Habitats of Bivalves in the Lower-Cretaceous Aptian Tanohata and Aptian to Albian Hiraiga Formations, Iwate Prefecture, Northeastern Japan

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ABSTRACT

We reconstructed the depositional environments, assemblages, and habitats of characteristic bivalve species in the Cretaceous Miyako Group, Iwate Prefecture, Northeast Japan. The upper part of the Aptian Tanohata Formation and the lower part of the Aptian to Albian Hiraiga Formation are composed mainly of wave- and storm-dominated shoreface and inner-shelf fossiliferous deposits. The shoreface deposits contain abundant allochthonous bivalve shells. In-situ preserved *Cucullaea acuticarinata* Nagao, *Pterotrigonia hokkaidoana* (Yehara), *Pterotrigonia yokoyamai* (Yehara), and *Goniomya subarchiachi* Nagao are common in inner-shelf deposits. These fossils provide important knowledge concerning the evolutionary history of Lower to mid-Cretaceous shallow marine benthic communities.

Keywords: Bivalve, Depositional environment, Mid-Cretaceous, Miyako Group, Palaeoecology

INTRODUCTION

The mid-Cretaceous, an important age for studies of evolutionary history, is characterized by the diversification of bivalves such as glycymerids and venerids and a decline in Jurassic to Early-Cretaceous bivalves. Glycymerids and venerids are common recent shallow marine bivalves that appeared in the Lower Cretaceous and have continuously radiated since the Cretaceous [1–2]. Pterotrigoniids and inoceramids also flourished from the mid-Cretaceous, although these groups became extinct in the Upper Cretaceous [2–4].

The Lower Cretaceous Aptian to Albian Miyako Group contains abundant, well-preserved bivalves such as *Glycymeris*, *Pterotrigonia*, *Astarte*, *Eriphyla*, *Anthonya*, *Nagaoella, Phoradomya*, *Panopea*, and *Goniomya* [5–7]. Glycymerids (*Glycymeris*) and the forerunners of venerids (*Nagaoella*) appeared in the Aptian, and these groups have flourished from the Upper Cretaceous through the Cenozoic to the Recent. *Astarte*, *Eriphyla*, *Phoradomya*, and *Goniomya* were rather diversified in the Jurassic, but declined in the mid-Cretaceous [8]. Therefore, during the Lower to mid-Cretaceous, the bivalve faunal composition changed drastically, and bivalve assemblages of the Miyako Group probably represent a replacement of the Jurassic to Lower-Cretaceous bivalve fauna by a mid- to Upper–Cretaceous fauna that contains many families and genera common in

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Recent shallow marine seas. In this paper, we reconstruct the depositional environments, assemblages, and habitats of bivalves in the type sections of the Tanohata and Hiraiga Formations, Miyako Group, based on facies analysis and modes of fossil occurrence.

GEOLOGIC SETTING

The Lower Cretaceous Aptian to Albian Miyako Group, consisting of the Raga, Tanohata, Hiraiga, and Aketo Formations, is exposed in coastal areas of Iwate Prefecture, northeastern Japan (Figs. 1, 2)

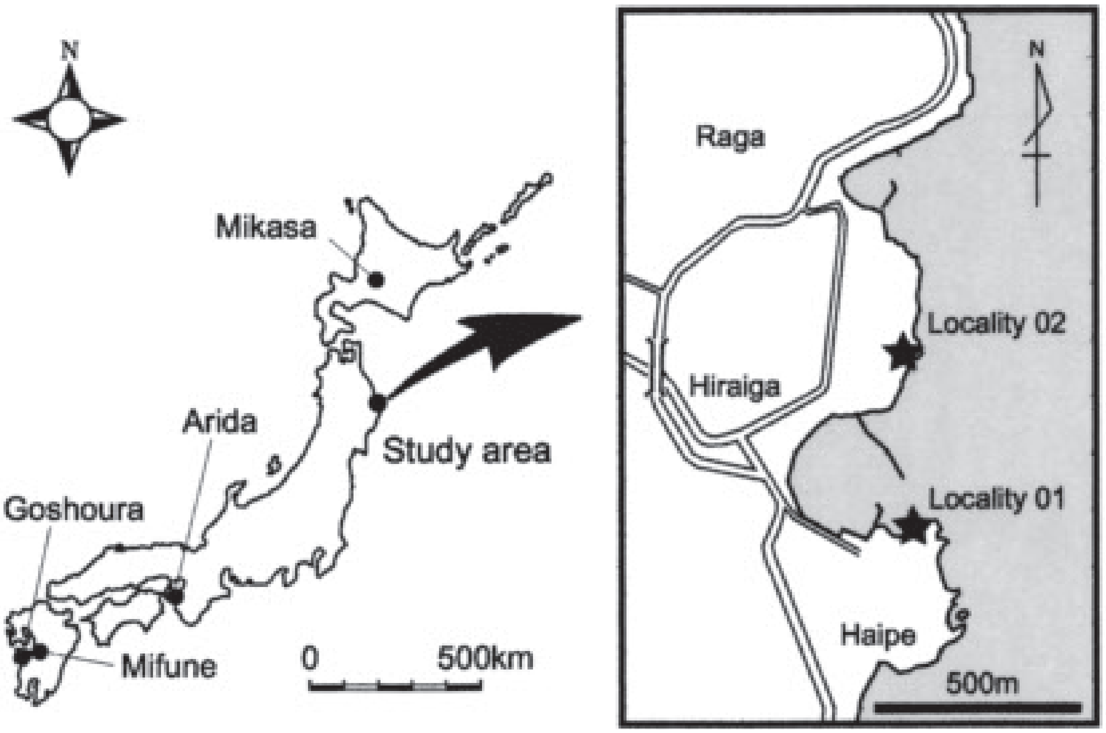

Fig. 1 Map of Japan (left) showing location of the study area, enlarged in box (right) to show localities of the Miyako Group.

Formation	Thickness	Lithology	Ammonoids
Aketo Fm.	30m	Muddy sandstone	*Pseudoleymeriella* sp. (Lower Albian)
Hiraiga Fm.	80m	Sandy mudstone Calcareous sandstone	*Hypacanthoplites subcornuerianus*
Tanohata Fm.	70m	Sandy mudstone Muddy sandstone	*Diadochoceras nodosocostatiforme*
		Sandstone Conglomerate	(Upper Aptian)
Raga Fm.	40m	Sandstone Conglomerate	

Fig. 2 Stratigraphy of the Miyako Group, including divisions, lithology, and age-diagnostic ammonoids; simplified from Ref. 10.

and is composed mainly of fossiliferous shallow marine deposits [9–10]. Specifically, various well-preserved marine invertebrates have been well documented from the Tanohata and Hiraiga Formations in the study area (Localities 01 and 02) [5–7, 11–14].

According to Ref. 10, around the study area the Raga Formation (about 40 m thick) unconformably overlies basement rocks such as granodiorite and folded sedimentary strata. This formation is composed mainly of non-marine deposits consisting of conglomerate, coarse-grained sandstone, and red siltstone, and is conformably overlain by the shallow marine Tanohata Formation.

The Tanohata Formation (about 70 m thick) is subdivided into lower and upper parts. The lower part is dominated by conglomerate, gravelly sandstone, and cross-stratified sandstone, and abundantly yields corals, gastropods, and shallow marine bivalves such as oysters and pterotrigoniids. The upper part is composed of sandy mudstone, muddy sandstone, and fine-grained sandstone, and commonly contains bivalves, gastropods, ammonoids, and echinoids. Some ammonoid species such as *Hypacanthoplites subcornuerianus* (Shimizu) and *Valdedorsella akuschaensis* (Anthula) suggest an Upper Aptian age [10, 15].

The Hiraiga Formation (about 80 m thick) is characterized by calcareous sandstone yielding *Orbitolina* (Foraminifera), bivalves, gastropods, ammonoids, and abundant crinoid stems. The Upper Aptian ammonoids *Hypacanthoplites subcornuerianus* (Shimizu), *Diadochoceras nodosocostatiforme* (Shimizu), and *Eodouvilleiceras matsumotoi* Obata occur in the lower part of the Hiraiga Formation [16–18]. The Upper Aptian shallow marine bivalve *Neithea ficalhoi* (Choffat) is commonly obtained from the upper part of the Tanohata Formation and the lower part of the Hiraiga Formation [5, 10].

The Aketo Formation (over 30 m thick) is composed mainly of muddy sandstone containing bivalves, gastropods, ammonoids, and echinoids. The Lower Albian ammonoid *Douvilleiceras mammillatum* (Schlotheim) occurs in the upper part of the Hiraiga Formation and the Aketo Formation [16]. The Aketo Formation is probably overlain by the Yezo Group on the sea bottom [19–21]. Ref. 19 reported *Inoceramus* (*Birostrina*) sp. cf. *I.* (*B.*) *concentricus* Nagao and Matsumoto, *Pterotrigonia brevicula* (Yehara), *Thetis japonica* (Yabe and Nagao), *Goshoraia crenulata* (Matsumoto), and gastropods from a sandstone block dredged from the sea bottom about 30 km off the southern coast of Kuji, Iwate Prefecture. The species composition is quite similar to the shallow marine fauna in the lower part of the Mikasa Formation, Yezo Group, central Hokkaido. These Cretaceous shallow marine deposits accumulated in the western parts of the Yezo forearc basin [20–21].

DEPOSITIONAL FACIES AND ENVIRONMENTS

In the study area, shallow marine bivalves are found in two depositional facies: 1) an alternation of hummocky cross-stratified (HCS) sandstone and bioturbated sandstone, and 2) an alternation of HCS sandstone and bioturbated muddy sandstone to sandy mudstone (Figs. 3, 4). Generally, hummocky cross-stratification is a diagnostic sedimentary struc-

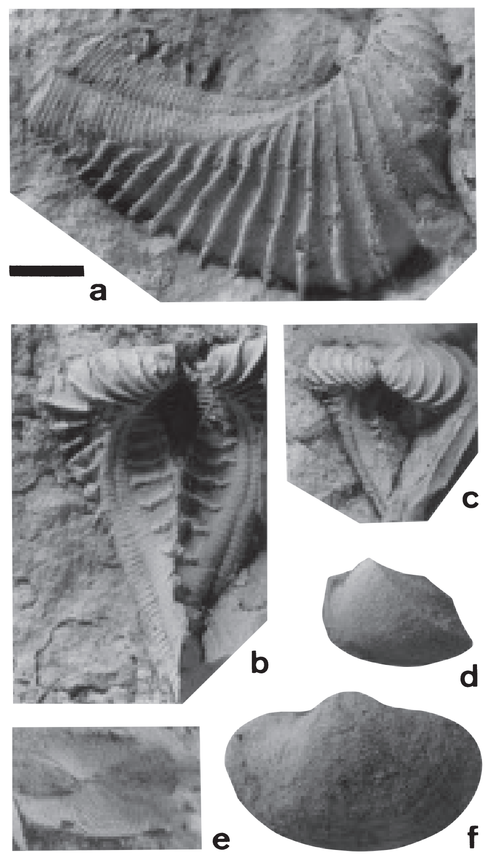

Fig. 3 Bivalve fossils from bioturbated sandy mudstone of the upper part of the Tanohata Formation (Locality 01). Scale bar, 1cm. (a-c) *Pterotrigonia hokkaidoana* (Yehara). (a) Right valve, gum cast of external mold. (b, c) Articulated valves, gum casts of external molds, showing life positions in the bedding plane. (d) *Cucullaea* (*Idonearca*) *acuticarinata* Nagao. Left valve, gum cast of external mold. (e) *Goniomya subarchiaci* Nagao. Articulated valves, gum cast of external mold, showing bedding plane. (f) *Periploma* sp. Left valve, gum cast of external mold.

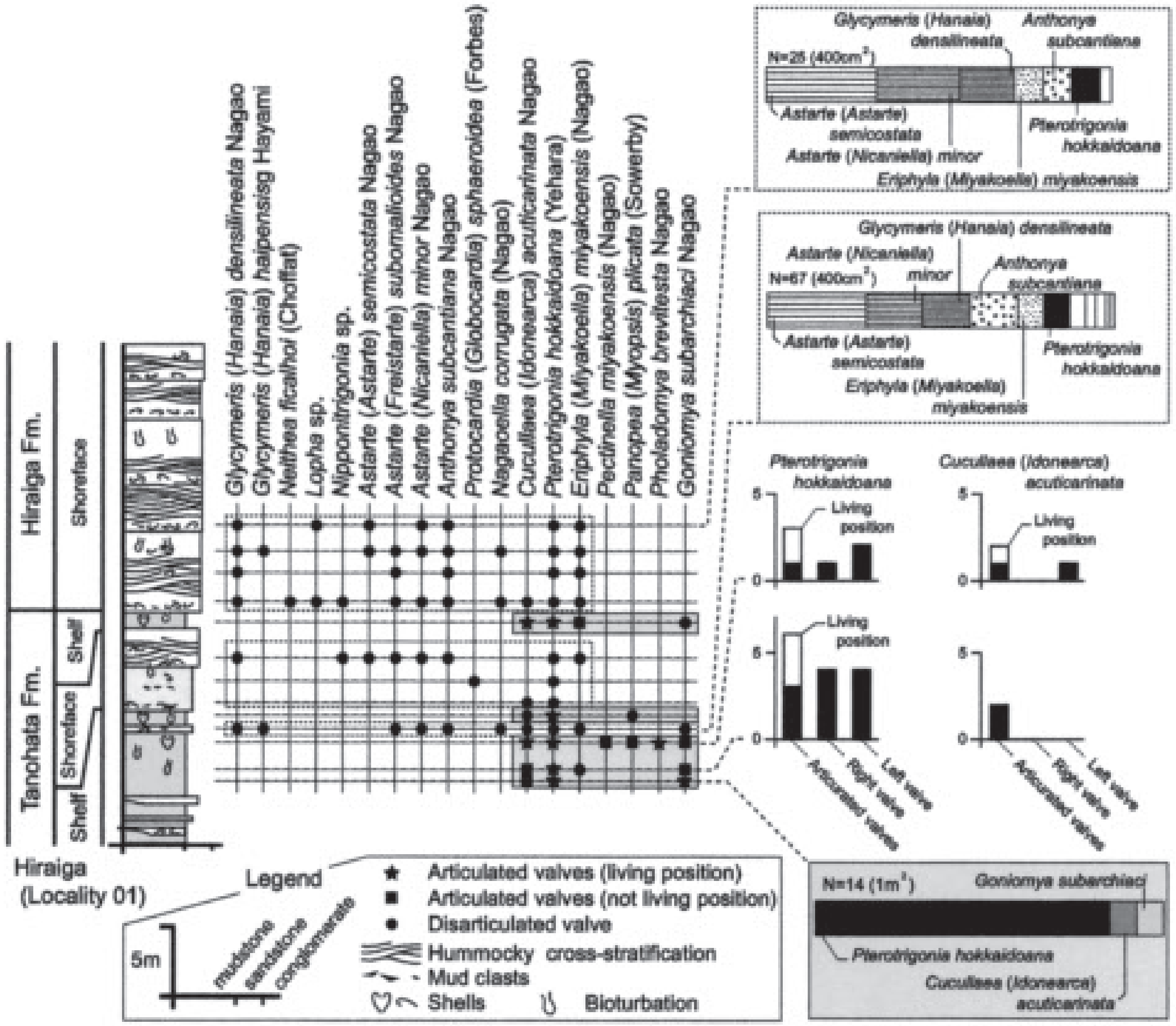

Fig. 4 Stratigraphic occurrences and compositions of bivalves in the section of the Tanohata and Hiraiga Formations (Locality 01).

ture formed under waning storm and wave conditions [22–23]. HCS sandstones without associated muddy sediments imply deposition shallower than the fair-weather wave base, and alternation of HCS sandstone and bioturbated mudstone is indicative of inner shelf environments between the storm and fair-weather wave bases [22]. Therefore, depositional facies 1 is interpreted to represent shoreface deposits above the fair-weather wave base. Overlying bioturbated sandstone indicates activity of benthic animals on a sandy bottom after a storm event. The bioturbated muddy sandstone and sandy mudstone of depositional facies 2 were also probably formed under calm conditions after storms, and may have been deposited in inner-shelf environments.

Locality 01 (Fig. 1), a transitional sequence between the Tanohata and Hiraiga Formations, is composed mainly of increasingly coarse units from facies 2 (inner shelf) to facies 1 (shoreface), and is characterized by typical wave- and storm-dominated facies. Locality 02 is dominated by facies 2 (inner shelf) of the lower part of the Hiraiga Formation.

MODES OF OCCURRENCE

Autochthonous, parautochthonous, and allochothonous occurrences are found in wave- and storm-dominated coastal deposits in the upper part of the

Tanohata (Loc. 01) and Hiraiga (Locs. 01, 02) Formations. Most of the bivalves are preserved as disarticulated valves in a shell concentration. The shell concentration covers a basal erosional surface of HCS sandstone. In depositional facies 1, especially, the shell concentration is made up of disarticulated, convex-up valves. These bivalves represent typical allochothonous occurrences.

In the bioturbated sandstone and mudstone of depositional facies 1 and 2, infaunal species are occasionally preserved in life positions, which represent typical autochthonous occurrences (Fig. 3). These bivalves are arranged with their sagittal plane perpendicular to the bedding plane and with their posterodorsal or posterior margin pointing upward. In addition, randomly arranged articulated valves are abundant in the bioturbated sandstone and mudstone. These modes of occurrence represent the parautochthonous condition and indicate that the species were preserved at or near their habitat. Epifaunal bivalves are commonly preserved as articulated valves in facies 2. In addition, disarticulated right and left valves of the same individual occasionally overlap in depositional facies 2 and 3. These epifaunal bivalves are also interpreted to represent parautochthonous occurrences.

HABITATS OF THE BIVALVES

Locality 01

In the shoreface deposits of facies 1, shell concentrations 2–20 cm thick and 0.5–5 m wide are composed of disarticulated valves and fragments. *Cucullaea acuticarinata* Nagao, *Glycymeris* (*Hanaia*) *densilineata* Nagao, *Nipponitrigonia tashiroi* Matsuda, *Pterotrigonia hokkaidoana* (Yehara), *Astarte* (*Astarte*) *semicostata* Nagao, *Astarte* (*Freistarte*) *subomalioides* Nagao, *Astarte* (*Nicaniella*) *minor* Nagao, *Eriphyla* (*Miyakoella*) *miyakoensis* (Nagao), *Anthonya subcantiana* Nagao, *Nagaoella corrugate* (Nagao), the ammonoid *Hypacanthoplites subcornuerianus*, and gastropods are abundant in the shell concentrations, and are characterized by allochthonous occurrences.

Locality 02

Shell concentrations 1–5 cm thick and 30–120 cm wide are embedded in the bioturbated mudstone of facies 2 and consist mainly of disarticulated valves of *Pterotrigonia yokoyamai* (Yehara), *Goniomya subarchiachi*, and *Panopea* (*Myopsis*) *plicata*, and abundant mud clasts. Facies 2 rarely contains in-situ preserved *Pterotrigonia yokoyamai* and *Goniomya subarchiachi*, or randomly arranged articulated valves of *Panopea* (*Myopsis*) *plicata* and *Periplomya* sp. Therefore, we conclude that *Pterotrigonia yokoyamai* and *Goniomya subarchiachi* inhabited inner-shelf environments. *Panopea* (*Myopsis*) *plicata* and *Periplomya* sp. are interpreted to represent parautochthonous occurrences. The inner and outer surfaces of *Pterotrigonia yokoyamai* in intense bioturbated mudstone (facies 2) are commonly encrusted by cheilostome bryozoan colonies.

MID-CRETACEOUS FAUNAL CHANGE IN THE SHALLOW MARINE BENTHOS

The upper part of the Tanohata Formation and the lower part of the Hiraiga Formation are composed of wave- and storm-dominated shoreface and inner-shelf deposits. In the inner-shelf deposits (Fig. 5), the bivalves *Cucullaea acuticarinata*, *Pterotrigonia hokkaidoana*, *Pterotrigonia yokoyamai*, and *Goniomya subarchiachi* are commonly preserved autochthonously in life positions.

Pterotrigonia and *Cucullaea* are dominant in the mid-Cretaceous inner-shelf deposits. *Cucullaea amaxensis* Matsumoto and *Pterotrigonia pustulosa* (Nagao) account for over 50% of the inner-shelf bivalve assemblage in the Upper Albian to Lower Cenomanian Enokuchi Formation, Goshoura Group, Kyushu, Japan, and represent autochthonous occurrences [24–25]. In-situ preserved *Cucullaea ezoensis* Yabe and Nagao, *Pterotrigonia kobayashii* (Nakano), and *Pterotrigonia pustulosa* (Nagao) are common in the Lower-Cenomanian Lower Mikasa Formation, Hokkaido [26].

In the mid-Cretaceous, pterotrigoniids were a highly diversified infaunal bivalve group in various depositional environments from the tide-dominated and brackish-water influenced subtidal to the outer-shelf facies, and occurred abundantly in each bivalve assemblage [24–25]. Fourteen pterotrigoniid species have been reported from various depositional facies in the Goshoura Group, and six species from in the Upper Cenomanian shallow marine (shoreface?) sandstone of the Mifune Group, Kyushu, southwestern Japan [4]. The Barremian pterotrigoniids are not diversified [4], although *Pterotrigonia pocilliformis* (Yokoyama) is dominant in lower shoreface deposits in northeastern and southwestern Japan [2, 27]. In the Miyako Group, two species, *Pterotrigonia hokkaidoana* and *Pterotrigonia yokoyamai*, are abundant in shoreface and inner-shelf deposits, and their environments were probably shoreface to inner shelf. During the Lower to mid-

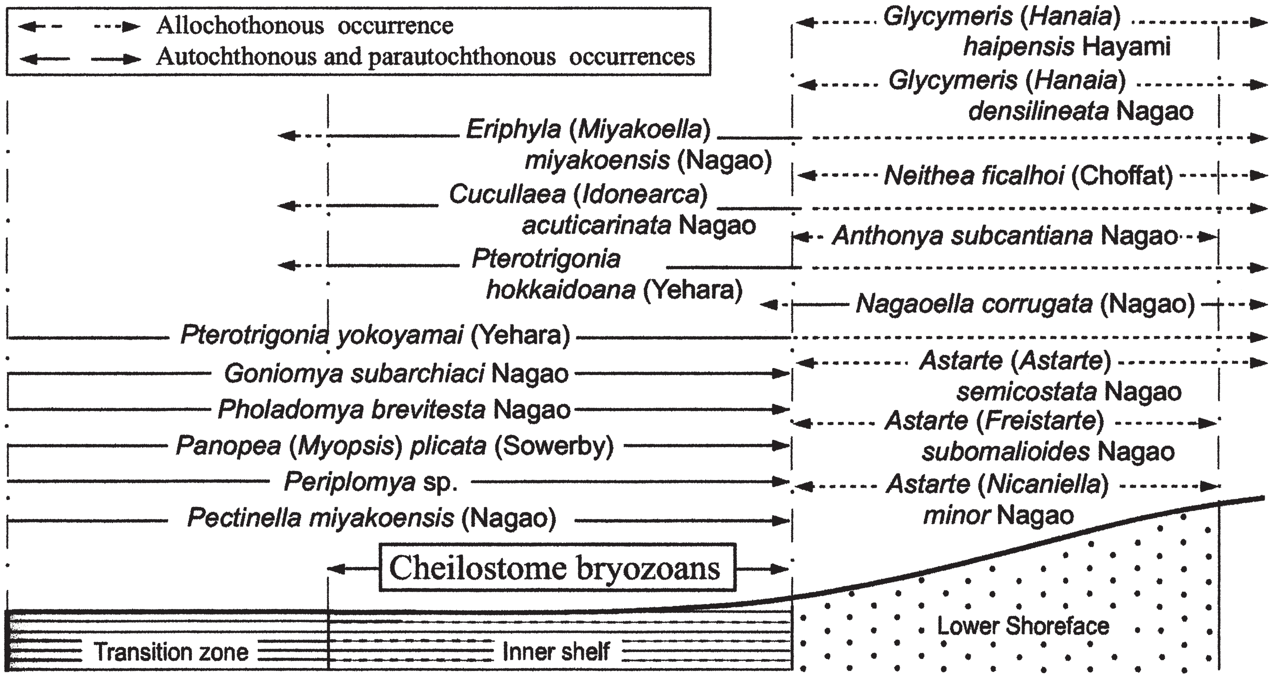

Fig. 5 Reconstructed habitats of the characteristic species of fossil bivalves treated in this study; the occurrence of cheilostome bryozoans is also noted.

Cretaceous in Japan, pterotrigoniid species increased in number, and their habitats gradually expanded from the shoreface to various shallow marine environments.

Goniomya is a common genus in Jurassic to Lower Cretaceous bivalve assemblages. In the Lower Cretaceous Barremian Arida Formation, Wakayama Prefecture, southwestern Japan, inner-shelf deposits commonly contain autochthonous *Goniomya hayamii* Tashiro and Kozai [27]. However, the genus is rare in the Upper Albian and Cenomanian, and it is never found in Upper Cretaceous Turonian to Maastrichtian strata in Japan. Pholadomyidae such as *Pholadomya Homomya* and *Periplomya* are also rare in Upper Cretaceous strata.

Shoreface deposits of the Miyako Group commonly contain glycymerids (*Glycymeris* [*Hanaia*] *densilineata* and *Glycymeris haipensis*), astarteids (*Astarte* [*Astarte*] *semicostata*, *Astarte* [*Freistarte*] *subomalioides*, *Astarte* [*Nicaniella*] *minor*, and *Eriphyla* [*Miyakoella*] *miyakoensis*), and venerids (*Nagaoella corrugate* and *Nagaoella* sp.). The astarteids account for over 50% of the shoreface bivalve assemblage. Seven species of *Astarte* and three species of *Eriphyla* have been reported from Aptian to Lower Albian shallow marine deposits in Japan [28]. However, *Astarte* has never been reported from the Upper Albian to Cenomanian Goshoura Group or the Cenomanian to Turonian Mikasa Formation, Yezo Group [24, 29–30]. Many astarteid species have been described from the Jurassic to the Lower Albian in Japan, though *Eriphyla japonica* Ichikawa and Maeda and *Eriphyla elegans* Ichikawa and Maeda have rarely been reported from the Upper Cretaceous Izumi Group [31]. Astarteids probably diversified until the Lower Albian, and then declined in the Upper Cretaceous.

Glycymerids and venerids appeared in the Lower Cretaceous and are abundant in mid- to Upper Cretaceous shoreface sandstone in Japan [8, 24, 32]. *Glycymeris* (*Hanaia*) *densilineata* and *Nagaoella corrugate* are common in shoreface deposits of the Miyako Group. In the Lower Cretaceous, four species of glycymerids appeared, and eight species have been described from Upper-Cretaceous shallow marine strata [5, 32]. About 10 species of venerids have been reported from the Upper Cretaceous [28]. *Goshoraia crenulata* and *Goshoraia* sp. (venerids) are common in tidal flat, shoreface, and shelf deposits of the Albian to Cenomanian Goshoura Group [24, 25], which possibly indicates an expansion of their habitat. Glycymerids and venerids flourished from the mid-Cretaceous Upper Albian to the Cenozoic [1, 2, 8]. In the Miyako Group, Jurassic to

Lower-Cretaceous species and genera characterize bivalve assemblages, and the shallow marine bivalve fauna likely underwent a change in the mid-Cretaceous Albian.

CONCLUDING REMARKS

The upper part of the Tanohata Formation and the lower part of the Hiraiga Formation are composed of wave- and storm-dominated shoreface and inner-shelf deposits. In the inner-shelf deposits, *Cucullaea acuticarinata*, *Pterotrigonia hokkaidoana*, *Pterotrigonia yokoyamai*, and *Goniomya subarchiachi* are commonly preserved in life positions. The shoreface bivalve assemblage is characterized by diarticulated shells of *Nipponitrigonia tashiroi*, *Pterotrigonia hokkaidoana*, *Astarte*, and *Eriphyla*, which represent typical allochothonous occurrences. These bivalves, comprising mainly trigoniids and characteristic species and genera, diversified in the Jurassic to Lower Cretaceous.

The Miyako Group is important for the study of marine benthic communities, because the composition of bivalve assemblages represents a drastic change in the mid-Cretaceous. Furthermore, cheilostome bryozoans, which began an explosive diversification in the mid-Cretaceous, are commonly found in the Miyako Group. Abundant crinoids are preserved in-situ in shoreface and inner-shelf deposits of this group, though crinoids inhabit deep-sea environments in the Upper Cretaceous, Cenozoic, and Recent [4]. Therefore, the shallow marine fossils in the Miyako Group likely provide a key to understanding mid-Cretaceous faunal changes in marine benthic communities.

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