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Additional occurrence of Capitanian (Guadalupian, Permian) gigantic bivalve Alatoconchidae from NE Japan and Primorye (Far East Russia): paleobiogeographical implication to NE segment of Greater South China

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Abstract The occurrence of the Permian large aberrant bivalve fossil Alatoconchidae is confirmed for the first time from the South Kitakami belt, NE Japan, and from the Sergeevka belt in southern Primorye, Far East Russia. Both cases are recognized in the Capitanian (late Guadalupian) shallow marine limestones of shelf facies. In the top part of the Iwaizaki limestone in the South Kitakami belt, abundant shell fragments of bivalves form multiple coquina beds, with the largest fragment of over 40 cm long and ca. 1 cm thick. Based on their large size, large aspect ratio between width and thickness, and uniquely tight bending along shell margins, these bivalves are identified as Alatoconchidae gen et sp. indet. Bivalve shells of similar characteristics, although much smaller and rarer, are detected also in the coeval shallow marine limestone of the Chandalaz Formation in the Sergeevka belt, Primorye. The correlation of these Permian shallow marine carbonates of shelf facies of the two belts is positively supported, particularly by the occurrence of the bizarre bivalve Alatoconchidae with associated fauna with a clear Tethyan fingerprint. The occurrence of the unique Capitanian fossil assemblage from NE Japan and Primorye indicates that warm-water Tethyan environments under tropical/subtropical climates developed along a mid-Permian continental margin in Far East Asia, almost at the eastern edge of Pangea. The occurrence of the Alatoconchidae-bearing unique fauna further indicates that proto-Japan and proto-Primorye had been geotectonically connected side-by-side along the Panthalassan (Paleo-Pacific) margin of the Permian Greater South China in accordance with the results of latest provenance analysis on Paleozoic terrigenous clastics in Japan and Primorye.
Key words: Permian, Alatoconchidae, NE Japan, Far East Russia, Greater South China

Introduction

The Permian bivalves of Family Alatoconchidae are extremely unique in fossil records, as they are characterized by aberrant morphology and by unusually large size sometimes over 1 meter in length (e.g., Yancey and Boyd, 1983; Seilacher, 1990; Asato *et al.*, 2017). Such bivalve gigantism rarely developed during the Phanerozoic except for 5 episodes, i.e., the Silurian/Devonian, Permian, Triassic, Jurassic/Cretaceous, and Miocene-Quaternary; therefore, their repeated appearance and termination are noteworthy with respect to the long-term global climate changes (Isozaki and Aljinovic, 2009).

To date, the occurrences of Permian alatoconchids were known from 12 areas of the world, including East Asia (SW Japan, Malaysia, W. Philippines, Thailand, China, and Myanmar; Ozaki, 1968; Runnegar and Gobbet, 1973; Kiesling and Flugel, 2000; Udchachon *et al.*, 2007; Chen *et al.*, 2018; Kyi Pyar Aung and Isozaki, 2020), Mid-East (Afghanistan, Oman, and Iran; Termier *et al.*, 1974; Pillevat, 1993; Thiele and Ticky, 1980), southern Europe (Croatia; Kochansky-Devide, 1978; Aljinovic *et al.*, 2008), northern Africa (Tunisia; Boyd and Newell, 1979), and northwestern North America (Alaska; Blodgett and Isozaki, 2013). Most of these fossil localities were in low-latitude, tropical/subtropical domains along the Paleo-Tethys during the Permian, where shallow marine fossiliferous shelf carbonates were ubiquitously accumulated. In contrast, the three examples from SW Japan, W. Philippines, and Alaska were derived from accreted paleo-atoll carbonates, which were deposited primarily in a mid-oceanic domain of the Permian Panthalassa (Isozaki, 2006).

The associated fauna and coeval stable carbon isotope signatures indicate that this unique Permian bivalves lived probably in warm-water shallow marine settings by utilizing photo- and/or chemo-symbiosis under tropical/subtropical climates (Isozaki and Aljinovic, 2009; Asato *et al.*, 2017). In addition, their emergence from the late Cisuralian (early Permian) and disappearance by the end of Guadalupian (middle Permian) suggest a particular significance with respect to the end-Guadalupian (Middle Permian) environmental changes, which were related to the global warming/cooling and also to the coeval mass extinction (e.g., Isozaki, 2009; Isozaki and Aljinovic, 2009; Chen *et al.*, 2021).

This short report adds two more late Guadalupian occurrences of Alatoconchidae from Far East Asia to the list, i.e., from Kesen'numa, NE Japan, and Partizansk, southern Primorye, Russia (Fig. 1A–C). As these two alatoconchid-bearing strata were deposited as shallow marine shelf carbonates along a major continental margin during the Permian, which are regarded to have belonged to the north-eastern segment of the Greater South China (GSC) block (Isozaki *et al.*, 2014, 2015, 2017, 2021; Isozaki, 2019, 2023). Therefore, the new occurrence in NE Japan is totally distinct in the Permian bio-geographical context with respect to those previously reported case from the coeval paleo-atoll limestones in SW Japan (Isozaki, 2006), which were derived from mid-Panthalassa. The geological and paleobiogeographical significances of new findings are briefly discussed.

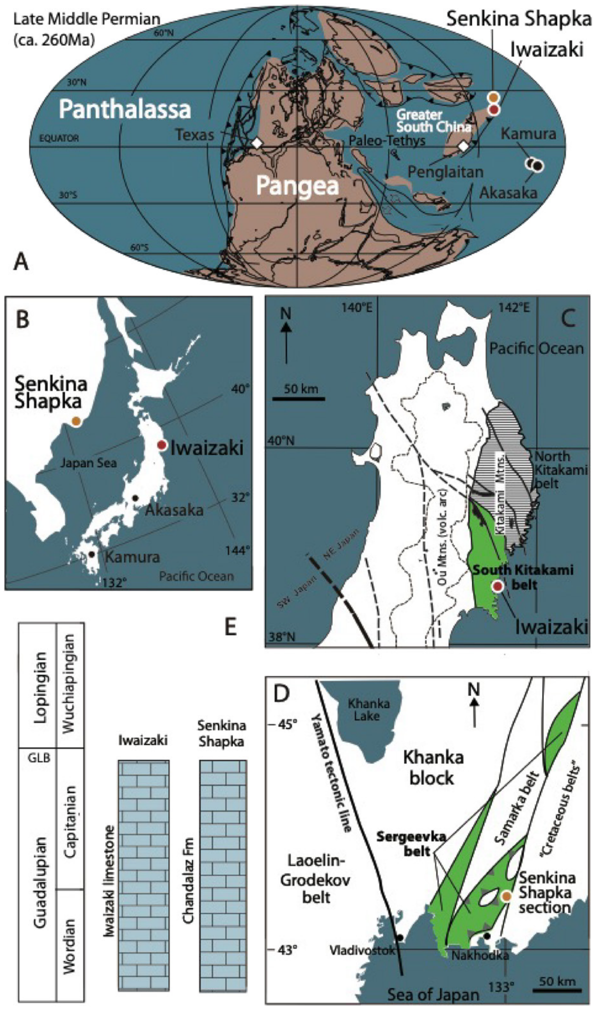

Fig. 1. Index maps (A–D) and simplified stratigraphic column (E) of the two study sections with Permian gigantic bivalves in NE Japan and southern Primorye, Far East Russia. (modified from Kani *et al.*, 2018 according to Isozaki *et al.*, 2021).
The South Kitakami belt in NE Japan and the Sergeevka belt in southern Primorye are composed of alamost identical geologic units, i.e., Cambrian-Ordovician arc-relevant crustal rocks (granitoids and ophiolites) covered by Paleozoic-early Mesozoic shallow marine strata. This similarity suggests the past continuity between the two belts, which became separated by the Miocene-opening of the Japan Sea. Red circles are for fossil localities reported here.

Geologic setting

For reporting the first occurrence of the Permian gigantic bivalves not only from NE Japan but also from southern Primorye, Far East Russia (Fig. 1), a brief description is given below for the two fossil-bearing sections and units.

Iwaizaki limestone: The South Kitakami belt in NE Japan (Fig. 1B) is characterized by the Cambrian-Silurian arc-related basement composed of igneous suites (ophiolite and granitoids) without Precambrian crustal rocks (Ozawa, 1988; Isozaki *et al.*, 2015). The latest zircon geochronology of the early-middle Paleozoic granitoids and sandstones confirmed that the belt has a close affinity to South China block, particularly to the Cathaysian part on the Pacific side (Okawa *et al.*, 2012; Isozaki *et al.*, 2014, 2015; Isozaki, 2019). The Paleozoic South Kitakami belt probably formed a segment of an active continental margin along the proto-Pacific (Panthalassan) side of the GSC.

These basement rocks are covered by a thick pile of Paleozoic-Mesozoic sedimentary rocks, i.e., fossiliferous carbonates of shallow marine shelf facies with associated marine/non-marine clastics. The accompanied shallow marine Middle-Late Paleozoic fauna concordantly suggests an intimate link to that from South China (e.g., Ehiro, 1998; Isozaki, 2019).

The Permian strata of the belt are composed of shallow marine terrigenous clastics and carbonates (e.g., Tazawa, 1988; Kawamura *et al.*, 1990). The Guadalupian Iwaizaki limestone in Kesen'numa city in the southern South Kitakami belt (Fig. 1B) is exposed along a small peninsula, which displays the entire sequence of an isolated reef complex within a mudstone-dominant shelf setting (Kawamura and Machiyama, 1995; Shen and Kawamura, 2001; Tobita *et al.*, 2018). Morikawa *et al.* (1958) and Morikawa (1960) established the biostratigraphic framework of the ca. 180 m-thick Iwaizaki limestone based on fusulines. Figure 2 depicts the overall stratigraphic column of the Iwaizaki limestone (Kawamura and Machiyama, 1995) and the detailed distribution of representative bioclasts, such as fusulines, calcareous algae, rugose corals, brachiopods, crinoids, bryozoans, and mollusks, from the top part (Tobita *et al.*, 2018). The occurrences of two fusuline taxa, i.e., *Monodiexiodina matsubaishi* from the basal part and *Lepidolina multiseptata* from the upper part, constrain the age of the limestone in the Guadalupian, although the topmost 30 m-thick interval is barren in index fossils (Fig. 2E). The limestones are composed mostly of packstone and wackestone with minor amount of grainstone. These fossil contents and lithofacies recorded a shallow marine depositional setting under warm climates. Kawamura and Machiyama (1995) and Shen and Kawamura (2001) particularly demonstrated the unique development of reef structure in the lower-middle parts of the limestone.

Detailed stratigraphic subdivision of the limestone was summarized by Morikawa *et al.* (1958) and Kawamura and Machiyama (1999); e.g. subdivision into Units 1 to 9 in ascending order (Fig. 2). The interval from Unit 3 to Unit 8 represents the core of reef complex, whereas Unit 9 corresponds to the surrounding marginal facies. From this section, Zakharov *et al.* (2000) preliminarily reported significantly high $\delta^{13}C$ values of $> +4$ permil in carbonate carbon. The unique interval of unusually high $\delta^{13}C$ positive values in the Capitanian (Late Guadalupian) was later recognized as the "Kamura event" for a globally correlative signature (Isozaki *et al.*, 2007a, 2007b, 2011), based on detailed stratigraphic analyses for mid-oceanic paleoatoll limestone in Japan and in shelf limestones along the Tethyan margin in Croatia. Kani *et al.* (2018) also documented an interval with extremely low $^{87}Sr/^{86}Sr$ ratios of <0.7068 in the upper half of the section, which is correlated with the coeval global

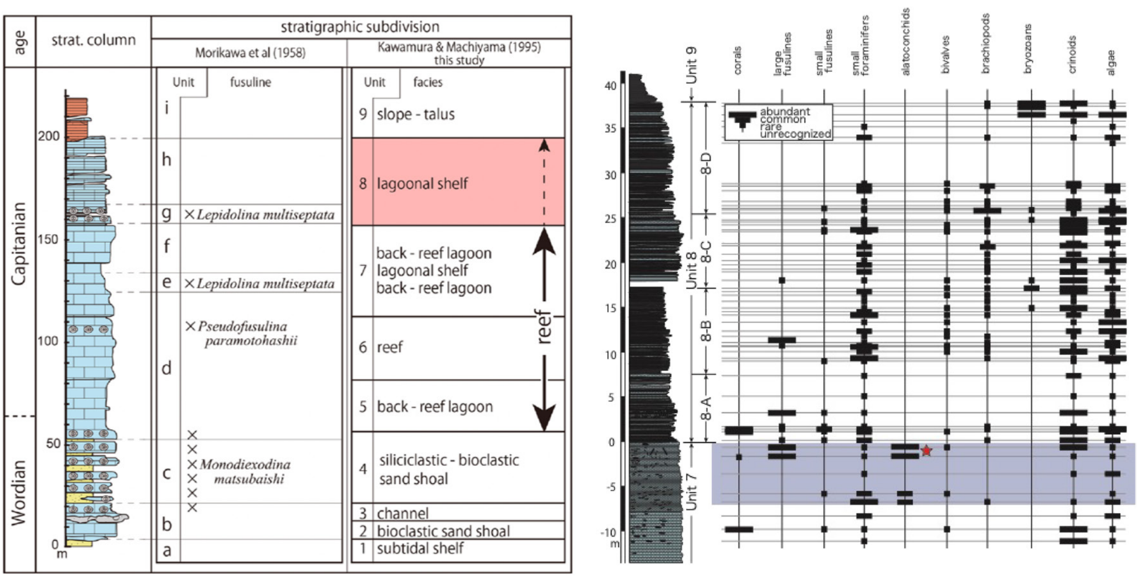

Fig. 2. Stratigraphy of the Iwaizaki limestone in the South Kitakami belt, NE Japan.
Left: Overall stratigraphy adopted from Morikawa *et al.* (1968) and Kawamura and Machiyama (1999). Right: Detailed distribution of biolcalsts within the uppermost ca. 50 m-thick interval (topmost Unit 7 to basal Unit 9) of the Iwaizaki limestone modified from Tobita *et al.* (2018). Note the bluish grey interval with large bivalve fossils. Red star indicates the main horizon with abundant specimens illustrated in Fig. 3A–D.

signature called the "Capitanian minimum" (Kani *et al.*, 2008, 2013; Kani & Isozaki, 2021).

Tobita *et al.* (2018) described detailed stratigraphy for the upper half of the limestone, particularly for the Capitanian interval with the index fusuline *Lepidolina* (Fig. 2). The unique gigantic bivalve assemblage was recognized solely from the top part (ca.8 m thick) of Unit 7 with the *Lepidolina*-interval.

Chandalaz Formation: Almost identical to the above-described South Kitakami belt in NE Japan, the Sergeevka belt in southern Primorye (Fig. 1C) is underlain by Cambrian arc granitoids and Ordovician ophiolite (Kanchuk *et al.*, 1996), which were covered by mid-Paleozoic to Mesozoic sedimentary rocks of shelf facies (Kotlyer *et al.*, 1997). This similarity in rock type potentially suggests the primary continuity between the two belts in the past, although they became separated by the Miocene-opened Japan Sea (Isozaki *et al.*, 2017; Isozaki, 2019, 2023).

The Permian strata of the Sergeevka belt comprise terrigenous clastics associated with shallow marine limestones of continental shelf facies (Belyaeva *et al.*, 1997), which are called the Chandalaz Formation (Horizon). The best-exposed limestone of the Chandalaz Formation is observed at the Senkina Shapka section next to a railway track along the Partizanskaya river, ca. 40 km to the north of Nakhodka (Fig. 2C). This section, over 200 m thick, is composed of well-bedded limestone with abundant and diverse fusulines, small foraminifers, bryozoans, corals, and brachiopods. According to Ueno *et al.* (2005), Kotlyar *et al.* (2006), and Kossovaya and Kropatcheva (2013), this section comprises three fusuline zones; i.e., 1) the *Monodiexodina sutchanica-Metadoliolina dutkevitchi* Zone, 2) *Parafusulina stricta* Zone, and 3) *Metadoliolina lepida-Lepidolina kumaensis* Zone, in ascending order. The *M. sutchanica-M. dutkevitchi* Zone and *M. lepida-L. kumaensis* Zone are correlated with the Wordian (Middle Guadalupian) and Capitanian, respectively. The *P. stricta* Zone is correlated also with the Wordian except for its topmost horizon with an early Capitanian conodont *Jinogondolella postserrata* (Behnken). A preliminary analysis of stable carbon isotope was done for this section by Zakharov *et al.* (2000) and a positive excursion in $\delta^{13}C$ up to 4 ‰ was recognized for the correlation with the coeval Kamura event (Isozaki *et al.*, 2007a). Kani *et al.* (2018) reported the uniquely low $^{87}Sr/^{86}Sr$ ratio of <0.7068 from this section for the correlation with the "Capitanian minimum".

Alatoconchids

Although detailed paleontological analysis has not yet been conducted for the newly found gigantic bivalves, an overview of the fossils is briefly given here. Their occurrence is more abundant in the Iwaizaki limestone than the Chandalaz Fm; thus most of the descriptions given below are for the specimens from the former. The bivalve fossils from the Chandalaz Fm are highly limited in number and quality; nonetheless, their occurrence is indeed significant, as discussed later.

Horizons: In the Iwaizaki limestone, the large bivalve fossils occur abundantly in a ca. 8 m thick interval of the topmost Unit 7 (Fig. 2). This part is composed of massive gray limestone with numerous fragments of bivalves, which was previously described as coquina beds by Kawamura and Machiyama (1999). This interval between 2 horizons with the Capitanian fusuline *Lepidolina* (Morikawa, 1960) corresponds to the Capitanian in age. In the uppermost 8 m-thick interval of Unit 7, abundant bivalve shells occur in a bedded manner, most concentrated in the topmost part (Fig. 2, 3A). All shells are fragmented, and original intact morphology is lost. This mode of occurrence clearly recorded the post-mortal transportation from the living habitat and re-deposition. The matrix of the bivalve-bearing limestone is composed of fine-grained lime mud with scattered bioclasts, suggesting the deposition by high-energy flows, such as debris flow.

In the Chandalaz Fm at Senkina Shapka, the occurrence of large bivalve shells is extremely poor, and restricted to a particular horizon (Bed 19) within the *Lepidolina*-bearing Capitanian interval in the uppermost part of the section (Fig. 1E). The rest of the Permian limestone, over 200 m thick (Ueno *et al.*, 2005), is free from bivalve shells. The bivalve-bearing light grey limestone is less than 1 m thick without clear internal structures. Fragmented shells are scattered in matrix without forming concentrated coquina beds.

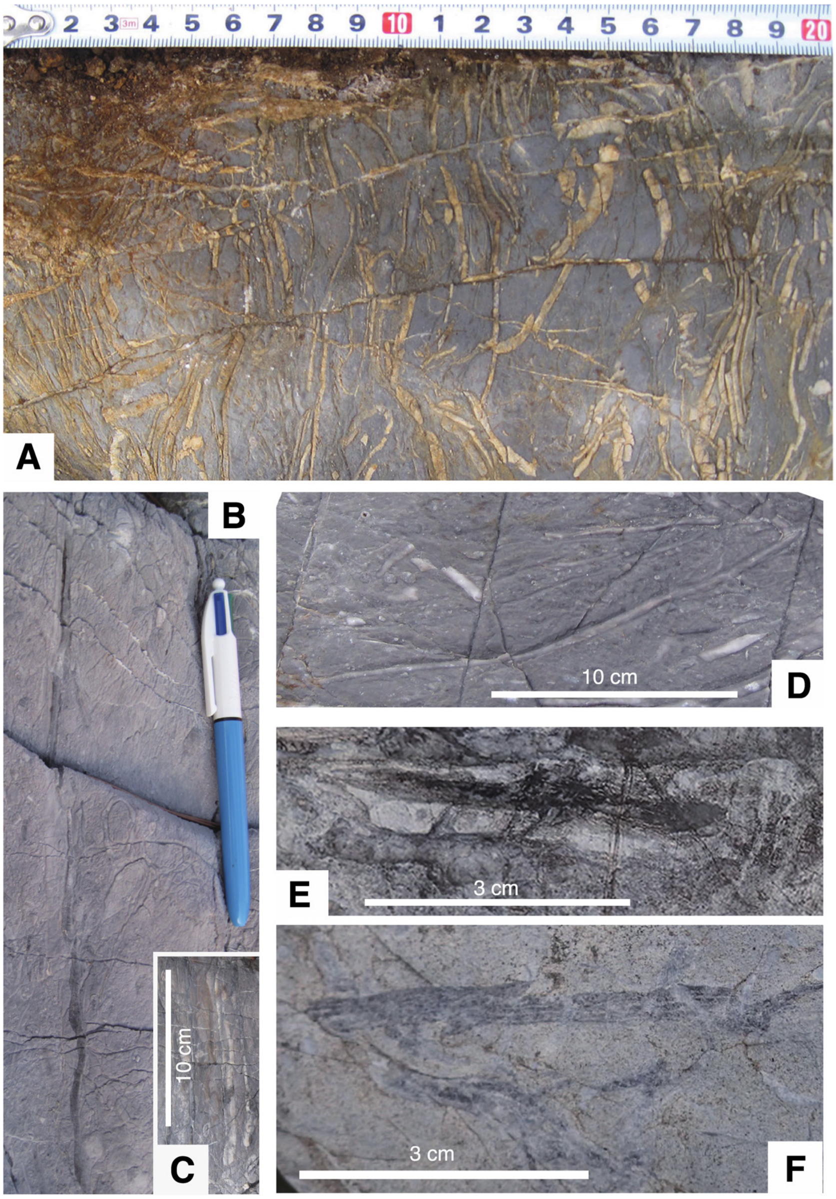

Fig. 3. Mode of occurrence of large-tested bivalve fossils from the Capitanian intervals of the Iwaizaki Limestone (NE Japan) (A–D) and the Chandalaz Formation (Primorye, Russia) (E and F).
A: Coquina bed replete with large shell fragments aligned in a bedded manner. B: Fragment of a large shell with the observed maximum length ($>$ 40 cm), suggesting a much larger primary shell width. C: Shell fragment with the observed maximum thickness (1 cm), suggesting a large aspect ratio between width and thickness of the living shell. D–F: U-shaped turn of a shell between two curved planes in section, probably showing a hinge corner of a side flank of an original shell, which is unique to Alatoconchidae for the Permian time.

Shells: As to the Iwaizaki bivalve fossils, size of shell fragments observed on outcrop surfaces are mostly less than 10 cm in length, and less than 5 mm in thickness (Fig. 3A). Shell fragments longer than 20 cm are rare, although the longest specimen reaches ca. 40 cm in length (Fig. 3B), suggesting much greater original shell width. The thickness of shells, less than 1 cm (Fig. 3C), implies that the bivalve shell had a large aspect ratio between width and thickness. In addition, some specimens preserve double-layered shell structure (Fig. 3E, F) that characterizes the family (Isozaki, 2006; Asato *et al.*, 2017). The most peculiar morphological feature of the shells observed in sections is tight folding/bending along the side/top margins of shells (Fig. 3D). In the Chandalaz Fm, not many specimens were recovered; nonetheless, the dimension and unique shell form (Fig. 3E, F) are nearly identical to those from the Iwaizaki limestone.

All shell fragments are tightly associated with the surrounding limestone matrices in both sections, therefore, extracting individual shells was not successful to date. Ligament structures, a significant criterion as to bivalve taxonomy, are unfortunately unknown at present. Judging from their size, width/thickness ratio, and unique U-turn bending of the shells, nonetheless, these bivalve shells from the two Capitanian sections appear most probably belong to Family Alatoconchidae for Permian aberrant bivalves (Yancey & Boyd, 1983; Asato *et al.*, 2017). At present, no further detailed taxonomical information is available; thus in this preliminary report on their occurrence from new localities, they are described as Alatoconchidae gen et sp. indet.

Discussion

Habitable domain of Alatoconchidae: Previous analyses on the sedimentary facies and associated faunal composition suggested that the Guadalupian Iwaizaki limestone in the South Kitakami belt primarily has formed a patch reef system developed on a continental shelf under a tropical/subtropical climate (Kawamura and Machiyama, 1995; Shen and Kawamura, 1999), although no precise paleolatitudinal constraints were available, such as direct measurements of paleomagnetism. On the other hand, according to the occurrence of the Tethyan elements in Late Paleozoic fossil assemblages, e.g. ammonoids, rugose corals, fusulines, and giant gastropods (e.g. Ehiro, 1998; Isozaki and Kase, 2014; Asato *et al.*, 2016), the South Kitakami belt in NE Japan has been regarded to have been positioned, at least during the Permian, in a low-latitude domain, much closer to South China rather than North China, although some brachiopod fossils in part contend to support the proximity to North China (Tazawa, 1992). For clarifying this conundrum, the present finding of Alatoconchidae for the first time from NE Japan positively supports the paleobiogeographical connection to South China, and so does that from Primorye, Far East Russia. In good accordance with these notions, the concentrated occurrence of Alatoconchidae is restricted to the top 10 m-thick interval of Unit 8 with typical reef features (Fig. 2; Kawamura and Machiayma, 1995; Shen and Kawamura, 1999). Thus, the present findings provide a new piece of supporting evidence to the previous interpretation for the low-latitude origin of the Iwaizaki limestone.

By listing up all alatoconchid localities in the world, Isozaki and Aljinovic (2009) emphasized the following two common aspects of the occurrence of Alatoconchidae; i.e., 1) the intimate association with large-tested fusulines (e.g., *Neoschwagerina*, *Yabeina*, and *Lepidolina*) and rugose corals (e.g., *Waagenophyllum*), and 2) their common utilization of photo- and/or chemo-symbiosis in shallow marine, warm-water, oligotrophic environments in tropical domains, on the basis of almost the same fossil assemblage reported from the Cisuralian-Guadalupian limestones (Fig. 4); i.e., Malaysia (Runnegar and Gobbett, 1975), Thailand (Udchachon *et al.*, 2007), Myanmar (Kyi Pyar Aung and Isozaki, 2020), South China (Chen *et al.*, 2018), Afghanistan (Termier *et al.*, 1973), Iran (Thiele and Thicky, 1980), Oman (Pillevat, 1993), Croatia (Kochansky-Devide, 1978; Aljinovic *et al.*, 2008), and Tunisia (Boyd and Newell, 1979).

It is noteworthy that these occurrences are restricted mostly to the Tethyan domain, i.e., the well-known Permian warm–water pool mostly in low latitude domains (Fig. 4). In contrast, the alatoconchids from Akasaka, Neo, and Kamura in SW Japan (Ozaki, 1968; Yancey and Ozaki, 1980; Isozaki 2006; Asato *et al.*, 2017), Palawan in W. Philippines (Kiessling and Flugel, 2000), and the Kenai peninsula in Alaska (Blodgett and Isozaki, 2013) occur in Mesozoic accreted paleo-atoll complexes primarily developed on mid-oceanic seamounts like those in modern southern Pacific Ocean. The paleomagnetic data confirmed that the alatoconchid-bearing Permian limestone in Kamura, SW Japan, was deposited at 12°S (Kirschvink *et al.*, 2015), indicating the habitat for Alatoconchidae in low-latitude mid-oceanic paleoatolls. Those with similar assemblage in W. Philippines and Alaska are regarded to have derived likewise from the low-latitude mid-Panthalassa (Fig. 4). All available data to date, therefore, suggest that the Permian alatoconchids from 12 areas in the world have thrived all in tropical/subtropical domains mostly between paleolatitude less than 30°, as pointed out by Isozaki and Aljinovic (2009).

Pre-Japan Sea link between NE Japan and S. Primorye: The present finding of Alatoconchidae from the Capitanian shallow marine shelf carbonates from the two study sections, on the opposite sides of the Japan Sea, further adds a piece of sup-

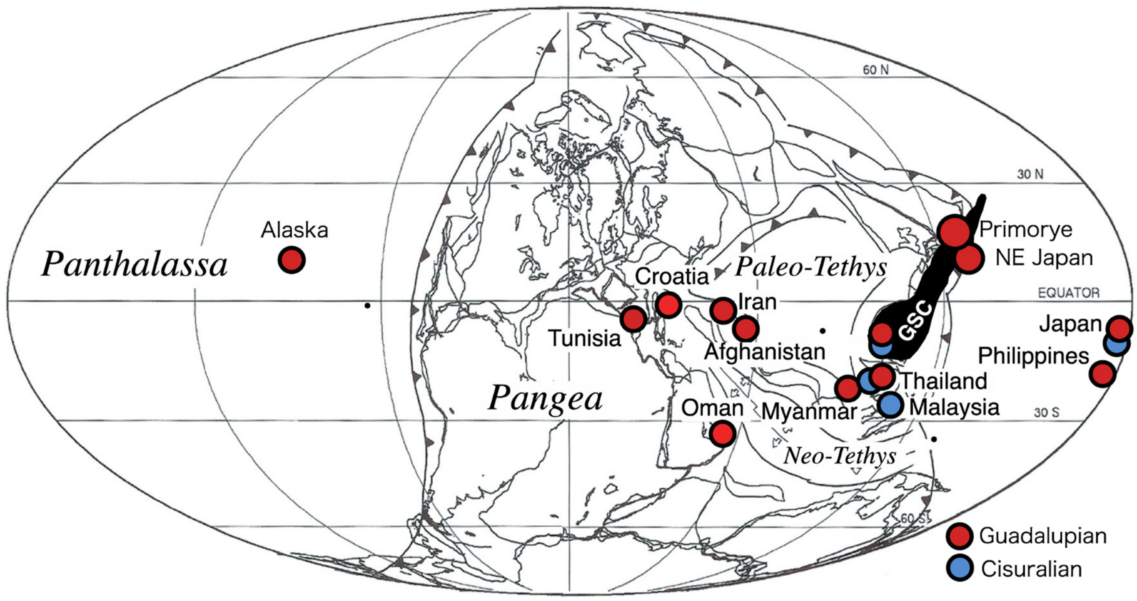

Fig. 4. World occurrence of Alatoconchidae during the Permian (modified from Isozaki & Aljinovic, 2009 with additional information by Udchachon *et al.*, 2008; Blodgett and Isozaki, 2015; Chen *et al.*, 2018; Kyi Pyar Aung and Isozaki, 2020; this study).
The new occurrences from NE Japan and S. Primorye are concordant with the previous view, that assumed their restricted habitat in low-latitude domains mostly in Paleo-Tethys and in the wide-open Panthalassa Ocean. Nonetheless, it is noteworthy that NE Japan and S. Primorye belonged to the northeastern segment of Greater South China (GSC: Isozaki, 2023), because these two areas mark the easternmost distribution of the warm-water Tethyan fauna along the western margin of Pangea. In contrast, those from SW Japan and Alaska were not along continental shelf of Pangea but in mid-Panthalassa paleo-atolls.

porting evidence for their primary geotectonic relation between the South Kitakami belt and Sergeevka belt (Fig. 1). Previously reported fossil lists from the two Permian sections indicate that almost the same fauna in fusulines and rugose corals occur (Morikawa *et al.*, 1960; Ueno *et al.*, 2005; Kossovaya and Kropatcheva, 2013). Alatoconchidae is a member of the Permian symbiotic tropical trio (Isozaki and Aljinovic, 2009), thus their occurrence appears crucial for the correlation, because the trio has a uniquely characteristic Tethyan fingerprint. It is noteworthy that other Permian sedimentary units on the west, i.e., the Laoelin–Grodekov belt in southern Primorye (Kotlyer *et al.*, 2006) and correlative ones in west-neighboring NE China and North Korea, in contrast, lack such typically Tethyan Alatoconchidae-bearing fossil assemblage.

The Permian strata in the South Kitakami and the Sergeevka belts also share almost the same Paleozoic basement rocks, and naturally they had common provenance for Paleozoic terrigenous clastics (Isozaki *et al.*, 2024, 2017). All these lines of evidence confirm the direct linkage between the South Kitakami and Sergeevka belts during the Permian prior to the Miocene opening of a back-arc basin (Japan Sea).

Paleobiogeographical implication of Alatoconchidae in northeastern GSC: On a regional context, the occurrence of Alatoconchidae from the NE Japan and Primorye provides the following geotectonic and paleogeographical implications. The Japanese Islands became tectonically separated from mainland Asia through the Japan Sea opening mostly during the Miocene (Fig. 1; Otofuji and Matsuda, 1986). Owing to this non-restorable large-scale reforming of pre-Miocene continental margin of Far East Asia, the origin of paleo-Japan was long left unsolved. Traditionally, the South Kitakami belt with thick Paleozoic fossiliferous strata was regarded to have been originally connected to the North China (Sino-Korean) block, mostly based on the apparent proximity at present. On the contrary, middle-late Paleozoic fossil assemblages of dominant Tethyan affinity suggest relatively intimate link to the South China (Yangtze) block (e.g., Ehiro, 1998), although some Permian fauna from South Kitakami and Sergeevka belts include Boreal elements, which were common in high-latitudes. To reconcile this apparent disagreement, Isozaki (2019) emphasized the physiological proximity between the North China and GSC already during the Permian, because their mutual collision/amalgamation occurred immediately after in the mid-Triassic.

The latest dating of U–Pb ages of numerous igneous and detrital zircons and associated provenance analyses in NE and SW Japan provided strong constraints to terminate this long-term conundrum on the origin not only of NE Japan but also of the entire Japanese Islands. Through the comparison of age composition of the basement crusts in the two China blocks and age spectra of zircons in Paleozoic rocks of Japan (Okawa et al, 2013; Isozaki *et al.*, 2014, 2015, 2017, 2021, 2023) confirmed that the proto-Japan, at least during the Paleozoic, had an intimate connection to South China, particularly to its eastern part called Cathaysia, rather than North China (Isozaki *et al.*, 2014, 2015). The same signature was reported also from the Devonian to Permian sandstones from the Sergeevka belt (Isozaki *et al.*, 2017). These indicate that Paleozoic South China block has extended northeastward into proto-Japan and proto-Khanka in southern Primorye to altogether form a larger continental block named GSC, which was nearly twice larger than the South China *per se* on the present continent (Isozaki, 2019, 2023).

The record of Alatoconchidae from the Sergeevka belt is relatively poor in quality with respect to that from the South Kitakami belt; nonetheless, it suggests that the habitat of the warm water-loving Permian large bivalves has once extended up into Permian Primorye. The Khanka block in Primorye (Fig. 1D) was previously explained as a detached continental fragment from the Siberian margin to the north (e.g. Wilde, 2015); however, the occurrence of the tropical trio with Alatoconchidae from Primorye supports their origin in GSC rather than the claimed origin in the Siberian block. Given the reconstruction of GSC (Isozaki, 2019), it is noteworthy in paleobiogeographical context that the northeastern tip of GSC was likely located even on the north of North China block during the Permian, where biota of the Boreal elements may have commonly arrived from the north.

Conclusions

The occurrence of Permian large bivalve fossil Alatoconchidae was detected for the first time from the South Kitakami belt, NE Japan, and also from the Sergeevka belt in southern Primorye, Far East Russia. These new findings lead the following conclusions.

1. In the top part of the Iwaizaki limestone in the South Kitakami belt, shell fragments of large bivalve form significant coquina beds, with the largest fragment over 40 cm long. Based on the large size, large aspect ratio between width and thickness, and uniquely tight bending of shells, these fossil bivalves are identified as Alatoconchidae gen et sp. indet. Bivalve shells of similar characteristics, much smaller and rarer though, were detected also in the coeval shallow marine limestone of the Chandalaz Fm in the Sergeevka belt, southern Primorye.
2. The correlation of Permian shallow marine carbonates of shelf facies between the South Kitakami and Sergeevka belts was confirmed by the common occurrence of the Tethyan tropical trio, which features bizarre but unique bivalve Alatoconchidae.
3. The occurrence of the unique Permian fossil assemblage from NE Japan and S. Primorye indicates that warm-water Tethyan environments under tropical/subtropical climates developed in the middle Permian continental margin in Far East Asia, almost at the eastern edge of Pangea.
4. The occurrence of the Alatoconchidae-bearing unique fauna indicates that the South Kitakami belt and Sergeevka belt had been located side-by-side along the Panthalassan (Paleo-Pacific) margin of the Permian GSC. This reconstruction concordantly agrees with the results of latest provenance analysis on Paleozoic terrigenous clastics in Japan and Primorye, Russia.

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