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THE LOWER TRIASSIC SYSTEM IN THE ABREK BAY AREA, SOUTH PRIMORYE, RUSSIA

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Contents

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Abstract

The stratigraphy and paleontology of a Lower Triassic section exposed within a quarry along the northeastern coast of Abrek Bay, South Primorye has been the subject of an intense investigation. This 165 meter thick section is divided lithostratigraphically into the Lazurnaya Bay and Zhitkov formations in ascending order. The Lazurnaya Bay Formation, which unconformably overlies the Permian Abrek Formation, consists mainly of sandstone exhibiting an upward-fining sequence, whereas the overlying Zhitkov Formation consists of dark gray, laminated mudstone intercalated with thin, turbiditic fine sandstone beds.

The Lazurnaya Bay Formation consists of the following three facies types in ascending order: a distal deltaic facies deposited during a transgressive event; a shelf environment above storm wave base; and a transitional facies from a shelf to a slope environment. A lower slope environment represents the lower part of the Zhitkov Formation, while the main part consists of a proximal basin-floor facies. This thick monotonous succession of barely bioturbated, laminated mudstone suggests deposition in a stable anoxic basin-floor setting.

Aside from the lower part of the Lazurnaya Bay Formation, the remaining Lower Triassic strata are very fossilferous. Ammonoids, nautiloids, gastropods, bivalves, brachiopods, conodonts and shark fossils are abundant throughout the sequence, while crinoids and scaphopods are present only in the upper part. Nine ammonoid zones (taxon-rang zones) and beds, *Lytophiceras* sp. Zone, *Gyronites subdharmus* Zone, *Ambitoides fuliginatus* Zone, *Clypeoceras spitiense* “bed”, *Paranorites varians* Zone, *Clypeoceras timorense* Zone, *Radioprionites abrekensis* “bed”, *Balhaeceras balhaense* “bed”, and *Arctoceras subhydaspis* “bed”, as well as three conodont zones, *Neogondolella carinata* Zone, *Neospathodus dieneri-N. pakistanensis* Zone, and *Neospathodus* ex gr. *waageni-N. novaeholladiae* Zone are recognized in ascending order. Based on these ammonoids and conodonts, the sequence ranges in age from Early Induan (Griesbachian) to middle Early Olenekian (middle Smithian). Even though the ammonoid faunas contain a few species that are common to other realms, the majority of ammonoids are essentially endemic. In contrast, the bivalve fauna appears to be more related to the Maizuru fauna of Southwest Japan. While the grypoceratid nautiloids exhibit diverse shell forms and siphuncle positions, evidence suggests that they diversified primarily in the western Panthalassa area during the Early Triassic. The existence of *Holocrinus* in beds of early Smithian age, which represents the oldest known occurrence in the world, suggests that crinoids experienced an earlier recovery in South Primorye following the Permian-Triassic (P/Tr) mass extinction.

The transition from the Lazurnaya Bay Formation to the Zhitkov Formation occurred during the early Late Induan (early Dienerian). Sedimentation appears to be continuous from the Late Induan to the Early Olenekian, and faunal successions during this interval are relatively complete and exceptionally well preserved. This phenomenon likely resulted from deposition under much deeper and quieter environmental conditions than other areas in the western part of the “Ussuri Basin”. Although this fining-upward sequence is for the most part typical throughout South Primorye, the datum planes of fossil zones obviously extend across lithostratigraphic boundaries. In the Abrek Bay area, the Induan/Olenekian boundary exists within the Zhitkov Formation, whereas in other western areas of the region, it occurs in the Lazurnaya Bay Formation. These facts support an eastward-deepening setting of the Triassic System in the basin.

Ammonoids are rare in the laminated mudstone of the Zhitkov Formation, but they are common in the very fine sandstone beds that are intercalated within the mudstone. These occurrences suggest that these ammonoids were not indigenous to the slope-basin environment, but rather were of allochthonous origin. Most of the ammonoids likely lived in shallower facies, and after death their empty shells were transported from their biotope to the anoxic basin-floor by low-density turbidite gravity flows.

Sandstones exhibit a strong monazite age peak at 500 Ma and a subordinate peak at 270 Ma. These age patterns indicate that Triassic sediments in the Abrek Bay area were derived from the Khanka Block and/or the adjacent Jiamusi Block, with no contribution from the nearby Sino-Korea Craton. Similar age patterns have been recognized in Permian and Lower to Middle Triassic sandstones in the Maizuru Belt of southwest Japan, which suggests that both areas belonged to either the Khanka Block or the Jiamusi Block during the Early Triassic. This assumption is also supported by the faunal similarity of bivalves between South Primorye and the Maizuru belt.

Eight new genera (ammonoids: *Shamaraites*, *Ussuridiscus*, *Ambitoides*, *Abrekites*, *Radioprionites*, *Ussuriflemingites*, and *Balhaeceras*; gastropoda: *Abrekopsis*) and sixteen new species (nautiloids: *Gyronautilus popovi*, *Xiaohenautilus abrekensis*, and *Menuthionautilus evolutus*; ammonoids: *Ambitoides orientalis*, *Abrekites editus*, *A. planus*, *Radioprionites abrekensis*, *Ussuriflemingites abrekensis*, *U. primoriensis*, *Balhaeceras balhaense*, *Rohillites laevis*, and *Parahedenstroemia kiparisovae*; gastropods: *Warthia zakharovi*, *Bellerophon abrekensis*, *Chartronella maedai*, and *Strobeus shigetai*) are described.

Key words: Abrek, ammonoids, conodonts, Induan/Olenekian, Lower Triassic, recovery, South Primorye, stratigraphy.

ロシア・南部プリモーリエ・アベレック湾地域の下部三畳系（重田康成・ Yuri D. Zakharov ・前田晴良・ Alexander M. Popov 編）：

アベレック湾北東岸の採石場に露出する下部三畳系について、層序学的研究と古生物学的研究を行った．下部三畳系はインドゥアン前期（グリンスバキアン期）からオレネキアン前期の中頃（スミシアン中期）に及び，層厚は 165 m に達する．下位からラズルナヤ・ベイ層とジトコフ層に区分される．ラズルナヤ・ベイ層はペルム系アベレック層を不整合で覆い，主に上方細粒化を示す砂岩より成る．一方，ジトコフ層は葉理の発達した暗灰色泥岩と細粒砂岩の薄いタービダイト層より成る．

ラズルナヤ・ベイ層は下位から海進期に堆積したデルタ末端相，暴風時波浪限界より浅海の陸棚相，陸棚から陸棚斜面への漸移相を示す．一方，ジトコフ層下部は陸棚斜面下部相，主部は堆積盆の中で陸に近い領域 (proximal basin) を示す．ジトコフ層主部の厚い単調な泥岩層は葉理が発達し生物攪乱をほとんど欠く．これは泥岩層が貧酸素環境下の安定した堆積盆内で堆積したことを示す．

化石は，ラズルナヤ・ベイ層下部を除き，豊富に産出する．特にジトコフ層には異地性の化石密集層がしばしば挟まれる一方，周囲の泥岩中には化石は希である．化石はアンモノイド類，オウムガイ類，巻貝類，二枚貝類，腕足類，コノドント類，サメ類を中心とし，ウミユリ類やツノガイ類も産出する．アンモノイド区間帯（タクソン区間帯）および化石層は下位から *Lytophiceras* sp. 帯，*Gyronites subdharmus* 帯，*Ambitoides fuliginatus* 帯，*Clypeoceras spitiense* 層，*Paranorites varians* 帯，*Clypeoceras timorense* 帯，*Radioprionites abrekensis* 層，*Balhaeceras balhaense* 層，*Arctoceras subhydaspis* 層が認められた．また，コノドント化石帯は下位から *Neogondolella carinata* 帯，*Neospathodus dieneri-N. pakistanensis* 帯，*Neospathodus* ex gr. *waageni-N. novaehollandiae* 帯が認められた．産出したアンモノイドのうち，他域と共通するのは数種にすぎず，大部分は固有種である．一方，二枚貝化石群は西南日本の舞鶴化石群に類似する．産出したグリポセラス科オウムガイ類は多様な殻形態と連室細管位置をもち，オウムガイ類が三畳紀前期にパンサラッサ海西部地域で多様化したことを示す．スミシアン前期から産出した *Holocrinus* は本属の最古の記録であり，プリモーリエ南部地域ではペルム紀／三畳紀 (P/T) 境界後のウミユリ類の回復が早かったことを示す．

ラズルナヤ・ベイ層からジトコフ層への遷移はインドゥアン後期の前期（ディーネリアン前期）頃に起きた．インドゥアン後期からオレネキアン前期にわたる連続的な堆積作用のため，例外的に保存が良い化石群がジトコフ層中に保存された．下部三畳系の上方細粒化はプリモーリエ南部地域では顕著であり，化石帯は岩相層序境界と斜交する．アベレック湾地域ではインドゥアン期／オレネキアン期境界はジトコフ層中に位置するが，より西側の地域ではラズルナヤ・ベイ層中に位置する．アベレック湾地域の下部三畳系は「ウスリー堆積盆」の西部地域よりも水深が深い環境下で堆積したと思われる．

アンモノイド類はジトコフ層の葉理が発達した泥岩中では稀であるが，泥岩に挟まれる細粒砂岩層中からは多産する．これらの産状はアンモノイド類が陸棚斜面－陸棚環境よりも浅海に生息し，死後その殻が低密度重力流により貧酸素環境の堆積盆に運搬されたことを示す．

砂岩に含まれるモナズ石の形成年代には 5 億年前と 2.7 億年前が認められた．同様の年代パターンは西南日本の舞鶴帯のペルム系と下部～中部三畳系砂岩にも認められている．これらは両地域の三畳紀前期の堆積物がハンカ地塊あるいは隣接するジャムシ地塊に由来し，中朝地塊には関係しないことを示す．

本論文では，8 新属（アンモノイド類： *Shamaraites*, *Ussuridiscus*, *Ambitoides*, *Abrekites*, *Radioprionites*, *Ussuriflemingites*, *Balhaeceras*，巻貝類： *Abrekopsis*）と 16 新種（オウムガイ類： *Gyronautilus popovi*, *Xiaohenautilus abrekensis*, *Menuthionautilus evolutus*, アンモノイド類： *Ambitoides orientalis*，*Abrekites editus*, *A. planus*, *Radioprionites abrekensis*, *Ussuriflemingites abrekensis*, *U. primoriensis*, *Balhaeceras balhaense*, *Rohillites laevis*, *Parahedenstroemia kiparisovae*，巻貝類： *Warthia zakharovi*, *Bellerophon abrekensis*, *Chartronella maedai*, *Strobeus shigetai*）を記載した．

猪郷久義・ Andrzej Kaim ・熊谷太朗・前田晴良・中澤圭二・大路樹生・
Alexander M. Popov ・重田康成・辻野泰之・堤　之恭・山岸　悠・横山一己・ Yuri D. Zakharov

Introduction

(by. Y. Shigeta, Y. D. Zakharov, H. Maeda, A. M. Popov, K. Yokoyama and H. Igo)

Marine Lower Triassic deposits are widely distributed in South Primorye, Russian Far East and have attracted the attention of many scientists since pioneer workers D. L. Ivanov, C. Diener, and A. Bittner described ammonoids, bivalves and other fossils from the area in the 1890s. During the 20th century, numerous fossils of various kinds of taxa have been described, and subsequently, it is now recognized that South Primorye may provide an important key to the establishment of a precise biostratigraphic framework for the Lower Triassic (Markevich & Zakharov, 2004).

The Lower Triassic in South Primorye yields numerous well-preserved fossils from various horizons within a relatively complete biostratigraphic sequence, including some biozones with species common to the Boreal, Tethyan and Eastern Panthalassa realms (Kiparisova, 1938, 1961, 1972; Burij, 1959; Burij & Zharnikova, 1962, 1981; Zakharov, 1968, 1996, 1997a, 1997b; Buryi, 1979, 1997; Zakharov *et al.*, 2002, 2004a, 2004b, 2005a, 2005b). Consequently, Y. D. Zakharov proposed the Tri Kamnya Cape and Abrek Bay sections as candidates for the Global Stratotype Section and Point (GSSP) for the Induan-Olenekian (I/O) boundary (Zakharov, 1994, 1996; Zakharov & Popov, 1999; Zakharov *et al.*, 2000, 2002). Although the two sections were later withdrawn as GSSP candidates due to magnetostratigraphy problems (Zakharov, 2004, 2006), future paleontological and geological studies of both sections will surely contribute to a better understanding of the dynamics of the biotic recovery following the Permian-Triassic (P/Tr) mass extinction, as well as to the establishment of a biostratigraphic framework. Moreover, its mid-paleolatitudinal setting in western Panthalassa makes it a key biogeographical reference, since the majority of recent works dealing with Early Triassic faunas are from low-paleolatitudinal regions in the Tethys and eastern Panthalassic basins (e.g., Schubert & Bottjer, 1995; Krystyn *et al.*, 2003; Twitchett *et al.*, 2004; Pruss & Bottjer, 2004a, 2004b; Fraiser & Bottjer, 2004; Twitchett & Barras, 2004; Mu *et al.*, 2007; Brayard & Bucher, 2008; Komatsu *et al.*, 2008).

The Abrek Bay section is worthy of consideration as one of the reference sections for Triassic stratigraphy in South Primorye (Markevich & Zakharov, 2004). Zakharov *et al.*, (2000) have already outlined the regional geology of the area, and a number of Triassic mega-fossils have been described by previous authors (Diener, 1895; Bittner, 1899b; Kiparisova, 1938, 1960, 1961, 1972; Dagys, 1974; Zakharov & Shigeta, 2000). However, most fossils as well as microfossils have not yet been described and many fossil assemblages are still unknown.

In order to better understand the fossil assemblages and establish the area's biostratigraphy, a Japanese-Russian Joint Research Program was started in 1998, and scientific expeditions to Abrek Bay and other areas were successfully carried out for ten years. This paper includes the results of the field survey and laboratory investigations as well as pertinent discussions regarding the Abrek Bay section.

Research methods

During field work, we investigated most distinctive sedimentary features of the Triassic sequence, carefully observed the mode of fossil occurrence and followed bedrock-controlled collection techniques in order to establish the biostratigraphy of ammonoids and conodonts. Most megafossil samples were carefully recovered from the strata with special attention to detailed taphonomic considerations.

In an effort to investigate conodonts and other microfossils, we have examined a total of twenty-seven rock samples. Microfossils were removed from the rocks by applying 5% acetic acid to approximately 0.5 kg of sample material, then sieving (2 mm, 0.42 mm, and

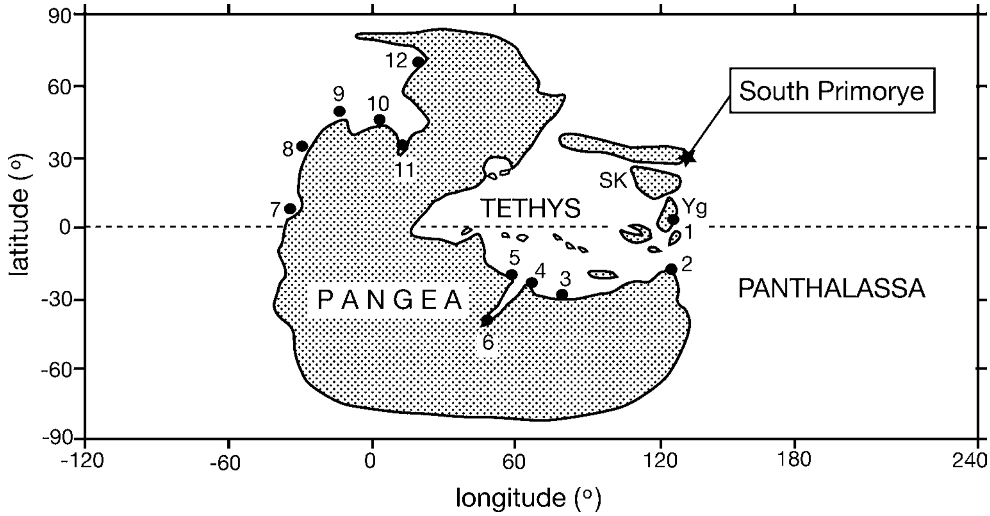


Fig. 1. Paleogeographical map of the Early Triassic period showing the paleoposition of South Primorye and other areas (modified after Péron *et al.*, 2005; Brayaed *et al.*, 2006). SK: Sino-Korea (North China) Craton, Yg: Yangtze (South China) Craton, 1: South China, 2: Timor, 3: Spiti, 4: Salt Range, 5: Oman, 6: Madagascar, 7: Nevada, 8: British Columbia, 9: Ellesmere Island, 10, Spitbergen, 11: Greenland, 12: Olenek River area.

0.1 mm screens) and washing. Laboratory residues were hand-picked using a binocular microscope, and microfossils were mounted onto cardboard microslides with water soluble glue (gum tragacanth).

Most of the conodonts are discrete segminate elements. Fragile ramiform elements are also present, but they are fragmented and difficult to identify. The orientation of elements is now largely modified by intensive analyses of multielement reconstruction of conodont animals (e.g., Purnell *et. al.*, 2000). The specimens treated herein are mostly P elements, thus we apply traditional usage of orientation terms such as defined by Sweet (1988).

The conventional approach to provenance studies of sandstones is based on the determination of palaeo-current trends, the nature and modal proportion of the constituent rock and mineral clasts, and chemical analyses of the heavy minerals in the sandstones. The development of analytical techniques that allow age determination to be made for individual mineral grains has provided powerful tools for use in provenance studies. Many age dating methods have been applied to the provenance studies of zircon e.g., SHRIMP (Ireland, 1991; Tsutsumi *et al.* 2003), fission-track (Garver *et al.* 1999), and ICPMS (Wyck & Norman, 2004; Evans *et al.* 2001), and of monazite by EPMA (Suzuki, *et al.* 1991; Yokoyama *et al.*, 2007). In order to discuss the provenance of various Lower Triassic sandstone detritus in the Abrek Bay area, we analyzed a total of seven sandstone samples, and calculated the age of 188 grains of monazite.

Repository of specimens

All fossils and rock samples investigated herein were collected during field work and transported from Russia to Japan with permission from the Russian Government and other concerned authorities. Specimens of cephalopods, gastropods, bivalves, scaphopods, and conodonts are kept at the National Museum of Nature and Science, Tokyo. Shark teeth and scales, and crinoid columnals and cirrals are kept at the University Museum, University of Tokyo. Specimens of brachiopods are kept at the Far Eastern Geological Institute, Vladivostok.

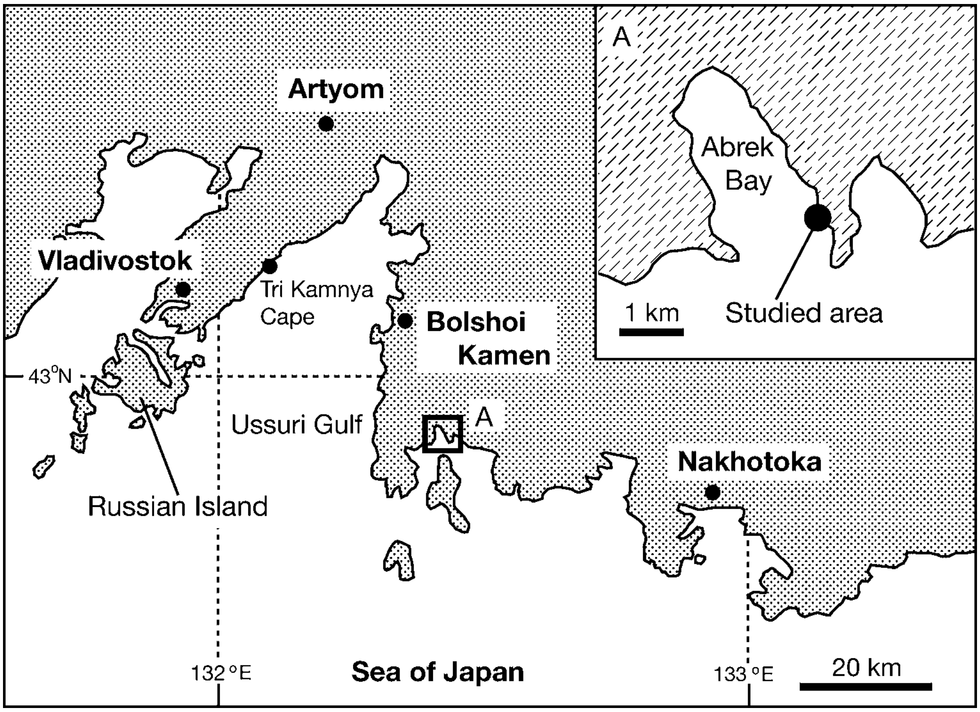


Fig. 2. Map showing location of Abrek Bay area, South Primorye, Far East Russia. Area is located about 45 km southeast of Vladivostok.

Paleogeographical and geological setting
(by Y. Shigeta, H. Maeda, K. Yokoyama and Y. D. Zakharov)

Collision and amalgamation of continental or microcontinental blocks are recognized as one of the major tectonic processes responsible for the formation of East Asia during the Permian to Triassic period. Lower Triassic marine deposits in South Primorye belong to the Khanka Block, which is composed of Precambraian metamorphic rocks covered by thick Paleozoic-Mesozoic volcanic-sedimentary deposits (Khanchuk, 2001). The Khanka Block was part of the continent that was amalgamated with the Northeast China Block, including the Jiamusi and Shongliao-Zhangguangcai blocks during the Early Permian (Jia *et al.*, 2004). Collision of the Khanka Block and the Sino-Korea Craton began during the Late Permian-Early Triassic and was completed by the Late Triassic. The Yangtze Craton also collided with the Sino-Korea Craton during the Triassic to form a huge continent that essentially is the present-day Eurasian continent.

The Lower Triassic System in South Primorye, consisting mainly of clastic rocks deposited in various environments, was probably deposited along the eastern continental margin of the Khanka block, which was probably situated in the middle northern latitudes (Fig. 1, Péron *et al.*, 2005; Zakharov *et al.*, 2008). These outcrops are distributed in two areas, 1) the Russian Island-Vladivostok-Artyom area and the western coast of the Amur Gulf, and 2) the eastern coast of the Ussuri Gulf and Abrek Bay area. The former belongs to "the Voznesenka Block" and the latter to "the Sergeevka Block", both of which are subblocks of the Khanka Block (Khanchuk *et al.*, 1996). In the Russian Island-Vladivostok-Artyom area, shallow marine facies predominate in the southwestern part (Russian Island), while offshore facies dominate in the north-

Fig. 3. Satellite photograph of Abrek Bay area, South Primorye. Well exposed Lower Triassic section is located in quarry along northeastern coast of Abrek Bay. Quarry is visible just southeast of southernmost ships.

eastern part (Artyom). As indicated by Zakharov (1968, 1997a), an eastward-deepening setting is inferred. In the other area, thick basal conglomerate is characteristic of the western part (eastern coast of Ussuri Gulf). The Lower Triassic Abrek section represents the typical eastern offshore facies as described below.

Stratigraphy

(by H. Maeda, Y. Shigeta, Y. Tsujino and T. Kumagae)

Located about 45 km southeast of Vladivostok, the Abrek Bay Lower Triassic section is well exposed in a quarry on the northeastern coast of Abrek Bay (Figs. 2–5), in which a 165 m thick continuous succession of Lower Triassic strata is visible. These sediments unconformably overlie the Permian Abrek Formation, dip 15–50° westward, and strike N40–70°E. Lithostratigraphically, they are divided into the Lazurnaya Bay and Zhitkov formations in ascending order.

Lazurnaya Bay Formation

Stratotype: Lazurnaya (=Shamara) Bay on the western coast of Ussuri Gulf, South Primorye (Zakharov, 1996).

Thickness: 84.8 m in total. Detailed stratigraphic level and interval are shown as height from the base, e.g., 15 m level and 25–30 m interval (see Figs. 6–8, 11–13).

Fig. 4. Triassic outcrop in Abrek Bay area. Upper: Distant view of northern part of quarry. In addition to the Lower Triassic section, overlying sediments of Middle Triassic age are partially exposed in distance. Ammonoids and radiolarians of Anisian age occur in calcareous concretions in dark gray, laminated mudstone (Zakhrov *et al.*, 2000). Middle: View of studied outcrop from the north. Lower: View of studied outcrop from the south. A 165 m thick continuous succession of Lower Triassic strata is observable in the quarry. Lithostratigraphically, the section is divided into the Lazurnaya Bay and Zhitkov formations in ascending order. The Lazurnaya Bay Formation, which unconformably overlies the Permian Abrek Formation, consists mainly of sandstone exhibiting an upward-fining sequence. In contrast, the overlying Zhitkov Formation consists of dark gray, laminated mudstone intercalated with thin, fine sandstone beds of turbidic origin, some of which are fossiliferous.

Lithology: The formation consists mainly of sandstone and exhibits a fining-upward sequence. Sandstone and conglomerate comprise the lower part (0–26.5 m level), while the middle part (32–59.2 m) consists of bedded sandstone intercalated with wavy-mudstone layers. Alternating beds of fine-grained sandstone and mudstone intercalated with slump breccia dominate the upper part (62–84.8 m).

Although covered by soil and vegetation, the basal part above the unconformity consists of greenish gray, medium to fine-grained thickly bedded sandstone exhibiting a coarsening-upward sequence (0–6 m). It is succeeded by alternating beds of coarse-grained sandstone and granule conglomerate (6.0–8.9 m), and pebble conglomerate composed mainly of rounded to subrounded volcanic rock and chert pebbles and cobbles ranging from 30–100 mm in diameter in a greenish gray, medium-grained sandstone matrix (8.9–14.4 m; Fig. 11). The top of the lower part of the formation consists of greenish gray, medium-grained thickly bedded sandstone containing mudstone patches and shell patches (14.4–26.5 m). Each sandstone bed grades upward into bioturbated muddy sandstone via laminated fine-grained sandstone.

The middle part (32–59.2 m) consists mainly of ill-sorted, greenish gray, fine-grained sandstone intercalated with wavy-mudstone layers. The sandstone beds are 5–20 cm thick, and sometimes contain thin lenticular shellbeds, while the intercalated wavy mudstone layers are 1–5 cm thick, intensely mottled (Fig. 12), and contain *Phycosiphon* tubes (Figs. 6, 7).

Yellowish gray, 20–100 cm thick, fine to medium-grained sandstone beds are also occasionally intercalated in the middle part (37–38.2 m, 38.2–38.8 m, 43.4–43.8 m, 47.2–48 m; Figs. 6, 7). These sandstone beds, which sometimes contain mudstone patches, are, in turn, intercalated with thin shellbeds containing poorly preserved bivalve shells (AB1005, 1006). Current ripples exhibiting a NW to SW direction are clearly visible in the basal plane of some sandstone beds (37 m at AB1006). A greenish gray, medium to fine-grained sandstone at the 54–57 m level is also intercalated with wavy-mudstone layers, but fewer than the middle part in general, and it also contains calcareous concretions in the lower part (Fig. 7). A wavy-layer at 56.8 m displays climbing ripples, suggesting a NW direction.

The upper part (62–84.8 m), beginning immediately above an unexposed interval (59.2–62 m), consists of alternating beds of bluish-gray to greenish-gray, fine-grained sandstone (2–20 cm thick) and dark gray wavy-laminated mudstone (1–10 cm thick). These sandstone beds, which sometimes become thicker, 30–80 cm (77–79 m, 81–82 m, 82–84.6 m), are ill-sorted and slightly mottled, and grade upward into wavy-mudstone layers. Bioturbation has usually obscured the top surface of the sandstone. Current ripples suggesting a direction of S74°W to N74°E are observable on the top surface of the sandstone bed (84.6 m; Fig. 8).

Slump breccia, consisting of angular mudstone blocks and subangular or subrounded fine-grained sandstone blocks, and yellowish gray, fine-grained muddy sandstone matrix, is intercalated in the upper part (79–81 m, Fig. 13).

Fossils: Megafossils are rare in the lower part of the Lazurnaya Bay Formation. Shell patches in the bedded sandstone contain the following taxa: ammonoid—*Lytophiceras*? sp. indet.; bivalve—*Promyalina putiatinensis* (Kiparisova); and brachipods—*Orbiculoidea* sp. indet. at AB1004 (23–24.5 m).

The middle part of the Lazurnaya Bay Formation is more fossiliferous. Lenticular shellbeds contain brachiopods—*Lingula borealis* Bittner and *Orbiculoidea* sp. indet. at AB1005 (33.1 m) and AB1006 (37.2 m). Poorly preserved ammonoids—*Lytophiceras* sp. indet. and *Tompophiceras* sp. indet.; bivalve—*Claraia stachei* Bittner; and brachiopod—*Orbiculoidea* sp. indet. were collected at AB1007 (39.2 m). Various brachiopod taxa were found along with *Lingula borealis* and *Abrekia sulcata* Dagys in the sandstone bed at AB1008

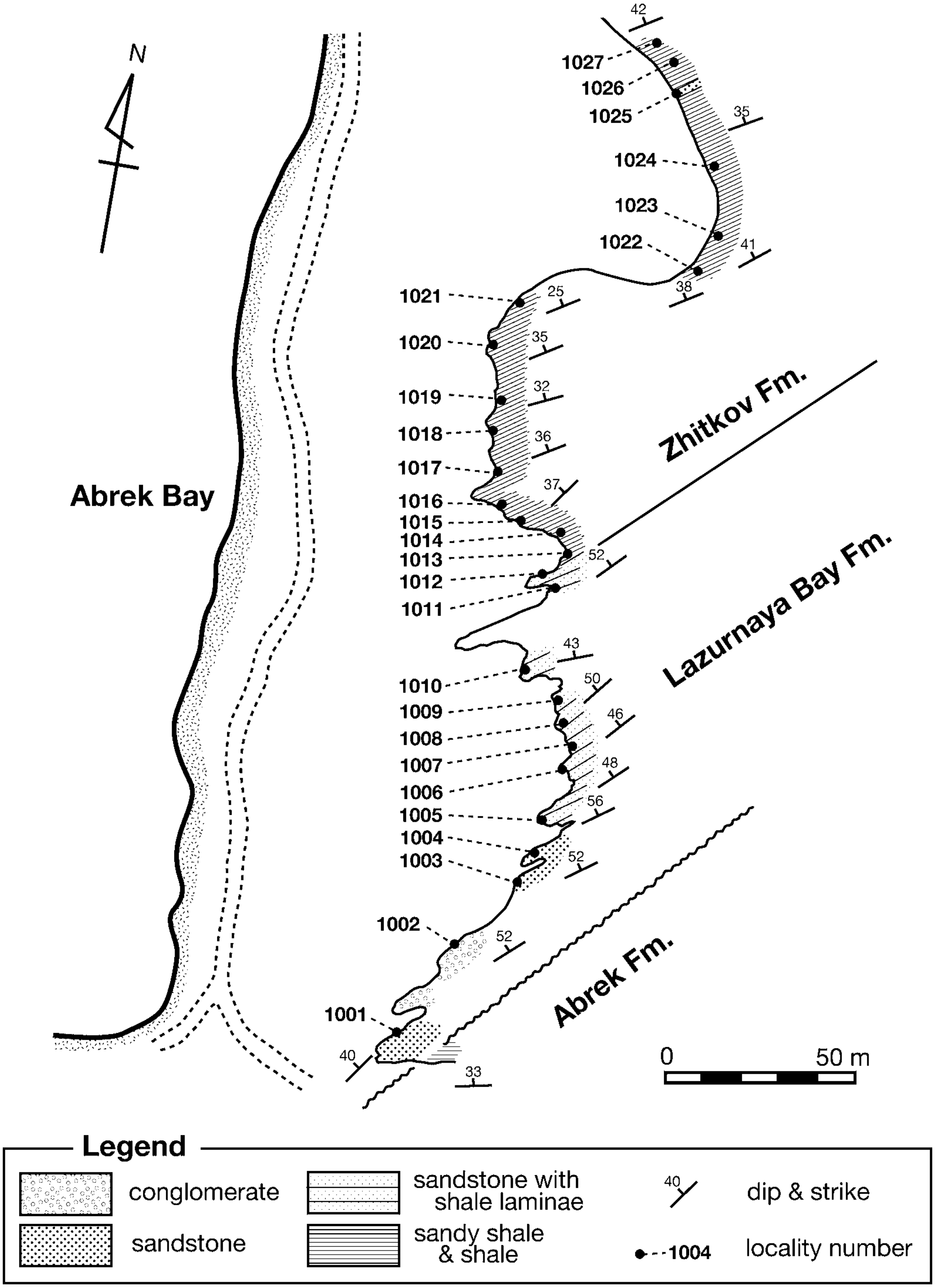


Fig. 5. Plan view of Abrek Bay section showing rock types and structural attitude of beds as well as locality numbers. In text, locality numbers are preceded by prefix “AB”.

(43.5 m). This bed also contains the following taxa: ammonoid—*Bukkenites*? sp. indet.; nautiloid—*Gyronautilus popovi* Shigeta and Zakharov sp. nov.; gastropod—*Warthia zakharovi* Kaim sp. nov.; and conodont—*Neogondolella carinata* (Clark, 1959). Ammonoids collected from calcareous concretions at AB1009 (53.8–54.6 m) include *Lytophiceras*? sp. indet., *Pseudoproptychites hiemalis* (Diener) and *Ussuridiscus varaha* (Diener) gen. nov.

Megafossils are very common in the upper part of the Lazurnaya Bay Formation. The following fossils along with many microgastropods were collected from calcareous concretions at AB1010 (64.8–67 m): ammonoids—*Pseudoproptychites hiemalis*, *Ussuridiscus varaha*, *Wordieoceras* cf. *wordiei* (Spath), *Dunedinites magnumbilicatus* (Kiparisova), and *Gyronites subdharmus* Kiparisova; nautiloid—*Gyronautilus praevolutus* (Kiparisova); bivalves—*Claraia stachei*, *Leptochondria minima* (Kiparisova), "*Modiolus*" sp. indet., *Neoschizodus* cf. *laevigatus* (Ziethen), *Promyalina schamarae* (Bittner), *Pteria ussurica* (Kiparisova), *Myoconcha* sp. indet., *Triaphorus* aff. *multiformis* Kiparisova, *Ochotomya*? sp. indet., *Unionites canalensis* (Catullo), and *Unionites fassaensis* (Wissmann); gastropods—*Bellerophon abrekensis* Kaim sp. nov., *Worthenia* sp. indet., *Abrekopsis depressispirus* (Batten and Stokes) gen. nov., *Coelostylina* sp. indet.; and conodont—*Neogondolella carinata*.

The following fossils are abundant in the sandstone bed at AB1011 (81–82 m): ammonoids—*Ussuridiscus varaha*, *Gyronites subdharmus* and *Pachyproptychites otoceratoides* (Diener); and nautiloid—*Xiaohenautilus abrekensis* Shigeta and Zakharov sp. nov. A large sized specimen of the gastropod—*Omphaloptycha hormolira* Batten and Stokes was also obtained.

The following megafossils along with the conodont—*Neogondolella carinata* were collected from calcareous concretions at AB1012 (82–84.6 m): Nautiloid—*Menuthionautilus evolutus* Shigeta and Zakharov sp. nov.; ammonoid—*Ambitoides fuliginatus* (Tozer) gen. nov.; bivalves—*Claraia stachei*, *Promyalina schamarae*, and *Unionites fassaensis*; gastropod—*Bellerophon abrekensis* Kaim sp. nov.

Depositional environment: The lower part of the Lazurnaya Bay Formation mainly represents a distal deltaic facies deposited during a transgression. Fluvial facies and tidal facies sensu stricto seem to be absent in the Abrek Bay section although coarse-grained deposits are predominant in a transgressive succession (Bhattacharya, 2006). The occurrence of marine fossils supports this view.

The middle part of the Lazurnaya Bay Formation represents a shelf environment above the storm wave base (Sutter, 2006). Various benthic activities indicate that the facies were not deposited under the oxygen-minimum zone, but in the aerobic surface-water column. Wave dominated sedimentary structures are not preserved because of bioturbation.

The upper part of the Lazurnaya Bay Formation represents a transitional facies from a shelf to a slope environment. The intercalation of slump deposits supports this view (Sutter, 2006; Posamentier & Walker, 2006).

Zhitkov Formation

Stratotype: Zhitkov Cape on the eastern coast of Russian Island, South Primorye (Zakharov, 1997a).

Thickness: Greater than 81 m (84.6–165.6 m interval above the base of the Lazurnaya Bay Formation; Figs. 8–10, 13, 14).

Lithology: The Zhitkov Formation consists mainly of dark gray, laminated mudstone intercalated with thin (1–20 cm thick), turbiditic fine sandstone beds, some of which are fossiliferous. It conformably overlies the Lazurnaya Bay Formation and is subdivided into the lower part (84.6–95.8 m) and the main part (95.8–165.6 m).

The lower part (84.6–95.8 m) consists of alternating beds of dark bluish-gray, laminated mudstone and fine sandstone, many of which

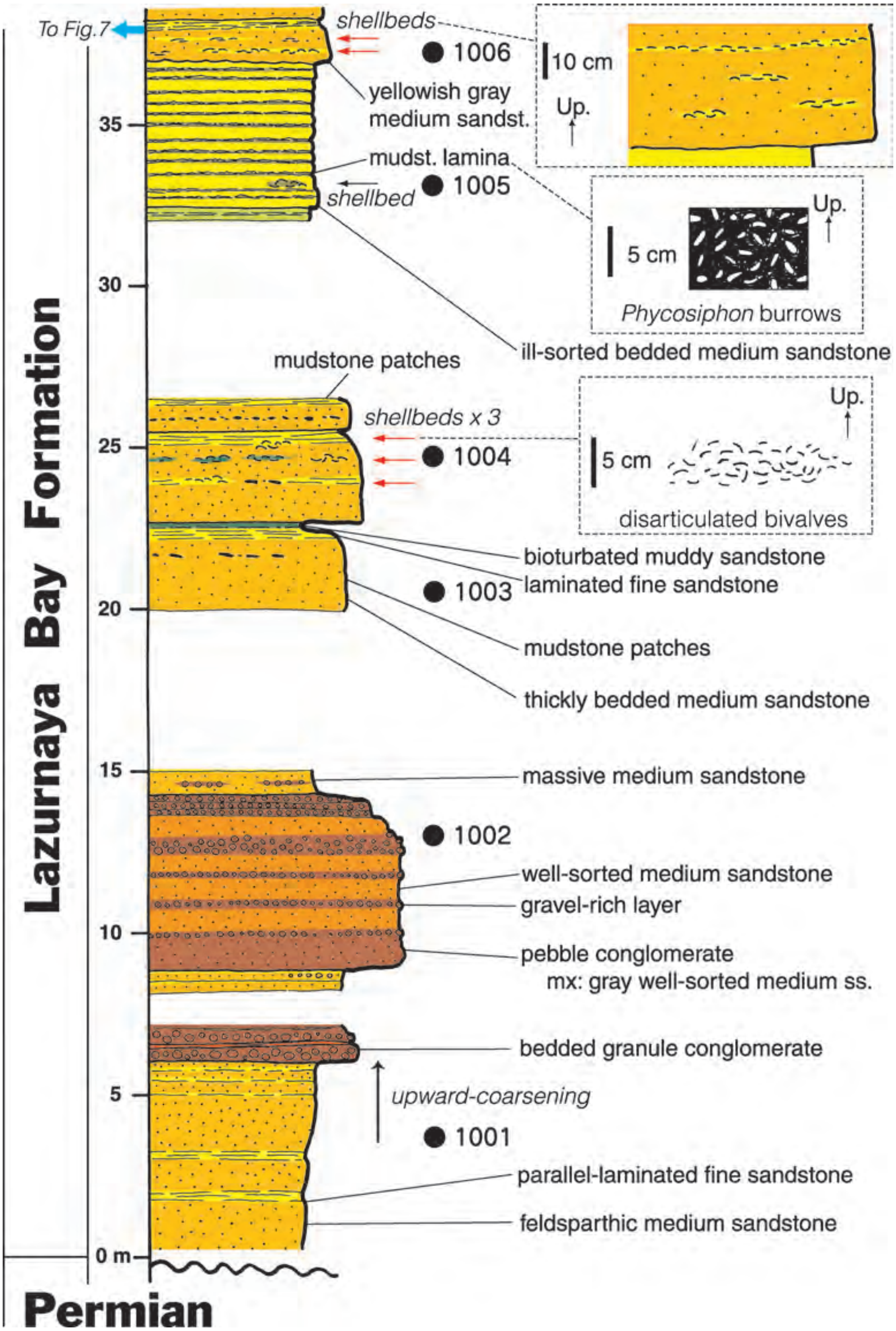


Fig. 6. Columnar section of the Lower Triassic System in the Abrek Bay area (part 1). Top of the figure connects to the bottom of the next Fig. 7. Legend is in Fig. 10. Metric figures by the column indicate the stratigraphic levels above the base of the Triassic System.

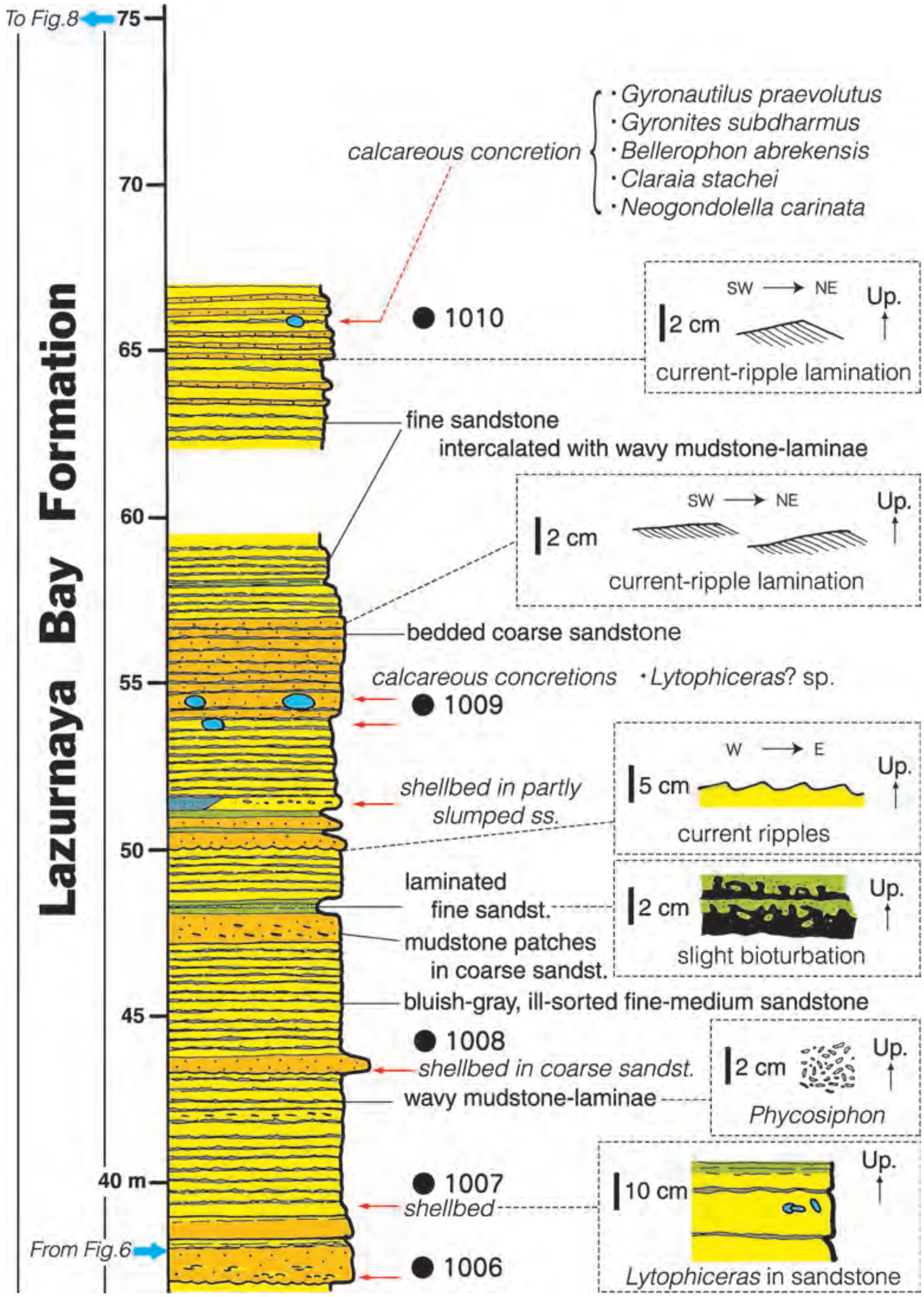


Fig. 7. Columnar section of the Lower Triassic System in the Abrek Bay area (part 2). Bottom of the figure continues from Fig. 6, and the top connects to the bottom of the next Fig. 8. Legend is in Fig. 10. Metric figures by the column indicate the stratigraphic levels above the base of the Triassic System.

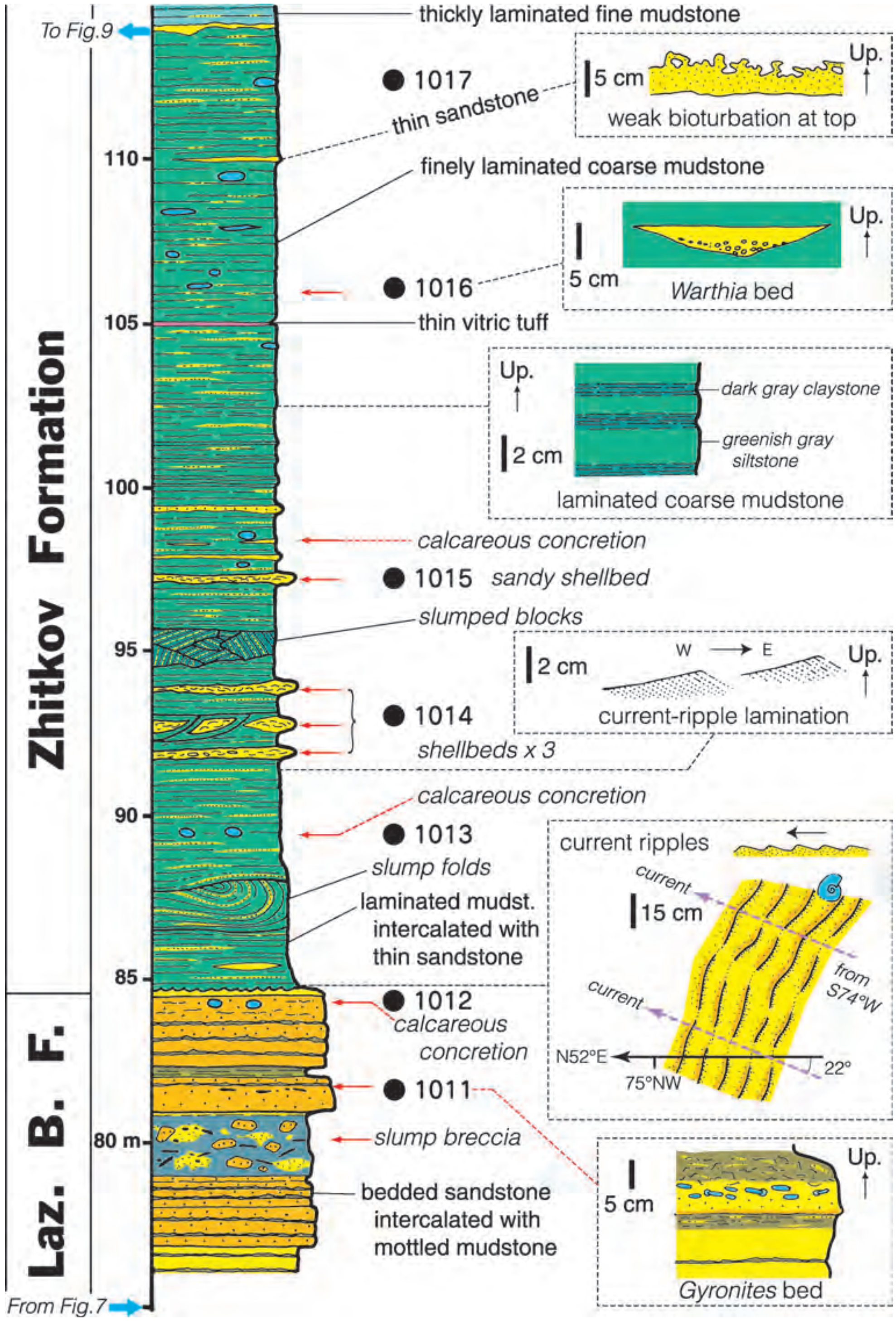


Fig. 8. Columnar section of the Lower Triassic System in the Abrek Bay area (part 3). Bottom of the figure continues from Fig. 7, and the top connects to the bottom of the next Fig. 9. Legend is in Fig. 10. Metric figures by the column indicate the stratigraphic levels above the base of the Triassic System.

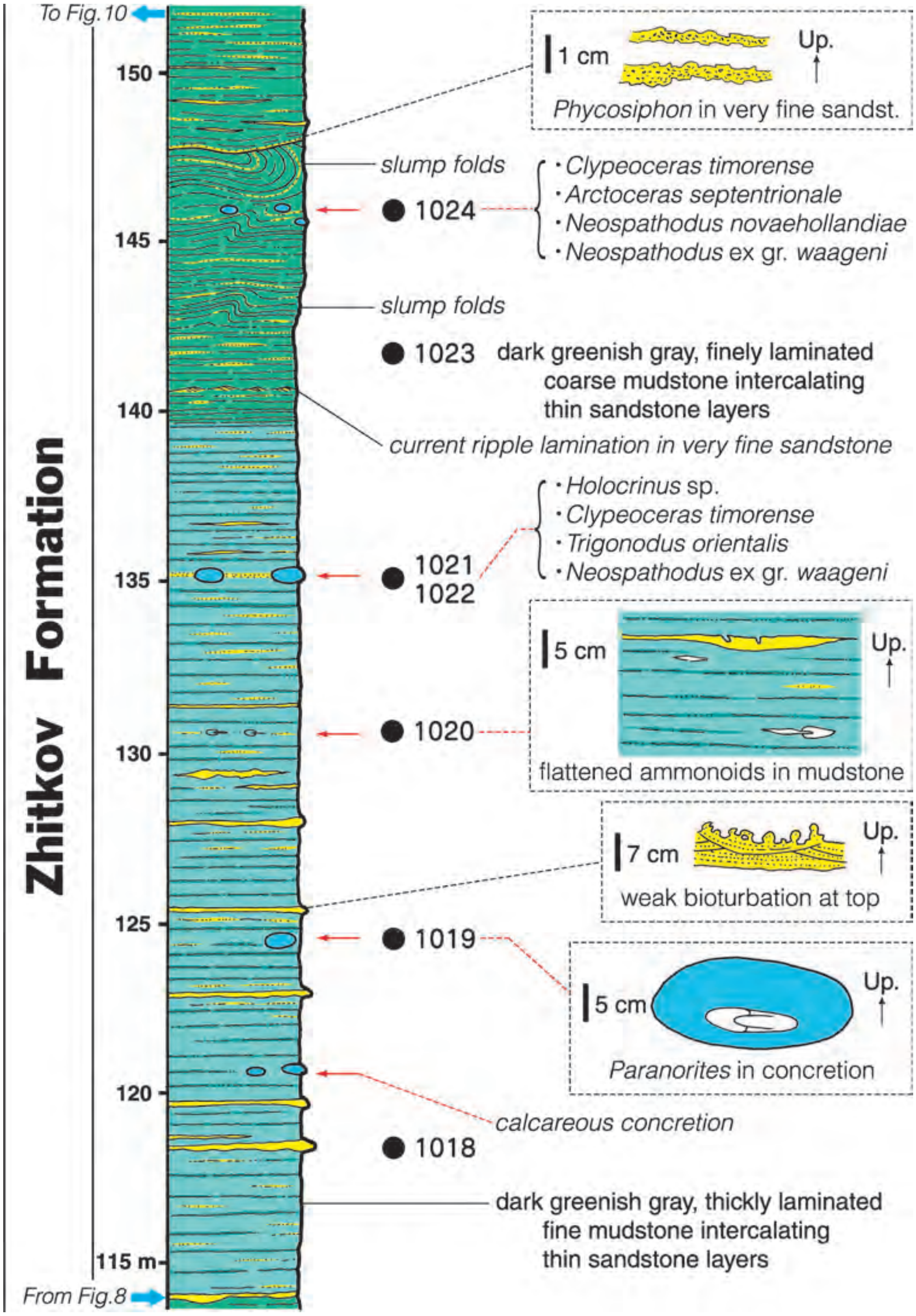


Fig. 9. Columnar section of the Lower Triassic System in the Abrek Bay area (part 4). Bottom of the figure continues from Fig. 8, and the top connects to the bottom of the next Fig. 10. Legend is in Fig. 10. Metric figures by the column indicate the stratigraphic levels above the base of the Triassic System.

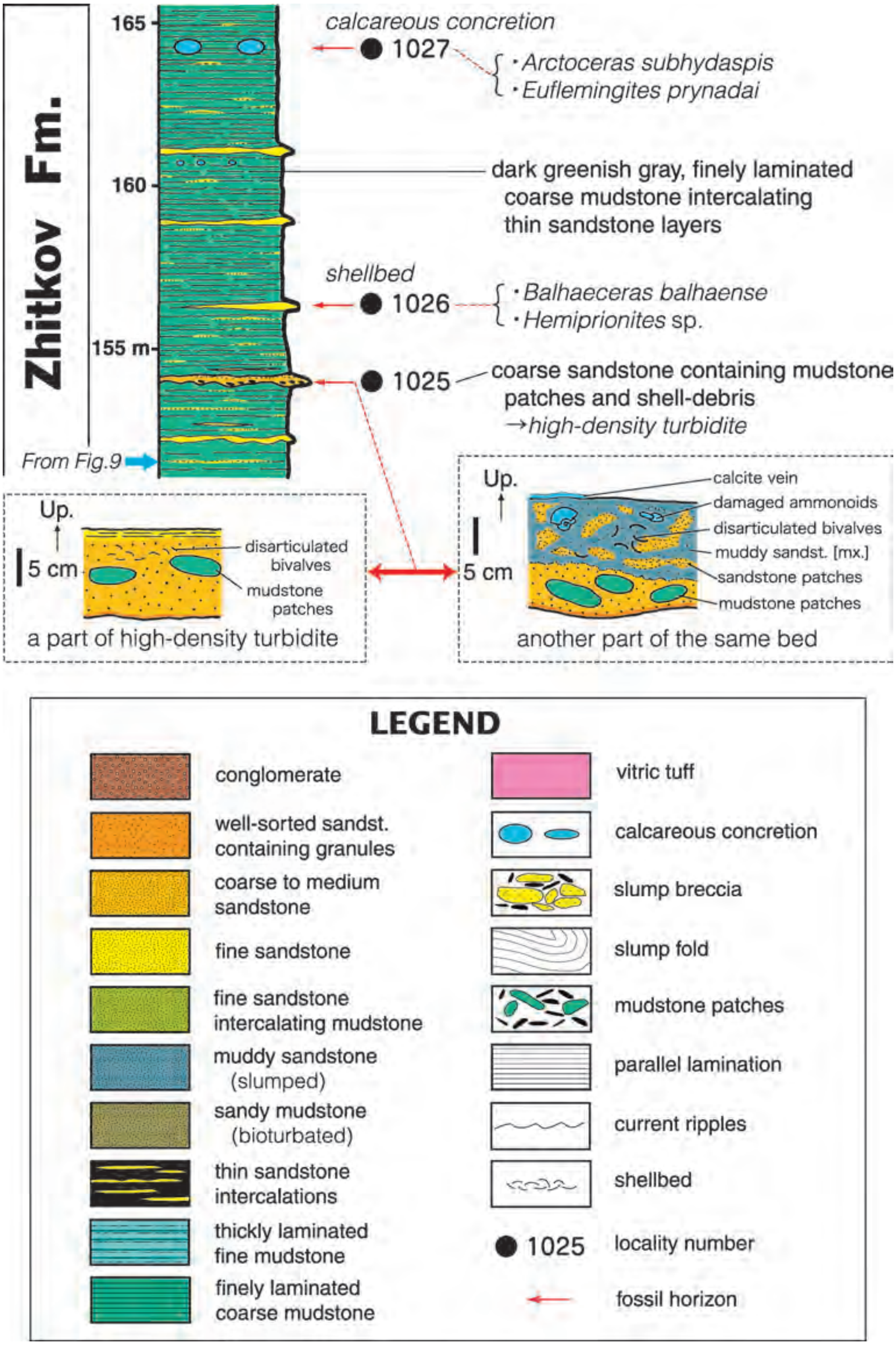


Fig. 10. Columnar section of the Lower Triassic System in the Abrek Bay area (part 5). Bottom of the figure continues from Fig. 9. Metric figures by the column indicate the stratigraphic levels above the base of the Triassic System.

Fig. 11. Conglomerate in lower part of Lazurnaya Bay Formation at AB1002. Upper: Alternating beds of coarse-grained sandstone and granule conglomerate. Lower: Pebble conglomerate composed mainly of rounded to sub-rounded volcanic rock, chert pebbles and cobbles ranging from 30–100 mm in diameter in matrix of greenish gray, medium-grained sandstone.

Fig. 12. Upper: Bedded sandstone intercalated with wavy-mudstone layers in middle part of Lazurnaya Bay Formation. Lower: Ill-sorted, greenish gray, fine-grained sandstone intercalated with wavy-mudstone layers at AB1005.

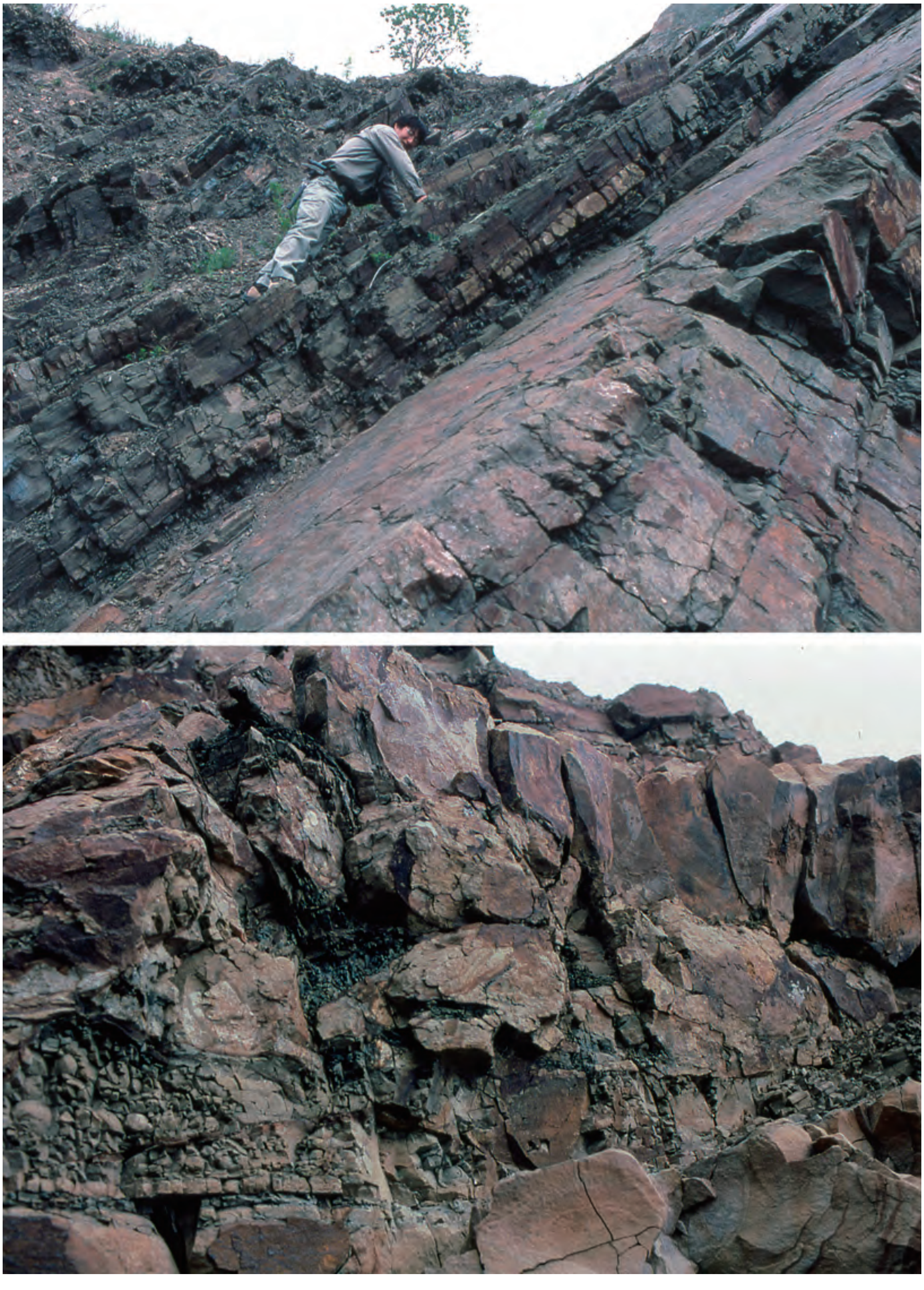


Fig. 13. Upper: Man is standing on approximate contact between Lazurnaya Bay Formation and Zhitkov Formation. Lower: Slump breccia consisting of angular mudstone blocks and subangular or subrounded fine-grained sandstone blocks in matrix of yellowish gray, fine-grained muddy sandstone in upper part of Lazurnaya Bay Formation.

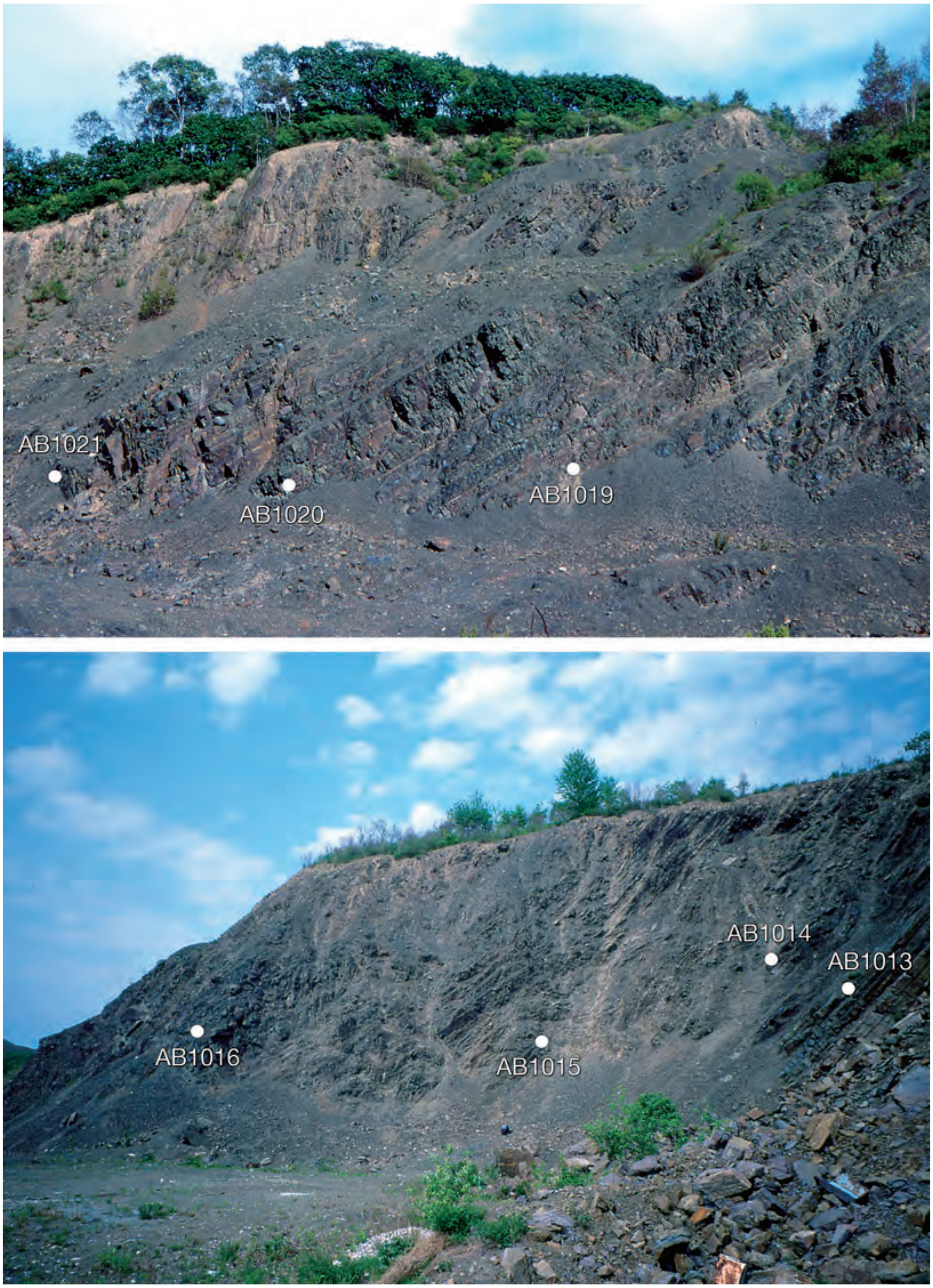


Fig. 14. Dark gray, laminated mudstone intercalated with thin turbiditic fine sandstone beds in Zhitkov Formation. Megafossils are very rare in mudstone in which very little bioturbation is present. In contrast, some sandstone beds are very fossiliferous. Upper: Main part of formation. Induan/Olenekian boundary occurs between AB1021 and AB1019. Lower: Lowermost part and lower main part of formation.

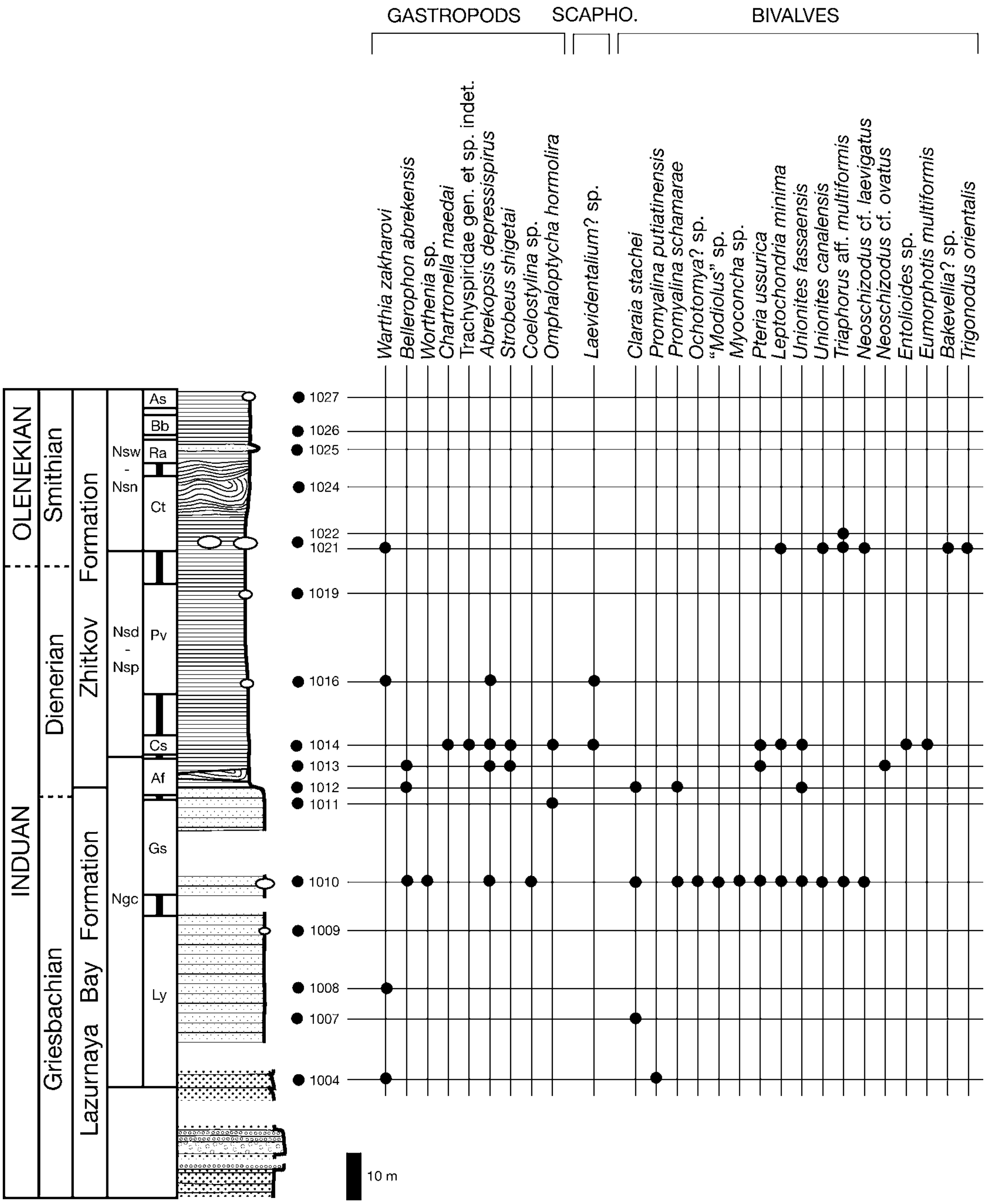
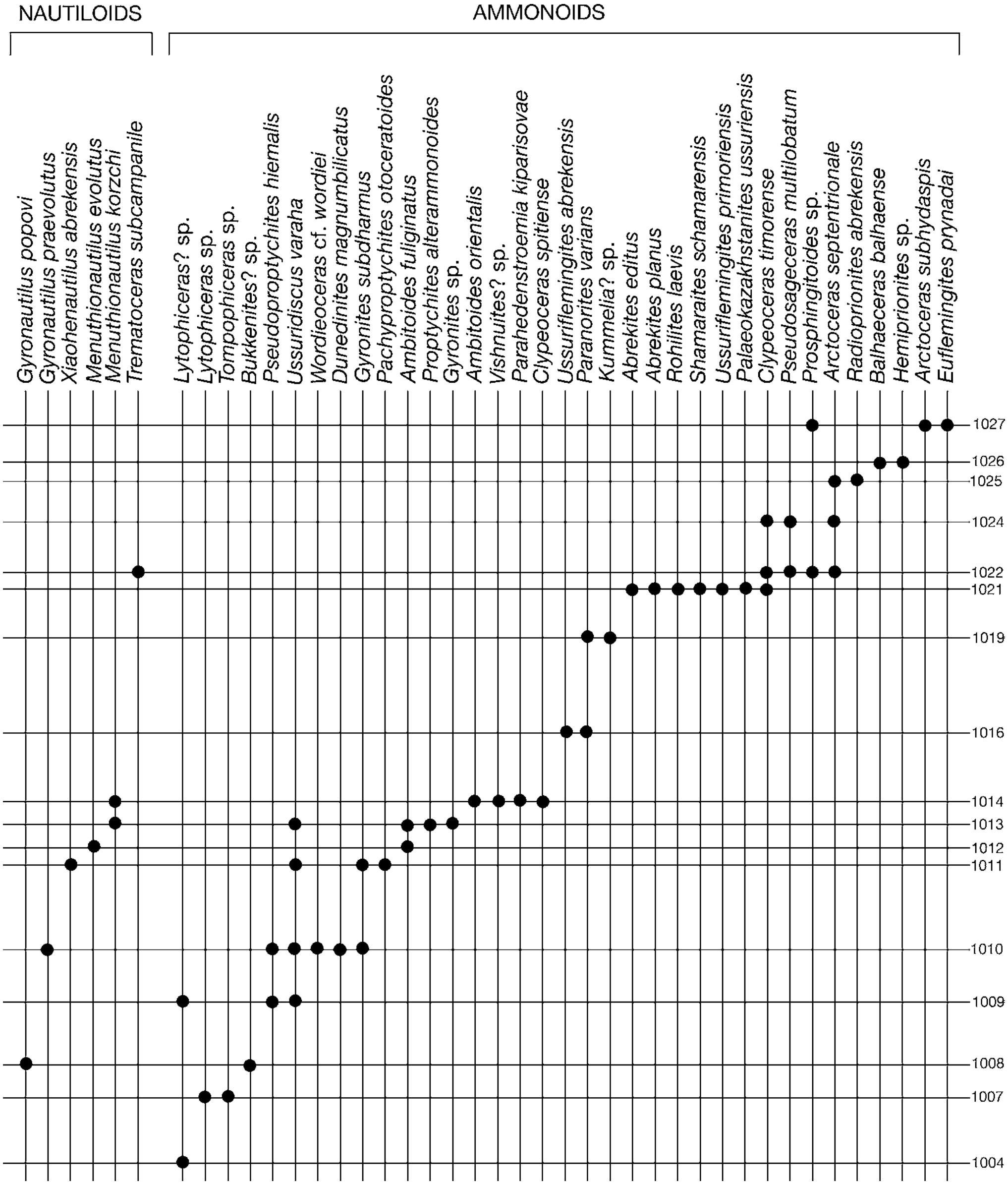


Fig. 15. Distribution of gastropod, scaphopod, bivalve, nautiloid, and ammonoid taxa in Abrek Bay section. Ly: *Lytophiceras* sp. Zone, Gs: *Gyronites subdharmus* Zone, Af: *Ambitoides fuliginatus* Zone, Cs: *Clypeoceras spitiense* "bed", Pv: *Paranorites varians* Zone, Ct: *Clypeoceras timorense* Zone, Ra: *Radioprionites abrekensis* "bed", Bb: *Balhaeceras balhaense* "bed", As: *Arctoceras subhydaspis* "bed", Ngc: *Neogondolella carinata* Zone, Nsd-Nsp: *Neospathodus dieneri-N. pakistanensis* Zone, Nsw-Nsn: *Neospathodus* ex gr. *waageni-N. novaehollandiae* Zone.


NAUTILOIDS
AMMONOIDS
Gyronautilus popovi
Gyronautilus praevolutus
Xiaohenautilus abrekensis
Menuthionautilus evolutus
Menuthionautilus korzchi
Trematoceras subcampanile
Lytophiceras? sp.
Lytophiceras sp.
Tompophiceras sp.
Bukkenites? sp.
Pseudoproptychites hiemalis
Ussuridiscus varaha
Wordieoceras cf. wordiei
Dunedinites magnumbilicatus
Gyronites subdharmus
Pachyproptychites otoceratoides
Ambitoides fuliginatus
Proptychites alterammonoides
Gyronites sp.
Ambitoides orientalis
Vishnuites? sp.
Parahedenstroemia kiparisovae
Clypeoceras spitiense
Ussuriflemingites abrekensis
Paranorites varians
Kummelia? sp.
Abrekites editus
Abrekites planus
Rohillites laevis
Shamaraites schamarensis
Ussuriflemingites primoriensis
Palaeokazakhstanites ussuriensis
Clypeoceras timorense
Pseudosageceras multilobatum
Prosphingitoides sp.
Arctoceras septentrionale
Radioprionites abrekensis
Balhaeceras balhaense
Hemiprionites sp.
Arctoceras subhydaspis
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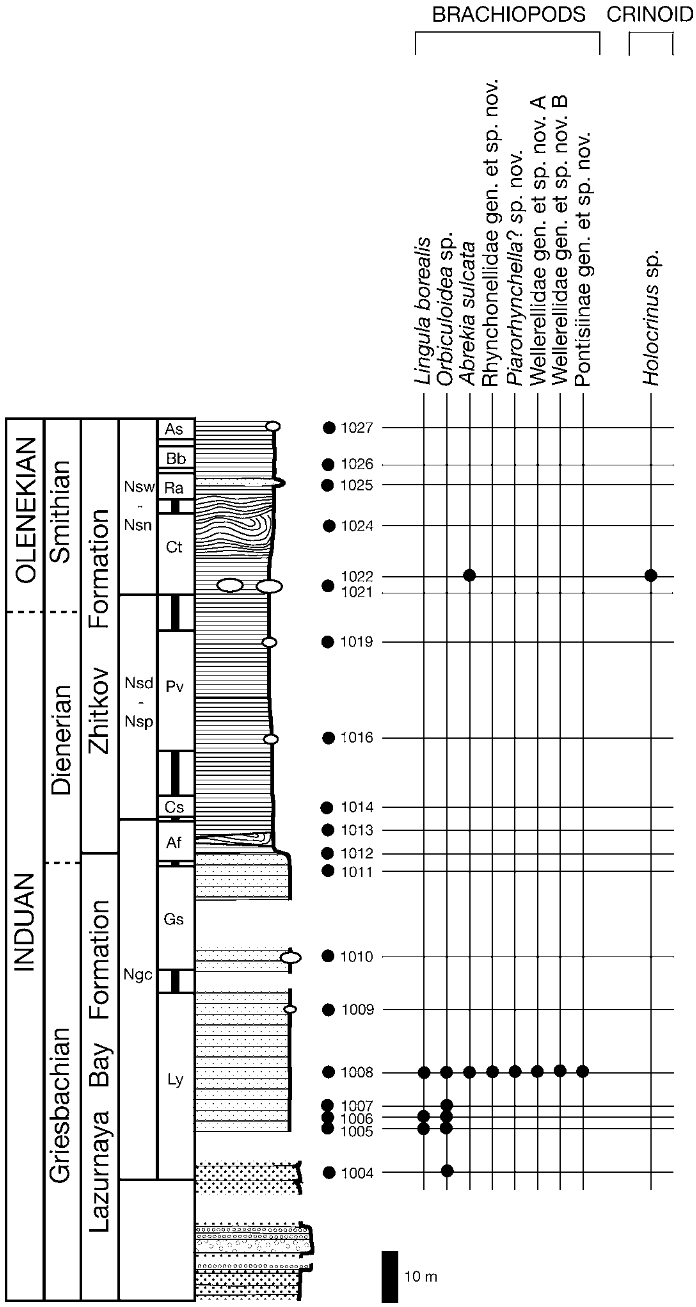


Fig. 16. Distribution of brachiopod and crinoid taxa in Abrek Bay section. Ly: *Lytophiceras* sp. Zone, Gs: *Gyronites subdharmus* Zone, Af: *Ambitoides fuliginatus* Zone, Cs: *Clypeoceras spitiense* "bed", Pv: *Paranorites varians* Zone, Ct: *Clypeoceras timorense* Zone, Ra: *Radioprionites abrekensis* "bed", Bb: *Balhaeceras balhaense* "bed", As: *Arctoceras subhydaspis* "bed", Ngc: *Neogondolella carinata* Zone, Nsd-Nsp: *Neospathodus dieneri-N. pakistanensis* Zone, Nsw-Nsn: *Neospathodus* ex gr. *waageni-N. novaehollandiae* Zone.

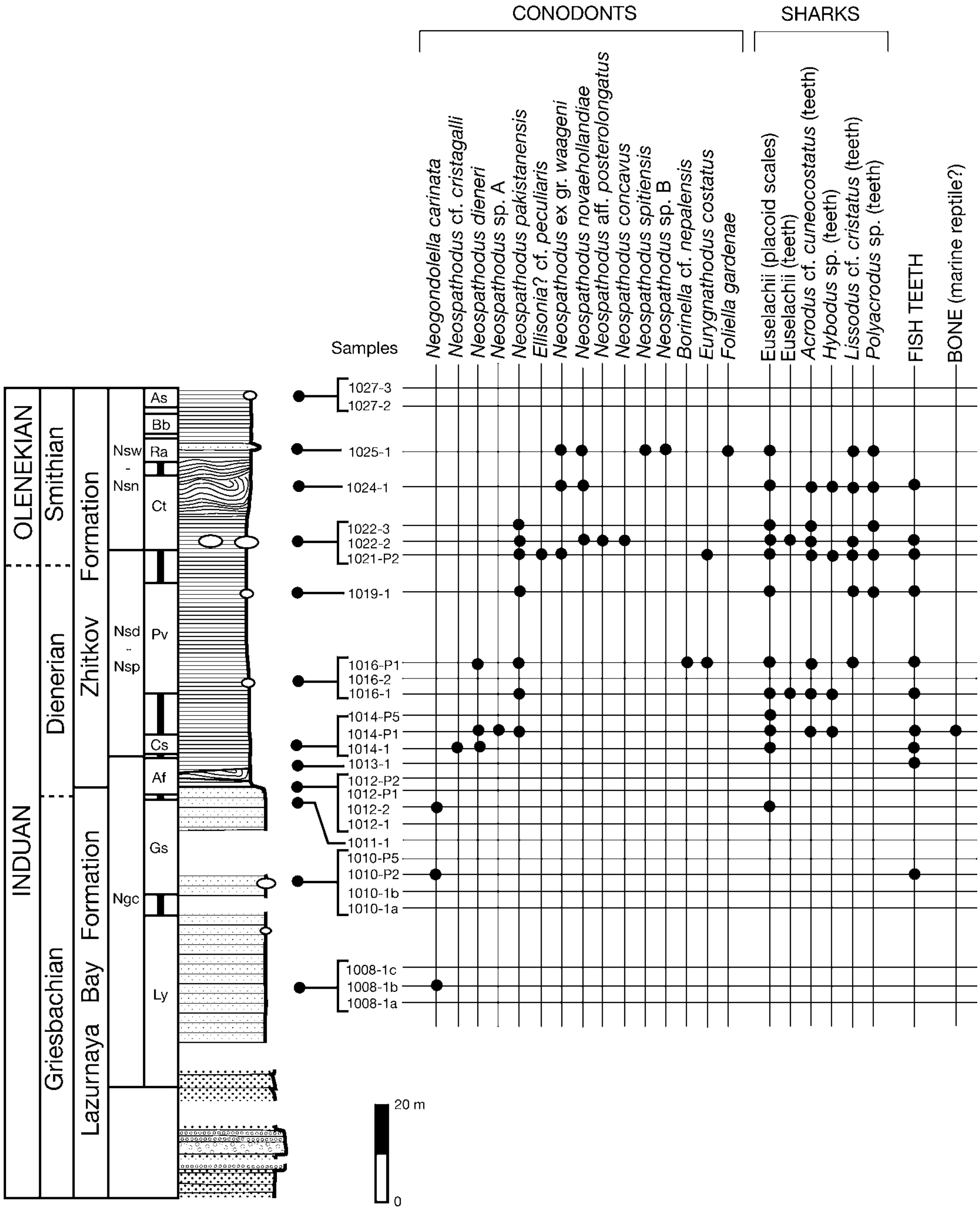


Fig. 17. Distribution of conodonts and shark fossils in Abrek Bay section. Ly: *Lytophiceras* sp. Zone, Gs: *Gyronites subdharmus* Zone, Af: *Ambitoides fuliginatus* Zone, Cs: *Clypeoceras spitiense* “bed”, Pv: *Paranorites varians* Zone, Ct: *Clypeoceras timorense* Zone, Ra: *Radioprionites abrekensis* “bed”, Bb: *Balhaeceras balhaense* “bed”, As: *Arctoceras subhydaspis* “bed”, Ngc: *Neogondolella carinata* Zone, Nsd-Nsp: *Neospathodus dieneri-N. pakistanensis* Zone, Nsw-Nsn: *Neospathodus* ex gr. *waageni-N. novaehollandiae* Zone.

form slumped sheets and blocks (Figs. 8, 13, 14). The 30–200 cm thick slump sheets are piled on each other and bounded by low-angle synsedimentay faults, and a few of them exhibit slump folds. The slump blocks are 30–120 cm in diameter and angular shaped (Fig. 8). Several fossiliferous, 10–20 cm thick, fine sandstone beds exhibiting turbiditic features are also intercalated in the basal part.

The main part of the Zhitkov Formation (95.8–165.6 m) consists mainly of dark bluish gray or greenish gray, laminated mudstone intercalated with a few thin (0.5–3 cm), fine-grained sandstone layers (Fig. 14). Very little bioturbation is present in the mudstone, and it occasionally contains spherical or ellipsoidal calcareous concretions ranging in size from 10 to 40 cm. The sandstone layers exhibit parallel and/or current-ripple laminations that resemble the sedimentary features of the upper part of a Bouma sequence, which is suggestive of their distal-turbidite origin. Also intercalated in the main part is a 15 cm thick feldspathic, coarse-grained sandstone bed (99.5 m) as well as a thin bentonitic tuff bed (105 m). A burrowed upper surface is present on a 7 cm thick intercalated sandstone bed at the 110 m and 125.5 m levels (Figs. 8, 9).

Slump deposits (142.5–148 m), characterized by folds and consisting of dark greenish gray, laminated sandy mudstone with intercalations of fine-grained sandstone, are intercalated in the upper part of the main part of the Zhitkov Formation. Ellipsoidal calcareous concretions occur in the mudstone. All of the intercalated sandstones are weakly bioturbated and contain *Phycosiphon*-type burrows, some of which are calcified and fossiliferous (Fig. 9). Also intercalated in the upper part of the main part of the Zhitkov Formation is a 60 cm thick feldspathic, coarse-grained sandstone bed, which exhibits features of a high-density turbidite (154.2–154.4 m; Fig. 10). The lower half consists of coarse-grained sandstone containing sub-rounded to elongated mud patches attaining a diameter of 8 cm, while the upper half consists of ill-sorted muddy sandstone containing abraded shells of ammonoids and bivalves.

Fossils: Calcareous concretions at AB1013 (89.5 m) contain the following taxa: ammonoids—*Ussuridiscus varaha* (Diener) gen. nov., *Ambitoides fuliginatus* (Tozer) gen. nov., *Proptychites alterammonoides* (Krafft) and *Gyronites* sp. indet.; nautiloid—*Menuthionautilus korzchi* (Kiparisova); bivalves—*Neoschizodus* cf. *ovatus* (Goldfuss) and *Pteria ussurica* (Kiparisova); and gastropods—*Bellerophon abrekensis* Kaim sp. nov., *Abrekopsis depressispirus* Kaim gen. nov., and *Strobeus shigetai* Kaim sp. nov.

The calcareous portions of the sandstone beds as well as the calcareous concretions from the 91.8–94.2 m interval at AB1014 are quite fossiliferous. The following fossils along with many microgastropods and a bone fragment, possibly from a marine reptile, were collected: ammonoids—*Ambitoides orientalis* Shigeta and Zakharov gen. nov. sp. nov., *Vishnuites*? sp. indet., *Parahedenstroemia kiparisovae* Shigeta and Zakharov sp. nov., and *Clypeoceras spitiense* (Krafft); nautiloid—*Menuthionautilus korzchi*; gastropods—*Chartronella maedai* Kaim sp. nov., Trachyspiridae gen. et sp. indet., *Abrekopsis depressispirus*, *Strobeus shigetai*, and *Omphaloptycha hormolira* Batten and Stokes; bivalves—*Entolioides* sp. indet., *Eumorphotis multiformis* (Bittner), *Leptochondria minima* (Kiparisova), *Pteria ussurica*, and *Unionites fassaensis* (Wissmann); scaphopod—*Laevidentalium*? sp. indet.; conodonts—*Neospathodus* cf. *cristagalli* (Huckriede), *Neospathodus dieneri* Sweet, *Neospathodus pakistanensis* Sweet, and *Neospathodus* sp. A; placoid scales, and shark teeth—*Acrodus* cf. *cuneocostatus* Cuny, Rieppel and Sander and *Hybodus* sp. indet. Microgastropod preservation is remarkably good, and the protoconch can be observed in most specimens.

In the main part, the following assemblages were collected from calcareous concretions at

AB1016 (106.2 m): Ammonoids—*Ussuriflemingites abrekensis* Shigeta and Zakharov gen. nov. sp. nov. and *Paranorites varians* (Waagen); gastropods—*Warthia zakharovi* Kaim sp. nov. and *Abrekopsis depressispirus*; scaphopod—*Laevidentalium*? sp. indet.; conodonts—*Neospathodus dieneri*, *Neospathodus pakistanensis*, *Eurygnathodus costatus* Staesche, and *Borinella* cf. *nepalensis* (Kozur and Mostler); placoid scales, and shark teeth—*Acrodus* cf. *cuneocostatus*, *Hybodus* sp. indet., and *Lissodus* cf. *cristatus* Delsate and Duffin. Specimens of *Warthia zakharovi* are usually found in a clusters in the calcareous concretions. (Fig. 8)

The following fossils were collected from calcareous concretions at AB1019 (124.6 m): Large ammonoid, *Kummelia*? sp. indet. and *Paranorites varians*, conodont—*Neospathodus pakistanensis*; placoid scales and shark teeth—*Polyacrodus* sp. indet. and *Lissodus* cf. *cristatus*. The calcified fine-grained sandstone at AB1021 and AB1022 (135.2 m) is very fossiliferous, and the following well-preserved fossils along with many microbivalves were collected: ammonoids—*Abrekites editus* Shigeta and Zakharov gen. nov. sp. nov., *Abrekites planus* Shigeta and Zakharov gen. nov. sp. nov., *Rohillites laevis* Shigeta and Zakharov sp. nov., *Shamaraites schamarensis* (Zakharov) gen. nov., *Ussuriflemingites primoriensis* Shigeta and Zakharov gen. nov. sp. nov., *Palaeokazakhstanites ussuriensis* (Zakharov), *Clypeoceras timorense* (Wanner), *Pseudosageceras multilobatum* Noetling, *Prosphingitoides* sp. indet., and *Arctoceras septentrionale* (Diener); nautiloid—*Trematoceras subcampanile* (Kiparisova); bivalves—*Bakevellia*? sp., *Leptochondria minima*, *Neoschizodus* cf. *laevigatus* (Ziethen), *Triaphorus* aff. *multiformis* Kiparisova, *Trigonodus orientalis* Bittner, and *Unionites canalensis*; gastropod—*Warthia zakharovi*; brachiopod—*Abrekia sulcata* Dagys; crinoid columnals and cirrals—*Holocrinus* sp. indet.; conodonts—*Ellisonia*? *peculiaris* (Sweet), *Neospathodus pakistanensis*, *Neospathodus* ex. gr. *waageni* Sweet, *Neospathodus novaehollandiae* McTavish, *Neospathodus* aff. *posterolongatus* Zhao and Ochard, *Neospathodus concavus* Zhao and Orchard, and *Eurygnathodus costatus* Staesche; placoid scales and shark teeth—*Acrodus* cf. *cuneocostatus*, *Hybodus* sp. indet., *Lissodus* cf. *cristatus*, and *Polyacrodus* sp. indet.

In the upper part of the main part of the Zhitkov Formation, calcareous concretions from the slump deposits at AB1024 (146 m) contain the following fossils: ammonoids—*Clypeoceras timorense*, *Pseudosageceras multilobatum* and *Arctoceras septentrionale*; conodonts—*Neospathodus* ex. gr. *waageni* and *Neospathodus novaehollandiae*; placoid scales and shark teeth—*Acrodus* cf. *cuneocostatus*, *Hybodus* sp. indet., *Lissodus* cf. *cristatus*, and *Polyacrodus* sp. indet.

At AB 1025 (154.2–154.4 m), the high-density turbidite, consisting of feldspathic coarse-grained sandstone and ill-sorted muddy sandstone, is fossiliferous, and the following fossils were collected: ammonoids—*Arctoceras septentrionale* and *Radioprionites abrekensis* Shigeta and Zakharov gen. nov. sp. nov.; conodonts—*Neospathodus* ex. gr. *waageni*, *Neospathodus novaehollandiae*, *Neospathodus spitiensis* Goel, *Neospathodus* sp. B, and *Foliella gardenae* (Staesche); placoid scales, and shark teeth—*Lissodus* cf. *cristatus*, and *Polyacrodus* sp. indete.

In addition, the calcified sandstone beds intercalated with mudstone at AB1026 (156.5 m) yielded: ammonoids—*Balhaeceras balhaense* Shigeta and Zakharov gen. nov. sp. nov. and *Hemiprionites* sp. indet. Calcareous concretions at AB1027 (161.4–166 m) contain the large ammonoids *Arctoceras subhydaspis* (Kiparisova) and *Euflemingites prynadai* (Kiparisova).

Depositional environment: The lower part of the Zhitkov Formation represents a lower slope environment, which is suggested by the predominance of a slump-deposit intercalations

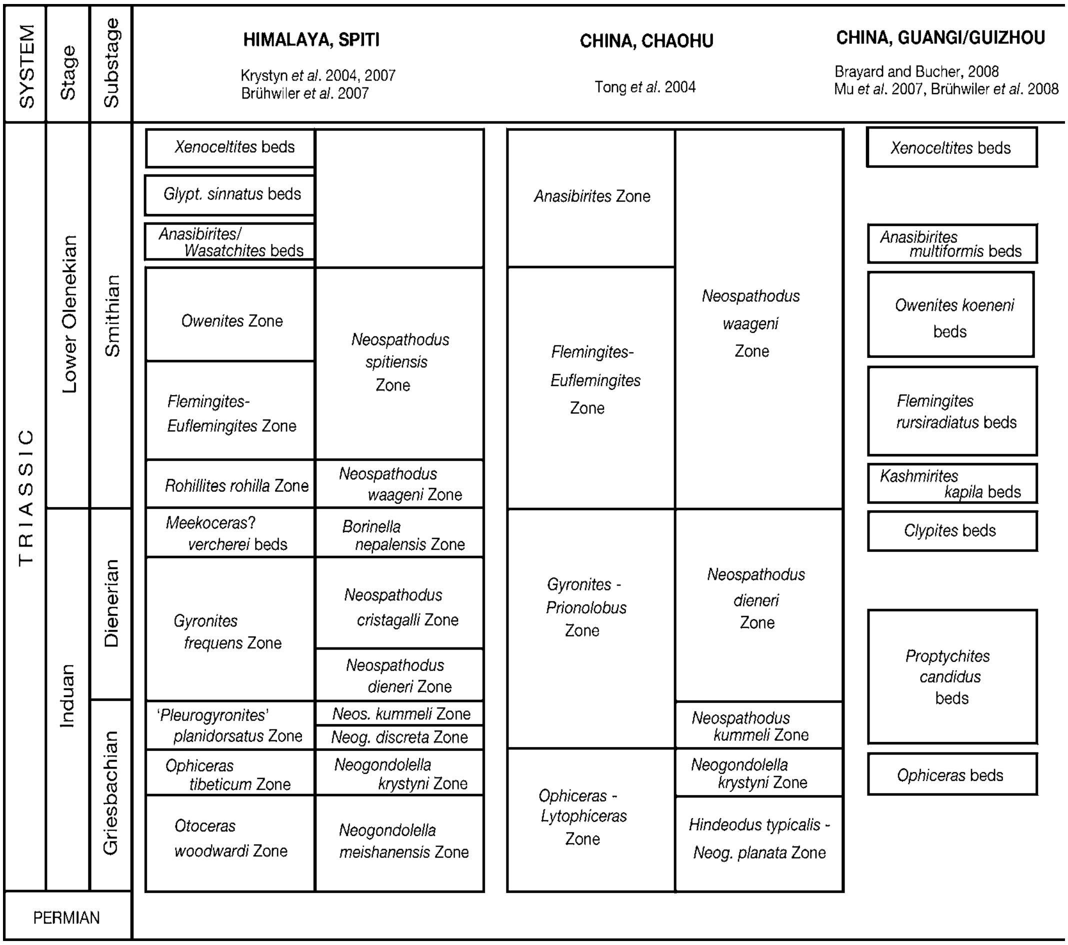


Fig. 18. Ammonoid and conodont biostratigraphic subdivisions of the Early Triassic of South Primorye and correlation with other regions.

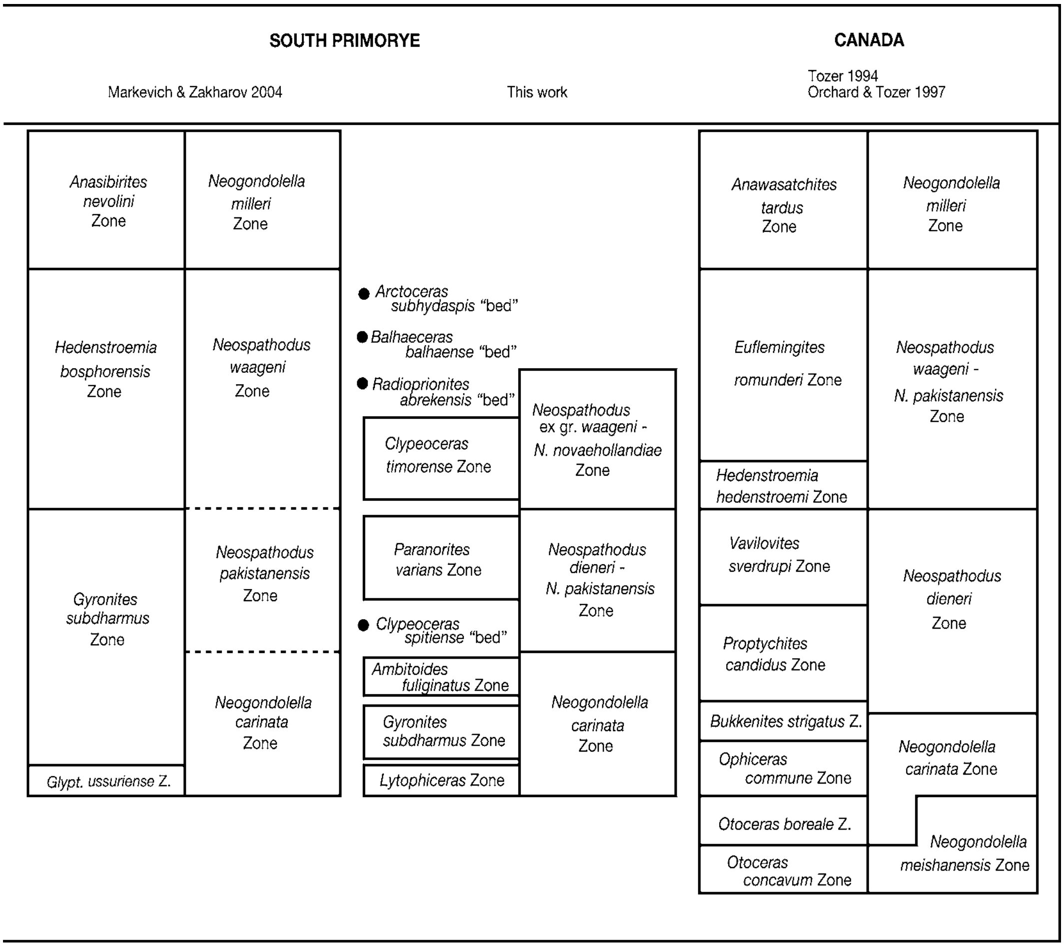
(Sutter, 2006; Posamentier & Walker, 2006), while the main part of the Zhitkov Formation represents a proximal basin-floor facies (Sutter, 2006; Posamentier & Walker, 2006). The thick monotonous succession of barely bioturbated, laminated mudstone suggests deposition in a stable anoxic basin-floor setting.

Biostratigraphy

Ammonoid succession (by Y. Shigeta, H. Maeda and Y. D. Zakharov)

Markevich and Zakharov (2004) established an early Triassic ammonoid biostratigraphic scheme for South Primorye, in which they recognized the following four ammonoid zones, ranging from the Griesbachian to the Smithian: *Glyptophiceras ussuriense* Zone, *Gyronites subdharmus* Zone, *Hedenstroemia bosphorensis* Zone, and *Anasibirites nevolini* Zone. However, none of the zonal index taxa were found in the Abrek Bay section other than *Gyronites subdharmus* Kiparisova.

Our carefully controlled bed-by-bed sampling program has produced abundant material, which significantly adds to the knowledge



of these biostratigraphic subdivisions (Fig. 18). However, at this point it would be premature to introduce formal zones because fossil occurrence is not stratigraphically continuous but confined mostly to a few fossils beds. Our knowledge of Early Triassic ammonoid faunas in South Primorye is still somewhat inadequate. Hence, we provisionally utilize the "bed" or zone (taxon-range zone) approach as documented below. Here, the "bed" means the case that the index taxon occurs only from a fossil-bed. The zone means a taxon-range zone of the index species, and consists of two or much more fossil beds. Boundary between such zones remains obscure because of intermittent fossil-occurrence.

Lytophiceras *sp. Zone*: This zone, which are partly correlative with the *Glyptophiceras ussuriense* Zone of Markevich and Zakharov (2004), is characterized by the occurrence of the typical Early Induan (Griesbachian) ammonoid genus *Lytophiceras*. At AB1007, this genus is associated with *Tompophiceras* sp. indet. and at AB1009, it is found with *Pseudoproptychites hiemalis* (Diener) and *Ussuridiscus varaha* (Diener) gen. nov.

Gyronites subdharmus *Zone*: Zone is mainly characterized by *Gyronites subdharmus*, but other taxa are also found at various levels as follows: *Dunedinites magnumbilicatus* (Kiparisova) and *Wordieoceras* cf. *wordiei* (Spath) in the lower part, *Pachyproptychites otoceratoides* (Diener) in the upper part, and *Ussuridiscus varaha* in the zone. The genus *Wordieoceras* is typical of the late Griesbachian, and *W. wordiei* is known from late Griesbachian beds in Greenland (Spath, 1930, 1935) and Arctic Canada (Tozer, 1994). Zone in the lower part are partly correlative with the *Ophiceras commune* Zone (early late Griesbachian) of Arctic Canada (Tozer, 1994).

Age diagnostic ammonoid taxa have not been found in the upper part, which probably is of late Early Induan (late Griesbachian) age, but the nautiloid *Xiahenautilus abrekensis* sp. nov. occurs at AB1011. In South China, the stratigraphic range of *Xiaohenautilus* is restricted to the upper Griesbachian (Mu *et al.*, 2007). Markevich and Zakharov (2004) assigned a Late Induan (Dienerian) age to the *G. subdharmus* Zone. However, the local range biozone of *G. subdharmus* should be correlated with the late Early Induan (late Griesbachian).

Ambitoides fuliginatus *Zone*: Index ammonoid, *Ambitoides fuliginatus* (Tozer) gen. nov., occurs with the following taxa: *Proptychites alterammonoides* (Krafft), *Ussuridiscus varaha* and *Gyronites* sp. indet. *Proptychites alterammonoides* is known to occur in the "*Meekoceras*" beds (Dienerian) of the Northwest Himalayan region (Krafft, 1909; Waterhouse, 2002), while *Ambitoides fuliginatus* occurs in the *Proptychites candidus* Zone (early Dienerian) of northeastern British Columbia (Tozer, 1994). These ammonoids strongly suggest that the *A. fuliginatus* Zone is of early Late Induan (early Dienerian) age.

Clypeoceras spitiense "*bed*": Bed contains index species *Clypeoceras spitiense* (Krafft) as well as *Ambitoides orientalis* Shigeta and Zakharov gen. nov. sp. nov., *Parahedenstroemia kiparisovae* Shigeta and Zakharov sp. nov. and *Vishnuites*? sp. indet. *Clypeoceras spitiense* is a well known Himalayan Dienerian ammonoid, and the bed is correlative with the "*Meekoceras*" beds (Dienerian) of the Northwest Himalayan region (Krafft, 1909; Waterhouse, 2002).

Paranorites varians *Zone*: Zone contains index species *Paranorites varians* (Waagen) as well as *Ussuriflemingites abrekensis* Shigeta and Zakharov gen. nov. sp. nov. in the lower part and *Kummellia*? sp. indet. in the upper part. *P. varians* is known from the Lower Ceratite Limestone of the Salt Range (Waagen, 1895), and *Kummellia* is known from the *Paranorites-Vishnuites* Zone (Dienerian) of Kashmir (Bando, 1981; Waterhouse, 1996a). Zone is probably Late Induan (Dienerian) in age.

Clypeoceras timorense *Zone*: Zone contains a very abundant, diverse fauna, which include the following genera: *Clypeoceras*, *Abrekites* gen. nov., *Rohillites*, *Shamaraites* gen. nov., *Ussuriflemingites* gen. nov., *Palaeokazakhstanites*, *Pseudosageceras*, *Prosphingitoides*, and *Arctoceras*. *Clypeoceras timorense* (Wanner), the most common ammonoid, is known from the Lower Olenekian (lower Smithian) of Timor, and *Rohillites* is also a typical early Smithian genus. Therefore, this subdivision is of early Early Olenekian (early Smithian) age.

Radioprionites abrekensis "*bed*": Bed is characterized by the occurrence of the newly described index ammonoid *Radioprionites abrekensis* Shigeta and Zakharov gen. nov. sp. nov. as well as *Arctoceras septentrionale* (Diener). Neither species is age diagnostic, but *Arctoceras* is a typical Smithian genus. According to Markevich and Zakharov (2004), the upper part of the *Arctoceras septentrionale* bearing beds in South Primorye contains *Owenites koeneni* Hyatt & Smith and *Balhaeceras balhaense* Shigeta and Zakharov gen. nov. sp. nov. Hence, this subdivision is correlative with the bed under the *O. koeneni* beds (middle Smithian) of the Tethyan and Eastern Panthalassic realms (Kummel & Steele, 1962;

Brühwiler *et al.*, 2007; Brayard & Bucher, 2008).

Balhaeceras balhaense *"bed"*: Newly described index ammonoid *Balhaeceras balhaense* also occurs in the *Owenites koeneni* beds in other sections in South Primorye (Zakharov, 1968), and hence, this subdivision is correlated with the middle Early Olenekian (middle Smithian).

Arctoceras subhydaspis "*bed*": Bed is characterized by the occurrence of the index species and *Euflemingites prynadai* (Kiparisova). *A. subhydaspis* (Kiparisova) is always found immediately below the *Anasibirites nevolini* Zone (upper Smithian) in other sections in South Primorye (Markevich & Zakharov, 2004). Therefore, the subdivision is of middle Early Olenekian (middle Smithian) age.

Conodont succession (by H. Igo)

The Lower Triassic section in the Abrek Bay area can be divided into three conodont zones in ascending order as follows: *Neogondolella carinata* Zone, *Neospathodus dieneri-N. pakistanensis* Zone, and *Neospathodus* ex gr. *waageni-N. novaehollandiae* Zone (Fig. 18).

Neogondolella carinata *Zone*: Zone is not well defined because specimens of the index species, which occur sporadically in the middle to upper part of the Lazurnaya Bay Formation, are mostly fragmental or attrited. *Neogondolella carinata* (Clark) is a worldwide species and ranges from the Greisbachian to the Smithian (Orchard, 2007a). Zone encompasses the following ammonoid zones: *Lytophiceras* sp. Zone and *Gyronites subdharmus* Zone of the Lazurnaya Bay Formation, and the *Ambitoides fuliginatus* Zone of the lowermost Zhitkov Formation.

Neospathodus dieneri-N. pakistanensis *Zone*: Zone begins with the first appearance of *Neospathodus dieneri* Sweet and *N. pakistanensis* Sweet and ends with the first occurrence of *N.* ex gr. *waageni* Sweet. *N. pakistanensis* occurs frequently throughout the zone, but *N. dieneri* appears mainly in the lower part. The following other taxa rarely co-occur: *N.* cf. *cristagalli* (Huckriede), *Eurygnathodus costatus* Staesche, *Borinella* cf. *nepalensis* (Kozur and Mostler), and *Neospathodus* sp. A. Zone encompasses the *Clypeoceras spitiense* ammonoid bed and *Paranorites varians* ammonoid Zone in the Zhitkov Formation.

N. dieneri is a well-known species and ranges from the Dienerian to the Smithian (Orchard, 2007a). Zhao *et al.* (2007) summarized the Lower Triassic conodont sequence in the Pingdingshan section in Chaohu, Anhui, China. They defined the *N. dieneri* Zone in the upper part of the Yinkeng Formation (Upper Induan, Dienerian) and further subdivided it into three subzones as defined by the successive occurrence of *N. dieneri* Morphotypes 1, 2, and 3, which also range upward into higher subzones. In the Abrek Bay section, a form of *N. dieneri* similar to the above-mentioned Morphotypes 1 and 2 occurs in the lower part of the zone, and Morphotype 3, characterized by a posterior cusp that is broader and shorter than other denticles, occurs in the middle part of the zone.

N. pakistanensis, the other characteristic species of the zone, ranges upward into the lowest part of the next higher zone. As pointed out by several authors (e.g., Matsuda, 1983), *N. pakistanensis* exhibits considerable morphological variation in terms of size, general lateral profile, shape of basal cavity, and number of denticles. Specimens from the lower and middle parts of the zone have slightly shorter elements and fewer denticles compared with those from the next higher zone.

These conodonts strongly suggest that the zone, which is mainly of Upper Induan (Dienerian) age, is correlative with the *N. dieneri* Zone of China, India and other regions.

Neospathodus ex gr. waageni-N. novaehollandiae *Zone*: Zone is defined by the first occurrence of *Neospathodus* ex gr. *waageni* and *N. novaehollandiae* McTavish, both of which occur frequently throughout the zone. *N.* ex gr. *waageni* is a well-known index species of the Early Olenekian (Smithian) throughout the world (Orchard, 2007a). Consequently, the zone is correlated with the Early Olenekian (Smithian). Zone encompasses at least the *Clypeoceras timorense* ammonoid Zone and *Radioprionites abrekensis* ammonoid "bed" of the Zhitkov Formation.

N. waageni, originally described from the Salt Range (Sweet, 1970), has been described several times by subsequent authors from Lower Triassic rocks elsewhere in the world. These authors all report morphological variation mainly in the profile of the basal margin, length of the posterior process, and shape of the basal cavity (e.g., Matsuda, 1983). Zhao *et al.* (2004) reported the occurrence of abundant specimens in the Pingdingshan Section of China and recognized three distinct subspecies that clearly occur in succession. Consequently, they subdivided the zone into three subzones, to which Zhao and Orchard (in Zhao *et al.*, 2007) applied the following names: *N. waageni eowaageni*, *N. waageni waageni*, and *N. posterolongatus*.

N. waageni (s.l.) is also abundant in the Muth Section in Spiti. According to Orchard and Krystyn (2007) and Orchard (2007a), *N. waageni* (s.l.) occurs in Smithian strata and consists of six morphotypes including two subspecies, *N. waageni waageni* and *N. waageni eowaageni*. Their Morphotype 1 is characterized by the development of platform flanges at the posterior end. Morphotype 2 corresponds to *N. waageni waageni* and Morphotype 3 has a length to height ratio of about 1 : 1 and upturned denticles identical to those of *N. waageni eowaageni*. Morphotype 4 is characterized by the presence of a posterior-most small denticle. Morphotype 5 has an unusually large triangular cusp. Morphotype 6 exhibits denticles that tend to radiate in a fan-like fashion from the base. It is difficult to determine the morphological variation of these morphotypes, given that the authors illustrated each of their types with only one lateral and basal view. In the present study, the author treats the species in a broad sense as *N.* ex gr. *waageni* and detailed identification is reserved for future research. However, the following comments are intended to discuss similarities of the present *N. waageni* (s.l.) with the above-mentioned six morphotypes from Spiti. *N.* ex gr. *waageni* from the Abrek Bay section exhibits variation in the profile of the basal margin, basal cavity, and denticulation, which have already been pointed out by their authors. Specimens obtained from the basal part of the zone (AB1021) have a similar profile as observed in *N. waageni waageni*. Most specimens from the lower part of the zone (AB1024) have the same configuration that is characteristic of *N. waageni eowaageni*.

N. aff. *posterolongatus* Zhao and Orchard from the basal part of the zone is represented by a single specimen that exhibits close similarity in general profile to *N. posterolongatus*, a proposed species based on *N. waageni* subsp. nov. B by Zhao *et al.* (2004). Several other specimens identified as *N.* ex gr. *waageni* were obtained from the middle part of the zone in association with *N. spitiensis* and *Foliella gardenae* (Staesche).

The basal part of the zone yields abundant, well-preserved elements of *N. novaehollandiae*, which is the other characteristic species in the zone. Although a few specimens were recovered, *N. pakistanensis* is associated with *N. novahollandiae* in this part of the zone. Both species are similar and previous authors, such as Matsuda (1983) and Nicora (1991), considered them to be conspecific. Recently, Orchard (2007a) discussed the validity of both species and pointed out that the shape of the basal cavity is an important criterion for distinguishing between species, rather than the lateral profile of the underside or the degree of platform flange growth. The characteristic morphology observable in both species exhibits considerable variation in the present material. However, the occurrence of *N. novaehollandiae* in the

Abrek Bay section is more common at higher levels than *N. pakistanensis*. Furthermore, in our collection, *N. novaehollandiae* includes many large-sized individuals and some exhibit pathological or aberrant features in the basal cavity and lateral process. The present author concluded that *N. pakistanensis* and *N. novaehollandiae* are independent species, and the former is a precursor of the latter species within the same species lineage.

Several specimens identified as *N. spitiensis* occur in the middle part of the zone. According to Orchard (2007a) this species is a direct descendant of *N. posterolongatus*, and the stratigraphic level of *N. spitiensis* in the Abrek Bay section supports this view, but *N. posterolongatus* apparently is missing in the section.

Only one specimen identifiable as *Foliella gardenae* was recovered from the middle part of the zone in association with *N. spitiensis*. This interesting Smithian aged conodont, originally described from the upper Campiller Formation of South Tirol, Austria (Staesche, 1964), also occurs in Smithian aged equivalent rock units in Slovenia (Kolar-Jurkovsek & Jurkovsek, 1996), Primoryie, Far East Russia (Buryi, 1979), Sichuan, Southwest China (Dai & Tian, 1983), and other Chinese localities.

The lower to middle part of the zone yields other conodont elements identified as *Neospathodus concavus* Zhao and Orchard, *Neospathodus* sp. B, and *Ellisonia*? cf. *peculiaris* (Sweet), but these occurrences are rare and the specimens are fragmentary. A single specimen of *N. concavus* recovered from the basal part of the zone is characterized by an arched, large and long element, and it has a short cusp compared with that of the original Chinese specimen (Zhao & Orchard, in Zhao *et al.*, 2007). Orchard & Krystyn (2007) illustrated the other type of this species from Spiti that bears 13 denticles on its strongly arched blade. The general configuration of the present element agrees with the Spiti specimen, except for a large cusp and the size of the sixth denticle.

Correlation (by Y. Shigeta and H. Igo)

The geological age of the basal part of the Lazurnaya Bay Formation remains uncertain because no direct, age diagnostic evidence has been found. In contrast, the overlying lower and middle parts of the formation, containing the *Lytophiceras* sp. Zone and the lower part of the *Neogondolella carinata* Zone, is supposedly of Early Induan (Griesbachian) age. Furthermore, the upper part of the formation, characterized by the *Gyronites subdharmus* Zone and the middle part of the *Neogondolella carinata* Zone, is correlatable with the late Early Induan (late Griesbachian).

A change in the ammonoid assemblage in the uppermost part of the Lazurnaya Bay Formation and the overlying lowest part of the Zhitkov Formation, in which *Ambitoides fuliginatus* is common, suggests that these parts are early Late Induan (early Dienerian) in age. The lower part of the Zhitkov Formation yields *Clypeoceras spitiense* and is of Late Induan (Dienerian) age. This correlation is also supported by the occurrence of *Neospathodus dieneri* and *N. pakistanensis*.

The First Appearance Datum (FAD) of *N. waageni* (s.l.) has been basically accepted as the primary marker for the definition of the Induan-Olenekian (I/O) boundary (Tong *et al.*, 2003; Krystyn *et al.*, 2007; Zhao *et al.*, 2007). *N.* ex gr. *waageni* first appears at AB1021 (and AB1022) in the main part of the Zhitkov Formation. Therefore, the I/O boundary should be placed at a horizon between AB1019 and AB1021 (or AB1022), given that Late Induan (Dienerian) ammonoids occur at AB1019.

The uppermost part of the main part of the Zhitkov Formation yields the middle Early Olenekian (middle Smithian) ammonoid *Arctoceras subhydaspis*, which is characteristic member of the horizon immediately underlying the upper Smithian *Anasibirites nevolini* Zone in South Primorye.

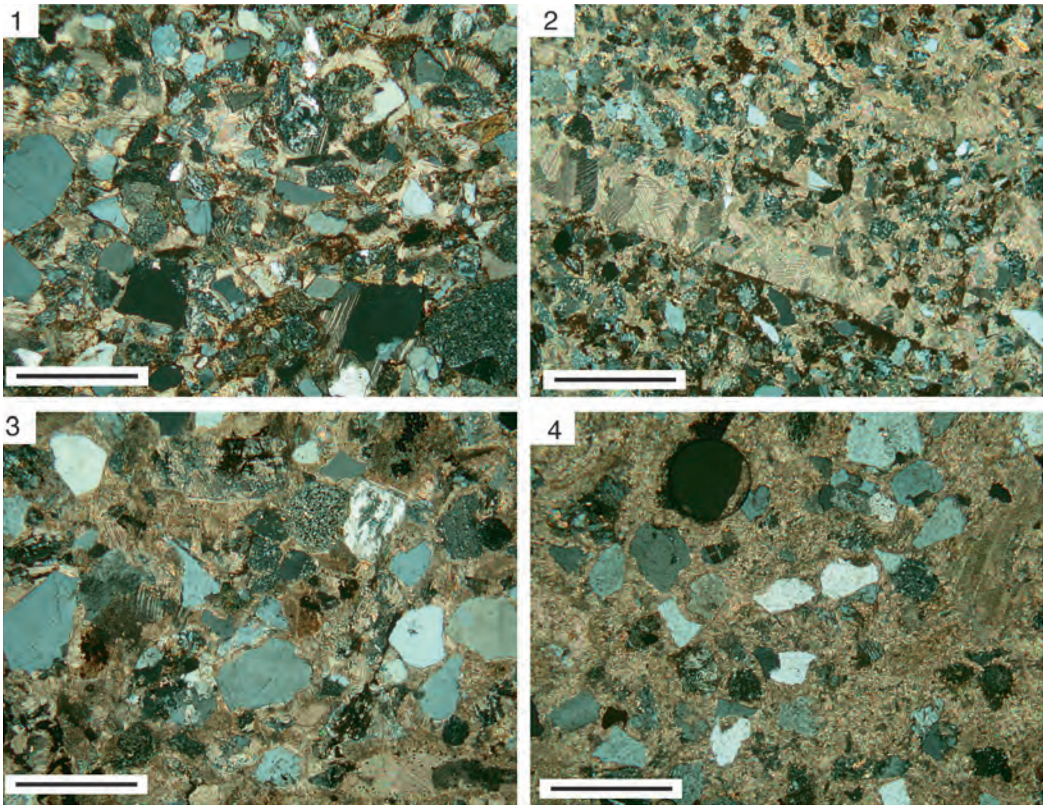


Fig. 19. Photomicrographs, under cross polarized light, of calcareous sandstones and limestone from the Abrek Bay area. 1, Calcareous sandstone from AB1004. 2, Calcareous sandstone from AB1011. 3, Calcareous sandstone from AB1014. 4, Limestone with detrital minerals from AB1025. Scale bar=0.5 mm.

Age distribution of detrital monazites in the sandstone

(by K. Yokoyama, Y. Shigeta and Y. Tsutsumi)

Seven sandstone samples, three from the Lazurnaya Bay Formation at AB1004, AB1007 and AB1011 and four from the Zhitkov Formation at AB1014, AB1016, AB1019 and AB1025, were investigated for age analyses of monazite (Figs. 5–10). All sandstones are fossiliferous sandstones, consisting mainly of calcite with subordinate amounts of detrital mineral and lithic fragment (Fig. 19). Technically, these rocks should be identified as limestone or calcareous sandstone, but they are tentatively denoted as sandstone in this paper. Sandstones of Permian to Triassic age from the Japanese Islands and a sample of sand from Khabarovsk, along the Amur River, were analyzed to compare with those from the Abrek Bay area.

Analytical procedure

Procedures for the separation of heavy minerals and their subsequent analysis for monazite are the same as described by Yokoyama *et al.* (1990). The theoretical basis for monazite age calculation is essentially the same as that developed by Suzuku *et al.* (1991).

Monazites were analyzed with an electron probe micro-analyzer (EPMA) fitted with a Wavelength Dispersive Spectrometer (WDS), JXA-8800 situated in the National Museum of Nature and Science, Tokyo. Analytical condi-

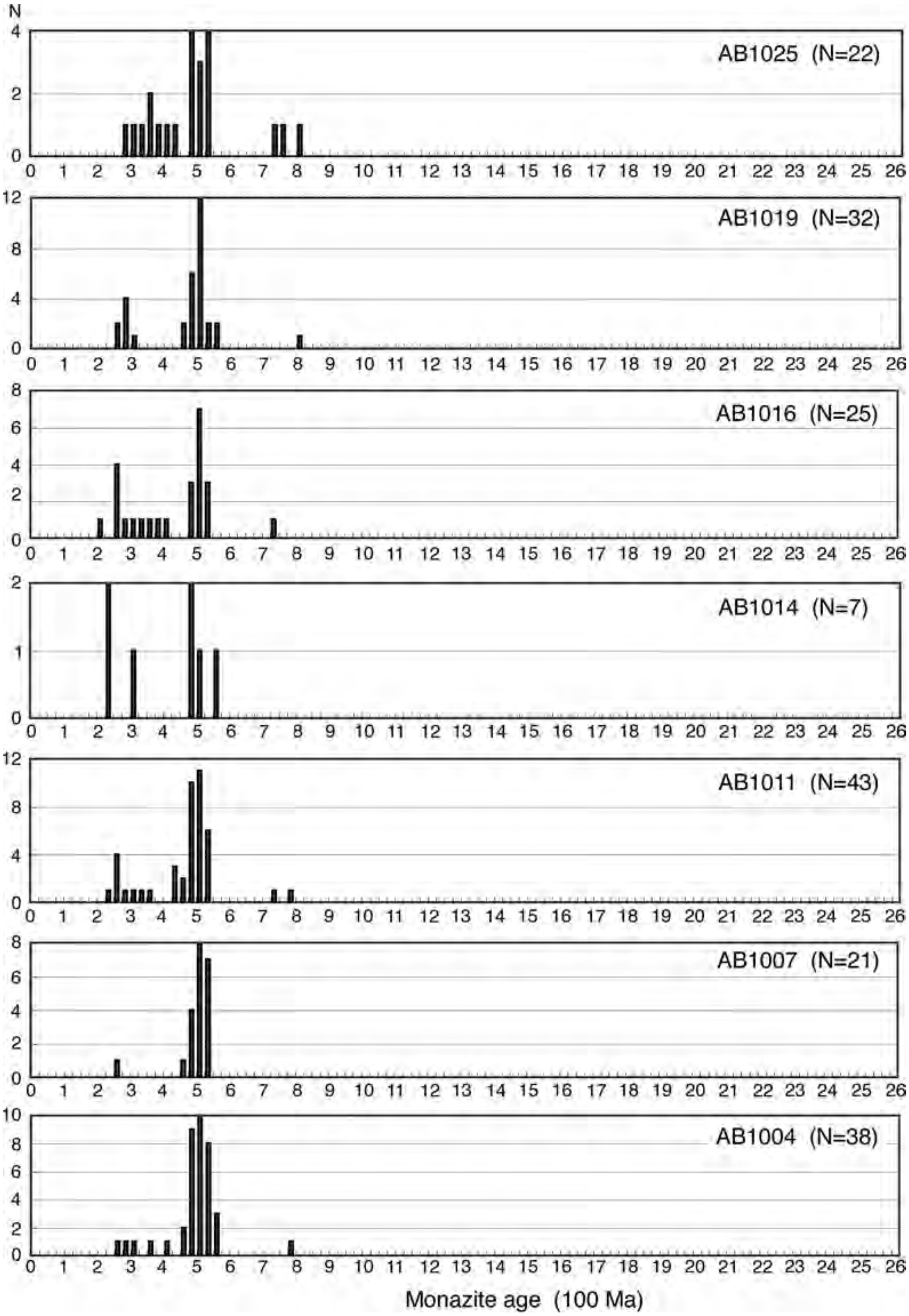


Fig. 20. Age histograms of detrital monazites from sandstones in the Abrek Bay area. Vertical axis represents number of analyzed monazite grains.

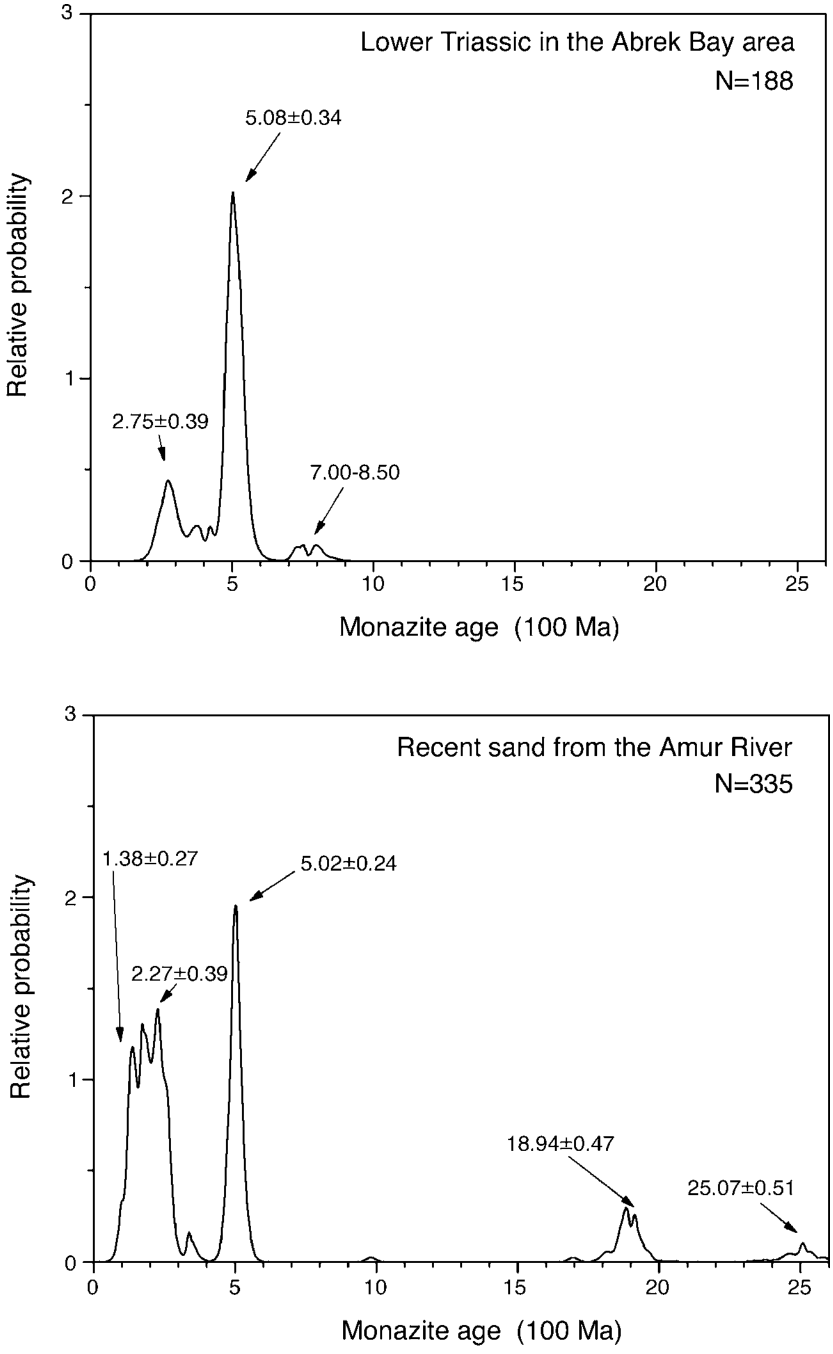


Fig. 21. Probability distribution diagrams of monazite ages of sandstones from the Abrek Bay area (upper) and the sand sample from the Amur River (lower). Numerical value (N) denotes the number of analyzed monazite grains.

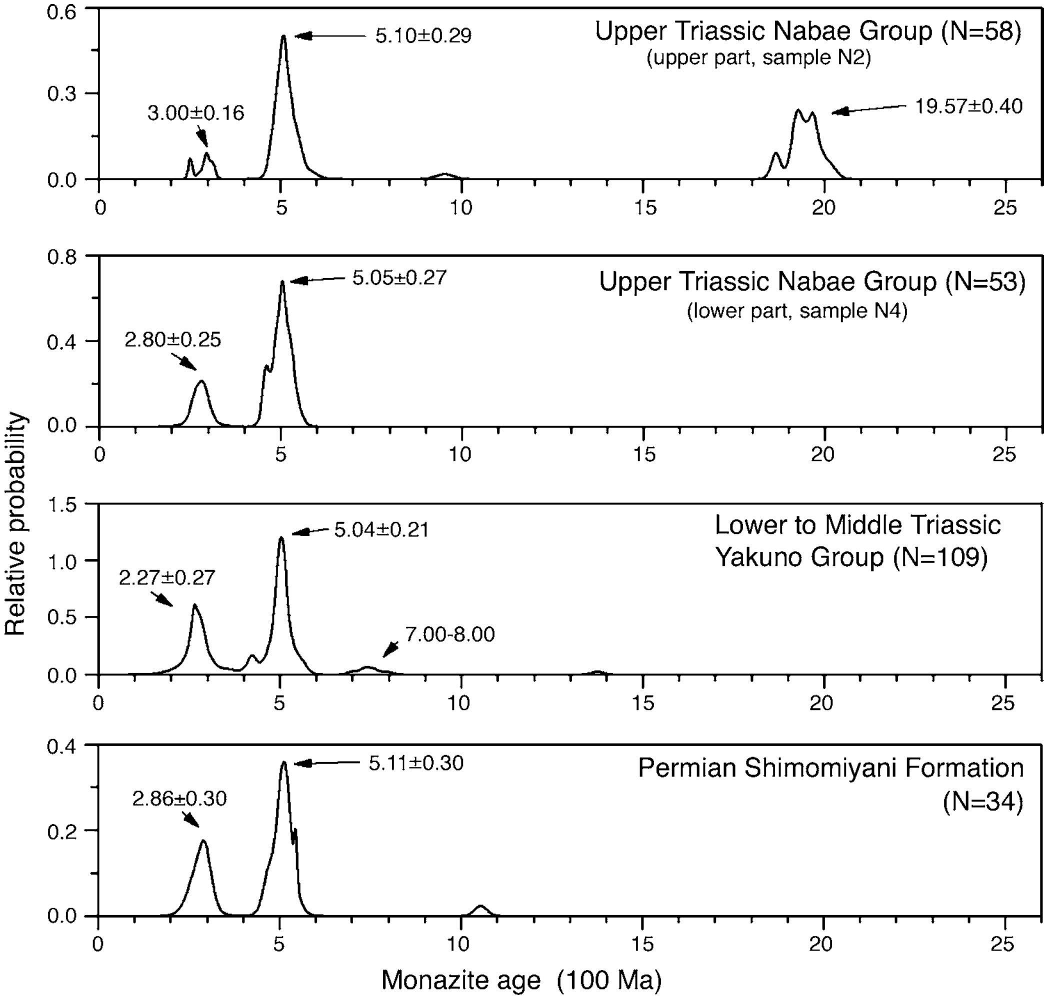


Fig. 22. Probability distribution diagrams of monazite ages of sandstones from the Maizuru Belt. Numerical value (N) denotes the number of analyzed monazite grains.

tions are the same as those described by Santosh *et al.* (2006). Age calibrations were carefully performed by comparing data obtained by EPMA dating with those acquired by the SHRIMP technique (Santosh *et al.*, 2006). Apart from minor shifts due to machine drift and variations in standard conditions, the ages obtained from both techniques were found to have good consistency. Monazites with ages of 3020 Ma and 64 Ma, obtained from SHRIMP and K-Ar methods, respectively, were used as internal standards for age calibrations. The standard deviation of the obtained ages depends mostly on the PbO content of the monazite, and age errors are within a few percent for most of the analyzed monazites that were rich in ThO_2.

Results

Although monazite grains are not common in the samples, due probably to their calcareous nature, about 200 grains were recovered and analyzed. Monazite ages are presented as frequency diagrams in Fig. 20.

Monazite ages range from ca. 240 Ma to 1000 Ma with a strong peak at around 500 Ma and a subordinate peak at around 270 Ma. Although there is no drastic change in monazite age throughout the sequence, and a notably different age distribution pattern is not observed in the sandstones, it is noteworthy that younger monazites are not common in the lower sequence, and weak peaks at 300–400 Ma and 700–800 Ma are observed in sample AB1025. Each age datum has a more or less moderate standard deviation. Then, all data were represented in Fig. 21 by a probability distribution diagram calculated with a multi-peak Gauss fitting method (Williams, 1998). Peak positions are 508 Ma and 275 Ma. Several data are plotted in 700–850 Ma, but no clear peak has been recognized in the range older than 600 Ma.

Monazite ages in the recent sand sample from the Amur River are shown in Fig. 21 together with that from the Abrek Bay area. The river mainly cuts through the Northeast China Block (Jiamusi and Songliao-Zhangguangcao blocks), which formed a continent with the Khanka Block during the Early Permian. The drainage basin of the river also includes a part of the Sino-Korea and Siberian cratons. A major peak much older than 300 Ma occurs at 500 Ma, similar to the sandstones in question. Weak peaks appear at 1900 and 2500 Ma, due probably to the Sino-Korea Craton (Yokoyama *et al.*, 2007). The southern part of the Siberian Craton has undergone granulite facies metamorphism between 488 and 478 Ma (Salnikova *et al.*, 1998). The contribution from the Siberian Craton to age data for the Amur River is represented by the huge peak at 500 Ma.

Most sandstones in the Japanese Islands have a strong peak at 1900 Ma, but no peak around 500 Ma (Yokoyama & Saito, 1996, 2001),which is similar to those from the Korean Peninsula (Yokoyama *et al.*, 2007). Permian to Upper Triassic sandstones in the Maizuru belt have different peaks than other sandstones in the Japanese Islands, but they are similar to those from sandstones in the Abrek Bay area. The Permian sandstones in the Maizuru belt are associated with chert (Ishiga & Suzuki, 1984), and belong to part of a subduction complex, thus indicating a deep sea origin, whereas the Lower to Middle Cretaceous Yakuno Group and the Upper Triassic Nabae Group are composed mostly of shallow marine sediment with a trace amount of fresh or brackish water sediment (Nakazawa, 1958), and overlie Permian rocks, either by unconformity or fault contact. Probability diagrams of sandstones from the Maizuru Belt are presented in Fig. 22. While a major peak appears at 500–510 Ma in all samples, an age near 700–800 Ma is recognized in Lower to Middle Triassic sandstones of the Yakuno Group, but only the Upper Triassic sandstone from the upper part of the Nabae Group shows a moderate peak at 1900 Ma, similar to the other sandstones in the Japanese Islands.

Discussion

The significance of the Lower Triassic section in the Abrek Bay area can be summarized as follow.

1) A newly discovered fossiliferous succession in South Primorye ranging in age from Induan (Griesbachian, Dienerian) to Early Olenekian (Smithian) is described.

2) The mode of occurrence of ammonoids is documented.

3) The age of detrital monazites in the sandstone is determined.

Age data of monazites (by K. Yokoyama, Y. Shigeta and Y. Tsutsumi)

Age analysis of detrital monazite provides us with prehistorical information about river drainage systems. These age data are especially important in the area and time frame encompassing the collision and amalgamation of continental or microcontinental blocks. In Far East Asia, the Khanka Block collided with the Jiamusi and Songliao-Zhangguangcao blocks during the Early Permian (Jia *et al.*, 2004). The collision of the Khanka Block and the Sino-Korea Craton started during Late Permian-Early Triassic time and was completed by the Late Triassic to form the huge continent that is essentially the Eurasian continent of today.

Age data for the Khanka Block are restricted. As far as recent data are concerned, approximately 500 Ma was reported from granite and gneiss samples (Khanchuk *et al.*, 1996), which is similar to those from the Jiamusi Block (Wilde *et al.*, 2000, 2003). A Precambrian age was recognized as a discordant age for zircon: 1179$\pm$80 Ma (Jia *et al.*, 2004). Monazite with a Precambrian age of 700–800 Ma is rarely observed in Lower Triassic sandstones from the Abrek Bay area (Fig. 21). These data show the presence of a Precambrian terrane in the Khanka or Jiamusi blocks. Even if Precambrian rock occurs widely as a basement rock, it is hard to elucidate through monazite age determination because monazite age is easily reset by later stage high-grade metamorphism, which occurred commonly in these blocks.

River drainage systems in the East Asia region have changed with geological time as evidenced by collision events during Permian to Triassic time. Age data, revealing a strong concentration at 500 Ma and an absence of 1900 Ma in the sandstones from the Abrek area, demonstrate that their provenance was within the Khanka Block and a portion of the Jiamusi Block, and that there is no contribution from the Sino-Korea Craton. If detrital minerals were supplied by a huge river such as the Amur, their age distribution would present a peak at 1900 Ma. An absence of the 1900 Ma peak is due to local supply or an incomplete amalgamation of the Sino-Korea Craton and Khanka Block during the Early Triassic.

The sandstones in the Abrek Bay area have the same age pattern as those of the Lower to Middle Triassic shallow marine sandstones of the Yakuno Group in the Maizuru belt, i.e., a major peak at 500–519 Ma, a subordinate peak at 270–280 Ma and sporadic data at 700–850 Ma (Figs. 21, 22). They are essentially similar to other sandstones in the Maizuru belt. A clear difference is found in the sandstone of the Upper Triassic Nabae Group. The lower sandstone of the Nabae Group is similar to the sandstones mentioned above, whereas the upper sandstone has a clear peak at 1900 Ma in addition to a major peak at 500 Ma (Fig. 22). This signifies that the provenance of the detritus includes not only the Khanka-Jiamusi Block, but also the Sino-Korea Craton, thus indicating an almost complete amalgamation of the craton and block.

The Samarka Belt at the eastern side of the Khanka Block is a Jurassic accretionary complex. It is now understood to be a northern extension of the Mino-Tamba Belt of the Inner Zone of southwest Japan, based on similarities of lithology, age and geologic structure (Kojima, 1989). These complexes were originally constructed through a series of accretionary processes as continuous belts, which were later separated into several remnants following tectonic movements. Other small belts including the Maizuru belt are not yet well understood. Sandstones in the Maizuru belt have a different age pattern than Jurassic and Triassic sandstones in other areas of the Japanese Islands (Yokoyama & Saito, 1996, 2001). The coincidence in monazite data from sandstones in the Maizuru Belt and the Abrek Bay area, South Primorye, suggests that the Maizuru Belt belongs to the Khanka Block or Jiamusi Block, and that the belt should be located near South Primorye. Tectonic reconstruction in the region of the Sea of Japan is still enigmatic because collisions, opening of back-arc basins and rotation of small blocks were common even after deposition of Triassic sediments. Furthermore, many faults with lateral displacement have been described along the continental margin. At present, monazite age data of the sandstones will more or less place a constraint on any tectonic model for the Far

East Asia region. Wilde *et al.* (2003) discussed that the Jiamusi Block was located along the northern margin of the Australian block, based on the presence of the late Pan-African magmatic event at ~500 Ma. It is possible that the Khanka Block, with a major peak at 500 Ma, will be closely associated with the Jiamusi Block, and that both were once located near the northern part of the Australian Block. Some data with a 700–800 Ma peak corresponds to the Mozambique event, which is also common in the areas affected by the Pan-African magmatic event. However, it is premature to discuss tectonic reconstruction due to a lack of substantial age data for the Khanka and Jiamusi blocks.

This analysis is a reconnaissance study of the sandstones in Far East Asia. Further monazite age data, including that derived from Upper Triassic sandstones in both, the Khanka Block and the Sino-Korean Craton, will more clearly reveal the timing of the amalgamation. Furthermore, this type of study regarding both the block and the craton will clarify their boundaries and will provide a more realistic history of the collision and amalgamation that formed the continent.

The position of the Abrek Bay section in the "Ussuri Basin" (by Y. Shigeta and H. Maeda)

Lower Triassic deposits unconformably overlie Permian rocks with basal conglomerate throughout the South Primorye region. The lower portion, consisting mainly of sandstone and conglomerate of the Lazurnaya Bay Formation, represents a shallow marine facies above the storm wave-base. This sequence is overlain by the Zhitkov Formation, consisting of laminated sandy mudstone and mudstone with intercalations of sandstone, which suggests an offshore facies deposited in a deep anoxic basin. Such a fining-upward sequence is characteristic of deposits in the Triassic sedimentary "Ussuri Basin".

Regardless of lithological uniformity, datum planes of fossil zones obviously extend across lithostratigraphic boundaries. For example, in the Seryj and Tri Kamnya Capes areas, the Induan/Olenekian boundary occurs in the upper part of the Lazurnaya Bay Formation (Zakharov, 1996; Markevich & Zakharov, 2004). In contrast, in the Abrek Bay area the boundary occurs within the Zhitkov Formation.

Shallow marine facies appear in the Induan and Olenekian (Smithian, Spathian) at Atlasov Cape and Russian Island in the western part of the "Ussuri Basin" (Markevich & Zakharov, 2004). Certain fossil zones are not recorded in these localities since strong wave and current action frequently interrupted sedimentation.

Conversely, shallow marine facies change to offshore facies within the lower Upper Induan (lower Dienerian) in the Abrek Bay area in the eastern part of the basin. In this area, sedimentation appears to be continuous during the Late Induan and Early Olenekian, and stratigraphic and faunal successions are exceptionally well preserved. This setting most likely resulted from deposition under the much deeper and quieter environmental conditions that were prevalent in the Abrek Bay area as compared to the western part of the basin, and it supports an eastward-deepening setting of the Triassic System in the "Ussuri Basin" (Zakharov, 1968, 1997a).

Ammonoid mode of occurrence (by H. Maeda and Y. Shigeta)

In the upper part of the Lazurnaya Bay Formation and the overlying Zhitkov Formation, ammonoids are mainly preserved in gravity-flow deposits such as turbidites and slump deposits. In contrast, background deposits represented by laminated mudstone are almost barren of megafossils.

Ammonoids in particular are abundant in the fine-grained muddy sandstone beds, which are sporadically intercalated in the laminated mudstone (Figs. 8–10). These sandstone beds lack a coarse-grained portion, and their sedimentary features resemble the upper half of a Bouma sequence. They are interpreted as dis-

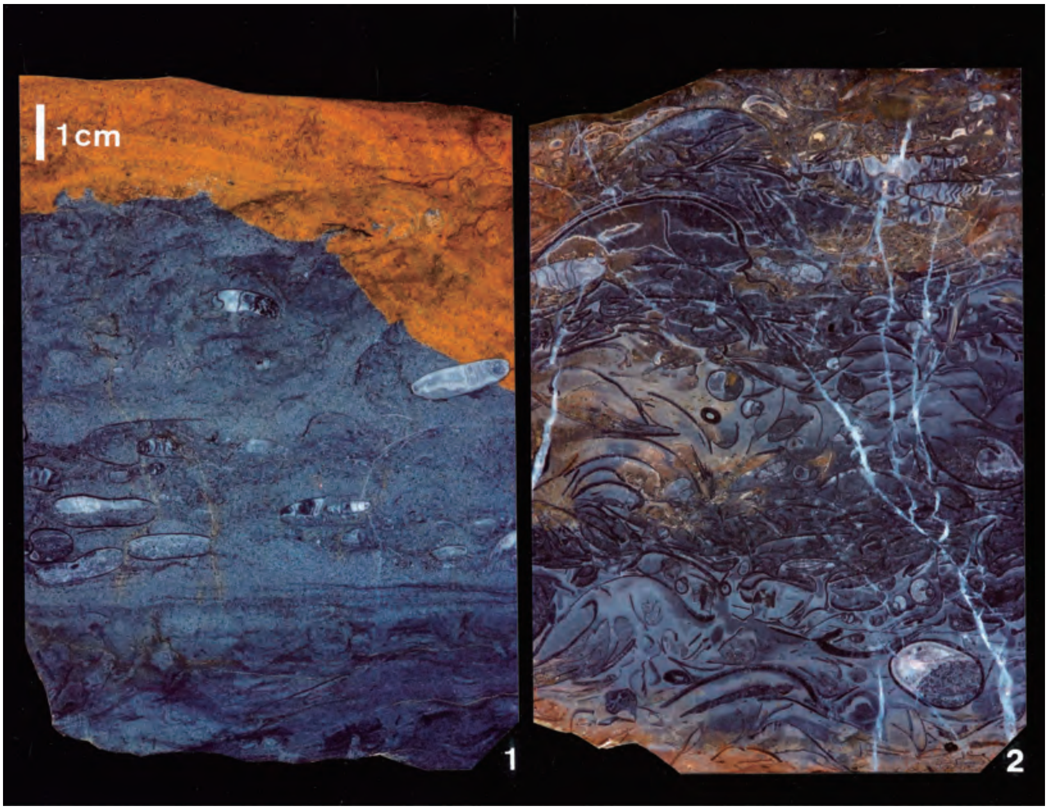


Fig. 23. 1, Vertical profile exhibiting ammonoid mode of occurrence in fossiliferous turbidic fine sandstone bed (AB1011) in upper part of Lazurunaya Bay Formation. Light-colored elliptical sections represent sparry calcite-filled septate portions of *Gyronites subdharmus* Kiparisova shells. Note that shells are aligned parallel to bedding plane and are mainly accumulated in middle part of sandstone. Some shells exhibit geopetal strucuture. 2, Vertical profile exhibiting bivalve mode of occurrence in fossiliferous turbidic fine sandstone bed (AB1014) in lower part of Zhitkov Formation. Dark colored platy material represents bivalve shell tests. In contrast with ammonoids, bivalve shells are accumulated in all orientations throughout the fine-grained turbiditic sandstone bed.

tal turbidites, whose density is much lower than that of coarser-grained proximal turbidites (Reineck & Singh, 1973).

Fig. 23 illustrate a vertical profile of the fossiliferous turbidite beds that at AB1011 and AB1014. Ammonoid shells are well-preserved, aligned parallel to the bedding plane, and are mainly accumulated in the middle part of a low-density turbidite (Fig. 23.1). Some even exhibit a geopetal strucuture.

On the other hand, bivalve shells, which are also abundant in the fine-grained sandstone beds, exhibit different taphonomic features. Compared with ammonoids, bivalve shells are accumulated in a jumbled mass, one on top of the other within the fine-grained turbiditic sandstone bed from the bottom to the top (Fig. 23.2). This occurrence is attributable to hydrodynamic sorting, which occurs during deposition of the turbidites, and is caused by differences in shell density (Maeda & Seilacher, 1996). Thickly-shelled bivalves have a shell density of 2.0 g/cm^3 or higher. In contrast, the density of empty ammonoid shells remains around 1.1–1.2 g/cm^3, even though they are fully waterlogged (Maeda, 1987, 1999; Maeda & Seilacher, 1996).

The scarcity of ammonoids in the surrounding mudstone (back ground) suggests that they were not indigenous to the slope-basin envi-

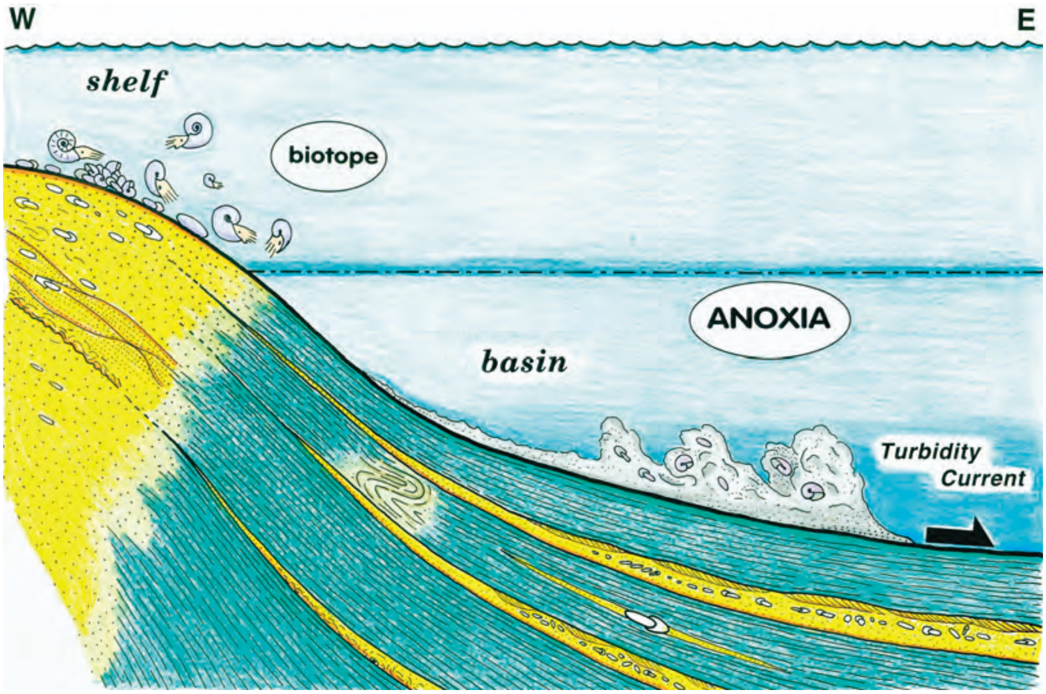


Fig. 24. Schematic paleoenvironmental profile during Early Triassic period in South Primorye, Russia. In the western area, shallow marine sandstone facies was predominated; e.g., Russian Island. Many ammonoids show indigenous mode of occurrence, and their biotope seemed in such shelf environment. On the other hand, laminated mudstone facies deposited under anoxia is widespread in the eastern area, e.g., Abrek Bay area. Paleo-current directions also suggest development of deep basinal environment eastward. Ammonoids are scarce in surrounding mudstone but occur restrictedly from intercalated very fine sandstone beds. These features may suggest that those ammonoids were allochthonous and that they were transported from their biotope to deep anoxic basin by low-density turbidite after death.

ronment, but rather, were of allochthonous origin. The majority of ammonoids from these formations probably lived at shallower depths, and after death, their empty shells were transported from their biotope to the anoxic basin-floor by gravity flows, most likely low-density turbidites (Fig. 24). Unlike the resultant severe damage expected from high-density gravity flows such as slump deposits, turbulence within low-density turubidites caused minimal damage to ammonoid shells during transport. Therefore, their shells were well preserved even though they were of allochthonous origin.

Aspects of ammonoid faunas (by Y. Shigeta)

Even though most members of the Griesbachian, Dienerian and early Smithian ammonoid faunas from the Abrek Bay area are clearly endemic, these faunal groups do contain a few species that are common to other realms. For instance, the occurrence of the late Griesbachian ammonoid *Wordieoceras* cf. *wordiei* (Spath) certainly indicates a relationship with the Boreal realm, given that this taxon is common in Greenland and Arctic Canada. Likewise, the early Dienerian fauna includes *Ambitoides fuliginatus* (Tozer) gen. nov., which also occurs in northeastern British Columbia, as well as *Proptychites alterammonoides* (Krafft) and *Clypeoceras spitiense* (Krafft), both of which are known from the Northwest Himalayan area. These ammonoids suggest relationships with the Eastern Panthalassic and Tethyan realms, respectively.

Brayard *et al.* (2008) recently discussed the paleobiogeography of Smithian ammonoids from South Primorye and concluded that the fauna exhibits strong affinities at the generic level with South China. However, early Smithian faunas in South Primorye and South China contain many endemic genera and species and they actually share very few common species (Kiparisova, 1961; Zakharov, 1968; Brayard & Bucher, 2008; Brühwiler *et al.*, 2008). This fact suggests that the ammonoid fauna of South Primorye exhibits only a very weak relationship with South China during the early Smithian.

Present-day East Asia was formed by the collision and amalgamation of several microcontinental blocks, which were located at the interface between the Panthalassic and Tethyan Oceans during the Early Triassic period. South China, which is part of the Yangtze (South China) Craton, was located at the paleoequator, and South Primorye was probably situated in the middle northern paleolatitudes of the Northeast China Block (Fig. 1).

As discussed earlier, ammonoids lived only in the shallower environment above the storm wave base due to the anoxic conditions thought to be so prevalent in deeper waters during the Early Triassic period (Fig. 24). Ammonoids had a nektobenthic mode of life similar to recent *Nautilus* (e.g., Scott, 1940; Tanabe, 1979; Cecca, 1992; Westermann, 1996), but their migration between microcontinents may have been severely restricted by the surrounding oxygen-poor deeper waters (Wignall & Twitchett, 2002).

For many benthic gastropods and bivalves, the duration of the planktonic stage is a very important factor controlling the extent of their geographical distribution (Jablonski & Lutz, 1980, 1983; Scheltema, 1971). Most ammonoids had a planktic life after hatching, but its duration is still obscure (Landman *et al.*, 1996). In contrast with ammonoids, conodonts from the Abrek Bay area include many pandemic species. They had a nektonic mode of life and may have swum the oceans between the microcontinents. If Lower Triassic ammonoids had a long interval of planktic life after hatching, they likely would have shown a pandemic distribution much like the conodonts. Their restricted habitat along with a relatively short planktonic stage may have combined to cause endemism in Early Triassic ammonoids.

Holocrinus **species from the early Smithian**
(by T. Oji)

Assuming the ammonoid based age assignment is correct, the existence of *Holocrinus* within the early Smithian *Clypeoceras timorense* beds represents the oldest known occurrence of this taxon in the world. Prior to this discovery, the oldest occurrence of *Holocrinus* sp. was in the late Smithian *Glyptophiceras aequicostatus* Zone of the Hiraiso Formation in northeast Japan (Nakazawa *et al.*, 1994; Kashiyama & Oji, 2004; Brühwiler *et al.*, 2007). Spathian aged *Holocrinus* columnals and other skeletal fragments are common in the upper Thaynes Formation and the Virgin Limestone Member of the Moenkopi Formation of the western United States (Shubert & Bottjer, 1995; Shubert *et al.*, 1992; Baumiller & Hagdorn, 1995). *Holocrinus* also has been reported from the Spathian member of the Werfen Formation in the Dolomites of northern Italy (Baumiller & Hagdorn, 1995; Twitchett, 1999).

Holocrinus is regarded as the first post-Paleozoic articulate crinoid (Twitchett & Oji, 2005) and its biogeographic distribution apparently indicates that the recovery of crinoids following the Permian-Triassic (P/Tr) mass extinction was earlier in the western Panthalassa represented by sections in Japan and South Primorye, than in the eastern Panthalass (western USA) and western Tethys (southern Europe). This difference in recovery patterns with respect to biogeographic areas is similar for certain other benthic animals, such as ichnofossils (Twitchett, 2006).

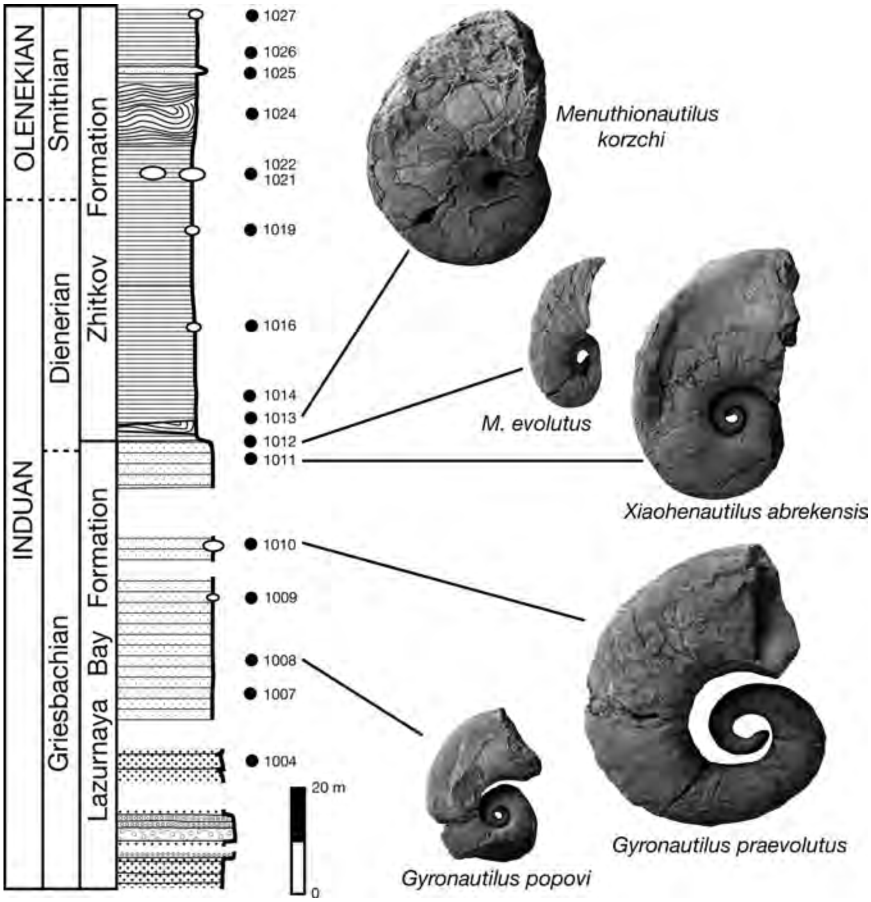


Fig. 25. Columnar section showing detailed occurrence of grypoceratid nautiloids in the Abrek Bay section.

Recovery of nautiloids in the Early Triassic (by Y. Shigeta)

As with most other organisms, the nautiloids underwent a major biotic crisis during the Permian-Triassic (P/Tr) transition. Unfortunately, the fossil record for this interval is far from complete and has been poorly understood. However, recent discoveries in the Abrek Bay area provide an important key for understanding their recovery during the Early Triassic.

The following five species, belonging to three genera of nautilids, have been found in succession in Induan (Greiesbachain and Dienerian) deposits in the Abrek Bay area: 1) *Gyronautilus popovi* Shigeta and Zakharov sp. nov., with evolute inner whorls, gyroconic outer whorls, and sub-central siphunle position; 2) *Gy. praevolutus* (Kiparisova), distinguished by a gyroconic shell throughout ontogeny and near-ventral siphuncle position; 3) *Xiaohenautilus abrekensis* Shigeta and Zakharov sp. nov., characterized by a moderately evolute shell and near-ventral siphuncle position; 4) *Menuthionautilus evolutus* sp. nov., with a moderately evolute shell and siphuncle located next to venter; and 5) *M. korzchi* Kiparisova, with a very involute shell and siphuncle located next to venter (Fig. 25).

Gy. popovi more closely resembles early Induan members of *Grypoceras* from the Himalayan area (Griesbach, 1880; Diener, 1897), and it seems best to consider *Gy. popovi* to be an offshoot of an early Induan species of

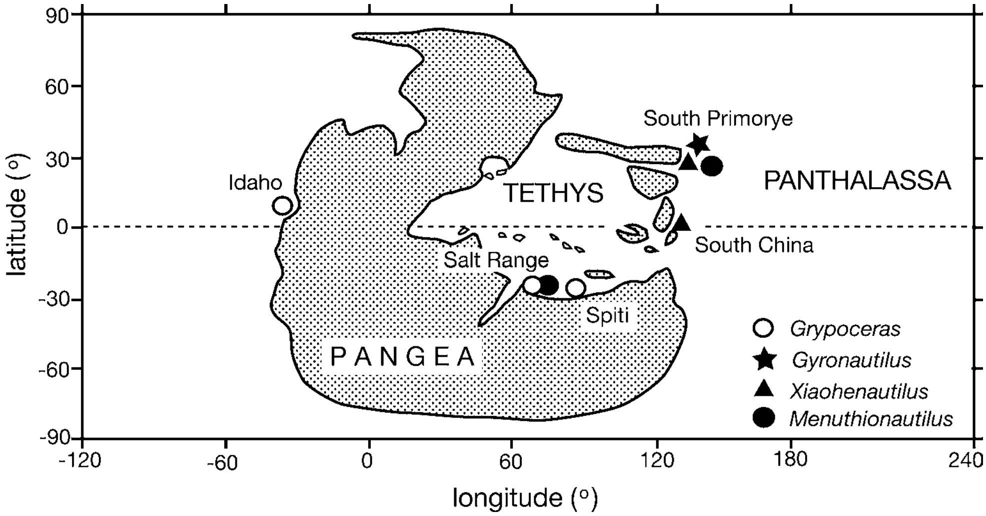


Fig. 26. Paleogeographical distribution of Induan aged grypoceratid nautiloids (Griesbach, 1880; Diener, 1897; Kummel, 1953a, b; Nakazawa & Dickins, 1985; Xu, 1988; Mu *et al.*, 2007). Map base after Fig. 1.

Grypoceras. *Gy. popovi* differs from *Gy. praevolutus* by its evolute inner whorls, but both species probably belong to the same evolutionary lineage. *Gy. praevolutus* and *X. abrekensis* both have a near-ventral siphuncle position, and if this morphological variable is considered as diagnostic in regard to phylogenetic relationships, then *X. abrekensis* would likely be an offshoot of *Gy. praevolutus*. The shell form of *M. evolutus* is very similar to *X. abrekensis*, but its siphuncle position is the same as that of *M. korzchi*. *M. korzch* likely evolved from *X. abrekensis* via *M. evolutus* Thus, the five species from the Abrek Bay section may belong to the same evolutionary lineage within the Grypoceratidae.

The Grypoceratidae, long recognized as one of the more successful nautiloid families, flourished during the Permian and developed diverse shell forms and siphuncle positions (Kummel, 1953a). However, most family members became extinct during the P/Tr transition, and only one genus, an ancestor of *Grypoceras*, survived (Kummel, 1953a). *Grypoceras* is characterized by a moderately involute shell and a central siphuncle, and Grypoceratid nautiloids from the Abrek Bay area suggest that this survivor again developed diverse shell forms and siphuncle positions after the P/Tr mass extinction. Induan aged Grypoceratids have been described from Idaho, the Salt Range, Spiti and South China (Fig. 26), and their biogeographic distribution shows that they diversified in the western Panthalassa and Tethys areas. In contrast, the nautilid families Tainoceratidae and Liroceratidae also crossed the P/Tr boundary, but they developed in the Boreal realm during the Early Triassic (Sobolev, 1989, 1994).

Gyronautilus is the only known uncoiled nautilid genus that lived during the Mesozoic and Cenozoic eras. During extinction periods, it has been shown that many ammonoids, under intense environmental stress, were affected by a drastic simplification of their shell geometory. Guex (2006) observed that a process termed “proteromorphosis” can result in relatively tightly coiled ammonoids giving rise to highly evolute forms or uncoiled heteromorphs. The appearance of *Gyronautilus* just after the P/Tr mass extinction seems to agree with this hypothesis, and its evolutionary clock may have been reinitialized by extreme environmental stress (Guex, 2006).

Table 1. Early Triassic bivalves of South Primorye and the occurrence of common or closely related species in other areas. 1: Maizuru Zone, Japan (Nakazawa, 1961), 2: Kamura Limestone, Japan (Kambe, 1963), 3: Northwest China (Yang *et al.*, 1983; Lu & Chen, 1986), 4: Southwest China (Editorial Group on Fossil Lamellibranchiata of China, 1976; Gan & Yin, 1978), 5: Siberia (Kurushin, 1992; Dagys *et al.*, 1996), 6: Greenland (Spath, 1930, 1935), and South Primorye (Bittner, 1899b; Kiparisova, 1938; added species in this paper *).

Species	Area					
	1	2	3	4	5	6
Palaeonucula goldfussi (Alberti)	—	—	○	—	—	—
Palaeonucula oviformis (Eck)	○	—	—	—	—	—
Palaeoneilo? *prinadae* Kiparisova	—	—	—		—	—
Palaeoneilo elliptica praecursor (Frech)	○	—	○	—	—	—
Palaeoneilo ledaeformis Kiparisova	—	—	—	—	—	—
Nuculana sp. nov. (Kiparisova)	○	—	—	—	—	—
Nuculana skorochodi (Kiparisova)	—	—	—	—	○	—
Nuculana aff. *becki* (Philippi)	—	—	—	—	—	—
“*Modiolus*” sp. indet.*	—	—	—	—	—	—
Promyalina schamarae (Bittner)	—	—	—	—	○	—
Promyalina putiatinensis (Kiparisova)	—	—	○	○	—	—
Promyalina aff. *blasingeri* (Philippi)	—	—	—	—	—	—
Pteria ussurica (Kiparisova)	—	○	—	—○	—	—
Bakevellia (*Neobakevellia*?) *exporrecta* (Lepsius)	—	○	○	—	—	—
Bakevellia (*Neobakevellia*?) *exporrecta linearis* (Gordon)	—	—	—	—	—	—
Bakevellia (*Neobakevellia*?) *mytiloides* (Schlotheim)	—	—	—	—	—	—
Bakevellia? sp. indet.*	—	—	—	—	—	—
Eumorphotis iwanowi Bittner	—	—	○	○	—	—
Eumorphotis maritima Kiparisova	○	—	—	—	—	—
Eumorphotis multiformis (s.l.) Bittner	○	○	○	○	—	○
Clarai aurita (Hauer)	—	—	○	○	—	—
Claraia stachei Bittner*	—	—	—	○	○	○
Claraia cf. *tridentina* Bittner	—	—	—	—	—	—
Crittendenia australaisatica (Krumbeck)	—	—	—	—	—	—
Crittendenia aff. *decidens* (Bittner)	○	—	—	○	—	—
Leptochondria bittneri (Kiparisova)	○	—	○	○	—	—
Leptochondria minima (s.l.) (Kiparisova)	○	○	○	○	○	—
Entolium microtis Wittenburg	○	—	○	—	—	—
Entolioides sp. indet.*	○	—	—	—	—	—
Scythentolium ussuricus (Bittner)	○	—	—	—	—	—
“*Pecten*” aff. *sojalis* Wittenburg	○	—	—	—	—	—
“*Etheripecten*” *amuricus* (Bittner)	—	—	—	—	—	—
Chlamys? *cryshtofowichi* Kiparisova	—	○	—	—	—	—
Chlamys? aff. *duronicus* Wittenburg	—	—	—	—	—	—
Chlamys sp. indet. Kiparisova	—	—	—	—	—	—
Camptonectes? *wittenbergi* Kiparisova	—	—	—	—	—	—
Unionites fassaensis (Wissmann)	—	—	○	○	○	—
Unionites fassaensis brevis (Bittner)	—	○	—	—	—	○
Unionites canalensis (Catullo)	—	○	○	○	—	—
Unionites aff. *borealis* Spath	—	—	—	—	—	○
Neoschizodus cf. *laevigatus* (Ziethen)	○	—	○	○	○	—
Neoschizodus laevigatus ovalis (Philippi) ?	—	—	○	—	—	—
Neoschizodus cf. *ovatus* (Goldfuss)	—	—	—	—	—	—
Neoschizodus ex. gr. *orbicularis* (Bronn)	—	—	—	—	—	—
Trigonodus orientalis Bittner	—	—	—	—	—	—
Myoconcha aff. *goldfussi* Dunker	—	—	—	—	—	—
Myoconcha plana Kiparisova	—	—	—	—	—	—
Myoconcha sp. indet.*	—	—	—	—	—	—

Table 1. Continued.

Species	Area 1	2	3	4	5	6
Triaphorus aff. *multiformis* Kiparisova	—	—	—	—	—	—
Ochotomya? sp. indet.*	—	—	—	—	—	—
Peribositria abrekensis (Kiparisova)	—	—	—	—	—	—
Peribositria mimer (Orberg)	—	—	—	—	○	—
Peribositria aff. *tenuissima* (Böhm)	—	—	—	—	○	—
Peribositria sp. indet.	—	—	—	—	—	—
Nos. of common or closely allied species to South Primorye fauna	13	7	14	12	8	4

Brief note on the bivalve fauna of South Primorye (by K. Nakazawa)

Bittner (1899b) and Kiparisova (1938) described nearly fifty species of bivalves from the Lower Triassic of South Primorye, and our study has resulted in an additional six species. Table 1 exhibits a list of bivalve species from South Primorye as well as common or closely related species from other areas.

Two Triassic bivalve faunas are recognized in Japan. Both are in southwest Japan and include the Maizuru fauna of the Maizuru Zone (Nakazawa, 1961) and the accreted limestone fauna from the Kamura Limestone (Kambe, 1963). The former occurs in a clastic rock facies, which probably was deposited near shore, whereas the Kamura Limestone, of oceanic origin, was primarily formed in a low latitudinal warm sea and then migrated northward and accreted in its present position. During the Early Triassic, there is not much difference between the two faunas, but by Late Triassic time, the Upper Triassic oceanic limestone fauna is more characteristic of a low latitudinal Tethyan setting, while the Maizuru fauna is more similar to faunas of South Primorye and Siberia (Nakazawa, 1991). The fauna of southwest China belongs to the Yangtze Craton, whereas the Quinghai fauna of northwest China belongs to the Sino-Korea Craton (Yang *et al.*, 1983; Lu & Chen, 1986). There is not much difference between these faunas due to the preponderance of cosmopolitan species during the Early Triassic.

All evidence indicates that the South Primorye fauna is more similar to those of Japan and China than to the Boreal faunas of Siberia and Greenland. Many Boreal taxa that are either common or related to those of South Primorye include rather widely distributed species belonging to *Eumorphotis*, *Claraia*, *Unionites*, *Neoschizodus* and *Leptochondria*. *Peribositria* from South Primorye exhibits a Boreal affinity, but the typical Boreal genus *Atomodesma* has not been found in South Primorye.

Based on the number of South Primorye species that are either common or intimately related, the Maizuru fauna contains nearly the same number as that of China. Furthermore, when considering the fact that the Maizuru Zone is far narrower and smaller in areal extent and contains a somewhat lesser number of species than China, one must conclude that the South Primorye fauna is more intimately related to the Maizura fauna than to the Chinese fauna. This conclusion is supported by the structural-geological continuity between the Inner Side of southwest Japan, which includes the Maizuru Zone and that of South Primorye (Kojima *et al.*, 2000; Ishiwatari & Tsujimori, 2003).