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Boreal molluscan records around the Jurassic–Cretaceous boundary in East Asia provide clues for the paleobiogeographical reconstruction in the mid-latitudes of the Northwest Pacific

SHIN-ICHI SANO

Graduate School of Science and Engineering for Research, University of Toyama, 3190 Gofuku, Toyama-Shi, Toyama 930-8555, Japan (E-mail: ssano@sus.u-toyama.ac.jp)

Abstract. **Studying marine paleobiogeographical conditions in the mid-latitudes of the Northwest Pacific around the Jurassic–Cretaceous boundary probably contributes to better understandings of the paleoclimatic and/or paleoenvironmental background of the evolution of the Late Mesozoic terrestrial ecosystem in East Asia. However, the uncertainty of paleogeography of the eastern margin of the Asian Continent has caused the difficulties for the paleobiogeographical discussion. In this paper, the strata containing Boreal faunal elements, *Buchia*, and cylindroteuthidid belemnites in East Asia (Far East Russia, Heilongjiang in northeastern China, and Japan) and their tectonic settings are reviewed.**

The Uda and Torom (northern Sikhote-Alin), Suibin (Heilongjiang), and Tetori (northern Central Japan) regions were located from north to south in the eastern margin of the already amalgamated Asian Continent around the Jurassic–Cretaceous boundary and can be considered the "fixed points for

paleobiogeographical reconstruction. On the other hand, ”*Buchia*-bearing strata in the Komsomolsk (northern Sikhote-Alin) and Dong’an (Heilongjiang) regions can be considered to be deposited in the fore-arc basin or trench slope basin on the accretionary complex along the East Asian continental margin. The stratum around the Jurassic–Cretaceous boundary in the Partizansk Basin (southern Sikhote-Alin) contains both *Buchia* and Tethyan ammonoids and was deposited on the Paleozoic continental basement or block (Sergeevka Belt). The paleo-position of these three regions around the Jurassic–Cretaceous boundary is highly debated.

The Tethyan–Pacific ammonoids, Boreal belemnites, and Tetori bivalve fauna, showing some similarities with those in the Boreal Realm and Early Cretaceous strata in Heilongjiang, are present in the late Tithonian–Berriasian Mitarai Formation of the Tetori Group in the Tetori Region. This stratum deposited in the eastern margin of the North China Block, provides evidence that the Boreal faunal elements reached the mid-latitudes of the Northwest Pacific. The position of the ecotone of the Boreal and Tethys realms in the Northwest Pacific can be discussed based on the comparison of the faunal elements among almost coeval strata in the Tetori Region (fixed point), the Sergeevka Belt, and the South Kitakami Belt (Pacific side of Northeast Japan), which is usually correlated with the Sergeevka Belt but contains only the Tethyan faunal elements. Further studies of the records of Tethyan and Boreal taxa in the “fixed points” and other localities could provide clues to reveal the paleoclimatic and/or paleoenvironmental background of the evolution of the terrestrial and marine ecosystems in East Asia around the Jurassic–Cretaceous boundary.

Key words: Boreal Realm, *Buchia*, cylindroteuthidid belemnites, East Asia, Jurassic–Cretaceous boundary, Tetori Group

Introduction

Recently, the discoveries of exceptionally well-preserved terrestrial fossils from northeastern China, called the Jehol (Early Cretaceous) and Yanliao (Middle to Late Jurassic) biotas, have attracted considerable attention in elucidating the evolution of the Late Mesozoic terrestrial ecosystem (e.g. Pan *et al*., 2013; Xu *et al*., 2016; Zhou and Wang, 2017). Because the paleobiogeographical differentiation in East Asia is suggested at least in the Early Cretaceous (e.g. Sano and Yabe, 2017), marine records in the mid-latitudes of the Northwest Pacific around the Jurassic–Cretaceous boundary are also important in revealing the paleoclimatic and/or paleoenvironmental background of the evolution of the terrestrial biota.

Marine strata around the Jurassic–Cretaceous boundary in Heilongjiang in northeastern China and in Sikhote-Alin in Far East Russia (Figure 1) have been correlated with the non-marine strata in northeastern China (e.g. Sha and Fürsich, 1993; Sey and Kalacheva, 1996; Kirillova and Kiriyanova, 2003; Sha, 2007; Sha *et al*., 2008, 2009; Kirillova *et al*., 2010; Li and Matsuoka, 2015; Wan *et al*., 2016). In previous studies, *Buchia* (the standard zonal index bivalve fossil in the Boreal Realm: e.g. Grey et al., 2008a, 2008b) is mainly used for the biostratigraphical age assignment of these strata (e.g. Urman *et al*., 2014) and overlaps its distribution with the Tethyan ammonoids at southern Sikhote-Alin, which represents the position of the biogeographical ecotone between the Boreal and Tethys realms (Zakharov *et al*., 1996;

Kirillova *et al*., 2000; Zakharov and Rogov, 2003).

The paleo-positions of each fossil locality in these studies are generally considered the same as their present positions; however, the large-scale displacement was often supposed to occur in the eastern margin of the Asian Continent in the Cretaceous (e.g. Yamakita and Otoh, 2000; Kemkin *et al*., 2016), Thus, as Zakharov and Rogov (2003) mentioned, the considerable uncertainty of paleogeographical reconstruction still exists, causing difficulties related to the paleobiogeographical discussion.

Boreal cylindroteuthidid belemnites have recently been recovered from the late Tithonian–Berriasian Mitarai Formation of the Tetori Group in northern Central Japan, representing additional evidence of the occurrence of the Boreal faunal element in East Asia (Sano *et al*., 2015, 2017). This stratum is deposited in the Hida Belt, which is generally considered the eastern margin of the North China Block before the Miocene opening of the Japan Sea (e.g. Takahashi *et al*., 2018). Thus, the Tetori Region can be considered the "fixed point for the paleobiogeographical reconstruction" in the eastern margin of the already amalgamated Asian Continent, providing concrete evidence that the typical Boreal fauna reached the mid-latitudes of the Northwest Pacific around the Jurassic–Cretaceous boundary.

In this paper, the occurrences of Boreal molluscan faunas in East Asia (Sikhote-Alin, Heilongjiang, and Japan) around the Jurassic–Cretaceous boundary are reviewed, focusing on the tectonic setting of the fossil-bearing strata. The recognition of the "fixed points for the paleobiogeographical reconstruction" in East Asia provides clues that reveal the southward migration of the Boreal taxa and the position of the biogeographical ecotone between the Boreal and Tethys realms in the Northwest Pacific around the Jurassic–Cretaceous boundary.

Recent advances in the depositional age and paleobiogeography of the Mitarai Formation of the Tetori Group

The Tetori Group (Oishi, 1933) is the Late Jurassic–Early Cretaceous siliciclastic stratum sporadically distributed in northern Central Japan (e.g. Maeda, 1961; Sano, 2015; Yamada and Sano, 2018) (Figure 2). Most continuous sequences of the Tetori Group can be observed in the Shokawa area and are divided into eight formations, Ushimaru, Akahoke, Mitarai, Otaniyama, Okurodani, Amagodani, Okura, and Bessandani formations, in ascending order (Maeda, 1952). Among them, marine horizons are recognized only in the Mitarai and Otaniyama formations (Maeda, 1952; Matsukawa and Nakada, 1999; Kumon and Umezawa, 2001; Yamashita *et al*., 2011). The Mitarai Formation is about 50 m in thickness and is mainly composed of black shale (Matsukawa and Nakada, 1999; Kumon and Umezawa, 2001).

Diversified marine invertebrate fossils have been described from the Mitarai Formation (Hayami, 1959a, b, 1960; Sato and Kanie, 1963; Komatsu *et al*., 2001; Sato *et al*., 2003, 2008; Kato and Karasawa, 2006; Nomura and Shimizu, 2008; Hunter *et al*., 2011; Sha and Hirano, 2012; Yano, 2012; Sano *et al*., 2015; Koarai and Matsukawa, 2016; Table 1). Because the systematic revision of each taxon is beyond the scope of this paper, its taxonomic assignment in recent papers is generally accepted.

Revision of the depositional age of the Mitarai Formation

Previous age assignment (Callovian) of the Mitarai Formation was based on a single incomplete ammonoid specimen (Sato and Kanie, 1963); however, Sato *et al*. (2003, 2008) described several ammonoid species, such as *Partsciceras* cf. *otokense*, *Lytoceras* sp., *Delphinella* cf. *obtusinodosa, Berriasella* sp., and *Neocosmoceras* sp., from the same formation and revised its age as the Berriasian, mainly based on the occurrence of *Neocosmoceras*. Recently, Yamada (2017) pointed out that because *Neocosmoceras* was also recognized in the late Tithonian *Himalayites* assemblage in the Himalaya Region (Pandey *et al*., 2013), the Mitarai Formation should be assigned to the Tithonian or Berriasian.

Sha and Hirano (2012) recognized four marine bivalve species of the Mitarai Formation: *Palaeonucula makitoensis*, *Entolium inequivalve*, *Thracia shokawensis*, and *Pleuromya hidensis*, which are cospecific with the Middle Barremian–Aptian strata in Heilongjiang, northeastern China. Regarding the numerical age data of the Mitarai Formation in Kusuhashi *et al*. (2006), they discussed the age of the Mitarai Formation as the Barremian–Aptian; however, *Pa*. *makitoensis*, *E*. *inequivalve*, and a comparable form of *T*. *shokawaensis* also occur in the Magawa and Kiritani formations, which are partly composed of the Oxfordian marine sediments discussed by Yamada and Sano (2018) in the northeastern part of the Tetori Region (Jinzu Geological Region) (Hayami, 1961; Koarai and Matsukawa, 2016). *Thracia shokawaensis* is also found in the Inagoe Formation of the Tetori Group (Matsukawa and Fukui, 2009; Koarai and Matsukawa, 2016; Matsukawa and Koarai, 2017). Ammonoid assemblages of the Mitarai and late Hauterivian Inagoe formations of the Tetori Group, and the Oxfordian marine sediments (the Arimine and Kiritani formations) in the northeastern part of the Tetori Region are remarkably distinct from one another (e.g. Sato *et al*., 2003, 2008; Matsukawa and Fukui, 2009; Sato and Yamada, 2014). Thus, the biostratigraphic value of these marine bivalves is still ambiguous (Matsukawa and Koarai, 2017), and the age assignment of the Mitarai Formation based on bivalves is not adopted here.

The occurrence of the cylindroteuthidid belemnites *Cylindroteuthis* aff.

knoxvillensis and *Arctoteuthis tehamaensis* was recently reported in the Mitarai Formation (Sano *et al*., 2015, 2017). *Cylindroteuthis knoxvillensis* and *A. tehamaensis* are important zonal index fossils of the Berriasian or the Upper Vogian to Ryazanian in northern California and northern Siberia (Dzyuba, 2010, 2012; Figure 3). Further systematic studies of these belemnites would likely provide additional information on the age assignment of the Mitarai Formation.

Kusuhashi *et al*. (2006) reported the zircon LA-ICPMS U–Pb age of tuffs in the Mitarai Formation to be 130.0 ± 1.7 Ma and 129.8 ±1.0 Ma (the errors of Kusuhashi *et al*. [2006] represent 2 SE), and thus there is a large discrepancy between ammonoid biostratigraphy and the numerical age data. A recent reinvestigation of the zircon LA-ICPMS U–Pb age of the tuff in the Okurodani Formation indicated it was 129.2 ± 0.7 Ma (the error represents 2σ) (Nagata *et al*., 2019). This data corresponds well with the two age data sets of the Okurodani Formation reported in Kusuhashi *et al*. (2006) of 132.9 ± 0.9 Ma and 131.4 ± 0.9 Ma but not with another datum in the same paper: 117.5 ± 0.7 Ma. Thus, the age of the Mitarai Formation (below the Okurodani Formation) should be much older than ca. 129 Ma, and the discussion of the depositional age of the Tetori Group in Kusuhashi *et al*. (2006) needs revision.

In summary, the depositional age of the Mitarai Formation can be considered broadly as the late Tithonian to Berriasian at present (Figure 3). The Jurassic–Cretaceous boundary is believed to be present in the Mitarai Formation or in underlying formations of the Tetori Group in the Shokawa area.

Molluscan paleobiogeography of the Mitarai Formation

Hayami (1961, 1962) pointed out that some bivalve species from the Mitarai Formation show a close similarity with those in the Boreal Realm, and the Tetori bivalve fauna is distinct from coeval Torinosu fauna, which contains Tethyan faunal elements, on the Pacific side of Japan. In addition, as mentioned, Sha and Hirano (2012) discussed the remarkable similarity of bivalve assemblages between the Mitarai Formation and the Middle Barremian–Aptian strata in Heilongjiang, northeastern China; however, Hayami (1987, 1990) argued that Japan belonged to a distinct marine faunal province—the East Asian Province—separated from the Boreal and Ethiopian (= Tethyan) realms in the Jurassic due to the abundance of endemic genera to this region and to the absence of typical Boreal genera, such as *Buchia*.

Recently, Matsukawa and Koarai (2017) discussed the similarity of bivalve genera among the Mitarai Formation, Early Jurassic strata in Thailand, and Early Cretaceous strata in Heilongjiang and concluded that the Tetori Region was influenced by both northerly (from the equatorial region) and southerly (from higher latitudes) oceanic currents around the Jurassic–Cretaceous boundary, which is contrary to Hayami’s opinion that the Tetori bivalve fauna show distinct similarities with those of the Boreal Realm and not with those of the Tethyan Realm; however, according to the comparison between Matsukawa and Koarai (2017; p. 154, fig. 12) and Table 1, common genera between the Mitarai Formation and the Early Jurassic strata in Thailand include seven genera: *Modiolus*, *Oxytoma*, *Entolium*, *Camptonectes*, *Protocardia*, *Homomya*, and *Thracia*. Those between the Mitarai Formation and the Early Cretaceous strata in Heilongjiang include ten genera: *Palaeonucula*, *Palaeonelio*, *Brachidontes*, *Modiolus*, *Entolium*, *Camptonectes*, *Chlamys*, *Limatula*, *Goniomya*, and *Thracia*. Among seven common genera between the Mitarai Formation and the Early Jurassic strata in Thailand, there are four genera: *Modiolus*, *Entolium*, *Camptonectes*, and *Thracia* are common elements among the three regions. A similar form of *Oxytoma tetoriensis* was described from the *Buchia*-bearing Berriasian part of the Dong’anzhen

Formation in Dong'an, Heilongjiang (Sha and Fürsich, 1994). *Homomya* is also common in the Lower Jurassic in Siberia (e.g. Meledina *et al*., 2005). Furthermore, Koarai and Matsukawa (2016) questioned the assignment of *Protocardia* sp. from the Mitarai Formation (Hayami, 1959b) to this genus. Thus, the purported similarity of the bivalve genera between the Tetori Region and Southeast Asia can be explained by their cosmopolitan distribution, and the northerly oceanic current is not necessary to explain such a distributional pattern. On the contrary, nine genera among 16 genera described by Hayami (1959a, 1959b, 1960) and one additional genus are common between the Mitarai Formation and the Early Cretaceous strata in Heilongjiang, reinforcing Hayami's (1961, 1962) paleobiogeographical view of the Tetori bivalve fauna.

The paleobiogeographic importance of the similarity of the bivalve faunas between the Tetori Region and other regions requires further confirmation, considering the presence or absence of characteristic genera of each biogeographic realm (e.g. Hallam, 1977). Comparisons with other Japanese records, such as those of Early Jurassic Toyora and Kuruma groups in the Inner Zone (Japan Sea side) of Southwest Japan, those in the Jurassic strata in the South Kitakami Belt on the Pacific side of Northeast Japan, and those of Late Jurassic–Early Cretaceous strata in the Outer Zone (Pacific side) of Southwest Japan, are also necessary.

The faunal composition of ammonoids in the Mitarai Formation clearly shows the Tethyan–Pacific affinity, as with coeval ammonoid fauna in the South Kitakami Belt (Sato *et al*., 2003, 2008, 2011; Sato and Taketani, 2008; Taketani, 2013). On the contrary, the recent discovery of cylindroteuthidid belemnites, *Cylindroteuthis* aff. *knoxvillensis* and *Arctoteuthis tehamaensis*, from the same formation clearly indicates that typical Boreal belemnites migrated into the Tetori Region (Sano *et al*., 2015, 2017).

In summary, the Tetori moluscan fauna shows the Tethyan–Pacific affinity in ammonoids, the Boreal affinity in belemnites, and the presence of the distinct marine faunal province, the East Asian Province, in bivalves, though some similarities with the bivalves in the Boreal Realm are recognized. Thus, the Tetori Region was probably located within the ecotone of mollusks between the Boreal and Tethys realms around the Jurassic–Cretaceous boundary.

Boreal faunal records in East Asia and their tectonic settings

To elucidate the paleobiogeographical conditions around the Jurassic–Cretaceous boundary, the strata containing Boreal faunal elements, *Buchia*, and cylindroteuthidid belemnites in East Asia (Far East Russia, Heilongjiang in northeastern China, and Japan) and their tectonic settings are briefly reviewed (Figures 1, 4). A coeval shallow marine stratum in the South Kitakami Belt, Northeast Japan, is also reviewed to discuss the position of the ecotone between the Boreal and Tethys realms.

Far East Russia

Marine sequences around the Jurassic–Cretaceous boundary in Far East Russia are recognized in the Uda, Torom, and Partizansk basins and also in the Sikhote-Alin accretionary complex (Kirillova and Kiriyanova, 2003; Kirillova *et al*., 2010; Kirillova, 2018). These strata contain abundant *Buchia* species and are assigned to the Late Jurassic to Berriasian. A recent study in the Komsomolsk Section in the northern part of the Sikhote-Alin accretionary complex established *Buchia* biostratigraphy in this region, which can directly correspond to the standard *Buchia* zonal scales (Urman *et al*., 2014; Figure 3). Because the necessity of a careful consideration of the *Buchia* biostratigraphy of other sections in Far East Russia was also pointed out by Urman *et al*. (2014), the detailed ages or *Buchia* zones in other sections are not discussed here.

Kirillova *et al*. (2002) stated that marine sequences in the Komsomolsk Section deposited in the fore-arc basin in the Sikhote-Alin accretionary complex along the East Asian continental margin. The Uda and Torom basins are located in the north of the Mongol–Okhotsk suture and were developed as syn-collisional basins or post-collision troughs along the Mongol–Okhotsk suture zone (Kirillova, 2003; Guo *et al*., 2017).

The Partizansk Basin has been considered the most important region to discuss the paleobiogeography in East Asia around the Jurassic–Cretaceous boundary because both *Buchia* and Tethyan ammonoids, including the zonal index species of the basal Berriasian, *Berriasella jacobi*, occur there (e.g. Sey and Kalacheva, 1996, 1999); however, a recent thorough revision of *Berriasella jacobi* around the world (Frau *et al*., 2016) suggested that purported *B. jacobi* from the Partizansk Basin is not true *B. jacobi*, and the age assignment as the Early Berriasian based on this species needs revision. The Partizansk Basin is located in the Sergeevka Belt, which is composed of Early to Middle Paleozoic igneous, plutonic, and metamorphic rocks and non-marine to shallow marine Paleozoic to Mesozoic sedimentary rocks, and can be considered the Paleozoic continental basement or block, possibly correlated with the South Kitakami Belt in Northeast Japan (e.g. Yamakita and Otoh, 1999; Isozaki *et al*., 2017).

Heilongjiang, northeastern China

The marine sequences around the Jurassic–Cretaceous boundary, containing abundant *Buchia*, are also known in the Suibin and Dong’an regions, Heilongjiang, northeastern China (e.g. Sha *et al*., 2006, 2008; Sha, 2007). The sequences in the Suibin Region are assigned to the Callovian to Berriasian in age, and those in the Dong’an

Region to the Middle Volgian (Tithonian) to Valanginian based on the biostratigraphy of *Buchia* and dinoflagellate cyst assemblages (Sha *et al*., 2006; Figure 3).

Marine Jurassic–Cretaceous stratum in the Suibin Region are recognized only in the boreholes (Sha, 2007) and unconformably overlies the Proterozoic or Permian basement (Sha *et al*., 2009). In the Dong'an Region, marine stratum shows a narrow distribution, and its basement is not exposed (Sha, 2007). Based on a comparison with the map of tectonic units in the eastern Central Asian Orogenic Belt (Wilde, 2015), the former belongs to the Jiamusi Block, and the latter likely belongs to the Sikhote-Alin accretionary complex (=Nadanhada Terrane), which is possibly the southwestern extension of that of the Komsomolsk Region. The depositional ages of the *Buchia*-bearing strata in the Dong'an and Komsomolsk regions are also concordant with one another (Figure 3). Thus, marine strata in the Dong'an Region can be considered to be deposited in the fore-arc basin or trench slope basin on the accretionary complex along the East Asian continental margin, as with that in the Komsomolsk Region (e.g. Sun *et al*., 2015; Li *et al*., 2019). On the contrary, the *Buchia*-bearing strata in the Suibin and Dong'an regions have different tectonic settings and possibly different paleogeographic positions around the Jurassic–Cretaceous boundary. Thus, in the paleobiogeographic reconstruction, two regions should be discussed separately.

Japan

The purported *Buchia* record from eastern Hokkaido (*Aucella* spp. in Kuroda and Teraoka [1964]) has been referred to in articles that discuss the worldwide distribution of this Boreal bivalve genus (e.g. Zakharov, 1981; Zakharov and Rogov, 2003); however, a subsequent study has revealed that these bivalve specimens do not belong to the Buchiidae but to the latest Cretaceous *Tenuipteria* (Obata *et al*., 1993), and thus any occurrences of *Buchia* are not known in Japan at present.

Typical Boreal fauna (cylindroteuthidid belemnites) around the Jurassic–Cretaceous boundary occurs only in the Mitarai Formation of the Tetori Group in Japan (Sano *et al*., 2015, 2017). It should be noted that the supposed depositional age of the Mitarai Formation is almost the same as that of *Buchia*-bearing strata in the Komsomolsk, Dong'an, and Suibin regions according to their correlation with the standard *Buchia* and belemnite zonations in northern Siberia (Figure 3). The Tetori Group is distributed in the Hida Belt (Sano, 2015), which is generally considered the eastern margin of the North China Block before the Miocene opening of the Japan Sea (e.g. Jin and Ishiwatari, 1997; Arakawa *et al*., 2000; Kim *et al*., 2007; Takahashi *et al*., 2018; Takehara and Horie, 2019).

Almost coeval shallow marine strata, such as the Koyamada Formation of the Somanakamura Group, in the South Kitakami Belt contain the Tethyan–Pacific ammonoids and the Tethyan belemnite *Hibolithes* spp. (e.g. Sato and Taketani, 2008; Sato *et al*., 2011; Li *et al*., 2015; Sano *et al*., 2015). Furthermore, the bivalve fauna of the Somanakamura Group is distinct from the Tetori bivalve fauna and contains some Tethyan faunal elements (Hayami, 1961, 1962; Sano *et al*., 2010a). Even the reefal limestone (the Koike Limestone Member) occurs in the Nakanosawa Formation underlying the Koyamada Formation (e.g. Mori, 1963; Kiyama and Iryu, 1998; Kakizaki and Kano, 2009). The South Kitakami Belt is considered the Paleozoic continental basement or block, which is composed of Early to Middle Paleozoic igneous, plutonic, and metamorphic rocks and non-marine to shallow marine Paleozoic to Mesozoic sedimentary rocks (e.g. Ehiro *et al*., 2016), which are likely correlated with the Sergeevka Belt in Far East Russia.

Paleogeographical relationships among the localities of the Boreal taxa

The Jurassic is the period of the final stage of the amalgamation of the Central Asian Orogenic Belt (Wilde, 2015). The final amalgamation of the Khanka/Jamusi Block with the Songliao and North China blocks probably occurred in 210–180 Ma (e.g. Wilde, 2015; Zhou and Li, 2017). The timing of the closure of the eastern Mongol–Okhotsk Ocean is still debated but has recently been considered to be the earliest Cretaceous (Guo *et al*., 2017). Because the Uda and Torom, Suibin, and Tetori regions are located in the north of Mongol–Okhotsk suture, the Jiamusi Block and the North China Block, respectively, their north–south oriented geographical relationship was probably almost the same as the present relationship.

The Partizansk and Soma-Nakamura regions belong to the Sergeevka and South Kitakami belts, respectively, for both of which the similarity with the South China Block is frequently discussed (e.g. Isozaki *et al*., 2014, 2017); however, the paleo-position of these belts around the Jurassic–Cretaceous boundary is highly debated. For example, their geographical relationship with North China Block is almost the same as the present one in Isozaki *et al*. (2017), whereas these belts were supposed to be located further south, possibly in the south of the present Korean Peninsula according to Kemkin *et al*. (2016).

The Komsomolsk and Dong'an regions are probably located in the Sikhote-Alin accretionary complex (including the Nadanhada Terrane), the western part of which has been frequently correlated with the Mino Belt in Central Japan (e.g. Kojima, 1989; Yamakita and Otoh, 1999). The large-scale sinistral displacement was supposed to occur in the eastern margin of the Asian Continent in the Early Cretaceous (Kemkin *et al*., 2016). Furthermore, sinistral cataclasite zones were recognized in the northern marginal part (innermost and continental side) of the Mino Belt (e.g. Sasaki *et* *al*., 2001). Thus, the two regions were possibly located in more southern positions than the current positions, though their paleo-latitudes are difficult to determine at present.

Marine molluscan paleobiogeography in East Asia around the Jurassic–Cretaceous boundary

In previous studies discussing on the southward migration of Boreal taxa and the position of the biogeographical ecotone between the Boreal and Tethys realms in the eastern margin of the Asian Continent, the paleo-positions of each fossil locality were insufficiently considered (e.g. Zakharov *et al*., 1996; Kirillova *et al*., 2000; Zakharov and Rogov, 2003). In this chapter, according to the discussion on paleogeographical relationships among fossil localities in the previous chapter, the distribution of the Boreal taxa in the mid-latitudes of the Northwest Pacific is discussed for future paleobiogeographical reconstruction.

Southward migration of the Boreal fauna in the Northwest Pacific around the Jurassic–Cretaceous boundary

The southernmost occurrences of cylindroteuthidid belemnites and *Buchia* in the Northwest Pacific around Jurassic–Cretaceous boundary are the focus of this chapter.

The definite record of the cylindroteuthidid belemnites around Jurassic–Cretaceous boundary is recognized only in the Tetori Region among the studied areas, though those of *Cylindroteuthis* and *Pachyteuthis* from the Kimmeridgian in the Torom Basin were mentioned by Kirillova and Kiriyanova (2003). Because the Tetori Region is probably located in the eastern margin of the North China Block, it is revealed that cylindroteuthidid belemnites could migrate into the mid-latitudes of the Northwest Pacific, which is more southward than previously believed (e.g. Doyle, 1987; Zell *et al*., 2013).

The *Buchia* records have been recognized in the Uda and Torom, Komsomolsk, Partizansk regions in Sikhote-Alin, Suibin, and Dong'an regions in Heilongjiang. The paleo-positions of the Uda and Torom and the Suibin regions around the Jurassic–Cretaceous boundary are well-established in the already amalgamated Asian Continent, whereas those of the Partizansk (Sergeevka Belt), Komsomolsk, and Dong'an (Sikhote-Alin accretionary complex) regions are still highly controversial, as discussed in the previous chapter; however, the Komsomolsk and Dong'an regions were probably situated more south than the present location. Even the Partizansk Region, which represents the southernmost occurrence of this bivalve genus in the Northwest Pacific at present, was also possibly located in a more southerly position. Thus, it is supposed that *Buchia* could migrate into the mid-latitudes of the Northwest Pacific, as with cylindroteuthidid belemnites, though the paleo-latitude of the southern limit of its distribution is difficult to determine at present.

It is intriguing that *Buchia* does not occur in Japan, even in the Tetori Region, where typical Boreal cylindroteuthidid belemnites have been recognized. If the Tetori Region was located to the south of the Partizansk Region, the southern limit of the distribution of *Buchia* was located between the latitudes of the Tetori and Partizansk regions, and cylindroteuthidids migrated further south than *Buchia*, though in the Northeast Pacific, both *Buchia* and cylindroteuthidids migrated further south into northeastern Mexico through northern California and mixed with the Tethyan faunal elements there (e.g. Zell *et al*., 2013, 2016, 2019; Zell and Stinnesbeck, 2015). In the opposite case, the Tetori Region was located to the north of the Partizansk Region, and

Buchia could have migrated more south than cylindroteuthidid belemnites, at least in the Northwest Pacific.

In the latter case, another explanation is necessary for the absence of *Buchia* in the Tetori Region. This scenario could be related to the possibility that the depositional environments or lithofacies in the Mitarai Formation are not suitable for the life and/or preservation of *Buchia*. It was already discussed that the absence of cylindroteuthidid belemnites in the Komsomolsk Section can be explained by a too-deep depositional environment for belemnite inhabitation (Urman *et al*., 2014). Their absence in other regions in Sikhote-Alin and Heilongjiang also can be explained by the lack of suitable depositional environments or lithofacies for the life and/or preservation of belemnites. Similar but opposite explanations can be applied to the absence of *Buchia* in the Tetori Group.

It should be noted that in the South Kitakami Belt, which is possibly correlated with the Sergeevka Belt and is generally positioned in the south to the Sergeevka Belt in almost all paleogeographical reconstructions (e.g. Yamakita and Otoh, 2000; Kemkin *et al*., 2016; Isozaki *et al*., 2017), the Tethyan–Pacific ammonoids, Tethyan belemnites and bivalves, and even reefal limestone are present, and no Boreal taxon has been found. Thus, it is likely that the Boreal taxa probably could not reach the paleo-latitude of the South Kitakami Belt.

As mentioned, ammonoids showing the Tethyan affinity also occur in the Tetori and Partizansk regions with Boreal faunas. Thus, the position of the biogeographical ecotone between the Boreal and Tethys realms in the Northwest Pacific is probably located north to the paleo-latitude of the South Kitakami Region and covers those of the Tetori and Partizansk regions at that time. Although the exact geographical positions of the South Kitakami and Sergeevka belts have not yet been determined, the paleo-position of the Tetori Region in the North China Block provides clues that elucidate the paleogeography and paleobiogeography in the mid-latitudes of the Northwest Pacific.

The ongoing debates of paleogeographical reconstruction in the eastern margin of the Asian Continent usually cause unavoidable difficulties for paleobiogeographical discussions regarding the Northwest Pacific; however, the north–south oriented geographical relationship among the Uda and Torom, Suibin, and Tetori regions in the already amalgamated Asian Continent is safely reconstructed. These regions, where the occurrences of the Boreal taxa are recognized, can be considered the “fixed points for paleobiogeographical reconstruction.” Further studies of the records of Tethyan and Boreal taxa, not only mollusks but also radiolarians and other fossils, in the “fixed points” and other localities provide clues that could reveal the paleoclimatic and paleoenvironmental background of the evolution of the terrestrial and marine ecosystems in East Asia around the Jurassic–Cretaceous boundary.

Concluding remarks

The Tethyan–Pacific ammonoids, Boreal belemnites, and Tetori bivalve fauna, showing some similarities with those in the Boreal Realm and Early Cretaceous strata in Heilongjiang, are present in the late Tithonian–Berriasian Mitarai Formation of the Tetori Group in northern Central Japan. This stratum deposited in the Hida Belt, which is located in the eastern margin of the North China Block, provides evidence that the Boreal faunal elements reached the mid-latitudes of the Northwest Pacific.

The tectonic settings of the *Buchia*-bearing strata around the Jurassic–Cretaceous boundary in Sikhote-Alin (Far East Russia) and Heilongjiang (northeastern China) have been reviewed. It has been revealed that the Uda and Torom (northern Sikhote-Alin), Suibin (Heilongjiang), and Tetori regions were located from north to south in the eastern margin of the already amalgamated Asian Continent and can be considered the "fixed points for paleobiogeographical reconstruction" around the Jurassic–Cretaceous boundary.

Buchia-bearing strata in the Komsomolsk (northern Sikhote-Alin) and Dong'an (Heilongjiang) regions can be considered to be deposited in the fore-arc basin or trench slope basin on the accretionary complex along the East Asian continental margin. The stratum around the Jurassic–Cretaceous boundary in the Partizansk Basin (southern Sikhote-Alin) contains both *Buchia* and Tethyan ammonoids and was deposited on the Paleozoic continental basement or block (Sergeevka Belt). The paleo-position of these three regions around the Jurassic–Cretaceous boundary is highly debated, causing unavoidable difficulties related to the paleobiogeographical discussion of the Northwest Pacific.

However, the position of the ecotone of the Boreal and Tethys realms in the Northwest Pacific can be discussed based on the comparison of the faunal elements among almost coeval strata in the Tetori Region (fixed point), the Sergeevka Belt, and the South Kitakami Belt (Pacific side of Northeast Japan), which is usually correlated with the Sergeevka Belt but contains only the Tethyan faunal elements. Further studies of the records of Tethyan and Boreal taxa in the "fixed points" and other localities could provide clues to reveal the paleoclimatic and/or paleoenvironmental background of the evolution of the terrestrial and marine ecosystems in East Asia around the Jurassic–Cretaceous boundary.

It should be noted that Boreal molluscan faunal elements have been found not only in the late Tithonian–Berriasian Mitarai Formation but also in the Early to Middle

Jurassic strata in Japan. The Boreal belemnite *Cylindroteuthis* also occurs in the Late Bathonian–Early Callovian Kaizara Formation of the Kuzuryu Group in the Tetori Region (Sano *et al*., 2010b). Boreal ammonoid *Kepplerites* species were described from the same formation and also from the Middle Jurassic strata in the South Kitakami Belt (Kobayashi, 1947; Sato, 1960; Takahashi, 1969; Handa *et al*., 2014).

Another Boreal ammonoid, *Amaltheus*, occurs in the Pliensbachian of the Toyora and Kuruma groups in the Inner Zone of Southwest Japan (Sato, 1955, 1960; Hirano, 1971; Nakada, 2011). Boreal bivalves, such as *Retroceramus* spp., *Kolymonectes staeschei*, and *Palmoxytoma cygnipes*, have been known to exist in the Early–early Middle Jurassic strata in the Inner Zone of Southwest Japan (i.e. the Toyora, Higuchi and Kuruma groups) and the South Kitakami Belt (Hayami, 1960, 1962, 1990; Hirano, 1973; Nagata *et al*., 2015).

Thus, Boreal faunal elements could have likely migrated, at least intermittently, to Japan for almost the whole Jurassic Period. Based on the recognition of accurate tectonic settings of the strata containing Boreal faunal elements and possible “fixed points for paleobiogeographical reconstruction”, Japanese records provide clues regarding the paleobiogeographical reconstruction in the mid-latitudes of the Northwest Pacific and/or East Asia at that time.

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Figure and Table captions

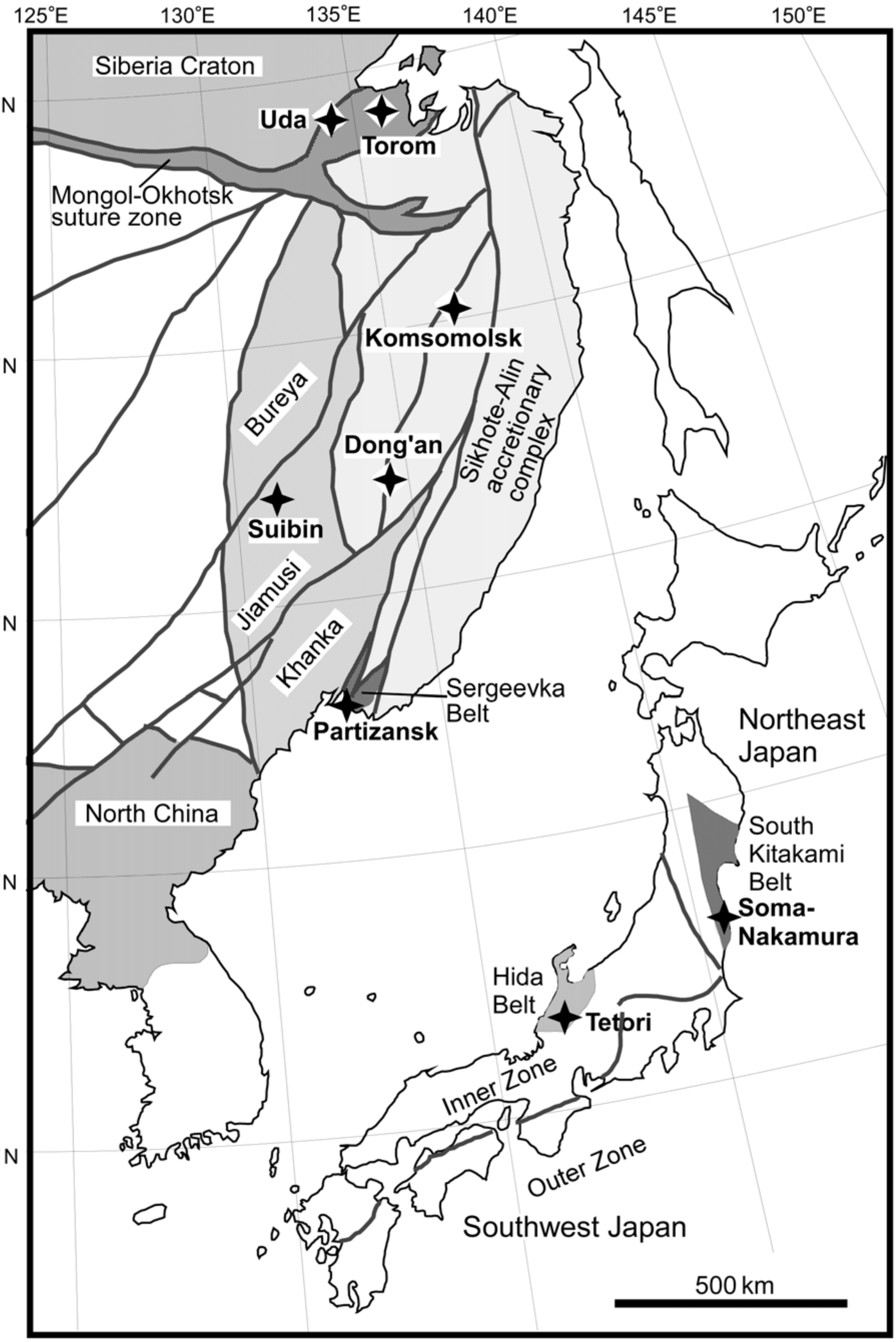
Figure 1. Map of the surveyed regions in East Asia where Boreal and/or Tethyan mollusks around the Jurassic–Cretaceous boundary occur. Major tectonic units (craton/continental blocks, tectonic belts, and accretionary complex) mentioned in this paper are shown. Bold lines represent the sutures dividing tectonic units in Far East Russia, northeastern China and Japan. Base map is modified from Tang et al. (2016) and Kemkin et al. (2016).

Figure 2. Index map showing the Shokawa area in the Tetori Region, northern Central Japan. Late Mesozoic strata are composed of the Kuzuryu and Tetori groups and Oxfordian marine sediments (see Yamada and Sano [2018] for details). Their distribution is modified from Maeda (1961) and Fujita (2003).

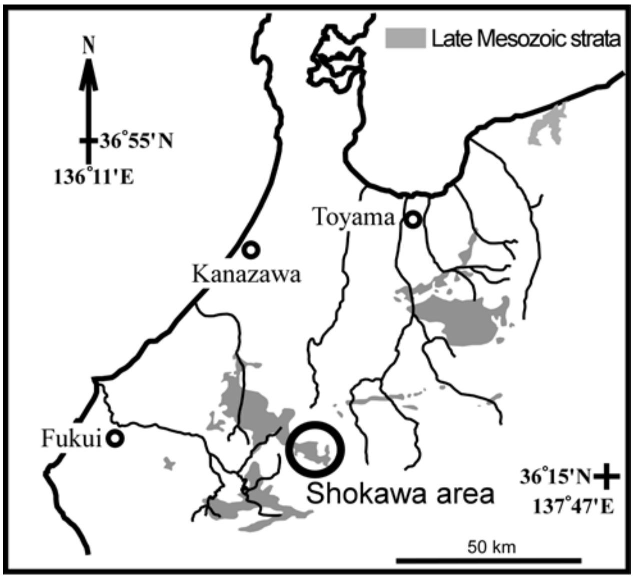
Figure 3. Correlation of the *Buchia* zonation around the Jurassic–Cretaceous boundary in selected regions in East Asia with the standard *Buchia* and belemnite zonations in northern Siberia. Note that the supposed depositional age of the Mitarai Formation is almost the same as that of *Buchia*-bearing strata in the Komsomolsk, Dong'an, and Suibin regions.

Figure 4. Boreal and Tethyan molluscan records in selected regions in East Asia.

Table 1. Animal fossils described or figured in previous articles from the late Tithonian–Berriasian Mitarai Formation of the Tetori Group in northern Central Japan.



125°E
130°E
135°E
140°E
145°E
150°E
55°N
50°N
45°N
40°N
35°N
Siberia Craton
Uda
Torom
Mongol-Okhotsk
suture zone
Komsomolsk
Bureya
Sikhote-Alin
accretionary
complex
Dong'an
Suibin
Jiamusi
Khanka
Sergeevka
Belt
Partizansk
North China
Northeast
Japan
South
Kitakami
Belt
Soma-
Nakamura
Hida
Belt
Tetori
Inner Zone
Outer Zone
Southwest Japan
500 km



Late Mesozoic strata
N
36°55'N
136°11'E
Toyama
Kanazawa
Fukui
Shokawa area
36°15'N
137°47'E
50 km

Tethayn stage	Boreal stage	Northern Siberia (standard *Buchia* zonation) Zakharov (1981)	Northern Siberia (standard belemnite zonation) Dzyuba (2012)	Suibin, NE China Sha and Fürsich (1993) Sha et al. (2006)	Dong'an. NE China Sha and Fürsich (1993) Sha et al. (2006)	Komsomolsk, Far-East Russia Urman et al. (2014)	Remarks
Lower Valanginian	Lower Valanginian	*B. keyserlingi*				*B. keyserlingi* *B. inflata*	
		B. inflata			*B. pacifica*		
Berriasian	Ryazanian	*B. volgensis*: *B. tolmatshowi*			*B. volgensis* *B.* cf.*subokensis* *B.* cf.*okensis* *B. unschensis*	*B. volgensis*	Age of the Mitarai Formation has not been finely tuned yet, but probably assigned to somewhere within this range, because of the occurrences of age-diagnostic fossils: *Neocosmoceras* sp., *Cylindroteuthis* aff. *knoxvillensis*, and *Arctoteuthis tehamaensis* (Sato et al., 2008; Sano et al., 2015, 2017).
		B. volgensis: *B. jasikovi*	*Cylindroteuthis knoxvillensis*				
		B. volgensis: *B. okensis*					
		B. unschensis	*A. tehamaensis*	(*B. fischeriana*)	*B. fischeriana* *B. unschensis*	*B. unschensis* *B. terebratuloides*	
Tithonian	Upper Volgian	*B. obliqua*	*Lagonibelus napaensis*			*B. terebratuloides*	
	Middle Volgian	? *B. taimyrensis*		*B.* cf.*mosquensis* *B.* cf.*rugosa* (*B.* ex.gr. *russiensis* *B.* ex.gr. *taimyrensis*)	*B. russiensis* *B. fischeriana*		
		B. russiensis					
	Lower Volgian	*B. rugosa*					
		B. mosquensis					

Region	Basement	*Buchia*	Boreal belemnites	Tethyan belemnites	Tethyan–Pacific ammonoids	reefal limstones
Uda* and Torom*	Mongol–Okhotsk Suture Zone	present	absent	absent	absent	absent
Komsomolsk	Fore-arc basin? on accretionary complex	present	absent	absent	absent	absent
Dong'an	Fore-arc basin? on accretionary complex	present	absent	absent	absent	absent
Suibin*	Jiamusi Block	present	absent	absent	absent	absent
Partizansk	Sergeevka Belt	present	absent	absent	present	absent
Tetori*	Hida Belt (North China Block)	absent	present	absent	present	absent
Soma-Nakamura	South Kitakami Belt	absent	absent	present	present	present

*, regions considered as the "fixed points for the paleobiogeographical reconstruction" in this paper.

Higher classification / species	References	Remarks
Ammonitida		
Partschiceras cf. *otokense* Stevens	Sato et al. (2003)	= *Lilloetia* sp. in Sato and Kanie (1963) = *Megaphylloceras grossicostatum* in Sato and Westermann (1991)
Lytoceras sp.	Sato et al. (2003)	
Delphinella cf. *obtusenodosa* (Retowski)	Sato et al. (2003)	
Berriasella sp.	Sato et al. (2003)	
Neocosmoceras sp.	Sato et al. (2008)	
Belemnitida		
Cylindroteuthis aff. *knoxvillensis* Anderson	Sano et al. (2015)	
Bivalvia		
Palaeonucula makitoensis (Hayami)	Hayami (1959a); Yano (2012); Sha and Hirano (2012); Koarai and Matsukawa (2016)	
Palaeonucula sp.	Hayami (1959a); Koarai and Matsukawa (2016)	
Palaeoneilo ? sp.	Hayami (1959a); Koarai and Matsukawa (2016)	
Solemya suprajurensis Hayami	Hayami (1959a); Komatsu et al. (2001); Yano (2012); Koarai and Matsukawa (2016)	
Brachidontes ? sp.	Hayami (1959a); Yano (2012); Koarai and Matsukawa (2016)	
Modiolus (*Modiolus*) *maedae* Hayami	Hayami (1959a); Komatsu et al. (2001); Yano (2012); Koarai and Matsukawa (2016)	
Pinna (*Pinna*) aff. *sandsfootensis* Arkell	Hayami (1959a); Yano (2012); Koarai and Matsukawa (2016)	
Inoceramus (*Inoceramus*) *maedae* Hayami	Haymi (1960); Komatsu et al. (2001); Yano (2012); Koarai and Matsukawa (2016)	including *Inoceramus maedae* var. a and var. b in Hayami (1960) (see Hayami, 1975)
Oxytoma tetoriensis Hayami	Hayami (1959a); Komatsu et al. (2001); Yano (2012); Koarai and Matsukawa (2016)	including *Pteria* (s. l.) sp. in Hayami (1959a) (see Koarai and Matsukawa, 2016)
Oxytoma sp.	Yano (2012)	
Entolium inequivalve Hayami	Hayami (1959b); Komatsu et al. (2001); Yano (2012); Sha and Hirano (2012); Koarai and Matsukawa (2016)	
Camptonectes ? sp.	Hayami (1959b); Yano (2012) ; Koarai and Matsukawa (2016)	
Chlamys (*Chlamys*) *mitaraiensis* Hayami	Hayami (1959b); Yano (2012) ; Koarai and Matsukawa (2016)	
Limatula ? *iwayae* Hayami	Hayami (1959b); Komatsu et al. (2001) ; Yano (2012) ; Koarai and Matsukawa (2016)	
Turus sp.	Yano (2012)	
Protocardia ? sp. Hayami	Hayami (1959b); Komatsu et al. (2001); Yano (2012); Koarai and Matsukawa (2016)	
Tetorimya carinata Hayami	Hayami (1959b); Komatsu et al. (2001); Yano (2012); Koarai and Matsukawa (2016)	
Pleuromya hidensis Hayami	Hayami (1959b); Komatsu et al. (2001); Yano (2012); Sha and Hirano (2012); Koarai and Matsukawa (2016)	
Homomya sp.	Yano (2012)	
Goniomya sp.	Komatsu et al. (2001); Yano (2012)	
Thracia shokawensis Hayami	Hayami (1959b); Komatsu et al. (2001); Yano (2012); Sha and Hirano (2012); Koarai and Matsukawa (2016)	
Cirripedia		
Scalpellomorpha fam. gen. et sp. indet.	Nomura and Shimizu (2008)	
Decapoda		
Glyphea sp.	Kato and Karasawa (2006)	
Crinoidea		
Chariocrinus japonicus Hunter, Oji, Ewin et Kitazawa	Hunter et al. (2011)	