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New Findings of Latest Early Olenekian (Early Triassic) Fossils in South Primorye, Russian Far East, and Their Stratigraphical Significance

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ABSTRACT: Information on latest early Olenekian (latest Smithian) ammonoids is available apparently from only seven regions of the world, including South Primorye. Latest Smithian evidences on this topic are recorded from the West SMID (abbreviation from the Russian name of the quarry: "Building Materials and Details"), East SMID and Golyj Cape areas in South Primorye. This provides additional information on systematic composition of latest Smithian ammonoid, as well as conodont and brachiopod assemblages from the recently identified *Shimanskyites shimanskyi* Zone, located between lower Olenekian *Anasibirites nevolini* Zone and upper Olenekian *Tirolites subcassianus* Zone. There are many common ammonoid species in the *Shimanskyites shimanskyi* Zone and the underlying *Anasibirites nevolini* Zone, e.g., *Prosphingitoides* sp., *Arctoceras septentrionale* (Diener), *Churkites syskoi* Zakharov et Shigeta, *Submeekoceras*? *subhhydaspis* (Kiparisova), *Prionites markevichi* Zakharov et Smyshlyaeva, '*Anasibirites*' *simanenkoi* Zakharov et Smyshlyaeva, *Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva, and *Mianwaliites zimini* Zakharov et Smyshlyaeva. The base of the *Shimanskyites shimanskyi* Zone, marked by a negative $\delta^{13}C_{org}$ excursion in the Kamenushka-2 Section by our previous study, coincides with the FO (first occurrence) of ammonoids *Shimanskyites shimanskyi* Zakharov et Smyshlyaeva and *Glyptophiceras* cf. *sinuatum* (Waagen) and conodont *Hindeodella budurovi* Buryi. This zone is characterized additionally by some fossils common for the overlying upper Olenekian *Tirolites subcassianus* Zone: ammonoids of the genus *Kamenushkaites*, brachiopods *Bittnerihyris margaritovi* (Bittner) and *Lepismatina* sp. and conodont '*Neogondolella*' (=?*Borinella*) *jubata* Sweet. The latest Smithian ammonoids recorded from the *Shimanskyites shimanskyi* Zone totally consist of 30 taxa belonging to 11 families (Sageceratidae, Ussuiriidae, Aspenitidae, Paranannitidae, Arctoceratidae, Proptychitidae, ?Galfetitidae, Prionitidae, ?Kashmiritidae, Xenoceltitidae and Palaeophyllitidae). The problems of global correlation of uppermost Smithian strata are also discussed.
KEY WORDS: ammonoids, conodonts, brachiopods, biostratigraphy, Smithian, Russia.

0 INTRODUCTION

Latest Smithian ammonoids are only reported from a few places globally: (1) Salt Range, Pakistan (Brühwiler et al., 2012c); (2) Spiti, India (e.g., Brühwiler et al., 2012b, 2010); (3) South Tibet, Southwest China (e.g., Brühwiler et al., 2010); (4) Guangxi, South China (Widmann et al., 2020); (5) Utah, USA (Brayard et al., 2013); (6) Nevada, USA (Jenks and Brayard, 2018; Jenks et al., 2010); and (7) South Primorye (Smyshlyaeva et al., 2018; Zakharov et al., 2016). The Smithian is considered to be the lower substage of the Olenekian stage, and the Spathian to be its upper substage in this study. Despite the fact that there are quite a few uppermost Smithian sections that have been studied, little information is available regarding taxonomic diversity of latest Smithian ammonoids. South Primorye is long known for providing important information on Early Triassic ammonoids (e.g., Zakharov et al., 2016, 2013; Zakharov and Smyshlyaeva, 2016; Zakharov and Moussavi Abnavi, 2013; Shigeta et al., 2009; Zakharov, 1978, 1968; Kiparisova, 1961; Diener, 1895).

Earlier latest Smithian ammonoid studies in South Primorye were conducted on the basis of collections from the Kamenushka-2, Smolyaninovo and West SMID (abbreviation from the Russian name of the quarry: "Building Materials and Details") sections, where the layers containing them (*Shimanskyites shimanskyi* Zone) occupy a stratigraphic position between the lower Olenekian *Anasibirites nevolini* (Zakharov et al., 2013) and the upper Olenekian "*Tirolites-Amphistephanites*" (Zakharov et al., 2016) zones. Even the first stage of the *Shimanskyites shimanskyi* Zone of South Primorye (Smyshlyaeva et al., 2018; Zakharov et al., 2016) documented that it is characterized by significantly more representative ammonoid and conodont assemblages than the uppermost Smithian regional zones and beds in Pakistan, India, South China and the western USA (e.g., Jenks and Brayard, 2018;

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Brühwiler et al., 2012a, b).

The purpose of this article is to provide information on new findings of latest Smithian ammonoids, conodonts and brachiopods in South Primorye (West SMID, East SMID and Golyj Cape), systematic composition of their assemblages and their significance for global correlation.

1 GEOLOGICAL SETTING

The study area is a cratonic fragment (the Sergeevka terrane) obducted into a Jurassic accretionary wedge; together with the Bureya-Jiamusi-Khanka superterrane, it was located between the Sino-Korean Craton and the Sikhote-Alin orogenic belt (Isozaki et al., 2017; Golozubov, 2006; Kemkin, 2006; Khanchuk et al., 1995). The age spectra of detrital zircons of Devonian and Carboniferous sandstones in South Primorye (Sergeevka belt) show similarities to those of coeval sandstones in Japan (e.g., Hida and Kurosegawa belts; Isozaki et al., 2017), which is in agreement with the concepts of 'Greater South China' (Isozaki et al., 2014). This concepts is consistent in particular with the mutual similarities recognized in Paleozoic faunas of these regions (e.g., latest Changhsingian brachiopod and ammonoid faunas (Zakharov et al., 1997; Zakharov and Oleinikov, 1994).

According to paleobiogeographic and paleomagnetic data (Zakharov et al., 2008; Zakharov and Sokarev, 1991), South Primorye was located within the tropical-subtropical climate zone (the paleolatitude is constrainted to less than 24.2°N) during the Middle Permian–Early Triassic time.

The Lower–Middle Triassic sequences of the Sergeevka terrane in Primorye are represented by shallow marine sandy facies in their lower part (Induan Lazurnaya Bay Formation) and a deeper silty-pelitic facies in their upper part (Olenekian Zhitkov Cape and Anisian Karazin Cape formations (e.g., Zakharov and Moussavi Abnavi, 2013; Shigeta et al., 2009; Zakharov, 1997, 1978, 1968; Kiparisova, 1972; Burij, 1959; Korzh, 1959). A broad spectrum of marine fossils are recorded from the Olenekian, although brachiopods are abundant only from the lower Spathian level with *Tirolites* ammonoid fauna.

The Smithian in this region consists of the following zones in ascending order: (1) *Mesohedenstroemia bosphorensis* (with *Ussuriflemingites abrekensis* Beds in its lower part and *Euflemingites prynadai* Beds in its upper part), (2) *Anasibirites nevolini* (lower *Churkites syaskoi* Beds) and (3) recently introduced *Shimanskyites shimanskyi* (upper *Churkites syaskoi* Beds (Smyshlyaeva et al., 2018; Zakharov et al., 2016; Zakharov and Moussavi Abnavi, 2013). Zones of the upper Olenekian (Spathian), identified in South Primorye, are: (4) "*Tirolites-Amphistephanites*" (*Bajarunia magna* Beds), (5) *Neocolumbites insignis* (*Inyoceras singularis* Beds) and (6) *Subfengshanites multiformis* (Zakharov et al., 2018a; Zakharov and Moussavi Abnavi, 2013). Since the *Tirolites subcassianus* Zakharov (="*T. cassianus*" and "*T. longilobatum*"; Shigeta and Kumagae, 2016; Burij and Zharnikova, 1981) is known now in a number of Lower Triassic sections of South Primorye (e.g., Schmidt, Golyj and East SMID), we propose to rename the *Tirolites-Amphistephanites* Zone (Zakharov, 1968) to the *Tirolites subcassianus* Zone.

2 MATERIALS AND METHODS

Well-preserved Smithian cephalopod, brachiopod, bivalve and conodont fossils, were used for paleontological investigation and biostratigraphical reconstructions were collected in this stage of our study in the West SMID, East SMID and Golyi Cape sections of South Primorye (Fig. 1). Conodonts were examined with a scanning electron microscope (SEM, EVO 50 XVP) at the Analytical Center of the Far Eastern Geological Institute (DVGI). Paleontological and biostratigraphical data on the upper Smithian interval in the East SMID and Golyi Cape sections have been obtained for the first time. The studied fossil collections are kept at the DVGI (Vladivostok) under Nos. 852 and 853 (ammonoids), 19 and 28 (conodonts), 2051, 2052 and 2054 (brachiopods).

3 OBSERVATIONS AND RESULTS

3.1 Smithian Ammonoid and Conodont Successions from the West SMID Section

The West SMID Section is located in SMID quarry near Artyom, about 6 km northeast of the railway station of Uglovaya. The geographic coordinates is 43°19′07.3″N and 132°10′03.4″E. It is represented by the Induan Lazurnaya Bay, Olenekian Zhitkov Cape and Anisian Karazin Cape formations (Smyshlyaeva et al., 2018; Shigeta and Kumagae, 2016; Zakharov et al., 2004a).

The upper Smithian sequences of the West SMID, as well as some of other sections in South Primorye, are characterized by abundant and well-preserved ammonoids (Fig. 2; Zakharov et al., 2016, 2013), associated with conodonts (Bondarenko and Popov, 2020; Bondarenko et al., 2013), brachiopods, bivalves and some other fossils.

Latest Smithian xenoceltitid and some other ammonoids assemblages from the West SMID Section were first published in 2018 (Smyshlyaeva et al., 2018). The new data obtained for this and some other sections in South Primorye make it possible not only to clarify the position the Smithian-Spathian boundary (SSB), but also to investigate the diversity patterns of ammonoid and conodont faunas (Table 1). Shigeta and Kumagae (2015) provided evidence verifying the presence of the *Tirolites subcassianus* Zone at SMID quarry. Unfortunately, however, Spathian deposites of this zone do not yield characteristic fossils *in situ* in both sections of the SMID quarry (i.e., West SMID and East SMID). Therefore, the position of the SSB in the SMID quarry was not strictly determined. Smithian deposits, located in the West SMID Section below lowermost Spathian *Bittnerites*-bearing deposits (Shigeta and Kumagae, 2016) are in descending order (Fig. 3).

Smithian

Zhitkov Formation

Member 16: *Shimanskyites shimanskyi* Zone

About 17 m of dark grey mudstone and siltstone with calcareous-marl lenses and rare concretions. The lower boundary of the zone is drawn according to the first appearance of the index species. The assemblages of this unit contain the following species: brachiopod *Nudirostralina* aff. *mangyshlakensis* (Dagys), bivalve *Peribostria* sp., ammonoids *Pseudosageceras* sp., *Ussurijuvenites popovi* Smyshlyaeva et Zakharov, *Juvenites* sp., *Prosphingitoides* sp., *Pseudowenites* sp., *Galfetites*? sp., *Nyalamites*? sp., *Arctoceras* cf. *septentrionale* (Diener), *Churkites* cf.

syaskoi Zakharov et Shigeta, *Submeekoceras*? *subhydaspis* (Kiparisova), *Vercherites subcristatum* (Kiparisova), *Hemiprionites ovalis* Burij et Zharnikova, *Hemiprionites klugi* Brayard et Bucher, *Prionites subtuberculatus* Zakharov et Smyshlyaeva, *Prionites markevichi* Zakharov et Smyshlyaeva, '*Anasibirites*' *simanenkoi* Zakharov et Smyshlyaeva, *Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva, *Xenoceltites* aff. *variocostus* Brayard et Bucher, *Shimanskyites shimanskyi* Zakharov et Smyshlyaeva (Fig. 4) *Mianvalliites zimini* Zakharov et Smyshlyaeva, nautiloid *Trematoceras* sp. and conodonts *Scythogondolella mosheri* (Kozur et Mosher), *Neospathodus* sp., *Smithodus* aff. *longiusculus* (Buryi), *Furnishious triserratus* Clark, *Ellisonia nevadensis* Müller, *Hadrodontina subsymmetrica* Müller, *Hadrodontina* sp., *Pachycladina oblique* Staesche, *Pachycladina tricuspidata* Staesche, *Pachycladina inclinata* Staesche, *Parachirognathus ethingtoni* Clark, *Prioniodella ctenoides* Tatge, *Prioniodella* sp., '*Prioniodella*' *prioniodellides* (Tatge), *Roundia magnidentata* Tatge, *Chirodella dinoides* (Tatge), *Neohindeodella nevadensis* Müller, *Neohindeodella triassica* Müller and *Cypridodella* sp. (field specimens 751-4, 5, 5a, 5b, 5c, 5d, 6 and 741-2017-2, 2a, taken *in situ*; other samples (741-2016-1, 2, 3, 4, 5, 6 7, 8; 753-2) were taken in blocks).

Members 13–15: *Anasibirites nevolini* Zone

Member 15 About 7 m of dark grey mudstone with numerous small calcareous-marl concretions and lenses, containing bivalve *Peribositria* sp., ammonoids *Pseudosageceras* sp., *Ussuriaspenites evlanovi* Zakharov et Smyshlyaeva, *Ussurijuvenites popovi* Smyshlyaeva et Zakharov, *Prosphingitoides* sp., *Arctoceras septentrionale* (Diener), *Churkites syaskoi* Zakharov et Shigeta, *Submeekoceras*? *subhydaspis* (Kiparisova), *Brayardites involutus* Zakharov et Smyshlyaeva, *Monneticeras kalinkini* Zakharov et Smyshlyaeva, *Vercherites subcristatum* (Kiparisova), *Dieneroceras chaoi* Kiparisova, *Hemiprionites klugi* Zakharov et Smyshlyaeva, *Hemiprionites contortus* Zakharov et Smyshlyaeva, *Hemiprionites ovalis* Burij et Zharnikova, *Prionites subtuberculatus* Zakharov et Smyshlyaeva, *Prionites markevichi* Zakharov et Smyshlyaeva, *Anasibirites nevolini* Burij

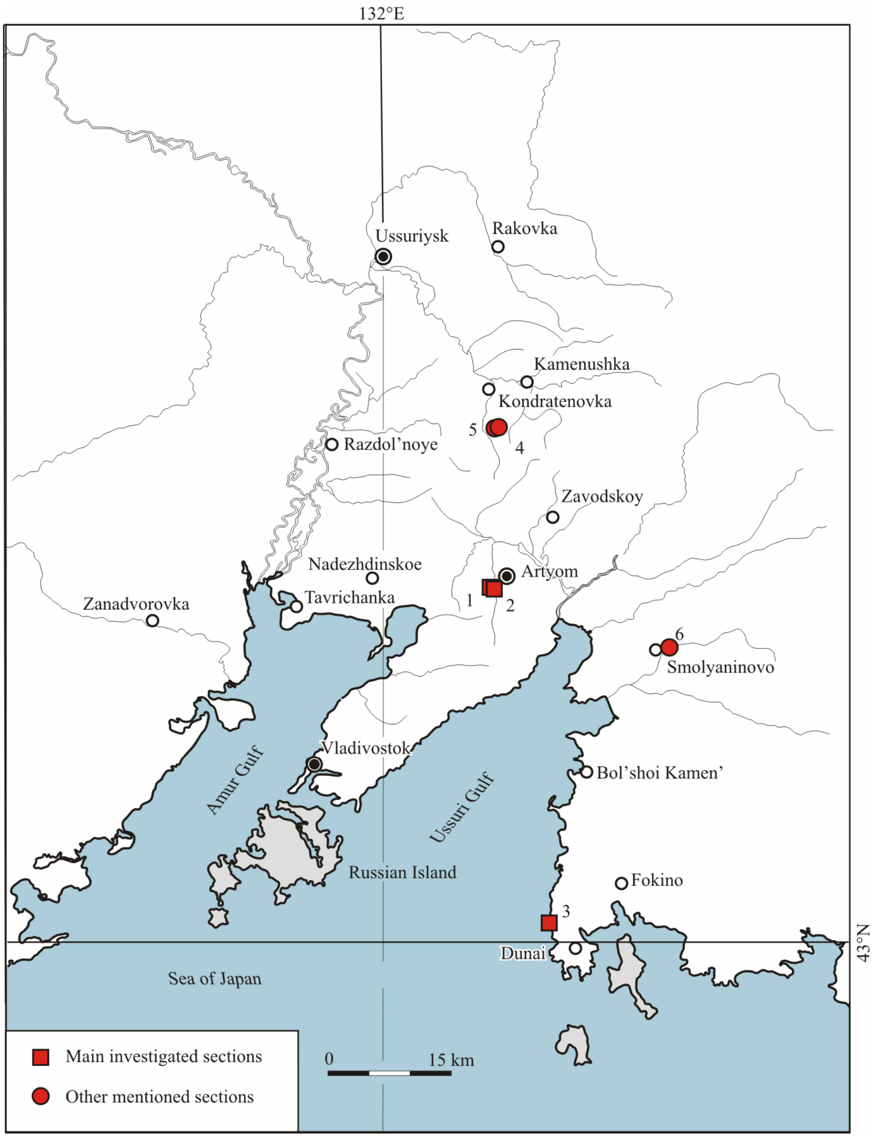

Figure 1. Geographical location of the *Shimanskyites shimanskyi* Zone in South Primorye. 1. West SMID; 2. East SMID; 3. Golyj (Kom-Pikho-Sakho) Cape; 4. Kamenushka-1; 5. Kamenushka-2; 6. Smolyaninovo.

Figure 2. Important guide ammonoid fossils from the *Anasibirites nevolini* (1–4) and *Shimansk*yites *shimanskyi* (5–32) zones of South Primotye. Scale bar=1 cm. 1–2. *Anasibirites nevolini* Burij et Zharnikova; 1. DVGI 1/853 (field No. 5-5), East SMID; 2. DVGI 2/853 (field No. 5-5), same locality; 3–4. *Anasibirites* cf. *nevolini* Burij et Zharnikova; 3. DVGI 3/853 (field No. 5-4), East SMID; 4. DVGI 4/853 (field No. 5-5), same locality; 5. '*Anasibirites*' *simanenkoi* Zakharov et Smyshlyaeva, DVGI 121/852 (field No. 959-19); 6–18. *Shimanskyites shimanskyi* Zakharov et Smyshlyaeva; 6. holotype DVGI 101/852 (field No. 955-15), Kamenushka-2; 7. DVGI 129/852 (field No. 959-19), same locality; 8. DVGI 130/852 (field No. 959-19), same locality; 9. DVGI 6/853 (field No. 40G), Golyj Cape; 10. DVGI 7/853 (field No. 40G), same locality; 11. DVGI 8/853 (field No. 40G), same locality; 12. DVGI 9/853 (field No. 40G), same locality; 13. DVGI 153/840 (field No. 741-2017-2a), West SMID; 14. DVGI 152/840 (field No. 741-2017-1(2)), same locality; 15. DVGI 12/853 (field No. 753-2), same locality; 16. DVGI 13/853 (field No. 753-2), same locality; 17. DVGI 14/853 (field No. 745-2017a), East SMID; 18. DVGI 15/853 (field No. 745-2017a), same locality; 19. *Shimanskyites* cf. *shimanskyi* Zakharov et Smyshlyaeva, DVGI 15/853 (field No. PK-120), East SMID; 20. *Prionites markevichi* Zakharov et Smyshlyaeva, DVGI 17/853 (field No. 43G), Golyj Cape; 21–22. *Nyalamites*? sp.; 21. DVGI 134/852 (field No. 959-2), Kamenushka-2; 22. DVGI 136/852 (field No. 959-19), same locality; 23, 25–27. *Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva; 23. DVGI 19/853 (field No. PK-120), East SMID; 25. DVGI 20/853 (field No. PK-120), same locality; 26. DVGI 21/853 (field No. PK-120), same locality; 27. DVGI 22/853 (field No. PK-120), same locality; 24. *Xenoceltites* aff. *variocostatus* Brayard et Bucher, DVGI 151/840 (field No. 741-2016-1), West SMID; 28. *Glyptophiceras* cf. *sinuatum* (Waagen), DVGI 23/853 (field No. PK-120), East SMID; 29. *Galfettites* sp. nov. B, DVGI 24/853 (field No. 745-2017a), East SMID; 30–31. *Larenites*? sp.; 30. DVGI 18/853 (field No. 959-15), Kamenushka-2; 31. DVGI 25/853 (field No. 741-2017a), East SMID; 32. *Kamenushkaites* sp., DVGI 138/852 (field No. 959-2), Kamenushka-2.

Table 1 Latest Smithian fossils of the *Shimanskyites shimanskyi* Zone in South Primorye

No.	Species	Family	Kamenushka-2 (Zakharov et al., 2016; this sudy)	West SMID (Smyshlyaeva et al., 2018; this study)	East SMID	Golyj Cape	Smolyaninovo (Popov and Zakharov, 2017; Zakharov and Popov, 2014; this study)
1	*Bittnerithyris margaritovi* (Bittner)	Dielasmatidae	+	-	-	-	-
2	*Lepismatina* sp.	Lepismatinidae	+	-	-	-	-
3	*Nudirostralina mangyshlakensis* (Dagys)	Rhynchonellidae	+	+ (aff.)	-	-	-
4	'*Posidonia*' (=*Peribostria*) aff. *ussurica* (Kiparisova)	?Inoceramidae	+	+	-	+	+
5	*Eumorphotis* sp.	Aviculoperctinidae	-	-	+	-	-
6	*Trematoceras* sp.	Orthoceratidae	+	+	-	-	-
7	*Pseudosageceras longilobatum* Kiparisova	Sageceratidae	+	-	-	-	-
8	*Pseudosageceras* sp.	Sageceratidae	-	+	-	-	-
9	Ussuriidae gen. et sp. nov.	Ussuriidae	+	-	-	-	-
10	*Ussuriaspenites* sp.	Aspenitidae	+	-	-	-	-
11	*Ussurijuvenites popovi* Smyshlyaeva et Zakharov	Paranannitidae	-	+	+	-	-
12	*Ussurijuvenites* sp.	Paranannitidae	+	-	-	+	-
13	*Juvenites* sp.	Paranannitidae	-	+	-	-	+
14	*Prosphingitoides* sp.	Paranannitidae	+	+	-	+	-
15	*Owenites carpenteri* Smith	Owenitidae	+	-	-	-	+ (sp.)
16	*Pseudowenites* sp.	Owenitidae	-	+	-	-	-
17	*Arctoceras septentrionale* (Diener)	Arctoceratidae	+	+ (cf.)	-	-	-
18	*Arctoceras* sp.	Arctoceratidae	-	-	-	+	-
19	*Churkites syaskoi* Zakharov et Shigeta	Arctoceratidae	+	+ (cf.)	-	-	+
20	*Submeekoceras*? *subhydaspis* (Kiparisova)	Arctoceratidae	+	+	+	+	-
21	*Monneticeras kalinkini* Zakharov et Smyshlyaeva	Proptychitidae	+	-	-	-	-
22	*Galfettites* sp. nov. B	Galfetitidae	-	+ (sp.)	+	-	(sp.)
23	*Vercherites subcristatum* (Kiparisova)	Galfetitidae	-	+	-	-	+
24	*Hemiprionites klugi* Brayard et Bucher	Prionitidae	+	+	-	-	-
25	*Hemiprionites ovalis* Buryi et Zharnikova	Prionitidae	-	+	-	-	-
26	*Prionites markevichi* Zakharov et Smyshlyaeva	Prionitidae	+	+	-	+	-
27	*Prionites subtuberculatus* Zakharov et Smyshlyaeva	Prionitidae	+	+	-	-	-
28	*Radioprionites abrekensis* Shigeta et Zakharov	Prionitidae	+	-	-	-	-
29	'*Anasibirites*' *simanenkoi* Zakharov et Smyshlyaeva	Prionitidae	+	+	-	-	-
30	*Nyalamites*? sp.	?Kashmiritidae	+	+	-	-	-
31	*Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva	Xenoceltitidae	+	+	+	+	+ (cf.)
32	*Glyptophiceras* cf *sinuatum* (Waagen)	Xenoceltitidae	-	-	+	-	-
33	*Shimanskyites shimanskyi* Zakharov et Smyshlyaeva	Xenoceltitidae	+	+	+	+	+

Table 1 Continued

No.	Species	Family	Kamenushka-2 (Zakharov et al., 2016; this sudy)	West SMID (Smyshlyaeva et al., 2018; this study)	East SMID	Golyj Cape	Smolyaninovo (Popov and Zakharov, 2017; Zakharov and Popov, 2014; this study)
34	*Larenites*? sp.	Flemingitidae	+	-	+	-	-
35	*Anaxenaspis* sp.	Palaeophyllitidae	+	-	-	-	-
36	*Kamenushkaites* sp.	Palaeophyllitidae	+	-	-	-	-
37	*Mianwaliites zimini* Zakharov et Smyshlyaeva	Palaeophyllitidae	+	+	+ (sp.)		+ (sp.)
38	*Scythogondolella mosheri* (Kozur et Mostler)	?Gladigondolellidae	-	+	-	-	-
39	‘*Neogondolella*’ *jubata* Sweet	Gondolellidae	-	-	+	-	-
40	*Neogondolella buurensis* Dagis	Gondolellidae	+	-	+	-	-
41	*Neogondolella composita* Dagis	Gondolellidae	+	-	+	-	-
42	*Neospathodus* sp.	Gondolellidae	+	+	-	-	-
43	*Novispathodus waageni* (Sweet)	?Novispathodontidae	+	-	+	-	-
44	*Novispathodus* aff. *pingdingshanensis* (Zhao and Orchard)	?Novispathodontidae	-	-	+	-	-
45	*Smithodus* aff. *kongiusculus* (Buryi)	?Novispathodontidae	-	+	-	-	-
46	*Furnishius triserratus* Clark	Ellisoniidae	+	+	-	+	-
47	*Ellisonia magnidentata* (Tatge)	Ellisoniidae	+	-	-	-	-
48	*Ellisonia triassica* Müller	Ellisoniidae	-	-	-	+	-
49	*Ellisonia nevadensis* Müller	Ellisoniidae	-	+	-	-	-
50	*Hadrodontina subsymmetrica* Müller	Ellisoniidae	-	+	-	+	-
51	*Hadrodontina* sp.	Ellisoniidae	+	+	-	+	+
52	*Pachycladina oblique* Staesche	Ellisoniidae	-	+	-	-	-
53	*Pachycladina tricuspidata* Staesche	Ellisoniidae	-	+	-	-	+
54	*Pachycladina inclinata* Staesche	Ellisoniidae	-	+	-	-	-
55	*Parachirognathus ethingtoni* Clark	Ellisoniidae	-	+	-	-	-
56	*Prioniodella ctenoides* Tatge	Prioniodinidae	-	+	-	-	-
57	*Prioniodella* sp.	Prioniodinidae	-	+	-	+	-
58	“*Prioniodella” prioniodellides* (Tatge)	Prioniodinidae	-	+	-	-	-
59	*Ligonodina triassica* Müller	Prioniodinidae	-	-	-	+	-
60	*Roundia magnidentata* Tatge	Hibbardellinae	-	+	-	-	-
61	*Chirodella dinoides* (Tatge)	Prioniodinidae/ ?Xaniognathidae	-	+	-	+	-
62	*Neohindeodella nevadensis* Müller	?Gondolellidae	-	+	-	+	-
63	*Neohindeodella triassica* Müller	?Gondolellidae	-	+	-	+	-
64	*Cypridodella* sp.	?Xaniognathidae	-	+	-	+	-
65	*Hindeodella budurovi* Buryi	?Coleodontidae	-	-	-	+	-
66	Ostracods	?Bairdiidae	+	-	-	-	-

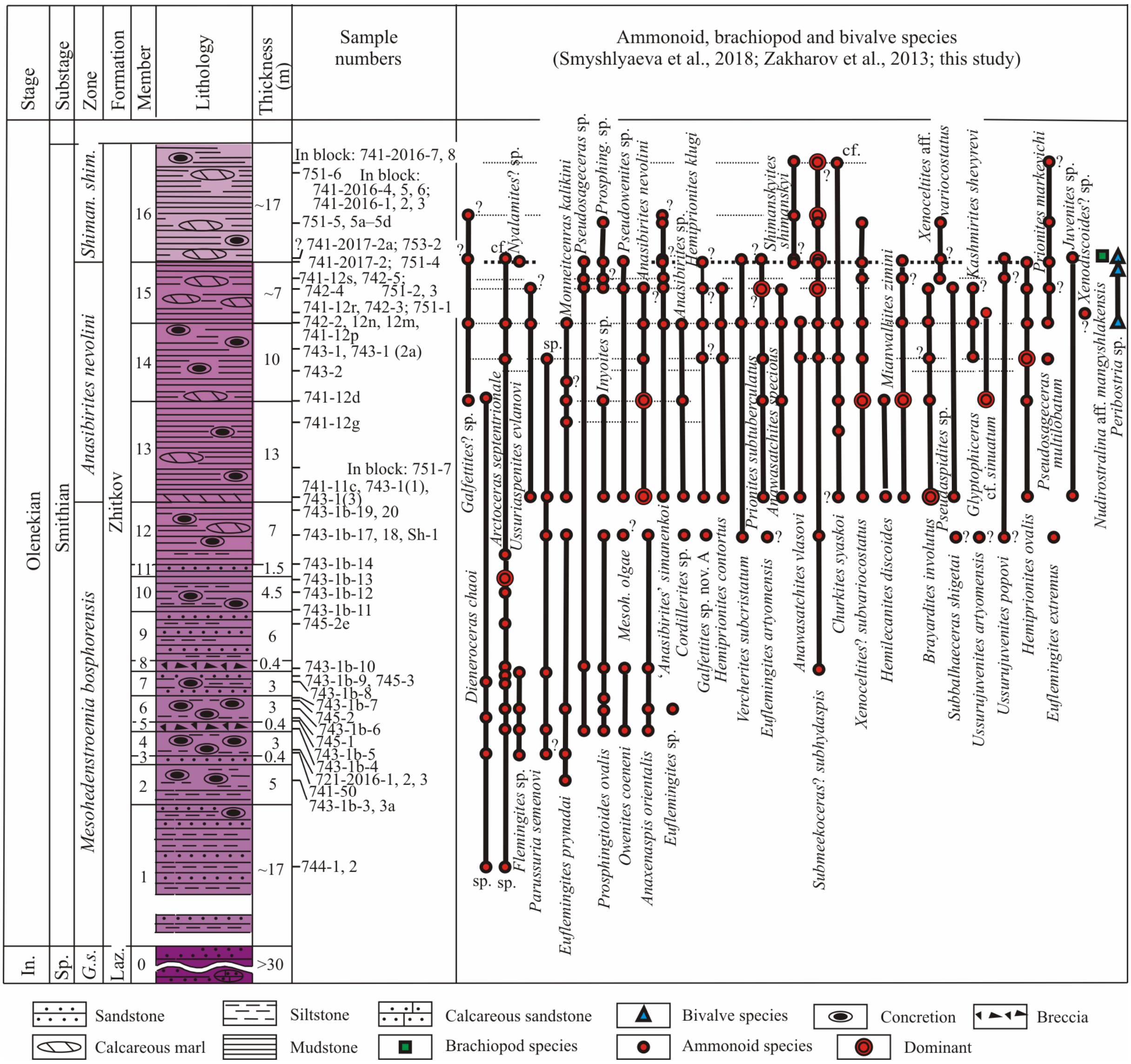

Figure 3. Occurrence and relative abundance of early Olenekian macrofossils (ammonoids, brachiopods and bivalves) from West SMID, Artyom area. In. Induan; Sp. Spathian; *G.s. Gyronites subdharmus*; *Shiman. shim. Shimanskyites shimanskyi*; Laz. Lazurnaya Bay; *Mesoh. olgae. Mesohedenstroemia olgae*; *Prosphing. Prosphingites.*

et Zharnikjva, *Anasibirites* sp., *Anawasatchites specious* Zakharov et Smyshlyaeva, *Kashmirites shevyrevi* Zakharov et Smyshlyaeva, *Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva, *Glyptophiceras* cf. *sinuatum* (Waagen), *Mianwalliites zimini* Zakharov et Smyshlyaeva, nautiloid *Trematoceras* sp. and conodonts *Discritella discreta* (Müller), *Furnishious triserratus* Clark, *Neospathodus novaehollandiae* McTavish and others (field specimens 741-12s, 12r, 12n, 12m; 742-2, 3, 4; 751-1, 2, 3 and 4, taken *in situ*).

Member 14 !0.0 m of dark grey mudstone with a calcareous-marl lens at the base, thin layers and numerous concretions of calcareous marl in other parts of member, yielding bivalve *Peribositria* sp. and numerous ammonoids, known from member 15. Other fossils are represented by ammonoids *Parussuria* sp., *Anawasatchites vlasovi* Burij et Zharnikova, *Hemilecanites discus* Burij et Zharnikova and *Glyptophiceras* cf. *sinuatum* (Waagen), and conodont *Scythogondolella milleri* (Müller) (field specimens 741-12d, 12p; 743-1, 2 and 1(2a), taken *in situ*).

Member 13 About 13 m of dark grey mudstone with a bed of grey marl (30–40 cm) at the base and numerous calcareous-marl lenses and concretions at other places of the member, yielding brachiopod *Paranorellina* sp., bivalve *Peribositria* sp., ammonoids *Ussuriaspenites evlanovi* Zakharov et Smyshlyaeva, *Pseudaspenites* sp., *Parussuria* sp., *Juvenites* sp., *Owenites* sp., *Inyoites* sp., *Churkites syaskoi* Zakharov et Shigeta, *Monneticeras kalinkini* Zakharov et Smyshlyaeva, *Brayardites involutus* Zakharov et Smyshlyaeva, *Hemiprionites klugi* Zakharov et Smyshlyaeva, *Hemiprionites contortus* Zakharov et Smyshlyaeva, *Hemiprionites ovalis* Burij et Zharnikova, *Hemiprionites* cf. *butleri* (Mathews), *Prionites subtuberculatus* Zakharov et Smyshlyaeva, *Anasibirites nevolini* Burij et Zharnikova, ‘*Anasibirites*’ *simanenkoi* Zakharov et Smyshlyaeva, *Anawasatchites specious* Zakharov et Smyshlyaeva, *Anawasatchites vlasovi* Burij et Zharnikova, *Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva, *Hemilecanites discus* Burij et Zharnikova, *Mianwalliites zimini* Zakharov et Smyshlyaeva, and

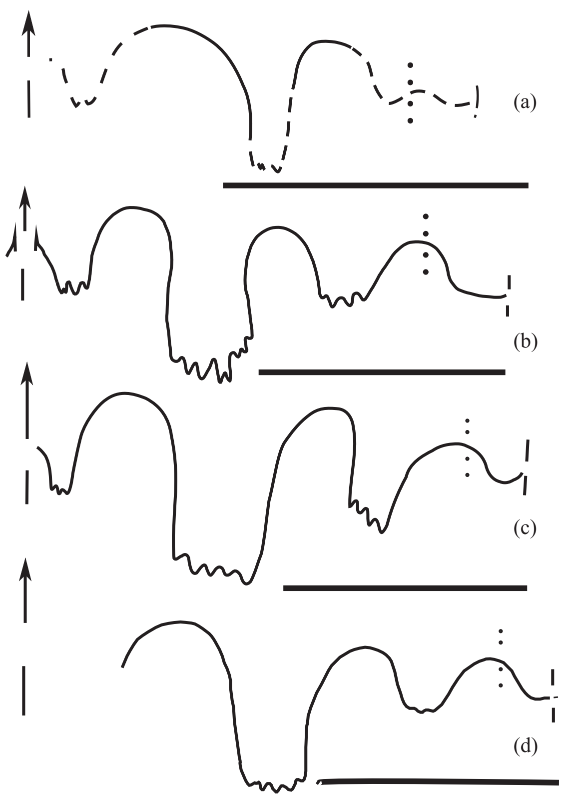

Figure 4. Suture lines of some latest early Smithian ammonoids from the *Shimanskyites shimanskyi* Zone, South Primorye. Scale bar=0.5 cm. (a) *Xenoceltites* aff. *variocostatum* Brayard et Bucher, DVGI 158/840, at *H*=7.2 mm, West SMID; (b)–(d) *Shimanskyites shimanskyi* Zakharov et Smyshlyaeva; (b) holotype DVGI 101/85 (field No. 955-15), Kamenushka-2; (c) DVGI 151/840 (field No. 741-2017-2a), West SMID; (d) DVGI 6/853 (field No. 40G), Golyj Cape.

conodonts *Furnishious triserratus* Clark, *Neospathodus* ex gr. *waageni* Sweet, *Scythogondolella milleri* (Müller) and *Scythogondolella dolosa* Bondarenko and vertebrate remains (field specimens 741-11c, 12g, 743-1(1), 743-1(3), taken *in situ* and 751-7, taken in block). The lower boundary of the zone is drawn according to the first appearance of the index species and conodont *Scythogondolella milleri* (Müller), which are espacially abundant in the basal bed of marl.

Members 1–12: *Mesohedenstroemia bosphorensis* Zone

Member 12 7.0 m of dark grey mudstone with calcareous-marl concretions and lenses, yielding ammonoids *Cordillerites* sp., *Mesohedenstroemia olgae* Zakharov et Moussavi Abnavi, *Ussurijuvenites popovi* Smyshlyaeva et Zakharov, *Ussurijuvenites artyomensis* Smyshlyaeva et Zakharov, *Prosphingitoides ovalis* (Kiparisova), *Arctoceras septentrionale* (Diener), *Submeekoceras*? *subhydaspis* (Kiparisova), *Vercherites subcristatum* (Kiparisova), *Subbalhaeceras shigetai* Zakharov et Moussavi Abnavi, *Galfettites* sp. nov. A, *Euflemingites prynadai* (Kiparisova), *Euflemingites artyomensis* Smyshlyaeva, *Euflemingites extremus* Smyshlyaeva et Zakharov, *Anaxenaspis orientaliis* (Diener) (field specimens 743-1b-14, 17, 18, 19, 20 and Sh-1, taken *in situ*).

Member 11 1.1 m of grey sandstone with intercalations of siltstone.

Member 10 4.5 m of dark grey siltstone with calcareous-marl concretions, containing of ammonoid *Arctoceras septentrionale* (Diener) (field specimens 743-1b-11, 12 and 13 *in situ*).

Member 9 6.0 m of intercalation of grey siltstone and fine-grained sandstone with ammonoid *Arctoceras* sp. (field specimen 745-2c, taken *in situ*).

Member 8 0.4 m of calcareous breccia, yielding ammonoids *Pseudosageceras* sp., *Parussuria semenovi* Zakharov, *Prosphingitoides ovalis* (Kiparisova), *Owenites koeneni* Hyatt et Smith, *Arctoceras septentrionale* (Diener) and nautiloid *Trematoceras* sp. (field specimen 743-1b-10, taken *in situ*).

Member 7 About 3.0 m of dark grey siltstone and mudstone with layers of fine-grained sandstone and calcareous-marl concretions, yielding of ammonoids *Dieneroceras* sp. and *Arctoceras septentrionale* (Diener), conodonts *Furnishius triserratus* Clark and *Pachycladina symmetrica* Staesche, fish teeth and ostracods (field specimens 743-1b-9, 10; 745-3, taken *in situ*).

Member 6 About 3.0 m of dark grey siltstone with calcareous-marl concretions containing foraminifera *Ammodiscus* sp. and *Ammobaculites*? sp., bivalve *Myophoria* sp., ammonoids *Prosphingitoides ovalis* (Kiparisova), *Dieneroceras chaoi* Kiparisova, *Arctoceras septentrionale* (Diener), *Euflemingites* sp. and *Anaxenaspis orientaliis* (Diener), nautiloids, conodont *Ellisonia triassica* (Müller) and fish remains (scales) (field specimens 743-1b-6, 7; 745-1, 2, taken *in situ*).

Member 5 0.4 m of calcareous breccia, yielding ammonoids *Pseudosageceras* sp., *Parussuria semenovi* Zakharov, *Prosphingitoides ovalis* (Kiparisova), *Owenites koeneni* Hyatt et Smith, *Arctoceras septentrionale* (Diener) and nautiloid *Trematoceras* sp. (field specimen 743-1b-5, taken *in situ*).

Member 4 About 3.0 m of dark grey siltstone and mudstone with small calcareous-marl concretions, containing ammonoids *Dieneroceras chaoi* Kiparisova, *Arctoceras septentrionale* (Diener), *Flemingites* sp. and *Euflemingites prynadai* (Kiparisova) (field specimens 721-2016-1, 2, 3; 741-5; 743-1b; 741-50, taken *in situ*).

Member 3 0.4 m of grey fine-grained sandstone.

Member 2 5.0 m of dark-grey siltstone with calcareous-marl concretions, yielding ammonoids *Parussuria semenovi* Zakharov, *Flemingites* sp. and *Euflemingites prynadai* (Kiparisova) (field specimens 743-1b-3, 3a, taken *in situ*).

Member 1 About 17.0 m of dark grey siltstone and mudstone with layers of fine-grained sandstone and rare calcareous-marl concretions, yielding bivalve *Bakevellia* sp., ammonoids *Dieneroceras* sp. and *Arctoceras*? sp. and nautiloid *Trematoceras* sp. (field specimens 744-1, 2, taken *in situ* and blocks).

The exposed part of the underlying Induan Lazurnaya Formation is represented by a thick (more than 30 m) succession of grey coarse-grained sandstone with lenses of conglomerate and calcareous sandstone.

The lower boundary of the *Mesohedenstroemia bosphorensis* Zone is drawn according to the first appearance of Smithian ammonoid species.

3.2 Smithian Ammonoid and Conodont Successions in the East SMID Section

The East SMID Section is located in the eastern part of SMID quarry, 250 m east of the West SMID Section; the coordinates are 43°19′07.3″N/132°10′03.4″E. Smithian deposits are located in this section below the unit, which can be approximately correlated with the *Tirolites subcassianus* Zone, because brachiopod *Lepismatina* sp., usually known in South Primorye from the Spathian, has been recorded from it (Member 16) and ammonoid *Tirolites subcassianus* Zakharov has been recently found in block near this locality (Shigeta and Kumagae, 2016). The following Smithian units are documented in the East SMID Section in descending order (Fig. 5).

Zhitkov Formation

Member 16: *Shimanskyites shimanskyi* Zone

The 16.8 m of dark grey mudstone with very rare calcareous-marl concretions and lenses. In this section ammonoid *Shimanskyites* cf. *shimanskyi* Zakharov et Smyshlyaeva occures together with *Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva, *Glyptophiceras* cf *sinuatum* (Waagen), *Submeekoceras*? *subhydaspis* (Kiparisova) and conodont '*Neogondolella*' *jubata* Sweet (from the block PK-120 up to 0.7 m thick; Fig. 6). It is noteworthy that the block (745-2017a) up to 0.5 m thick, originating from Member 16, contains *Shimanskyites shimanskyi* Zakharov et Smyshlyaeva, together with *Prionites markevichi* Zakharov et Smyshlyaeva, *Glyptophiceras* cf. *sinuatum* (Waagen), *Larenites*? sp. and *Mianvaliites* sp. The upper boundary of the zone is not precisely defined here.

Members 13–15: *Anasibirites nevolini* Zone

Member 15 3.5 m of dark grey siltstone with calcareous-marl concretions and numerous lenses, containing of small

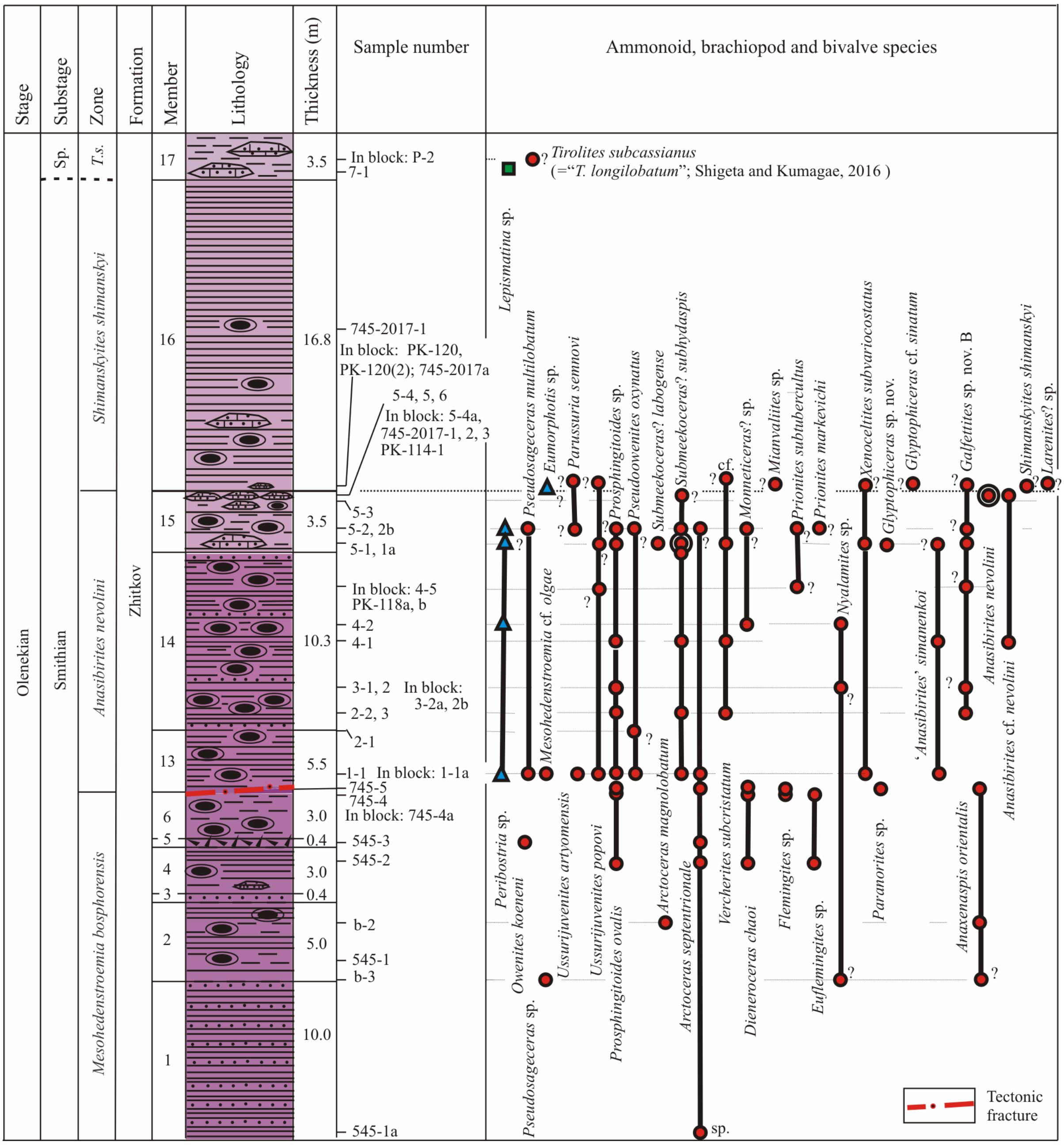

Figure 5. Occurrence and relative abundance of early Olenekian macrofossils (ammonoids, brachiopods and bivalves) from East SMID, Artyom area. Sp. Spathian; *T.s. Tirolites subcassianus*.

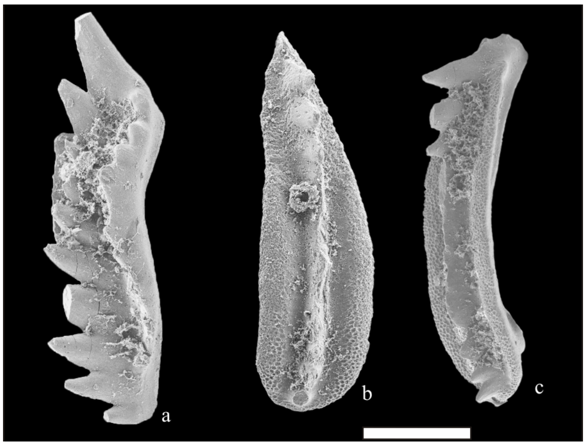

Figure 6. Late Smithian key species conodont and unusual conodonts from the East SMID Section. Scale bar=200 μm. a. *Scythogondolella milleri* (Müller), DVGI 21/19 (field No. 5-4), *Anasibirites nevolini* Zone (this sample was found together with ammonoids *Hemiprionites klugi* Brayard et Bucher, *Hemiprionites ovalis* Burij et Zharnikova, *Prionites markevichi* Zakharov et Smyshlyaeva, *Anasibirites nevolini* Burij et Zharnikova, *Anasibirites* cf. *nevolini* Burij et Zharnikova, *Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva, *Glyptophiceras*? sp. and nautiloid *Trematoceras* sp.; b, c. '*Neogondolella*' *jubata* Sweet; b. DVGI 12/28 (field No. PK-120), *Shimanskyites shimanskyi* Zone (this sample was found together with ammonoids *Submeekoceras*? *subhydaspis* (Kiparisova), *Shimanskyites* cf. *shimanskyi* Zakharov et Smyshlyaeva, *Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva, nautiloid *Trematoceras* sp. and large bivalve *Eumorphotis* sp.; c. DVGI 5/28 (field No. PK-120), same locality and same association.

bivalve *Peribostria* sp., ammonoids *Pseudosageceras multilobatum* Kiparisova, *Parussuria semenovi* Zakharov, *Ussurijuvenites popovi* Smyshlyaeva et Zakharov, *Prosphingitoides* sp., *Pseudowenites oxynatus* Chao, *Arctoceras septentrionale* (Diener), *Submeekoceras*? *labogense* (Zharnikova), *Submeekoceras*? *subhydaspis* (Kiparisova), *Monneticeras*? sp., *Galfettites* sp. nov. B, *Vercherites subcristatum* (Kiparisova), *Prionites subtuberculatus* Zakharov et Smyshlyaeva, *Prionites markevichi* Zakharov et Smyshlyaeva, *Anasibirites nevolini* Burij et Zharnikova, *Anasibirites* cf. *nevolini* Burij et Zharnikova, '*Anasibirites*' *simanenkoi* Zakharov et Smyshlyaeva, *Xenoceltites subvariocostatus* Zakharov et Smyshlyaeva and *Glyptophiceras* sp. nov. and conodonts *Scythogondolella milleri* (Müller) and others (field samples 5-1, 5-1a, 5-2, 5-2b, 5-3, taken *in situ*; Table 1). Index species is abundant in calcareous lenses exposed at the top.

Member 14 10.3 m of dark grey mudstone with layers of fine-grained sandstone and numerous calcareous-marl concretions, yielding small bivalve *Peribastria* sp., ammonoids *Ussurijuvenites popovi* Smyshlyaeva et Zakharov, *Prosphingitoides* sp., *Pseudoowenites oxynatus* Chao, *Submeekoceras*? *subhydaspis* (Kiparisova), *Monneticeras*? sp., *Galfettites* sp. nov. B, *Vercherites subcristatum* (Kiparisova), *Prionites markevichi* Zakharov et Smyshlyaeva, *Prionites subtuberculatus* Zakharov et Smyshlyaeva, *Anasibirites nevolini* Burij et Zharnikova, '*Anasibirites*' *simanenkoi* Zakharov et Smyshlyaeva and *Nyalamites* sp. (field samples 2-2, 2-3, 3-1, 3-2,4-1, 4-2, taken *in situ*; other samples (3-2a, 3-2, 4-5; PK-118a, b; 3-2a, b; 4-5), taken in blocks).

Member 13 5.5 m of dark grey mudstone with numerous calcareous-marl concretions, yielding bivalve *Peribastria* sp., ammonoids *Pseudosageceras multilobatum* Kiparisova, *Mesohedenstroemia* cf. *olgae* Zakharov et Moussavi Abnavi, *Ussurijuvenites artyomensis* Smyshlyaeva et Zakharov, *Ussurijuvenites popovi* Smyshlyaeva et Zakharov, *Prosphingitoides* sp., *Pseudoowenites oxynatus* Chao, *Arctoceras septentrionale* (Diener), *Submeekoceras*? *subhydaspis* (Kiparisova), *Prionites markevichi* Zakharov et Smyshlyaeva, '*Anasibirites*' *simanenkoi* Zakharov et Smyshlyaeva, *Xenoceltites subvariocostatus* Zakharov et Smyshlyaeva (field samples: 1-1, taken *in situ*; 1-1a, taken in block).

The base of the *Anasibirites nevolini* Zone is not exposed in this section (the outcrops in the lower part of the section are largely truncated by faulting).

Members 1–6: *Mesohedenstroemia bosphorensis* Zone

Member 6 3.0 m of dark grey siltstone with numerous calcareous-marl concretions, yielding *Prosphingitoides ovalis* (Kiparisova), *Arctoceras septentrionale* (Diener), *Dieneroceras chaoi* Kiparisova, *Flemingites* sp., *Euflemingites* sp., *Paranorites* sp. and *Anaxenaspis orientalis* (Diener) (field samples 745-4, 5, taken *in situ*; and 745-4a, taken in block).

Member 5 0.4 m of calcareous breccia, containing ammonoids, including *Owenites koeneni* Hyatt et Smith and *Arctoceras septentrionale* (Diener) (field specimen 545-30, taken *in situ*).

Member 4 3.0 m of dark grey mudstone with rare calcareous-marl concretions and lenses, yielding *Prosphingitoides ovalis* (Kiparisova), *Arctoceras septentrionale* (Diener), *Dieneroceras chaoi* Kiparisova and *Euflemingites* sp. (field sample 545-2, taken *in situ*).

Member 3 0.4 m of grey fine-grained sandstone.

Member 2 5.0 of dark grey mudstone and siltstone with calcareous-marl concretions, containing ammonoids *Pseudosageceras* sp., *Arctoceras magnolobatum* (Kiparisova), *Nyalamites* sp. and *Anaxenaspis orientalis* (Diener) (field samples b-2, b-3, 545-1, taken *in situ*).

Member 1 10.0 m of intercalation of dark grey mudstone and siltstone and grey fine-grained sandstone with rare calcareous-marl concretions, yielding ammonoid *Arctoceras septentrionale* (Diener) (field sample 545-1a, taken *in situ*).

The lower part of Member 1 is not exposed.

3.3 Distribution of Late Smithian Ammonoid and Conodont Taxa in the Golyi Cape Section

The Golyi Cape Section is located on the eastern coast of the Ussuri Gulf, directly north of Golyi Cape, about 5 km northwest of the town of Dunai; the coordinates are 42°55′05.2″E/132°17′34.6″E. Its lower part is represented by shallow marine sandy facies of the Induan Lazurnaya Bay Formation, comprising conglomerate and sandstone with lenses of calcareous sandstone-coquina). These deposites overlie older rocks (tuffaceous mudstone with thin-bedded siliceous rock intercalations apparently Permian age) with regional angular unconformity (Zakharov et al., 2004b). Lenses of calcareous sandstone-coquina consist of numerous bivalve molluscs (*Eumorphotis multiformis* (Bittner), *Promyalina putiatinensis* (Kiparisova), *Unioites*? *fassaenses* (Wissman) and rare ammonoid *Gyronites subdharmus* Kiparisova, showing that these deposits, totaling about 145-m in thickness, correspond, possibly with exception of their basal beds, to the local *Gyronites subdharmus* Zone of the Induan Stage (Zakharov, 1997). In ascending order, the overlying deposits are composed of the Olenekian Zhitkov Cape and the lower Anisian Karazin Cape formations, represented by deeper silty-pelitic sequence about 235 and 130 m thick, respectively.

Till now, the following zones have been documented in the Olenekian of the Golyi Cape Section: *Mesohedenstroemia bosphorensis*, *Anasibirites nevolini*, "*Tirolites-Amphistephanites*" and *Neocolumbites insignis* (Zakharov et al., 2004b). New data allowed us to recognize an additional zone (*Shimanskyites shimanskyi*), located between the *Anasibirites nevolini* and *Tirolites subcassianus* zones.

The *Anasibirites nevolini* Zone in this section consists of dark grey mudstone and siltstone with lenses and large concretions of calcareous-marl, yielding ammonoids *Pseudosageceras* sp. indet., *Owenites koeneni* Hyatt et Smith, *Juvenites simplex* Chao, *Prosphingitoides ovalis* (Kiparisova), *Arctoceras septentrionale* (Diener), *Submeekoceras*? cf. *labogense* (Zharnikova), *Hemiprionites dunajensis* Zakharov and *Prefloreanites* cf. *radians* Chao. The thickness of the *Anasibirites nevolini* Zone is more than 6.5 m (it is not precisely defined, since the zone is exposed in the upper hard-to-reach part of the cliff and its identification is difficult due to the lack of an index-species for this zone in this section).

The *Shimanskyites shimanskyi* Zone in the Golyi Cape Section is composed of frequently altering dark grey mudstone and calcareous sandstone, 15.0 m thick (Fig. 7), yielding abundant small bivalves, including *Peribostria* sp., ammonoids *Ussurijuvenites* sp., *Prosphingitoides* sp., *Arctoceras* sp., *Submeekoceras*? *subhydaspis* (Kiparisova), *Vercherites*? sp., *Xenoceltites* cf. *subevolvens* (Zakharov), *Shimanskyites shimanskyi* Zakharov et Smyshlyaeva, conodonts *Furnishius triserratus* Clark, *Elliisonia triassica* Müller, *Hadrodontina subsymmetrica* Müller, *Hadrodontina* sp., *Prioniodella* sp., *Ligonodina triassica* Müller, *Chirodella dinoides* Tatge, *Neohindeodella nevadensis* Müller, *Neohindeodella triassica* Müller, *Cypridodella* sp. and *Hindeodella budurovi* Buryi. The lower boundary of the zone is drawn according to the first appearance of the index species.

The overlying *Tirolites subcassianus* Zone is represented by appoximately 30 m of dark grey sandy siltstone with rare calcareous-marl lenses, containing athyridid and spiriferinitid brachiopods and ammonoids *Tirolites subcassianus* Zakharov. and *Bandoites elegans* (Zakharov).

3.4 Taxonomic Composition of Ammonoid, Conodont and Brachiopod Fossils of the *Shimanskyites shimanskyi* Zone

Twenty-five ammonoid genera (*Pseudosageceras*, Ussuriidae gen. nov., *Ussuriaspinites*, *Ussurijuvenites*, *Juvenites*, *Owenites*, *Pseudoowenites Prosphingitoides*, *Arctoceras*, *Churkites*, ?*Submeekoceras*, *Monneticeras*, *Galfettites*, ?*Vercherites*, *Hemiprionites*, *Prionites*, *Radioprionites*, *Anasibirites*, ?*Nyalamites*, *Xenoceltites*, *Glyptophiceras*, *Shimanskyites*, *Anaxenaspis*, *Kamenushkaites* and *Mianwaliites*) of 14 families, consisting of about 32 species, are now reported from the *Shimanskyites shimanskyi* assemblage in South Primorye (Table 1). Their phylogenetic connections at family level are shown in Fig. 8.

The genus *Shimanskyites* seems to be restricted to a narrow stratigraphic interval within the upper part of the Smithian. It is interesting that the genus *Kamenushkaites*, origionally described from the lower Spathian *Tirolites subcassianus* Zone (*Inyoceras singularis* Beds), has been found from the *Shimanskyites shimanskyi* Zone of the Kamenushka-2 Section, which displays a most complete *Shimanskyites shimanskyi* ammonoid assemblage in South Primorye (Fig. 9; Table 1).

The conodont assemblage of the *Shimanskyites shimanskyi* Zone is also characterized by relatively high taxonomic diversity, represented by 8 families, 17 genera (*Scythogondolella*, *Neogondolella*, *Novispathodus*, *Neospathodus*, *Smithodus*, *Furnishius*, *Ellisonia*, *Hadrodontina*, *Pachicladina*, *Parachirognatus*, *Prioniodella*, *Ligonodina*, *Roundia*, *Chirodella*, *Neohindeodella*, *Cypridodella* and *Hindeodella*), and consisting of 28 species (Table 1).

The late Smithian key species conodont *Scythogondolella milleri* (Müller) was not recovered from the *Shimanskyites shimanskyi* Zone in Souh Primorye. At the same time conodont '*Neogondolella*' *jubata* Sweet was documented not only from the lowermost Spathian *Tirolites-Amphistephanites* Zone of the earliest Spathian age (Buryi, 1979) in this region, but also from the uppermost Smithian level (*Shimanskyites shimanskyi* Zone in the East SMID Section), where it was found in association with the following typical late Smithian ammonoids: *Shimanskyites* cf. *shimanskyi* Zakharov et Smyshlyaeva, *Xenoceltites*? *subvariocostatus* Zakharov et Smyshlyaeva and *Submeekoceras*? *subhydaspis* (Kiparisova). Till now, '*Neogondolella*' *jubata* was documented only from the lowermost part of the Spathian (e.g., Kiliç et al., 2020).

Articulate brachiopods in the *Shimanskiites shimanskyi* Zone, as well as in another upper Smithian zone (*Anasibirites nevolin*), are rare, although they are abundant in the overlying *Tirolites-Amphistephanites* Zone (Zakharov and Popov, 2014). At the same time two brachiopod species (*Bittnerithyris margaritovi* (Bittner) and *Lepismatina* sp.), common in the *Tirolites-Amphistephanites* Zone, were also found from the *Shimanskyites shimanskyi* Zone (Table 1). The former became a numerically dominant brachiopod in the *Tirolites-Amphistephanites* Zone (*Bajarunia magna* Beds) at Kamenushka-2 (Zakharov et al., 2018a).

4 DISCUSSION

4.1 Late Smithian Ammonoid Successions and Some SSB Events

Paleogeographical distribution of late Smithian ammonoid faunas, containing *Wasatchites* and/or *Anasibirites*, includes several wide regions in both the Boreal and the Tethyan realms, where they are abundant, but usually not so diverse.

The *Wasatchites tardus* Zone in Siberia, for instance, yields 3–4 ammonoid genera (*Wasatchites*, *Anasibirites*, *Xenoceltites* and possibly *Anakashmirites*), belonging to the families Prionitidae, Xenoceltitidae and Kashmiritidae (Dagys and Ermakova, 1990). The same zone in Canada is characterized by 9 ammonoid genera (*Pseudosageceras*, *Prosphingites*, *Arctoceras*, *Wasatchites*, *Prionites*, *Arctoprionites*, *Anasibirites*, *Xenoceltites*,

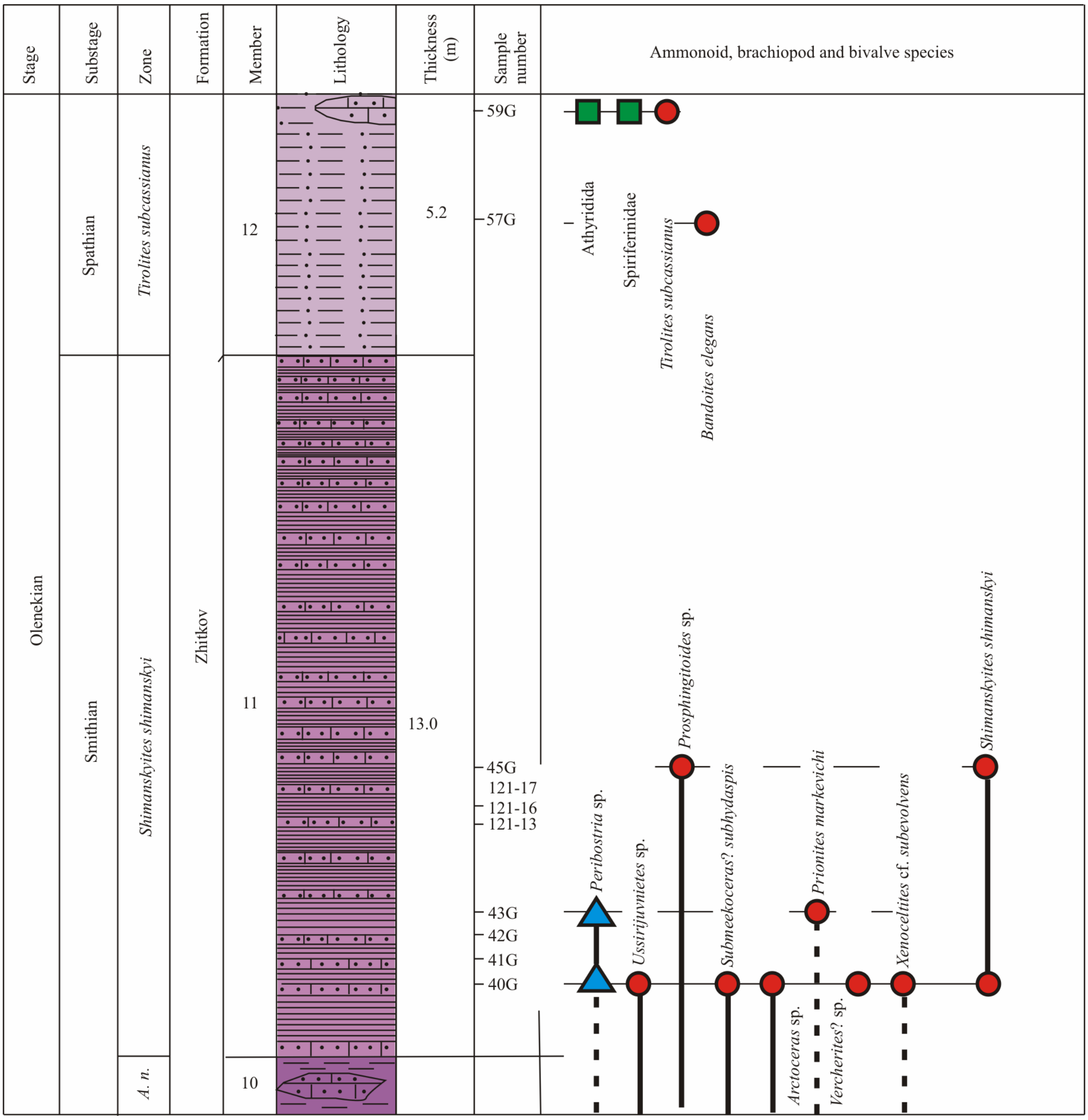

Figure 7. Stratigraphical range chart of ammonoid, brachiopod and bivalve macrofossils from the SSB transition of Golyj Cape. *A. n. Anasibirites nevolini.*

?*Kashmirites*), belonging to the families Sageceratidae, Nannitidae, Arctoceratidae, Prionitidae, Xenoceltitidae and Kasmiritidae (Tozer, 1994).

Only two ammonoid genera (*Wasatchites* and ?Xenoceltitidae gen. indet. B) were documented from the upper Smithian *Wasatchites distractus* Beds of the Tulong Formation in South Tibet (Brühwiler et al., 2010). *Anasibtrites multiformis* fauna in Oman shows 4–5 ammonoid genera (e.g., *Prionites*, Prionitidae gen. indet., *Anasibirites* and *Subvishnuites*), belonging to the families Prionitidae and Inyonitidae (Brühwiler et al., 2012a). From the *Wasatchites distractus* Beds in Salt Range, Pakistan five ammonoid genera (*Pseudosageceras*, *Wasatchites*, *Hemiprionites*, *Subinyoites* and *Mianwaliites*), belonging to the families Sageceratidae, Prionitidae, Inyonitidae and Paleophyllitidae, have been reported (Brühwiler et al., 2012c), but from the same zone in Spiti, India only three genera (*Pseudosageceras*, *Wasatchites* and *Anasibirites*) are known (Brühwiler et al., 2012b). *Anasibirites* fauna in Timor consists of five ammonoid genara (*Pseudosageceras*, *Wasatchites*, *Hemiprionites*, *Anasibirites* and *Galfetites*), belonging to the families Sageceratidae, Prionitidae and Galfettitidae (Jattiot et al., 2020). Seven ammonoid genera (*Pseudosageceras*, *Inyoites*, *Anasibirites*, *Wasatchites*, *Arctoprionites*, *Hemiprionites* and *Xenoceltites*) have been reported within the *Anasibirites multiformis* Zone at Crittenden Spring in Nevada (Jenks and Bryard, 2018; Jenks et al., 2010; Kummel and Steele, 1962), but only four of them (*Anasibirites*, *Wasatchites*, *Arctoprionites*, *Hemiprionites*) were documented from the *Anasibirites kingianus* Beds in Idaho (Brayard et al., 2013).

Somewhat higher diverse late Smithian ammonoid fauna are known from South China. From the upper Smithian *Anasibirites*- and *Pseudoowenites*-bearing deposites of Guangxi 10 families are reported, including 12 ammonoid genera (*Pseudosageceras*, *Pseudohedenstroemia*, *Metussuria*, ?*Prosphingitoides*, *Owenites*, *Pseudoowenites*, *Juvenites*, *Pseudoaspidites*, *Anasibirites*, ?*Vercherites*, *Xenoceltites*, ?*Kashmirites*) (Brayard and

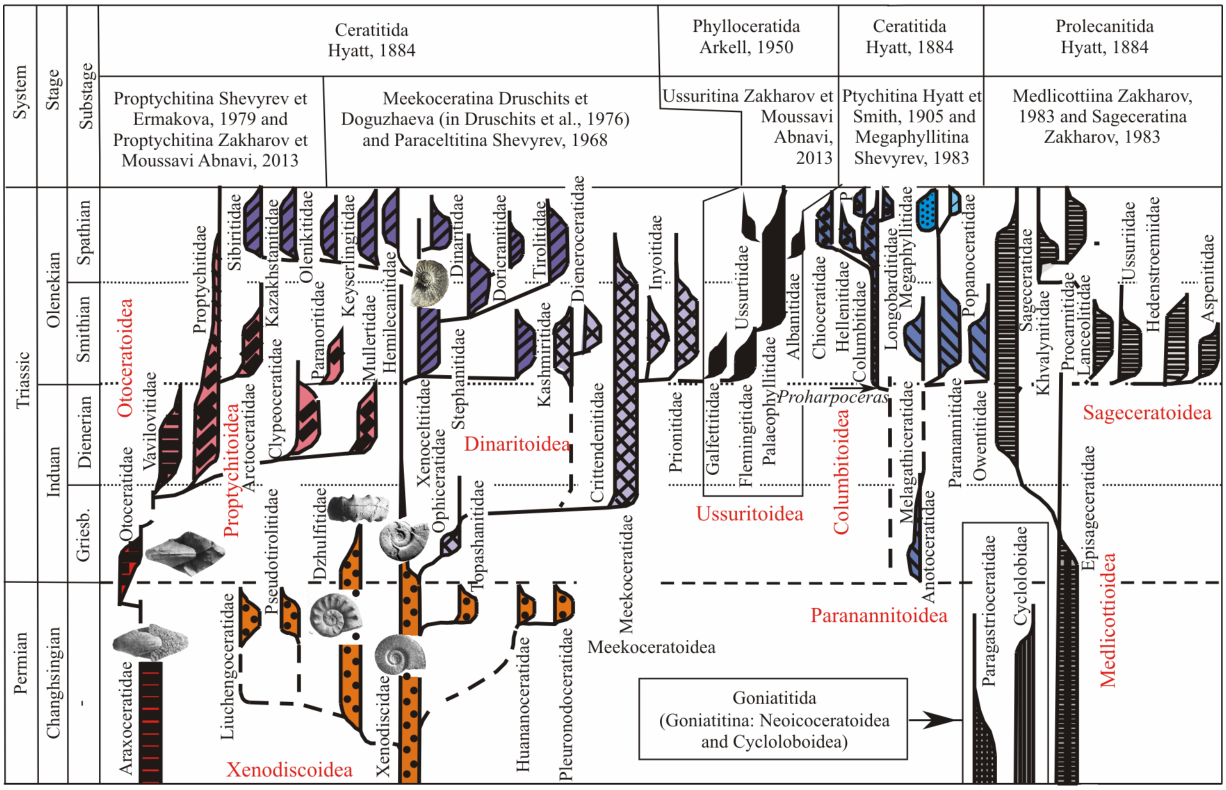

Figure 8. Suggested phylogenetic relationships in the Changhsingian, Induan and Olenekian ammonoid taxa (modified from Zakharov and Moussavi Abnavi, 2013). Griesb. Griesbachian; P. Paragoceratidae.

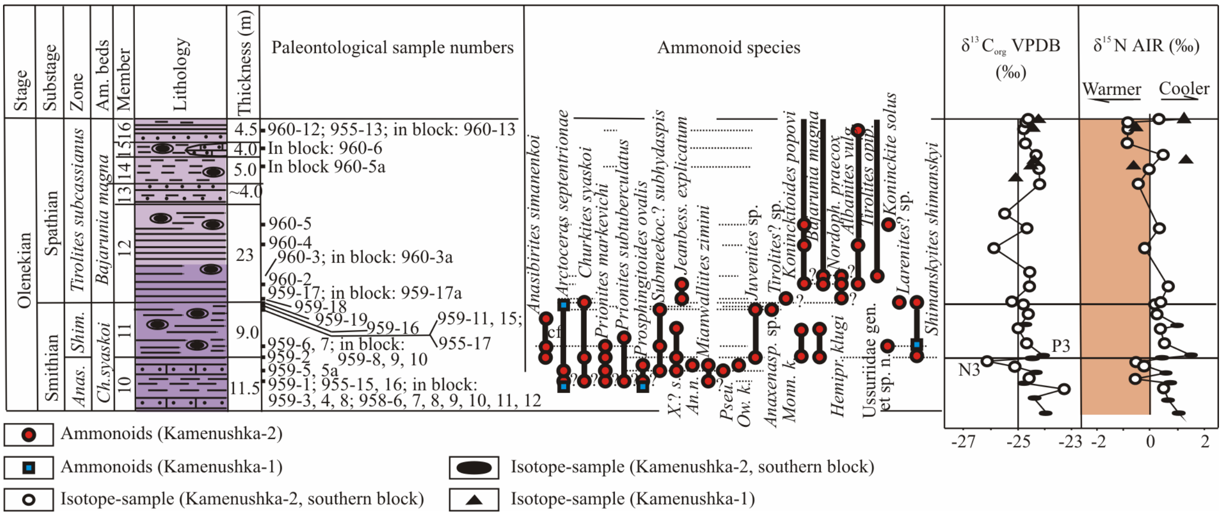

Figure 9. Occurrence and relative abundance of ammonoids from the SSB transition of Kamenushka-2 and some C- and N-isotope data (modified from Zakharov et al., 2018b). Am. beds. ammonoid beds; *Anas. Anasibirites nevolini*; *Shim. Shimanskyites shimanskyi*; *Submeekoc.?. Submeekoceras?*; *Jeanbess. Jeanbessaiceras*; *Albanites vulg. Albanites vulgaris*; *Tirolites opip. Tirolites opiparus*; *X.? s. Xenoceltites? subvariocostatus*; *An. n. Anasibirites nevolini*; *Pseu. Pseudosageceras* sp.; *Anaxenasp. Anaxenaspis*; *Monn. k. Monneticeras kalinkini*; Designations: N3, negative $\delta^{13}C_{org}$ shift, correlated with the negative $\delta^{13}C_{carb}$ shift in the South Majiashan Section, South China (it peaked, reaching a minimum value just below the SSB; Song et al., 2013); P3. positive $\delta^{13}C_{org}$ shift, correlated with the positive $\delta^{13}C_{carb}$ shift in the South Majiashan Section, South China (it peaked rapidly in the lowerest Spathian *Neospathodus crassatus* Zone; Song et al., 2013). Other designations as in Fig. 3.

Bucher, 2008; Kummel and Steele, 1962; Chao, 1959). The real number of their species is not precisely determined.

Data on the Lower Triassic of South Primorye provide evidence on the most complete late Smithian ammonoid assemblages. Available data on the ammonoid assamblage of the *Anasibirites nevolini* Zone show these assamblages to be both highly abandent and taxonomically diverse. It is characterized by 37 genera (*Pseudosageceras*, *Parussuria*, *Mesohedenstroemia*, *Parahedenstroemia*, *Ussuriaspinites*, *Juvenites*, *Ussurijuvenites*, *Prosphingitoides*, *Owenites*, *Pseudoowenites*, *Pseudaspedites*, *Monneticeras*, *Arctoceras*, *Submeekoceras*, *Churkites*, *Brayardites*, *Xenoceltites*, *Glyptophiceras*, *Hemilecanites*, *Kashmirites*, *Nya-

lamites, *Dieneroceras*, *Galfettites*, *Inyoites*, *Vercherites*, *Prionites*, *Hemiprionites*, *Arctoprionites*, *Anasibirites*, *Wasatchites*, *Anawasatchites*, *Gurleyites*, ?*Guangxsiceras*, ?*Xenodiscoides*, *Mianwaliites*, *Birijites* and *Subalbanites*), belonging to 18 families (Sageceratidae, Ussuriidae, Hedenstroemiidae, Melagathiceratidae, Paranannitidae, Owenitidae, Proptychitidae, Arctoceratidae, Xenoceltitidae, Kashmiritidae, Dieneroceratidae, ?Meekoceratidae, Galfetitidae, Inyotidae, Prionitidae, ?Flemingitidae, Paleophyllitidae and Noritidae) (Smyshlyaeva and Zakharov, 2013; Zakharov et al., 2013; Zakharov, 1978; this study).

Judging from data on Early Triassic ammonoids from South Primorye, their taxonomic diversity in this region gradually decreased during the late Smithian time, as was mentioned above (up to 26 genera of 13 families in the *Shimanskyites shimanskyi* Zone; Table 1). Outside South Primorye, only a few latest Smithian taxa, mainly belonging to the Xenoceltitidae (*Xenoceltites*, *Glyptophiceras*) and Sageceratidae (*Pseudosageceras*) are known now (e.g., Zhang et al., 2019; Brühwiler et al., 2010). If the uppermost Smithian interval is believed to be characterized by only a few ammonoid families (Zhang et al., 2019), as previously reported from the sections of Pakistan, India, and South China (Jattiot et al., 2020; Brühwiler et al., 2012a, b, c, 2010), holds true, we could conclude in this case that a large number of Spathian phylogenetic lineages were originated from these supposed ancestral highly cosmopolitan families. However, the latter looks clearly unrealistic. Therefore, following Jattiot et al. (2020), we assume that there is a hiatus in sedimentation at the SSB in the mentioned regions. Furthermore, following the same logic, we admit the possible existence of gaps at the lower boundary of the upper Smithian *Anasiberites*-bearing *Wasatchites distractus* Zone and its equivalents in many regions of the world (Fig. 10), caused apparently by some changes in facies and/or tectonic associations.

The results of a comparison of the faunas of ammonoids and other organisms of the Smithian and Spathian times and some corresponding chemostratigraphical data lead many researchers to the conclusion that the Smithian-Spathian transition was a critical time marked by a series of biological and environmental changes (Zhang et al., 2019). However, most results from these studies (e.g., Zhang et al., 2019; Zakharov, 1978, 1974) represent a generalization obtained from the comparison of data rather than from the large stratigraphic units.

The Kamenushka-2 Section in South Primorye, previously paleontologically and isotopically investigated by Zakharov et al. (2018b), illustrates the features of the replacement of ammonoid assemblages in the Smithian-Spathian boundary sequence. The following early Olenekian ammonoid species, belonging to the families Ussuritidae, Juvenitidae, Arctoceratidae, Prionitidae, Xenoceltidae and Paleophyllitidae, are documented now from the *Shimanskyites shimanskyi* Zone of the Kamenushka-2 Section: Ussuritidae gen. et sp. nov., *Juvenites* sp., *Arctoceras septentrionale* (Diener), *Submeekoceras*? *subhydaspis* (Kiparisovae), *Churkites syaskoi* Zakharov et Shigeta, *Anasibirites simanenkoi* Zakharov et Smyshlyaeva, *Prionites markevichi* Zakharov et Smyshlyaeva, *Shimanskyites shimanskyi* Zakharov et Smyshlyaeva and *Anaxenaspis* sp. (Fig. 9).

However, the overlying lowermost Spathian *Bajarunia magna* Beds are characterized by a sharply different assemblage, consisting of Tirolitidae, Dinaritidae and Northophiceratidae. An earliest Spathian evolutionary step in this ammonoid succession is revealed by the appearance of the following characteristic forms: *Jeanbesseiceras* sp. nov., *Bajarunia magna* Zakharov et Smyshlyaeva, *Tirolites opiparus* Zakharov et Smyshlyaeva., *Tirolites*? sp., *Koninkitoides popovi* (Kummel), *Koninkitoides solus* Zakharov et Smyshlyaeva, *Northophiceras praecox* Zakharov et Smyshlyaeva (Zakharov et al., 2018a).

Of the 16 ammonoid families, assumed for the latest Smithian time on the basis of new and published data (Fig. 8) seven of them (Sageceratidae, Proptychitidae, Meekoceratidae, Prionitidae, Columbitidae, Paleophyllitidae and apparently Paranannitidae) survived the end-Smithian extinction and only three families (Tirolitidae, Dinaritidae and possibly Doricranitidae) first appeared in the earliest Spathian. The families that became extinct at the very end of the Smithian time include Ussuriidae, Owenitidae, Arctoceratidae, ?Galfetitidae and Flemingitidae (Fig. 8, Table 1).

In many regions of the world the SSB is located between the middle Smithian $\delta^{13}C_{carb}$ minimum, marked as N3, and the early Spathian $\delta^{13}C_{carb}$ maximum marked as P3 (Zhang et al., 2019, 2017; Song et al., 2013; Tanner, 2010). In South Primorye, in addition to the well-pronounced middle Smithian $\delta^{13}C_{org}$ minimum established in the Abrek Section (Zakharov et al., 2018a), there is a late Smithian $\delta^{13}C_{org}$ minimum documented at the base of the *Shimanskyites shimanskyi* Zone in the Kamenushka-2 Section (Fig. 9; Zakharov et al., 2018b). The possible lack of complete information on the chemostratigraphy of the upper Smithian interval in the sections of Pakistan, India, China and western USA (Utah), seems to be associated with the presence of a significant hiatus in their SSB (Widmann et al., 2020).

The reasons for the faunal extinction at the very end of the Smithian time are still debated by the scientific community. Sun et al. (2012) assumed on the basis of O-isotope composition of conodonts from South China and available biostratigraphical data that a thermal maximum in this area extended from the late Smithian to the earliest Spathian, followed by a cooling event in the early Spathian resulting in the late Smithian extinction, which were associated to oceanographic changes causing hyperthermia. However, this is not confirmed by recent bio- and chemostratigraphical data (Widmann et al., 2020; Shen et al., 2019; Zhang et al., 2019, 2015), including N-isotope data from South Promorye (Fig. 9; Zakharov et al., 2018b). In some opinions, Sun et al. (2012) did not define precisely the position of the boundary between the substages in the Olenekian Stage using conodont data (Goudemand et al., 2019, 2013; Zhang et al., 2019). According to recent data, the Smithian thermal maximum was middle Smithian in age and the SSB coincided, in contrary, with a subsequent major cooling event and sharp eustatic fall (Widmann et al., 2020; Zhang et al., 2019). Taking into account the positive C-isotope shift around the SSB, one would assume that the Smithian-Spathian ecological crisis was caused by volcanic activity (e.g., Galfetti et al., 2007) and the associated processes, for example: global expansion of anoxic conditions (e.g., Zhang F F et al., 2018; Zhang L et al., 2017; Galfetti et al., 2007), sea-level fluctuation (e.g., Grosjean et al., 2018; Embry, 1997), organic matter inputs (Sephton et al., 2005), and/or marine productivity changes (e.g., Meyer et al., 2011; Galfetti et al., 2007), or combination of these factors (Algeo et al., 2011). However, this does not agree with the notions of some authors (Lyu et al., 2019; Shen et al., 2019; Song et al., 2019; Stebbins et al., 2019a, b; Zhang et al., 2019) concerning possible cessation of volcanism during latest Smithian.

4.2 Global Correlation of Uppermost Smithian Units

Correlatives of late Smithian fauna, containing ammonoids *Wasatchites* or/and *Anasibirites* and conodont *Scythogondolella milleri*, are known to occur widely in both the Tethyian and the Boreal realms (Jattiot et al., 2020; Zhang et al., 2019; Jenks and Brayard, 2018; Bondarenko et al., 2013; Zakharov et al., 2013; Brühwiler et al., 2012a, b, c, 2010; Brayard and Bucher, 2008; Orchard, 2007; Zakharov, 1996; Tozer, 1994; Dagys and Ermakova, 1990; Dagis, 1984; Sweet, 1970). However, information on latest Smithian assemblages is available, as was mentioned above, from only seven regions of the world: Salt Range, Spiti, Tibet, Guangxi, Utah, Nevada, and South Primorye (Fig. 10).

4.2.1 Salt Range

Rocks of the *Glyptophiceras sinuatum* and possibly bivalve beds of the Nammal and Chiddru areas, Salt Range (Pakistan) (Fig. 10), based on their stratigraphical position between *Anasibirites*-bearing *Wasatchites districtus* Beds below (Brühwiler et al., 2012a) and *Tirolites*-*Columbites* Zone above (Guex, 1978), may be considered as a part of the *Shimanskyites shimanskyi* Zone in South Primorye. The age of the bivalve beds, lying directly on the *Glyptophiceras sinuatum* Beds in these areas, is not precisely established (Zhang et al., 2019; Brühwiler et al., 2012a).

The ammonoid assemblage of the *Glyptophiceras sinuatum* Beds is very pure: it contains only three species (*Pseudosageceras multilobatum* (Waagen), *Xenoceltitites* cf. *variocostatus* Bryard et Bucher, and *Glyptophiceras sinuatum* (Waagen)) of two families (Sageceratidae (or Hedenstroemiidae, in Brühwiler's et al. (2012a) opinion) and Xenoceltitidae). It has been shown the occurrence of *Novispathodus pingdingshanensis* Zhao et Orchard (common for the early Spathian *Tirolites*- bearing Beds) within the uppermost Smithian *Glyptophiceras sinuatum* Beds in Nammal (Zhang et al., 2019).

4.2.2 Spiti Valley

The lower interval of the *Shimanskyites shimanskyi* Zone in South Primorye correlates most likely with the *Subvishnuites posterus* and *Glyptophiceras sinuatum* Beds at Mud and Guling, Spiti Valley (India) (Fig. 10), based on their stratigraphical position between *Anasibirites*- and *Scythogondolella milleri*-bearing *Wasatchites districtus* Beds below (Brühwiler et al., 2012b), and *Tirolites*-*Columbites* Zone above (Krystyn et al., 2007a, b).

The ammonoid assemblage of the *Subvishnuites posterus* Beds yields three species: *Pseudosageceras augustum* Brayard et Bucher (Sageceratidae), *Subvishnuites posterus* Brühwiler, Busher et Krystyn (Inyotidae), and *Xenoceltites* cf. *variocostatus* Brayard et Bucher (Xenoceltitidae). The *Glyptophiceras sinuatum* Beds at Mud and Gulung is characterized by only an index species (Brühwiler et al., 2012b). Conodont *Scythogondolella milleri* (Müller), common for the *Anasibirites nevolini* Zone in South Primorye, is reliably known only from the *Wasatchites distractus* Beds in Spiti.

4.2.3 Tulon, Guangxi (China), Idaho and Nevada (USA)

The correlation of Lower Triassic units of China and the western USA on the basis of ammonoids and conodonts is given in Fig. 10. Conodont *Scythogondolella milleri* (Müller), common for the *Anasibirites nevolini* Zone in South Primorye, is reliably known from the *Anasibirites kingianus*/*Anasibirites multiformis* Beds in Idaho and Nevada (Jattiot et al., 2020).

A duration of the hiatus between the late Smithian *Glyptophiceras*-*Xenoceltitites* Beds and the basal Spathian unit (*T*. n. gen. A Zone) in South China has been calculated on the basis of U-Pb zircon data (Widmann et al., 2020). We do not have any information on a new late Smithian zone, located between upper Smithian *Glyptophiceras*-*Xenoceltites* Beds, which is coeval to the *Glyptophiceras sinuatum* Beds in the Salt Range and Tibet (Brühwiler et al., 2012b, 2010) and lowermost Spathian *T*. n. gen. A Zone in NE Nevada (Widmann et al., 2020). It could correlate with the upper part of the *Shimanskyites shimanskyi* Zone in South Primorye. However, the mentioned record is still not verified nor published. More information on this topic will be given later by Hugo Bucher (ongoing work; Widmann et al., 2020).

5 CONCLUSIONS

(1) There are many common species in ammonoid assemblages of the upper Smithian *Anasibirites nevolini* and *Shimanskyites shimanskyi* zones (South Primorye), but the latter is distinguished by somewhat lower taxonomic diversity of fossils, the development of xenoceltitid ammonoids, including *Shimanskyites shimanskyi* Zakharov et Smyshlyaeva, the FO of ammonoids of the genus *Kamenushkaites* (Paleophyllitidae), as well as conodonts '*Neogondolella*' *jubata* Sweet (Gondolellidae) and *Hindeodella budurovi* Buryi (?Coleodontidae) and brachiopods *Bittnerithyris margaritovi* (Bittner) (Dielasmatidae) and *Lepismatina* sp. (Lepismatinidae), but the lack of ammonoid *Anasibirites nevolini* Burij et Zharnikova and conodont *Scythogondolella milleri* (Müller), common for underlying deposites. Thus, the uppermost part of the Smithian in South Primorye, *Shimanskyites shimanskyi* Zone, is characterized by the co-occurrence of the ammonoids, brachiopods and conodonts and some other fossils, originally reported from the lower Spathian.

(2) Uppermost Smithian units are only reported from a few regions of the world. New studies demonstrate, however, that South Primorye seems to be the only place so far in the world, where this unit is characterized by a relatively high taxonomic diversity of ammonoids and conodonts. Latest Smithian ammonoids of the *Shimanckyites shimanskyi* Zone in South Primorye are represented by about 31 species of 26 genera (13 families), while the number of species taxa of ammonoids from the uppermost Smithian units, for example, from the Salt Range and Spiti, do not exceed five. This agrees with Widmann et al. (2020) concerning the possible existence of a glacio-eustatic hiatus on the continental shelf in many regions of the world during the latest Smithian. Our new data allow the construction of a high-resolution ammonoid succession spanning the late Smithian (including latest Smithian) time interval.

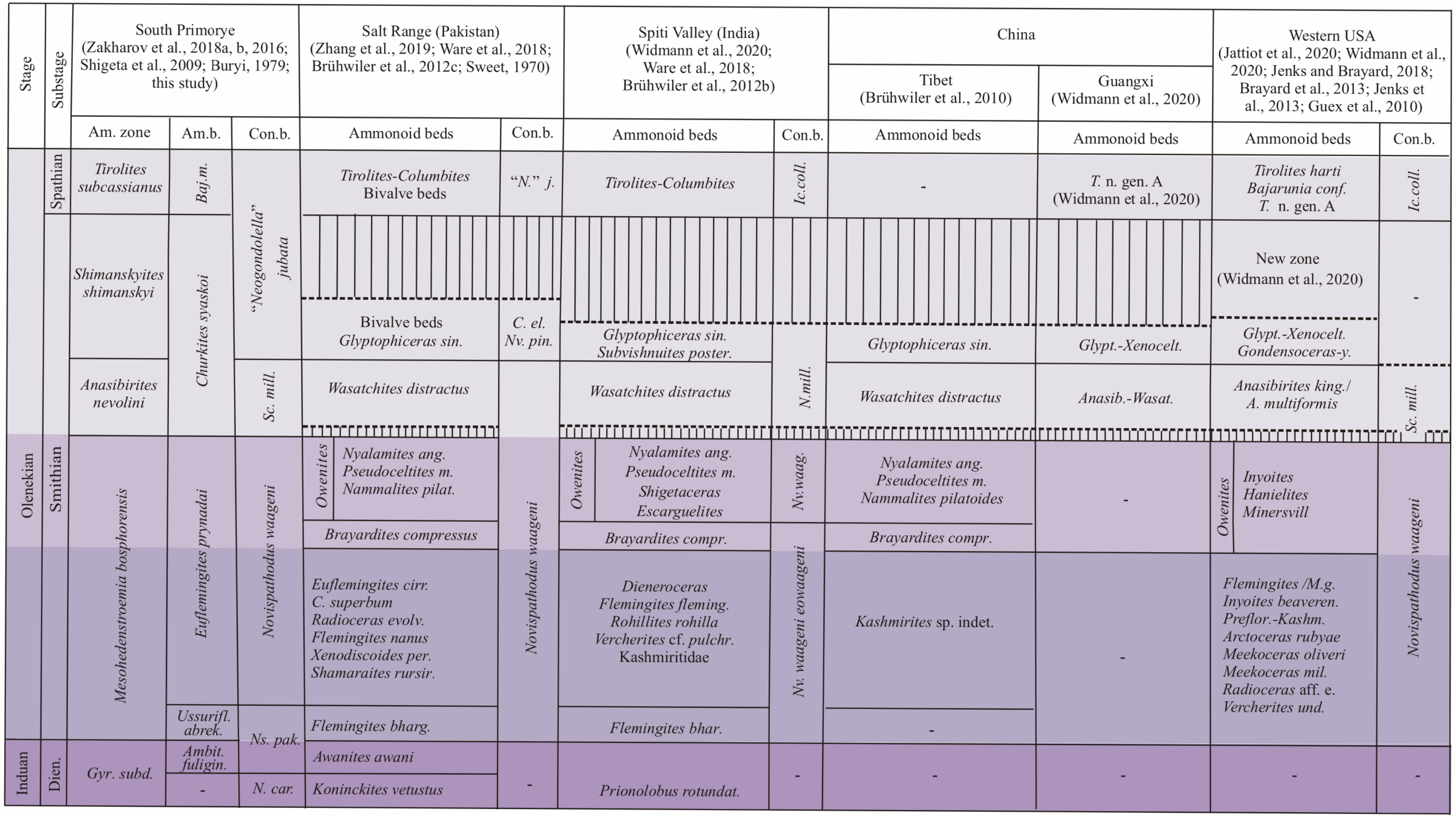

Figure 10. Correlation of Smithian and lowest Spathian units of South Primorye, Salt Range (Pakistan), Spiti Valley, Tibet (western China), Guangxi (South China) and Nevada and Idaho (western USA) from ammonoid and conodont data. Am. zone, ammonoid zone; Dien. Dienerian; *Gyr. subd. Gyronites subdharmus*; *Sc. mill. Scythogondolella milleri*; *Flemingites bharg. Flemingites bhargavai*; *Shamaraites rursir. Shamaraites rursiradiatus*; *Xenodiscoides per. Xenodiscoides perplicatus*; *Radioceras evolv. Radioceras evolvens*; *C. superbum. Clypeoceras superbum*; *Euflemingites cirr. Euflemingites cirratus*; *Nammalites pilat. Nammalites pilatoides*; *Pseudoceltites m. Pseudoceltites multiplicatus*; *Nyalamites ang. Nyalamites angustecostatus*; *Glyptophiceras sin. Glyptophiceras sinuatum*; Con.b. conodont beds; *Nv. pin. Novispathodus pindingshanensis*; *C.el. Columbitella elongata*; *"N." j. "Neogondolella" jubata*; *Prionolobus rotund. Prionolobus rotundatum*; *Vercherites* cf. *pulchr. Vercherites* cf. *pulchrum*; *Flemingites fleming. Flemingites flemingianus*; *Subvishnuites poster. Subvishnuites posterus*; *Anasib.-Wasat. Anasibirites*-'*T.* n. gen. A'; *Vercherites und. Vercherites undulatus*; *Radioceras* aff. *e. Radioceras* aff. *evolvens*; *Meekoceras mil. Meekoceras millardense*; *Preflor.-Kashm. Preflorianites-Kashmirites*; *Inyoites beaveren. Inyoites beaverensis/Arctoceras rubyae*; *Flemingites/M.g. Flemingites/Meekoceras gracilitatis*; *Anasibirites king. Anasibirites kingianus/Anasibirites multiformis*; *Condensoceras y. Condensoceras youngi*; *Bajarunia conf. Bajarunia confusionensis*; *Ic. coll. Icriospathodus collinsoni.*

(3) The lower part of the *Shimanskyites shimanskyi* Zone exposed in South Primorye is thought to correlate with the *Glyptophiceras sinuatum* Beds in Salt Range, Pakistan (Brühwiler et al., 2012a), Tibet, South China (Brühwiler et al., 2010), *Subvishnuites posterus* and *Glyptophiceras sinuatum* Beds in Spiti Valley, India (Brühwiler et al., 2012b) and *Glyptophiceras-Xenoceltites* Beds in Guangxi, South China (Widmann et al., 2020) and western USA (Widmann et al., 2020). Correlation of the upper part of the *Shimanskyites shimanskyi* Zone is less precise. It corresponds most likely to a new uppermost Smithian zone, as defined by Hugo Bucher in northwestern Nevada (Widmann et al., 2020).

(4) The break in the sedimentary succession, reported for the SSB in the Tethys on the basis of investigations on radioisotopes from Guangxi (Widmann et al., 2020) is also confirmed apparently from comparison with the most complete late Smithian ammonoid records from South Primorye (Zakharov et al., 2018a) and partly from NE Nevada (Widmann et al., 2020).

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