Mexico, Venezuela, Sicily, Japan, China, and others, we found them to be most similar to the complexes of Southeast Asia, and especially to the Changxing complex of South China. The sphinctozoan assemblage of the third level has 12 species in common with sphinctozoans of the second level of the Changxing Stage in China.

The third level includes the ammonoids *Stacheoceras orientale* Zakharov, *Eumedlicottia nikitinae* Zakharov, *Neogeoceras thaumastum* Ruzhenzev, *Xenodiscus subcarbonarius* Zakharov; the nautiloids *Pseudorthoceras* sp., *Permonautilus* sp., and others. In the reef part of the Nakhodka massif, the conodonts *Sweetognathus* n. sp. aff. *iranicus* Kozur et al. and a fragment of *Gondolella*, apparently *G. orientalis* Barskov et Kozur (according to H. Kozur) were collected, and in the Ekaterinovka massif on Zolotaya Mountain, (the conodont *Gondolella* ex gr. *subcarinata* (Sweet) (S. V. Rybalka personal communication) was found.

We did not find any biogenic buildups above the third level. Only isolated lenses of limestones occur. When comparing the faunal assemblagees from biogenic limestones of different reef levels with the corresponding fauna from other occurrences of the World, we found the most similarity with those from Southeast Asia (Japan, India, and particularly China).

3. Discussion

In Pre-Chandalaz (i.e. Murgabian) time, a large part of the Southern Primorye was an area of denudation the relatively shallow marginal South-Primorye sea, formed in Midian time, abounded in bays, straits, and islands, and contained abundant and diverse fauna of a predominantly Alpine-Himalayan type. Volcanic activity, intense at the beginning of Permian time, began to die out, and in Southeast Primorye it practically ceased. From the mountainous land, mainly polymictic terrigenous material was supplied to the basin, and carbonaceous sediments were deposited.

In the marine-basin, three facies zones predominated: strongly mobile, mobile, and poorly mobile shallow water. At the boundary of the latter zones, the reef formation zone occurred. Biogenic buildups formed as knolls, which, judging from the siltstone-clay composition of the enclosing rocks and high purity of limestones, were at a significant distance from the areas of denudation and were under conditions of sinking movements almost continuously in Early Midian time. In Late Midian time, opposite movements took place and in the most shallow parts of the basin, sedimentation ceased in places. In the deep-sea parts of the basin, sedimentation continued near to the end of Permian, and reef formation may have finished at the beginning of Dorashamian time.

But at present, it is impossible to give the accurate age of the Permian reef formation, as specialists on different faunal groups are in some disagreement. The Midian age of

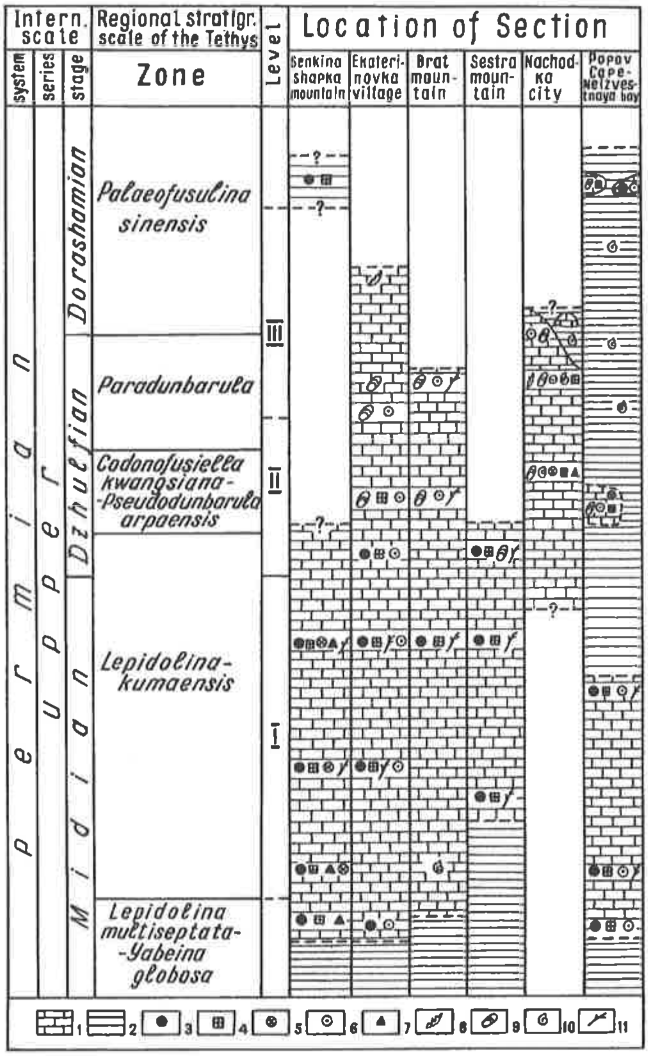

Fig. 2. Levels of formation of a different biogenic types buildups in the Southern Primorye Upper Permian sections

1 - limestone, 2 - clay shale and siltstone, 3 - fusulinids, 4 - bryozoans, 5 - corals, 6 - crinoids. 7 - brachiopods, 8 - conodonts, 9 - sphinctozoans, 10 - ammonoids, 11 - algae.

the first stage of reef formation (appearance of isolated bioherms and biostromes) and the previous process of bank formation is beyond question. The second stage of reef formation, in some authors opinion (Boiko, et al., 1991; Kiseleva, 1982; Kotlyar et al., 1989) is restricted to the beginning of Dzhulfian time, and in other authors view (Zakharov and Pavlov, 1986) to Midian time. Respectively, the third stage of reef formation, in the opinion of the first group of specialists, corresponds to begins at the end of Dzhulfian and probably even the beginning of Dorashamian time. Y. D. Zakharov and others consider it older-Midian.

Reef formation was preceded, as a rule, by bank formation, above which initially separate buildups of bioherm and biostrome type formed, then they became more integrated bioherm massifs that later took on the signs of a reef: characteristic reef facies appeared (fore-reef wave-cut, core, and back-reef lagoon). Biogenic carbonaceous massifs of the Southern Primorye reflect different stages of reef formation. For example, the massif, of Sen'kina Shapka Mountain is an initial stage - banks, and in the upper part of the massif, isolated bioherms and biostromes occur. The Nakhodka massif represents the stage of bioherms in the lower part and the stage of an early reef in the upper part. The massif near Ekaterinovka Village (Verblyud Mountain) is the stage of banks and bioherms.

The massif of Sestra Mountain is represented by separate and close banks and bioherms. The massif of Plemyannik Mountain is composed of banks and separate bioherms and biostromes (coral-algal). The massif of Brat Mountain represents banks and bioherms (algal-sphinctozoan): in the upper part, it is possibly close bioherms and early reef facies, etc.

Thus, in the Late Permian biogenic buildups of the Southern Primorye one can observe stages of reef development from banks, through isolated bioherms and biostromes, then the same bodies combined in to massifs, to buildups with distinct reef facies (fore-reef, core, and back-reef) (Fig. 2). The absence of later reef formation stages in some biogenic buildups may be explained either because growth for some reason ceased at an early stage, or by the fact that later stages of reef formation were not preserved through the subsequent processes of denudation.

Acknowledgements

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STRATIGRAPHIC LEVELS OF TRIASSIC LIMESTONES OF THE SOUTH SIKHOTE-ALIN (ON THE BASIS OF CORAL STUDY)

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Abstract

Six stratigraphical units, *Coryphyllia moiseevi, Volzeia badiotica, Margarosmilia melnikovae, Gablonzeria kiparisovae, Meandrostylis tener,* and *Retiophyllia buonamici* Beds, are suggested for Ladinian-Rhaetian limestones of the South Sikhote-Alin.

1. Introduction

Triassic limestones of the South Sikhote-Alin (Dalnegorsk region) (Fig. 1) contain numerous remains of scleractinian corals. The first findings of these organisms described by A.S. Moiseev (1951) are represented by a assemblage *Thecosmilia caesspitosa* Reus var. *ussuriensis* (Moiseev), *Th. angaraensis* (Moiseev), *Th.* ex gr. *subdichotoma* Volz, *Isastraea* ex gr. *austriaca* Frech, and *Margarastraea* sp.), that was dated as Carnian. A.S. Moiseev's collection that is stored in Museum of Russian Geological Institute (St. Petersburg) has been sampled in the centre of Dalnegorsk region in the massifs of Sakharnaya, Partizanskaya, and Verkhny Rudnik Mountains. In addition, previous findings of B.Y. Briner were included in the work, though they had no good labels and their localities were not indicated exactly enough. Later on, one of the species from this collection was redescribed by T.G. Iljina and G.K. Melnikova (1987). *Thecosmilia angaraensis* Moiseev was proved to be Permian tetracoral (*Donophyllum*). I.V. Burij et. al. (1986) characterized briefly Late Ladinian - Late Norian scleractinians sampled from different massifs of the region. Coral remains collected often together with bivalves (*Pteria caudata* (Stoppani), *Parallelodon curionii* (Bittner), *Otapiria* cf. *ussuriensis* (Voronetz), etc.) support Triassic age.

In the present paper, for the first time, some data on Triassic coral assemblages of Dalnegorsk region are given.

Fig. 1. Location of Middle and Upper Triassic limestones in Primorye region (Dalnegorsk).

2. Analysis of the Units

2.1. *Coryphyllia moiseevi* Beds (Ladinian-Lower Carnian)

Late Ladinian - Early Carnian coral reef complex is the most ancient of those distinguished in Dalnegorsk region. It includes individual forms: *Coryphyllia tenuiseptata* Melnikova (Pl. 1), *C. moiseevi* Punina et Melnikova, *C.* ex. gr. *regularies* Cuif, *Margarophyllia* cf. *capitata* (Muenster), and *M. inculta* Deng. et Kong. This assemblage was found together with bivalve molluscs - *Pteria insolita* Bittner, *Urma distincta* Bittner etc. and gastropods in marls on the south-west slope of Bolnichnaya Mountain. The representatives of *Margarophyllia* and *Coryphyllia* are known from Ladinian deposits of China and Cassian Beds of the Alps (Volz, 1896).

2.2. *Volzeia badiotica* Beds (Upper Carnian)

Late Carnian coral assemblages of Dalnegorsk region is mainly represented by dendroid and faceloid forms: *Volzeia subdichotoma* (Muenster) *V. badiotica* Volz, *Pachysolenia primorica* Iljina, *Distichomeandra* sp., *Margarosmilia* sp., etc. This assemblage was found together with bivalve molluscs - *Parallelodon currioni* Bittner, *Neoschizodus decussatum* (Muenster), *Cardita pichleri* Bittner, *etc; conodonts - Paragondolella* cf. *polygnathiformis* Budurov et Stefanov, *Ancyrogondolella triangularis* Budurov, etc.

As the layers of massive and bedded limestones (biostrome), containing this assemblages, are well traced in some massifs (Sakharnaya, Bolnichnaya, Kamennye Vorota, Verkhny Rudnik), they were suggested to be distinguished as the *Volzeia badiotica* Beds. The thickness of the layers (Sakharnaya Mountain) is about 100 m.

2.3. *Margarosmilia melnikovae* Beds (Lower Norian)

Early Norian coral assemblages was determined in biostromes of Sakharnaya, Verkhny Rudnik, Kamennye Vorota, Bolnichnaya, Partizanskaya, and Izvestkovaya Mountains. It is represented by numerous dendroid, faceloid, and cerioid forms: *Margarosmilia charlyana* (Frech), *M. melnikovae* Punina, *M. culta* n. sp. (Pl. 2), *Protoheterastraea konosensis* (Kanmera), *Astraeomorpha confusa* (Winkler), *Retiophyllia weberi* (Vinassa de Regny), *Gablonzeria reussi* Cuif, *Distichomeandra primorica* Punina, and *Stylophyllopsis* sp. This unit was named by the predominant species of this level occurring in all limestone massifs. This assemblage was found together with bivalves - *Halobia* cf. *austriaca* Mojsisovics, *Entolium tridentina* Bittner; conodonts - *Epigondolella abneptis* (Huekeiede), *Metapolygnatus primitia* (Mosher), *M.vialovi* Biryi. The thickness of the *Margarosmilia melnikovae* Beds in the type section (Sakharnaya Mountain) is about 220 m.

2.4. *Gablonzeria kiparisovae* Beds (Middle Norian)

Middle Norian assemblage was found in massive limestones (biogerm) of the same massifs as Early Norian. In it, in addition to previous representatives of the species, we found also: *Gablonzeria kiparisovae* Punina, *G. singularis* Punina, *G. dalnegorica* Punina (Pl. 3), *Toechastraea plana* Cuif, *Retiophyllia fenestrata* (Reuss), *R. norica* (Frech), *Distichomeandra primorica* Punina. The thickness of the *Gablonzeria kiparisovae* Beds in the type section (Sakharnaya Mountain) is about 180 m. This assemblage was found in association with bivalves - *Otapiria ussuriensis chankaika* (Voronetz), *Entolium* cf. *kolyaense* Kiparisova; conodonts - *Epigondolella abneptis* (Huckriede), *Metapolygnathus linguiformis* Hayashi, etc.

2.5. *Meandrostylis tener* Beds (Upper Norian)

In the deposits of the reef core of Sakharnaya and Verkhny Rudnik, we found the extensive Late Norian assemblage: *Retiophyllia buonamici* (Stoppani), *R. cyathophylloides* (Frech), *Meandrostylis tener* n. sp. (Pl. 41), *Astraeomorpha crassisepta* Reuss, and *Palaeastraea alnigmata* Punina, etc.

The thickness of the *Meandsostylis tener* Beds in the proposed type section (Sakharnaya Mountain) is about 80 m. The representatives of *Meandrostylis* are known from Upper Norian of the South-East Pamirs and the Alps (Melnikova, 1983; Frech, 1890; Roniewicz, 1989). In Dalnegorsk region they are restricted only to this stratigraphic level that allows us to distinguish the *Meandrostylis tener* Beds. This assemblages was found together with bivalves - *Pteria* cf. *tofanae* Bittner, *Tosapecten tetuckensis* Kiparisova, etc.

2.6. *Retiophyllia buonamici* Beds (Rhaetian)

Rhaetian corals in Dalnegorsk region were found in the area of Verkhny Rudnik and Sakharnaya Mountain. They are represented by dendroid and faceloid colonies of abundant *Retiophyllia cyathophylloides* (Frech), *R. buonamici* (Stoppani), *Heterastraea profunda* Reuss., and *Pamiroseris meriani* Stoppani. This assemblage was found in association with foraminifera - *Triassina hantkeni* Majzon, *Aulotortus sinuosus* (Weynschenk), etc., conodonts - *Misikella posthernsteini* Kozur et Mock.

The Beds distinguished were called by the predominant species of the complex - *Retiophyllia buonamici*. The thickness of them in the proposed type section (Sakharnaya Mountain) is about 50 m.

* * *

When considering as a whole the coral assemblage of Dalnegorsk region, one can notice that the Late Ladinian - Early Carnian initial stage of carbonate accumulation is characterized by the presence of individual and poorly dendroid corals, and the Late Carnian - Norian - Rhaetian stage, when the intense reef formation took place, is characterized by the presence of colonial forms.

When comparing the Dalnegorsk coral complexes with those from other regions, we can see their close similarity at generic level with coral complexes from the South-East Pamirs and the Alps, and at species level - with coral reefs from Japan and China (Iljina T.G., Melnikova G.K., 1986; Melnikova G.K, 1983. Roniewicz E., 1989; Kanmera K., Furukawa, 1964; Xia Jinbao, Liao Weihua, 1986). Below, the new species of reef-building corals are described.

3. Systematics

Family STYLOPHYLLIDAE Frech, 1890
Genus *Meandrostylis* Frech, 1890

Meandrostylis tener n. sp.
Plate 5, figs. 1-3; Plate 4, figs. 1,2

The name of the species is from *tener* (lat.) - thin.

Holotype - DVGI 460/323, Primorye, Dalnegorsk, Verkhny Rudnik; Upper Norian, *Meandrostylis tener* Beds.

Diagnosis: Colonies cerio-meandroid, septal apparatus consisting of 28-30 septa of the three orders. Calicular mean diameter 5-6 mm.

Description: Cerio-meandroid colony; cerioid condition permanent. Corallites are star-like, rounded, 5-6 mm in diameter. Corallites are arranged in rows. Septal apparatus irregular, consisting of 28-30 septa of three order. We distinguish 8-9 septa of the first order, the inner ends of which are broken up into individual grains in the centre, and 7-8 septa of the second order. 12-15 septa of the third are more than half the length of septa first order. The septa are composed of inclined spines arranged in a single row. Microstructure of the spines is fibrous. Interseptal apparatus is represented by tabula-like concave dissepiments. For 1 mm of the corallite height there are 5 dissepiments.

Comparison: It is similar to *Meandrostylis frechi* Haas (Roniewics, 1989, p. 132, pl. 39, fig. 11) in colony structure and septal and interseptal apparatus and differs in smaller sizes of corallites and more numerous septa.

Distribution: Upper Norian, Primorye region.

Material: Four specimens from Dalnegorsk (Verkhny Rudnik), DVGI 460/323, DVGI 460/187, DVGI 460/68, DVGI 460/72.

Family MARGAROPHYLLIIDAE Cuif, 1976
Genus *Margarosmilia* Volz, 1896

Margarosmilia culta n. sp.
Plate 2, figs. 3-5; Plate 5, figs. 4,54

The name of the species is from *cultus* (lat.) - elegans.

Holotype - DVGI 460/229; Primorye, Dalnegorsk, Sakharnaya Mountain; Lower Norian, *Margarosmilia melnikovae* beds.

Diagnosis: Corallites cyclindrical, 3-6 mm in average diameter, with 60-80 septa strongly granulated.

Description: Facelodendroid colony reproducing by double fussion. The distance between corallites is 0,2 to 5 mm. Corallites are cylindrical, protothecas are round, 3-6 mm in diameter. Radial elements are septa of four orders, in amounts of 60-80. Septa of the first and second order are about of the same length and strongly ornate with round grains arranged in chess-board order. Septa of the third order are thin and ornamentation is poor. Septa of the fourth order are thin and smooth and reach a half of length of the first order septa. The wall is parathecal, dense and thin (0,2 mm). Interseptal apparatus consists of vesicular, almost round dissepiments. In the peripheral part of the corallite, the dissepiments are more round than in the centre.

Comparison: It is similar to *Margarosmilia confluens* Volz (Volz, 1896, p. 34, pl. 1, fig. 8-12) in shape and size of protothecas and septum amount. It is characterized by more branched shape of colonies and septum structure. It has more macronate grains on the septa outer margins.

Distribution: Lower Norian, Primorye region.

Material: Five isolated corallites DVGI 229/460, DVGI 229/186, DVGI 229/187, DVGI 229/190. DVGI 229/202 and three fragmentary colonies DVGI 299/461, DVGI 229/465, DVGI 229/185 from Dalnegorsk (Sakharnaya and Verkhny Rudnik).

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Plate I

Fig. 1-3. *Coryphyllia moiseevi* Punina et Melnikova, DVGI 186/16, 1 - proximally abraded corallum, x 1; 2 - transverse section of corallum, x 2,5; 3 - transverse section of corallum, x 5; Ladinian - Lower Carnian; Primorye region, Dalnegorsk, Sakharnaya Montain.

Fig. 4. *Volzeia subdichotoma* (Muenster) DVGI 460/162, transverse section of colony, x 7; Carnian; Primorye region, Dalnegorsk, Verkhny Rudnik.

Plate II

Fig. 1. *Margarosmilia charlyana* (Frech), DVGI, N 460/200, transverse section of Colony, x 5; Lower Norian; Primorye region. Dalnegorsk. Verkhny Rudnik.

Fig. 2. *Margarosmilia melnikovae* Punina, DVGI 460/2-86, transverse section of corallites, x 5. Lower Norian, Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 3-5. *Margarosmilia culta* n. sp., DVGI 460/229: holotype. 3 - tranverse section of colony, x 10; 4 - trancverse section of colony, x 6; 5 - septum in transverse section showing arrangement of trabeculae, x 100; Lower Norian, Primorye region, Dalnegorsk. Sakharnaya Mountain.

Plate III

Fig. 1. *Gablonzeria Kiparisovae* Punina, DVGI 460/4-187, transverse section of corallites, x 5. Middle Norian; Primorye region, Dalnegorsk, Verkhny Rudnik.

Fig. 2. *Gablonzeria krasnovi* Punina, DVGI 460/248, transverse section of corallites, x 6. Middle Norian, Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 3. *Gablonzeria singulari* Punina, 186/200, transverse section of colony, x 2; Upper Norian, Primorye region, Dalnegorsk, Verkhny Rudnik.

Fig. 4. *Gablonzeria dalnegorica* Punina et Melnikova, 186/203, transverse section of colony, x 20. Middle Norian; Primorye region. Dalnegorsk, Verkhny Rudnik.

Plate IV

Fig. 1-2. *Meandrostylis tener* n. sp., DVGI 460/323: holotype. 1 - transverse section of corallites, x 8: 2 - longitudinal section of colony, x 2: Upper Norian: Primorye region, Dalnegorsk, Verkhny Rudnik.

Fig. 3-4. *Retiophyllia norica* (Frech), DVGI 460/221: 3 - transverse section of corallites, x 3; 4 - transverse section of corallites, x 2.

Fig. 5. *Retiophyllia buonamici* (Stoppani), DVGI 460/159; transverse sectionof colony, x 2; Rhaetian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Plate V

Fig. 1-3 - *Meandrostylis tener* n. sp., DVGI 460/323: holotype. 1 - transverse section of corallites, x 10; 2 - longitudinal section of colony. x 15; 3 - transverse section of corallites, x 20; Upper Norian; Primorye region. Dalnegorsk. Verkhny Rudnik.

Fig. 4-5 - *Margarosmilia culta* n. sp., DVGI 460/229: holotype. 4 - transverse section, x 10; 5 - septum in transverse section showing arrangement of trabeculae, x 100; Lower Norian; Primorye region. Dalnegorsk. Sakharnaya Mountain.

Plate I

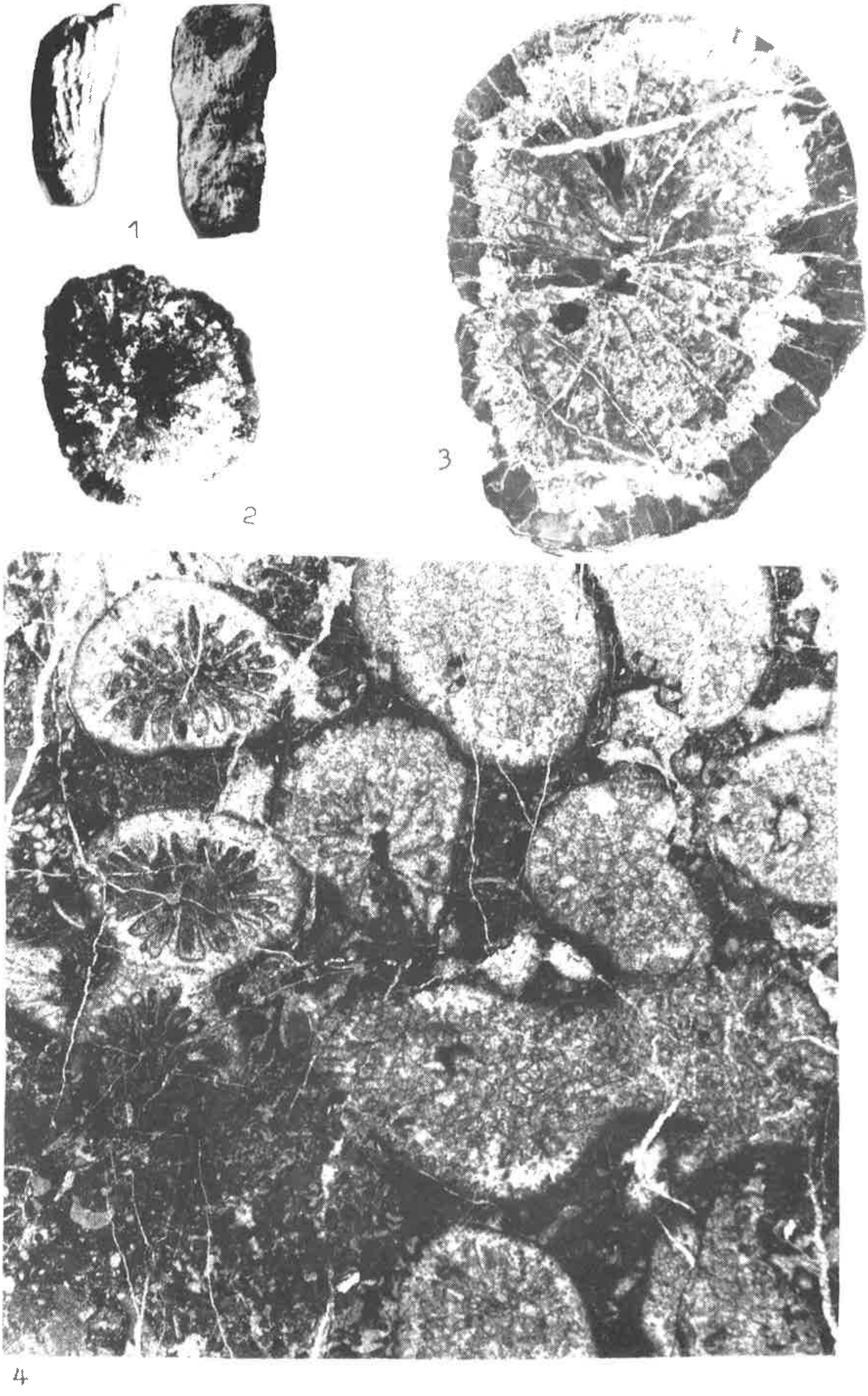


Plate II

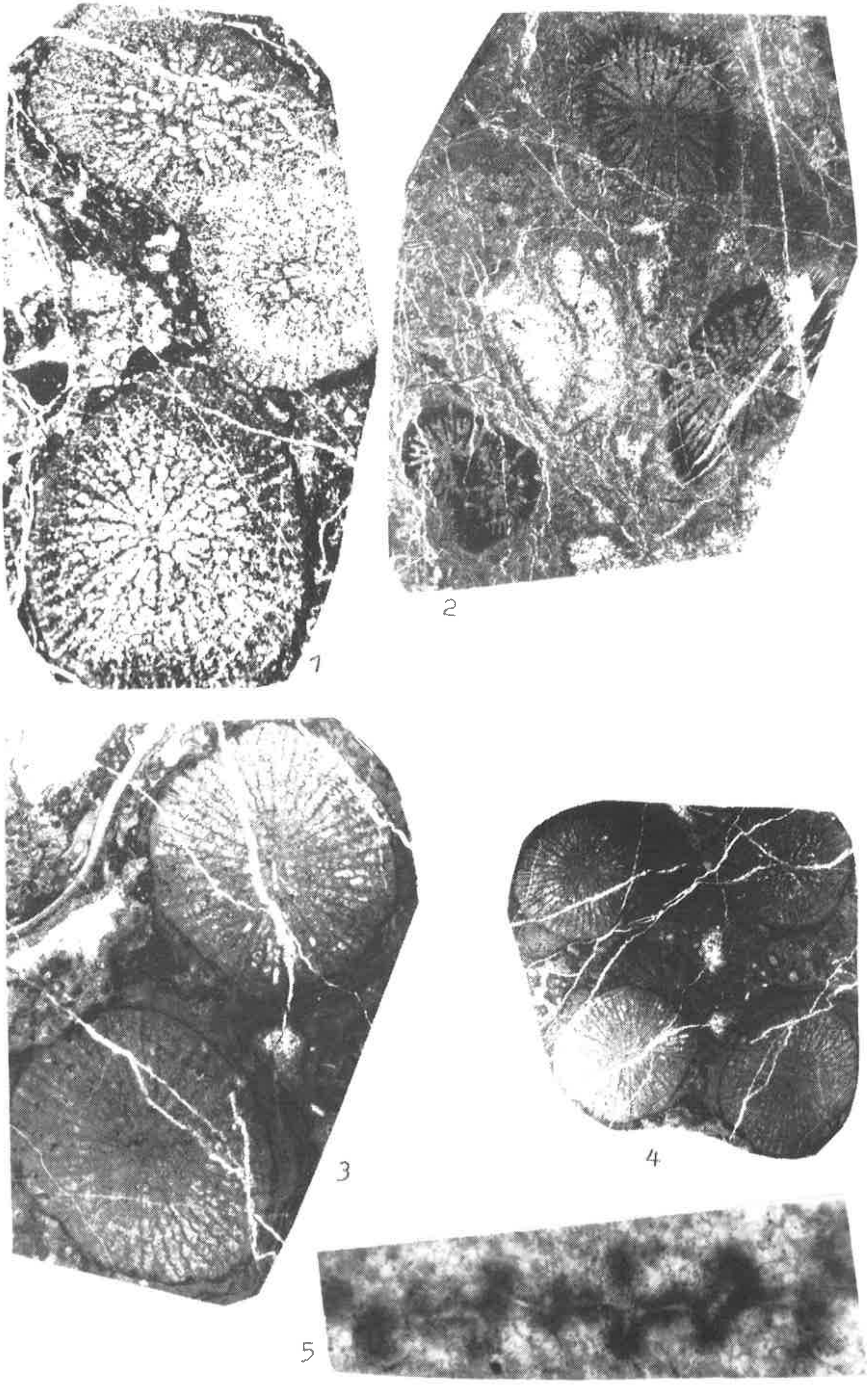


Plate III

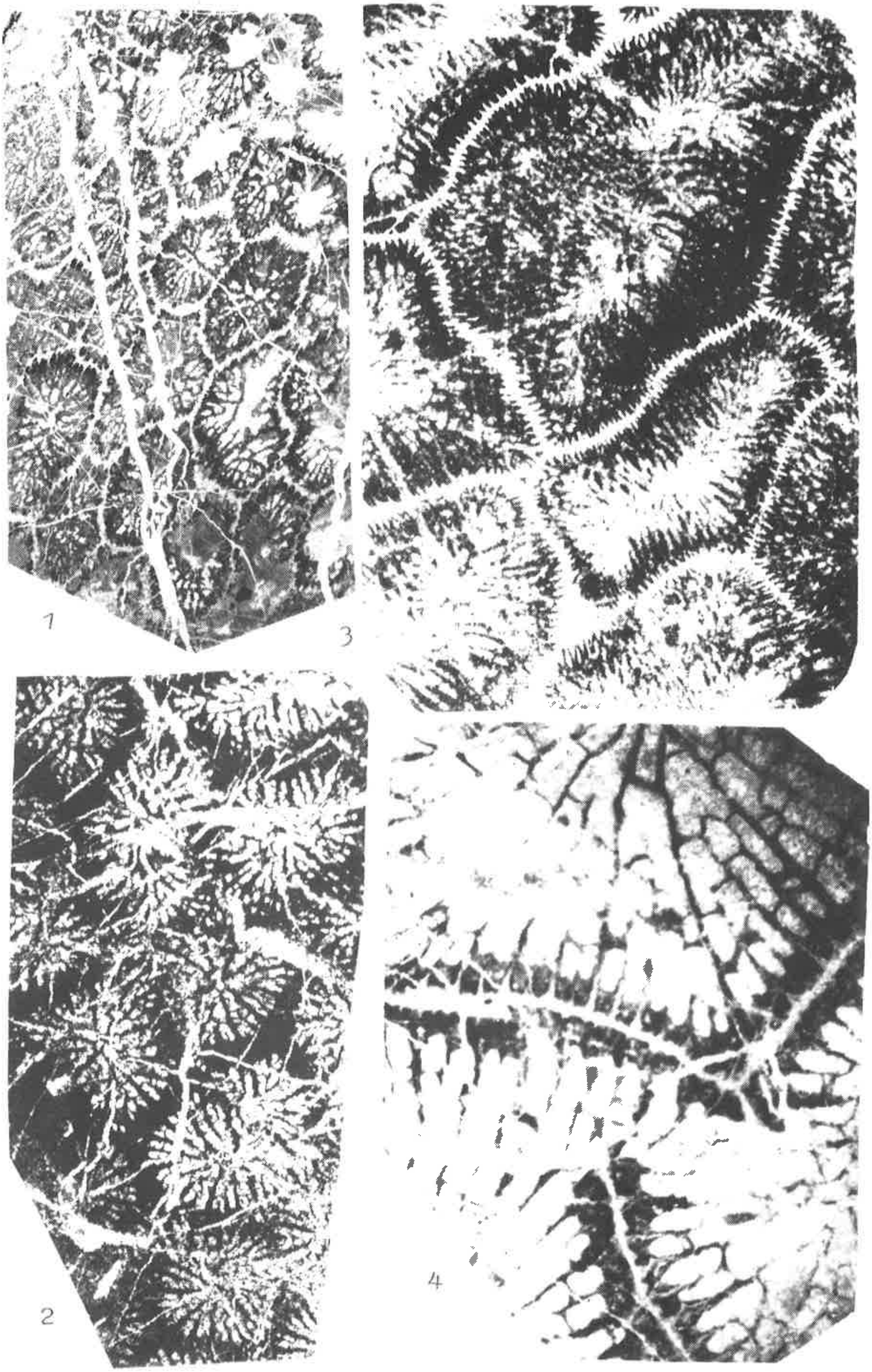


Plate IV

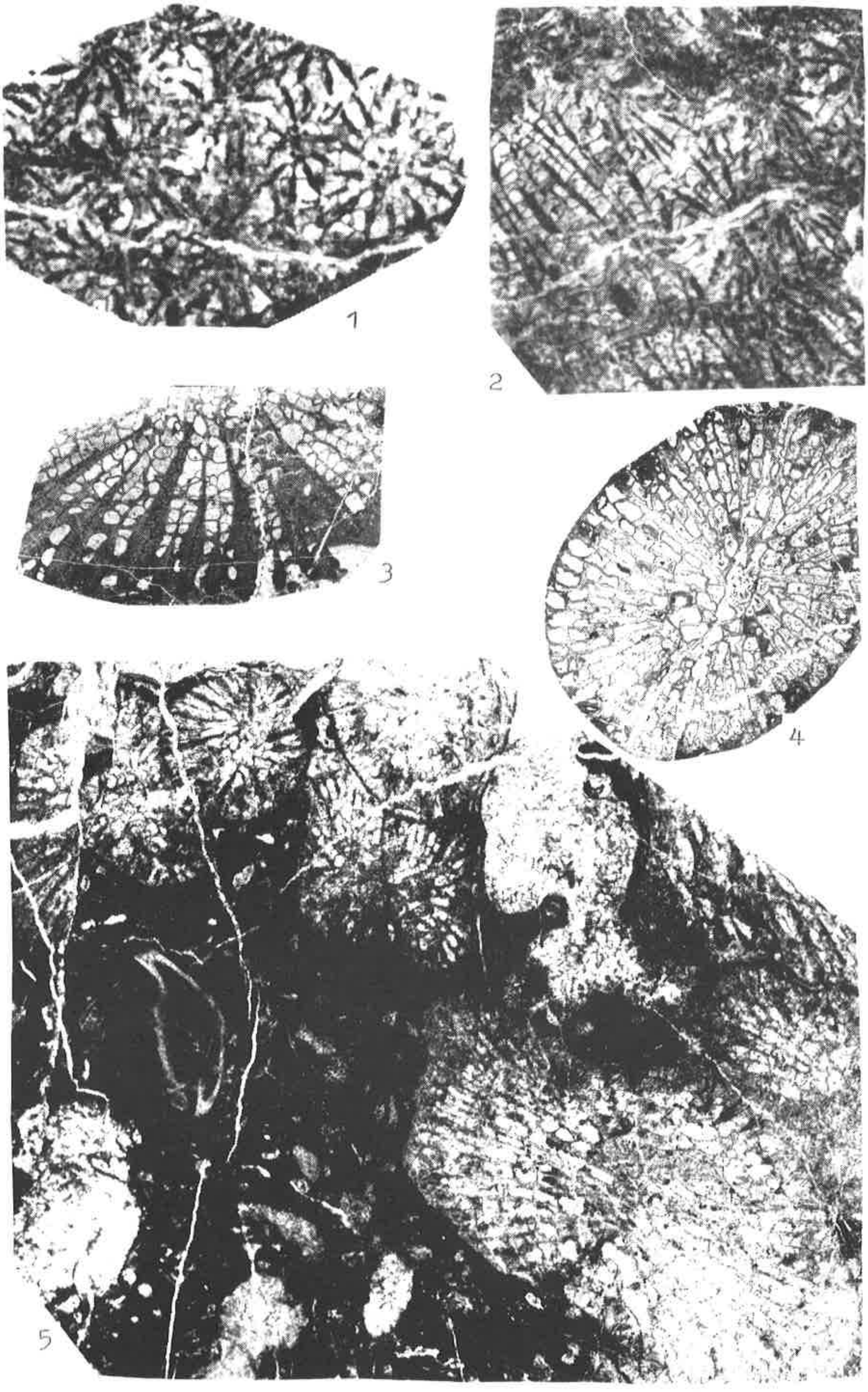
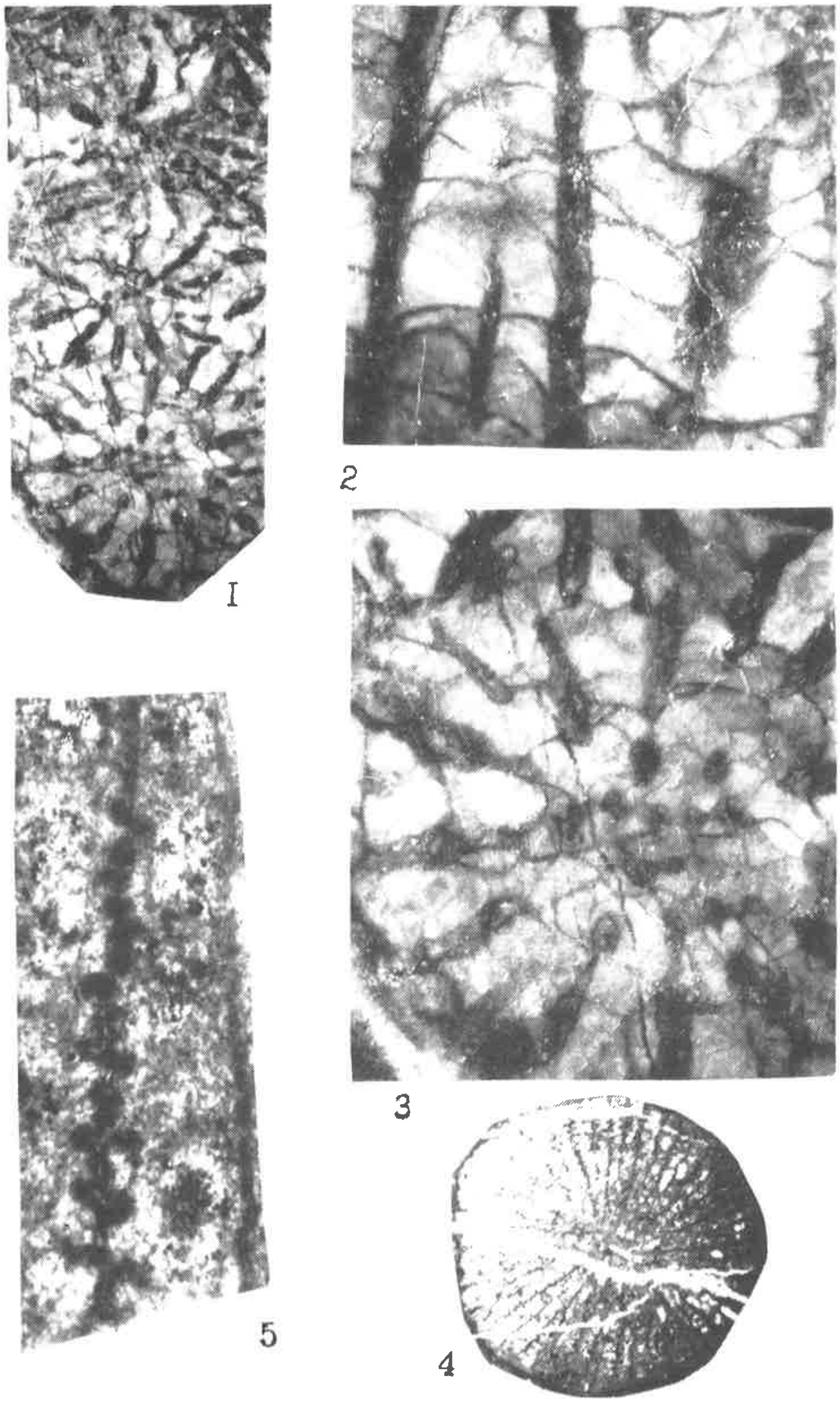


PLate V



STAGES OF THE DEVELOPMENT OF TRIASSIC BIOGENIC BUILDUPS IN SIKHOTE-ALIN

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Abstract

The study of the structure and composition of Triassic invertebrate communities in the Dalnegorsk region of Sikhote-Alin allows the determination of some stages (banks - biostromes - bioherm massifs - reefs) in this region.

1. Introduction

Triassic carbonate massifs of the Pribrezhnaya Zone of Sikhote-Alin have long attracted the attention of investigators, however, the debates about their origin, occurrence conditions, and age continue. Some workers (Burij and Zharnikova, 1981; Pezhenina and Punina, 1989) consider them reef, others (Moiseev, 1951; Kiparisova, 1937) banks, and some (Radkevich, Lobanova, Borodaev, 1960) consider them sheet deposits. After a large-scale geological survey had been carried out (Parnjakov, 1990), during which the remains of Early Cretaceous plants were collected in the immediate vicinity of Triassic carbonate bodies (Krassilov, Parnjakov, 1984), and structural-tectonic investigations were made, some doubts were cast upon the autochthonous character of the limestones occurring here. V.A. Krassilov, V.P. Parnjakov (1984) and Y.G. Yushmanov (1986), based on the discovery of Cretaceous plants in terrigenous deposits, came to recognize the olistostrome nature of the limestones. In A.I. Khanchuk's opinion (Khanchuk et al., 1988), the carbonate massifs were guyots in the past. He believes that the presence of basaltoids below the limestone massif foot provides the proof of that.

2. Discussion

The author of the present work analysed in detail the limestone massifs of the Dalnegorsk region (Punina, Krasnov, 1983; Punina, 1987; Krasnov, Punina, 1987; Pezhenina, Punina, 1989). It has been revealed that all limestone structures are biogenic, however, only two of them are true reefs in the ecological sense. These are Sakharnaya and Verkhny Rudnik Mountains. The detailed description of one of them (Sakharnaya Mountain) is given below, but first it is necessary to determine the place of carbonate construction in the geological structure of the region. Large limestone bodies are arranged by chains along a north-east trend and are controlled by faults. The limestone bodies, like the plates of synchronous siliceous rocks also occurring here, are enclosed in Lower Cretaceous matrix (Khanchuk, 1988; Parnjakov, 1988). All large carbonate massifs of the Dalnegorsk region are characterized by a series of facies peculiar to reef complexes. Their age is Ladinian - Rhaetian, and the limestones of some small olistoliths are Anisian and even Late Permian. The detailed study of litho-facies and paleoecological features of biogenic limestones made it possible to trace the character of massif development and distinguish some stages of the succession during Triassic time.

The first stage (Ladinian - Middle Carnian). It is characterized by the formation of coquina (*Megalodon*) banks (Pl. I) occurring at the bottom of many limestone massifs (Sakharnaya, Verkhny Rudnik, Kamennye Vorota, Nikolaevskaya, and other Mountains). The flat laminated colonies of hydroids, sponges, corals, and bryozoans settled on them. These organisms, repeatedly overgrowing each other, were overlapped by algae thallus and formed small (up to 2 m in diameter) and median (up to 15 m) biostromes.

The second stage (Late Carnian - Middle Norian). The activity of the organisms listed above resulted in the formation of large (20 to 40 m in diameter) biostromes, which on further development, accreted to each other and formed large biohermal massifs (Pl. I).

The third stage (Middle and Upper Norian). At this stage, bioherms formed. As a whole, they are composed f massive coral-hydroid limestones, having in place the non-distinct wavy bedding and containing lenses of sliced detrital foraminiferan limestones. Up section, one can see the rapprochement of biostromes that form bioherms (Pl. II).

The fourth stage (Late Norian - Rhaetian). In Late Norian - Rhaetian time, favourable conditions appeared for the formation of reefs with peculiar facies (core, slope and lagoon). In the facies of the reef core, one can observe the closest coral settlements, and sponges, hydroids, sphinctozoans, calcareous algae, and abundant reef-lovers were also luxuriant.

Successive change of the stages is not traced in each limestone massif of the Dalnegorsk region. For example, on Karyernaya and Gorbusha Mountains we have found only coquina banks (the first stage). In the massifs of Nikolaevskaya, Kamennye Vorota, and Bolnichnaya Mountains, banks, biostromes, and bioherms were found (one to three stages). All four stages of reef formation were established only in two massifs (Sakharnaya and Verkhny Rudnik Mountains). Attention is drawn to the fact that paleobiocoenoses of even coeval constructions show certain differences. Each massif has a specific complex of reef-building organisms, and only reef-lovers have a relative uniform composition.

3. Sakharnaya Mountain.

To reveal the specificity of the construction formation conditions, I studied the systematic composition of organisms (coral first of all), determined the percentage of reef-building and reef-loving organisms, and defined the interrelationship and nature of different ecological groups.

Below, some details of the structure of Sakharnaya Mountain massif are reported. In the paleoecological aspect, it is the most interesting though controversial object of the region. In due time, it was on Sakharnaya Mountain, where the stratotype of so called Tetyukhe Suite was proposed. The attempt to distinguish the reef facies in the limestones of Sakharnaya Mountain was first made by I. V. Burij and N. K. Zharnikova (1981). They described the back-reef complex and reef core considering the facies of the slope to be washed out in Pre-Cretaceous time. However, it is difficult to agree with such an interpretation. Moreover, these workers believe the siliceous formations (olistoliths of olistostrome series) to be back reef facies.

It was established, that in the region of Sakharnaya Mountain (north-west slope), the limestones occurred immediately on basalts. At the contact, they are represented by dark-gray, almost black pelitomorphic varieties (10 to 15 m) containing bivalve remains (including megalodons), foraminifers, and gastropods.

Up section, they change to detritus-slime carbonates with shells of gastropods, bivalves, rare sponges, sphinctozoans, hydroids, and corals of Early Carnian age. These reef-builders settled in separate groups of two to three individuals. During the Early Carnian, the succession of communities took place and the diversity and abundance of reef-builders and reef-lovers increased. Poorly-branching corals (*Pachysolenia, Stylophyllopsis* and *Volzeia*) formed small brushes. Algae, represented by coating forms, were also of significant importance (Pl. II).

Up section, larger (up to 20 m across) biostromes appeared gradually. Biostrome carcass limestones are distributed in nests between which pelitomorphic carbonate, more rarely sparite, are common. In some places, the rock is fully replaced by pelitomorphic limestone, containing only indistinct relics of biogenic structure. Such replacement is undoubtedly related to diagenetic processes. In the Middle-Upper Norian, constructions of bioherm type appeared gradually, represented by massive light-grey limestones. Active reef-builders of bioherms were obviously hydroids (*Stromatomorpha* and *Actinostromallites*), sphinctozoans (*Parauvanella, Colospongia,* and *Uvanella*), sponges (*Molengraaffia* and *Hodzia*), and algae (*Solenopora* and *Diplopora*). Abundant were foraminifera (*Textulariida* and *Lageniida*), bivalves (*Halobia* and *Cassianella*), gastropods, and conodonts (*Epigondolella abneptis* (Huckiede), *Metapolygnathus nodosus* (Hayashi), *Paragondolella foliata* (Budurov)) (Buryi, 1989).

Corals are predominantly represented by faceloid and cerioid forms: *Gablonzeria, Protoheterastraea, Margarosmilia, Pamiroseris* (Pl. III). Coral shape and the direction of colony growth make it possible to conclude that they lived under conditions of a weak stream supplying pure sea water to the reefogenic constructions.

It must be emphasized, that only by the end of Norian, in the region of Sakharnaya Mountain, a construction of complicated structure - breakwater reef (with facies of reef core, slope and central lagoon) formed (Pl. IV, V). Light-grey organic limestones of the core, often strongly marbled, contain remains of sponges (*Hodsia, Molengraaffia* and *Eueppirisia*), sphinctozoans (*Celyphia* and *Colospongia*), hydroids (*Heterastridium, Blastochaetetes, Spongiomorpha* and *Stromatomorpha*), and corals (*Retiophyllia, Margarosmilia, Gablonzeria, Toechastraea, Distichomeandra,* and other). Carcass limestones compose predominantly the north-west part of the massif. Towards the central part of the massif, carcass limestones are replaced by oolite and oncolite limestones with abundant foraminifera, molluscs, algae and stunted corals (*Margarosmilia* and *Stylophyllopsis*). The facies of the slope in the region of Sakharnaya Mountain are represented by carbonate-clay rocks, biogenic-detrital limestones with shells of gastropods, bivalves, foraminifera, and echinoderms, and fragments of reef-builders peculiar to the facies of the core and the lagoon. In the present paper, we discussed in detail only one massif (Sakharnaya Mountain), however, it is interesting to note that other biogenic massifs of the Dalnegorsk region are also characterised by a similar spatial orientation of facies zones: in the north - west side, lagoons occur and in the south-east, fore-reef belts. The cause of this is not clear.

All data discussed above allow the author to suggest that the carbonate constructions of the Dalnegorsk region are biogenic massifs that have preserved in great part their initial integrity.

Acknowledgements

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Plate I

Fig. 1. Medium to coarse-grained shell mudstone, containing gastropods and bivalves, facies of banks. DVGI 460/18-86, x 1. Lower Carnian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 2. Echinoderms in a bioclastic wackestones, biostrome facies. DVGI 460/28-88, x 6. Upper Carnian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 3. *Solenopora* sp., biostrome facies. DVGI 460/6-28, x 3. Middle Middle Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 4. Calcisponge-Hydrozoa boundstone, biostrome facies. DVGI 460/6-30, x 2. Middle Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 5. *Bauneia* sp., biostrome facies. DVGI 460/12-32, x 2. Middle Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Plate II

Fig. 1. Hydrozoa-algae-bryozoan limestone, facies of bioherm. DVGI 460/258, x 14. Upper Norian; Primorye region, Dalnegorsk, the watershed of Burnyi and Blizhny Creeks.

Plate III

Fig. 1. Reefogenic fragmental limestone, skeletal fragments of corals, and other organisms carried from the top of reef. Facies of the reef slope. DVGI 460/125, x4. Upper Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 2. Facies of the lower part of the reef underwater slope. Wackestone rich in organic and clay matter.

Fig. 3. Poorly sorted shell-coral packstone with bivalve and gastropod shells, corals, and echinoderm bioclasts; facies of the reef slope. DVGI 460/117, x 3. Upper Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 4. *Retiophyllia* encrusted by microbial micrite, facies of the reef slope. DVGI 460/190, x 5. Upper Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Plate IV

Fig. 1. Medium to coarse-grained coasted bioclastic grainstone with solenoporacean bioclasts and foraminifer shells. Sedimentation took place on the sea shoals. DVGI 460/199, x 10. Upper Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 2. The fine-grained sediment between the corallites *Margarosmilia* is pelmicrite, facies lagoon. DVGI 460/227, x 5. Upper Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 3. Ooid-grainstone, facies lagoon. DVGI 460/120, x 3. Upper Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Fig. 4. Foraminifera from facies framework reef. DVGI 460/208, x 100. Upper Norian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Plate V

Fig. 1. Coral pafflestone formed by *Retiophyllia*. DVGI. 460/198, x 5. Rhaetian. Primorye region. Dalnegorsk, Sakharnaya Mountain.

Fig. 2. Coral pafflestone formed by *Pamiroseris*. DVGI 460/199, x 5. Rhaetian; Primorye region, Dalnegorsk, Sakharnaya Mountain.

Plate I

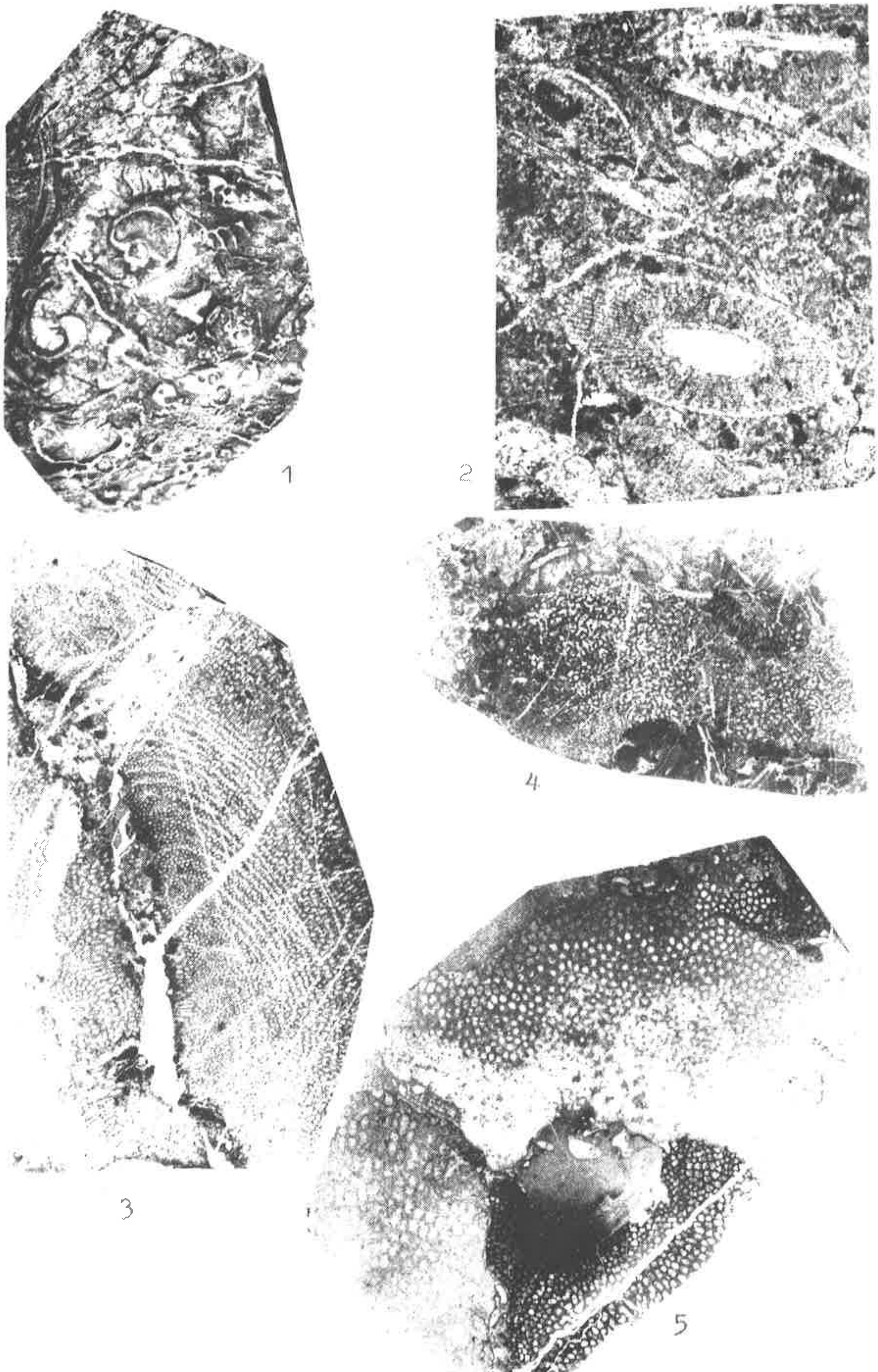


Plate II

Plate III

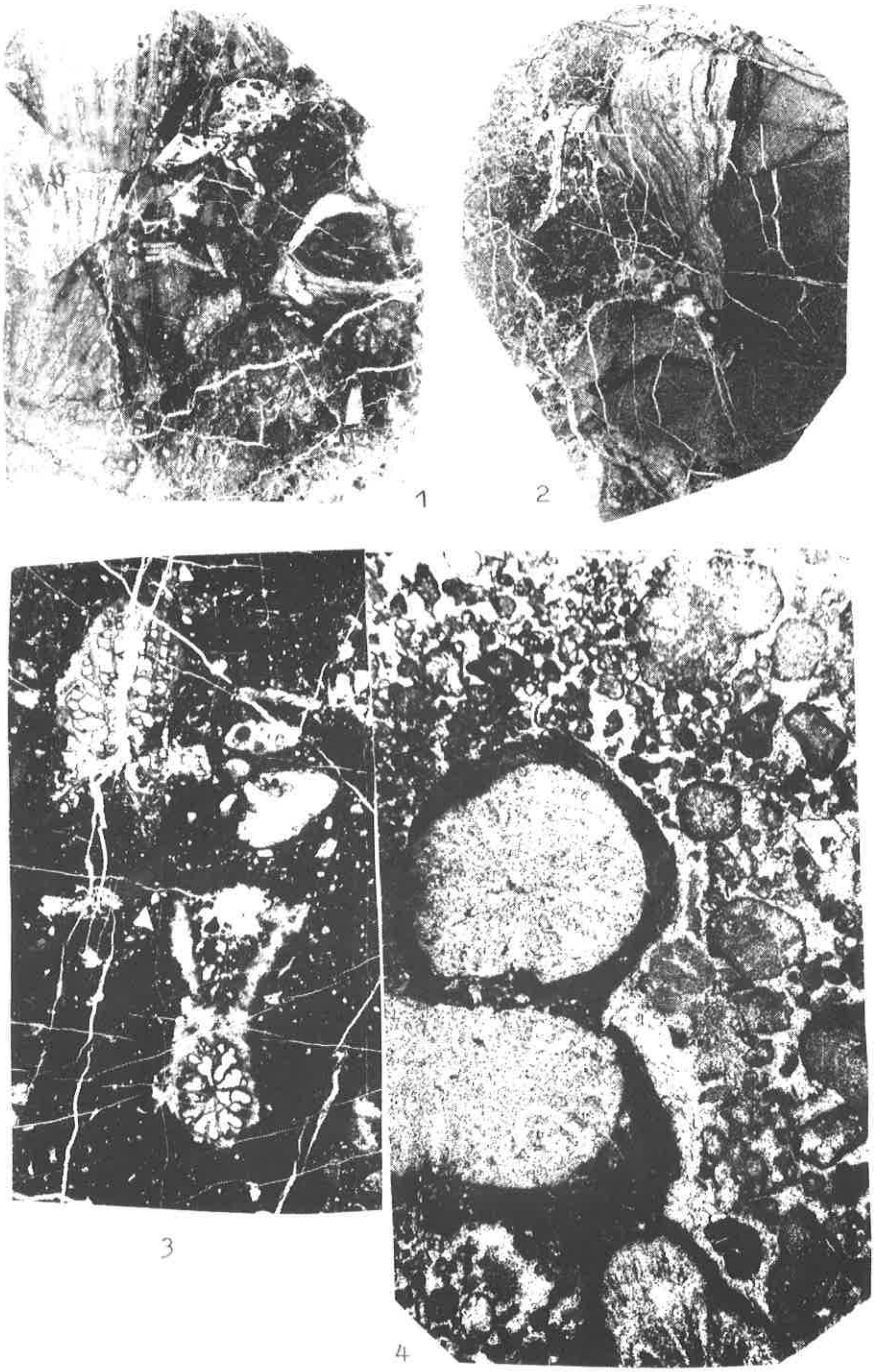


Plate IV

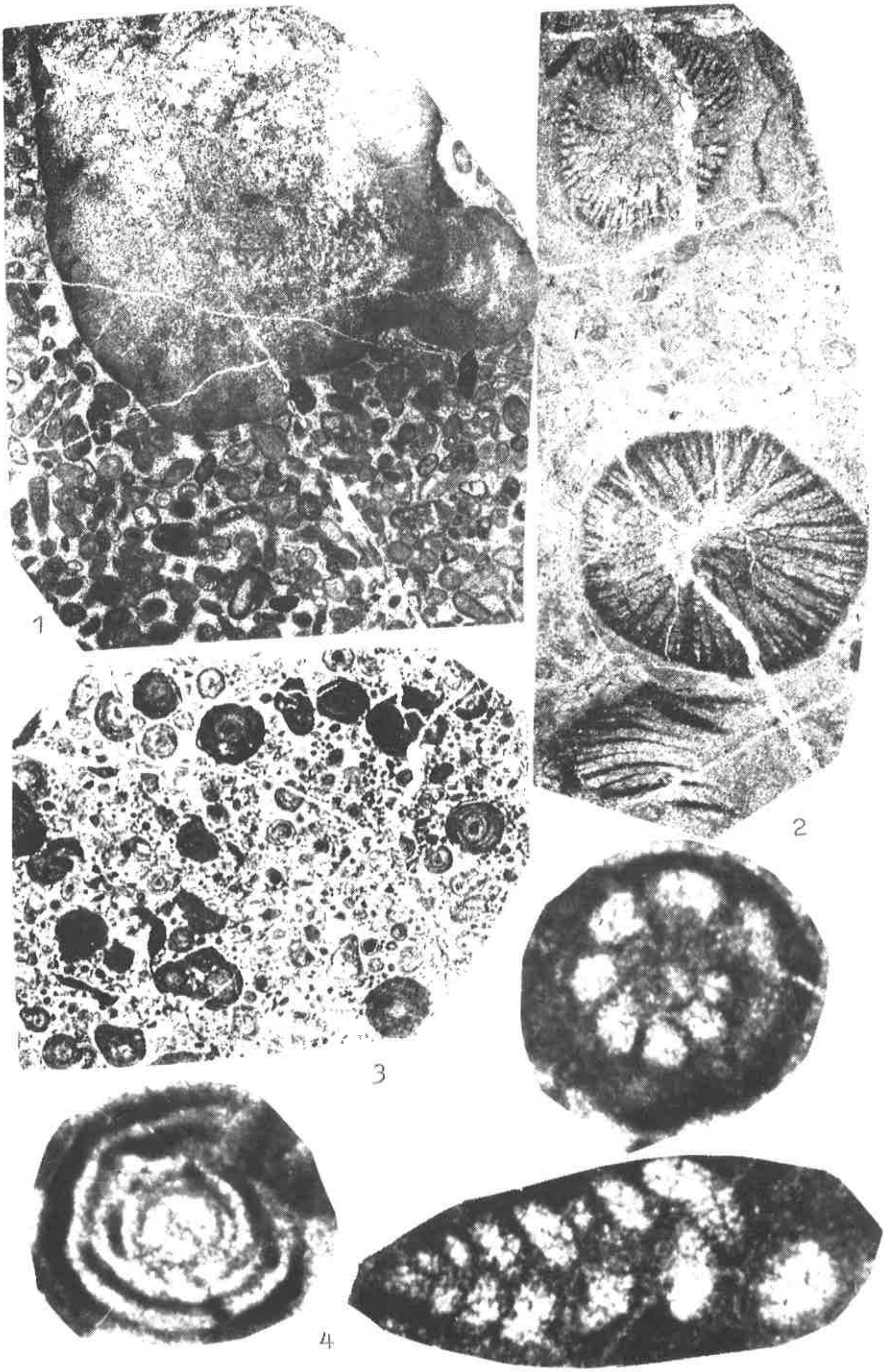
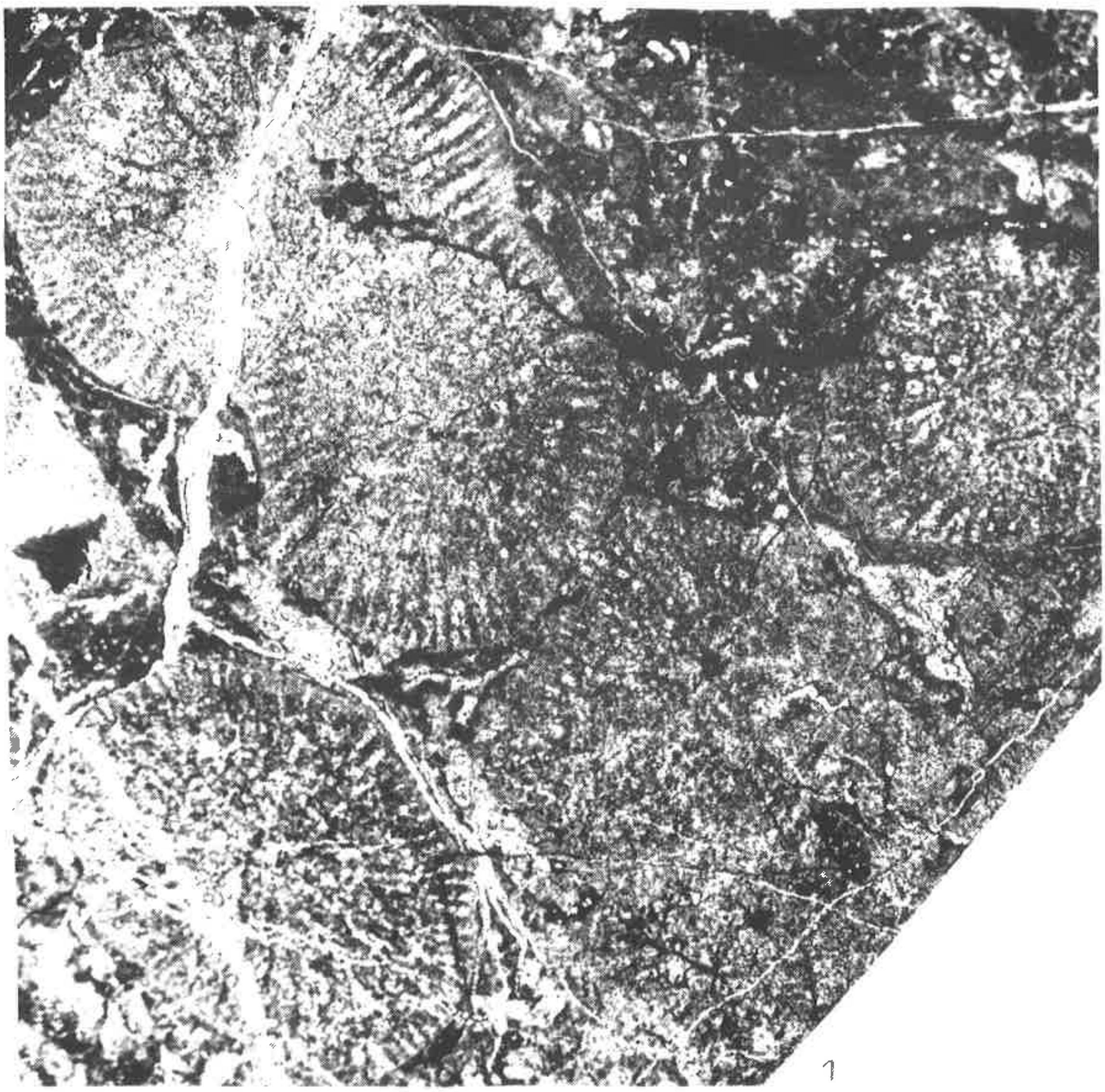


Plate V



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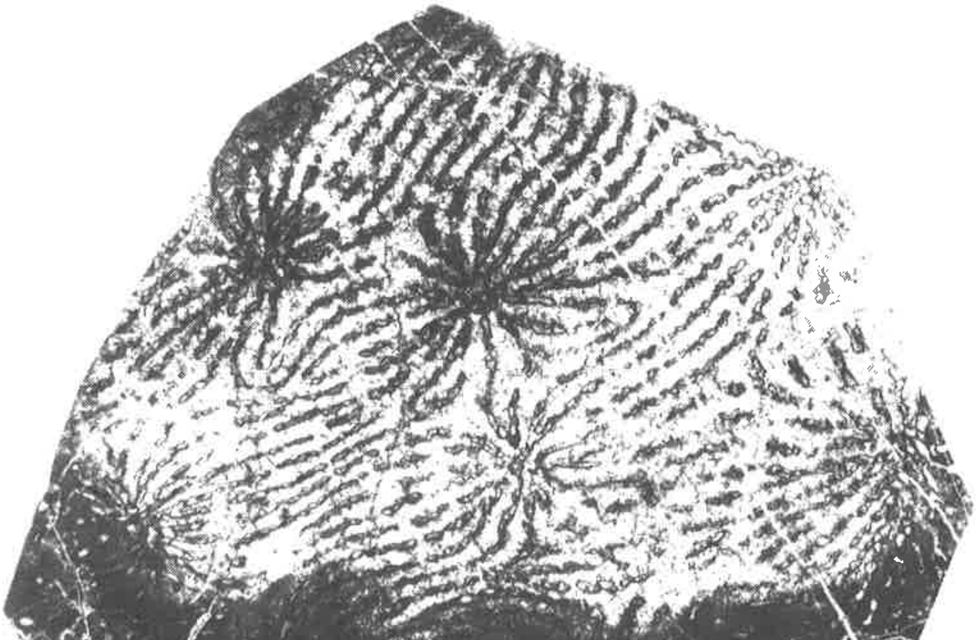

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EPITHERMAL GOLD-SILVER MINERALIZATION OF LATE PALEOZOIC VOLCANO-PLUTONIC COMPLEXES OF SOUTH-WEST PRIMORYE (FAR EAST RUSSIA)

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Abstract

This article reports the first results of the investigation of epithermal gold-silver mineralization of porphyry type, associated with Permian volcano-plutonic complexes of the Khanka median massif framework.

1. Introduction

The first endogenous epithermal shows of gold-silver mineralization in the Far East of Russia were found a hundred years ago. At the end of the last century, S. A. Konradi studied epithermal streaky-veined bodies localized among Cretaceous-Paleogene volcanites, intensively transformed metasomatically, in the Belaya Mountain region. This occurrence is in the Nizhny Amur area known for its gold placers.

Later on, in the Far East and Trans-Baikal region, purposeful searches for epithermal deposits of precious metals were carried out mainly within Meso-Cenozoic volcano-tectonic constructions. Especially active investigations began in the late 1950s. In the past 30 years, in different regions of the Far East (Kuril Islands, Kamchatka, Chukotka, Okhotsk area, Amur area, Primorye and other), sufficiently many epithermal gold and silver deposits were discovered among the effusive-extrusive and subvolcanic magmatic formations of Late Mesozoic and Tertiary age (Khomich, Ivanov and Fatyanov, 1989). Some of the deposits were investigated in detail, and some of them are explored.

In the last decade, the attention of geologists searching for the deposits of precious metals was attracted by the fields of Paleozoic volcano-plutonic complexes in the marginal parts of the Omolon (North Far East) and Khanka (South Far East) median massifs (Fig. 1). In both regions, relatively long ago, gold placers were known combined spatially with areas of Paleozoic stratified deposits and magmatic formations. Information on the placer gold content in South-West Primorye has been available for

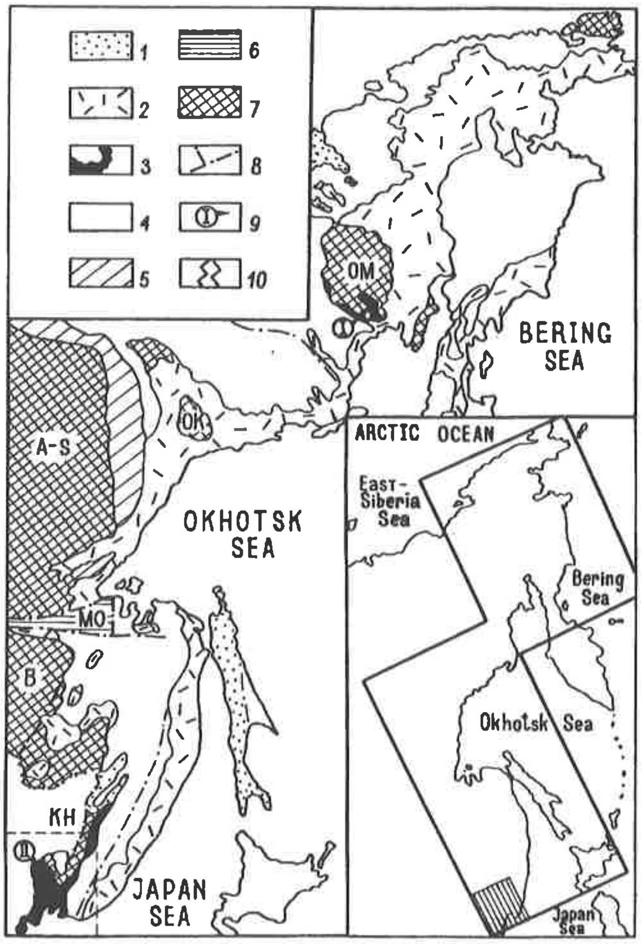

Fig. 1. The scheme of the distribution of the main volcano-plutonic belts and zones of the Russian Far East.
1 - Neogene-Quaternary deposits; 2-3 - main volcano-plutonic belts (VPB) and zones: 2 - Meso-Cenozoic; 3 - Paleozoic; 4-6 - folded constructions of the basement of Mezo- Cenozoic VPB; 4 - undisjuncted; 5 - Verkhoyansk marginal trough; 6 - Mongol-Okhotsk system (M-O); 7 - structures of the Paleozoic VPB basement. *Eastern part of the Siberian platform* (A-S - Aldan-Stanovoi block) and median massif (B - Bureya, KH - Khanka, OK - Okhotsk, OM - Omolon); 8 - some regional faults; 9 - regions of distribution of gold-silver mineralization among Paleozoic volcano-plutonic complexes (I - Omolon, II - Khanka); 10 - boundaries of the scheme on the contour map of the Far East.
Vertical shading in the lower left corner shows the area imaged in Fig. 2.

more than a hundred years (I. A. Lopatin and D.I. Ivanov's data). Purposeful searches revealed indigenous shows of gold-silver mineralization among the Paleozoic paleo-volcanic constructions of the median massifs.

In the Okhotsk area, the promise of new shows of the marginal part of the Omolon massif was quickly estimated. Some of them are even explored. Data on the structure of one of these deposits and of the geochemical peculiarities of its ores, are presented in publications (Voevodin and Rozenblyum, 1989; Kalinin, Rozenblyum and Fadeev, 1989; Rozenblyum et. al., 1992).

In the more favourable geographic-economic situation in Primorye, searches for ore gold in the marginal part of the Khanka massif - among the fields of Paleozoic volcano-plutonic complexes - were episodic and of small volume. Nowdays, they are more active.

In this paper, we present the first results of the study of the geology, metasomatic transformations of the rocks, and the mineralogical and geochemical peculiarities of ores of one of the promising deposits in South-West Primorye, discovered recently.

2. Regional setting

The mineralized area is a member of the West Primorye structural-formation zone belonging to the Laoelin-Grodekovo folded system (Bazhanov, 1987; Fig. 2). The system is characterized by widespread subaerial volcanic and continental sedimentary deposits. In some places, shallow-sea facies are also shown. They are typical of the submeridional Tumangan-Suifun Trough (Kobayashi, 1959), separated from the contiguous crystalline massifs (Kvanmo, Kentaisky, and Khanka) by deep faults. Some workers consider this Trough, made up of exclusively Permian deposits, as aulacogen, i.e., a newly formed structure of riftogenic type that originated during the late Paleozoic on a hard sialic basement in the marginal part of the Sino-Korean shield (Vrzhosek and Sakhno, 1990). In palaeogeodynamic aspect, the Trough is comparable with the basin of a marginal sea framing the active margin of the continent. Such comparison supports the primary occurrence of volcanogenic deposits in the slopes of the Trough and shallow-sea ones in its axial part.

On the area of the Laoelin-Grodekovo folded system, subvolcanic and plutonic magmatic formations are common enough. Of intrusive complexes, the earliest one is a gabbroidal complex combining bodies of gabbro, gabbro-diorites and diabases. Granitoidal magmatic formations proper are divided into two complexes by morphological, mineralogical, petrochemical, and metallogenic characters, and by the depth of formation and relative age (Vrzhosek, Sakhno, 1990): plutonic tonalite-granite (Grodekovo) and subvolcanic complex of granophyric granites (Sedankinsky).

The Late Permian age of the tonalite-granite complex was supported by isotopic study (within 280-240 m.y.) and the existence of thick aureoles of intense contact metamorphism in Upper Permian deposits described faunistically. Intrusions of the complex belong to three successive phases composing independent large massifs, and dike and vein bodies. The first phase (I) is represented by the massifs of biotite-horneblende tonalites, that sometime come to quartz diorites or plagiogranodiorites. The second and third phases are represented by the massifs of porphyry and alaskite granites (II) and bodies of

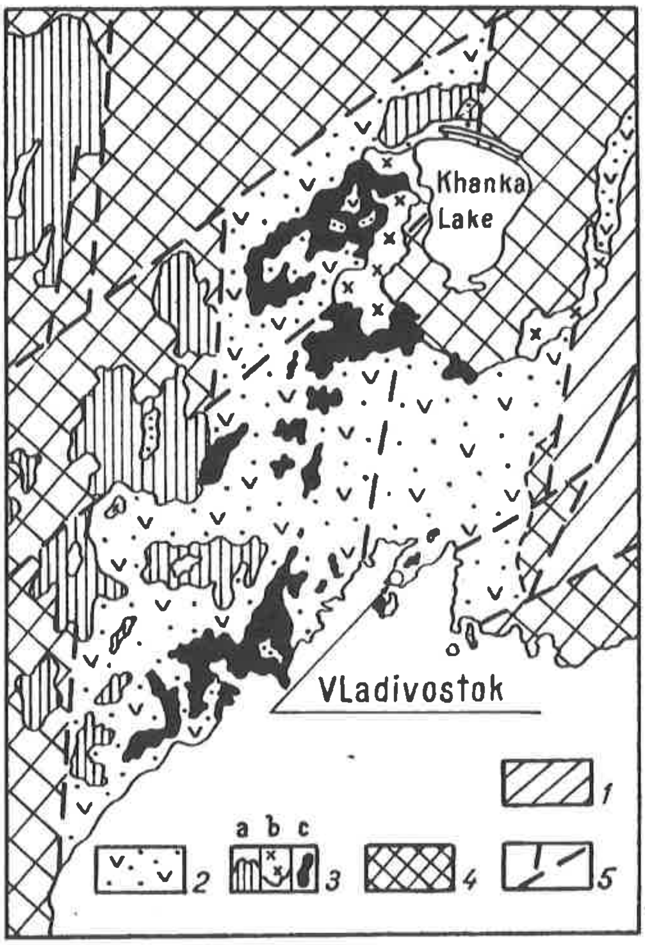

Fig. 2. The scheme of distribution of Late Paleozoic (Permian) volcano-plutonic complexes of the South Primorye.
1-4 areas of the distribution of different-age stratified and intrusive formations: 1 - Mesozoic volcanogene-sedimentary deposits; 2 - Late Paleozoic (Permian) sedimentary-volcanogene deposits; 3 - Late Palaeozoic intrusive complexes (A - undisjuncted, B - tonalite-granite, C - granophyric); 4 - structures of Proterozoic-Early-Paleozoic consolidation; 5 - great faults.

leucocratic granites (III). All of them are of the calc-alkali series, and their genesis is related to palingenetic melting of crustal matter of continental type.

A specific feature of the massifs of biotite-hornblendite tonalites and plagiogranodiorites (I) is the conformity of their inner structure to that of the enclosing rocks. The contacts of intrusive bodies, boundaries between magmatic facies, orientation of plane-parallel structures (gneissous nature), and elongated shape of xenoliths of the enclosing rocks in the massif roofs usually coincide with the elements of the enclosing rock occurrence. The massifs of biotite and alaskite granites have no such signs. This fact is considered as evidence, on the one hand, of the syntectonic injection of tonalite magma intrusions, and, on the other hand, of the succeeding formation of granite massifs in more stable tectonic environment. Stocks, dike-like bodies of leucocratic granites (III), and veined bodies of alaskite granites, aplites, and pegmatites gravitate to the narrow linear zones of crush controlling the dislocations by folding. With leucocratic granite injection, the appearance of aureoles of intense potassic and silicic metasomatosis is related. In such aureoles, the granite bodies often contain muscovite and garnet, indicating the processes of acidic leaching. The shows of scheelite, bismuth (with gold), and polymetallic mineralization are associated with the same aureoles.

The complex of granophyric granites is the youngest of Late Permian intrusive formations. It is restricted predominantly by the fields of volcanic accumulations. Petrologists believe it to be an intrusive comagmat of Upper Permian effusive-extrusive formations. The shape of the massifs is irregular, stock-like, and discordant with respect to the folded constructions. They cut the intrusives of early gabbroids and have active contacts with granitoids of the tonalite-granite complex. These are precisely the rocks of this complex, on which the Lower Triassic (Induan stage) conglomerates occur transgressively in Russky Island.

The complex includes the rocks of two intrusive phases: hornblende-biotite and biotite granodiorites (I) and leucocratic granophyric granites (II). Dike bodies, cutting the rocks of the complex, are represented by aplite-like granites and, more rarely, spessartites. The rocks of the complex are characterized by leucocratic composition, non-uniform porhyry structure, and wide development of granophyric microstructures (Vrzhosek and Sakhno, 1990). Characteristic of granophyric granites are: extremely low calc and potassium content, but significant enrichment in sodium, related to the late magmatic (or autometasomatic) processes of rock albitization. With these granites, the garnet-magnetite skarn (sometimes with chalcopyrite) and gold and silver shows are localized in the zones of the intrusion exocontact among volcanogenic formations.

3. Geology

The mineralized area is adjacent to the spare margin of the Khanka median massif (Khanka terrane) (Khanchuk et. al., 1992) near the north periclinal closure of the Tumangan-Suifun Trough. Stratified deposits of the Lower and Upper Permian and Late Permian intrusive formations are common there. All deposits are divided into three series (suite rank), and each of them is composed of two members: lower member with sedimentary deposit prevalence and upper one where volcanogenic deposits predominate. The total thickness of Permian deposits is 3500-4000 m.

The lower Kazachkinshkaya (P_1kz) series (450-700 m thick) occurs on the eastern margin of the mineralized area (Fig. 3). The series is divided into two packets, the interrelations of which were not studied in detail due to poor

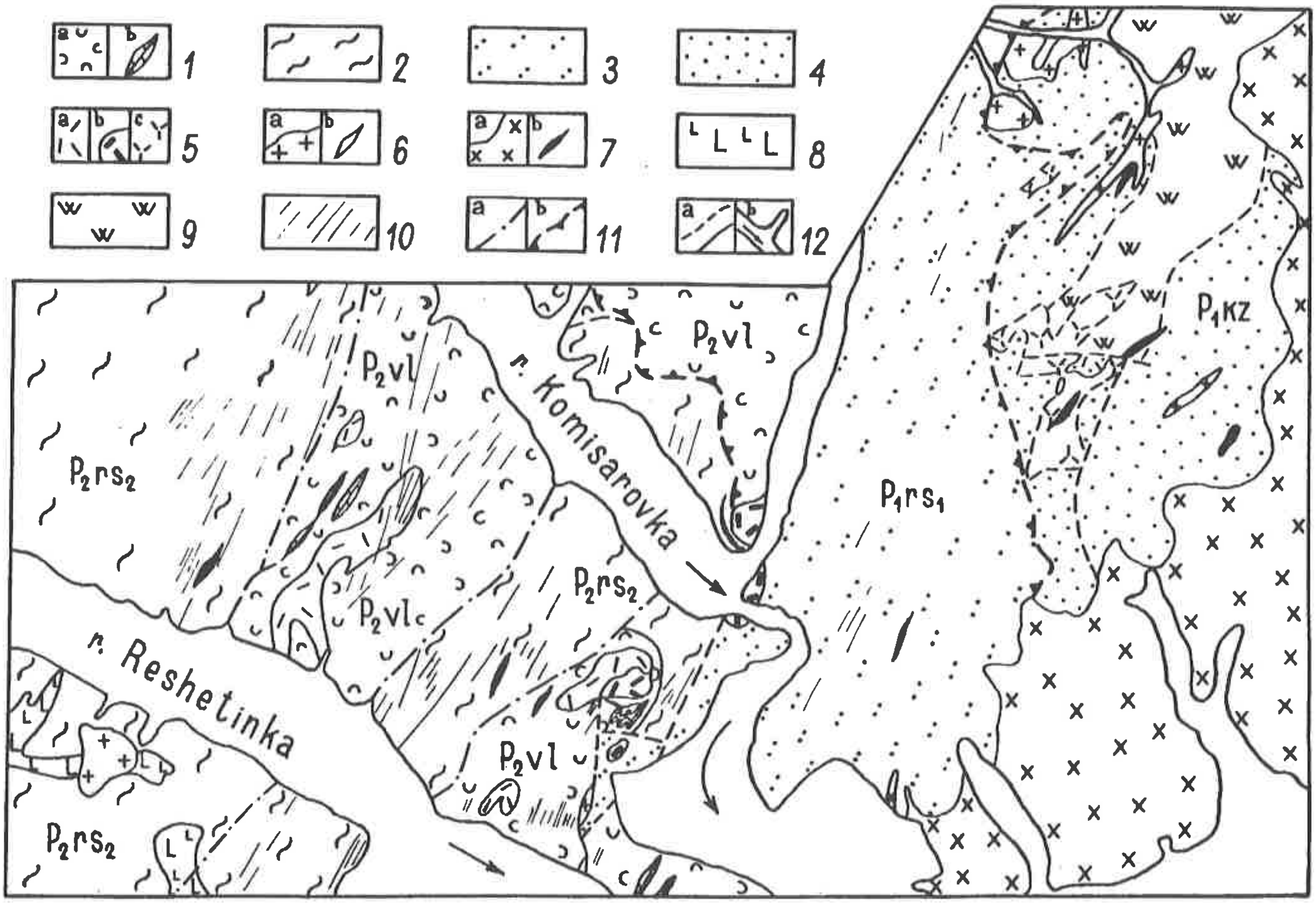

Fig. 3. Schematic geological map of ore-bearing area, compiled by A. L. Zenin, A. N. Rodionov and V. G. Khomich. 1-4 - stratified deposits: 1 - Vladivostok Formation (P_2vl). Lava of acid and moderate-acid composition and their tuffs (a), shaly siltstones and mudstones with lenses of murbled limestones (b). 2-3 - Reshetnikovo Suite ds($P_{1-2}rs$): 2 - upper part (P_1rs_2). Coaly-clay shales, and carbonaceous shaly mudstone and siltstones with interlayers of santones; 3 - lower part (P_1rs_1). Sandstones (arkose and polymict) with interlayers of black shaly siltstones and clay sandstones. Lava of moderate-acid and acid composition. 4 - Kazachkinskaya Formation (P kz). Sandstones (arkose and graywacke) with interlayers of conglomerate, tuffites, laminated mudstones and lava of acid and moderate-acid composition and their tuffs. 5-8 - magmatic formations: 5 - volcanogene bodies of acid (a, b) and moderate-acid (c) composition: a and c - extrusive-effusive, b - extrusive. 6-8 - plutonic (a) and subvolcanic dike (b) bodies: 6 - granophyric complex: granodiorites, plagiogranites, aplite-likr granites and dikes of middle composition; 7 - tonalite-granite complex: alkaline porphyry-like granites; 8 - gabbroid complex: gabbro, gabbro-diorites. 9-10 - veined-metasomatic formations: 9 - quartz-sericite, biotite-sericite-quartz, and quartz-sericite-biotite metasomatites with veined-impregnated (porphyry) mineralization; 10 - zones: veinlet, brecciation and isolated quartz and sulphide-quartz veins. 11 - great tectonic dislocations: a - steeply dipping, b - gently dipping. 12 - boundaries: a - geological bodies, b - distribution of modern and Quaternary deposits (in river and creek valleys).

exposure. The lower packet is represented by arkose and graywacke sandstones with interlayers of gridstones, tuffites, bedded clay sandstones and mudstones, and the upper packet by tuffs of acid composition, dacites, rhyodacites, and rhyolites. The Early Permian age of the series was dated from the plant remains found in contiguous areas.

The middle Reshetnikovo formation ($P_{1-2}rs$) has a much wider distribution. It overlaps the underlying deposits conformably with gradual transition. The basal - Lower Permian - part of the series (1500 m thick) is mainly of sandstone composition. Medium - and coarse-grained arkose, and more rarely polymict sandstones, contain interlayers and lenses of conglomerates, siltstones, mudstones as well as tuffs and lava of moderate-acid and acid composition. Up section, one can observe the gradual decrease of sandstone grain size and an increasing number of black siltstones and mudstones enriched in carbonized organic matter. The Upper Permian part of the series (1000 m thick) is mainly composed of coaly-clay, clay, sericite, and sericite-chlorite shales as well as shaly carbonaceous mudstones and claystones containing interlayers of clayey sandstones and sandstones.

The upper - Vladivostok formation (P_2vl) is 400-500 m thick and is characterized by the prevalence (especially in the section lows) of shaly siltstones and mudstones with lenses of marbled limestones (containing recrystalline remains of crinoids), that alternate with calcareous siltstones, clay sandstones, and polymict sandstones. Characteristic of the upper part of the series are tuffs and lava of medium, moderate-acid, and acid composition. Among the latter, in the central part of the mineralized area, the dome-shaped extrusions of dacites, dacite-rhyolites, and rhyolites, sometimes with magnophyric texture, are mapped.

Intrusive and dike bodies occurring in the mineralized area (Fig. 3) belong to three Late Permian magmatic complexes: gabbroid, tonalite-granite, and granophyric granite. The intrusive formations of the gabbroid complex are represented by hornblende gabbro and gabbro-diorites; tonalite-granite complex - by porphyritic medium-coarse grained granites, predominantly leucocratic, alaskite, more rarely biotitic; complex of granophyric granites - by medium - fine-grained, and aplite-like granites and biotite and biotite-hornblende granodiorites grading to quartz diorites. The injection of dikes: gabbro-diorites (I), lamprophyres, diorite porphyrites, andesites (II), and granites (III) - is connected with the formation of each of the intrusive complexes cited. The greater part of the dikes together with extrusions form a distinct enough linear zone in the eastern part of the area, occupying the upper roof part of large granitoid massif stripped by erosion.

4. Structure of the ore field

The stratified deposits are crushed into linear folds of north-east trend and with angles of limbs that dip up to 30-50 degrees. Folds of higher order are also mapped. Steeply and gently dipping rupture dislocations are common. The first ones cluster into the links («echelons») and linear zones, of north-west, meridional, and north-east orientation. The second ones are of widespread occurrence in plastic rocks and along the boundaries of separation of interlayers, horizons, and packets differing in their competence. Geophysicists distinguish the steeply dipping displacements (from the shifts of fragments of linear anomalies ρ_k and η_k.and ΔT) and gently dipping (30-40 degrees) upthrust-overthrusts separating the fields with high and low parameters ρ_k and η_k.

Both stratified and many intrusive formations of the first two complexes are metamorphosed regionally and dynamic thermally. The former underwent sericitization and chloritization and schistosity is distinct in them. The action of both factors resulted in the transformation of some terrigeneous and volcanogenic-sedimentary rocks into sericite and chlorite-sericite shales, and the recrystallization of limestones.

5. Epigenesis

In the ore field, several structural-morphological and matter types of precious metal mineralization are known with specific associations of rock epigenetic changes. Veins and streaky-veined poor-sulphide quartz mineralization associated with extrusive bodies of moderate-acid and acid composition belong to the Vladivostok formation (P_2vl). In the marginal parts of rhyolite and rhyolite-dacite extrusions, quartz veins with gold mineralization were revealed. Sulphide-quartz veination and streaky-impregnated areas of mineralization occur among carbonaceous sedimentolites of the Reshetnikovian suite ($P_{1-2}rs$).

The fields of alkaline-cherty metasomatites occur predominantly among volcanogene and volcanogenic-sedimentary deposits. Gold and silver mineralization, analysed in this paper, is confined to one such field of the most metasomatically transformed rock. The deposit is localized among effusive-pyroclastic accumulations of the Kazachkino formation (P1kz) on the east flank of the ore field (Fig. 3). In the deposit, all types of stratified and magmatic formations underwent epigenetic changes. The earliest changes (mica-andalusite-quartz) were conditioned by the action of intrusive bodies to the enclosing rocks, and later transformations (mica-quartz) by the action of postmagmatic hydrothermas.

Mica-andalusite-quartz rocks are developed in the exocontact aureole of granitoids. In addition to the newly-formed biotite, muscovite, andalusite, and quartz, in them there are garnet (almandine), actinolite, chlorite, hydrobiotite, fiuorite, and others. Many of the minerals occur as morphologically different-type segregations in metavolcanites (for example, columnar and radiate - fibrous andalusite) and fill micro-cavites and thin veinlets: andalusite-muscovite-quartz, andalusite-biotite-muscovite, and others. The rocks of the exocontact aureole are diverse in colour (dark, grey, greenish, rosy, light, and other) and texture (massive, banded, spotted, breccia-like). The metaformations have the matter and structural-textural signs of hornfels, greisens, and secondary quartzites. Such combinations are very rare in the gold-silver deposits and therefore they are of heightened interest.

The formation of micaceous-quartz metasomatites was conditioned by hydrothermal processes and shown by silicification, biotitization, sericitization, adularization, and sulphidization of rock. Derivatives of hydrothermal activity appeared mainly as pseudomorphous mineral formations. Nested, streaky, and especially veined hydrothermal segregations are rare due to total increased tectonic working of rock. Stuntedness of veined-streaky formations is one of the morphological features of hydrothermalites in the deposit, that makes it distinct from other similar deposits in

Paleozoic and Meso-Cenozoic volcanogene complexes of Russia and the World.

Ore bodies of the deposit have no clear, visually mapped geological boundaries. They are delineated only by the sampling data and represent mineralized fields of metasomatites with rather irregular (bonanza) distribution of Au and Ag. The facts given above allow us to attribute such ores to a porphyry type. All the more, the impregnated and microstreaky-impregnated accumulations of ore mineralization predominate in them.

In the totality of micaceous-quartz epirocks, one can distinguish several facies differences by the set and coordination of main (biotite, sericite, muscovite, hydromica-hydrobiotite, clay minerals, quartz, pyrite) and minor (potassium feldspar, apatite, and other) newly formed minerals. Sericite-quartz, pyrite-sericite-quartz, sericite, biotite-sericite, biotite-sericite-quartz and proper quartz as well as transitional types of metasomatites are differentiated. Their relationships in space are partly connected with the character of the primary rock distribution.

Most common are sericite-quartz metasomatites. They are developed on dacites having porphyritic, microhypidiomorphic and more rarely felsitic structure of the groundmass. Sometimes, these are the clastolavas with breccia structure a fraction of the newly formed mineral complex (sericite, quartz, pyrite) in metarocks, varying within 25 to 90 %. Such varieties correspond to intermediate and complete metasomatites. They are often microporous due to the leaching of pyrite and other minerals. Rarely, sericite-quartz metasomatites are developed on diorite porphyrites in which porphyrocrysts are replaced by cryptocrystalline quartz aggregate. In them, pyrite concentrations are higher (to 10-15%). When the educt of sericite-quartz rocks were lithoclastic tuffs of rhyolite composition, they contain spot-like accumulations of clinozoisite. Quartz and sericite ratio in metasomatites, strongly developed on tuff-sandstones and tuff-gritstones, also varies widely. In the metasomatites, there are sericite-quartz, quartz, chlorite-hydromicaceous, quartz-chlorite-adular, adular, quartz-hydromicaceous-adular, adular-quartz, and other microstreaks. When the streaks accompany the adularized volcanites and quartz and pyrite-sericite metasomatites, adular content in them reaches 60-80%. Sometimes, fine quartz-albite streaks are fixed microscopically in hydromicaceous-quartz metasomatites developed on dacites. Albite content in the streaks is 40-50%. Rarely, in the streaks, chlorite associates with quartz and albite. Processes of acidic leaching took place under the intense compression accompanied by the development of sheared microfissures which were filled with the vein matter (sometimes monomineral) and represented microstreaks often oriented at an angle of 15 to 30 degrees to each other. In the selvage parts of some streaks cutting sericite-quartz metasomatites, recrystallization is observed in the rock of the sericite scales. They assume orientation subparallel to the streaks. Ore mineralization is sometimes developed here in association with apatite and chlorite, biotite, apatite and quartz, more rarely kornerupine (?).

A definite dependence of new mineral formation nature on the educt composition is shown also by the fact that dikes of spessartites differ only in chlorite content of hornblende and replacement of plagioclase core parts by clinozoisite.

Biotite metasomatites are exceeded in abundance only by sericite-quartz ones. They are predominantly developed on andesites, latites, and more rarely on dacites. These rocks have partly preserved the porphyritic, pilotaxitic, and intersertal structures. Sometimes, in biotite metasomatites, the relics of phenocrysts of amphibole, plagioclase, and potassium feldspar are observed. They are characterized by microlepidoblast, and more rarely microgranolepidoblast, structure. Close association of biotite and apatite is marked. In some cases, apatite forms strongly elongated crystals (indication of fluorine high activity), occurring in the association with not only biotite, but sulphide and epidote. Of interest are the intergrowths of biotite with metasomatic (?) zircon. Around the latter in biotite aggregate, one can see clear pleochroic haloes.

Numerous veinlets of biotite-apatite-quartz composition are common in the metasomatites. Sometimes, they are composed of 80-90% biotite. In such cases, in the central part of microveinlets, pyrrhotite occurs. Sometimes, in metasomatites, actinolite appears. Its crystals are significantly enlarged and many times bigger than the grain sizes of associated biotite.

In metasomatites, quartz streaks relatively large (0,5-1,5 sm.) for the deposit are also mapped. Quartz in them is columnar-grained and semi-transparent. Data of vacuum decreptometry show the temperature interval of most decrepitation activity to be within 300-400 degrees C, which is essentially higher than the corresponding values of Meso-Cenozoic Au-Ag deposits (Khomich, Ivanov and Fatyanov, 1989). Microscopic study of specially prepared quartz plates determined several genetic, morphological, and matter types of fluidal inclusions.

Significant is the availability of multiphase inclusions, including solid phase-gas-liquid ones. The solid phase is represented by cubic, rhomb-like, and elongated crystals as well as by globular and other opaque phases (ore minerals?). 1 to 3 phases are fixed that form 20-40% vacuole volume. Some types of primary-secondary fluid inclusions have signs of solution boiling. Significant is also the clear participation of carbon dioxide in hydrothermal processes, as gas or liquid phase. There is also evidence of bituminoid (?) matter. Primary-secondary inclusions in quartz are accompanied by secondary ones. The latter include varieties from purely carbonic-acidic to crystal-fluid ones with a highly varying ratio of different phases.

6. Mineralogy and Geology

The gold and silver ratio shows the mineralization of the deposits to be of clear silver profile. In the ore contour, Au/Ag varies from 0.03 to 0.3.

The metal pair discussed is accompanied by a wide spectrum of chemical elements in endogenous geochemical aureoles of different contrast, structure, and configuration. Poor spatial differentiation of chalcophile element aureoles is partly predetermined by special monotony of the rock sulphidization. Hypergene process affected it to a certain extent also. Both facts hamper the effective use of standard programs on mathematical handling of analytical data obtained by spectral analysis. So, step-by-step clasterization of the element correlation leaves rather narrow set of elements which may be indicated as to gold and silver mineralization of the type discussed. Furthermore, the sharp change of nature and strength of gold and silver correlation with other elements is observed when statistics on different types of epigenetically altered rock are compared. For example, Au associates rather constantly only with Ag, Cu, Pb, Sn and in part with Sb and As. On the polyelement geochemical map, the coincidence of many element anomalies is observed. Au, Ag, As, and other elements have relatively contrasting geochemical fields of distribution. Often, heightened and extreme areas of Ag and As aureoles coincide with the largest aureoles of greater-then-average and anomalous Au contents.

On the flanks of the deposits, the aureoles of the elements are separated. This is particularly true of As anomalies marking the places of arsenide and sulpho-arsenide impregnation in sericite-biotite-andalusite-quartz rock. The peculiarities of the structure of gold and other chalcophile primary aureoles are in the complicated grouping of isometric and ribbon-like local anomalies. Subparallelism of the axes of ribbon-like anomalies most likely answers the orientation of local zones of heightened dislocation where the infiltrate circulation of paleo-hydrothermas could take place. The character of co-ordination of different-rank mono- and polyelement anomalies reflect also the peculiarities of successive superposition of the products of contact transformations, pre-ore metasomatosis, and processes of diffusion-infiltrate transport of the matter during sin-ore mineral accumulation. The morphology and composition of aureoles were also affected by the redistribution of some elements in the oxidation zone.

The cross section of the gold aureoles reaches 500 m. In their contours, the width of linear anomalies is 5-80 m. The latter form 10-20% area of Au greater-than-average concentrations.

The main mineral-concentrators of gold and silver are gold-silver solid solutions, native silver, and chalcogenides of silver, visible, as a rule, only under microscope. Other ore minerals of the deposit (sulphides of zinc and lead, sulphides, sulphoarsenides and arsenides of iron, etc.) are represented by similar fine, rare impregnation. In spite of such fine size of impregnation of Au-Ag alloys, they are regularly fixed through the washing of heavy concentrates from loose eluvial-talus deposits. Besides, in channels, draining volcanogene-sedimentary series, there are placer gold shows. In genetically different loose deposits, scanty scheelite, and cinnabar are also found.

Submicroscopic and finely dispersed impregnation of gold-silver alloys is mainly represented by electrum. The variogram of its assay distribution (Au/Au+Ag x 1000) is bimodal at a total range of variability from 435 to 795 per mil. The phenocryst morphology of electrum is diverse (xenomorphic, interstitial, dendritic, and so on). Chemical etching and electron probing reveal the concentration heterogeneity of its grains. It was found in different-type mineral formations: in small quartz veinlets, in very short silicate-quartz streaks among micaceous-quartz meta-somatites, and in mica-andalusite-quartz rocks of the contact aureole.

Native silver was determined through metallography in hypergene acanthite in the form of finely dispersed isolated inclusions or their distinctive «rash» (Fig. 4, 5). As expected, X-ray spectral microanalysis shows no gold admixture in it. One-component composition and close association with secondary acanthite, and relict phases of pyrargyrite evidence to the exogenetic nature of such silver segregations.

Acanthite (previousely named argentite) is one of the main silver minerals of subsurface levels of the deposit, where it is developed in thin, partly filled, fractures cutting mica-quartz metasomatites. Several varieties of its segregations, differed by microtextural signs, are distinguished. These are colloform rhythmic-banded, tracery microaggregate, and more rarely homogenous xenomorphic microsegregations. The varieties of acanthite grains are accompanied by the finest whimsical streaks of the same composition. In an acanthite mass or in the margins of acanthite new formations, the lens-like elongated, oval and isometric silversulphoantimonide phases are fixed. These are the relics of hypogenic segregation, in particular pyrargyrite. With such acanthite, the hydro-oxide iron compounds associate. Different peculiar intergrowths with acanthite are observed. The secondary acanthite is rather common for the oxidation zone and other Au-Ag deposits. It was also found in the Belaya Mountain deposit, Amur region, mentioned above (Ivanov, Zinkov and Taskaev, 1983).

The scales of hypergene action on the initial precious metal mineralization have not been estimated yet. When judging universal essential clarification of the rocks, the influence of endogenous processes may be significant due to the oxidation of early sulphide impregnation of meta-somatites. These pre-ore sulphides and sulphoarsenides,

Fig. 4. Colloform-aggregate segregation of hypergene acanthite (groundmass) with relict phases of pyrargyrite (grey uniform separation in the middle) and finely-dispersed «rash» of the secondary native silver (white bright micrograins and dots).

Fig. 5. Colloform-rhythmic-zonal segregations of hypergene acanthite in the combination with pyrargyrite (oval uniform phases).

distributed in the rocks as dispersed phenocrysts, have been preserved in dark-grey cores of blocks of weathered rocks. We observed an analogous situation in the deposits of Chukotka, Amur region (Belaya Mountain), and so on.

Mineralogical features of dispersed, spotted-clotted, and microstreaky chalcogenide mineralization are in the nature of ratio variability of pyrite, marcasite, and pyrrhotite on the one hand, and arsenopyrite and löllingite on the other hand. Arsenic profile of ore content is typical of mica-andalusite-quartz rocks. Arsenopyrite and partly löllingite play the main role. Iron sulphides are of secondary importance. Pyrite predominates in mica-quartz hydrothermalites with variable marcasite, pyrrhotite, and arsenopyrite contents. Pyrrhotite and marcasite predominate in dikes.

We should note the high gold and silver content in pyrite from ore-bearing sericite-quartz metasomatites. In some samples, gold and silver content in this sulphide exceeds 100 g per ton. Total gold content of the rock may be connected with this fact.

7. Conclusion

Geological, petrographical, and mineralogical - geochemical investigations of Upper Paleozoic volcano-plutonic complexes of the west margin of Khanka massif support their potential ore content and great probability of discovery of Paleozoic epithermal gold and silver deposits in the region.

The late Paleozoic age of gold-silver mineralization revealed in the West-Primorye structural-formation zone is proved, on the one hand, by spatial and structural restriction of veined-metasomatic bodies to the extrusions of dacites and rhyolite-dacites belonging to the Upper Permian Vladivostok formation (Murgabian) of effusive-pyroclastic deposits, and on the other hand, by the location of ore-bearing deposits of epigenetically-transformed volcanites in the exocontact zone of Late Permian granitoid intrusives. Moreover, in Permian carbon-bearing sedimentary series there are signs of stratiform gold mineralization.

Hypogene transformations of ore-bearing rocks in the exocontact zone of the granitoid massif, belonging to the Sedanka intrusive complex, were shown in successive change (from intrusive) in metavolcanites of garnet-bearing mica-andalusite-quartz formations by different-facies mica-quartz hydrothermal metasomatites with ore.

That gold-silver mineralization belongs to porphyry type is supported by the absence of clear geological boundaries of ore bodies (distinguished only by sampling data), poor veined-streaky mineralization and widespread impregnated and microstreaky-impregnated ones. The latter are characterized by orthogenetic associations of minerals of precious metals, i.e., co-existence of products of hypo- and hypergene mineral formation.

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TECTONO-SEDIMENTARY COMPLEXES OF THE DALNEGORSK ORE REGION (PRIMORYE)

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Abstract

The geological structure of the Dalnegorsk ore region is mostly composed of pre-Upper Cretaceous folded assemblages that are characterized by wide spread of allochthonous formations of compound tectono-sedimentary origin, for which corresponding nomenclature has been worked out. Two tectono-sedimentary complexes are distinguished: the Tetiukhe and Gorbusha. Each of them has a two-member structure, including olistostromal formations (Lower Cretaceous) - the Subtetiukhe olistostrome and the Subgorbusha olistostrome and associated consedimentary nappes - the Tetiukhe carbonate unit (Middle-Upper Triassic) and Gorbusha siliceous-terrigenous unit (Lower Triassic - Lower Cretaceous), respectively, which form thrust sheet packets.

1. Introduction

The tectono-sedimentary complexes of the Dalnegorsk ore region (DOR) refer to the pre-Upper Cretaceous folded assemblages of the Pribrezhnaya zone of the Sikhote-Alin and are distributed in the Rudnaya and Zerkalnaya River basins, stretching along the Japan Sea coast for more than 100 km (Fig.1). They are crumpled into linear, narrow (2-4 km) to steep (70-90 m) folds of NE strike, and crop out beneath the Late Cretaceous volcanic cover of the Eastern-Sikhote Alin volcanic belt, in discrete windows about 300 sq. km. in size.

For over 70 years they had been sparsely studied paleontologically, and were interpreted as autochthonous formations with undisturbed rock sequences (Geology..., 1969). New biostratigraphic data has shown the mainly allochthonous nature of these formations (Krassilov, Parnjakov, 1984, Parnjakov, 1988, Bragin, Olejnik, Parnjakov, 1988), that has led to a review of the tectonic structure of the DOR and has influenced the initiation of new concepts about the geology of the Sikhote-Alin region. The practical importance of the allochthonous formations problem is that they are associated with the most important deposits of useful minerals, particularly the Dalnegorsk ore bodies.

Consedimentary nappes, thrust sheets, thrust slices are distinguished among allochthonous bodies in the DOR. Consedimentary nappes were formed at the same time with deposition. Formations (Suites) and members or parts of the formation (subsuites) are distinguished among autochthonous assemblages of the DOR.The suite is the principal taxonomic unit of local stratigraphic subdivision in Russia. It is mostly distinguished by facial-lithological characteristics and limited in its distribution by limits of a geological region. Formations are subdivided into parts.

In 1992 the typical sections of allochthonous formations in the environs of Dalnegorsk had been examined by the participants of the International Field Conference on Permian-Triassic biostratigraphy and tectonic.

2. The Basic Signs

The combination of signs of both tectonic and sedimentary origin of the allochthonous bodies had been repeatedly noted during discussion of the genesis of these bodies. C.R. Longwell (1951) was one of the first who had noted this characteristic in the allochthonous formations of the Mid Lake region on the south of Nevada. He mapped a unit partly of sedimentary origin and partly of tectonic origin consisting of megabreccia, forming overthrust nappes on their proper fragments. In Russia the allochthonous formations of the «tectono-sedimentary-gravitation» type are described in the works done by I.V. Khvorova and M.N. Illynskaya (1981), G. Leonov (1981), and other investigators. Studying the allochthonous formations of the DOR allowed the discovery of a number of sedimentary and tectonic peculiarities, proving analogous to other described sections in this region.

The signs of tectonic transportation of material, the correlation of autochthonous and allochthonous bodies, the peculiarities of their distribution was specially investigated to resolve the questions concerning the origin of the allochthonous formations of the DOR. The signs of both sedimentary and tectonic history of the allochthonous formations has been distinguished as a result of this study.

The signs of tectonic origin of allochthonous bodies are indicated by the earliest deformation of these rocks. They have been determined from analysis of general structure: block-chaotic formations contain fragments of, and are overlapped by, large allochthonous blocks of more ancient rocks (Fig. 2). The allochthonous bodies are often folded and broken with the fractures having no continuation in the surrounding rocks. Brecciation increases at the margins of bodies, where the brecciated rocks grade to the tectonic breccias.

The noted peculiarities are combined with the signs of sedimentary origin of the allochthonous formations. Allochthonous bodies occur within normal sedimentary deposits in the form of blocks as fragments in breccias

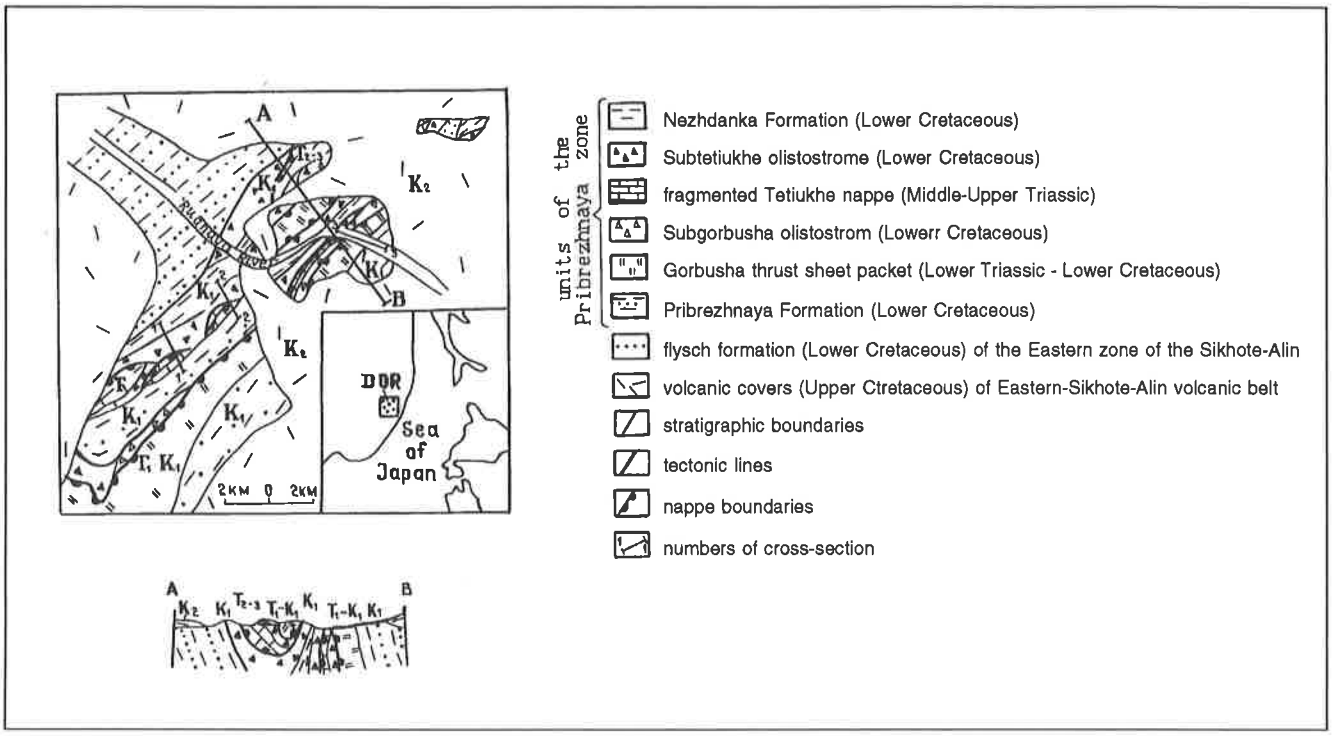

Fig. 1. Sketch map of the Dalnegorsk ore region central area.

and basal conglomerates of sedimentary sections. Allochthonous bodies often have the sedimentary boundaries, analogous to typical contacts of blocks and matrix in sedimentary breccias.

The most sharply compound origins of the DOR allochthonous formations are observed in examples of the progressive passage from the separate large allochthonous bodies to monomictic tectonic breccia and to sedimentary breccia, in which sedimentary matrix appears and fragmentary material becomes more variable.

In spite of a wide spread similar assemblages in folded areas, their stratigraphic status is unknown, so they cannot be correlated with known autochthonous formations. It is proposed to distinguish the special characteristics of the tectono-sedimentary units (Krassilov, 1985), for which stratigraphic classification nomenclature are in progress. The allochthonous formations represent part of a recent geological structure of the region and must be classified along with autochthonous formations.

3. Stratigraphy

The tectono-sedimentary assemblages of the DOR are properly named, proceeding from the recommendations of the International stratigraphic guide (1976). They are subdivided into two units: the Tetiukhe and Gorbusha ones. Each of them has two-member structure, including olistostromal formations - the Tetiukhe and Subgorbusha olistostromes, accordingly, and the consedimentary nappes - the Tetiukhe and Gorbusha, which form thrust sheet packets.

The tectono-sedimentary units of the DOR overlie the deposits of the autochthon represented by the Nezhdanka Formation and are overlain by the deposits of the neoautochthon - the Pribrezhnaya Formation. On the whole, the stratigraphic scheme of the pre-Upper Cretaceous folded assemblages of the DOR is represented as follows:

The Nezhdanka Formation is represented by alternating siltstones and sandstones of the Neocomian age. Formerly it had been distinguished as a barren formation, overlain by the Middle-Upper Triassic Tetiukhe formation and was considered to be Lower-Middle Triassic (Geology..., 1969). The age of this unit has since been defined by Early Cretaceous spores and pollen (determination of V.S. Markevich), Jurassic-Cretaceous belemnites (determination of V.P. Konovalov), and also by stratigraphic position beneath beds containing organic remains of Neocomian age (Parnjakov, 1988). Relations with the underling formations were not observed. The thickness of this unit is 870 m.

The Tetiukhe tectono-sedimentary complex - siliceous-carbonate-terrigenous assemblages, in which allochthonous bodies of Triassic limestones are contained in the clastic deposits of the Neocomian age. The economic skarn-ore deposits of the DOR are confined to the Triassic limestones. Formerly the deposits of this complex had been designated as the Middle-Upper Triassic Tetiukhe formation. Two parts were distinguished in the section of this unit: the Lower predominately siliceous-carbonate-terrigenous part (100-950 m) and the Upper mainly carbonate part (400-450 m). The total thickness ranges from 1200 m to 1500 m (Geology..., 1969). The age of the formation was defined by fossils contained in limestones, and was assigned to the whole sequence but the predominant clastic deposits were undated. The majority of geologists considered of the Tetiukhe formation as a Triassic reef complex, consisting of a reef core, bordered by a reef breccia (Geology..., 1969; Buriy, Zharnikova, 1981). It was believed that the Tetiukhe formation was overlain by the sandy-mudstone formation, of Lower-Middle Triassic age, and was overlain by the Jurassic Gorbusha formation.

At present fossils younger than the Triassic limestones have been found in the clastic deposits of the Lower part

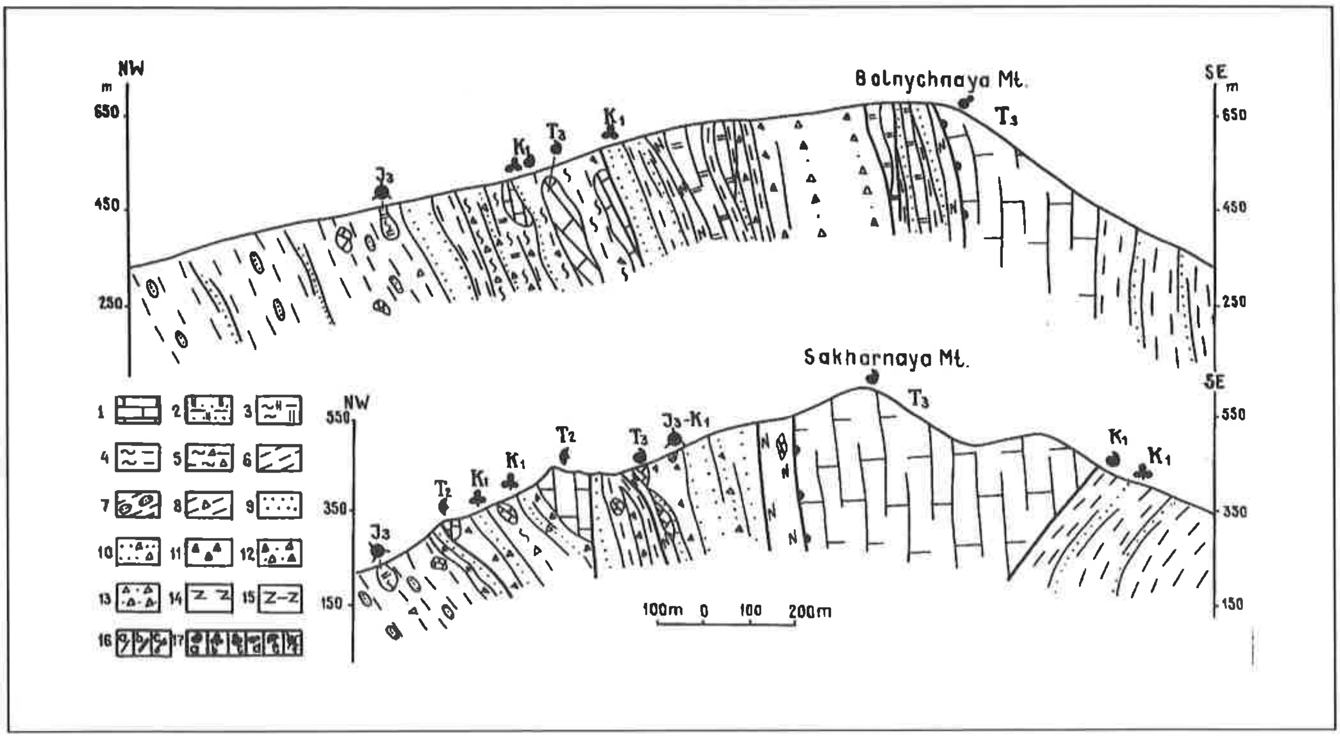

Fig. 2. The key-sections of the Tetiukhe tectono-sedimentary complex along Bolnichnaya Mt.(A) and Sakharnaya Mt.(B) (lines 1 and 2 on Fig. 1).

1 - limestones. 2 - cherts. 3 - clay-siliceous rocks. 4 - mudstones. 5 - mudstones with fragments of rocks. 6 - siltstones. 7 - siltstones with bovidies of sandstones. 8 - s~ltstones with fragments of rocks. 9 - sandstones. 10 - gravelstones. 11 - carbonate breccia. 12 - carbonate-siliceous breccia. 13 - polymictic breccia. 14 - basalts and greenstones. 15 - basalts with flow textures. 16 - boundaries: geological (a), tectonical (b), cosedimentary nappes basements (c). 17 - places of macrofauna (a), plants (b), palinomorphs (c), foraminifera (d), conodonts (e), radiolaria (f), discoveries.

which is the matrix of the «reef breccia» (Krassilov, Parnjakov, 1984). The new data require re-interpretation of the Lower part as an olistostromal unit (the Subtetiukhe olistostrome) and the Upper part - as a correlative nappe of Triassic limestones (the Tetiukhe nappe), forming the lower and upper elements, respectively, of the Tetiukhe tectono-sedimentary complex (Fig. 2).

The Subtetiukhe olistostrome - the sandy-mudstone formation of the Neocomian age with allochthonous bodies of the Triassic limestones and the Triassic-Jurrasic cherts. The olistoliths (15%), the individual olistostromes (45%) and the inter-olistostromal members of the normal-sedimentary rocks (40%) are distinguished in the structure of the Tetiukhe olistostrome. The olistoliths are generally represented by the Triassic limestones. They are lithologically and paleontologically correlated with the overlapping Tetiukhe nappe limestones. The olistoliths of Triassic cherts, containing the radiolarians *Spongosaturnalis gracilis* Kozur, *Lithocampe lasseni* Rust, etc., as well as Jurassic siliceous clay deposits, characterized by the radiolarians *Mirifusus mediodilatatus* Rust, *Dictyomitra apiarium* Rust, etc. (Parnjakov, 1988) are more rarely encountered. The small olistoliths of sandstones containing Middle-Late Triassic palynological assemblages with *Dictyophyllides harrisii* and *D. mortonii,* etc. (Markevich, Parnjakov, 1989) are found in some places. The individual olistostromes are often represented by lenticular beds of different structure and composition. Inter-olistostromal assemblages are represented generally by units of terrigenous flysch. Horizons of basalts are observed in some cases.

Formerly the Subtetiukhe olistostrome had been considered as the Middle-Upper Triassic Lower Subsuite of the Tetiukhe formations. Fauna *Thurmaniceras* sp., *T.* cf. *jenkinsi* (Anders), *Buchia* sp., etc. (Parnjakov, 1988), plants *Marchantitetas yabej* Krysht., *Ruffordia* goeppertii (Dunk.) Sew., etc. (Krassilov, Parnjakov, 1984) have been discovered in the terrigenous deposits of the inter-olistostromal units and in individual olistostromes. Certain of them are characterized as the Berriasian-Valanginian Taukhe formation, others indicate a younger age in the Neocomian. The Tetiukhe olistostrome concordantly overlies the Nezhdanka Formation. The thickness of the Tetiukhe olistostrome ranges from 130 m to 1030 m.

The Tetiukhe nappe - is fragmented and crops out in the form of the platy massifs of carbonate rocks from 3,0 to 7,5 km long, from 0,4 to 0,4 km thick, in elongate belts. The massifs are oriented conformably to bedding in limestones and wall-rocks. The predominant part of the sequence is represented by light grey massifs of biogenic-detrital and lumpy-cloddy limestones (80-90%). Bituminous limestones and marls (up to 10%), as well as the oolitic (10%) and biomorphic (5%) limestones, have less significance. The latter is composed of biostromes and banks, more rarely - bioherms and taphostromes up to 1 m thick, even up to 10 m sometimes. Their main rockforming organisms are foraminifers, conodonts, bivalves and gastropods, rarely crinoids, bryzoan, corals. The bivalves *Halobia dilatata* Kittl., *Megolodon* ex gr. *triqueter* Wulf. etc., conodonts *Eplgondolella postera* Kozur, Mostler, *E. bidentata* Mosher etc., (Burij, Zharnikova, 1981) are the most diagnostic organisms. The Anisian, Ladinian (up to

10 m), Karnian (up to 100 m), Norian (up to 700 m), Rhaetian stages are distinguished in a sequence of carbonate rocks of the Tetiukhe nappe (Kiparisova, 1972; Burij, Zharnikova, 1981, Buryi, 1989, Punina, 1990 and other investigators). Four conodont zones (Buryi, 1989) and six coral assemblages (Punina, 1990) have been distinguished to date. The total thickness of the sequence of carbonate rocks of the Tetiukhe nappe is 780 m. The Tetiukhe nappe overlaps the Subtetiukhe olistostrome (Fig. 2).

The Gorbusha tectono-sedimentary complex is characterized by wide-spread Triassic-Lower Cretaceous siliceous-terrigenous rocks, generally in allochthonous occurrence. Formerly they had been related to the Jurassic Gorbusha formation (1000-1200 m). Four Subsuites of identical composition and structure, ranging from 100 m to 1000 m thick had been distinguished in the structure of the latter (Geology..., 1969). The age of the formation was defined according to Middle-Upper Jurassic radiolarian assemblages. It was believed that the Gorbusha formation overlay the Upper Triassic and was overlain by the Lower Cretaceous rocks.

Lately great differences in the age of the siliceous and terrigenous deposits intercalated in the section has been found (Parnjakov, 1984; Bragin, Olejnik, Parnjakov, 1988; Buryi, 1989). This data provides evidence for the conclusion about wide-spread allochthonous formations in D0R. In the lower part of the section they are chaotically distributed among dominantly schistose fine-grained metasediments forming the siliceous-terrigenous olistostromes. In the upper part fine-grained sediments almost disappear and the allochthonous bodies are piled up one on another forming the thrust sheet packets (Fig. 3). Thus the Gorbusha tectono-sedimentary complex, like the Tetiukhe one, consist of the olistostrome overlapped by a consedimentary nappe.

The Subgorbusha olistostrome - the mudstone formation of the Neocomian age, containing the allochthonous bodies of the Triassic and Jurassic cherts and also sandstones. Formerly this unit had been related to the Lower Member of the Jurassic Gorbusha formation lower part. The olistoliths (40%), the individual olistostromes (50%), and the inter-olistostromal members (10%) are distinguished in the structure of this unit. The olistoliths are represented by sandstones, more rarely as cherts, from 1 m to 100 m in size. They are lithologically and paleontologically correlated with rocks of the overlapping thrust sheets. Triassic conodonts *Triassocampe deweveri, T. nova* Yao, etc. (determination of N.Yu. Bragin) and Jurassic-Cretaceous radiolarians *Thecosphaera conosphaerica, Zhamoidellum ovum,* etc. (Parnjakov, 1988) were found in olistoliths of cherts. The individual olistostromes represent the lenticular members of silty-mudstones and siltstones with rare boudinaged interbeds and fragments of sandstones (0,2-1,0 m) from 10 m to 100 m thick. The rocks are usually foliated and characterised by tectonic flow textures. Lenticular horizons of greenstones (20 m) corresponding with the Tetiukhe olistostrome basalt are noted.

The inter-olistostrome assemblages are represented by the units of intercalated siltstones and sandstones containing siliceous clay lenses (0,1-1,0 m), up to 10 m thick. In the latter, Late Jurassic - Early Cretaceous radiolarians *Stichocapsa pyramidalis, Parvicingula altissima ?*, etc. are found (Parnjakov, 1988). Based on this data and also by position in the section, the age of the Subgorbusha olistostrome is defined as Neocomian.

The Subgorbusha olistostrome overlies the Tetiukhe nappe, with the Subtetiukhe olistostrome in one window. The thickness of the Subgorbusha olistostrome ranges from 50 m to 600 m.

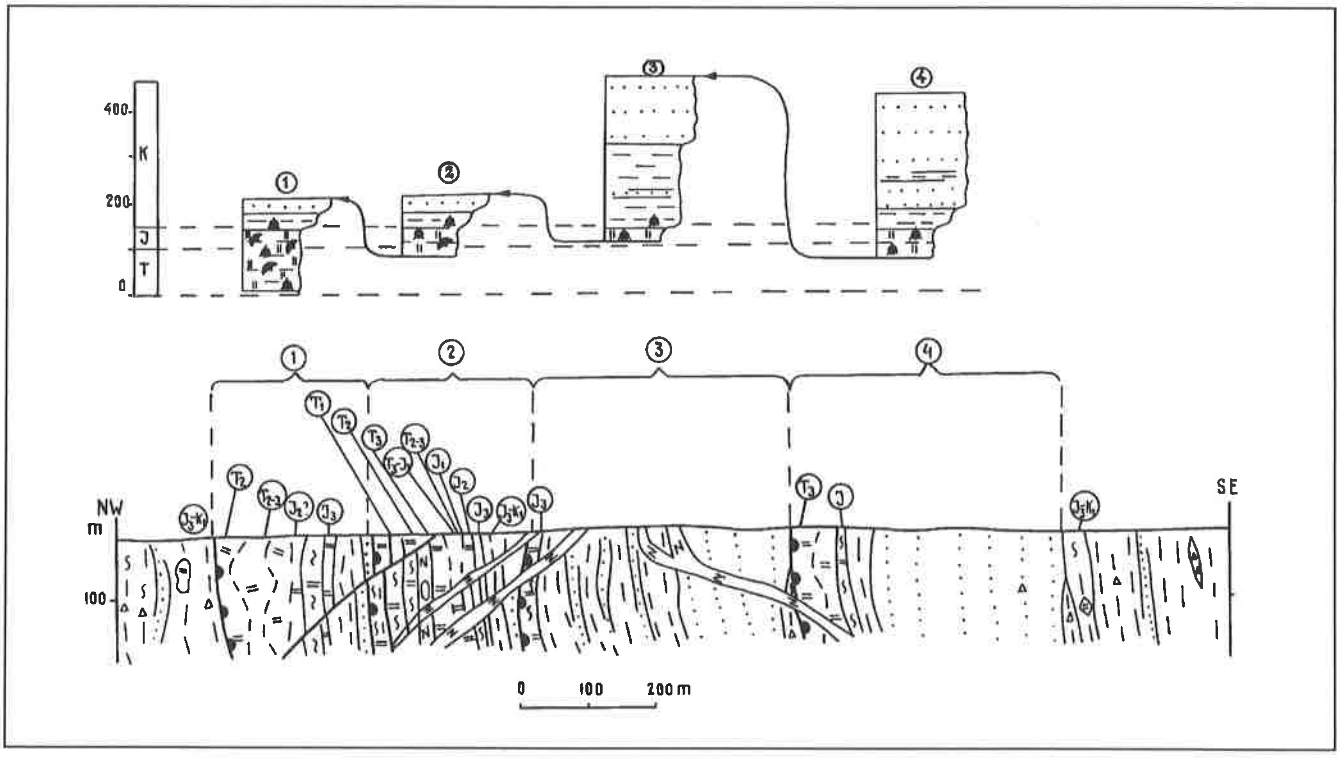

Fig. 3. The key-section of the Gorbusha thrust sheets packet and comparision of the found out thrust sheets section along Rudnaya River (line 3 on Fig. 1) 1,2,3,4 - numbers of the thrust sheets determined. The symbols are as in Fig. 2.

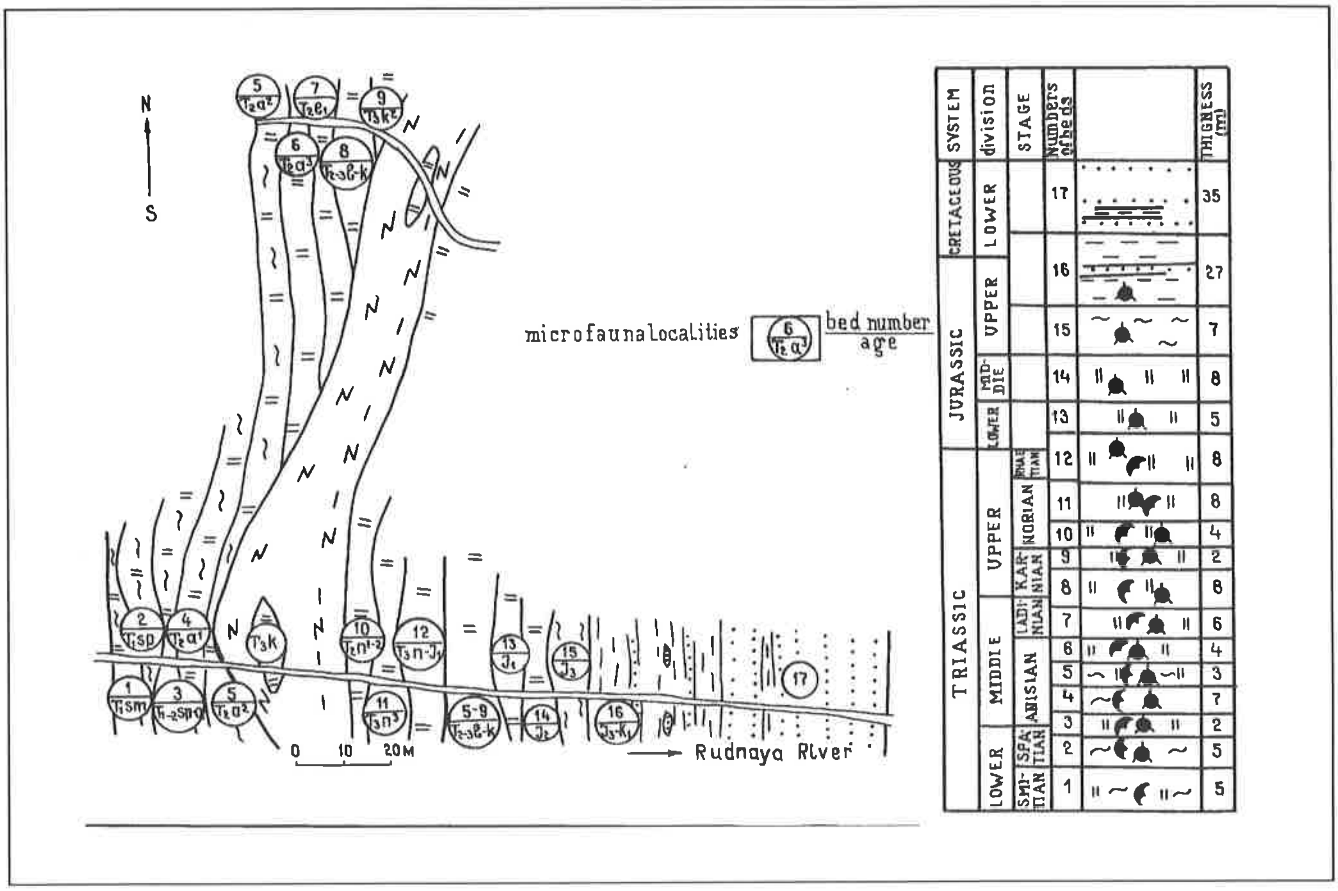

Fig. 4. Geological sketch of the Gorbusha nappe stratotype region and stratigraphic column of the deposits ore (thrust sheets in Fig. 3). The symbols are as in Fig. 2.

The Gorbusha thrust sheet packet is represented by the piling up of the recurrent thrust sheets, characterized by identical siliceous-terrigenous composition, and the «regressive»-asymmetric structure and the same fossil succession (Lower Triassic - Lower Cretaceous) (Fig. 3). Formerly the latter had been considered as the Second, Third and Fourth Subsuites of the Jurassic Gorbusha formation (Geology..., 1969).

The first-order allochthonous bodies - the thrust sheets play a dominant role in structure of the Gorbusha packet. Each of them is characterized by «regressive» changes of rocks in the sequence: cherts (Lower Triassic-Upper Jurassic, up to 140 m) - siltstones (Upper Jurassic-Lower Cretaceous, up to 170 m) - sandstones (Upper Jurassic-Lower Cretaceous, up to 500 m). The thickness of the thrust sheets is up to 700 m. The second-order allochthonous blocks - the thrust slices of mono-lithological composition, containing fragments of the marked sequence (up to 10 m thick), have less significance. 2-4 thrust sheets and 3-4 thrust slices are represented in the structure of the Gorbusha packet. The total thickness of the Gorbusha thrust sheet packet ranges from 1000 m to 1200 m.

The thrust sheets and thrust slices sequences are more or less, respectively, full fragments of the sequence, corresponding with the Gorbusha nappe (Fig. 4). The sequence of rocks of the Gorbusha nappe begins with the Lower Triassic green-grey and red clay-siliceous rocks, containing the conodonts *Neospathodus waageni* Sweet, *N. pakistanensis* Sweet, etc. (Bragin, Olejnik, Parnjakov, 1988; Buryi, 1989) from 10 to 12 m in thickness. They are overlain by Middle Triassic-Middle Jurassic fine-platy radiolarites, characterized by conodont and radiolarian assemblages successively replacing each other up the sequence (Bragin, Olejnik, Parnjakov, 1988; Buryi, 1989) - up to 100 m thick. They are covered by light-grey clayey-siliceous rocks of Late Jurassic age, containing the radiolarians *Mirifusus guadalupensls* Pessagno, M. mediodilatatus *(Rust)*, etc. (Bragin, Olejnik, Parnjakov, 1988) - from 7 to 34 m. The clay-siliceous rocks are overlain by black massive clay-mudstones and siltstones (3 to 9 m). The massive rocks are overlain by thin-bedded siltstones (contourites), 3 m thick, thin- and medium-bedded, fine- and medium-grained, polymictic sandstones, with predominant siltstone (distal turbidites), 30 to 170 m thick, thick-bedded alternating sandstones and siltstones with predominant fine- and coarse-grained polymictic and arkosic sandstones (proximal turbidites) - up to 500 m thick. The Late Jurassic radiolarians *Stichocapsa japonica* Yao, *Diacantocapsa sp.,* etc. (determination LB. Tikhomirova) in some places (Rudnaya river), and the Early Cretaceous radiolarians *Parvicingula cretacea* Baumgartner, *Alievium helenae* Shaaf, etc. (determination of N.Yu. Bragin) in other places (Tigrovyi Stream) are found in the mudstones. Remains of the Early Cretaceous plants *Alsophilites nipponensis* (Oishi) Krassil. from the Tigrovyi Stream (Parnjakov, 1984) and the Late Jurassic radiolarians *Mirifusus mediodilatatus* Rust, etc. (determitation of L. Olejnik) from the Krivaya River basin are found in the sandstones of the upper part of the sequence. The Gorbusha thrust sheet packet overlaps the Subgorbusha olistostrome. The thickness of the Gorbusha nappe sequence ranges up to 700 m. The Triassic-Jurassic chert nappe ranges up to 150 m. The thickness of the Gorbusha tectono-sedimentary complex ranges from 1100 m to 1800 m, and the total thickness of the tectono-sedimentary units of the DOR ranges from 1600 m to 3600 m.

The Pribrezhnaya Formation is represented by alternating siltstones and sandstones of Neocomian age. Formerly these deposits had been related to the Valanginian Kluchevskaya formation in the DOR central area and to the Berriasian-Valanginian Taukhe formation elsewhere (Geology..., 1969). The stratotypes of these formations are situated 150-180 km to south-eastwards from the DOR. Recently organic remains from these deposits have been redeterminated as Late Valanginian-Hauterivian fossils (Sej, Kalachova, 1989). A number of the lithological and structural peculiarities are found: 1) the presence of certain thrust slices of the pre-Jurassic chert (up to 20 m), 2) the presence of few horizons of the terrigenous breccia, and 3) the absence of thick members of conglomerates. The noted data are the basis for establishing of the Pribrezhnaya Formation. The latter is characterized by invertebrates *Neocomites sp., Onichiopsi s sp., Buchia (?) cf. uncitoides (Pavl),* etc., plants *Cladophlebis exiliformis* Oishi, *Dictiozamites* cf. *falcatus* (Morris) Medlicott, etc. (Parnjakov, 1988). The age of the Formation is defined as Neocomian. The Pribrezhnaya Formation overlies the Gorbusha tectono-sedimentary complex in the majority of sections. The thickness of the Pribrezhnaya Formation ranges up to 1400 m.

It is proposed that Early Mesozoic carbonate and siliceous deposits were tectonically piled up on the Early Cretaceous flysch in the form of nappes, at whose front the olistostromes were formed. Origin of the tectono-sedimentary complexes of the DOR is related to replacement of the extension with the compression regimes at the continental margin.

The described peculiarities of lithology, structure and age of the tectono-sedimentary units of the DOR are similar to other areas of the Pacific region (Fig. 5).The condensed sections of siliceous rocks of the Triassic-Jurassic age, composing recurrent thrust sheet packets in combination with olistostromes of the Cretaceous age are characterized especially. They are wide spreaded in structures of Central and Northern Sikhote-Alin, Eastern Sakhalin, the Ekonaj zone of the Korjak ridge (Bragin, 1991), and Central (Yao et al., 1980) and South-Eastern Japan. In Japan correspondence of the lithological and structural signs and the age of the Togano Group, Sambosan Formation and Gorbusha tectono-sedimentary complex of the DOR allowed consideration of the South Chichibu zone of South-Western Japan as analogous to the Pribrezhnaya zone of the Sikhote-Alin (Golozubov et al.,1992).

On the whole, the obtained data has great significance for discovering the character of ore deposits both in the Dalnegorsk ore region and beyond, and allows more confident geological correlation in the Pacific region.

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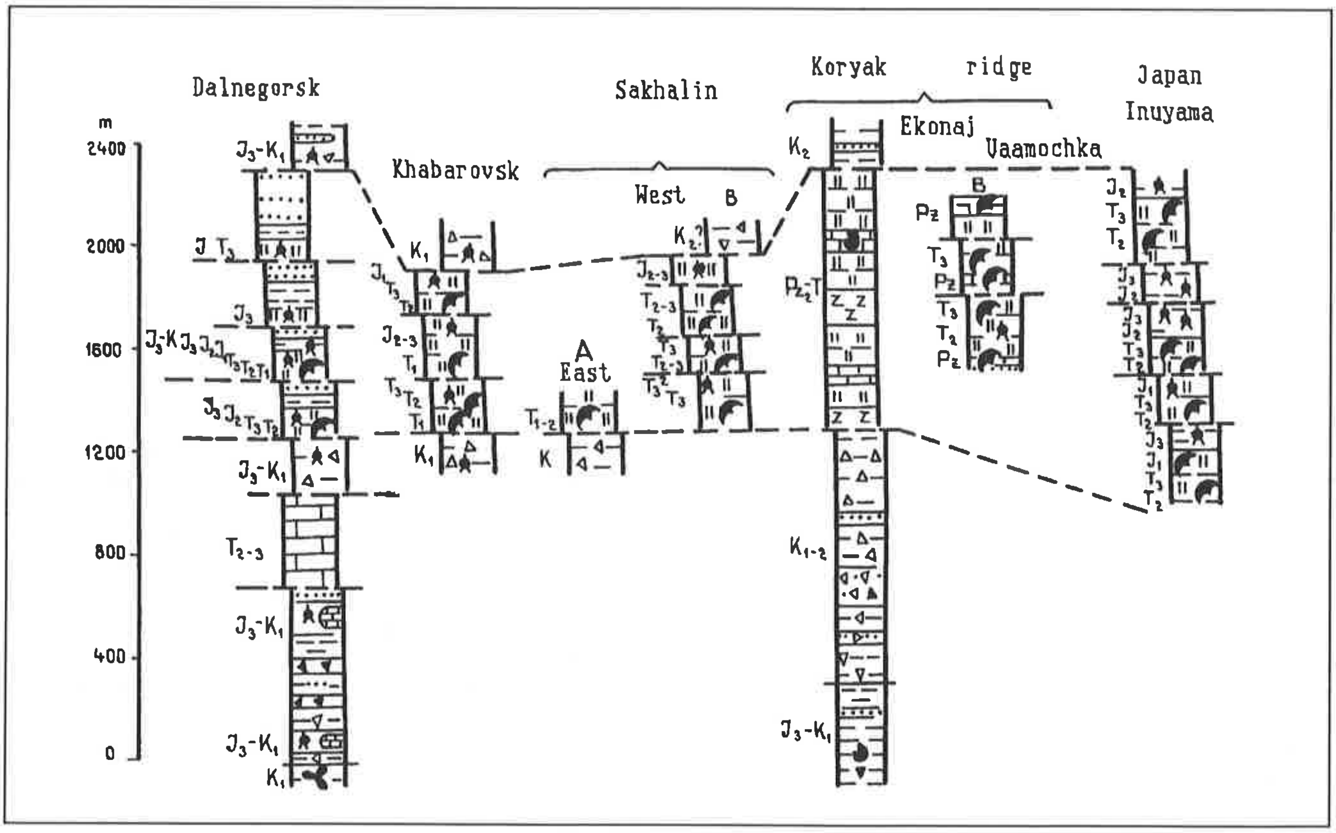

Fig. 5. Comparison of the cosedimentary nappes and olistostromes sections of different areas of the Pacific region. The symbols are as in Fig. 2.

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LATE MESOZOIC ORE-BEARING OLISTOSTROMES OF SIKHOTE-ALIN AND ITS FORMATION EQUIVALENTS IN JAPAN SEA REGION

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Abstract

Late Mesozoic volcanogenic carbonate siliceous terrigenous olistostromes of the Sikhote-Alin have equivalents in Nadankhada-Alin (China), Japanese Islands and, possibly, in the Korea Peninsula. They encompass: (1) commercial tungsten deposits of scheelite-pyrite type, skarn deposits of polymetalls and boro-silicate ores, copper-pyrite and pyrite polymetallic occurrences (Sikhote-Alin); (2) numerous payable pyrite deposits and strata bound iron-manganese deposits (Japanese Islands); (3) industrial tungsten skarn deposits (Korea Peninsula).

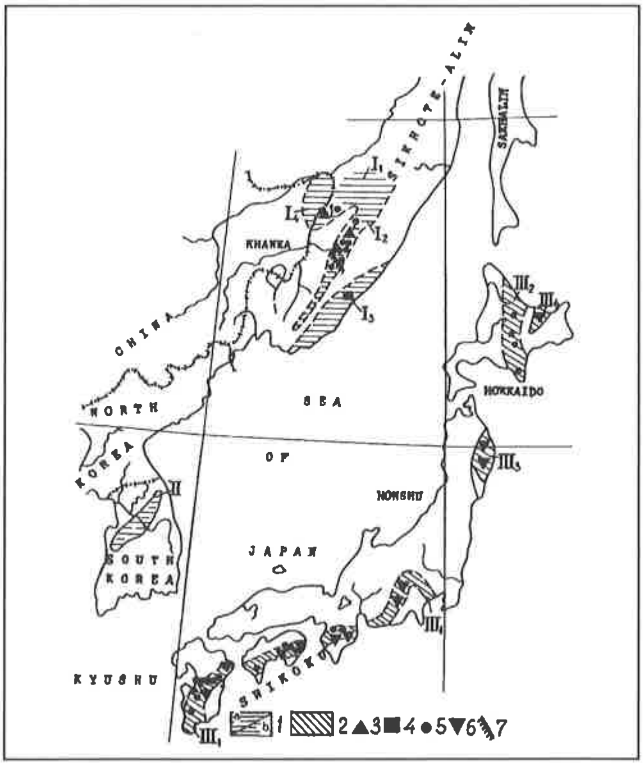

Fig. 1. Scheme of distribution of Late Mesozoic olistostromes and associated ores in the Japan Sea region 1-2 - nappe - folded zones: 1 - Sikhote-Alin (a) and Korea Peninsula (b); 2 - Japanese Islands (I1 - Bikin, I2 - West Sikhote-Alin, I3 - East Sikhote-Alin (Pribrezhnaya), I4 - Nadankhada-Alin, II - Ogcheon, III1 - Shimanto, III2 - Hidaka, III4 - Northern Kitakami, III5 - Tokoro); 3 - scheelite-pyrite: Lermontovka (1) and Vostok-2 (2) deposits; 4 - skarn polymetallic and boric-silicate deposits; 5 - pyrite deposits on Japanese Islands and pyrite manifestations of the Sikhote-Alin; 6 - strata bound manganese and ferric-manganese deposits; 7 - geologic-geochemical sequence of the nappe-folded complex of the Sikhote-Alin.

1. Introduction

Wide distributed in the Sikhote-Alin Late Jurassic - Early Cretaceous (Berriasian-Valanginian) olistostromes have volcanogenic carbonate siliceous- terrigenous composition and contain industrial tungsten, polimatallic, boric-silicate deposits and have pyrite manifestations. These strata belong to the Sikhote-Alin nappe-folded Realm. In the west it borders the North-Eastern Nose of Chinese platform (Smirnoff, 1963), and in the east it is separated from accretional Mesozoic structure of Japanese Islands by the Japan Sea (Fig. 1).

2. Metallogeny

The general metallogenic feature of Late Mesozoic mixtite complexes in this region is that they are constantly accompanied by various intensive mineralization: scheelite-pyrite and pyrite ores occur throughout in the Bikin and Western Sikhote-Aline zones, while skarn polymetallic and boro-silicate deposits are in the Eastern Sikhote-Aline zone (Pribrezhnaya).

2.1. Mixtite complexes of the tungsten-bearing fields

Both commercial tungsten deposits of the Sikhote-Alin (Lermontovka and Vostok-2) are localise in Late Jurassic-Early Cretaceous olistostrome (Izosov et al., 1988; Levashov et al., 1990; Fig. 1-4). As a whole, formational successions of these ore-bearing fields reveal obvious similarity: they comprise associations of siliceous (T_2-J_3), flysch and ophiolite (J_3-K_1), and molasse (K_1) types. Flysh contains mixtite complexes (the «wild flysh», after N.S. Shatskii), shows an imbricated structure and is found over vast fault zones, dipping to south-east. Thick olistostrome, bearing Late Triassic and Middle Jurassic radiolaria are

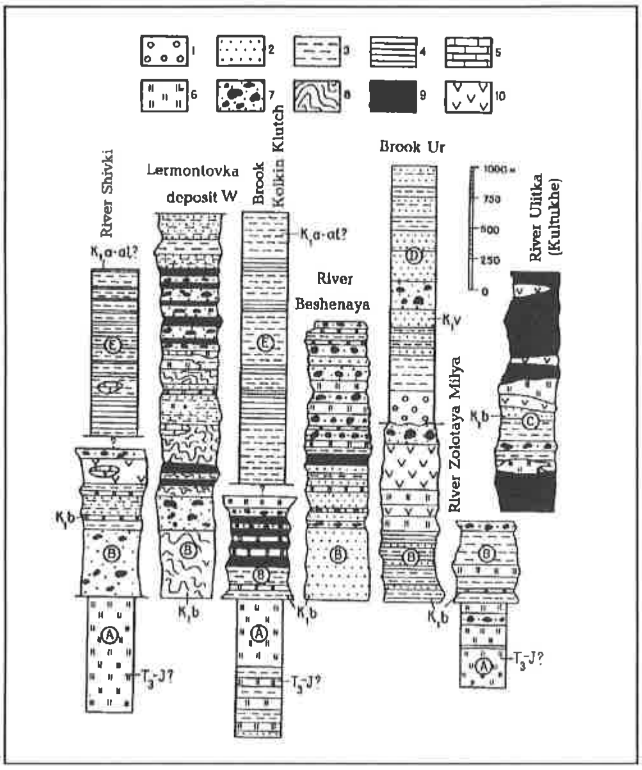

Fig. 2. The Mesozoic sequences of Lermontovka ore field.

Formations: A - Late Triassic-Jurassic (?) carbonate-terrigenous-siliceous; B - Early Cretaceous (Berriasian) carbonate-siliceous-volcanogenic-terrigenous (ore-bearing); C - Early Cretaceous (Berriasian) siliceous-terrigenous-volcanogenic (ore-bearing potential); D - Early Cretaceous (Valanginian) terrigenous (conglomerate-sandstone-siltstone); E - Early Cretaceous (Aptian-Albian?) terrigenous (sandstone-siltstone).

Legend: 1 - conglomerate; 2 - sandstone and tuff-sandstone; 3 - siltstone and tuff-siltstone; 4 - slate and phyllite; 5 - limestone and marble; 6 - siliceous rock; 7 - mixtite; 8 - turbidite; 9 - basite; 10 - andesite.

Footnote: the recent data testify Late Jurassic - Early Cretaceous age of formation B and C (Vrublevskii et al., 1988).

known in west of Lermontovka ore-bearing field (Fig. 1): at the Nadankhada-Alin ridge (Kojima, 1989).

Tungsten-bearing olistostromes of the Sikhote-Alin and their equivalents are alternately displaced by ophiolite formations along the strike. Limestone bodies in mixtites, in general, are fragments of consedimental nappes. Paleontological data indicate Early Carboniferous, Late Permian, rarely, Late Triassic age for these exotic slabs. Terrigenous rocks are composed of poor-sorted, poor-rounded grains and are believed to be feldspathic gray-wacke and graywacke arkose. Volcanics generate beds, necks and dykes in the flysh. They are represented by spilites, diabases, andesites, their tuffs potassium-sodium alkaline, rarely tonalitic-varieties.

Closely associated with them in the Lermontovka ore field are augitic camptonites, monchiquites and pyroxenites.

Tungsten-bearing bodies are hosted in strata of various lithological composition and rocks sharply different in chemical composition such as: gravitational and tectono-gravitational mixtites, basic rocks and andesites, tuffs, cherts and limestones. These strata differ strikingly from other Mesozoic formations of the Sikhote-Alin in rather irregular distribution of ore-forming elements, primarily of tungsten with according rock alteration (Izosov et al., 1988). The highest tungsten contents (3,7-34,0 p.p.m.) were measured in most strongly altered rocks (hornfels, skarns, greisens) and lowest (0,8-2,4 p.p.m.) - in weakly altered varieties. The lithological types of other Mesozoic formations are richer in ore-forming elements as opposed to weakly altered varieties of tungsten-bearing olistostromes and they show regular distribution (tungsten - 1,3-5,1 p.p.m.). Thus, there are negative geochemical anomalies - zones of around scheelite-pyrite fields. These anomalies zones lie within commercial tungsten-bearing formations.

It is worthy to note, that the interval between olistostrome accumulation (Late Jurassic - Valanginian) and intrusion of tungsten-bearing granites (Hauterivian - Late Albian) was short (Levashov et al., 1990). This caused high permeability and high chemical activity of the Upper Jurassic - Lower Cretaceous formations as geochemical concentrators of tungsten. Primary high concentrations of ore substance both in chaotic strata and in granites may be explained that fact, that they evolved in the zones of ore-controlling ophiolitic deep faults.

J.G. Ivanov (1975) related commercial tungsten ores of Primorye to skarn-greisen ore formation (scheelite-apatite-pyrite mineral type) and mentioned, that in some cases ore bodies have a strata bounded character and occur concordant with host rocks. It is typical also that copper was found in commercial concentrations (0,5-2,37%) in tungsten ores.

2.2. Mixtite complexes in the regions with pyrite mineralization

Late Jurassic - Early Cretaceous formation, which contains thick olistostrome complexes (Fig. 5, 6) and to which belong almost all the known in pyrite-bearing and similar to them deposits in Sikhote-Alin are thought to be the most favourable commercial pyrite mineralization. The volcanics composing the formation, form weakly differentiated basalt-andesite-rhyolite series predominantly of sodium type.

Rocks of olistostromes are marked by elevated concentrations of copper (69-137 p.p.m.), zinc (87-155 p.p.m.), silver (0,03-0,07 p.p.m.) and arsenic (6-172 p.p.m.) while basalts and andesites show sharp variations of copper concentrations (38-126 p.p.m. and 28-108 p.p.m. respectivly), inherent in pyrite-bearing rocks (Seravkin, 1986). Worthy of mentioning are significant variations of concentrations of copper (73-210 p.p.m.), lead (9-510 p.p.m.) and zinc (60-200 p.p.m.), when they enrich metasomatites in ore fields.

This may testify to high migration activity of these elements and their extraction from host rocks.

2.3. Mixtite complexes of the polymetallic fields

Commercial skarn polymetallic and boro-silicate mineralization occurs in the East Sikhote-Alin (Pribrezhnaya zone, Dalnegorsk ore field). Of greatest importance are the deposits where skarn ores are developed after limestone and limestone breccias which are found as

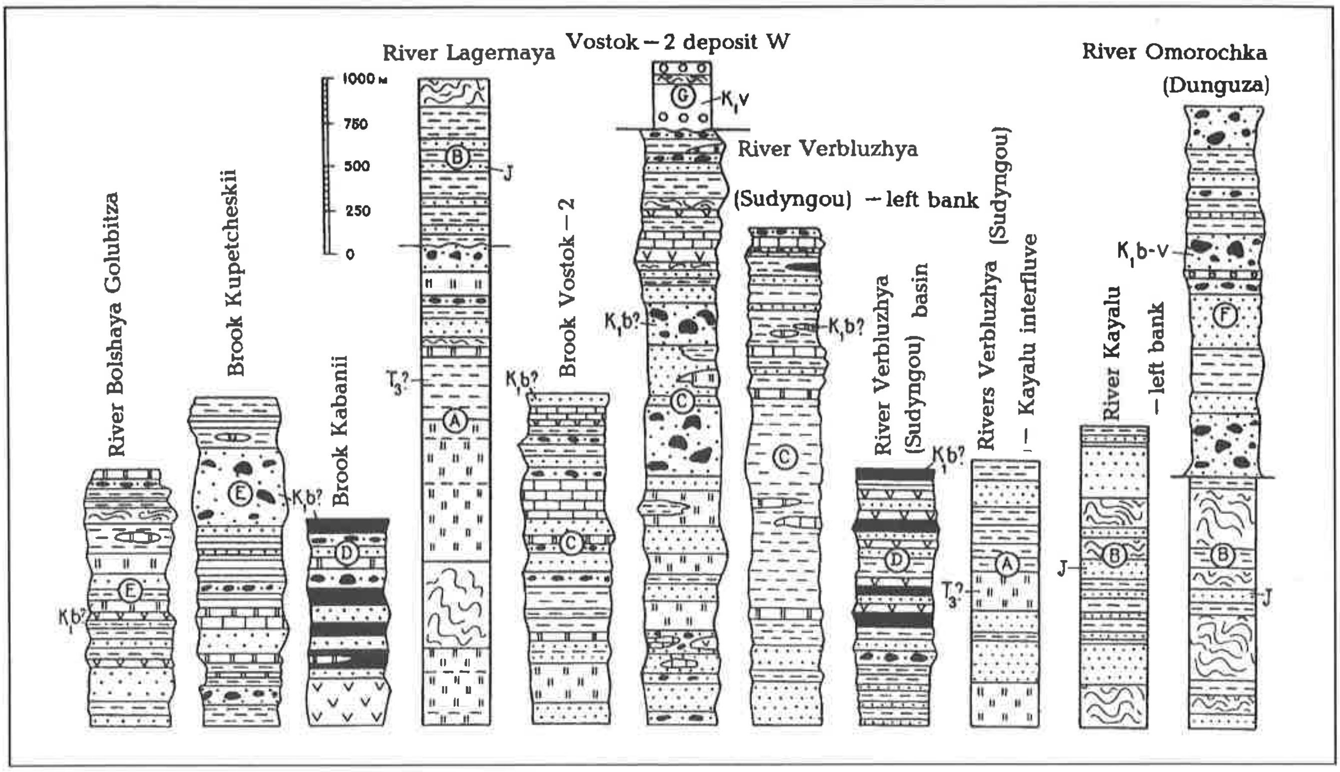

Fig. 3. The Mesozoic sequences of Vostok-2 ore field.

Formations: A - Late Triassic(?) carbonate-siliceous-terrigenous; B - Jurassic terrigenous (siltstone-sandstone); C - Early Cretaceous (Berriasian) volcanogenic-carbonate-siliceous- terrigenous (ore-bearing) and it potential equivalents; D - siliceous-volcanogenic-terrigenous; E - siliceous-terrigenous; F - Early Cretaceous (Berriasian-Valanginian) volcanogenic-terrigenous; G - Early Cretaceous (Valanginian) terrigenous (siltstone-sandstone-conglomerate).

Legend (see Fig. 2).

Footnote: at latest data (Levashov et al., 1990) formations A and C are of Middle Triassic-Late Jurassic and Late Jurassic-Early Cretaceous age.

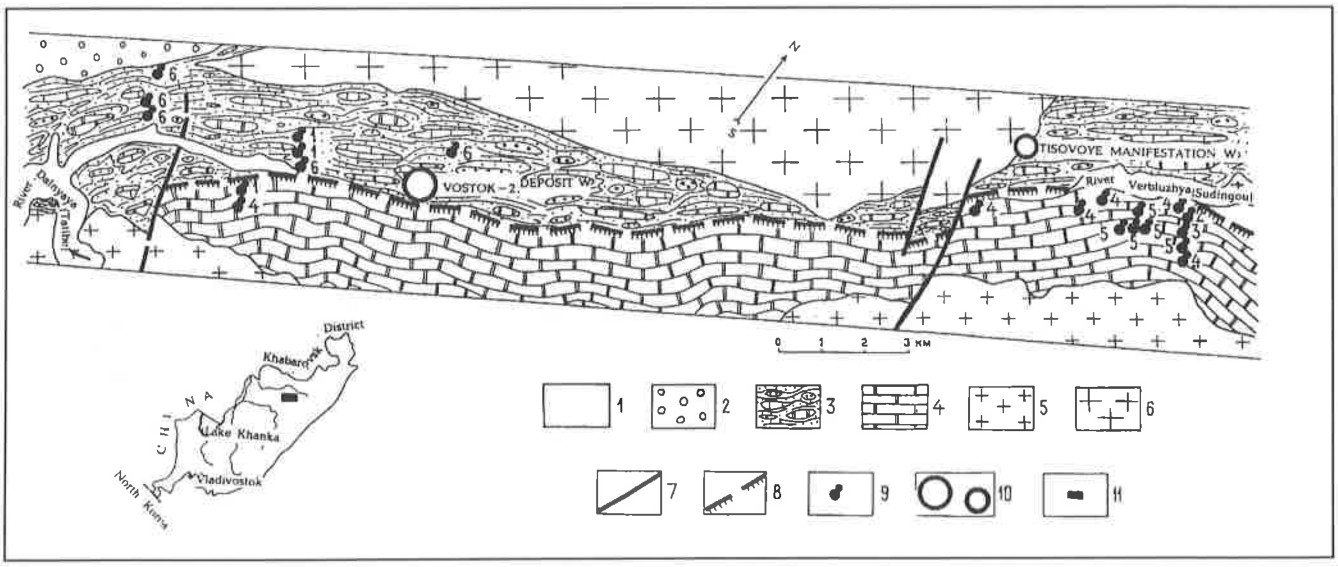

Fig. 4. Simplified geological map of Vostok-2 ore field.

1 - Quaternary rocks; 2 - Klutchevsk Suite (K_1kl): conglomerates and sandstones; 3 - Tatibi Suite (J_3-K_1tt): olistostromes; 4 - Siliceous Suite (T_2-J_3): cherts, siltstones, sandstones; 5-6 - Early Cretaceous (5) and Late Cretaceous (6) granites; 7 - faults; 8 - nappes; 9 - radiolaria (1 - J_3-K_1, 2 - T_2, 3 - J_{1-2}, 4 - J_2, 5 - J_{2-3}, 6 - J_3); 10 - Vostok-2 deposit and Tisovoye tungsten mineralization; 11 - ore field locations on the scheme.

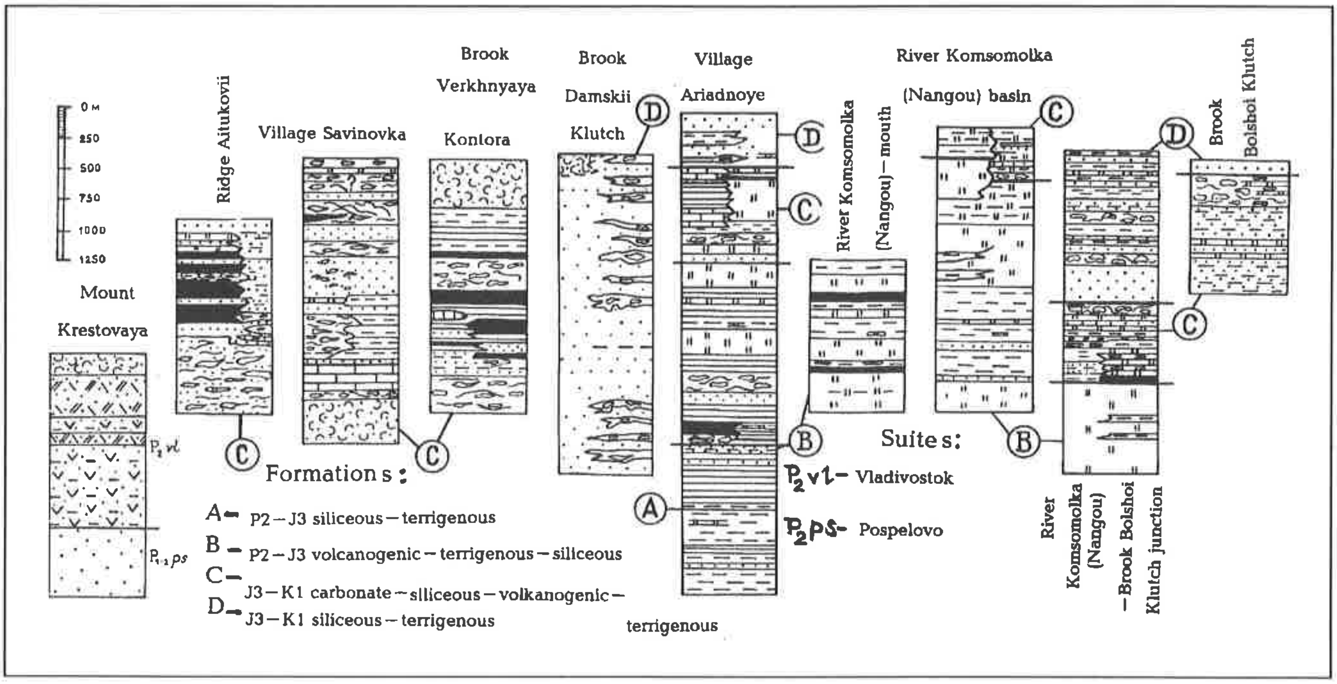

Fig. 5. Upper Permian - Lower Cretaceous sequences of the Malinovka River (Tudo-Waka).

Legend: 1 - limestone; 2 - chert and microquartzite; 3 - conglomerate; 4 - sandstone; 5 - tuff-sandstone; 6 - siltstone; 7-8 - mixtite with siltstone (7) and sandstone (8) matrix; 9 - slate; 10 - siliceous slate; 11 - basite; 12 - tuffite of acidic and intermediate composition; 13 - rhyodacites and their tuff.

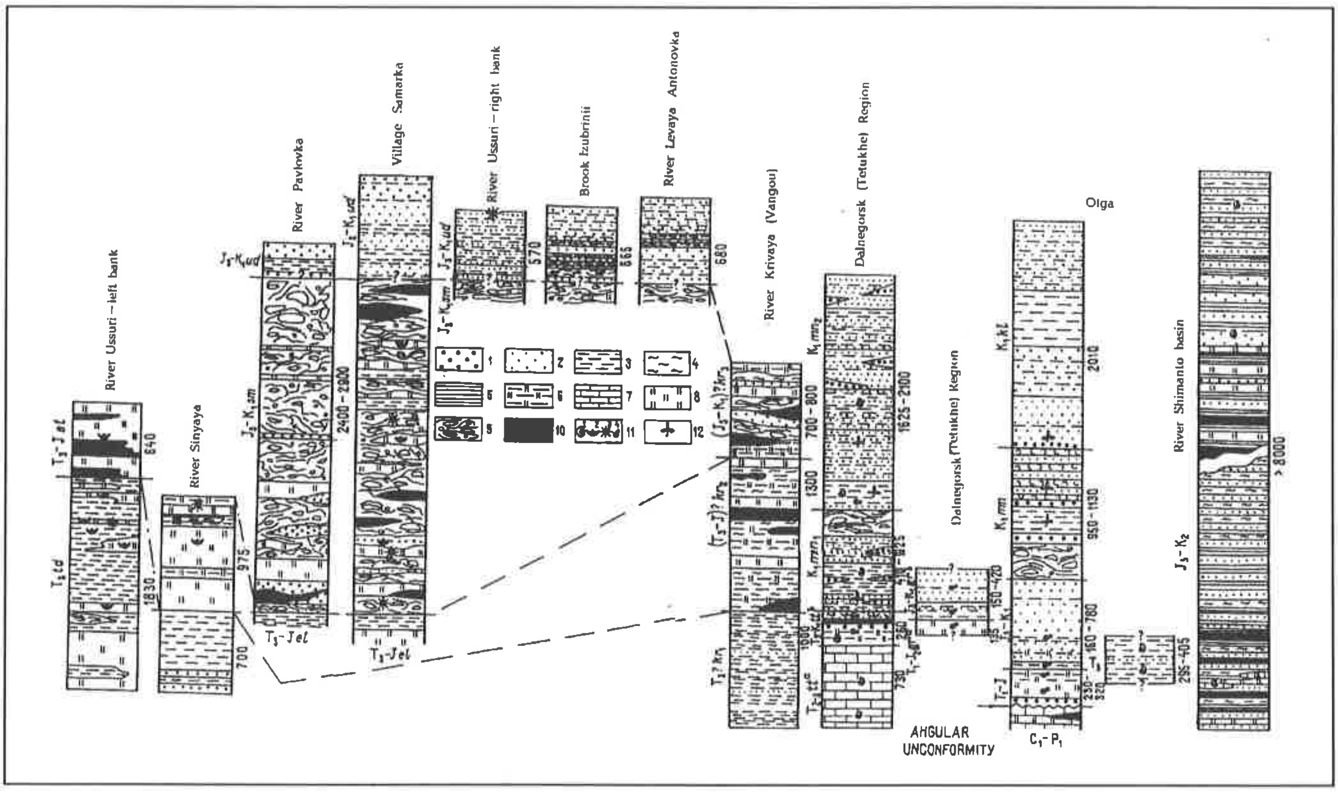

Fig. 6. The Mesozoic sequences of Southern Sikhote-Alin and Shimanto Supergroup (Japan) (after Vrublevskii et al., 1988, «The geological», 1968).

Strata: T_1-K_1gr - Gorbusha Series, T_2-K_1tt - Tetukhe Series, T_3td - Tudowaka Suite, T_3-Jel - Eldowak Suite, T_3-K_1kr - Kryvaya Suite, J_3-K_1sm - Samarka Suite, J_3-K_1ud - Udekova Suite, K_1mn - Monomakhovo Series, K_1kl - Kluchevsk Suite.

Legend: 1 - gravel; 2 - sandstone; 3 - siltstone; 4 - phyllite; 5 - slate; 6 - siliceous slate; 7 - limestone; 8 - chert; 9 - mixtite; 10 - basite and andesite; 11-12 - fossils: 11 - macrofauna (1), conodont (2), radiolaria (3), foraminifera (4); 12 - flora.

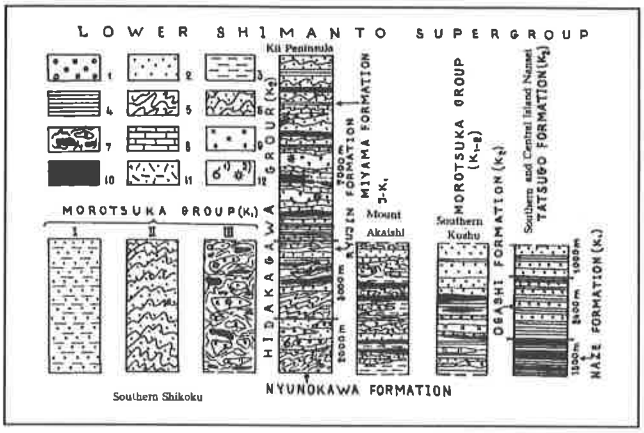

Fig. 7. Sequences of the Shimanto Supergroup (Compiled L.A. Izosov on data Taira et al., 1982).

I-III - types of sequences: I - shallow marine; II - turbidite; III - mixtite.

Legend: 1 - conglomerate; 2 - sandstone; 3 - siltstone; 4 - slate and argillite; 5 - siltstone turbidite; 6 - sandstone turbidite; 7 - mixtite; 8 - limestone; 9 - chert; 10 -basalt (pillow-lava); 11 - rhyolite tuff; 12 - fossils: macrofauna (1), radiolaria (2).

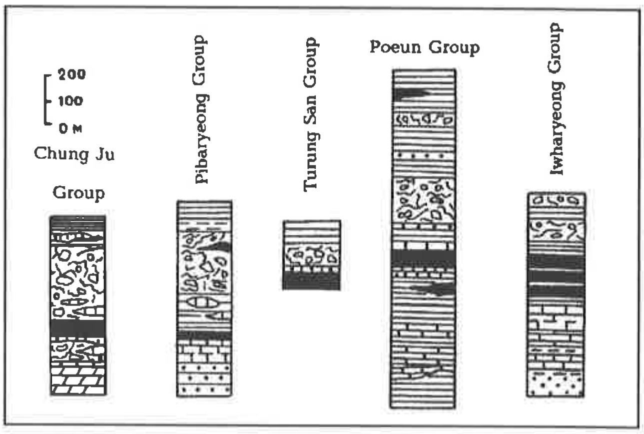

Fig. 8. Sequences of the Ogcheon Supergroup (From Cluzel et al., 1990) with author changes.

Legend: 1 - quartzite and sandstone; 2 - mudstone; 3 - coal seams in mudstones; 4 - debris flow (mixtite); 5 - dolomite; 6 - limestone; 7 - intraformational limestone conglomerate; 8 - volcanics.

allochthonous sheets in the Early Cretaceous (Berriasian-Valanginian) olistostrome complex (Vrublrvsky et al., 1988; Fig. 6).

Flysh formation contains abundant mixtites which have siltstone-sandstone matrix with landslide slabs, slices and small limestone fragments, cherts with Triassic and Jurassic fauna, and also - spilites. Similar deposits are known in the Olga region (Fig. 6). Mixtite matrix distinguished by sharp variations of ore-forming elements: lead (15-31 p.p.m.), zinc (42-166 p.p.m.), silver (0,09-0,18 p.p.m.), bismuth (0,3-0,7 p.p.m.), manganese (118-707 p.p.m.). This might imply that they were derived from siltstone-sandstone varieties during mineralization.

The East Sikhote-Alin zone is promising for strata bound ores: interlayers of iron and manganese ores, similar in geochemical parameters to iron manganese nodules and ore-bearing sediments in the oceans are found there between Early Triassic - Early Cretaceous alternating layers of jasper, cherts and siliceous siltstones (Khanchuk et al., 1988). Positive prognosis for copper-pyrite ores of Hawaian type in alkaline-basaltic complexes, made by the authors proved to be correct.

3. Equivalents

The Mesozoic structural zones of the Sikhote-Alin are closely related to tectonic belts of Japanese Islands, where thick mixtite complexes often bear pyrite, iron, manganese and other ores («The geological...», 1968; Wakita, 1989; Taira et al., 1982; Kojima, 1989; fig. 1, 7).

Typical chaotic accumulations of Late Mesozoic Ogcheon zone of the Korea Peninsula (Filatova et al., 1991; Cluzel et al., 1990), where the large skarn-scheelite Sandong deposit is known, can be arbitrarily assigned to olistostrome (Fig. 1, 8).

4. Conclusions

Thus, we conclude that the Japan Sea region contains thick Late Mesozoic mixtite complexes linked to Asian continental margin. They were formed at early stages of accretional crust formation and are ore bearing. They are unique for they host commercial deposits: (1) scheelite-pyrite, sckarn-polimetals and boro-silicate (Sikhote-Alin), (2) pyrite- and iron-manganese strata bound deposits (Japanese Islands). Besides, numerous pyrite ore bodies associated with Late Jurassic - Early Cretaceous olistostrome are found in the Sikhote-Alin and mixtite strata similar to those described may also occur in the Korea Peninsula (Late Mesozoic Ogcheon zone), where the Sandong skarn-scheelite deposit is known.

In essence, the continental framework of the Japan Sea is a unified tungsten-copper-polimetallic-iron-manganese metallogenic province. This allows us to expect payable pyrite and iron-manganese deposits in the Sikhote-Alin, and skarn tungsten, polymetallic boro-silicate ores in mixtites of the Japanese Islands.

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PHOSPHATE GRAINS (PELLETS) OF PHOSPHORITES FROM THE PHOSPHORIA FORMATION, USA

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Abstract

Samples of pellet of granular, oolitic phosphorites from the well known Permian Phosphoria Formation, Rocky Mountains, USA, were studied under a scanning electron microscope to test the idea of pellet origin from the rewashing of irregularly phosphatized, cherty spongolite rocks of the formation. The absence of evidence of pellet passage through the alimentary canal of organisms disproves previous ideas of their faecal nature. The predominantly shallow-water character of the chert deposits together with in-situ phosphatization makes the relationship of this phosphate genesis to upwelling disputable.

1. Introduction

The Phosphoria Formation in the Rocky Mountains, USA, is one of the largest (if not the largest) accumulations of granular (pelleted) phosphorites in the world. It is a huge field of several hundred thousand square kilometres that was studied in detail in the 1950s and 1960s (Cressman and Swanson, 1964; Sheldon, 1957; and others).

2. Discussion

According to the nomenclature adopted in Russia, phosphorites are mainly granular, and more likely micro-granular. USA geologists define such phosphorites as pelleted. The phosphorites are usually associated with black shale, bedded chert, more rarely with dolomite, and with sandstone. Other phosphate components of the Phosphoria phosphorites are (in descending order): ooliths (concentric phosphate coatings, often around pellets), bioclasts (with the initial phosphate skeleton - lingulid shells, bones and teeth of vertebrates, etc.), micro-concretions (nodules), and phosphatized calcareous skeletons of vertebrates. All workers believe that understanding of the genesis of the predominant components - pellets and ooliths - will help to define the origin of the phosphorites as a whole.

The hypotheses proposed before were summarised in an overview by G.I. Bushinsky (1969). Pellets were regard as aggregates produced by bacteria and by chemical processes at the bottom of a shallow sea, micro-concretions, pseudomorphs of calcareous particle replacement, and phosphatized coprolites of small marine organisms (Bushinsky, 1969; Cressman and Swanson, 1964).

G.I. Bushinsky (1969) distinguished three types of phosphate pellets in the Phosphoria: phosphatized coprolites, microconcretions, and pseudomorphs of calcareous particle replacement. The first type is predominant. Although no strong proofs of the pellet faecal origin were given-only a formal resemblance to modern coprolites was used which as we know, are not always phosphatic. Possibly, this suggestion was based on the widespread, somewhat elongated rounded shape of the pellets. The third type is beyond question - pseudomorphs due to carbonaceous skeleton replacement (echinoderms, foraminiferans, etc.), but whether they are fragments of carbonaceous biogenic rocks or individual skeleton remains is still a problem.

The micro concretionary nature was substantiated by R.A. Gulbrandsen's (1960) observation that some pellets showed signs of compression as a result of growth in a confined space. However, the ambiguity of such interpretation is evident. G.I. Bushinsky (1969), is a great expert in studying different concretions from the Russian Platform, emphasises that they show no signs of compression, so this cannot be a criterion for distinguishing micro-concretions from faecal pellets.

Commonly, Phosphoria ooliths consist of: a nucleus core and several (one to eight) concentric coatings enveloping it. The core may be a phosphate pellet, quartz grains, teeth or other, often rounded, fragments of organic remains, proper ooliths or their fragments. Coatings are different in colour - from light to dark. These forms were suggested (Bushinsky, 1969) to be produced by chemical or colloid-chemical processes at the silty bottom of the Phosphoria sea, and judging from the observations, in its shallow zone, because they are accompanied by rounded sand grains and phosphorite pebbles, and sometimes by quartz grains.

Thus, a close examination of the problem showed that further studies were necessary. We had a relatively representative collection of samples of phosphorites and host rocks from the Phosphoria Formation, gathered and kindly given to us by E.A. Eganov and Y.N. Zanin. E.L. Shkolnik's (1989) study of the collection showed that aggregates of undoubtedly in-situ phosphate not in the form of pellets or grains are characteristic only of some cherty rocks of the formation. In carbonate and clay rocks, only pellets were found.

The cherty rocks, which contain in-situ phosphate aggregates, are spongolites, composed of micro- (locally mega-) sclere accumulations (Fig. 1). The fact that the cherts of the Phosphoria are essentially spongolites has long been known. Sheldon (1957) indicates that in some (up to 20%) chert samples from some members of the Phosphoria, spicules can be observed by naked eye. Kressman and Svenson (1964) note that the major it of cherts (up to 2/3) are spongolites composed of sponges of the Demospongiae.

However, the structure of the cryptocystalline part of the chert and some of their layers remains uncertain (Cressman and Swanson, 1964). Lobenfelse's (in Cressman and Swanson, 1964) idea that in those cases cherts were composed of either microscleres or remains of cherty plankton seems reasonable. He thinks that these sponges are shallow-water forms common only within the photic zone (up to isobath 50 m), although there are exceptions. General estimations of paleoconditions for cherts are: depth less than 50 m, normal salinity, and moderate rates of current. So, we must admit with assurance that at certain intervals of the Phosphoria Formation, tremendous sponge colonies («meadows») occurred.

Those sponge accumulations might be both the source and the place where initial in-situ phosphate aggregates formed. The destruction of soft tissues of these and other organisms resulted in phosphorus accumulations with subsequent diagenetic phosphate sedimentation and replacement in numerous local areas of spongolite beds (Fig. 1). In the areas of such phosphate development, spicules are almost indiscernible, they are completely replaced and they have lost their individual features. The aggregates are of irregular shape and are up to 3 mm across. The chaotic distribution in spongolite, comparatively broad variation of sizes, in distinctive boundaries, rare visible relics of non-replaced spicules and spicule distribution from phosphate mass into spongolite leave no doubt of their in-situ nature and early diagenetic formation. We consider them initial phosphate concentrations that occurred in spongolite layers, where the fragments of sponge soft tissues have been preserved. The proper mechanism was outlined by Bushinsky (1969).

It is natural to assume that the rewashing of partly phosphatized spongolites resulted in the formation of phosphate grains (pellets), according to the mechanism described by Shkolnik (1989). Then, it would be expected that at least some of the phosphate pellets were phosphatized spongolites. When studying closely many pellets of the common phosphorites of the Phosphoria under the optical microscope, we observe one or two oblique or transverse non-replaced sections of spicules, which is some evidence, although inadequate for certain statements. Pellet volume of 95-98% is still composed of homogeneous phosphate, which, although it contains much dispersed organic matter (average content of $CO2$ in Phosphoria phosphorites is 2-4%, sometimes up to 15%), does not show evidence of phosphate spicule composition when observed under the light microscope.

For a more detailed analysis of pelleted and oolitic phosphorites using a special technique, a dozen of sections were made of randomly chosen samples, which were studied under scanning electron microscope Cam-Scan-4 (Paleontological Institute [Moscow]). The following results were obtained.

Most pellets consist of fragments of phosphatized spongolites representing a mass of siliceous sponge microscleres replaced by phosphate (Fig. 2a). The arrangement of the microscleres is mostly chaotic to poorly oriented. Rarely, pellets include detritus of invertebrate skeletons (Fig. 2b). Good preservation allowed A.Y. Zhuravlev to determine the presence of representatives of the Tetractinomorpha (Demospongiae) (Fig. 3). Some microscleres have a hollow central canal, others have the central canal replaced by phosphate, but it is not clear if this is caused by the replacement of organic matrix. We do not see signs of the dissolution of microscleres and other skeletal remains (Fig. 2b) and signs of mechanical breakage, which would testify to the passage through the alimentary canal of organisms. The cement of the pellets sharply differs from their inner filling in structure, texture, and even reflective capacity. Apparently, one should consider it secondary.

A lesser part of the pellets has another character. They are composed of fragments with cellular texture and not very sharp boundaries. The fragments represent an irregular net of phosphate tubes that may be considered the algae covers (Fig. 4). Similar material occurs also in the cement filling between the pellets.

SEM investigations of oolitic aggregates showed them to be extremely similar to oncolites of Osagia type (Fig. 5). Phosphate composing them is similar in reflectivity to cement rather than phosphate of spongolite pellets, thus presumably suggesting its formation over organic matrix-, a SS type stromatolith.

Sometimes in some pellets one can see the accumulations of spheric aggregates of two sizes (about 4-5 and about 1 mkm), which may be defined as bacterial forms (Fig. 6). Such forms in phosphorites are found very often and testify to an early diagenetic mechanism of phosphate sedimentation (replacement) on organic components including soft tissues.

Thus, the results of analyses support independently the hypothesis that some, possibly major pellets of the Phosphoria Formation consist of the fragments of phosphatized spongolites and in part, possibly of the fragments of phosphatized algae mats. «Oolitic» differences represent phosphatized oncolites. Of course, the material we had at our disposal may not be representative of the total section of the Phosphoria Formation and all lateral variation of the huge phosphate field. However, the random character of the material excludes the possibility of subjective selection. If the geological organisations of the USA obtain a proper complete collection, it would be appropriate to investigate them using the technique developed.

There are some questions that require discussion. Are the pellets faecal formations, as G.I. Bushinsky suggested? As known, siliceous sponges have relatively few enemies (Koltun, 1968). Their excellent protection is a mineral skeleton, made up by thin spicules, as well as their unpleasant smell and excretions. Some molluscs, holothurians, and crustaceans parasitize sponges or live inside of them, but do not do essential harm. So, it is difficult to suppose that the occurrence of numerous extended layers of faecal pellets several meters thick resulted from the eating away of the «meadows». At the same time, if the idea of faecal pellets is true, then the problem of pellet phosphatization remains uncertain. The SEM study does not suggest the passage of sponge ooze through an alimentary canal. So, we think that the idea of faecal pellets must be given up, especially as recent faecal bodies (except for vertebrate predators) are not significantly phosphatized. As for the pellets from the supposed balls of tubular algae, although evidence of the action of digestion is also absent, some uncertainty in this respect remains, as algae are usually attractive food for marine organisms. However, direct evidence is also required, in particular, a proper mechanism of phosphatization.

Thus, the accumulation of essentially sponge deposits and sometimes algae mats took place. There, early diagenetic phosphatization occurred. Macro- and micro-concretions appeared in the mass of biogenic sapropel, and in this sense R.A. Gulbrandsen's (1960) ideas are most likely true, although not all of them coincide with the hypothesis discussed. Rewashing of those not fully lithified deposits produced the beds of pellets, more precisely granular phosphorites. Thus, it is the beds of phosphorite and spongolite chert of the Phosphoria, rather than clay shale, that are genetically similar to each other. If the opinion that Phosphoria sponges lived in very shallow water is true, then up welling was of no importance in the formation of the Phosphoria phosphorites (given that above the 50 m isobath there is no up welling). In addition, no clear evidence of the accumulation of planktonic forms connected with up welling have been found yet.

Finally, it should be noted that the process of sponge deposit phosphatization is common-examples are known from Cretaceous deposits of the Russian platform, Silurian deposits of the Russian Far East, and other places. It was nowhere so dramatically productive. In this sense, the Permian phosphate genesis of Phosphoria is unique.

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Plate I and II

Fig. 1. Partly phosphatized spongolite. Dark - irregular in-situ phosphate separations; light - microscleres. Phosphoria Formation. Ritort Member, Khoback Creek (pebble from carbonate-phosphate conglomerate). Thin section, optical microscope, 50.

Fig. 2. Phosphate pellet - phosphatized spongolite. SEM, thin section (after treatment). Pellet phosphorate, Phosphoria Formation, Mid-Pick. Peris Canyon.
a - rather chaotic distribution of microscleres;
b - remains of phosphatized invertebrates in a pellet;
c - large magnification of part of a phosphate pellet - phosphate spongolite.

Fig. 3. Part of a phosphate pellet with spicule remains - microsclere of a Demospongiae genus, Tetractinomorpha order. SEM, thin section (after treatment). Pellet phosphorite, Phosphoria Formation, Mid-Pick, Peris Canyon.

Fig. 4. Phosphate pellet - a fragment of phosphatized algae mat. SEM, thin section (after treatment). Pellet phosphorite, Phosphoria Formation, Ritort Member, Khoback Canyon.

Fig. 5. Phosphate oolite - oncholite of Osagia type. SEM, thin section (after treatment). Oolite-grained phosphorite, Phosphoria Formation, Mid-Pick, Brezer Canyon.

Fig. 6. Phosphate bacterial forms. SEM, thin section (after treatment). Pellet phosphorite, Phosphoria Formation, Ritort Member, Khoback Canyon.

Plate I

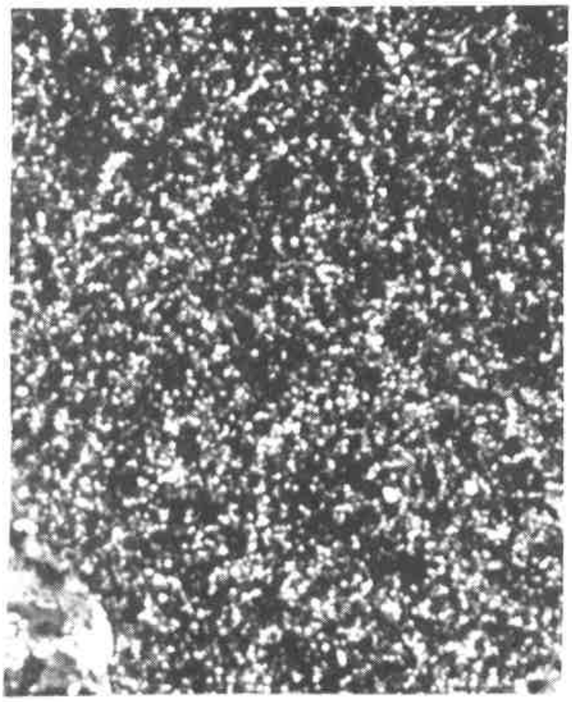

Fig. 1

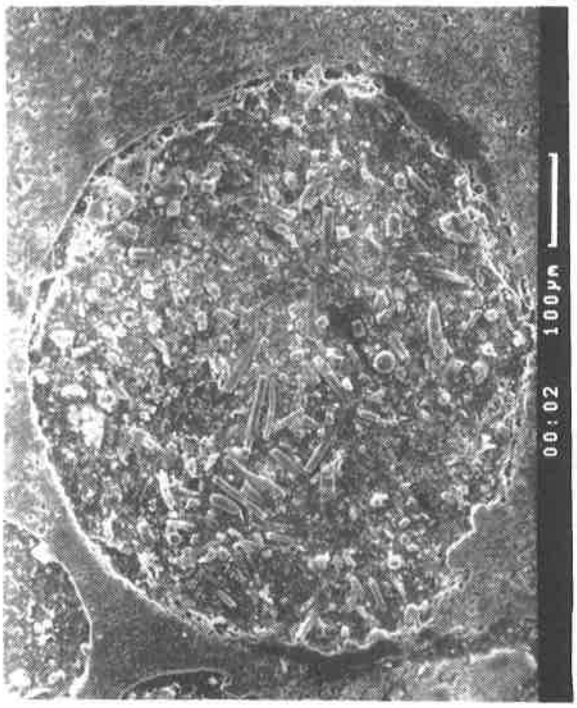

Fig. 2a

Fig. 2b

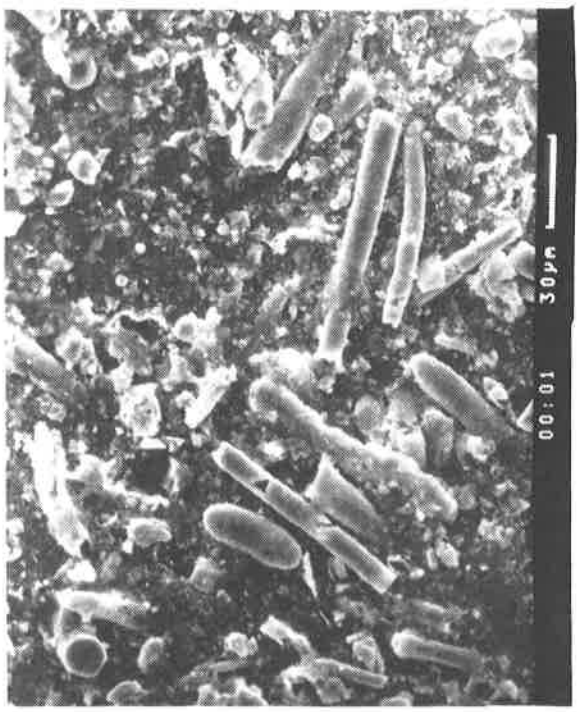

Fig. 2c

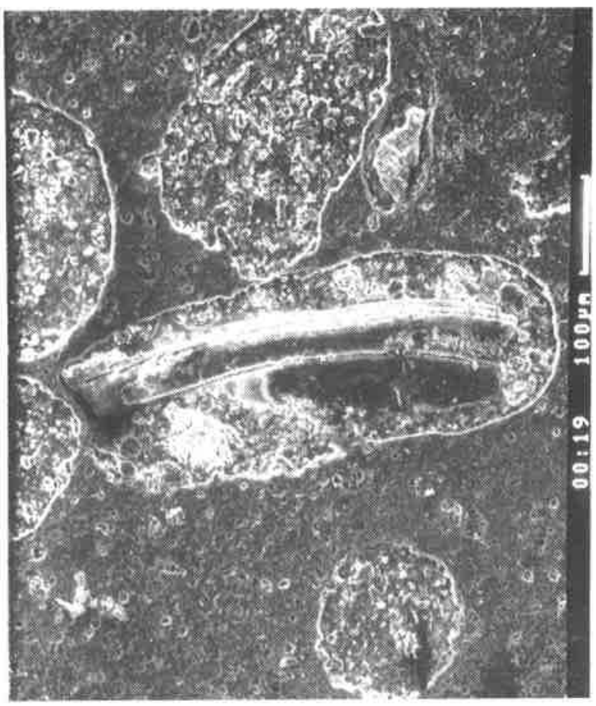

Plate II

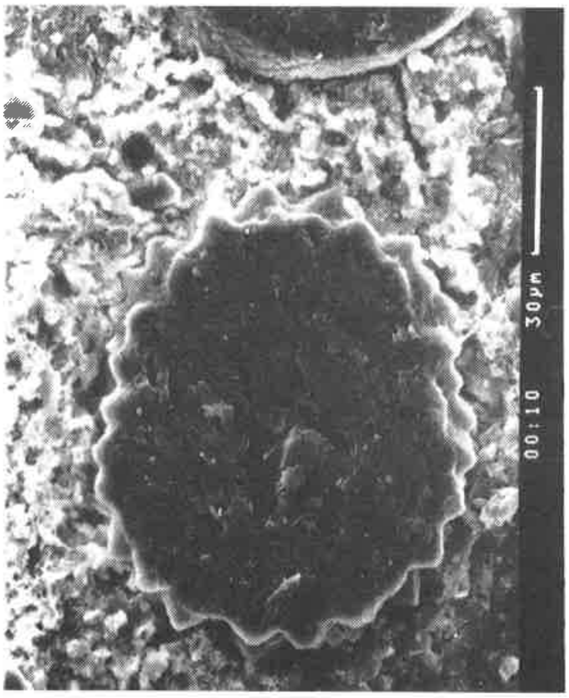

Fig. 3

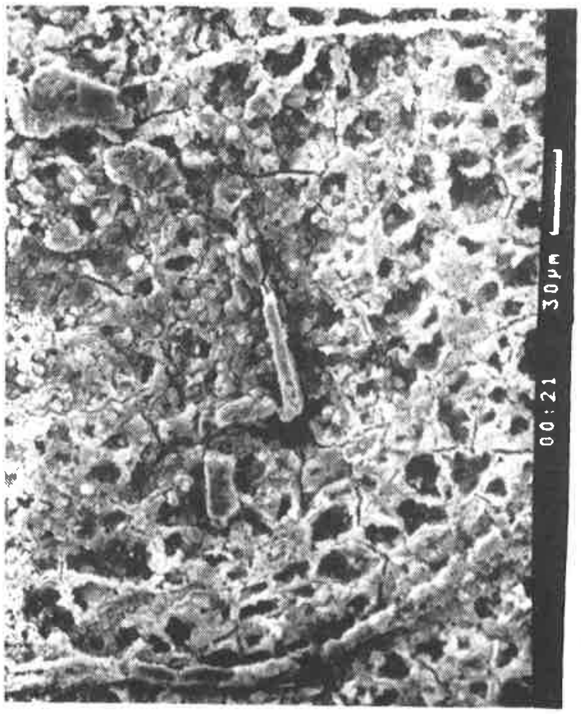

Fig. 4

Fig. 5

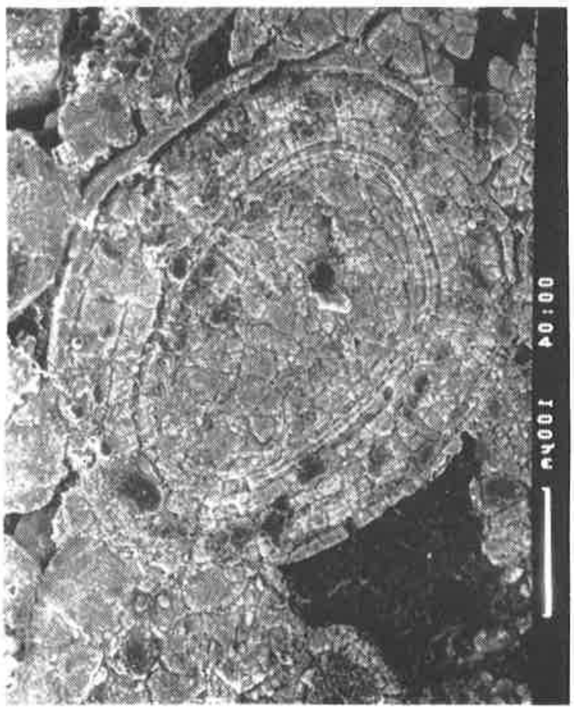

Fig. 6

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