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EARLY CRETACEOUS NON-MARINE BIVALVE FAUNAL GROUPS FROM CENTRAL AND EAST SHIKOKU, JAPAN

Takeshi KOZAI [1] and Keisuke ISHIDA [2]

[1]Laboratory of Geosciences, Naruto University of Education, 748 Takashima, Naruto, Tokushima 772-8502, Japan
[2]Laboratory of Geology, Faculty of Integrated Arts and Sciences, Tokushima University, 1-1 Minamijosanjima, Tokushima 770-8502, Japan

ABSTRACT

Cretaceous non-marine faunas in Central and Eastern Shikoku can be classified into the Masaki and Sakashu faunal groups on the basis of their taxonomic components and a new stratigraphy and tectonic subdivision of the Chichibu Superbelt. The non-marine bivalves from the Monobegawa Group in the Masaki Belt belong to the Masaki Faunal Group which are identified the Hauterivian Tatsukawa fauna, Late Barremian Yunoki fauna and Early Aptian Hibihara fauna. The non-marine bivalves from the Nankai and Takegatani groups of the Sakashu Belt belong to the Sakashu Faunal Group which are identified the Hauterivian Shobu fauna. The three faunas of the Masaki Faunal Group in Central and East Shikoku are found in stratigraphic order. The Masaki Faunal Group is characterized by the brackish- and freshwater mollusks. On the other hand, the Sakashu Faunal Group is characterized by the brackish-water mollusks. It suggests that salinity is the main differential factor between the Hauterivian faunas in the Masaki and Sakashu faunal groups.

A Hauterivian mixed assemblage of the Tatsukawa and Shobu faunas was found in Central Shikoku. The finding suggests that the two faunas were formed in different salinity environment and adjoining areas.

Key words: Paleobiogeography, Early Cretaceous, non-marine bivalves, Chichibu Superbelt, Shikoku.

香西　武・石田啓祐（2003）四国中・東部の前期白亜紀非海生二枚貝動物群．福井県立恐竜博物館紀要 2：133–148.

四国中・東部秩父累帯下部白亜系の非海生二枚貝類について種構成や群集の生息環境を考察し，再編された地帯区分との対応を検討した．これらの白亜紀非海生動物群は新たな秩父累帯の地帯区分及び種構成に基づいて，互いに共通種を持たない正木動物群（Masaki Faunal Group）と坂州動物群（Sakashu Faunal Group）に区分される．正木帯に属する物部川層群の非海生二枚貝類は正木動物群に帰属し，立川フォーナ（Hauterivian），柚ノ木フォーナ（Late Barremian），日比原フォーナ（Early Aptian）で構成される．坂州帯に属する南海層群，竹ヶ谷層群の非海生二枚貝類は坂州動物群に帰属し，菖蒲フォーナ（Hauterivian）で特徴づけられる．四国中・東部における正木動物群は，汽水生－淡水生軟体動物で特徴づけられ，坂州動物群は汽水生軟体動物で特徴づけられる．このことは，坂州動物群は正木動物群より塩分濃度の高い環境で生息したことを示す．また，四国中央部では両動物群の混在が確認され，正木動物群と坂州動物群は，隣接して存在し，塩分濃度の異なる環境に生息したことが推測される．

INTRODUCTION

Lower Cretaceous non-marine deposits are widely distributed on the Asian continental mainland. To establish a Lower Cretaceous molluscan biostratigraphic correlation in East Asia, we have examined non-marine bivalve faunas of the Haidateyama-, Pre-Sotoizumi-, Monobegawa-, Takegatani-, Nankai- (Outer Zone), Tetori-, Toyonishi-, Kanmon- (Inner Zone) groups and the Lower Cretaceous formations in Kanto (Outer Zone) in Japan, and the Shindong Group (Kyongsang Basin). In the field, intertonguing of marine and non-marine formations is remarkable in the Monobegawa and Takegatani groups of the Outer Zone of Japan.

In Central and East Shikoku, a biostratigraphy is established

Corresponding author — Takeshi KOZAI
Phone and Fax: +81-88-687-6414
E-mail: kozai*naruto-u.ac.jp (*を半角@に変えてご入力ください)

on the basis of marine faunas consisting of ammonites, radiolarians and bivalves. It provides time constraints to each non-marine intercalation, the alternating marine and non-marine beds reflecting eustatic sea-level changes.

In the Monobegawa Group of Central Shikoku, brackish-water faunas were recognized in three formations: the Ryoseki, Yunoki and lower part of the Hibihara formations (Tashiro and Kozai, 1994). In the Monobegawa Group of East Shikoku, brackish-water faunas occur in the Tatsukawa, Hiura facies of the Lower Hanoura and Upper Hanoura formations (Ishida et al., 1992, 1996). The Group consists of non-marine and marine deposits that form three mega sedimentary cycles, each characterized by an upward fining sequence. Marine deposits contain abundant bivalves and ammonites. Recently, radiolarians were also extracted from these rocks, allowing further detailed age clarification (Ishida et al., 1992, 1996). In the Takegatani Group of East Shikoku, brackish-water mollusks are known from the Shobu Formation (Tashiro and Matsuda, 1985; Kozai et al., 2001). Radiolarians were extracted from the upper horizon of this formation (Suyari and Ishida, 1985). Recently reported freshwater bivalves (Tashiro and Okuhira, 1993), and new materials of non-marine mollusks, collected by the authors, provide clues for the comparison of the fauna between the Outer and the Inner zones of Southwest Japan.

Ishida and Kozai (2003) established recently a new stratigraphy and tectonic subdivision of the Chichibu Superbelt. In this paper, the Lower Cretaceous non-marine mollusks of Shikoku are subdivided into two faunal groups, matching the subdivision of the Chichibu Superbelt. The environmental conditions, which caused the differences between the two faunal groups, are also discussed.

STRATIGRAPHY AND FAUNAL CONTENT

Southwest Japan is subdivided into Outer and Inner zones by the Median Tectonic Line. Early Cretaceous non-marine beds occur in both zones (Fig. 1). In the Outer Zone, brackish-water beds are known in the Chichibu Superbelt, which extends in Kyushu, Shikoku, the Kii peninsula and the Kanto area of Honshu. On the other hand, in the Inner Zone, mainly freshwater beds are known in North Kyushu, West Chugoku and Hokuriku areas of Honshu.

In East Shikoku, the Chichibu Superbelt is subdivided from north to south into five belts, the Kumosoyama, Masaki, Yoshigahira, Sakashu and Nakagawa belts (Ishida and Kozai, 2003) (Fig. 2). Early Cretaceous non-marine bivalves occur in the Masaki, Yoshigahira and Sakashu belts. The Masaki Belt is composed of the accretionary complex (AC) of Permian with slope basin deposits (SL) of Early and Late Cretaceous. The Yoshigahira Belt is composed of the Siluro–Devonian Kurosegawa Tectonic Zone, Permian-, Late Triassic-, Early Jurassic-, Middle–Late Jurassic-ACs, and Early Cretaceous SL. The Yoshigahira Belt is a tectonic unit that was formed after the sedimentation of the Early Cretaceous SL. The Sakashu Belt is composed of Permian AC with Siluro–Devonian blocks, latest Permian, Middle–Late Triassic, Jurassic and Early Cretaceous SLs.

Masaki Belt

The Early Cretaceous Monobegawa Group is characteristic for the Masaki Belt extending north of the Shokuta Tectonic Line (Ishida and Kozai, 2001) (Fig. 3). The Central Shikoku Monobe area is the type locality of the Monobegawa Group. Here, the group is subdivided into the Ryoseki, Monobe, Yunoki and Hibihara formations in ascending order (Tashiro and Kozai, 1984). The Ryoseki–Monobe, Yunoki and Hibihara formations represent the three sedimentary mega-cycles of the group.

In the East Shikoku Tokushima area, the group is subdivided into the Tatsukawa, Lower Hanoura (containing the Hiura Facies), Upper Hanoura, Hoji and Fujikawa formations (Ishida et al., 1992, 1996). These formations are correlative with those of the type area: i.e. Tatsukawa Formation and Ryoseki Formation; Lower Hanoura Formation and Monobe Formation; Hiura Facies of Lower Hanoura Formation and Yunoki Formation; Upper Hanoura Formation and lower part of Hibihara Formation; Hoji Formation and middle part of Hibihara Formation; Fujikawa Formation and upper part of Hibihara Formation. The contacts among all these formations are conformable. Characteristic non-marine bivalve faunas are distinguished in three formations of the Monobegawa Group, and known as the Tatsukawa, Yunoki and Hibihara faunas (Fig. 4).

1. Ryoseki and Tatsukawa formations

Reddish conglomerates with thin interbeds of reddish mudstone dominate the lower part, unconformably overlying the Permian Accretionary Complexes (PAC). On the other hand, the upper part is composed of gray conglomerate, fine-grained sandstone and dark gray mudstone. Total thicknesses of the formations are about 400 m. The conglomerate consists of poorly sorted angular to sub-rounded pebbles. The sandstone and mudstone beds contain plant fossils, called Ryoseki-type flora, and brackish-water mollusks, such as *Costocyrena otsukai*, *Hayamina naumanni*, *H. bungoensis*, *Pulsidis antiqua and Isodomella shiroiensis*.

The mudstone beds in the Tatsukawa Formation yield freshwater mollusks, such as *Unio ogamigoensis*, *Trigonioides* (*Wakinoa*) *tetoriensis*, *Batissa*? *antiqua* and *Viviparus onogoensis*. The Tatsukawa and Ryoseki formations are overlain by the Barremian Lower Hanoura and Monobe formations and can therefore be regarded as Hauterivian in age (Tanaka et al., 1984; Ishida et al., 1992).

2. Monobe and Lower Hanoura formations

The formations are subdivided into two parts. Total thickness

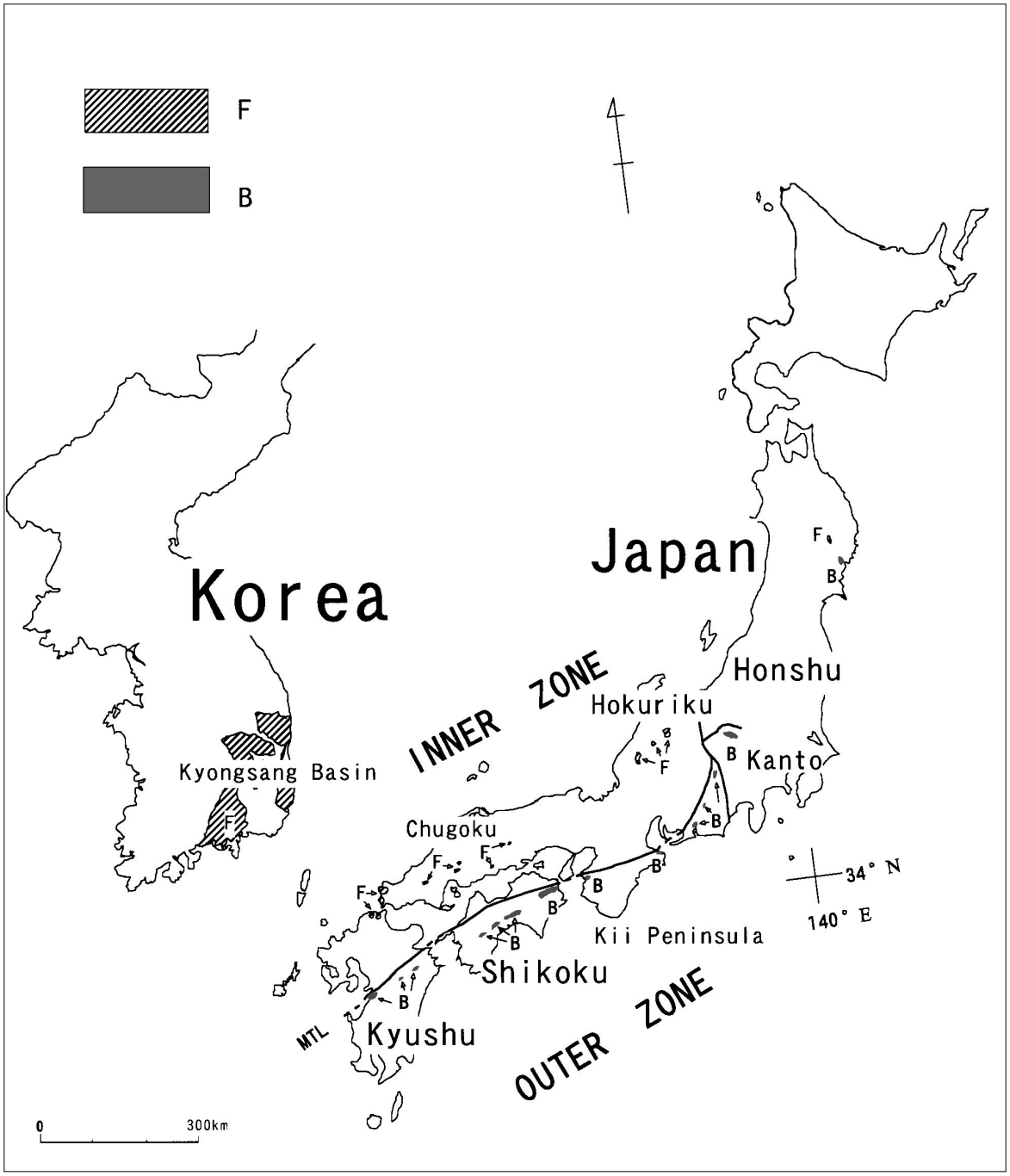

FIGURE 1. Distribution of Lower Cretaceous non-marine deposits in Japan and Korea. **F**: exclusively non-marine deposits, **B**: non-marine deposits with marine intertongues, **MTL**: Median Tectonic Line.

is about 350 m. The lower part consists of conglomerate and sandstone. The sandstone beds contain marine bivalves, such as *Pterinella shinoharai*, *Plicatula kiiensis* and *Pterotrigonia pocilliformis*. The upper part is composed of mudstone. The mudstone beds yield marine bivalves and ammonites, such as *Yabea shinanoensis*, *Nanonavis yokoyamai*, *Shasticrioceras nipponicum*, *Pulchellia ishidoensis*, *Crioceratites asiaticum* and *Olcostephanus candoceroides* and the radiolarian assemblage of *Archaeodictyomitra pseudoscalaris* that indicate a Barremian age (Tanaka et al., 1984; Ishida et al., 1992).

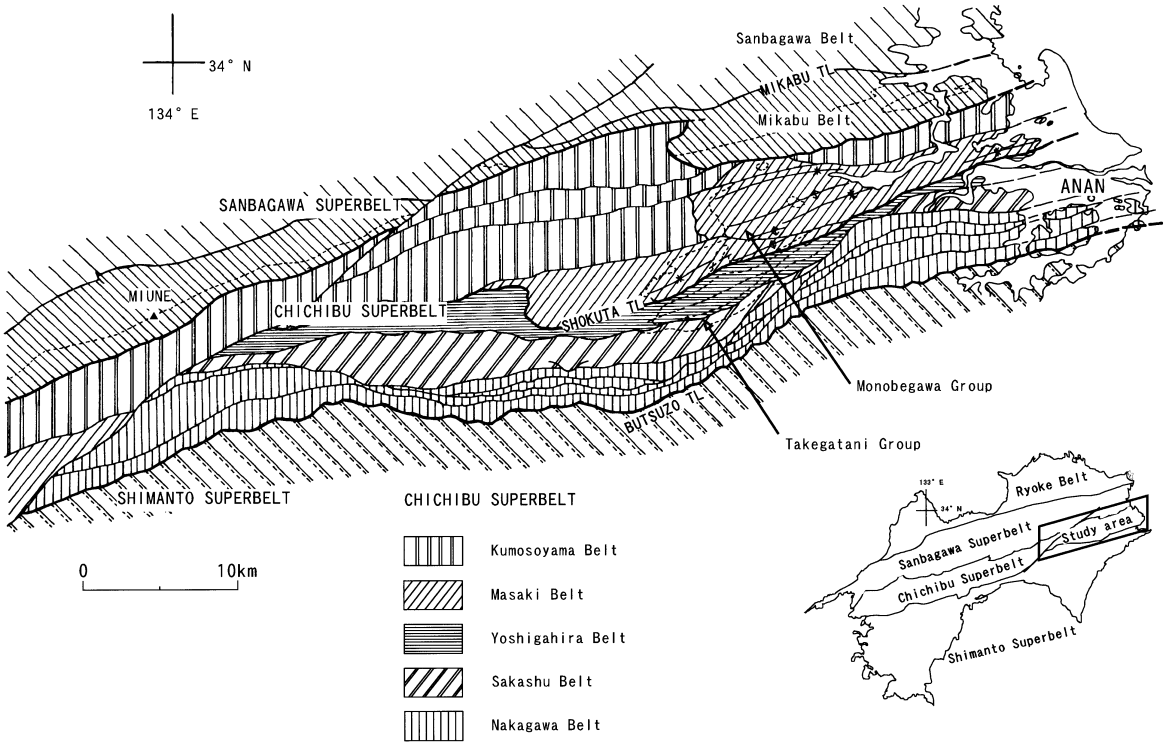

FIGURE 2. Tectonic subdivision of the Chichibu Superbelt in East Shikoku (after Ishida and Kozai, 2003), with the distribution of the Monobegawa, Takegatani and Nankai groups.

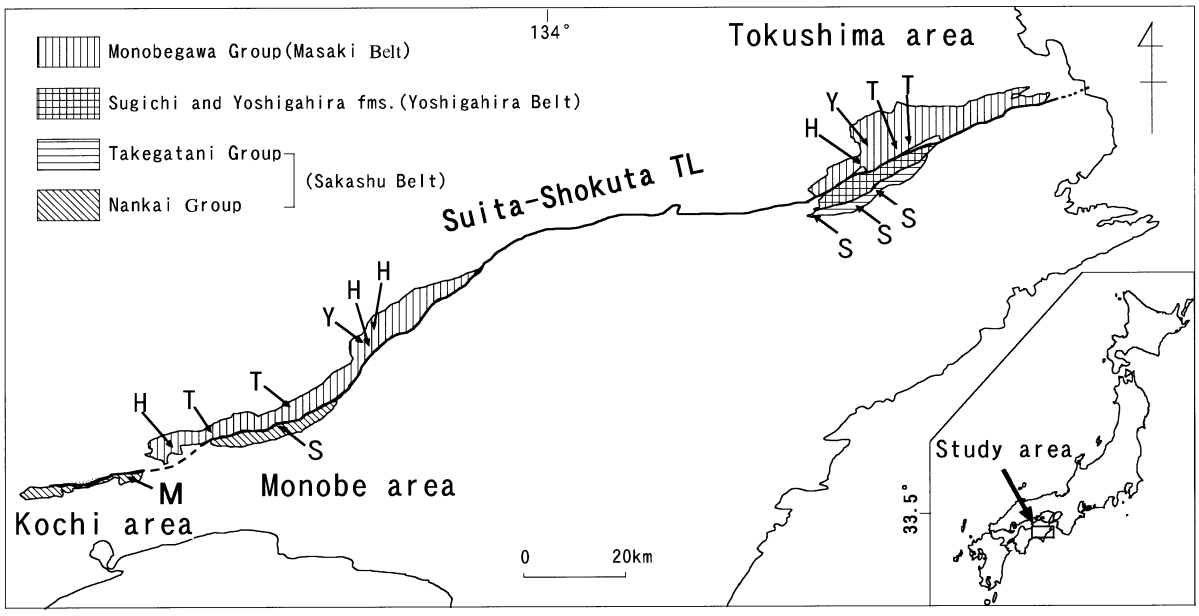

FIGURE 3. Map showing distribution of the Lower Cretaceous groups and formations with localities of the non-marine faunas in Central and East Shikoku. **M**: mixed assemblage, **T**: Tatsukawa fauna, **Y**: Yunoki fauna, **H**: Hibihara fauna, **S**: Shobu fauna.

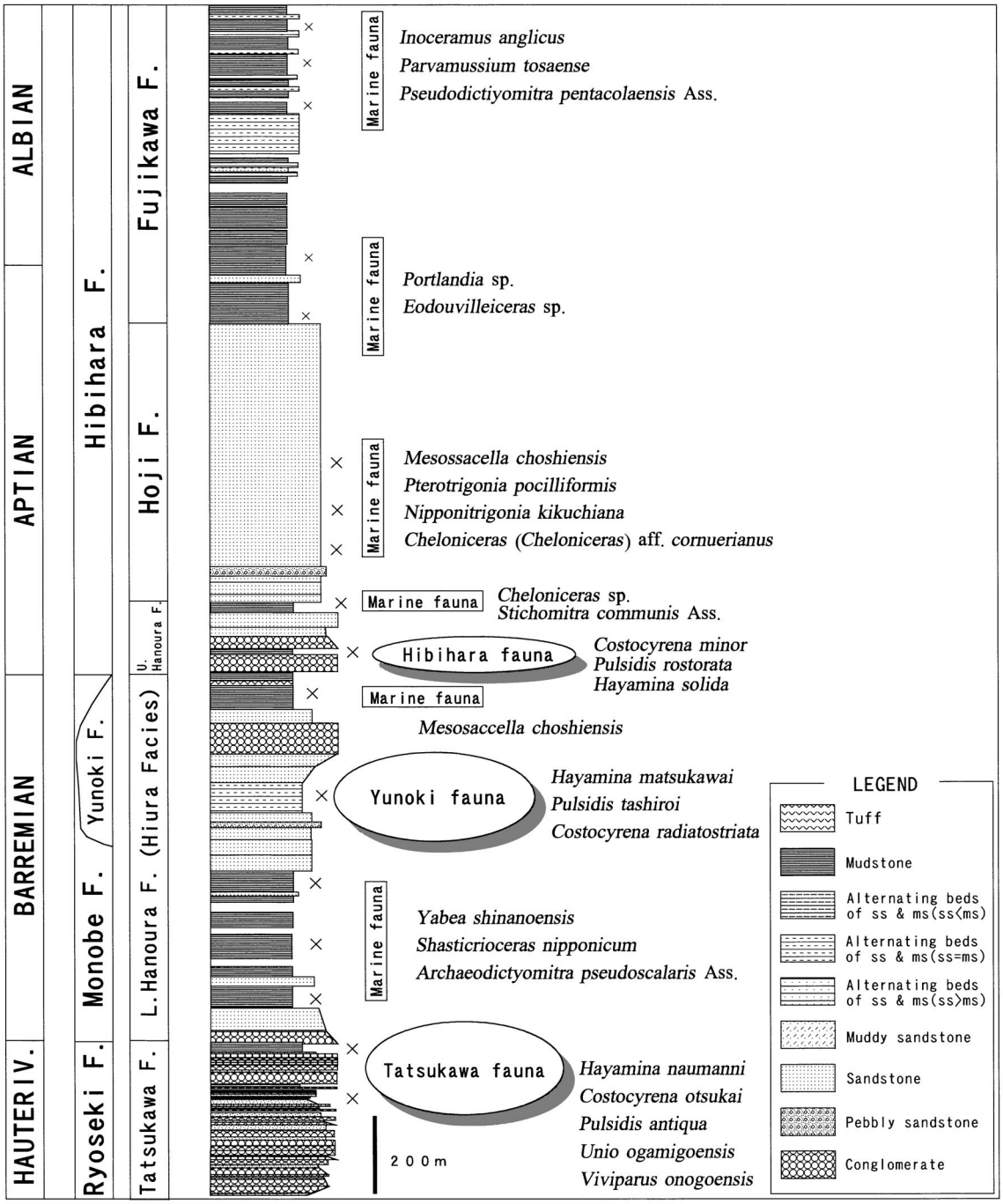

FIGURE 4. Generalized columnar section of the Monobegawa Group in the Masaki Belt.

3. Yunoki Formation and Hiura Facies

The formation is subdivided into three parts. Total thickness is about 450 m. The lower part is composed of gray sandstone with intercalations of thin layers of black mudstone and alternating beds of gray sandstone and dark gray muddy sandstone. The sandstone and mudstone contain many plant fragments, named Yunoki Flora (Matsuo and Kozai, 1982) and brackish-water bivalves, such as *Hayamina matsukawai*, *Costocyrena radiatostriata* and *Pulsidis tashiroi*.

The middle part consists of alternating beds of sandstone and muddy sandstone, gray sandstone, pebbly sandstone and conglomerate. The sandstone contains many plant fragments.

The upper part is composed of mudstone that contains some intercalated acidic tuff and alternating beds of mudstone and fine-grained sandstone. The mudstone contains radiolarians and some mollusks, such as *Portlandia sanchuensis*, *Parvamussium kimurai* and *Paracrioceras* sp. The uppermost part is Late Barremian (Tanaka et al., 1984)

4. Lower part of Hibihara Formation and Upper Hanoura Formation

The formations are subdivided into two parts. Total thickness is about 200 m. The lower part is composed of conglomerate. The conglomerate mainly comprises pebbles and cobbles of well-rounded granite, quartz porphyry and older sedimentary rocks. The igneous rocks ratio of about 50% in these conglomerates (Ishida, 1999) is larger than that of the Yunoki Formation (Miyamoto, 1980). The intercalated mudstone bed in the lower part of the formation yields abundant brackish-water bivalves such as *Hayamina solida*, *Costocyrena minor* and *Pulsidis rostrata*, and plants named Hibihara Flora (Matsuo and Kozai, 1982).

The upper part consists of sandstone and mudstone. The mudstone of the upper part contains very rare fossils, among which the Aptian ammonite *Cheloniceras* sp. and the radiolarian *Stichomitra communis* Assemblage (Ishida et al., 1992). These confer an Aptian.

5. Middle part of Hibihara Formation and Hoji Formation

The formations are subdivided into two parts. Total thickness is about 700 m. The lower part consists of conglomerate and pebbly sandstone. The upper part is composed of sandstone with intercalations of mudstone and acidic tuff. Hummocky cross stratification is observed in the sandstone beds. The sandstone contains abundant marine mollusks, such as *Pterotrigonia pocilliformis*, *Goshoraia minor*, *Nipponitrigonia sakamotoensis*, *Parahoplites* sp. and *Cheloniceras* (*Cheloniceras*) aff. *cornuelianus*. Especially, *P. pocilliformis* and *N. sakamotoensis* are abundant in the so-called "*Trigonia* sandstone". These fossils indicate Middle or Late Aptian.

6. Upper part of Hibihara Formation and Fujikawa Formation

The formations start with thick black mudstone, overlain by alternating beds of sandstone and mudstone. Total thickness is about 750 m. The mudstone of the lower part yields *Eodouvilleiceras* sp. and *Portlandia sanchuensis*. The upper part contains mollusks, such as *Inoceramus angulicus*, and the radiolarian *Pseudodictiyomitra pentacolaensis* Assemblage (Ishida et al., 1992, 1996). The formations are regarded as Late Aptian to Late Albian.

Yoshigahira Belt

The Yoshigahira Belt lies south of the Masaki Belt, being separated from it by the Suita–Shokuta Tectonic Line (Ishida and Kozai, 2001). Two Cretaceous formations, the Yoshigahira and Sugichi formations represent SL. Aptian non-marine mollusks are recognized in the Sugichi Formation (Fig. 5).

1. Yoshigahira Formation

The Yoshigahira Formation is subdivided into three parts. Total thickness is about 350 m. The lower part consists of a thick conglomerate that is characterized by dominant chert pebbles. The middle part consists of sandstone that contains marine mollusks such as *Pterotrigonia kesadoensis Ptychomya densicostata Rutitrigonia yeharai* and *Neithea atava*. The upper part consists of alternating beds of sandstone and mudstone, and mudstone. *Pterotrigonia kesadoensis* and *Rutitrigonia yeharai* are known from the Aptian Kesado Formation (Tanaka et al., 1998). *Rutitrigonia yeharai* regarded as the same species as R. sanchuensis by Tashiro (1990), also occurs in the Barremian Ishido Formation (Nakano, 1957; Hayami, 1975). *Neithea atava* is known from the Barremian Monobe and Lower Hanoura formations (Tashiro and Kozai, 1986). Therefore the Yoshigahira Formation can be regarded as Barremian–Aptian.

2. Sugichi Formation

The Sugichi Formation conformably overlies the Yoshigahira Formation. The formation is subdivided into two parts. Total thickness is about 250 m. The lower part is composed of conglomerate, calcareous sandstone and muddy sandstone. Intercalated mudstone in the conglomerate of the basal part contains rare brackish-water bivalves such as *Eomiodon* sp. The calcareous sandstone contains marine mollusks, such as *Pterotrigonia moriana*, *Xenocardita amanoi* and *Cheloniceras* sp. The upper part consists of alternating beds of sandstone and mudstone, with mudstone on top. The alternating beds yield marine mollusks such as *Plicatula takahashii*, *Leptosolen amabilis*, *Mesomiltha japonica* and *Isocyprina japonica*. *Cheloniceras* sp. confers an Aptian age to the formation.

Sakashu Belt

The Sakashu Belt lies south of the Yoshigahira Belt. The Sakashu Belt contains Cretaceous sediments, which build up the Nankai Group in the Monobe–Kochi area of Central Shikoku and the Takegatani Group in the Tokushima area of eastern Shikoku (Ishida, 1999). The Nankai Group is subdivided into the Funadani, Igenoki and Hagino formations (Tashiro, 1985; Kozai and Ishida, 2000). These until now partially investigated formations yield Early Cretaceous non-marine mollusks in the Funadani Formation, showing an affinity with the Shobu fauna. Aptian marine mollusks, including ammonites and bivalves, occur in the Igenoki and Hagino formations and resemble the faunas of the Uchiyama Formation of the Takegatani Group. The Takegatani Group is subdivided into the Shobu, Momijigawa and Uchiyama formations in ascending order

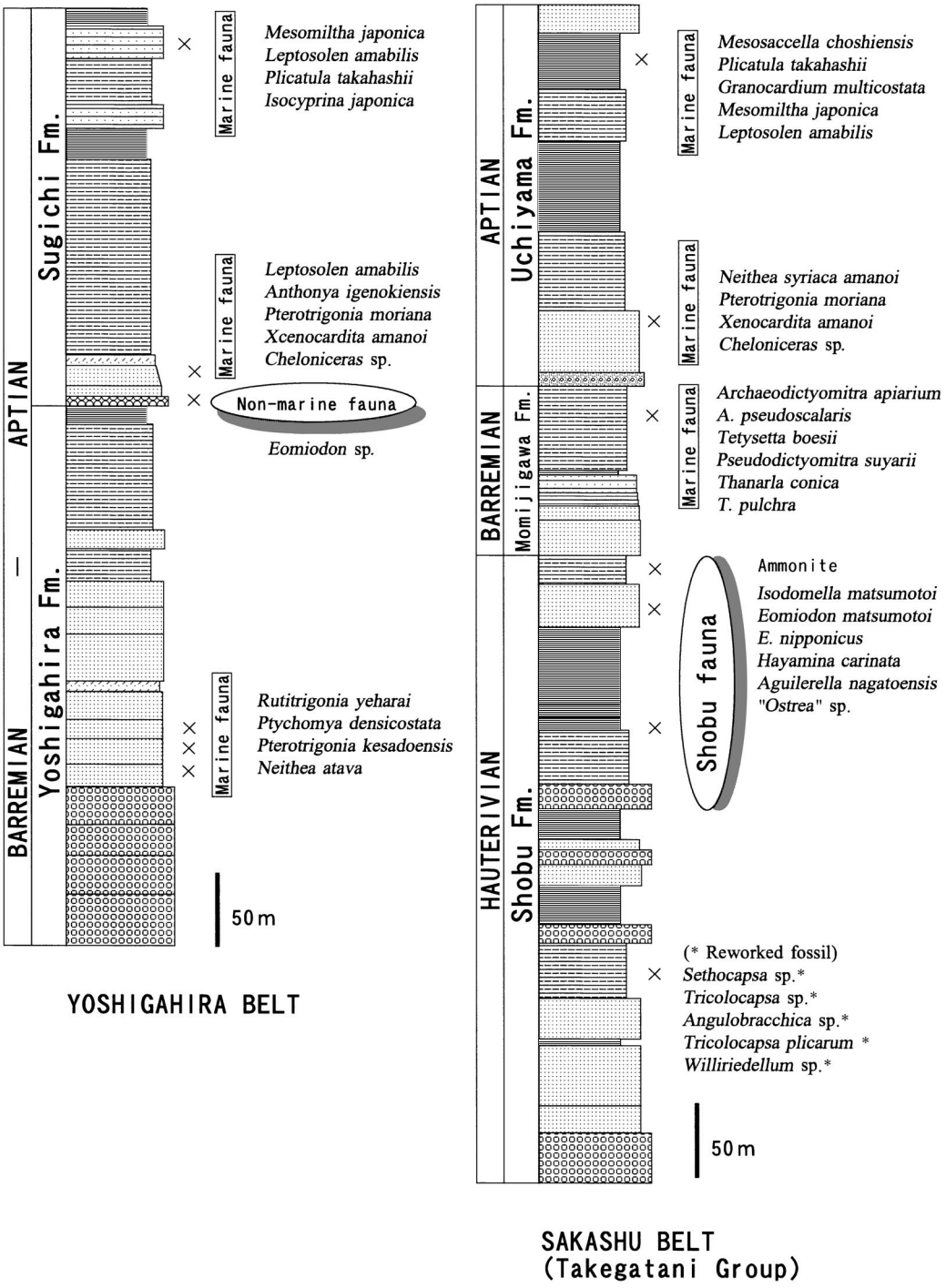

FIGURE 5. Generalized columnar section of the Lower Cretaceous formations in the Yoshigahira and Sakashu belts. Legend is the same as those in Fig. 4.

(Kozai et al., 2001; Ishida and Kozai, 2003) (Fig. 5). The Shobu Formation yields the non-marine Shobu fauna. The overlying Momijigawa and Uchiyama formations are dated as Barremian and Aptian by marine faunas. Contacts between these formations are conformable.

1. Shobu Formation

The Shobu Formation unconformably overlies the Early Jurassic–Earliest Cretaceous Kurisaka Formation of the Sakashu Belt. The formation is subdivided into three parts. Total thickness is about 400 m. The lower part starts with a

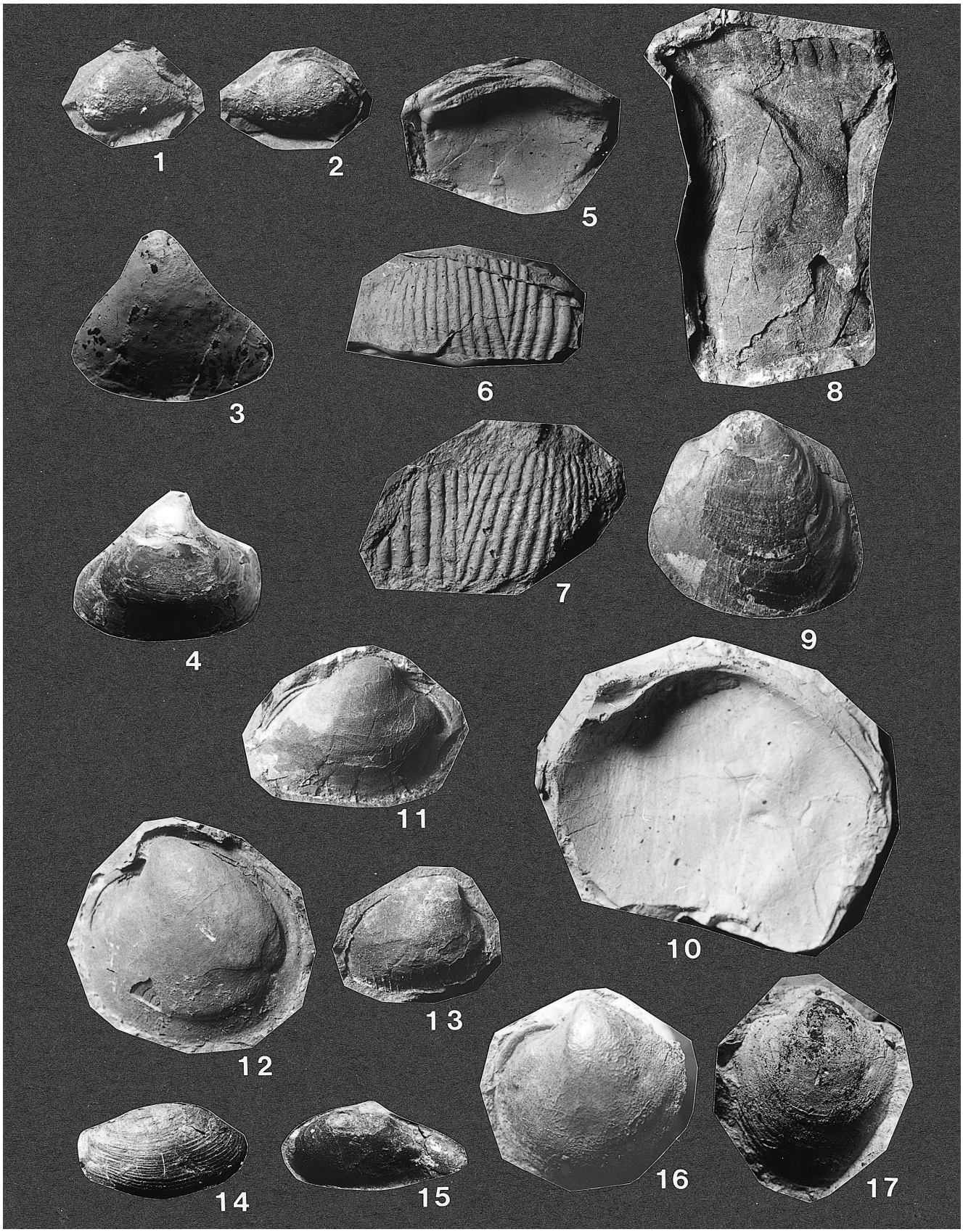

FIGURE 6.

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FIGURE 6. **1**−**2**: *Pulsidis nagatoensis* Ohta from the Funadani Formation（**1**: left valve, ×2; **2**: right valve, ×2）. **3**−**4**: *Hayamina carinata* Tashiro et Ohnishi from the Shobu Formation (**3**: left valve, ×1.5; **4**: right valve, ×1). **5**−**7**: *Trigonioides* (*Wakinoa*) *tetoriensis* Maeda from the Tatsukawa Formation (**5**: gum cast of internal mold of right valve, ×2; **6**: gum cast of right valve, ×1.5; **7**: gum cast of left valve, ×1.5). **8**: *Isognomon sanchuensis* (Yabe et Nagao) from the Yunoki formation, internal mold of left valve, ×1. **9**−**10**: *Batissa*? *antiqua* Kobayashi et Suzuki from the Tatsukawa Formation (**9**: left valve, ×2; **10**: gum cast of internal mold of right valve, ×1). **11**−**13**: *Tetoria sanchuensis* (Yabe et Nagao) from the Tatsukawa Formation (**11** and **13**: internal molds of right valves, ×2; **12**: internal mold of right valve. ×1.5). **14**−**15**: *Pulsidis tashiroi* Kozai from the Yunoki Formation (**14**: right valve, ×2; **15**: internal mold of left valve, ×2). **16**−**17**: *Tetoria yoshimoensis* Ohta from the Shobu Formation (**16**: internal mold of left valve, ×1.5; **17**: left valve, ×1.5).
All specimens are kept in Laboratory of Geosciences, Naruto University of Education.

conglomerate containing pebbles of igneous rocks and consistsupwards of sandstone and alternating beds of sandstone and mudstone. The latter contain reworked radiolarians, such as *Sethocapsa* sp., *Tricolocapsa plicarum*, *Angulobracchia* sp. and *Williredellum* sp. The middle part is composed of three sedimentary cycles of conglomerate, sandstone and mudstone. The mudstone of the third cycle yields the brackish-water bivalves *Hayamina carinata* and *Tetoria* sp. The upper part consists of sandstone and alternating beds of sandstone and mudstone. The sandstone and mudstone yield brackish-water bivalves *Hayamina carinata*, *Eomiodon nipponicus*, *E. matsumotoi*, *Isodomella matsumotoi*, *Aguilerella nagatoensis* and a fragment of ammonite.

2. Momijigawa Formation

The Momijigawa Formation mainly consists of sandstone in the lower part and mudstone and alternating beds of sandstone and mudstone in the upper part. Total thickness is about 110 m. The mudstone of the alternating beds in the upper part contains radiolarians, such as *Arcaeodictyomitra apiarium* and *A. pseudoscalaris* (Suyari and Ishida, 1985). These fossils indicate a Barremian age. Consequently the Shobu formation can be regarded Hauterivian.

3. Uchiyama Formation

The formation is subdivided into two parts. Total thickness is about 250 m. The lower part consists of pebbly sandstone and calcareous sandstone. The calcareous sandstone yields marine mollusks such as *Pterotrigonia moriana*, *Neithea syriaca amanoi*, *Xenocardita amanoi* and *Cheloniceras* sp. The upper part is composed of mudstone and alternating beds of sandstone and mudstone. The mudstone yields marine bivalves *Mesosaccella choshiensis*, *Granocardium multicostata*, *Leptosolen amabilis* and *Mesomiltha japonica*. These fossils indicate an Aptian age.

NON-MARINE MOLLUSCAN FAUNAS

Four non-marine faunas are identified within the Masaki and Sakashu belts. The data of non-marine bivalves from the Yoshigahira Belt is little, therefore it is not discussed here. The characteristic species of each fauna are described below (Figs. 6−8). All species from the Masaki and Sakashu belts are listed in Table 1. A paleontological study of these species is in preparation.

Masaki Belt

1. Tatsukawa fauna (Hauterivian)

Brackish-water bivalves from Lower Cretaceous formations are known under the broadly used name “Ryoseki fauna”. Recently non-marine mollusks were described from the Hauterivian Tatsukawa Formation (Tashiro and Okuhira, 1993; Kikuchi and Tashiro, 2002). The Tatsukawa Formation contains

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FIGURE 7. **1**−**2**: *Pulsidis antiqua* (Kozai) from the Tatsukawa Formation (**1**: internal mould of left valve, ×4; **2**: internal mold of right valve, ×4). **3**−**4**: *Pulsidis rostrata* Kozai from the Hibihara Formation, gum casts of left valves, ×3. **5**−**6**: *Unio ogamigoensis* Kobayashi et Suzuki from the Tatsukawa Formation (**5**: gum cast of right valve, ×1; **6**: right and left valves, ×1). **7**−**8**: *Hayamina naumanni* (Neumayr) from the Tatsukawa Formation (**7**: gum cast of internal mold of left valve, ×0.7, **8**: internal mould of right valve, ×1). **9**: *Hayamina bungoensis* Ohta from the Tatsukawa Formation, internal mold of right valve, ×1; **10**: *Costocyrena otsukai* (Yabe et Nagao) from the Tatsukawa Formation, left valve, ×2. **11**−**12**: *Eomiodon matsumotoi* from the Shobu Formation (**11**: left valve, ×1.5; **12**: right valve, ×1.5). **13**−**14**: *Aguilerella nagatoensis* (Ohta) from the Shobu Formation (**13**: internal mold of left valve, ×1; **14**: right valve, ×1). **15**−**16**: *Myopholas tanakai* Tashiro from the Tatsukawa Formation (**15**: right valve, ×1.5; **16**: gum cast of left valve, ×1).
All specimens are kept in Laboratory of Geosciences, Naruto University of Education.

FIGURE 8. **1**−**2**: *Isodomella matsumotoi* Ohta from the Funadani Formation (**1**: left valve, ×1.5; **2**: right valve, ×1.5). **3**−**4**: *Isodomella shiroiensis* (Yabe et Nagao) from the Tatsukawa Formation (**3**: gum cast of right valve, ×1; **4**: internal mold of right valve, ×1.5). **5**: *Myrene tetoriensis* (Kobayashi et Suzuki) from the Tatsukawa Formation, internal mold of left valve. ×1.3. **6**: *Hayamina solida* Tashiro et Ohnishi from the Hibihara Formation, right valve, ×1.3. **7**−**9**: *Costocyrena otsukai* (Yabe et Nagao) from the Tatsukawa Formation (**7** and **9**: gum casts of right valves, ×1.3; **8**: gum cast of right valve, ×1.3). **10**−**11**: *Costocyrena minor* Ohta from the Hibihara Foramtion, gum casts of right valves, ×5). **12**−**13**: *Costocyrena obsoleta* Tashiro from the Tatsukawa Formation, gum casts of right valves, ×2. **14**: *Protpcardia ibukii* Nalazawa et Murata from the Tatsukawa Formation, left valve, ×1. **15**−**16**: *Costocyrena radiatostriata* (Yabe et Nagao) from the Yunoki Formation (**15**: gum cast of left valve, ×1.3; **16**: gum cast of internal mould of right and left valves, ×1.5). **17**: *Hayamina matsukawai* Tashiro et Kozai from the Sebayashi Formation, left valve, ×1. **18**−**19**: *Eomiodon nipponicus* Ohta from the Shobu Formation, gum casts of right valves, ×1.5).
All specimens are kept in Laboratory of Geosciences, Naruto University of Education.

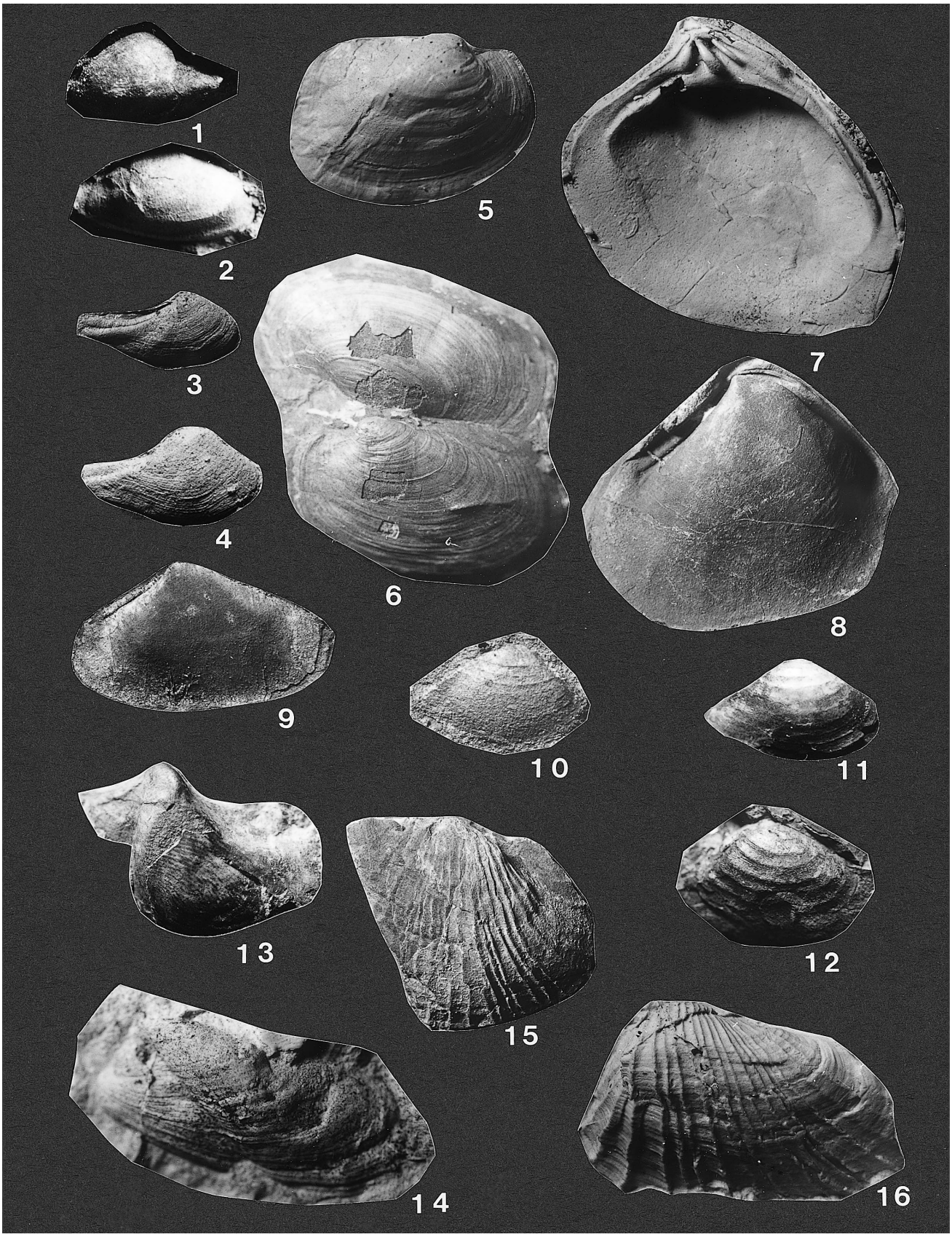

FIGURE 7.

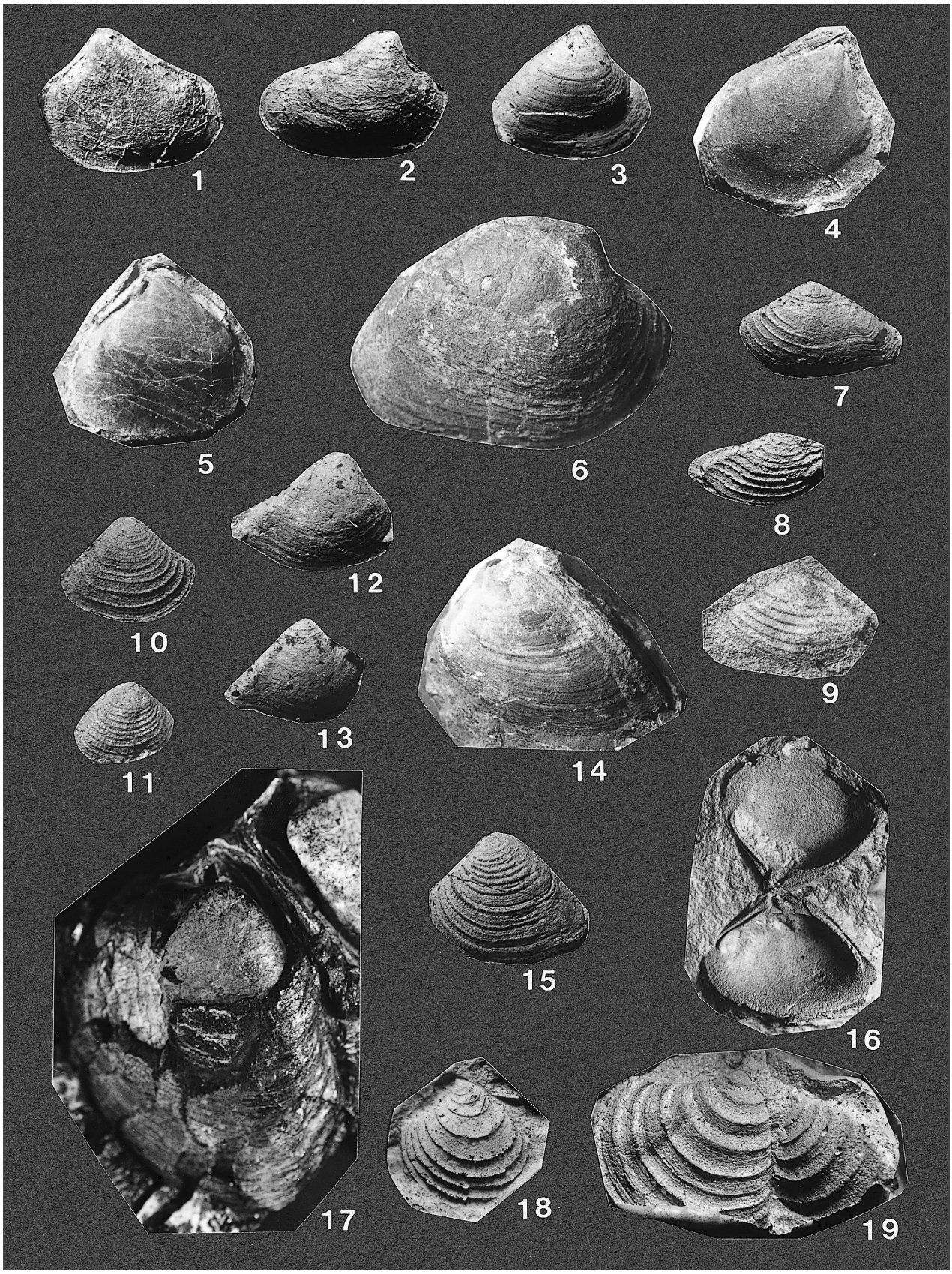

FIGURE 8.

TABLE 1. List of the Early Cretaceous non-marine bivalves of the Masaki and Sakashu faunal groups and the mixed assemblage.

	MASAKI FG			MIX	SAKASHU FG
	TA	YU	HI	TA/SHO	SHO
Species	Hauterivian	L. Barrem.	E. Aptian	Hauterivian	Hauterivian
Unio ogamigoensis Kobayashi et Suzuki	※				
Batissa? *antiqua* Kobayashi et Suzuki	※				
Triginioides (*Wakinoa*) *tetoriensis* Maeda	※				
Protopcardia ibukii Nakazawa et Murata	※			※	
Costocyrena otsukai (Yabe et Nagao)	※			※	
C. obsoleta Tashiro	※				
C. ohnishii Tashiro	※				
Hayamina naumanni (Neumayr)	※				
H. bungoensis Ohta	※				
H. minor Tashiro et Kozai	※				
Myrene tetoriensis (Kobayashi et Suzuki)	※				
Isodomella shiroiensis (Yabe et Nagao)	※				
Tetoria sanchuensis (Yabe et Nagao)	※	※		※	
Sphaerium coreanicum (Kobayashi et Suzuki)	※				
Pulsidis antiqua (Kozai)	※			※	
Myopholas tanakai Tashiro	※				
Viviparus onogoensis Kobayashi et Suzuki	※				
Aguilerella nagatoensis (Ohta)					※
Anomia pseudotruncata Yabe et Nagao					※
Ostrea ryosekiana Kobayashi et Suzuki					※
Eomiodon matsumotoi Ohta				※	※
E. nipponicus Ohta					※
Tetoria yoshimoensis Ohta					※
Hayamina carinata Tashiro et Ohnishi					※
Isodomella matsumotoi Ohta				※	※
Pulsidis nagatoensis Ohta					※
Bakevellia ominensis Nakazawa et Murata		※			
Isognomon sanchuensis (Yabe et Nagao)		※			
Costocyrena radiatostriata (Yabe et Nagao)		※			
Hayamina matsukawai Tashiro et Kozai		※			
Tetoria aff. *sanchuensis* (Yabe et Nagao)		※	※		
Pseudopisidium inflata Tashiro et Kozai		※			
Pulsidis tashiroi Kozai		※			
Barbatia hibiharensis Tashiro et Kozai			※		
Brachidontes pyriformis Tashiro et Kozai			※		
Placunopsis hibiharensis Tashiro et Kozai			※		
Scittila japonica Hayami			※		
Isocyprina hibiharensis Tashiro et Kozai			※		
Costocyrena minor Ohta			※		
Hayamina solida Tashiro et Ohnishi			※		
Resatrix japonica Tashiro et Kozai			※		
Pseudopisidium hibiharensis Tashiro et Kozai			※		
Pulsidis rostrata Kozai			※		

MASAKI FG: Masaki Faunal Group; MIX: Mixed assemblage; SAKASHU FG: Sakashu Faunal Group.
TA: Tatsukawa fauna; YU: Yunoki fauna; HI: Hibihara fauna; SHO: Shobu fauna.

a part of the brackish-water mollusks of the Ryoseki fauna together with freshwater mollusks. Therefore, the fauna from the Tatsukawa Formation is called Tatsukawa fauna.

The Tatsukawa fauna is characterized by brackish-water mollusks such as *Hayamina naumanni*, *Costocyrena otsukai*, *Myrene tetoriensis* and *Pulsidis antiqua*, and freshwater mollusks such as *Unio ogamigoensis*, *Trigonioides* (*Wakinoa*) *tetoriensis*, *Batissa*? *antiqua*, *Spaerium coreanicum* and *Viviparus onogoensis*. These brackish-water mollusks are known from the Hauterivian Koshigoe Formation of the Haidateyama Group in Kyushu (Tanaka, 1989) and the Hauterivian Shiroi Formation in Kanto (Matsukawa, 1979), Outer Zone of Southwest Japan, north of the Kurosegawa tectonic zone. Freshwater elements of the Tatsukawa fauna are common in the faunas of the Tetori Group and to a minor degree in the Myogog fauna of the Korean Kyongsang Basin. *Unio ogamigoensis*, *Batissa*? *antiqua*, *Myrene tetoriensis* and *Viviparus onogoensis* occur in the Okurodani, Kuwajima and

Izuki formations of the Tetori Group (Tamura, 1990).

2. Yunoki fauna (Late Barremian)

The Yunoki fauna is characterized by the occurrence of brackish-water mollusks such as *Hayamina matsukawai*, *Pulsidis tashiroi* and *Costocyrena radiatostriata*. *H. matsukawai* and *C. radiatostriata* are known from the Barremian–Aptian Sebayashi Formation of Kanto. The Sebayashi Formation also contains the freshwater bivalve *Nippononaia ryosekiana* (Hayami and Ichikawa, 1965), a good marker for correlation of the Sebayashi Formation and freshwater formations of other areas. *N. ryosekiana* also occurs in the Kitadani Formation, uppermost part of the Tetori Group (Isaji and Hasegawa, 1990; Tamura, 1990; Isaji, 1993), and it is important in the comparison of Japanese and Korean non-marine deposits. The Kitadani fauna contains six freshwater species (Tamura, 1990): *Nagdongia soni*, *Nippononaia tetoriensis*, *N. ryosekiana*, *Plicatounio naktongensis naktongensis*, *P. naktongensis multiplicatus*, *Pseudohyria matsumotoi*, and *Trigonioides* (*Wakinoa*) *tetoriensis*. *P. naktongensis naktongensis* and *P. naktongensis multiplicatus* are known from the Sengoku Formation of the Kanmon Group in Kyushu and from the Hasandong Formation, lowermost part of the Shindong Group in the Kyongsang Basin of Korea. *P. matsumotoi* and *N. ryosekiana* are known from the Yeonhwandong Formation (Nakdong Formation) of the Shindong Group (Yang, 1978, 1979) and also correlates with the Kitadani and the Sebayashi formations (Isaji and Hasegawa, 1990; Tamura, 1990; Isaji, 1993).

3. Hibihara fauna (Early Aptian)

The Hibihara fauna is characterized by the occurrence of brackish-water mollusks such as *Hayamina solida*, *Costocyrena minor* and *Pulsidis rostrata*, and shallow marine mollusks such as *Isocyprina hibiharensis*, *Resatrix japonica* and *Pseudopisidium hibiharensis*. Among them, *P. rostrata*, *H. solida* and *C. minor* are restricted to the Early Aptian.

Out of thirteen species composing the fauna, seven are brackish and six shallow marine. The shallow marine *P. hibiharensis* and *I. hibiharensis*, have joined valves, whereas the brackish-water *C. minor* and *P. rostrata* consist of separated right and left valves, suggesting that the brackish water elements were transported into the shallow marine environment.

Sakashu Belt

1. Shobu fauna (Hauterivian)

The Shobu fauna is characterized by the occurrence of brackish water mollusks such as *Hayamina carinata*, *Isodomella matsumotoi*, *Eomiodon matsumotoi*, *Eomiodon nipponicus*, *Pulsidis nagatoensis* and *Aguilerella nagatoensis*. These species are known from the Yoshimo Formation of the Toyonishi Group in Chugoku and the Kawaguchi Formation of the Pre-Sotoizumi Group in Kyushu. The Yoshimo Formation contains eleven brackish-water species (Ohta, 1981). Among them, *Ostrea ryosekiana*, *A. nagatoensis*, *E. nipponicus*, *E. matsumotoi*, *I. matsumotoi*, *P. nagatoensis*, *Myopholas carinatus* and *Tetoria yoshimoensis* are recognized in the Shobu fauna.

The Kawaguchi Formation contains *A. nagatoensis*, *I. matsumotoi*, *E. matsumotoi* and *P. nagatoensis* in common with the Shobu fauna (Ohta, 1977). Early to middle Hauterivian radiolarians and marine mollusks occur in the middle part of the Kawaguchi Formation (Tamura and Nishida, 1989; Kashiwagi et al., 2002) and an ammonite is found in the upper part of the Shobu Formation. This indicates the alternating marine and brackish-water environments within the same unit.

The Lower Cretaceous Funadani Formation of the Nankai Group in Shikoku contains *P. nagatoensis*, *I. matsumotoi* and *E. nipponicus*, typical elements of the Shobu fauna.

FAUNAL GROUPS

The four non-marine molluskan faunas from East and Central Shikoku define two mutually exclusive faunal groups (Table 1). The Masaki Faunal Group is restricted to the Masaki Belt and consists, based on their stratigraphic distributions, of the Tatsukawa, Yunoki and Hibihara faunas. The Sakashu Faunal Group is restricted to the Sakashu Belt and contains the Shobu fauna. In the Masaki Belt, only the Hauterivian Tatsukawa fauna can serve for faunal comparison between Masaki and Sakashu faunal groups.

Characteristic species of the Masaki Faunal Group belong to genus *Costocyrena* (Hauterivian–Aptian), *Hayamina naumanni* (Hauterivian), *H. matsukawai* (Late Barremian), H. *solida* (Aptian), *Isodomella shiroiensis* (Hauterivian), *Tetoria sanchuensis* and similar form (Hauterivian–Aptian), *Unio ogamigoensis* (Hauterivian) and *Batissa*? *antiqua* (Hauterivian).

On the other hand, characteristic species of the Sakashu Faunal Group are belong to genus *Eomiodon* (Hauterivian), *Hayamina carinata* (Hauterivian), *Isodomella matsumotoi* (Hauterivian), *Aguilerella nagatoensis* (Hauterivian) and *Tetoria yoshimoensis* (Hauterivian). The Sakashu Faunal Group in some cases occurs together with ammonite.

The brackish-water mollusks from the Tatsukawa fauna of the Masaki Faunal Group occur with freshwater mollusks. Joined valves of brackish-water bivalves such as *Hayamina naumanni* of the Tatsukawa fauna commonly occur in mudstone beds, and some of them show life position. Specimens of *Trigonioides* (*Wakinoa*) *tetoriensis* are fragmented and separated valves, but some specimens of *Unio ogamigoensis* are joined valves. Neomiodontidae, Corbiculidae and Corbulidae dominate in oligo- and mesohaline regimes (Fürsich, 1993). *Unio* and *Viviparus* are freshwater to lower oligohaline elements (Fürsich, 1993). Therefore the environment of the Tatsukawa fauna of the Masaki Faunal Group was freshwater to

mesohaline.

On the other hand, joined valves of *Aguilerella nagatoensis* of the Shobu fauna of Sakashu Faunal Group occur in mudstone and sandstone beds. The epifaunal bivalves become abundant only in brachyhaline regimes (Fürsich, 1993). The Sakashu Faunal Group is devoid of freshwater mollusks, ammonites occur and almost all specimens of *Eomiodon* and *Tetoria* are separated. Therefore the environment of the Shobu fauna of the Sakashu Faunal Group indicates oligohaline to euhaline environmental conditions. It exhibits a higher salinity than the age equivalent Tatsukawa fauna of the Masaki Faunal Group.

PALAEOGEOGRAPHIC CONSIDERATIONS

The Shikoku Early Cretaceous molluskan faunas are subdivided into two faunal groups, a northern Masaki Faunal Group and a southern Sakashu Faunal Group, separated by the Suita–Shokuta Tectonic Line (Fig. 3). The Tatsukawa fauna of the Masaki Faunal Group contains exclusively freshwater mollusks. The Shobu fauna of the Sakashu Faunal Group contains an ammonite fossil besides non-marine mollusks (Kozai et al., 2001). Tashiro (1985, 1986, 1994, 2000) pointed out that the Early Cretaceous bivalve faunas are separated into a Tethyan Nankai Group type (Shobu fauna) and a North Tethyan Monobegawa Group type (Tatsukawa fauna).

Two theories about the origin of these two faunal types were put forward: that of a sinistral fault movement (Tashiro 1985, 1986, 1994, 2000) and that of two different marine currents (Matsukawa and Eto, 1987; Matsukawa and Tsuneoka, 1993),

Matsukawa and Eto (1987) pointed to the existence during the Hauterivian–Barremian transgression of a boreal and an equatorial current along the Pacific coast of Japan, the influence of both currents being witnessed by the distribution of Barremian ammonites. Matsukawa and Tsuneoka (1993) infer that the Monobegawa and Nankai groups are contemporaneous heterotopic facies. Since water temperature is inferred as cause for the different faunal groups, radiolarian assemblages are expected to be different as well, this is, however, not the case, as the same radiolarian assemblage occurs in both groups (Ishida and Hashimoto, 1991).

The recent discovery of a mixed assemblage of Masaki and Sakashu faunal groups in the Kochi area (Fig. 3) revealed *Costocyrena otsukai*, *Protocardina ibukii*, *Tetoria sanchuensis* and *Pulsidis antiqua*, of the Tatsukawa fauna (Masaki Faunal Group), together with *Isodomella matsumotoi* and *Eomiodon matsumotoi* of the Shobu fauna (Sakashu Faunal Group) (Table 1) (Kozai and Ishida, 2003). This suggests that both faunal groups were not geographically isolated from each other and that mixed assemblage of both groups occurred in a transitional zone where environmental conditions permitted the dwelling of the two faunal groups.

In his sinistral fault movement hypothesis, Tashiro (1985, 1986, 1994, 2000) proposed an original south–north distance of at least 1,000 km separating the two groups, subsequently juxtaposed to each other into their present position by movement on the Kurosegawa Tectonic Line (Suita–Shokuta TL). The Tethyan and North Tethyan faunas that correspond respectively to our Sakashu and Masaki faunal groups, presently separated by the Suita–Shokuta Tectonic Line, were initially influenced by a south–north current originating from the equator. If we follow Tashiro's idea, the transitional zone was originally formed between the Tethyan and North Tethyan faunas. However, if the transitional zone was located somewhere between these distant domains during the Hauterivian, only the North Tethyan fauna should be expected south of the Suita–Shokuta Tectonic Line further northeast of Shikoku. This is not the case, since Tanaka et al. (2000) report the presence of taxa of the Tethyan fauna in the Kii Peninsula, situated northeast of Shikoku.

As such, both the "current" and "sinistral fault movement" theories are not supported in the field. As mentioned before, the Hauterivian environments differ in salinity, the Sakashu Faunal Group showing higher salinity than the Masaki Faunal Group. An iguanodontid tooth, described from the uppermost part of the Tatsukawa Formation (Morozumi et al., 1995), which also yields a fauna belonging to the Masaki Faunal Group (Tatsukawa fauna), supports a more continental origin than that of the age-equivalent exclusively Shobu fauna. It is therefore most likely that the factor controlling these faunal groups is salinity.

Since the Lower Cretaceous deposits of Japan were all formed on the same continental margin of Asia, it seems reasonable that relations between the different environmental conditions of two faunal groups show a geographic continuity and that a transitional zone existed between the Masaki Belt, nearest to a continent, and the Sakashu Belt, under increasing marine influence.

CONCLUSION

1. Four characteristic non-marine faunas are proposed: the Hauterivian Tatsukawa and Shobu faunas, the Late Barremian Yunoki fauna and the Early Aptian Hibihara fauna.
2. Lower Cretaceous non-marine faunas from Central and East Shikoku are divided into the mutually exclusive Masaki and Sakashu faunal groups, conforming with the recent subdivision of the Chichibu Superbelt.
3. Biostratigraphic clues for non-marine faunas of Japan and Korea are provided in Central and East Shikoku, where the four non-marine faunas alternate with marine ones.
4. Salinity is the main differential factor between the Masaki and Sakashu faunal groups.
5. Discovery of a mixed assemblage of the two faunal groups suggests the existence of a transitional zone where environments, defined by different salinity, possibly join.

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* : in Japanese with English abstract

** : in Japanese

*** : in Korean with English abstract