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Candidates for a Global Stratotype of the Induan–Olenekian Boundary (Lower Triassic) in Southern Primor'e

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Abstract—The Lower Triassic section in the Abrek Bay region, southern Primor'e, is described in detail along with its lithologic, paleontological, and magnetostratigraphic characteristics. This and another section in the Tri Kamnya Cape region, southern Primor'e, are proposed as candidates for the Global Stratotype Section and Point of the Induan–Olenekian boundary. The base of the Olenekian Stage is defined at the appearance level of ammonoid genera *Hedenstroemia* and *Meekoceras*.

Key words: Lower Triassic, Induan and Olenekian stages, biostratigraphy, magnetostratigraphy, southern Primor'e.

Many variants of the Lower Triassic stage subdivision were proposed during the investigation history of Triassic sediments. At the Lausanne Symposium of 1991, the Triassic Subcommission recommended the scheme by Kiparisova and Popov (1964) who suggested to subdivide the Lower Triassic into the Induan and Olenekian stages. At the Triassic Subcommission meeting held in Kyoto during the 29th International Geologic Congress, the subject was discussed again with regard to additional remarks by Baud and Gaetani (1992) and in view of a forthcoming work before the formal ratification of the scheme by the Executive Committee of the International Union of Geologic Sciences. The topical problem indicated by the Triassic Subcommission of the International Stratigraphic Commission is the choosing of a global stratotype of the boundary between the mentioned stages. In this connection, a special working group (IOBWG) chaired by one of the authors (Yu.D. Zakharov) with A. Baud (the Lausanne University) as a vice-chairman was formed in 1997.

The problem of the Induan–Olenekian boundary roots in the fact that none of the sections in the Induan (Salt Range, Pakistan) and Olenekian (Arctic Siberia) stratotype areas (Zakharov, 1996) is appropriate for the boundary stratotype because of the following reasons. (1) The Induan Stage in the Olenek River basin is mainly composed of lagoonal tuffaceous sediments lacking reliable paleontological characteristics. (2) In most sections known in the Indus River basin (Salt Range) and adjacent Himalayan regions, ammonoids are scarce or missing immediately in the boundary beds between the Ceratite Marl and Ceratite Sandstone, where the boundary between the Lower Triassic stages was suggested to be.

Consequently, there is a problem of global correlation of the Lower Triassic stages, which are distinct in different biochores. In this connection, intermediate regions between the Boreal and Himalayan provinces, which show some relations to both biochores, are of prime importance. Among such regions, there is the Ussuri Province, including the southern Primor'e area. Data on the Lower Triassic stratigraphy in this area were used by Kiparisova and Popov (1956, 1964) in their substantiation of the Induan–Olenekian boundary.

Several Lower Triassic reference sections are known in the southern Primor'e (Burii, 1959; Korzh, 1959; Kiparisova, 1961, 1972; Zakharov, 1968, 1978, 1997). Zakharov (1994, 1996) recently proposed the section in the Tri Kamnya Cape region on the western coast of the Ussuriiskii Bay for the candidate of the Induan–Olenekian boundary stratotype.

This paper is dedicated to substantiation of a second candidate for the global Induan–Olenekian boundary stratotype (the Olenekian stage limitotype) in the southern Primor'e, namely, in the Abrek Bay region. Paleomagnetic and petrographic research was performed in the Vladivostok Petrophysical Laboratory of the Primor'e Prospecting-Survey Expedition. Magnetic susceptibility was determined with the help of KLY-2 bridge. The remanent magnetization of samples was measured using roll-generators of JR-4 type. The temperature range during thermal demagnetization was from 100 to 600°C.

INVESTIGATION HISTORY OF LOWER TRIASSIC IN SOUTHERN PRIMOR'E

The Early Triassic ammonoids from the southern Ussuri region were first described in monograph by Diener (1895). These were mainly paleontological materials collected by D.L. Ivanov. The discovery of paleontological remains in Triassic sediments of the southern Far East was of great importance for the world stratigraphy, because only three regions with complete Lower Triassic sections were known before that moment, namely, the Alps (Mojsisovics, 1882), Arctic Siberia (Mojsisovics, 1886), and the Salt Range (Waagen, 1895).

Vittenburg (1910, 1916) distinguished *"Pseudomonotis" (=Eumorphotis) iwanowi, "Terebratula" (=Fletcherithyris) margaritovi*, and *"Xenodiscus" (=Kazakhstanites) nicolai* zones in the Lower Triassic of the southern Ussuri region. He referred basal conglomerates of the section to the Jurassic, erroneously considering that the underlying flora-bearing sequence in the Novik Bay region of the Russkii Island is of Jurassic but not of the Permian age, as it was established later on.

Kiparisova (1961) suggested the following Lower Triassic zonation based, in contrast to the scheme of Vittenburg, on ammonoids representing a single invertebrate group: (1) basal layers (conglomerates); (2) *Proptychites*, originally *Meekoceras* Zone; (3) *Flemingites* Zone (sandstones, siltstones, and shales); (4) *Prosphingites* Zone (siltstones and sandstones); and (5) *Subcolumbites* Zone (sandstones, siltstones, and shales). The Induan–Olenekian boundary was originally placed at the top of the *Flemingites* Zone (Kiparisova and Popov, 1956; Burii, 1959; Korzh, 1959; Kiparisova, 1961), and afterward, when the *Flemingites* and *Prosphingites* zones were united (Kiparisova and Popov, 1964; Kiparisova, 1972), at the base of the former.

When correlating different sections in Primor'e, Zakharov (1968) was first to note a significant facies variability of the Lower Triassic sediments in the region under discussion, where it was ignored earlier. As a result, he showed that some Induan and Olenekian zonal ammonoid assemblages distinguished by Kiparisova (1961) were misinterpreted.

By the moment, the following unified Lower Triassic zonation (Zakharov, 1968, 1978, 1997; Burii *et al.*, 1972; Burii and Zharnikova, 1981; Zakharov and Rybalka, 1987) is approved for the Far East by the 4th Interdepartmental Regional Stratigraphic Conference on the Precambrian and Phanerozoic of the southern Far East and eastern Transbaikal region (Khabarovsk, 1990).

Induan Stage: (1) *Glyptophiceras ussuriense* beds; (2) *Gyronites subdharmus* Zone.

Olenekian Stage: (1) *Hedenstroemia bosphorensis* Zone; (2) *Anasibirites nevolini* Zone; (3) *Tirolites* Zone (with *Bajarunia dagysi* and *Tirolites ussuriensis* beds); (4) *Neocolumbites insignis* Zone; (5) *Subcolumbites multiformis* Zone.

Burii and colleagues (Burii *et al.*, 1976, 1977, 1993; Burii, 1997) subdivided the Induan and Olenekian stages into the Lazurnaya, Tobizin, and Chernyshev horizons. After investigation of facies variability in the Lower Triassic sequences, both stages were additionally subdivided into formations (Zakharov, 1997).

The Early Triassic conodonts from southern Primor'e were first studied by Burii (1979). It should be noted however that using conodonts it is impossible to establish the exact position of the Olenekian lower boundary anywhere in the world, as stratigraphic range of index species of the *Neospathodus pakistanensis* Zone spans the uppermost Induan and lowermost Olenekian strata in both the Salt Range and Primor'e areas.

ABREK BAY SECTION OF THE LOWER TRIASSIC

The section is situated on the northeastern coast of the Abrek Bay, 0.8 km north of the Yunshi Cape (42°55′ N, 131°26′ E; Figs. 1 and 2).

Biostratigraphic Succession

Ivanov (see in Diener, 1895) was first to detect the Early Triassic bivalve and gastropod shells in the clayey deposits of the Abrek Bay (Strelok Inlet locality). Kiparisova (1938) cited the following taxa of Lower Triassic bivalves collected by Vittenburg in 1908–1923 and Krishtofovich in 1924 around the Abrek Bay: *Claraia aurita* Hauer, *Eumorphotis multiformis* (Bittner), *"Pecten" (=Chlamys?) kryshtofowichi* Kipar., *Myoconcha* aff. *goldfussi* Dunk., and *Posidonia abrekensis* Kipar.

The first and sole description of Triassic cephalopods from the Abrek Bay region was done by Kiparisova (1961) who investigated collections by Nozdreev, Trifonov, Burii, and Korzh of 1938-56. She described two nautiloid forms (*Menuthionautilus, "Syringoceras"*), seven ammonoids [(*Hedenstroemia, Arctoceras (="Proptychites"), Gyronites*, and *Meekoceras*] from Lower Triassic beds, and a shell identified as *Discoptychites.*

Kiparisova (1972) noted a considerable discrepancy between the stratigraphic schemes of Nozdreev (Kiparisova, 1972), Burii (1959), Korzh (1959), and Vasil'ev (Kiparisova, 1972), and this eventually has led her to their invalid correlation. She determined the Induan–Olenekian boundary at the appearance level of *Hedenstroemia* and *Meekoceras*, on the one hand, and at the transition from sandy to silty facies, on the other. Her conclusion comes into conflict with report by Nozdreev who encountered *Hedenstroemia* in the sandy facies. Dagys (1974) who described a new genus and species of an articulate brachiopod *Abrekia sulcata* Dagys from

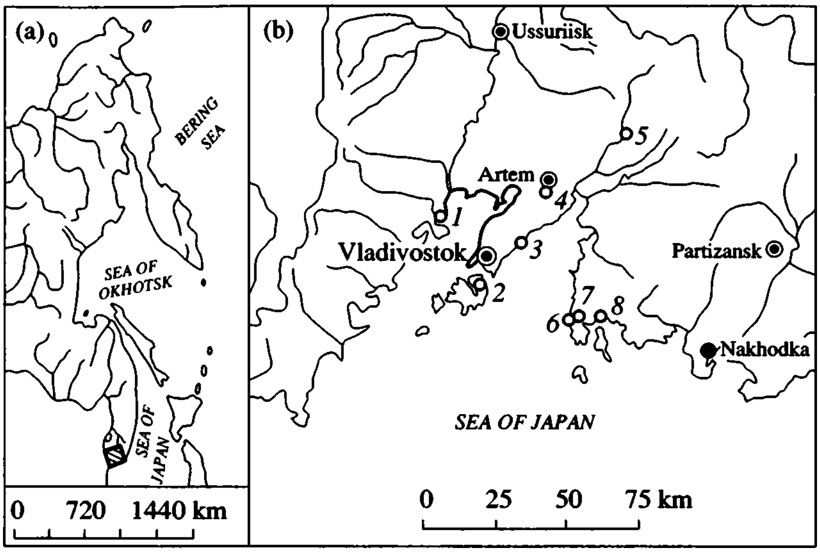

Fig. 1. Sections of the Induan–Olenekian boundary sediments (Lower Triassic) in the study area (a) crosshatched and southern Primor'e (b):

(*1*) western coast of the Amurskii Bay between the Atlasov and Ugol'nyi capes; (*2*) Ayaks Bay (Russkii Island); (*3*) Tri Kamnya Cape and Orel Cliff (western coast of the Ussuriiskii Bay); (*4*) "SMID" Quarry near the Artem; (*5*) left bank of the Artemovka River; (*6*) Kom-Pikho-Sakho Cape; (*7*) area of the Yuzhnorechensk railway station (Shimeuza); (*8*) Abrek Bay (Strelok Strait).

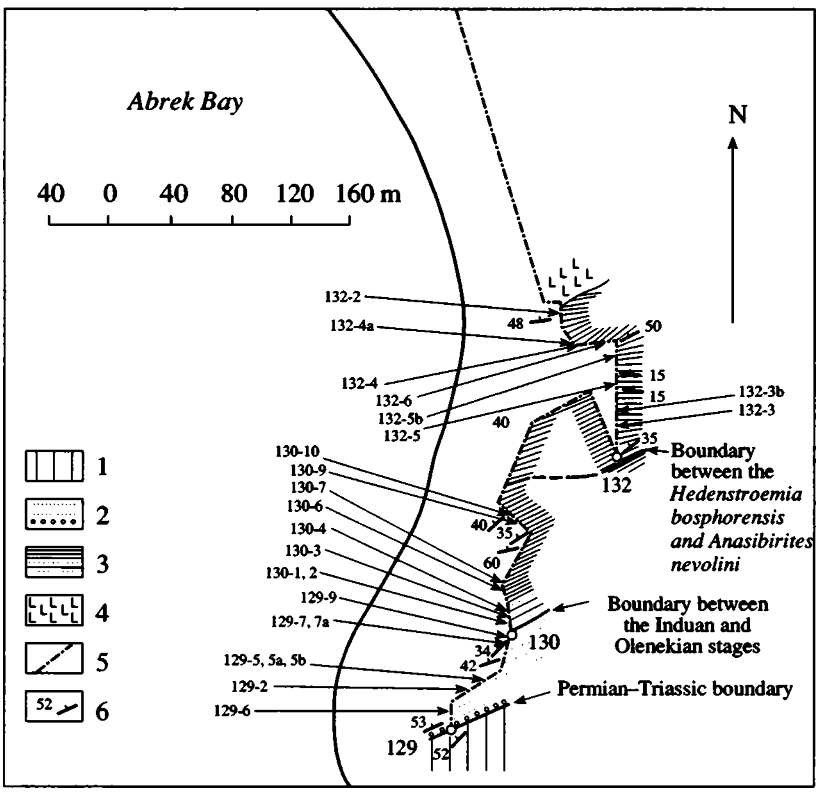

Fig. 2. Geology of the northeastern coast of the Abrek Bay: (1) continental sediments of the Murgabian Stage (Abrek Formation); (2) Induan marine sediments (lower and middle parts of the Lazurnaya Formation); (3) marine sediments of the Olenekian *Hedenstroemia bosphorensis* and *Anasibirites nevolini* zones (upper part of the Lazurnaya and lower part of the Zhitkov formations); (4) dykes of dioritic porphyrite; (5) route of investigation; (6) bed attitude.

the Lower Triassic sandstones of the Abrek Bay attributed them to the Induan Stage.

The description of the Lower and, partly, Middle Triassic sequence of the Abrek Bay region that is given below is based on more representative assemblages of invertebrates collected in 1997 and 1998. Continental deposits of the Murgabian Abrek Formation, which are represented at the top by light gray, fine- to medium-grained tuffaceous sandstones and gravelstones, are unconformably, with a hidden hiatus, overlain by the following Lower Triassic units (from the base upward).

Induan Stage

Gyronites subdharmus Zone

(1) Fine- to medium-pebbled conglomerate 1.3 m thick; pebbles are set in a greenish-gray sandy matrix differing from underlying sandstones by a good sorting. Pebbles of acidic and intermediate extrusive rocks prevail in the coarse clastic fraction.

(2) Greenish gray, fine-grained sandstone bearing numerous lenses (1 to 3 cm thick) of fine-pebbled conglomerates; total thickness is 4.0–4.5 m.

(3) Greenish gray, fine-grained sandstone enclosing separate molluscan valves, rare pebbles, small angular fragments of black siltstone and shale, and few thin lenses of fine-pebble conglomerates; the bed is 19.0 to 21.0 m thick.

(4) Greenish gray, fine-grained sandstone 8.0 m thick, bearing lenses of calcareous coquinoid sandstone up to 15 cm thick; an interlayer of banded sandstone with clayey laminae 1 to 3 mm thick occurs 5 m above the base of the member. The sediments yield remains of brachiopods *Lingula borealis* Bittner and *Orbiculoidea* sp., bivalves *Claraia australasiatica* Krumb., *Promyalina putiatinensis* (Kipar.), *Eupecten* cf. *ussuricus* (Bittner), and *Entolium microtis* Witt., ammonoid *Gyronites subdharmus* Kipar., crab nippers among arthropods, and skate teeth among chordates.

(5) Greenish gray, fine-grained, micaceous sandstone 6.0 m thick, enclosing numerous black siltstone and shale interbeds of 2 to 10, rarely to 40-mm in thickness, and calcareous coquinoid sandstone lenses 20 to 40 cm thick; asymmetric ripple marks on bedding planes represent traces of a southeastward (125°) current. Bivalve *Neoschizodus laevigatus* (Zieten), ammonoid *Lytophiceras?* sp., and large gymnosperm leaves were found in the member.

(6) Greenish gray, fine-grained sandstone 5.0 m thick, with thin black siltstone and shale interbeds separated by intervals of 0.5–0.6-m and with a calcareous coquinoid sandstone bed 30 cm thick at the base of the member; The bedding planes are decorated with asymmetric ripple marks. Sediments contain brachiopods *Lingula* sp. and *Orbiculoidea* sp., bivalves *Eumorphotis multiformis* (Bittner), *Neoschizodus laevigatus* (Zieten), and *Anodontophora fassaensis* (Wissm.), gastropods, and ammonoids *Gyronites subdharmus* Kipar., *Koninckites* sp. indet., and *Ambites?* sp.

The total thickness of Induan sediments in the section is 43 to 46 m.

Olenekian Stage

Hedenstroemia bosphorensis Zone

(7) Gray, fine-grained sandstone 2.6 m thick, enclosing a gray calcareous coquinoid sandstone interbed (30 cm) at the base, rare thin black siltstone and shale interlayers, and siderite concretions; sediments yield bivalve mollusks *Promyalina* sp., *Entolium microtis* (Witten.), *Velopecten minimus* Kipar., Pectinidae gen. et sp. nov., ammonoids *Meekoceras boreale* Diener, and *Ambites* sp., and nautiloid *Phaedrysmocheilus* sp.

(8) Light gray, fine-grained sandstone 1.8 m thick, intercalated with fine-grained, banded clayey sandstones and calcareous coquinoid sandstone lenses up to 50 cm thick; asymmetric ripple marks are seen on bedding planes. Brachiopods *Lingula borealis* Bittner, *Orbiculoidea* sp., and dominant *Abrekia sulcata* Dagys, scarce bivalves *Promyalina* sp., ammonoids *Arctoceras?* sp. indet., *Meekoceras boreale* Diener, and Melagathiceratidae gen. et sp. nov. are found along with few bryozoan remains.

(9) Alternating gray fine-grained and banded sandstones 2.15 m thick, enclosing numerous angular black siltstone fragments and a black silty shale layer 5 cm thick at the base; ammonoids Melagathiceratidae gen. et sp. nov. were encountered in sediments.

(10) Alternating light gray, fine-grained, banded (80 cm thick) and greenish gray fine-grained (5 cm thick) sandstones bearing scarce calcareous marly concretions; the total thickness is 8.0 m. The member yields nautiloids *Menuthionautilus korzchi* Kiparisova (Shigeta's collection) and *Gyronautilus praevolutum* (Kiparisova) (Zakharov and Shigeta, 2000), and ammonoids *Meekoceras boreale* Diener. The described ammonoid *Hedenstroemia* sp. indet. (Nozdreev's collection) and nautiloid *Menuthionautilus korzchi* Kipar. (Korzh's collection) (Kiparisova, 1961, 1972) most likely originated from these sandstones.

(11) Alternating black siltstone and argillite beds 50 cm thick, greenish-gray fine-grained banded sandstone layer up to 20 cm thick, and gray fine-grained sandstone bed 5 to 10 cm thick; total thickness is 2.7 m.

(12) Greenish gray, fine-grained sandstone, banded owing to thin shale laminae and bearing calcareous marly lenses and concretions; thickness is 10.0 m. Sediments contain bivalve mollusks *Palaeoneilo? prynadai* Kipar., *Pteria ussurica* Kipar., *Eumorphotis iwanowi* (Bittner), *Promyalina* sp., and *Anodontophora fassaensis* (Wissm.) and ammonoids *Hedenstroemia bosphorensis* (Zakharov) (Shigeta's collection), *Parahedenstroemia conspicienda* Zakharov, *Inyoites spicini* Zakharov, *Arctoceras septentrionale* (Diener), *Pseudoprosphingites magnumbilicatus* (Kipar.),

Ambites sp., *Koninckites* aff. *timorensis* Wanner, *Meekoceras boreale* Diener, *M. varaha* Diener, *Dieneroceras chaoi* Kipar., and *Preflorianites* cf. *radiatus* Chao.

(13) Greenish gray siltstone 8.6 m thick, banded because of thin shale laminae and bearing scarce calcareous marly concretions; ammonoids *Meekoceras varaha* Diener and *Meekoceras* sp. nov. were encountered at this level.

(14) Black siltstone 23.0 m thick, enclosing black shale beds with calcareous marly concretions and lenses, and rare gray fine-grained sandstone interlayers up to 15 cm thick; near the base, the member yields small bivalves *Velopecten minimus* Kipar., small gastropods, ammonoids *Pseudoprosphingites magnumbilicatus* (Kipar.), Gyronitidae?, *Koninckites timorensis* Wanner, dominant *Meekoceras varaha* Diener, *Flemingites radiatus* Waagen, and *Anaxenaspis* cf. *orientalis* (Diener).

Anasibirites nevolini Zone

(15) Alternating black siltstone and shale beds 35.0 m thick in total, bearing large calcareous marly lenses and concretions; sediments yield brachiopods *Abrekia?* sp., small bivalves *Promyalina* sp. and *Posidonia?* sp., and ammonoids *Pseudosageceras longilobatum* Kipar., *P.* sp., dominant *Arctoceras labogense* (Zharnikova), *A. subhydaspis* (Kipar.), *A. septentrionale* (Diener), *Pseudoprosphingites magnumbilicatus* (Kipar.), *Owenites koeneni* Hyatt et Smith, Gyronitidae gen. et sp. nov., dominant *Koninckites timorensis* Wanner, *Gurleyites* sp., *Anasibirites nevolini* Burij et Zharnikova, *Palaeokazakhstanites ussuriensis* (Zakh.), *Euflemingites prynadai* (Kipar.), and *Eophyllites* sp.

(16) Black siltstone and shale beds (5.0 m thick in total) with banded siltstone interlayers and calcareous marly concretions; ammonoids *Arctoceras labogense* (Zharnikova), *Pseudoprosphingites magnumbilicatus* (Kipar.), *Koninckites timorensis* Wanner, *Parakymatites* sp. nov., *Meekoceras varaha* Diener, *M.* sp. nov., *Hemiprionites dunajensis* Zakh., and *Preflorianites* cf. *radiatus* Chao. are found in the member. *Arctoceras abrekense* (Kipar.) encountered by Nozdreev, is likely derived from shales of the member.

(17) Gray banded siltstone 2 to 3 m thick.

The total thickness of two lower Olenekian zones is about 100 m.

Analysis of Faunal Assemblages

Bryozoans. Few fragments of branching bryozoan colonies were found in the calcareous sandstones of the lower Olenekian.

Brachiopods. About five or six brachiopod species are known from the Lower and Middle Triassic of the Abrek Bay region (Zakharov and Popov, 1999); all forms known from Induan sediments are inarticulate (in fauna). The lower Olenekian deposits are characterized by appearance and mass development of articulate brachiopod taxon *Abrekia sulcata.* Inarticulate *Lingula borealis* and *Orbiculoidea* sp. are typical of the Induan and lower Olenekian sandstones. *Orbiculoidea* forms are dominant in the upper Induan.

Bivalve mollusks. Bivalves, like other faunal remains, are extremely rare in the lower Induan sediments represented by shallow-water coarsely clastic facies, which contain only separate valves or broken shells. Similar bivalve assemblages are recorded in the upper Induan and lower Olenekian sandstones. Common species from these facies are *Entolium microtis, Neoschizodus laevigatus, Anodontophora fassaensis,* and some others. Among species abundant in the Induan sediments only, we can mention *Promyalina shamarae* and, likely, *P. putiatinensis*, though *Promyalina* sp. similar in morphology to the latter, occurs in the Olenekian as well.

Nautiloids. Remains of Early Triassic nautiloids were encountered only in the Olenekian sediments of the Abrek Bay. The trochospiral Olenekian forms are represented by species *Phraedrysmocheilus* sp., *Menuthionautilus korzhi*, and *Gyronautilus praevolutum.*

Ammonoids. Among Induan ammonoids only four species were classified. These are the zonal index species *Gyronites subdharmus, Lythophiceras?* sp., *Koninckites* sp. indet., and *Ambites?* sp. The *Hedenstroemia bosphorensis* Zone, the basal one in the lower Olenekian, is defined above the first occurrence level of *Meekoceras* forms, which are associated higher with *Hedenstroemia* and some other typical Olenekian taxa. The ammonoid assemblage of the zone is represented by 19 species of 14 genera (Fig. 3). The zonal index species was recently found in the lower part of the unit (Bed 12).

The base of overlying *Anasibirites nevolini* Zone marks the appearance level of its index species. *Arctoceras labogense* (dominating), *A. subhydaspis* (Kipar.), *A. abrekense, Gurleyites* sp., *Palaeokazakhstanites ussuriensis, Hemiprionites dunajensis, Eophyllites* sp., and *Parakymatites* sp. nov. are characteristic of the zone as well. Many other species, namely, *Arctoceras septentrionale, Pseudoprosphingites magnumbilicatus, Owenites koeneni, Koninckites timorensis, Meekoceras varaha, Euflemingites prynadai*, and others, are also known from the underlying zone of the described and other regional sections. In total, 20 species of 15 genera represent the assemblage of the *Anasibirites nevolini* Zone of the Abrek Bay section. Among them, one genus and two species are new.

Arthropods. Nipper remains of small crabs were encountered in the Induan sandstones.

Chordates. Presence of amphibian remains in the Olenekian clayey sediments (*Anasibirites nevolini* Zone) is inferred from found small fragments of bony

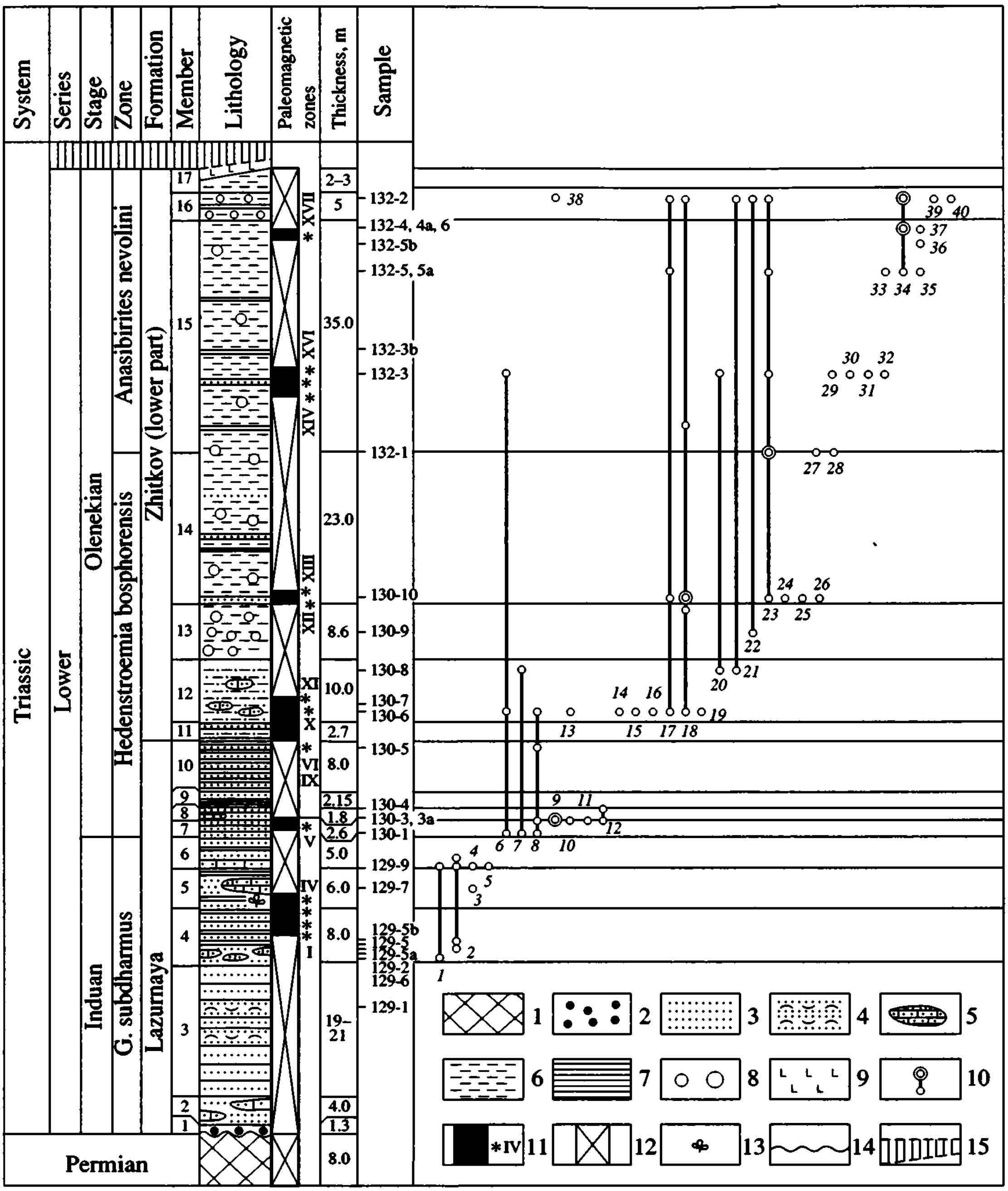

Fig. 3. Major invertebrate groups in the Lower and Middle Triassic of the Abrek Bay. Lithology: (1) Permian (Murgabian) sediments of the Abrek Formation; (2) conglomerate; (3) fine-grained sandstone; (4) sandstone bearing separate molluscan valves; (5) calcareous coquinoid sandstones; (6) silty shale; (7) shale; (8) calcareous marly concretions; (9) porphyrite dykes; (10) species range (dominating levels are marked by double circles); (11) normally magnetized rocks (asterisks and Roman numerals mark levels sampled for paleomagnetic measurements; (12) intervals unstudied for paleomagnetic properties; (13) leaf flora; (14) unconformity; (15) hidden interval. Species: (*1*) *Gyronites subdharmus* Kiparisova; (*2*) *Promyalina putiatinensis* (Kiparisova); (*3*) *Lytophiceras?* sp.; (*4*) *Promyalina schamarae* (Bittner); (*5*) *Koninckites* sp. indet.; (*6*) *Promyalina* sp.; (*7*) *Ambites* sp.; (*8*) *Meekoceras boreale* Diener; (*9*) *Abrekia sulcata* Dagys; (*10*) *Hedenstroemia* sp. indet.; (*11*) *Arctoceras?* sp. indet.; (*12*) Melagathiceratidae gen. et sp. nov.; (*13*) *Hedenstroemia bosphorensis* (Zakharov); (*14*) *Inyoites spicini* Zakh.; (*15*) *Koninckites* aff. *timorensis* Wanner; (*16*) *Dieneroceras chaoi* Kiparisova; (*17*) *Pseudoprosphingites magnumbilicatus* (Kiparisova); (*18*) *Meekoceras varaha* Diener; (*19*) *Parahedenstroemia conspicienda* Zakharov; (*20*) *Arctoceras septentrionale* (Diener); (*21*) *Preflorianites* cf. *radiatus* Chao; (*22*) *Meekoceras* sp. nov.; (*23*) *Koninckites timorensis* Wanner; (*24*) Gyronitidae?; (*25*) *Flemingites radiatus* Waagen; (*26*) *Anaxenaspis* cf. *orientalis* (Diener); (*27*) *Gurleyites* sp.; (*28*) *Anasibirites nevolini* Burij et Zharnikova; (*29*) *Owenites koeneni* Hyatt et Smith; (*30*) Gyronitidae gen. et sp. nov.; (*31*) *Palaeokazakhstanites ussuriensis* (Zakharov); (*32*) *Eophyllites* sp.; (*33*) *Pseudosageceras* sp. indet.; (*34*) *Arctoceras labogense* (Zharnikova); (*35*) *Euflemingites prynadai* (Kiparisova); (*36*) *Arctoceras subhydaspis* (Kiparisova); (*37*) *Pseudosageceras longilobatum* Kiparisova; (*38*) *Abrekia?* sp.; (*39*) *Parakymatites* sp. nov.; (*40*) *Hemiprionites dunajensis* Zakharov.

Table 1. Physical properties of the Lower Triassic sediments from the Abrek Bay region

Stratigraphic level	Mean parameter values			
	n	σ	χ	*In*
Induan (*Gyronites subdharmus* Zone)	49	2.550	186	0.8
Olenekian (*Hedenstroemia bosphorensis* and *Anasibirites nevolini* zones)	144	2.632	197	8.2

Note: (*n*) number of measurements; (σ) density (g/cm^3); (χ) magnetic susceptibility (10^{-6} SI); (*In*) remanent magnetization (mA/m).

Table 2. Paleomagnetic characteristics of Triassic sediments from the Abrek Bay locality

Stage	*N*(*n*)	*D*	*J*	*k*	*a*	Lt	Lng	O1	O2	Ltm	DMCM
Olenekian	10(23)	313.5	43.2	26.5	9.6	48.2	32.7	12	7	25.2	T400
Induan	4(9)	303.6	30.3	60.5	16.0	35.5	31.4	18	10	16.3	T400

Note: *N*(*n*), number of samples; (*D*, *J*) declination and inclination of the average vector of characteristic remanent magnetization; (*k*) concentration parameter of vectors; (*a*) confidence circle radius for the average vector at probability of 0.95; (Lt, Lng (O1, O2)) latitude and longitude (half axes of the definition error ellipsis) of the paleomagnetic north pole; (Ltm) geomagnetic latitude (paleolatitude) of the region; (DMCM) definition method of characteristic magnetization; (*T*) temperature of thermal demagnetization.

tissue. Skate teeth are found in the Induan and Olenekian sandstones.

Paleomagnetic Characteristics of the Induan–Olenekian Boundary Beds

As is known (Zakharov and Sokarev, 1991), it is difficult to use paleomagnetic data for the purpose of Lower Triassic magnetostratigraphy in southern Primor'e, because the investigated Triassic rocks from the Russkii Island and western coast of the Ussuriiskii Bay presumably reveal the metachronous (apart from primary and viscous) remanent magnetization of unclear origin. At the same time, the latest preliminary study showed that the Triassic rocks of the Abrek Bay locality are well suitable for magnetostratigraphic research. Sedimentary rocks, which were sampled here in a rather loose manner, revealed normal magnetization at 17 stratigraphic levels of the upper *Gyronites subdharmus* (Samples I–IV), *Hedenstroemia bosphorensis* (V–XIII), and *Anasibirites nevolini* (XIV–XVII) zones of the Induan and Olenekian stages (Fig. 3). At least some of them likely characterize a single extended zone of normal magnetization.

Table 1 includes data on physical properties of 17 orientated Lower Triassic rocks samples from the southeastern coast of the Abrek Bay. As one can see, the Induan rocks have lower density and remanent magnetization as compared to the Olenekian sediments despite the comparable parameters of magnetic susceptibility at both levels. The correlation analysis underlines these distinctions: a stable direct correlation between density and magnetic susceptibility is characteristic of the Induan rocks only. At the same time, rocks of both stages exhibit similar relationships between magnetic susceptibility and remanent magnetization parameters.

During the stepwise demagnetization by sample heating to 500°C, magnetic susceptibility of rocks remains almost constant, and changes do not exceed 10% of the initial value. As the heating temperature raises, the remanent magnetization of samples decreases down to 10–40% of the initial value at 400°C and to several percent at 500°C. At 600°C, the mineral composition changes considerably whereas magnetic susceptibility and remanent magnetization increase two–three times and more. Accordingly, we included in Table 2 only those paleomagnetic characteristics of studied Lower Triassic sediments, which have been measured by the thermal demagnetization up to the temperature of 400°C.

The presented data on the Abrek Bay section and published results on other Lower Triassic sections of southern Primor'e (Zakharov, 1994, 1996) show that beds, which yield the early Olenekian ammonoid assemblage, are easily distinguishable in the region. As far as it concerns the definition of the Induan–Olenekian boundary, the main problem is that the boundary beds proper are insufficiently exposed in the most known sections.

LOWER TRIASSIC LITHOLOGIC FACIES AND REGIONAL CORRELATION IN SOUTHERN PRIMOR'E

There are two major types of Lower Triassic sequences in southern Primor'e, which are composed of many and two lithologic facies. Western sections, which are situated in the Russkii Island and along western coast of the Amurskii Bay between the Atlasov and Ugol'nyi capes, are of the first type. Eastern sections of the second type are located in the following areas: the left bank of the Artemovka River, the Artem region, the Kom-Pikho-Sakho Cape on the eastern coast of the

Table 3. Correlated ammonoid and conodont zonations in the upper Induan and lower Olenekian sediments

Stage	Substage	Southern Primor'e				Salt Range		Northeastern Asia			Canada	
		Zakharov, 1997		Burii, 1979 (modified)		Waagen, 1895; Guex, 1978 (modified)	Sweet, 1970	Dagys, Ermakova, 1993 (modified)	Dagys, 1984		Orchard, Tozer, 1997	
Olenekian (lower part)	Ayaxian	*Tirolites–Amphistephanites*	*Tirolites ussuriensis*	*Icriospathodus collinsoni*		*Tirolites–Columbites* (lower part)	*Neogondolella jubata* (lower part)	*Northophiceras contrarium*	*Neogondolella jubata* (lower part)		?	*Neogondolella* aff. *sweeti*
			Bajarunia dagysi					*Bajarunia euomphala*				
		Anasibirites nevolini		*Neospathodus waageni*	*Neogondolella milleri*	*Anasibirites pluriformis*	*Neospathodus waageni*	*Anawasatchites tardus*	*Neospathodus waageni*	*Neogondolella milleri*	*Anawasatchites tardus*	*Neogondolella milleri*
		Hedenstroemia bosphorensis			*Parachirognathus–Furnishius*	*Flemengites flemengianus*		*Lepiskites kolymensis*		*Neogondolella moscheri*	*Euflemingites romunderi*	*Gladigondolella meeki* / *Neospathodus pakistanensis*
				Neospathodus pakistanensis			*Neospathodus pakistanensis*	*Hedenstroemia hedenstroemi*	*Neogondolella nepalensis*		*Hedenstroemia hedenstroemi*	?
Induan (upper part)		*Gyronites subdharmus* (upper part)				*Prionolobus rotundatus* (upper part)		?			*Vavilovites sverdrupi*	*Neospathodus cristagalli*
				Neogondolella carinata (upper part)			*Neospathodus cristagalli*	*Tompoprotychites turgidus*	?			
								Vavilovites sverdrupi				

Ussuriiskii Bay, vicinity of the Yuzhnorechensk railway station, and the Abrek Bay region. The Tri Kamnya Cape section on the western coast of the Ussuriiskii Bay is the intermediate between those groups, though closer to the western one.

The Russkii Island is a standard area of the polyfacies type sections. Zakharov (1997) distinguished here the following subdivisions: (1) the Lazurnaya Formation in the range of the Induan Stage and lower beds of the Olenekian *Hedenstroemia bosphorensis* Zone, which are most completely exposed in the Ayaks Bay of the Russkii Island, though the formation stratotype is situated in the western coast of the Ussuriiskii Bay between the Lazurnaya Inlet and the Tri Kamnya Cape (Zakharov, 1968); (2) the Tobizin Formation in the range of the *Hedenstroemia bosphorensis* Zone, its basal beds excluded, and the *Anasibirites nevolini* Zone, stratotype of which is located in the Tobizin Cape, Russkii Island; (3) the Schmidt Formation in the range of the *Tirolites-Amphistephanites* Zone with the stratotype on the Schmidt Cape, Russkii Island; and (4) the Zhitkov Formation in the range of the *Neocolumbites insignis* and *Subcolumbites multiformis* zones with the stratotype in the Zhitkov Cape, Russkii Island. Formations one to three are mainly represented by a sandy facies, though they differ from each other. The Lazurnaya Formation (110 m thick) shows predominance of coarse rocks in the lower part and occurrence of bivalve coquina lenses in the middle and upper parts. The Tobizin Formation (180 m thick) exhibits presence of cephalopod coquina beds and the appearance of a thin silty shale bed. The Schmidt Formation (40 m thick) encloses numerous and rather thick (up to 1.2 m) bivalve and brachiopod coquina lenses. The Zhitkov Formation (85 m thick) differs sharply from the underlying Lower Triassic formations in a wide distribution of silty shales bearing abundant ammonoid and bivalve remains.

In the eastern group of sections, the Lower Triassic is represented by two subdivisions only, the Lazurnaya and Zhitkov formations. The distinct boundary between them is within the lower Olenekian *Hedenstroemia bosphorensis* Zone, as it is exemplified by the section in the Abrek Bay southeastern coast (see Fig. 3).

In the eastern group of sections of southern Primor'e, the Zhitkov Formation corresponds to the *Hedenstroemia bosphorensis* (its lower part excluded), *Anasibirites nevolini, Tirolites-Amphistephanites, Neocolumbites insignis* and *Subcolumbites multiformis* zones. Only the lower part of the unit corresponding to the Tobizin Formation of the Russkii Island is exposed at the Abrek Bay locality.

The lower boundary of the Zhitkov Formation in southern Primor'e is obviously diachronous. The consecutive facies changes represent a result of the general basin deepening that progressed slower in its western or southwestern parts, as it is evident from lithology of the western sections.

CONCLUSION

The comprehensive analysis indicates that only two Lower Triassic sections of southern Primor'e, namely, that in the Tri Kamnya Cape area of the Ussuriiskii Bay western coast and the Abrek Bay section near the Strelok Inlet may be suggested as candidates for the Global Stratotype Section and Point of the Induan–Olenekian boundary. All alternative sections in southern Primor'e, despite some their disadvantages, may elucidate the total composition of the upper Induan–lower Olenekian zonal assemblages thus contributing to solution of the global correlation problem.

The Olenekian Stage base in southern Primor'e, Himalayas, Siberia, and Canada can be defined at the appearance level of *Hedenstroemia* forms coexisting with *Meekoceras* forms in the Tethyan Province. The recently discovered association of *Meekoceras gracilitatis* White with *Flemingites* and other ammonoid taxa typical of the *Hedenstroemia bosphorensis* Zone (Zakharov's collection from the western coast of the Ussuriiskii Bay in southern Primor'e) suggests that this zone is reliably correlative with the *Meekoceras gracilitatis* Zone of Idaho and with the *Flemingites flemingianus* Zone of the Salt Range. Currently it has been also found in southern Primor'e that *Euflemingites prynadai* (Kipar.) and *Arctoceras* forms are widespread in two lower zones of the Olenekian Stage. Since *Euflemingites* and *Arctoceras* species are also known in the Boreal areas, they may be used to refine correlation between the Smithian regional stage of Canada (Tozer, 1994) and lower Olenekian zones of the Primor'e (the regional Ayaxian Substage, Zakharov, 1997).

Judging from preliminary magnetostratigraphic data and distribution of *Arctoceras* and *Euflemingites* species, the inferred interval of an extended normal-polarity zone of the Ayaxian Substage in southern Primor'e can be correlated with the normal-polarity zone of comparable range that was recently established in Spitsbergen and Canada. In the last case, it spans at least the *Euflemingites romunderi* (upper part) and *Wasatchites tardus* zones of the Smithian regional stage (Mork *et al.*, 1999).

Dagys and Ermakova (1993); Dagys (1997) correctly noted the difficulty of correlating the Induan–Olenekian boundary sediments, when they are situated in different biogeographic areas despite an excellent global correspondence of the *Anasibirites* and *Wasatchites* (*Neogondolella milleri* Zone) beds (Table 3) and of some other Lower Triassic units of the conodont zonation. This is quite natural, though the problem is complicated, from our standpoint, by some fallacies in the Lower Triassic biostratigraphic scheme of northeastern Asia (Dagys and Ermakova, 1993), which has been repeatedly under debates (Zakharov, 1994a, 1994b, 1995, 1996; Dagys, 1995, 1997). It is appropriate to mention here just two points.

Paleontological characteristics of upper Induan deposits in northeastern Asia are inadequately investigated because of an extreme rarity of ammonoids and conodonts at this stratigraphic level. This explains to some extent so frequent revisions of the upper Induan biozonation in the region without any significant contribution of new factual data. In the new Lower Triassic biostratigraphic scheme of northeastern Asia, the *Kingites? korostelevi* Zone (Dagys and Ermakova, 1993) distinguished in the Burgagandzha River section of the eastern Verkhoyansk region was unsuccessfully suggested as an upper unit of the stage. The zone is obviously invalid, because all 16 investigated specimens of *Kingites korostelevi* Zakharov are obtained from the lower (Zakharov 1978), but not upper Induan strata in interpretation by Dagys and Ermakova (1993). Moreover, these ammonoids were found by Zakharov in association with the early Induan *Episageceras, Tompophiceras*, and *Ophiceras* forms.

Another innovation in zonation under discussion is the Olenekian *Lepiskites kolymensis* Zone placed by the aforementioned authors immediately above the *Hedenstroemia hedenstroemi* Zone. This contradicts the available records in the Ken'elichi River section of the Kulu River basin (Zakharov, 1978), where the *Lepiskites kolymensis* (Popow) holotype was found. The upper Induan sediments of this section yield mollusks *Promyalina schamarae* (Bittner), *Vavilovites (Vavilovites) kuluensis* Zakharov, and *Prionolobus* sp. nov. in association with abundant conchostracans *Lioesteria* (Zakharov and Vavilov, 1976; Zakharov, 1978). The early Olenekian ammonoids of the section are concentrated in large concretions at stratigraphic levels of 46 and 60 m above the base of the Olenekian Stage. The ammonoids are represented here mainly by *Hedenstroemia mojsisovicsi* Popow (= *H. borealis* Popow, *H. serta* Popow, *"Anahedenstroemia" tscherskii* Popow) typical of the *Hedenstroemia hedenstroemi* Zone. In some concretions from the mentioned levels, one of us encountered *H. mojsisovicsi* in association with *Lepiskites kolymensis* (Popow), *Pseudosageceras multilobatum* Noetling, and *Sakhaites subleptodiscus* (Popow). In the overlying beds up to 220 m thick, *Hedenstroemia mojsisovicsi* coexists with *Lepiskites* sp. and *Sakhaites subleptodiscus* (Popow) (Zakharov, 1978). The *Hedenstroemia* beds of the Kulu River basin are overlain by sediments yielding *Wasatchites* cf. *meeki* Mathews of the *Wasatchites tardus* Zone (Bychkov, 1972). Therefore, ranges of *Hedenstroemia* and *Lepiskites* forms most likely coincide in the upper reaches of the Kolyma River, and occurrence of *Lepiskites kolymensis* in the lower 50 to 60-m thick member of the Olenekian deposits is reliably established here. This fact casts doubt on validity of the *Lepiskites kolymensis* Zone distinguished in some regions of northeastern Asia.

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