THE CANDIDATES OF GLOBAL STRATOPYPE OF THE BOUNDARY OF THE INDUAN AND OLENEKIAN STAGES OF THE LOWER TRIASSIC IN SOUTHERN PRIMORYE

Annual Report 2000 of IOBWG

Yuri D. Zakharov, Yasunari Shigeta, Alexander M. Popov, Anatoly N. Sokarev, Galina I. Buryi, Vladimir V. Golozubov, Eugene S. Panasenko and Era A. Dorukhovskaya

Introduction

During the many years of investigations on the Lower Triassic several suggestions for stage and substage subdivisions have been made (e.g., Mojsisovics, 1882; Mojsisovics et al., 1895; Kiparisova & Popov, 1956, 1964a,b; Tozer, 1965, 1978; Vavilov & Lozovsky, 1970; Zakharov, 1973, 1978, 1986; Kozur, 1972, 1992; Kummel, 1973; Guex, 1978; Rostovcev & Dagys, 1984; Shevyrev, 1990). On the 29th International Geological Congress (Kyoto, 1992) Kiparisova & Popov's (1964a,b) scheme with a twofold division (Induan and Olenekian stages) has been approved at last. However, then another problem came up immediately: the choice of the Global Stratotype and Point for the boundary between these two stages. Therefore, a special working group (IOWG) was formed in 1997 with Prof. Yu.D. Zakharov (Vladivostok) as chairman and Dr. A. Baud (Lausanne) as vice-chairman.

The problem of the Induan-Olenekian boundary is complex because the Lower Triassic sections of the stratotype regions for the Induan (Hindustan, Indus River Basin) and Olenekian (Arctic Siberia, Olenek River Basin) cannot be used as boundary stratotypes for the base of the Olenekian and points for the following reasons:

(1) The Induan Stage in the Olenek River basin (Boreal realm) consists of lagoonal and littoral, tuffaceous and poorly fossiliferous strata that are difficult to date.
(2) In most Salt Range and Central Himalayan sections (Himalayan province) ammonoids are rare or absent, in Ceratite marls - Ceratite sandstone boundary beds, where the Induan-Olenekian boundary seems to have been recognized.

Hence, there are some problems with regard to the global correlation of the Lower Triassic, which concentrate on the Induan-Olenekian boundary sequence. However, we have representative Induan-Olenekian and Lower Olenekian sections (Burij, 1959; Korzh, 1959; Kiparisova, 1961, 1972; Zakharov, 1968, 1978, 1997) in the Ussuri province. This region is regarded as intermediate between the Boreal realm and the Himalayan province, having some common characters with both of them, and was often mentioned in discussions on problems of the Induan-Olenekian boundary by Kiparisova and Popov (1956, 1964 a,b). Most of these sections are located near Vladivostok in South Primorye.

Vladivostok was founded 1860 at Murav'ev, Amursky Peninsula as a military outpost. The construction of fortifications and a railroad necessitated geological investigations. The first geological studies there were carried out by Margaritov, a graduate from the St.- Petersburg

University, who arrived in Vladivostok in 1880 as mathematics teacher. He became an active member of the Society for the Investigation of the Amur Region, and head of several ethnographic and geological field parties, resulting in remarkable discoveries. For example, on the western coast of the Ussuri Gulf, between Tri Kamnya Cape and Shamara Bay (now Lazurnaya) he discovered, much to his surprise, some fossils, bivalves and ammonoids. Margaritov's collection fell into the hands of the President of the Russian Academy of Sciences, Karpinsky, a recognized expert in Late Paleozoic ammonoids, who distinguished Triassic bivalves (*«Pseudomonotis»*, *«Avicula»*) and ceratitid ammonoids including *Meekoceras*; *«Ceratites»*.

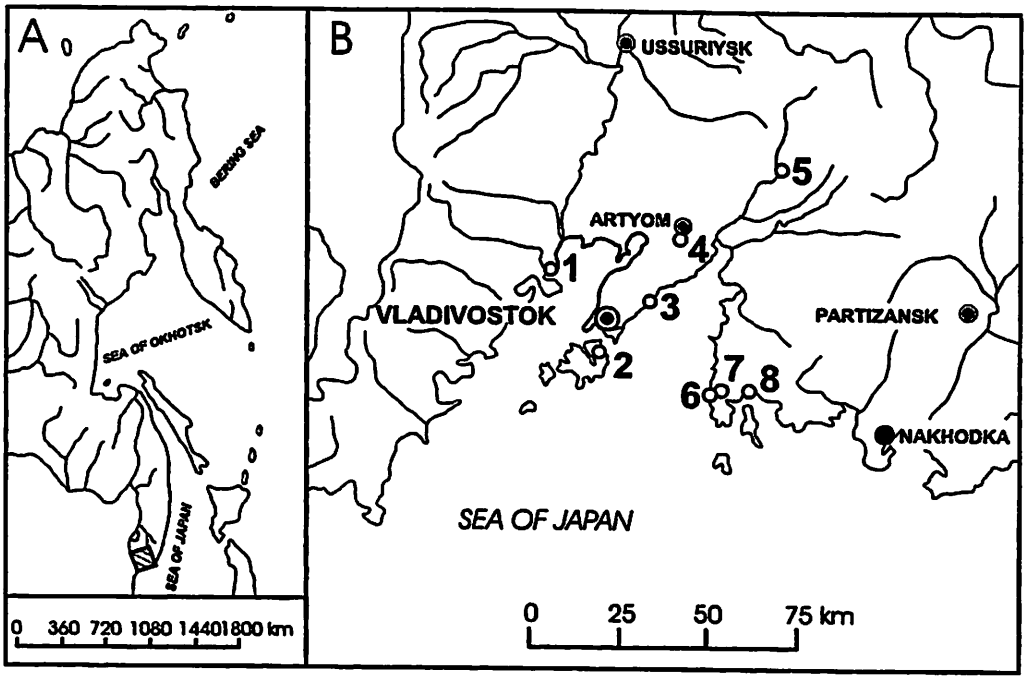


Fig. 1. Location of Induan-Olenekian transition outcrops, South Primorye. A -Location of the investigated area (shaded), B - South Primorye. Sections: 1 - Atlasov Cape, 2 - Ayax Bay, 3 - Tri Kamnya Cape and Orel clift, 4 - Artyom SMID quarry, 5 - Artyomovka River, 6 - Kom-Pikho-Sakho Cape, 7 - Yuzhnorechensk (Shimeuza) station, 8 - Abrek Bay.

Later, Triassic marine deposits in the Vladivostok region were studied by Ivanov (1891), chief of a geological team carrying out reconnaissance studies for the construction of the Trans-Siberian railroad. He also collected mollusc remains in the Shamara Bay area and he was the first who collected bivalves and ammonoids on Russian Island. He recognized the following succession of Triassic sediments in the South Primorye (Ussuri) region: (1) basal conglomerate, (2) sandstone and clay sandstone member and (3) thin-bedded sandstone member with algae and worm remains. On Karpinsky's initiative, a representative collection of Ivanov's and a part of Margaritov's collections were sent to the Austrian paleontologist Diener who studied them together with more abundant material that he had collected from the Lower Triassic of the Himalayas. From the lower part of the section, described by Ivanov, Diener (1895) identified the Early Triassic ammonoids *Proptychites* and *Lytophiceras*, and from the middle part the Early Triassic ammonoids *Pseudosageceras*, *Ussuria*, *Arctoceras* (=*«Meekoceras (Koninckites)»*), *Anaxenaspis* (=*«Xenaspis»*), *Kazakhstanites* (=*«Dinarites»*) and *Xenoceltites* (=*«Ceratites»*). From Ivanov's upper member he identified the Anisian forms *Ussurites* (=*«Monophyllites»*), *Ptychites* and

Acrochordiceras. Diener paid great attention to the discovery of Triassic marine deposits in the western Pacific, because at that time the Himalayas, Alps and Arctic Siberia were the only well known areas for the occurrence of Early Triassic ammonoids.

Ivanov's bivalve and brachiopod collections were later investigated and described by Bittner (1899). Stratigraphical investigations by Margaritov and Ivanov in the South Ussuri area were continued by Wittenburg (1910, 1916), who distinguished the (1) «*Pseudomonotis*» (=*Eumorphotis*) *iwanowi*, (2) «*Terebratula*» (=*Fletcherithyris*) *margaritovi* and (3) «*Xenodiscus*» (=*Kazachstanites*) *nicolai* Zones in the Lower Triassic and (4) the *Ptychites kokeni* Zone in the Anisian (Middle Triassic).

The importance of Lower and Middle Triassic rocks in the southern Primorye increased after the publication of the monographs by Kiparisova (1961, 1972) and later works. Kiparisova (1961) described more than 30 Early Triassic, and 28 Middle and Late Triassic ammonoid taxa and presented the following zonal scheme of the Lower Triassic: (1) basal conglomerate, (2) *Proptychites* Zone (or *Meekoceras* Zone), (3) *Flemingites* Zone, (4) *Prosphingites* Zone, and (5) *Subcolumbites* Zone. The Induan-Olenekian boundary was first recognized at the top of the *Flemingites* Zone (Kiparisova, Popov, 1956; Burij, 1959; Korzh, 1959), but later at its base (Kiparisova & Popov, 1964a,b; Kiparisova, 1972); moreover, instead of two zones (*Flemingites* and *Prosphingites*) the use of only a single Zone was suggested.

The fossil material collected by the major collective of Far Eastern geologists (Prynada, Nozdreev, Belyaevsky, Burij, Vasilyev, Korzh et al.) formed the basis of Kiparisova's 1961 work. The first used collection was made in 1928. It is necessary to keep in mind that Kiparisova's personal collections were restricted to the main material from the Middle Triassic and that for the Lower Triassic stratigraphical scheme she used material collected by other contributors.

Zakharov's (1968) monograph, with descriptions of 90 species of Triassic ammonoids from South Primorye, for the first time discussed the considerable facies variability of the Lower Triassic of this area. This was not taken into account in earlier correlation attempts. Consequently some ammonoid assemblages of some Lower Triassic zones were misrespresented.

The following zonation scheme for the Lower Triassic of the Far East (Zakharov, 1968, 1978. 1997); Zakharov, Rybalka, 1887; Burij et al, 1972; Burij & Zharnikova, 1981) accepted on the IVth Interdepartmental Regional Stratigraphic Conference in Khabarovsk (1990) will be discussed below:

Olenekian Stage

Upper Substage (Russian)

7. *Subcolumbites multiformis* Zone
6. *Neocolumbite insignis* Zone

Lower Substage (Ayaxian)

5. *Tirolites - Amphistephanites* Zone
   b. *Tirolites ussuriensis* beds
   a. *Bajarunia dagysi* beds
4. *Anasibirites nevolini* Zone
3. *Hedenstroemia bosphorensis* Zone

Induan Stage

2. *Gyronites subdharmus* Zone
1. *Glyptophiceras ussuriense* beds.

In 1976 Burij and co-authors (Burij, 1997; Burij et al., 1976, 1977, 1993) established four horizons in Induan, Olenekian and Anisian strata of South Primorye: Lazurnian, Tobizin, Chernyshev and Karazin. Recently in connection with research of facies variability of Lower and Middle Triassic sediments in limits of this interval the formations (suites) (Zakharov, 1997) were follow-up established.

Buryi (1979) was the first who studied Early Triassic conodont assemblages from South Primorye, but it must be noted that the review of conodont data from Primorye and other regions revealed the scarcity of age-diagnostic Late Induan and Early Olenekian conodonts.

Recently Zakharov (1995, 1996) proposed the Tri Kamnya Cape section as a Global stratotype for the Induan-Olenekian boundary. This contribution aims to propose the Abrek Bay section as a second candidate for the Global Stratotype of the lower boundary of the Olenekian.

The Abrek Bay section

The section is located in the Abrek Bay (north-eastern coast), about 0.8 km N of Yunshi Cape, South Primorye, at 42°55' N and 131°36' E.

Biostratigraphy

Ivanov first noted the presence of Triassic bivalve and gastropod mollusks in clay sediments of Abrek Bay in Strelok Gulf (Diener, 1895). Kiparisova (1938) later described *Claraia aurita* Hauer, *Eumorphotis multiformis* Bittner «*Pecten*» (=*Chlamys?*) *kryshtofowichi* Kiparisova, *Myoconcha* aff. *goldfussi* Dunk., and *Posidonia abrekensis* Kiparisova, collected in Abrek Bay by Wittenburg (1908-1923) and Kryshtofovich (1924). The first desciption of Triassic cephalopods of Abrek Bay area is from Kiparisova (1961). She described two Early Triassic nautiloid taxa (*Menuthionautilus* and «*Syringoceras*») and seven Early Triassic ammonoid taxa (*Hedenstroemia*, *Arctoceras* (=«*Proptychites*»), *Gyronites* and *Meekoceras*), collected by Nozdreev, Trifonov, Burij and Korzh (1938-1956). She described also one ammonoid (Kiparisova, 1961) collected by Nozdreev (1936), which she believed to be the Anisian form *Discoptychites* aff. *compressus* Yabe et Shimizu, although no suture is visible.

Kiparisova (1972) noted essential discrepancies between the Triassic stratigraphic schemes of Abrek Bay of Nozdreev (Kiparisova, 1972), Burij (1959), Korzh (1959) and Vasilyev (Kiparisova, 1972). The boundary between the Induan and Olenekian stages would on one hand be defined by the appearence of *Hedenstroemia* and *Meekoceras*; on the other the change from a sandy facies to silty one. This, however, conflicts with Nozdreev's data, who found *Hedenstroemia* in the sandy facies of the Lower Triassic.

Dagys (1974) described a new brachiopod genus (*Abrekia*) from Burij's collections from Lower Triassic sandstone of Abrek Bay and also regarded it as Induan in age.

From top to bottom, the sequence of the Anisian, Olenekian and Induan in the Abrek Bay section investigated by Zakharov, Shigeta, Popov and Panasenko in summer 1997-98 (Fig. 2 and 3) is as follows:

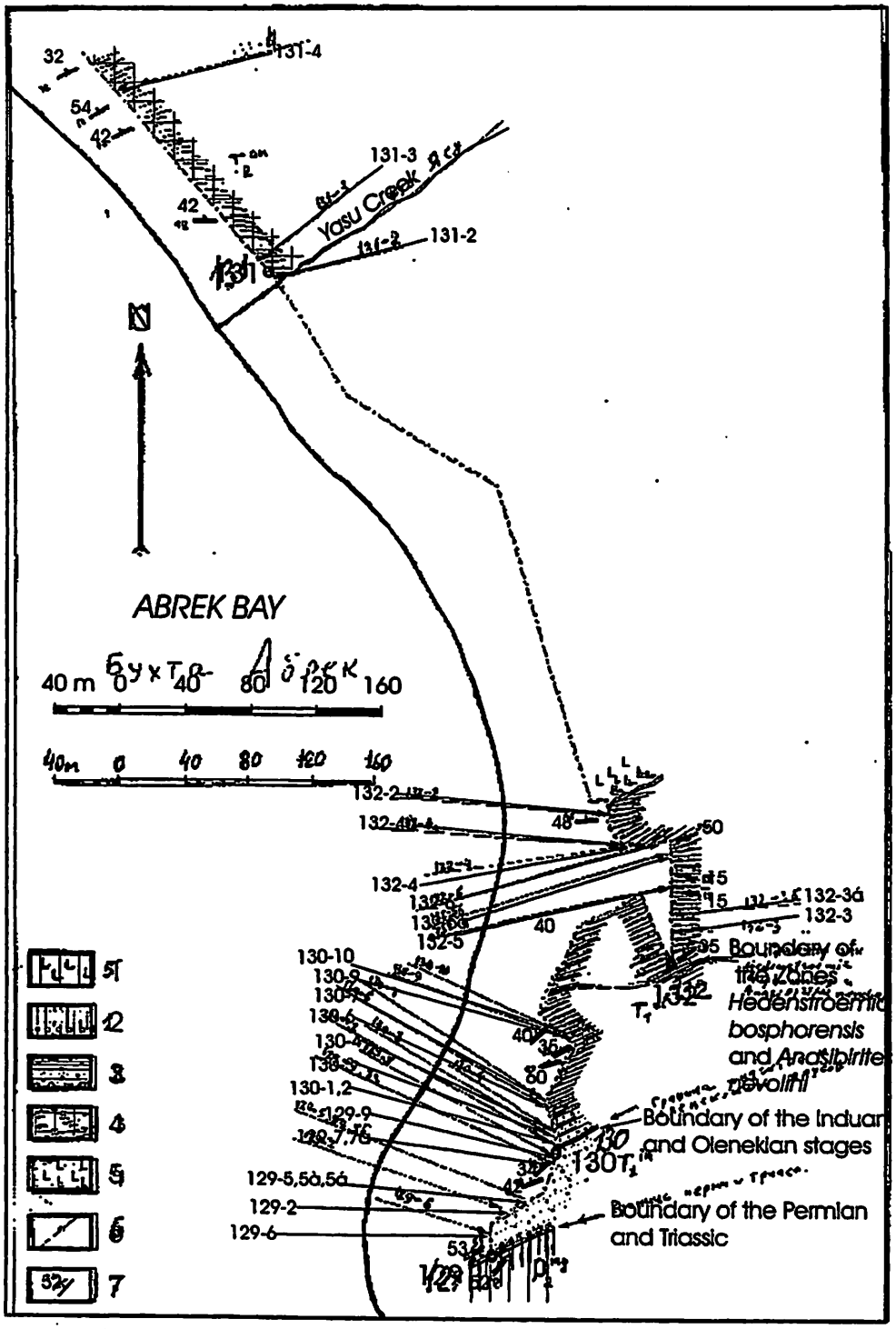


Fig. 2. Sketch map locating the Abrek Bay section. 1 - Murgabian (Abrek Formation), 2 - Induan (lower and middle Lazurnaya Formation), 3 - Lower Olenekian, Ayaxian (upper Lazurnaya and lower Zhitkov Formations), 4 - Anisian (Karazin Formation), 5 - dykes of porphyrite, 6 - geological route, 7 - bed elements.

Anisian Stage

Phyllocladiscites basarginensis Zone (lower part)

19. Dark grey mudstone with large nodules without mollusk remains — over 10 m
Nodules contain abundant of pure preserved radiolarians (spherical *Spumellaria*; det: Panasenko)

18. Dark grey mudstone and siltstone with interbeds of grey fine-grained striped sandstones, calcareous-marly nodules and lenses — 25.0 m
With ammonoids (*Leiophyllites* sp.) in the lower part and small bivalves, gastropods, ammonoids (*Cuccoceras* sp. nov.) and nautiloids (*Trematoceras* sp.) in the upper part.
Kiparisova (1961, 1972) has adduced information on a fragment of ceratitid ammonoid living chamber which was found by Nozdreev in dark-grey mudstone of Abrek Bay in association of *Posidonia abrekensis* Kiparisova. It was tentatively identified as the Anisian form *Discoptychites*. However, it rather may be *Parahedenstroemia*; representatives are known in both the *Hedenstroemia bosphorensis* and the *Anasibirites nevolini* of the Olenekian stage. Kiparisova (1938) was, apparently, right, when she firstly consider *Posidonia abrekensis* Kiparisova to be Early Triassic in age.

Unexposed interval — (over 100 m in thickness)

Olenekian Stage

Lower Olenekian (Ayaxian) Substage

Anasibirites nevolini Zone

17. Grey, striped siltstone (metamorphic near the contact with dyke of diorite porfirite) — 2-3 m

16. Dark grey mudstone with calcareous-marly nodules and lenses, intercalated with striped siltstone — 5.0 m
Contains ammonoids (*Arctoceras labogense* Zharnikova), *Pseudoprosphingites magnumbilicatum* (Kiparisova), *Koninckites timorensis* Wanner, *Parakymatites* sp. nov., *Meekoceras varaha* Diener, *Meekoceras* sp. nov., *Hemiprionites dunajensis* Zakharov, *Preflorianites* cf. *radians* Chao.
It is possible to speculate that *Arctoceras abrekensis* (Kiparisova) (1961) was found by Nozdreev just in the member 16.

15. Dark grey siltstone and mudstone with calcareous-marly nodules and thick lenses of coquinoid marl — 35.0 m
With brachiopods (*Abrekia sulcata* Dagys), small bivalves (*Promyalina* sp., *Posidonia?* sp.), ammonoids (*Pseudosageceras longilobatum* Kiparisova, *Pseudosageceras* sp., *Arctoceras labogense* (Zharnikova) (dominant), *Arctoceras subhydaspis* (Kiparisova), *Arctoceras septentrionale* (Diener), *Pseudoprosphingites magnumbilicatum* (Kiparisova), *Owenites koeneni* Hyatt et Smith, Gyronitidae gen. et sp. nov., *Koninckites timorensis* Wanner (dominant), *Gurleyites* sp., *Anasibirites nevolini* Burij et Zharnikova, *Palaeokazakhstanites ussuriensis* (Zakharov), *Euflemingites prynadai* (Kiparisova), *Eophyllites* sp.

Hedenstroemia bosphorensis Zone

14. Dark grey siltstone and mudstone with calcareous-marly nodules and lenses and rare interbeds (up to 15 cm) of grey medium-grained sandstone — 23.0 m
With small bivalves (*Velopecten minimus* Kiparisova), small gastropods and ammonoids (*Pseudoprosphingites magnumbilicatum* (Kiparisova), Gyronitidae?, *Koninckites timorensis* Wanner, *Meekoceras varaha* Diener (dominant), *Flemingites radiatus* Waagen, *Anaxenaspis* cf. *orientalis* (Diener) at the base of member.

13. Greyish-green, striped (because of very thin interlayers of mudstone) siltstone with rare nodules of marl — 8.6 m
With ammonoids (*Meekoceras varaha* Diener, *Meekoceras* sp. nov.)

12. Greyish-green, fine-grained striped (because of presence of very thin interlayers of mudstone) sandstone with dark grey, calcareoun-marly boulders and lenses — 10.0 m
With bivalves (*Palaeoneilo? prynadai* Kiparisova, *Pteria ussurica* (Kiparisova), *Eumorphotis iwanowi* (Bittner), *Promyalina* sp., *Anadontophora fassaensis* (Wissman), ammonoids (*Parahedenstroemia conspicienda* Zakharov, *Inyoites spicini* Zakharov, *Arctoceras septentrionale* Diener, *Pseudoprosphingites magnumbilicatum* (Kiparisova), *Ambites* sp., *Koninckites* aff. *timorensis* Wanner, *Meekoceras boreale* Diener, *Meekoceras varaha* Diener, *Dieneroceras chaoi* Kiparisova, *Preflorianites* cf. *radiatus* Chao.

11. Dark grey mudstone, intercalated with grey-green, fine grained striped sandstone (up to 20 cm thick) and grey medium-graines sandstone (5-10 cm thick) — 2.7 m

10. Light grey, striped, medium-grained sandstone, intercalated with grey green, fine-grained sandstone (5 cm thick) and with calcareous-marly boulders 8.0 m
Contains nautiloids (*Gyronautilus praevolutum* (Kiparisova)) and ammonoids (*Meekoceras boreale* Diener). *Hedenstroemia* sp. indet (Kiparisova, 1961) seems to be found by Korzh in the member 10 or just below.
9. Grey, middle-grained sandstone intercalated with grey thin-grained, striped sandstone, with small, acute-angled pieces of dark grey siltstone and thin (5 cm) layer of dark grey mudstone at the base 2.15 m
Yield ammonoids (*Melagathiceratidae* gen. et sp. nov.)
8. Light grey, medium-grained sandstone intercalated with grey, thin-grained, striped (because of presence of very thin layers of mudstone) sandstone and lenses of conquinoid calcareous sandstone (up to 50 cm thick); the surface of beds show distincted asymmetric signs of ripples 1.8 m
With brachiopods (*Lingula borealis* Bittner, *Orbiculoides* sp., *Albrekia sulcata* Dagys (dominant), bivalves (*Promyalina* sp.), ammonoids (*Arctoceras?* sp. indet., Melagathiceratidae gen. et sp. nov.).
7. Grey, medium-grained sandstone with rare and very thin layers of dark grey mudstone and siderite boulders and layer (30 cm) of grey, coquinoid calcareous sandstone at the base 2.6 m
Yields bivalves (*Promyalina* sp., *Entolium microtis* (Wittenburg), *Velopecten minimus* Kiparisova, Pectinidae gen. et sp. nov.), ammonoids (*Meekoceras boreale* Diener, *Ambites* sp.), Nautiloids (*Phaedrysmocheilus* sp.).

Induan Stage

6. Greyish-green, medium-grained sandstone with very thin interlayers of dark grey mudstone, that appear within every 0.5-0.6 m, and a layer (30 cm) of coquinoid calcareous sandstone at the base; asymmetric ripples are recognizable at bed surfaces 5.0 m
With brachiopods (*Lingula* aff. *borealiis* Bittner, *Orbiculoidea* sp.), bivalves (*Eumorphotis multiformis* (Bittner), *Neoschizodus laevigatus* (Zieten), *Anodontophora fassaensis* (Wissman)), gastropods, ammonoids (*Gyronites subdharmus* Kiparisova), *Ambites* sp.
5. Greyish-green, medium-grained, micaceous sandstone with many thin layers (2-10 mm, rarely 40 mm) of dark grey mudstone and lenses (up to 30 cm) of coquinoid calcareous sandstone; asymmetric ripples are recognizable at bed surfaces - and evidence of the SE (125°) flow 6.0 m
With bivalves (*Neoschizodus laevigatus* (Zieten), plant leafs
4. Greyish-green, medium-grained sandstone with lenses (up to 15 cm thick) of coquinoidal calcareous sandstone and layer of grey, striped (because of presence of very thin (1-3 mm) layers of mudstone (sandstone, 5 m above the base) 8.0 m
With brachiopods *Lingula borealis* Bittner, *Orbiculoides* sp.), bivalves (*Claraia australasiatica* Krumb., *Promyalina putiatinensis* (Kiparisova), *Eupecten* cf. *ussuricus* (Bittner), *Entolium microtis* Wittenburg), ammonoids (*Gyronites subdharmus* Kiparisova), arthropodes (crabs).
3. Greyish-green, medium-grained sandstone with rare pebbles and rare lenses (up to 1-3 cm thick) of conglomerate and small, angular pieces of dark grey siltstone and rare fragments of bivalve shells 19.0-21.0 m
2. Greyish-green, medium grained sandstone with many lenses (up to 1-3 cm thick) of conglomerate 4.0-4.5 m
1. Conglomerate with small and intermediate sized pebble and greish-green, sandy matrix, which characterized by well sorted disintegrated material. Pebbles consist of mainly felsic and intermediate effusive rocks 3 m
Triassic basal conglomerate overlies with unconformity and erosion Murgabian terrestrial sediments of the Abrek Formation, represented in its upper part by light-grey, coarse-grained, tuffaceous sandstone and gravelstone.

Analysis of the faunistic assemblages

Radiolarians

Triassic radiolarians in Far East (Sikhote-Alin, Japan) are to date only known from cherts in olistostrome strata. During our investigation in 1997 abundant pure preserved radiolarians (spherical *Spumellaria*) were found and identified by Panasenko in terrigenous sediments of the Lower Anisian (lower part of the *Phyllocladiscites basarginensis* Zone) in Abrek Bay (Zakharov et al., in press).

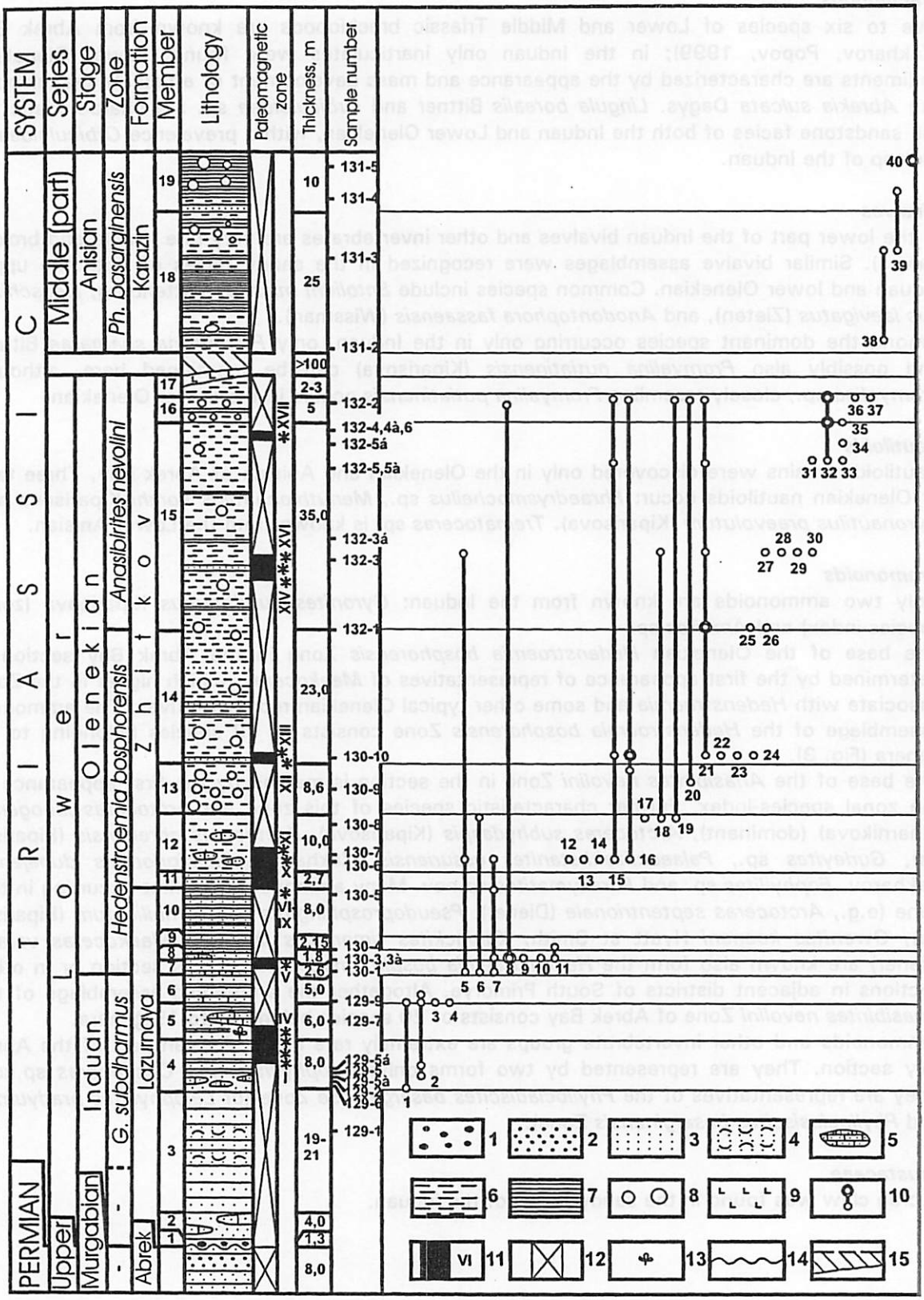
Brachiopods
Five to six species of Lower and Middle Triassic brachiopods are known from Abrek Bay (Zakharov, Popov, 1999); in the Induan only inarticulates were found. Lower Olenekian sediments are characterized by the appearance and mass development of articulate brachiopods like *Abrekia sulcata* Dagys. *Lingula borealis* Bittner and *Orbiculoidea* sp. are characteristic for the sandstone facies of both the Induan and Lower Olenekian, with a prevalence *Orbiculoidea* in the top of the Induan.

Bivalves
In the lower part of the Induan bivalves and other invertebrates are very rare (single and broken valves). Similar bivalve assemblages were recognized in the sandy facies of both the upper Induan and lower Olenekian. Common species include *Entolium microtis* Wittenburg, *Neoschizodus laevigatus* (Zieten), and *Anodontophora fassaensis* (Wissman).
Among the dominant species occurring only in the Induan, only *Promyalina shamarae* Bittner and possibly also *Promyalina putiatinensis* (Kiparisova) can be mentioned here, although *Promyalina* sp., closely resemling *Promyalina putiatinensis* occurs in the Lower Olenekian.

Nautiloids
Nautiloid remains were discovered only in the Olenekian and Anisian of Abrek Bay. Three taxa of Olenekian nautiloids occur: *Phraedrysmocheilus* sp., *Menuthionautilus korzhi* Kiparisova and *Gyronautilus praevolutum* (Kiparisova). *Trematoceras* sp. is known from the Lower Anisian.

Ammonoids
Only two ammonoids are known from the Induan: *Gyronites subdharmus* Kiparisova (zonal species-index) and *Ambites* sp.
The base of the Olenekian *Hedenstroemia bosphorensis* Zone in the Abrek Bay section is determined by the first appearance of representatives of *Meekoceras*, which higher in the Zone associate with *Hedenstroemia* and some other typical Olenekian representatives. The ammonoid assemblage of the *Hedenstroemia bosphorensis* Zone consists of 18 species belonging to 14 genera (Fig. 3).
The base of the *Anasibirites nevolini* Zone in the section is marked by the first appearance of the zonal species-index. Further characteristic species of this zone are *Arctoceras labogense* (Zharnikova) (dominant), *Arctoceras subhydaspis* (Kiparisova), *Arctoceras abrekensis* (Kiparisova), *Gurleyites* sp., *Palaeokazakhstanites ussuriensis* (Zakharov), *Hemiprionites dunajensis* Zakharov, *Eophyllites* sp. and *Parakymatites* sp.nov. Many ammonoid taxa first occurring in this zone (e.g., *Arctoceras septentrionale* (Diener), *Pseudoprosphingites magnumbilicatum* (Kiparisova), *Owenites koeneni* Hyatt et Smith, *Koninckites timorensis* Wanner, *Meekoceras varaha* Diener) are known also form the *Hedenstroemia bosphorensis* Zone of this section or in other sections in adjacent districts of South Primorye. Altogether the ammonoid assemblage of the *Anasibirites nevolini* Zone of Abrek Bay consists of 20 species belonging to 15 genera.
Ammonoids and other invertebrate groups are extremely rare in the Anisian part of the Abrek Bay section. They are represented by two forms only: *Leiophyllites* sp., *Cuccoceras* sp.nov. They are representatives of the *Phyllocladiscites basarginense* Zone (or *Leiophyllites pradyumna* and *Phylloclasiscites basarginensis* Zone).

Crustaceae
A crab claw was found in the sandy facies of the Induan.


SYSTEM
Series
Stage
Zone
Formation
Member
Lithology
Paleomagnetic zone
Thickness, m
Sample number
PERMIAN
Upper
Murgabian
Middle (part)
Lower
Olenekian
Induan
Anisian
Ph. basarginensis
Karazin
G. subdharmus
Hedenstroemia bosphorensis
Anasibirites nevolini
Zhitkov
Lazurnaya
Abrek
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Amphibians
The presence of amphibian remains in clayey sediments of the *Anasibirites nevolini* Zone is shown by small fragments of osteal tissue.

Paleomagnetic results

According to Sokarev & Golozubov's new data (Zakharov et al., in press) the at least several of the 17 stratigraphical levels of the *Gyronites subdharmus* (Fig. 3, levels I-IV), *Hedenstroemia bosphorensis* (levels V-XIII) and *Anasibirites nevolini* (levels XIV-XVII) zones show a normal polarity. This suggests that the enitre interval represents a uniform, extended normal polarity zone.

Induan-Olenekian boundary beds in some other sections of the Primorye region

2.1 Tri Kamnya Cape
Recently, Zakharov (1994, 1996) discovered *Hedenstroemia bosphorensis* (Zakharov), *Parahedenstroemia* sp., *Gyronites separatus* Kiparisova, *Gyronites* aff. *planissimus* Spath and *Ambites* sp. in the basal part of the Olenekian in the Tri Kamnya Cape section (in the sandy facies). The most representative ammonoid assemblage of the *Hedenstroemia bosphorensis* Zone (*Pseudosageceras, Parahedenstroemia, Ussuria, Arctoceras, Prosphingitoides, Paranannites, Ambites, Koninckites, Meekoceras, Anakashmirites, Flemingites* and *Euflemingites*) was found stratigraphically higher, in the clay facies, in association with the conodont *Neospathodus dieneri* Sweet (Buryi, 1979). The *Anasibirites nevolini* Zone has not been found in the section - the beds containing *Palaeokazakhstanites* and *Priololobus* (member 24) (Zakharov, 1996) could belong to this zone. Finds made during the last years in this section indicate that *Meekoceras gracilitatis* White occurs in the *Hedenstroemia bosphorensis* Zone, which is widespread in the western USA.

Fig. 3. Distribution ammonoids and some brachiopods and bivalves in the Induan, Olenekian and Anisian of Abrek Bay section. 1 - conglomerate, 2 - gravelstone, 3 - sandstone, 4 - sandstone with fragments of mollusk valves, 5 - coquinoid calcareous sandstone, 6 - siltstone, 7 - mudstone, 8 - nodule of marl, 9 - dike of porphyrite, 10 - interval of species distribution (domination is indicated by a double ring), 11 - paleomagnetic zone (interval of normal polarity), 12 - uninspected interval, 13 - plant remains, 14 - erosion, 15 - tuf-interval.

Species: 1 - *Gyronites subdharmus* Kiparisova, 2 - *Promyalina putiatinensis* (Kiparisova), 3 - *Promyalina schamarae* (Bittner), 4 - *Koninckites* sp. indet., 5 - *Promyalina* sp., 6 - *Ambites* sp., 7 - *Meekoceras boreale* Diener, 8 - *Abrekia sulcata* Dagys, 9 - *Hedenstroemia* sp. indet., 10 - *Arctoceras?* sp. indet., 11 - Melagathiceratidae gen. et sp. nov., 12 - *Inyoites spicini* Zakharov, 13 - *Koninckites* aff. *timorensis* Wanner, 14 - *Dieneroceras chaoi* Kiparisova, 15 - *Pseudoprosphingites magnumbilicatum* (Kiparisova), 16 - *Meekoceras varaha* Diener, 17 - *Parahedenstroemia conspicienda* Zakharov, 18 - *Arctoceras septentrionale* (Diener), 19 - *Preflorianites* cf. *radiatus* Chao, 20 - *Meekoceras* sp. nov., 21 - *Koninckites timorensis* Wanner, 22 - Gyronitidae?, 23 - *Flemingites radiatus* Waagen, 24 - *Anaxenaspis* cf. *orientalis* (Diener), 26 - *Anasibirites nevolini* Burij et Zharnikova, 27 - *Owenites koeneni* Hyatt et Smith, 28 - Gyronitidae gen et sp. nov., 29 - *Palaeokazakhstanites ussuriensis* (Zakharov), 30 - *Eophyllites* sp., 31 - *Pseudosageceras* sp. indet., 32 - *Arctoceras labogense* (Zharnikova), 33 - *Euflemingites prynadai* (Kiparisova), 34 - *Arctoceras subhydaspis* (Kiparisova), 35 - *Pseudosageceras longilobatum* Kiparisova, 36 - *Parakymatites* sp. nov., 37 - *Hemiprionites dunajensis* Zakharov, 38 - *Leiophyllites* sp., 39 - *Cuccoceras* sp. nov.

2.2. Orel cliff

This section is located at the western coast of the Ussuri Gulf, 2 km north of Tri Kamnya Cape. Induan-Olenekian transition strata are fully developed in the sandy facies of the Lazurnaya Formation. The upper Induan is here, like in the Tri Kamnya Cape section, characterized by *Gyronites subdharmus* (Kiparisova), associated with *Promyalina schamarae* (Kiparisova) and conodonts - *Neogondolella* cf. *carinata* juv. (Clark), *Neospathodus?* sp. indet., *Hindeodella* sp. indet., *Lonchodina* sp. indet. (the latter were recently discovered by G.I. Buryi). *Meekoceras* cf. *subcristatum* Kiparisova and *Gyronites separatus* Kiparisova have been discovered at the base of the Olenekian, from where Buryi identified some conodonts (*Neospathodus* sp. indet., *Diplododella* sp. indet. and *Lonchodina* cf. *triassica* (Müller)).

Isotopic analyses have shown, that $\delta^{13}C$ values in the upper part of the Induan reach +1.2‰, are slightly reduced at the Induan-Olenekian boundary (up to +0.3‰), and do not exceed +0.8‰ in the remaining exposed part of the lower Olenekian (Zakharov et al., 1999). It should be noted that in organogenic carbonates of the middle Olenekian (*Tirolites - Amphistephanites* Zone) of South Primorye anomalously high $\delta^{13}C$ values (up to 4.9‰) were measured (Zakharov et al., 1999); this correlates well with middle Olenekian anomalies of the North Caucasus (Zakharov et al., 1999b, 2000).

2.3. Kom-Pikho-Sakho Cape

The section (Fig. 1) has much in common with the Abrek Bay section. The Induan-Olenekian boundary also is located in the sandy facies at the first appearence of *Meekoceras.* An abundant early Olenekian ammonoid assemblage (*Pseudosageceras, Hedenstroemia, Parussuria, Metussuria, Tellerites, Arctoceras, Prosphingitoides, Juvenites, Owenites, Prionolobus, Meekoceras, Inyoites, Hemiprionites, Gurleyites, Preflorianites, Bandoites, Flemingites, Euflemingites*) of the *Hedenstroemia bosphorensis* Zone is known from the lower part of the clay facies associated with the conodont *Furnishius triseratus* Clark (Burij, 1979). The main disadvantage of this section is the presence of a series of small faults at the Induan-Olenekian transition strata (5-10 m offset).

2.4. Yuzhnorechensk (Shimeuza)

Like in a number of other sections (Abrek, Orel, Kom-Pikho-Sakho) the sandy facies is characterized by the occurrence of species of *Meekoceras* (*Hedenstroemia bosphorensis* Zone). In the clay facies that forms the upper part of this zone, ammonoids are extremely abundant and varied (*Hedenstroemia, Ussuria, Metussuria, Arctoceras, Prosphingitoides, Owenites, Dieneroceras, Koninckites, Prionolobus, Parakymatites, Meekoceras, Inyoites, Hemiprionites, Flemingites, Eophyllites*). Conodonts from this interval include *Neospathodus discreta* (Müller), *N. zharnikovae* Buryi, *Furnishius triserratus* Clark, *Parachirognatus symmetrica* (Staeshe), *Hadrodontina subsym-metrica* (Müller), *H. nevadensis* Müller, *Chirodella dinodoides* (Tatge), *Lonchodina triassica* Müller, *L. nevadensis* Müller (Buryi, 1979). In the overlying *Anasibirites nevolini* Zone the zonal index-species occurs together with *Arctoceras, Juvenites, Gurleyites* and *Melagathiceratidae* gen. et sp.nov. An major disadvantage of this section is that Induan deposits are absent.

2.5. Artyom environs

We here present the first information on a section in the SMD quarry, 6 kms NE of the Uglovaya railway station. In northern part of the quarry the *Anasibirites nevolini* Zone is exposed. This zone is characterized by an abundance of ammonoids - e.g., *Arctoceras labogense* Zharnikova, *Prosphingitoides ovalis* (Kiparisova), *Prosphingitoides* sp. nov., *Juvenites simplex* (Chao), *Prionolobus involutus* Zakharov, *Meekoceras* sp. nov., *Hemiprionites dunajensis* Zakharov, *Anasibirites nevolini* Burij et Zharnikova, *Xenoceltites* sp. nov., *Anaxenaspis* sp. nov., *Melagathi-*

ceratidae gen. et sp. nov. -, and bivalves - *Posidonia mimer* Oeberg, *Posidonia ussurica* Kiparisova, *Posidonia* sp., *Nuculana elliptica* (Goldfuss), *Pteria ussurica* (Kiparisova), *Leptochondria* cf. *bittneri* Kiparisova, *Atomodesma?* sp. (det.: Dorukhovskaya). Underlying sediments, inluding sandstones, are not exposed here (only found in loose blocks). Judging from the occurrence of *Leiophyllites* and *Hollandites?* the southern part of the quarry consists of Anisian sediments. The relationship of this member to underlying sediments is still uncertain.

2.6. Artyomovka River

Early Olenekian ammonoids are known from the clay facies of the *Hedenstroemia bosphorensis* Zone on the left bank of the Artemovka River (*Arctoceras*, *Prosphingitoides*, *Juvenites*, *Owenites*, *Dieneroceras*, *Meekoceras*, *Hemiprionites*, *Anaxenaspis*, and *Eophyllites*). Induan sediments are not exposed there. The ammonoid assemblage of the overlying *Anasibirites nevolini* Zone includes *Parahedenstroemia*, *Arctoceras*, *Paranannites*, *Owenites*, *Arctoprionites*, *Hemiprionites*, *Wasatchites*, *Gurleyites*, and *Subalbanites*. The following conodonts are known from the *Anasibirites nevolini* Zone: *Neogondolella milleri* (Müller), *Neospathodus waageni* Sweet, *N. discreta* (Müller), *Furnishius triserratus* Clark, *Hindeodella nevadensis* Müller, *H. budurovi* Buryi, *H. raridenticulata* Müller, *Hadrodontina adunca* Staesche, *H. symmetrica* (Staesche), *H. subsymmetrica* (Müller), *Parachirognathus symmetrica* (Staesche), *H. subsymmetrica* (Müller), *Parachirognathus symmetrica* (Staesche), *Lonchodina triassica* (Müller) This is the type section of the *Anasibirites nevolini* Zone in South Primorye (Burij et al., 1972; Zakharov, 1978).

2.7. Ayax Bay

Ayax Bay is the only place on Russian Island, where the Induan-Olenekian transition in a sandy facies can be studied. The top of the Induan, approximately 2 m thick, exposed on the coast, contains ammonoids (*Gyronites?* sp.) bivalves (e.g., *Eumorphotis multiformis* (Bittner), *Promyalina shamarae* (Bittner)(Zakharov, 1996), and also conodonts (*Neospathodus pakistanensis* Sweet, *Parachirognathus* sp. (Buryi, 1979). An index-species of the *Gyronites subdharmus* Zone obviously occur at the same stratigraphical level in an adjacent section of Novik Bay.

Somewhat higher in the sequence (at the roadside, and cliff in the south coast of the Ayax Bay) sandstone with small ammount of coquinoid calcareous sandstone are found. This sandstone is supposed to be of early Olenekian age because of the presence of *Proharpoceras carinatitabulatum* Chao and *Juvenites* cf. *simplex* (Chao). The little material from the Abrek Bay section and other Lower Triassic sections in South Primorye shows, that strata characterized by early Olenekian ammonoids are easily recognized. The major difficulty regarding the Induan-Olenekian transition in the area is its poor exposure in most of the sections.

Lithological facies of the Lower and Middle Triassic of South Primorye

There are two main lithologies in the Lower Triassic in South Primorye: (1) the polyfacies type and (2) the bifacies type. The first is characteristic for the western sections (Russian Island, western coast of the Amur Gulf between Alasov and Ugolnyi Capes), and the second for the eastern sections (Artyomovka River, Artyom environs, Kom-Pikho-Sakho Cape, Krasnorechensk (Shimeuza) station, Abrek Bay). The Tri Kamnya Cape section of western coast of the Ussuri Gulf lithologically holds an intermediate position between the series of sections but tends to the polyfacies type.

The sections of Russian Island are proposed as reference for the polyfacial type of the Lower Triassic in South Primorye. Zakharov (1997) recognized several formations there:

(1) The Lazurnaya Formation, comprising the Induan and the lower part of the Olenekian *Hedenstroemia bosphorensis* Zone (it is primarily exposed in Ayax Bay area of Russian Island, but its stratotype is located at western coast of the Ussuri Gulf, between Lazurnaya (Shamara) Bay and Tri Kamnya Cape (Zakharov, 1968)

(2) The Tobizin Formation, comprising the *Hedenstroemia bosphorensis* Zone (excluding its basal beds) and the *Anasibirites nevolini* Zone, with its stratotype at Tobizin Cape, Russian Island

(3) The Schmidt Formation, only comprising the *Tirolites* - *Aphistephanites* Zone with the stratotype at Schmidt Cape, Russian Island

(4) The Zhitkov Formation comprising the *Neocolumbites insignis* and *Subcolumbites multiformis* Zones, with the stratotype at Zhitkov Cape, Russian Island. The latter is overlain there by the Anisian Karazin Formation, having its stratotype in the district of Karazin Cape, Russian Island.

The first three formations are represented mainly by sandy facies, but the Lazurnaya Formation (110 m) differs by the predominance of coarse, disintegrated rocks at its base and the appearance of bivalve coquinas in its middle and upper parts. The Tobizin Formation (180 m) is characterized by the development of cephalopod coquinoids and the appearance of the thin siltstone member. The Schmidt Formation (40 m) is characterized by the abundance of rather thick (up to 1.2 m) lenses of bivalve and brachiopod coquinoid calcareous sandstone and limestone. The Zhitkov Formation (85 m) is strongly differs from the underlying formations of the Lower Triassic in the extensive development of siltstone and mudstone with abundant remains of ammonoid and bivalve shells. The Karazin Formation is characterized by a predominance of banded and spotted sandy siltstone alternating with sandstone, including unusually light, arkose, lacking benthonic mollusc remains (excep the basal beds), but with radiolarian and ammonoid remains.

The Lower Triassic of the eastern sections comprise only two formations: the Lazurnaya and Zhitkov formations. The sharp boundary between these - see e.g. the Abrek Bay section (Fig. 3) - lies in the *Hedenstroemia bosphorensis* Zone. The sequential change of facies correlates with a lower subsidence of the basin in the western or southwestern parts than in the eastern part.

The deposition of the sediments of the Karazin Formation seems to have taken place on the deepest parts of a shelf as is evidenced by radiolarian accumulations in boulders at Abrek Bay; radiolarians are not known from the more shallow shelf facies of the Lower Triassic. Typical Far East Anisian facies are widespread - from Little Khingan in the northwest up to South Primorye and Kitakami in the southeast. The reduction of the number of benthonic remains in Anisian sediments could be related with to the accumulation in the deepest parts of a shelf with an oxygen deficit. For the benefit of various conditions of sedimentation in Early and Middle Triassic more expressed intensivity of phosphatogenes during Anisian can testify in comparison with Induan and Olenekian (Zakharov & Shkolnik, 1994).

Concluding remarks

Our analysis shows that in the present stage of biostratigraphic investigation only two candidates for a global stratotype of the Induan-Olenekian boundary can be proposed: (1) the Tri Kamnya Cape – Orel cliff section, and (2) Abrek Bay section. All other investigated Lower Triassic sections of the Lower Triassic, can, even when less favourable, be used for studying ammonoid assemblages of the Upper Induan and Lower Olenekian in order to get a better overall view, and thus may help to solve many problems with regard to global correlations.

The position of the Induan-Olenekian boundary in South Primorye, the Himalayas, Siberia and Canada can be defined at first appearence of the ammonoid *Hedenstroemia*. The occurrence of *Meekoceras gracilitatis* White in association with *Flemingites* and other typical representatives of the *Hedenstroemia bosphorensis* Zone in South Primorye allows a sound correlation with both the *Meekoceras gracilitatis* Zone of Idaho and the *Flemingites flemingianus* Zone of the Salt Range. It recently became clear that *Euflemingites prynadai* (Kiparisova) and representatives of the genus *Arctoceras* occur throughout the lower two zones of the Olenekian in South Primorye. Because species of *Euflemingites* and *Arctoceras* are known from the Lower Triassic of the Boreal realm, there enable a more accurate correlation of the Smithian of the Boreal realm (Tozer, 1995) with the lower zones of the Ayaxian substage of the Tethys (Zakharov, 1997).

The extended interval of normal polarity assumed for the investigated part of the Olenekian in South Primorye and data the destribution of *Arctoceras* and *Euflemingites* could correspond to a large zone of normal polarity of Spitsbergen and Canada (Mørk et al., 1999) that has recently been established in the Smithian *Euflemingites romundary* (upper part) and *Wasatchites tardus* zones.

References

ARTHABER, G., 1911. Die Trias von Albanien. Beitr. Paläontol. Geol. Österr. -Ung. Anf. Orients. Wien., 24: 169-277.

BITTNER, A., 1899. Trias-Ablagerungen des Süd-Ussuri-Gebietes in der Ostsibirischen Küstenprovinz. Mém. Com. Géol., 7(4): 1-35, Taf.1-4.

BURIJ, I.V., 1959. Triassic stratigraphy of South Primorye. Trudy Dalnevost. Politekhn. Inst.,1959(1): 3-34. (In Russian.)

BURIJ, I.V., 1997. Paleogeography of Triassic sedimentation in South Primorye. Mém. Géol. (Lausanne), 30: 25-34 (in Russian).

BURIJ, I.V. & ZHARNIKOVA, N.K., 1981. Ammonods from Tirolites Zone of South Primorye. Paleont. Zhurn., 1981(3): 61-69 (in Russian).

BURIJ, I.V., ZAKHAROV, Y.D., ZHARNIKOVA, N.K.& NEVOLIN, L.A., 1972. On finding of *Anasibirites* fauna in South Primorye and its stratigraphical significance. In: Osadochnye i vulkanogennye formatsii Dalnego Vostoka (Sediment and volcanogenic formations of Far East), 1972: 79-81. Vladivostok, DVNC Akad. Nauk SSSR (in Russian).

BURIJ, I.V., ZHARNIKOVA, N.K., LOZOVSKY, V.R. & BURYI, G.I., 1977. K biostratigrafii nizhnego triasa Yuzhnogo Primorya (To Lower Triassic biostratigraphy of South Primorye). Izv. Vysshikh uchebnykh zavedenii, »Geolgiya i Razvedka«, VINITI, 1977 (243-77 Dep.): 1-34, Moskva (in Russian).

BURIJ, I.V., ZHARNIKOVA, N.K. & BURYI, G.I., 1976. To the problem of subdivision of the Lower Triassic of South Primorye. Geol. Geoph., 1976(7): 150-156 (in Russian).

BURIJ, I.V., BURYI, G.I. & ZHARNIKOVA, N.K., 1976. Stratigraphy and interrelationship of marine and continental Triassic deposits in South Primorye. In: S.G. Lucas & M. Morales (eds.), New Mexico Mus. Nat. Hist. Sci., Bull, 3: 47-49.

BURYI, G.I., 1979. Lower Triassic conodonts of South Primorye., 143 pp., pls. 1-21. Moskva, Nauka (in Russian).

CHAO KING-JOO, 1959. Lower Triassic ammonoids from Western Kwangsi, China. Palaeontol. Sinica, N.S.B., 9: 155-355.

DAGYS, A.S., 1974. Triassic brachiopods, 387 pp., pls. 1-49. Novosibirsk, Nauka (in Russian).

DIENER, C., 1895. Triadische Cephalopodenfaunen der ostsibirischen Küstenprovinz. Mém. Com. Géol., 14(3): 1-59, pls. 1-5, St.-Péterbourg.

GUEX, J., 1978. Le Trias Inférieur des Salt Ranges (Pakistan): problèmes biochronique. Eclog. Geol. Helv., 71: 105-144.

IVANOV, D.L., 1891. Geological report 1888. Gornyi Zhurn., 1891(8): 248-304 (in Russian).

KARPINSKY, A.P., 1888. Margaritov's investigations in Primorye area. Izv. Geol. Com., 21: 349-351 (in Russian).

KIPARISOVA, L.D., 1938. Lower Triassic bivalves of Ussuri region. Trudy GIN AN SSSR, 7: 197-311 (in Russian).

KIPARISOVA, L.D., 1961. Paleontological basis of Triassic stratigraphy of Primorye region. 1. Cephalopods. Trudy VSEGEI, n. ser., 48: 1-278, pls. 1-38 (in Russian).

KIPARISOVA, L.D., 1961. Paleontological basis of Triassic stratigraphy of Primorye region. 2. Late Triassic molluscs and general stratigraphy. Trudy VSEGEI, n. ser., 181: 1-246, pls. 1-17 (in Russian).

KIPARISOVA, L.D. & POPOV, Y.N., 1956. Subdivision of the Lower series of the Triassic system into stages. Dokl. Akad. Nauk SSSR, 109(4): 842-845 (in Russian).

KIPARISOVA, L.D. & POPOV, Y.N., 1964. The project of subdivision of the Lower Triassic into stages. XXII Int. Geol. Congress, Rep. Soviet Geologists, Problem 16a, p. 91-99 (in Russian).

KORZH, M.V., 1959. Petrographiya triasovykh otlozheniy Yuzhnogo Primorya i paleogeographiya vremeni ikh obrazovaniya (Petrography of Triassic sediments of South Primorye and paleogeography of the time of their accumulation), 83 pp.. Moskva, Izd. AN SSSR (in Russian).

KIPARISOVA, L.D., POPOV Y.N., 1964. A scheme for the subdivision of the Lower Triassic into stages. Intern. Geol. Congress (India). Report of the Twenty-Second Session. Pt. 8. Proceedings of section 8. Palaeontology and Stratigraphy., p. 223-232. New Delhi.

KOZUR, H., 1972. Vorläufige Mitteilung zur Parallelisierung der germanischen und tethyalen Trias sowie einige Bemerkungen zur Stufen- und Unterstufengliederung der Trias. Mitt. Ges. Geol. Bergbaustud., 21: 361-412.

KOZUR, H., 1992. The problem of the Lower Triassic subdivision. Albertiana, 10: 21-22.
KUMMEL, B., 1973. Aspects of the Lower Triassic (Scythian) stage. Mem. Canad. Soc. Petrol. Geol., 1973(2): 557-571.
MOJSISOVICS, E., 1882. Die Cephalopoden der mediterranen Triasprovinz. Abb. Geol. Reichsanst., 10: 1-322.
MOJSISOVICS, E, 1886. Arktische Triasfaunen. Beitraege zur palaeontologischen Charakteristik der arktisch-pazifischen Triasprovinz. Mem. Acad. Sci. Nat., 7(33): 1-159, St. Petersbourg.
MOJSISOVICS, E., WAAGEN, W. & DIENER, C., 1895. Entwurf einer Gliederung der pelagischen Sedimente des Trias-System. Sitz. Ber. Akad. Wiss. Wien, math. Naturwiss. Kl., 104: 1271-1302.
MØRK, A., ELVEBAKK, G., FOSBERG, A.W., HOUNSLOW, M.W., NAKREM, H.A., VIGRAN, J.O. & WEITSCHAT, W., 1999. The type section of the Vikinghogda Formation: new Lower Triassic unit in central and eastern Svalbard. Polar Res., 18: 51-82.
MOJSISOVICS, E., 1873-1875. Das Gebirge um Hallstatt. 1. Die Mollusken Faunen der Zlambach und Hallstaetter-Schichten. Abhandl. Geol. Reichsanst. Wien, 6(1,2): 1-174.
ROSTOVTSEV, K.O. & DAGYS, A.S., 1987. A standard for the Lower Triassic. 27th Int. Geol. Congress. Stratigraphy. C.01.1, 79-86. Moskva, Nauka (in Russian).
SHEVYREV, A.A., 1990. Ammonoids and Triassic chronostratigraphy. Trudy Paleont. Inst AN SSSR, 241: 1-179 (in Russian).
SHEVYREV, A.A., 1995. Triassic ammonites of Northwestern Caucasus. Trudy Paleont. Inst., 264: 174 pp. (in Russian).
TOZER, E.T., 1965. Latest Lower Triassic ammonoids from Ellsmere Island and north-eastern British Columbia. Bull. Geol. Surv. Can., 123: 1-45.
TOZER, E.T., 1978. Review of the Lower Triassic ammonoids succession and its bearing on chronostratigraphic nomenclature. Schriftern. Erdwiss. Kom. Oester. Akad. Wiss., 4: 21-36.
TOZER, E.T., 1994. Canadian Triassic ammonoid faunas. Geol. Survey Canada Bull., 467: 1-663.
VAVILOV, M.N. & LOZOVSKY, V.R., 1970. To the problem of Lower Triassic stage differentiation. Izv. Akad. Nauk SSSR, Ser. Geol., 1970 (9): 93-99 (in Russian).
WITTENBURG, P.V., 1910. Geological note on Murav'ev-Amursky Peninsula and Russian Island, 44 pp., S.-Petersburg (in Russian).
WITTENBURG, P.V., 1916. Geological description of Murav'ev-Amursky Peninsula and Imper. Evegene. Zapiski Obstchestva Izucheniya Amurskogo Kraya, 15: 1-480 (in Russian).
VOINOVA, E.V., KIPARISOVA, L.D. & ROBINSON, V.N., 1947. Class Cephalopoda. Atlas rukovodyaschikh form iskopaemykh faun SSSR (Atlas of guide fossil fauna of USSR), 7. Triassic System., p. 124-176. Moskva-Leningrad: Gosgeolizdat (in Russian).
WAAGEN, W., 1895. Salt Range fossils. 2. Fossils from Ceratite Formation. Paleont. Indica. Ser. 13, 2: 1-323.
ZAKHAROV, Y.D., 1968. Biostratiraphiya i ammonoidei nizhnego triasa Yuzhnogo Primorya (Lower Triassic biostratigraphy and ammonoids of South Primorye), 175 pp., pls. 1-31. Moskva, Nauka (In Russian).
ZAKHAROV, Y.D., 1973. New stage zone subdivision of the Lower Triassic. Geologiya i geophizika, 1973(7): 51-58 (in Russian).
ZAKHAROV, Y.D., 1978. Rannetriasovye ammonoidei Vostoka SSSR (Early Triassic ammonoids of the East USSR), 224 pp., pls. 1-19. Moskva, Nauka (in Russian).
ZAKHAROV, Y.D., 1986. The problem of stage-subdivision of the Lower Triassic. Albertiana., 6: 14-21.
ZAKHAROV, Y.D., 1994. Stratotype of the Induan-Olenekian boundary of the Lower Triassic. Tikhookeanskaya Geologiya, 1994(4): 33-44 (in Russian).
ZAKHAROV, Y.D., 1996. The Induan-Olenekian boundary in the Tethys and Boreal realm. Ann. Mus. Civ. Rovereto. Sec.: Arch., St., Sc. Nat., Suppl., 11: 133-156.
ZAKHAROV, Y.D., 1997. Ammonoid evolution and the problem of the stage and substage division of the Lower Triassic. Mém. Géologie (Lausanne), 30: 121-136.
ZAKHAROV, Y.D. & POPOV, A.M., 1999. New data on Induan/Olenekian boundary in South Primorye. Annual report 1999 of IOBWG. Albertiana, 22: 19.
ZAKHAROV, Y.D. & SHKOLNIK, E.L., 1994. Permian-Triassic cephalopod facies and global phosphatogenesis. Mém. Géologie (Lausanne), 22: 171-182.
ZAKHAROV, & RYBALKA, S.V., 1987. A standard for the Permian-Triassic in the Tethys. In:Y.D. Zakharov & Y.I. Onoprienko (eds.), Problems of Permian and Triassic biostratigraphy of the East USSR, p. 6-48, pls. 1-5. Vladivostok, DVNC AN SSSR (in Russian).
ZAKHAROV, Y.D. & SOKAREV, A.N., 1991. Biostratigraphiya i paleomagnetizm permi i triasa Evrazii (Permian and Triassic biostratigraphy and paleomagnetism of Eurasia), 135 pp. Moskva, Nauka (in Russian).
ZAKHAROV, Y.D., UKHANEVA, N.G., IGNATYEV, A.V., AFANASYEVA, T.B., BURYI, G.I., PANASENKO, E.S., POPOV, A.M., PUNINA, T.A. & CHERBADZHI, A.K., 2000. Latest Permian and Triassic carbonates of Russia: new palaeontological findings, stable isotopes, Ca-Mg ratio, and correlation. In: H.Yin, J.M. Dickins, G.R.Shi & J.Tong (Editors), Permian-Triassic evolution of Tethys and Western circum-Pacific. Developments in palaeontology and stratigraphy, 18: 141-171.
ZAKHAROV, Y.D., UKHANEVA, N.G., IGNATYEV, A.V., POPOV, A.M. & PUNINA, T.A., 1999. Prelimenery data on carbon and oxygen isotopic composition of Triassic organgenic carbonates of the Tethyan belt and biological productivity of Triassic seas. Tikhookeanskaya Geologiya, 18 (3):47-53 (in Russian).
ZAKHAROV, Y.D., UKHANEVA, N.G., IGNATIJEV, A.V., AFANASYEVA, T.B., BURYI, G.I., KOTLYAR, G.V., PANASENKO, E.S., POPOV, A.M., PUNINA, T.A., CHERBADZHI, A.K. & VUKS, V.Y., 1999. Dorashamian, Induan, Olenekian, Anisian, Ladinian, Carnian, Norian and Rhaetian carbonates of Russia: stable isotopes, Ca-Mg ratio, and correlation. Albertiana, 22. 27-30.
ZAKHAROV, Y.D., SHIGETA, Y., POPOV, A.M., SOKAREV, A.N., BURYI, G.I., GOLOZUBOV, V.V., & PANASENKO, E.S., in press. Candidates in global stratotype of the Induan-Olenekian boundary (Lower Triassic) in Primorye region. Stratigr. Geol. Correlation (in Russian).