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Early Paleozoic plankton evolution in the Paleo-Asian Ocean: insights from new and reviewed fossil records from the Gorny Altai, West Siberia

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Abstract. The mountainous Gorny Altai in southern Siberia constitutes the western part of the Altai–Sayan Folded Belt in the northwestern part of the Central Asian orogenic belt, which contains precious records of the lost major Proterozoic–Paleozoic ocean called the Paleo-Asian Ocean (PAO). This paper briefly introduces the latest microfossil (radiolarian and conodont) information recovered from the Lower Paleozoic siliceous and carbonate sequences of the Gorny Altai. The fossils of planktonic biota inhabited in PAO range back to the early Cambrian, in which the world's oldest radiolarians are included. In addition, numerous well-preserved conodonts as well as graptolites were recovered from Cambrian, Ordovician, and Silurian strata in the Gorny Altai. These recorded the Early Paleozoic biodiversity and their secular change both in pelagic and continental margin settings within PAO.

Keywords: conodonts, Early Paleozoic, Paleo-Asian Ocean, radiolarians

Introduction

The Central Asian orogenic belt (CAOB; e.g. Jahn *et al.*, 2000) contains numerous geological records, which are critical for reconstructing a lost major ocean domain called the Paleo-Asian Ocean (PAO; e.g. Berzin and Dobretzov, 1994). The PAO was not a single wide ocean but consisted of numerous continental blocks separated by oceans with several subduction systems. The closure of the PAO proceeded from the late Carboniferous to late Permian–early Triassic (Zonenshain *et al.*, 1990; Sengör *et al.*, 1993; Buslov *et al.*, 2001; Dobretsov, 2003; Ota *et al.*, 2007; Windley *et al.*, 2007; Safonova *et al.*, 2012; Xiao *et al.*, 2015, etc.). The remaining fragments of its sedimentary record bear evidence of distinct Early Paleozoic organisms, some of which differ from those from coeval strata in the rest of the world.

The Altai–Sayan Folded Belt (ASFB) in southern West Siberia represents a northwestern segment of the CAOB (Figure 1). The mountainous Gorny Altai in the western ASFB, in particular, exposes various orogenic units characterized by strong deformation/metamorphism in multiple orogenic stages during the Paleozoic (e.g. Buslov and Watanabe, 1996; Ota *et al.*, 2007). Previous research demonstrated that the Gorny Altai orogenic collage includes various distinct fragments derived from ancient oceanic seamount, volcanic arc, accretionary complex, and strata of shelf facies (Buslov *et al.*, 2001, 2004, 2013; Dobretsov, 2003; Uchio *et al.*, 2004; Buslov, 2011; Safonova *et al.*, 2011, etc.). Among these various rocks, deep-sea chert and shallow marine carbonates are particularly important in constraining the age of lost ocean floors and in reconstruction paleoenvironments of past oceans, as summarized by Isozaki (2014).

Ever since the first report on Cambrian radiolarians (Iwata *et al.*, 1997), the cherts in the Gorny Altai yielded various Early Paleozoic radiolarians, conodonts, and graptolites (Iwata *et al.*, 1997; Obut and Iwata, 2000; Sennikov *et al.*, 2003, 2008, 2018, 2019a, b; Obut, 2011) that include the oldest radiolarians of the world, and also other Neoproterozoic microfossils (Uchio *et al.*, 2004, 2008). In this regard, the microfossil data archive in the Gorny Altai is significant not only in the regional study of CAOB/PAO but also in the global study of faunal evolution and the Cambrian explosion. The present short article briefly introduces the current status of microfossil studies

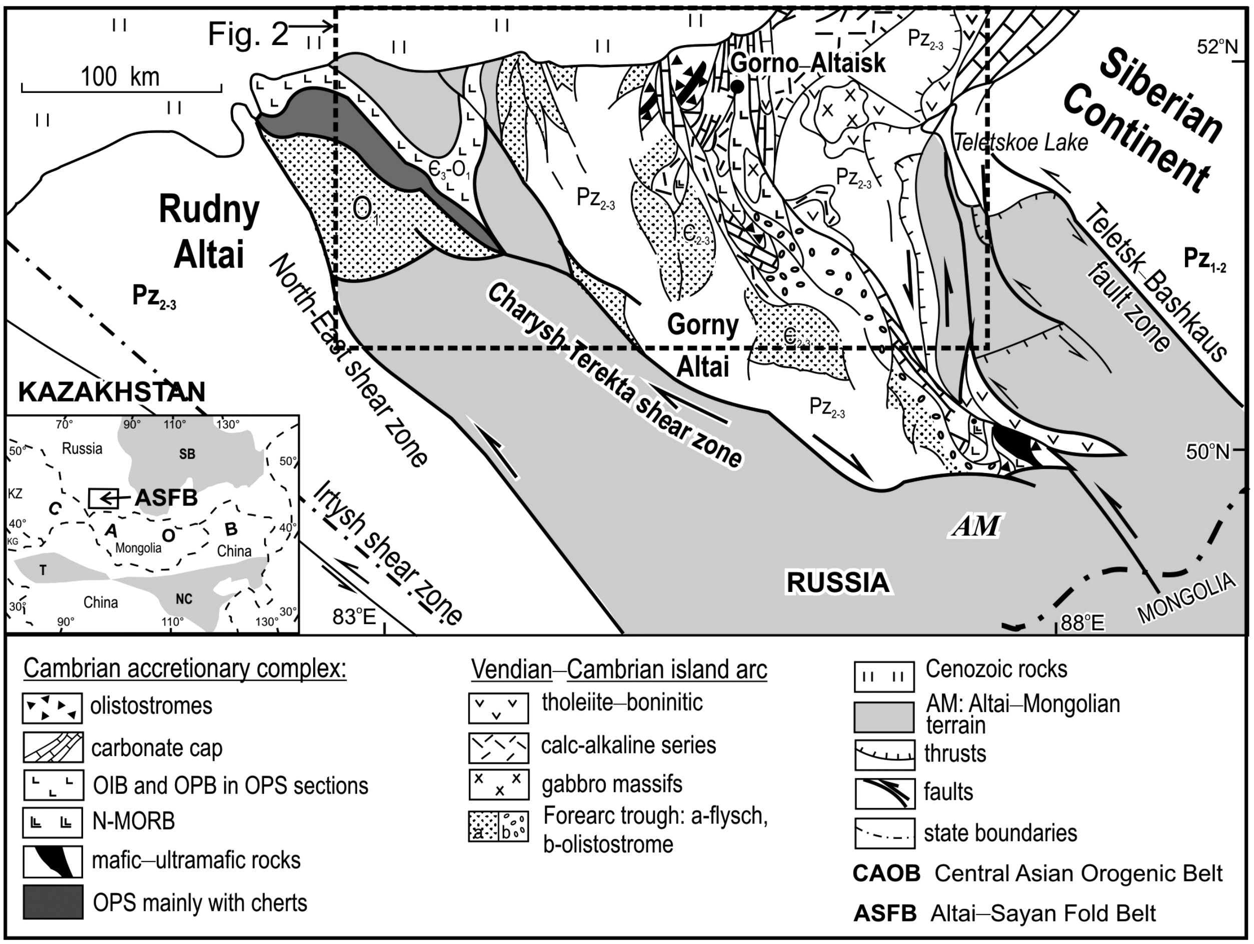

Figure 1. Sketch-map for the western part of the Altai–Sayan Folded Area, south of West Siberia, modified after Buslov *et al.* (2001) and Safonova *et al.* (2011b).

in the Gorny Altai, which include several potential new aspects on early animal evolution and relevant environmental changes since the time of the Proterozoic–Paleozoic boundary.

Microfossil-bearing strata

Ocean-derived Cambrian–Early Ordovician strata in the northwestern part of Gorny Altai are composed of volcanics and siliceous beds. They belong to the Sanashtykgol, Tayanza, and lower Tuloi horizons (Russian terminology for the regional stages) (Figures 2, 3). The Lower Cambrian Shashkunar Formation of the Sanashtykgol Horizon in the central Gorny Altai is composed of limestone interbedded with siliceous shale and chert (Obut and Iwata, 2000; Zybin *et al*., 2000), which occurs within the Katun' accretionary complex (Zybin *et al*., 2000; Dobretsov *et al*., 2004; Safonova *et al*., 2011a). These siliceous–carbonate sequences were primarily accumulated on the slope of an ancient mid-oceanic seamount of hotspot origin, according to the geochemistry of the underlying OIB-type basalts (Manzherok Formation). The cherts and limestones yielded radiolarians and small shelly fossils (SSFs) (Figure 2).

Particularly significant is the Upper Cambrian–Lower Ordovician Zasur'ya Group of the Tayanza and lower Tuloi horizons, which consist of three units in ascending order; i.e., Listvennaya, Talitsa, and Marcheta formations (Sennikov *et al*., 2008, 2018). Siliceous rocks of all three formations commonly yielded radiolarians and conodonts (Figures 2, 3). The Zasur'ya sequence, consists of MORB and OIB-type basalts associated with chert, siliceous mudstone, siltstone, and sandstone. Among these, fine-grained strata, such as chert and siliceous mudstone, are regarded to have been incorporated into ancient accretionary complexes in the NW Gorny Altai (Sennikov *et al*., 2008, 2019a; Safonova *et al*., 2011b), and they represent oceanic sedimentary settings with respect to the con-

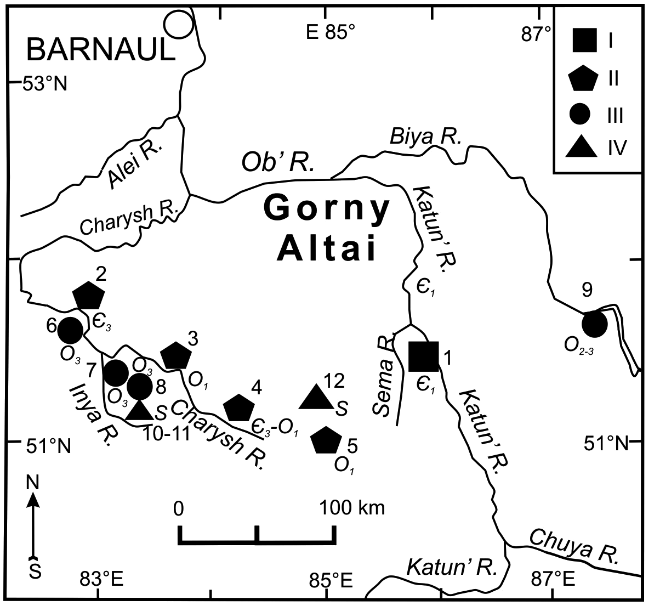

Figure 2. Localities of Early Paleozoic pelagic fauna (radiolarians and conodonts) at the Gorny Altai. I, Lower Cambrian sequences (1, Shashkunar Formation); II, Upper Cambrian-Early Ordovician sequences (2–4, Listvenny and Talitsa formations; 5, Marcheta Formation); III, Upper Ordovician sequences (6, 7, Siliceous-terrigenous Body; 8, Tekhten' Formation; 9, Gur'yanovka Formation); IV, Silurian sequences (10, Telychian Polaty Formation; 11, Gorstian-Ludfordian Kuimov Formation; 12, Pridoli Cherny Anui Formation). €1, lower Cambrian; €2, upper Cambrian; O_1, Lower Ordovician; $O_{2\text{-}3}$, Middle and Upper Ordovician; S, Silurian.

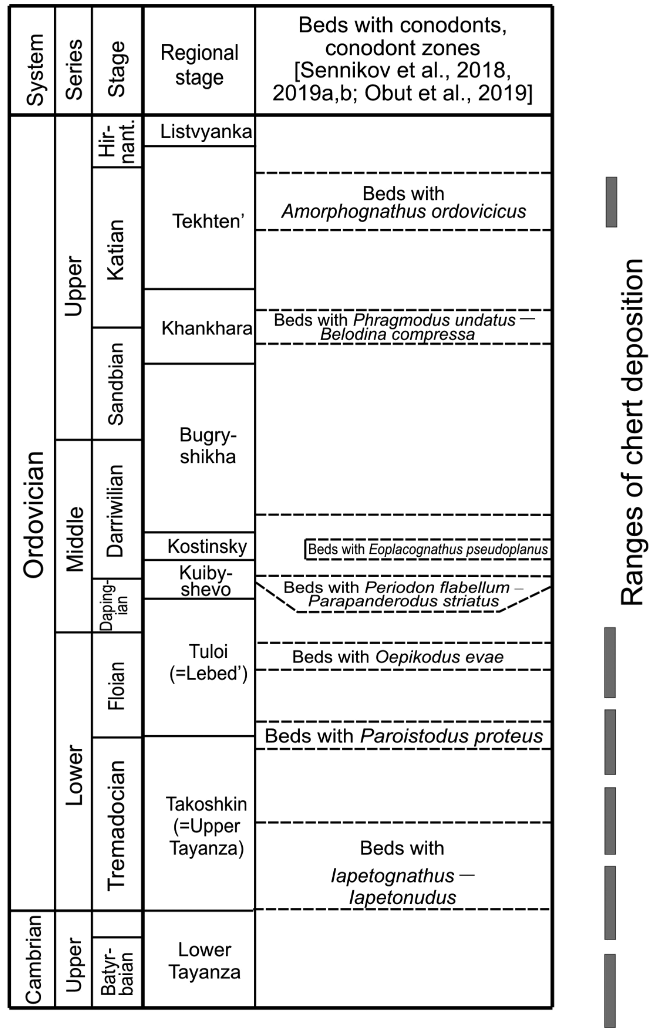

Figure 3. Biostratigraphic units defined by conodonts for the Ordovician of the Gorny Altai modified after Sennikov *et al.* (2019a) and ranges of chert deposition.

tinental margin strata of shelf and slope facies.

In contrast, Ordovician–Silurian shallow marine strata of continental slope and shelf facies are exposed in the central, northwestern, and northeastern Gorny Altai, which are represented by silici-/calci-clastic sequences (Sennikov *et al.*, 2018, 2019a, b). The Middle Ordovician Voskresenka Formation of the Tuloi Horizon in the western Gorny Altai consists of sandstone, siltstone, mudstone, and limestone (Sennikov *et al.*, 2008, 2019a). The Upper Ordovician Gur'yanovka Formation of the Khankhara Horizon in the north-eastern Gorny Altai is composed of siltstone, sandstone, limey-claystone, and limestone (Sennikov *et al.*, 2008, 2019a). The Late Ordovician Tekhten' Formation of the Tekhten' Horizon in northwestern Gorny Altai is dominated by limestone with rare intercalations of chert, whereas the so-called "Siliceous-terrigenous Body" in the same unit is composed of interbedded sandstone, siltstone and chert (Sennikov *et al.*, 2008, 2019a). The above-mentioned carbonate rocks in four formations yielded conodonts, whereas cherts of the Tekhten' Formation and "Siliceous-terrigenous Body" yielded radiolarians (Figures 2, 3). In summary, these fossiliferous cherts/siliceous mudstone and limestone recorded information of deep-sea pelagic and shallow marine continental settings within the same oceanic domain of PAO.

The Telychian (lower Silurian) Polaty, Gorstian–Ludfordian (late Silurian) Kuimov, and Pridoli (uppermost Silurian) Cherny Anui formations in the northwestern and western Gorny Altai are composed mainly of limestone and limey claystone (Yolkin and Zheltonogova, 1974; Sennikov *et al.*, 2008, 2019b, 2021). These carbonates yielded well-preserved conodonts (Figure 2); instead, no radiolarians were found yet in Silurian of the Gorny Altai.

In addition to radiolarians and conodonts, the occurrences of diverse Ordovician–Silurian faunas were also reported from the Gorny Altai, e.g. significant planktonic

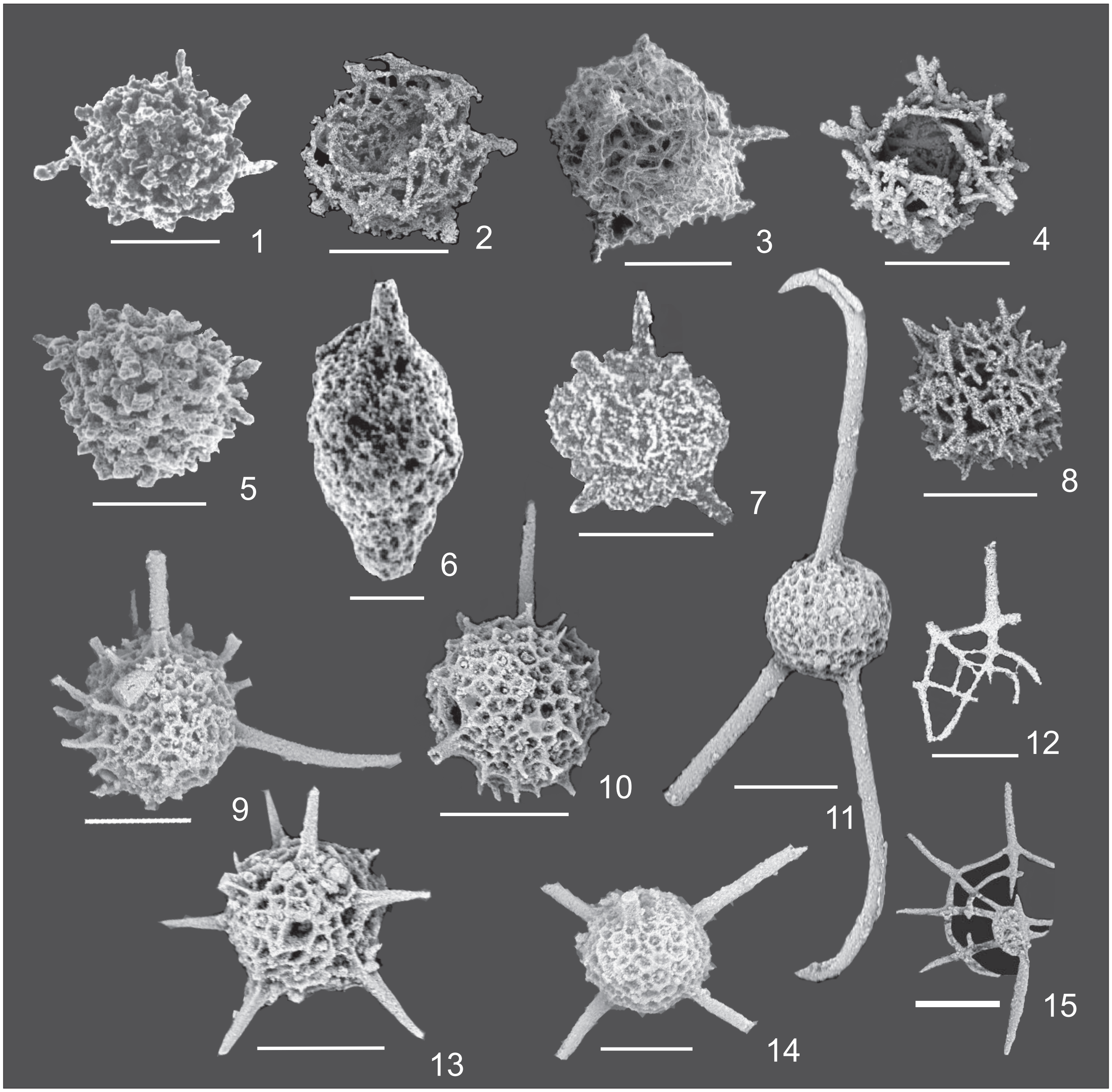

Figure 4. SEM photographs of the Lower Paleozoic radiolarians from the Gorny Altai. **1–5, 8,** Botoman (Lower Cambrian), Shashkunar Formation, central Gorny Altai: 1, *Altaiesphaera acanthophora* Obut et Iwata; 2, 3, *Archeoentactinia* sp.; 4, 8, *Parechidnina* sp.; 5, *Altaiesphaera* sp.; **6,** *Beothuka* sp., Furongian (Upper Cambrian), Zasur'ya Group, Listvennaya Formation, NW Gorny Altai; **7,** *Inanigutta* sp., Floian (Lower Ordovician), Zasur'ya Group, Marcheta Formation, NW Gorny Altai; **9–15,** Katian (Upper Ordovician), Siliceous-terrigenous Body, NW Gorny Altai; 9, 10, *Kalimnosphaera* cf. *maculosa* Webby et Bloom; 11, 14, *Borisella subulata* (Webby et Bloom); 12, *Protoceratoikiscum chinocrystallum* Goto, Umeda et Ishiga; 13, *Secuicollacta cassa* Nazarov & Ormiston; 15, *Protoceratoikiscum* cf. *clarksoni* Danelian & Floyd. Scale 100 µm.

groups, such as graptolites (Sennikov, 1996; Sennikov *et al.*, 2008, 2019b, etc.), which are under scrutiny. The next two sections overview the latest knowledge of two biostratigraphically significant taxa, i.e., radiolarians and conodonts, from the Gorny Altai.

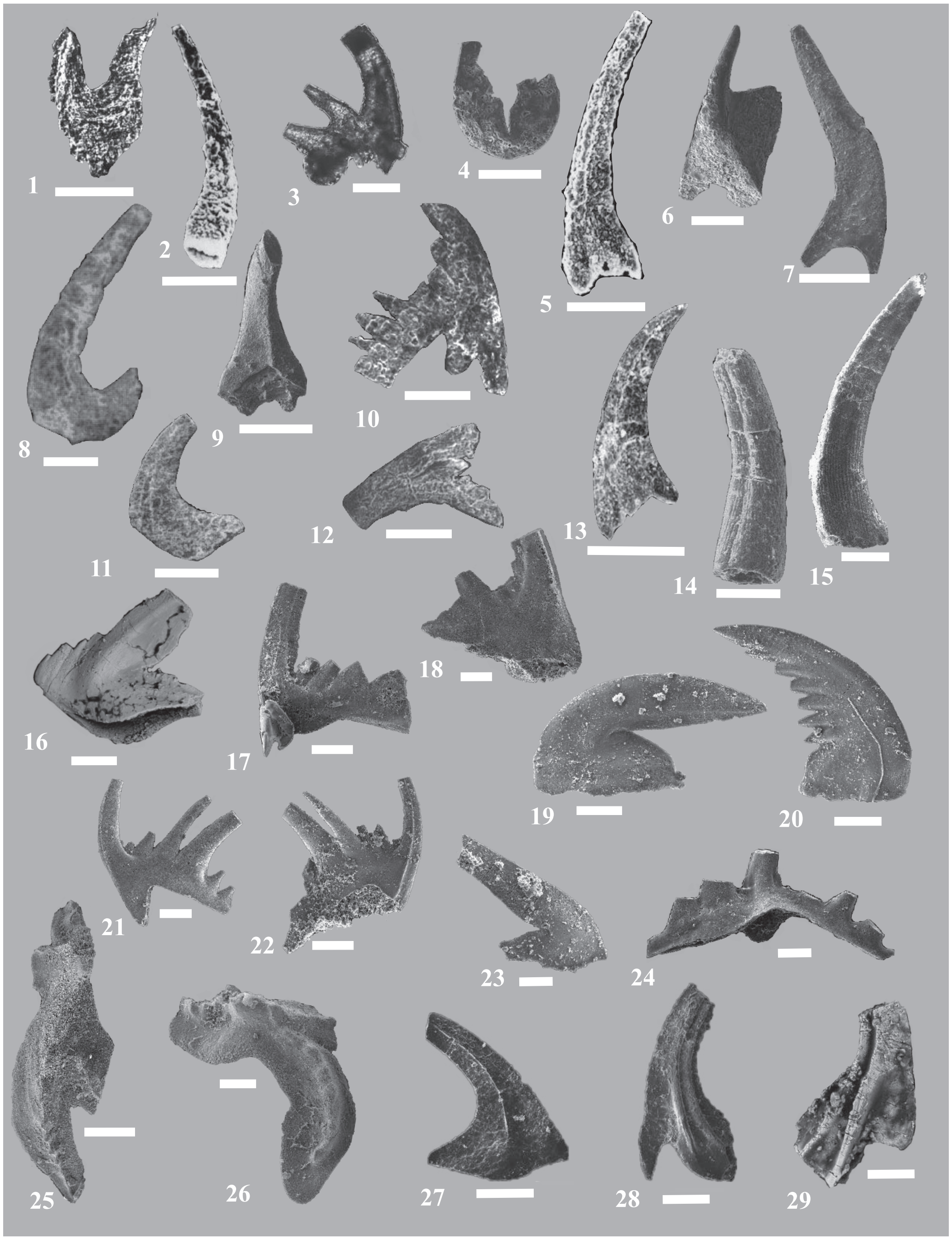

Figure 5. SEM photographs of the Lower Paleozoic conodonts from the Gorny Altai. **1, 2, 5, 13,** Furongian (Upper Cambrian), Listvennaya Formation, NW Gorny Altai; 1, *Westergaardodina bicuspidata* Müller; 2, *Hertzina elongata* (Muller); 5, *Eoconodontus notchpeakensis* (Miller), S element; 13. *Proconodonthus mulleri* Miller, S element; **3, 4, 6, 7, 9,** lowermost Ordovician (base), Kamlak Formation, central Gorny Altai; 3, *Cordylodus lindstromi* Druce & Jones, S element; 4, *Westergaardodina* sp.; 6, *Furnishina* sp.; 7, *Eoconodontus notchpeakensis* (Miller), S element; 9, *Iapetonudus* sp.; **8, 11,** Tremadocian (Lower Ordovician), Talitsa Formation, NW Gorny Altai; *Paroistodus* cf. *originalis* (Sergeeva), S elements; **10, 12,** Floian (Lower Ordovician), Zasur'ya Group, Marcheta Formation, NW Gorny Altai, *Oepicodus evae* (Lindstrom); 10, S element; 12, M element; **16–18,** Darriwilian (Middle Ordovician), Voskresenka Formation, NW Gorny Altai, *Periodon aculeatus* Hadding; 16, P element; 17, 18, S elements; **14, 15, 25, 26,** lower Darriwilian (Middle Ordovician), Voskresenka Formation, NW Gorny Altai; 14, 15, *Parapanderodus striatus* (Graves & Ellison), S elements; 25, 26, *Eoplacognathus pseudoplanus* (Viira), P elements. **19, 20,** upper Sandbian (Upper Ordovician), Gur'yanovka Formation, NE Gorny Altai; 19, 20, *Belodina compressa* (Branson & Mehl); 19, M element; 20, S element; **21–24,** *Phragmodus undatus* Branson et Mehl; 21, 22, S elements; 23, M element; 24, P element; **27–29,** Katian (Upper Ordovician), Siliceous-terrigenous Body, NW Gorny Altai; 27, 28, *Protopanderodus insculptus* (Branson & Mehl), S elements; 29, *Protopanderodus* sp., S element. Scale bar 100 μm.

Radiolarians

The oldest radiolarians in the fossil record were reported from pelagic chert, siliceous mudstone, and limestone in the central Gorny Altai (Obut and Iwata, 2000, 2005; Pouille *et al.*, 2011; Figure 2), which are correlated with the Botoman (Cambrian Stage 4 in Series 2) (Korovnikov *et al*., 2013; Sennikov *et al*., 2017). Those radiolarian-bearing beds of the Shashkunar Formation of the Sanashtykgol Horizon are regarded accumulated on the slopes of a paleo-seamount of hotspot origin.

It is noteworthy that recently found well-preserved polycystines include genera *Parechidnina* Kozur, Mostler and Repetsky*, Altaiesphaera* Obut et and Iwata, and *Archeoentactinia* Won of order Archaeospicularia (Obut and Danelian, 2017, 2019). These echidninid and archeoentactinian lineages of Archaeospicularia are characterized by a spherical to subspherical shell with an irregular three-dimensionally interwoven meshwork made of thin, thread-like, delicate elements and bars. Specimens assigned to genus *Archeoentactinia* possessed a 6-rayed point-centered internal spicule. These forms are important clues to reveal the evolutionary lineage of primitive radiolarians.

The Botoman age of these radiolarian-bearing strata was constrained by the co-occuring trilobites that represent the *Parapagetia-Serrodiscus* Zone, and also by the SSF *Rhombocorniculum cancellatum* Cobbold) (Korovnikov *et al*., 2013; Sennikov *et al*., 2017). They represent the oldest radiolarians known so far. Note that the previously reported "Early Cambrian (Cambrian Series 2, Stage 3) radiolarians" from the Bateny Ridge on the north-west of ASFA (Nazarov, 1973, 1988) were recognized as remains of the siliceous sponge spicules, thus cannot be listed as radiolarians (Obut and Danelian, 2019).

The second oldest radiolarians were reported from the Late Cambrian (Furongian)–Early Ordovician (Tremadocian–Floian) also in the Gorny Altai in its northwestern area (Iwata *et al.*, 1997; Sennikov *et al.*, 2003, 2019a, b; Obut, 2011; Figure 2). These fine-grained beds in the accretionary complex were primarily deposited in deep pelagic ocean floors. Poorly preserved spumellarians belong to inaniguttids (*Inanigutta* Nazarov et Ormiston and *Inanibigutta* Nazarov et Ormiston) and antygoporids (*Beothuka* Aitchison, Flood and Malpas) were recovered from the pelagic siliceous shale and chert of the Zasur'ya Group. The age of the radiolarian-bearing beds is constrained to the Furongian to Tremadocian/Floian, based on the associated conodonts of the *Protoconodontus muelleri–Eoconodontus notchpeakensis* and *Paroistodus proteus–Oepikodus evae* zones.

Better preserved radiolarians were found from the Upper Ordovician siliceous mudstone and chert of the Tekhten' Formation and of the "Siliceous-terrigenous Body" of the Tekhten' Horizon also in the northwestern Gorny Altai (Obut, 2011; Obut and Semenova, 2011). Both formations were deposited primarily in shallower marine settings; i.e., the former on shelf, and the latter on slope (Figure 2). Their radiolarian assemblages are more diverse than those from the above-mentioned deep-water beds mentioned above; i.e., with albaillellids (*Protoceratoikiscum chinocrystallum* G., Um. & I.), secuicollactids (*Secuicollacta ornatha* G., Um. & I., *S.* cf. *sceptry* McDonald and *S. silex* G., Um. & I.), entactiniids (*Borisella subulata* (Web. & Bl.), and inaniguttids (*Inanigutta complanata* Naz. and *Kalimnasphaera* cf. *maculosa* Web. & Bl.). The Katian age (Late Ordovician) is constrained by the associated conodonts of the *A. ordovicicus* Zone and graptolites of the *Cl. supernus* Zone (Obut, 2011; Sennikov *et al.*, 2018, 2019a, b).

Furthermore, the considerable diversification of Ordovician radiolarians was preliminarily mentioned for the assemblages from other accretionary complexes in CAOB, and also from shelf strata in central/eastern Kazakhstan (Nazarov, 1975, 1988; Nazarov and Popov, 1980; Pouille *et al.*, 2013, 2014) and Guansu and Junggar in China (Li, 1995; Buckman and Aitchison, 2001; Danelian *et al.*, 2013). Note that sporadic but rare pieces of information on the earliest radiolarians were mostly reported mostly from CAOB, if at all, and this suggests great potential for future research.

Conodonts

The occurrences of conodonts were confirmed from the upper Cambrian, Ordovician, and Silurian in the Gorny Altai. The earliest conodont record for the Gorny Altai was reported from the siliceous rocks of the Late Cambrian–Early Ordovician Zasur'ya Group of the Tayanza Horizon in the northwestern Gorny Altai (Iwata *et al.*, 1997; Sennikov *et al.*, 2008; Obut *et al.*, 2019) (Figure 2). The Upper Cambrian Listvennaya Fm. yielded assemblages composed of typical genera of the Furongian; i.e., *Westergaardodina*, *Proconodontus*, *Muellerodus*, *Furnishina*, *Eoconodontus*, and *Cambrooistodus*. The lowermost Ordovician *Iapetonudus* sp. and *Iapetognathus* sp., index taxa for the base of this system, were reported from carbonates of the Kamlak Fm. of the upper Tayanza Horizon in the central Gorny Altai (Sennikov *et al.*, 2014). Further diversification of conodonts is observed during the Ordovician and Silurian, although their occurrences are still rare in the Gorny Altai.

Lower Ordovician (upper Tremadocian − Floian) conodonts were found from fine-grained siliceous rocks of Zasur'ya Group in the Takoshkin–lower Tuloi horizons in the northwestern Gorny Altay (Figures 2, 3). These conodont-bearing strata were deposited in deep-sea environments (Sennikov *et al.*, 2018, 2019a, b; Obut *et al.*, 2019). Two biostratigraphic units were recognized (Figure 3). Beds with *Paroistodus proteus* (upper Tremadocian−lower Floian) occur strictly from the violet chert of the upper Talitsa Formation (Zasur'ya Group), and red chert/siliceous mudstone of the Marcheta Formation (Zasur'ya Group). The assemblage includes: *Paroistodus* cf. *proteus* (Lind.), *Paracordylodus gracilis* Lind., *Cornuodus longibasis* (Lind.), *Drepanodus reclinatus* (Lind.), *Oneotodus* sp., and some other species in open nomenclature. Beds with *Oepikodus evae* (late Floian) were recovered from red chert of the upper Marcheta Formation (Zasur'ya Group). The conodont assemblage includes: *Oepokodus evae* Lind., *Periodon* cf. *flabellum* (Lind.), *Prioniodus* cf. *P. elegans* Pander, *Baltoniodus* sp., and *Drepanoistodus* sp. Both biostratigraphic units are well defined for the deep-water Atlantic Realm Ordovician strata based on taxa of cosmopolitan distribution (Lindstrom, 1971; Lofgren, 1994; Albanesi *et al*., 1998; Pyle and Barnes, 2002; etc.). The index-species of the *Oepikodus evae* conodont Zone is regarded as an indicator of the deep-water environments in Baltoscandia and Kazakhstan (Tolmacheva, 2014). This level is one of the most globally recognized and aligned in the Ordovician, and appeared simultaneously on almost all continents (except the Siberian Platform) and considered to be a reflection of the eustatic transgressive event (Webby *et al.*, 2004; Wu *et al.*, 2010; Tolmacheva, 2014; Zhang *et al.*, 2019; etc.). As to the first appearance of conodonts in the PAO domain and further diversification in the Ordovician, more complete paleontological data were reported from the Upper Cambrian beds in South and Central Kazakhstan (Zhylkaidarov, 1998; Dubinina, 2000; Tolmacheva *et al.*, 2004; Tolmacheva, 2014, etc.).

Conodont-bearing beds are restricted to the lower Darriwilian (Middle Ordovician). Conodonts were recovered from shelf carbonates of the Voskresenka Formation of the Tuloi Horizon in the northwestern Gorny Altai (Izokh *et al.*, 2005; Sennikov *et al.*, 2018, 2019a, b; Obut *et al.*, 2019) (Figures 2, 3). Beds with *Periodon flabellum–Parapanderodus striatus* yield poorly preserved conodonts; i.e., *Acodus eletsus*, *Protoprioniodus* sp., *Cooperignathus* sp., *Periodon* cf. *P. flabellum* (Lind.), *Parapanderodus striatus* (Gr. & El.), *Juanognathus jaanussoni* Serp., *Drepanoistodus suberectus* (Br. & M.), *Triangulodus larapintinensis* (Cr.), *Anodontus longus* Stouge & Bag., *Naimanodus degtiarevi* Tolm., *Panderodus*? *nogami* (Lee), and others. Beds with *Eoplacognathus pseudoplanus* yield *Eoplacognathus pseudoplanus* (Viira), *Periodon aculeatus* Had., *Scolopodus* sp., *Drepanodus arcuatus* Pand., *Ansella* sp., and *Paroistodus* sp.

The *Periodon flabellum*/*Periodon macrodentatus* Zone was defined for the deep-water facies in Dapingian-lower Darriwilian (Middle Ordovician) of Kazakhstan (Tolmacheva, 2014). The *Eoplacognathus pseudoplanus* Zone was established in the lower Darriwilian of Baltoscandia (Lofgren, 2004) and South China (Zhang *et al*., 2019). The index-species of this zone was reported in abundance maximum in shallower waters (Viira *et al*., 2001; Lofgren, 2004), however presence of typical deep-water *Periodon* fauna in association indicates deeper-water environments.

Late Ordovician (late Sandbian–Katian) conodonts were detected in shallow-marine shelf carbonates of the Gur'yanovka Formation of the Khankhara Horizon, and in slope carbonates of the Siliceous-terrigenous Body of the Tekhten'Horizon in the north-eastern Gorny Altai (Sennikov *et al*., 2018, 2019a, b; Obut *et al*., 2019) (Figures 2, 3). Beds with *Belodina compressa* and *Phragmodus undatus* characterize the late Sandbian–early Katian conodont assemblage that include *Belodina compressa* (Br. & M.), *Phragmodus undatus* Br. & M., *Panderodus gracilis* (Br. & M.), *Aphelognathus* sp., *Phragmodus* sp., *Drepanoistodus suberectus* (Br. & M.), *Scolopodus* sp., and *Scandodus* sp. Beds with *Amorphognathus ordovicicus* include late Katian conodont assemblage: *Protopanderodus* cf. *liripipus* (Ken., Barn. & U.), *Protopanderodus insculptus* (Br. & M.), *Periodon grandis* (Eth.), *Amorphognathus* cf. *tvaerensis* Berg., *Amorphognathus* cf. *ordovicicus* Br. & M., *Yaoxianognathus* sp., *Panderodus* sp., *Decoriconus* sp., *Paroistodus* ?*mutatus* (Br. & M.) and *B. compressa* (Br. & M.).

The *Belodina compressa* and *Phragmodus undatus* conodont zones were assigned to the late Sandbian–early Katian for the Midcontinent Realm (Webby *et al.*, 2004; Goldman *et al.*, 2007), North China (Zhang *et al.*, 2019) and Australia (Zhen and Percival, 2017). They were also found on the Siberian Platform (Moskalenko, 1983). The conodont associations include species characteristic for both shallow (like *B. compressa*) and relatively deep-water slope facies. The *Amorphognathus ordovicicus* Zone is recognized in Late Katian−Hirnantian for the Atlantic Realm, Baltoscandia and South China (Webby *et al.*, 2004; Goldman *et al.*, 2007; Zhen and Percival, 2017; Zhang *et al.*, 2019; Yang *et al.*, 2021; etc.). Conodont association includes typical deep-water genera as *Periodon* and *Protopanderodus*, known from tropical environments (Rasmussen, 1998).

Conodonts are extremely scarce from Silurian strata in the Gorny Altai (Vorozhbitov, 1996; Sennikov *et al.*, 2008, 2019b; Obut *et al.*, 2013). They only occur in shelf carbonates of the Telychian Polaty Fm. and Gorstian−Ludfordian Kuimov Fm. in western Gorny Altai. No regional conodont zonation for the Silurian was established so far. The Telychian assemblage includes: *Ptero-*

spathodus amorphognathoides Wall., *Pt. celloni* (Wall.), *Pt. pennatus pennatus* (Wall.), *Ozarkodina pirata* Uyeno & Bar., *Oz.* cf. *excavata* (Br. & M.), *Oz. hadra* (Nic. & Rex.), *Oz.* cf. *waugoolaensis* Bischoff, *Aspidognathus tuberculatus* Wall., *Pseudobelodella silurica* Arm., *Panderodus gracilis* (Br. & M.), *P.* cf. *recurvatus* (Rhodes), *Johnognathus huddlej* Mash., *Aulacognathus bullatus* (Nic. & Rex.), ?*Aspelundia fluegeli* (Wall.), and *Pseudooneotodus tricornis* Dryg. The Gorstian−Ludfordian conodonts are represented by *Ozarkodina typica* Br. & M., *Spathognathodus* cf. *inclinatus* (Rhodes), *Spathognathodus* sp., *Trichonodella* sp. *Pelekysgnathus dubius* Jepp., *Belodella* cf. *anormalis* Coop.,*Wurmiella excavata* (Br. & M.), *Oz.* cf. *cadiaensis* Bisch., *Ozarkodina* sp., *Panderodus* sp. and *Belodella resima* (Philip). From the Pridoli Cherny Anui Fm. in the central Gorny Altai, more conodonts were recently discovered (Sennikov *et al.*, 2021). Recovered conodont associations are composed of cosmopolitan Silurian genera reported from North America, Baltoscandia, Avalonia, China, Australia (Walliser, 1964; Aldridge, 1985; Bischoff, 1986; Mannik, 1998, 2007; Wang and Aldridge, 2010; etc.) It should be noted that Silurian conodonts from the Gorny Altai require further investigation.

In contrast to conodonts, it is confirmed that graptolites with similar habitat were more diverse and common throughout the Ordovician and lower Silurian, with 17 established biozones for the entire Ordovician and 12 biozones in Llandovery of the Gorny Altai (Sennikov *et al.*, 2008, 2013, 2018, 2019a; Sennikov, 2013).

Discussion and conclusion

The early Paleozoic history of the Altaian segment of the Paleo-Asian Ocean is partly recorded in the siliceous and carbonate sequences of deep-sea and shelf facies, which occur as exotic blocks within the strongly deformed geologic units in the Gorny Altai. According to previous paleogeographical studies, these blocks were incorporated into island arc systems and relevant terranes along the Siberian margin; they were situated in an equatorial or low latitudinal position of the southern hemisphere (~ 10^0 s.l.) during the Late Cambrian−Ordovician (Berzin and Dobretsov, 1994; Dobretsov, 2003; Metelkin *et al*., 2012, etc.).

The early history of the planktonic groups which inhabited the Altaian segment of PAO goes back to the early Cambrian (Series 2, Stage 4) where the oldest radiolarians known so far worldwide have been found. Later in the Furongian, conodonts appeared first, followed at the beginning of the Ordovician by graptolites which become widespread in pelagic and shelf environments of the Altaian segment of PAO throughout the Early Paleozoic.

Conodont associations found in the Upper Cambrian-Ordovician strata of the Gorny Altai include many cosmopolitan taxa that allow world-wide correlations with those from North America, Baltoscandia, Avalonia, Kazakhstan, Australia, and China. Late Cambrian−Middle Ordovician conodont faunas recovered from the siliceous sequences of the Gorny Altai include pelagic taxa inhabited in tropical, deep-water environments, as reported from many localities belonging to the Tropical domain of the Open-Sea biogeographic Realm by Zhen and Percival (2003). Middle−Late Ordovician conodont associations from carbonate sequences of the Gorny Altai include characteristic taxa of deep-water *Protopanderodus*−*Periodon* biofacies, which are typical in outer-shelf environments of the epicontinental basins and continental slopes, as described from the both sides of the Iapetus Ocean (Rasmussen and Stouge, 1995; Rasmussen, 1998; Tolmacheva, 2014). The Silurian conodont fauna includes cosmopolitan species, however, detailed study is required to establish their paleogeographic relations.

The radiolarian associations from Upper Cambrian–Lower Ordovician strata show a clear connection to those from Kazakhstan (Nazarov, 1975, 1988). In addition, radiolarian faunas from Katian (Upper Ordovician) siliceous sequences of the Gorny Altai show great similarity with those from Australia (Noble and Webby, 2009) and North America (Renz, 1990). The Ordovician−Silurian graptolite associations are characterized by a large number of cosmopolitan taxa (Sennikov, 1996; Sennikov *et al*., 2008, 2019b), confirm openness of the paleobasin and allow broad inter-regional correlations.

This article briefly introduced results on micropaleontological research obtained from the Gory Altai through work of nearly 25 years. In particular, conodonts and radiolarians open new windows to look into the lost oceanic environments of the PAO that occupied an extensive oceanic domain during the early Paleozoic. Nonetheless, studied areas are still highly limited with respect to the entire CAOB; therefore, more detailed research is definitely needed to reveal the hidden secrets of the PAO, by utilizing the analytical scheme used for the microfossil-bearing strata in the Gorny Altai.

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