Geosciences Journal
Vol. 10, No. 3, p. 217 − 235, September 2006

Radiolarians, bivalves and the J/K boundary in the Birafu Formation, southern Kurosegawa Belt, Central Shikoku, SW Japan

Takeshi Kozai* *Laboratory of Geology, Faculty of Science Education, Naruto University of Education, 748 Takashima, 772-8502 Naruto, Japan*
Keisuke Ishida *Laboratory of Geology, Faculty of Integrated Arts and Sciences, University of Tokushima, 1-1 Minamijosanjima, Tokushima 770-8502, Japan*
Yasuo Kondo *Department of Natural Environmental Science, Faculty of Science, Kochi University, 2-5- 1 Akebono, Kochi 780-8520, Japan*

ABSTRACT: The Oxfordian–Berriasian Birafu Formation in the southern Kurosegawa Belt (Permian accretion terrane), Central Shikoku, SW Japan, yields micro- and mega-faunas that contribute to the biostratigraphy across the Jurassic-Cretaceous boundary. The type section consists of turbiditic sandstone and mudstone with an upward-fining tendency in the lower members (A1-A3). The middle members (B1-B2) are coarse sandstone and mudstone with muddy limestone intercalations, whereas the upper member C is characterized by a fine-grained turbiditic succession. Radiolarians define the assemblage zones (AZ): *Kilinora spiralis* AZ (Oxfordian) in member A2, *Loopus primitivus* AZ (Tithonian) in the upper part of member A3, and *Pseudodictyomitra carpatica* AZ (Berriasian - lower Valanginian) in members B2 and C. These give at least an Oxfordian - Berriasian total time-range to the Birafu Formation. The mixed marine and brackish bivalve assemblage of members B1 and B2 (lower part) comprises *Grammatodon takiensis* Tamura, *Pterotrigonia toyamai* (Yehara) and *Ctenoides tosanus* Kimura, the range of which is Late Jurassic to Earliest Cretaceous, and *Aguilerella nagatoensis* (Ohta), *Miltha japonica* Tashiro and *Isocyprina japonica* Tashiro and Kozai, having an Early Cretaceous range. The concurrent range of Jurassic to Cretaceous bivalves and exclusively Cretaceous species is significant for the clarification of bivalve evolution across the Jurassic - Cretaceous boundary. The Berriasian appearance of Cretaceous marine and non-marine bivalves takes place while Late Jurassic marine bivalves still survived. We consider Member B1 as Berriasian with the J/K boundary situated at its base.

Key words: Bivalves, radiolarians, J/K boundary, Kurosegawa, Japan

1. INTRODUCTION

Jurassic to Cretaceous non-marine, shallow marine and slope basin deposits are widely scattered over Japan. In Northeast Japan, some formations straddle the J/K boundary. The Isokusa Formation of the Karakuwa Group yields latest Jurassic and earliest Cretaceous ammonites with abundant bivalves (Sato, 1958; Hayami, 1960; Takahashi, 1973). The Ayukawa Formation of the Ojika Group yields Berriasian ammonites and bivalves. The Koyamada Formation of the Somanakamura Group yields ammonites and bivalves that indicate Tithonian and Berriasian ages. All these Late Jurassic and earliest Cretaceous bivalve faunas are very similar.

Southwest Japan is subdivided structurally into the Inner and Outer zones. In the Inner Zone, the J/K boundary falls within the non-marine deposits (Kobayashi and Suzuki, 1939; Hirano, 1971). The J/K boundary remains often concealed in the marine deposits of the Outer Zone (Tanaka, 1989), except in the Birafu Formation of the Sakashu Belt (a part of the Chichibu Superbelt), in the Monobe area of Central Shikoku (Ishida and Kozai, 2004).

Complementing the initial find of bivalves and ammonites by Yehara (1923), Kobayashi and Fukada (1947), the discovery of radiolarians, ranging from Oxfordian to Berriasian and the further identification of Jurassic marine bivalves and of an association of marine and brackish-water Cretaceous mollusks (Morino *et al*., 1989; Kozai *et al*., 2004) initiated the discussion of the remarkable correlation between radiolarians and particularly the earliest Cretaceous bivalves in the Birafu Formation.

The radiolarian biostratigraphy sets accurate age constraints for the completely different bivalve associations in the late Jurassic (Kimmeridgian–Tithonian) and Early Cretaceous (Hauterivian - Barremian). This exceptional situation may shed light on the evolution of the bivalve faunal association across the Jurassic–Cretaceous boundary in Japan. Detailed studies of Late Jurassic (Oxfordian-Tithonian) bivalves were carried out by Tamura (1959a-d, 1960a-c), Hayami (1961) and Kimura (1951, 1956), whereas for the Early Cretaceous (Hauterivian-Barremian) bivalves, investigations were done by Hayami (1965a,b), Ohta (1973, 1974) and Tashiro and Kozai (1984, 1986, 1988, 1989, 1991, 1994,). Hayami (1961) identified three bivalve association groups: Hettangian-Aalenian, Bajocian-Bathonian and Callovian-Tithonian. He also pointed out that some of the younger Jurassic elements survived into the earliest Cretaceous. Later, the J/L faunal turnover was placed within the "Neocomian" (Hayami, 1975).

*Corresponding author: kozai@naruto-u.ac.jp

2. GEOLOGICAL SETTING

The Inner and Outer zones of southwest Japan are separated by the Median Tectonic Line. The Outer Zone is subdivided into the Sanbagawa, Chichibu and Shimanto superbelts. In eastern Shikoku, the Chichibu Superbelt has been subdivided from north to south into five belts: the Kumosoyama Belt, the Masaki, Yoshigahira and Sakashu belts and the Nakagawa Belt (Ishida and Kozai, 2003). The Masaki Belt is composed of Permian accretionary complex (PAC) with Upper and Lower Cretaceous slope basin deposits (SL), e.g. the Monobegawa Group. The Yoshigahira Belt is a tectonic unit that was formed after the sedimentation of the Lower Cretaceous SL; it consists of the Siluro-Devonian Kurosegawa Tectonic Zone *sensu stricto*, Permian-Triassic and Jurassic accretionary complexes (AC), and Lower Cretaceous SL. The Sakashu Belt is composed of Permian AC with Siluro-Devonian blocks, uppermost Permian, Middle-Upper Triassic, Jurassic and Lower Cretaceous SLs. The Birafu Formation (Morino *et al*., 1989) is one of the slope-basin deposits within the Sakashu Belt (Kozai *et al*., 2004). The Birafu Formation extends between the Nankai Group (Yoshigahira Belt) and Monobegawa Group (Masaki Belt) to the North and the Nakagawa Belt to the South (Fig. 1).

3. DISTRIBUTION AND STRATIGRAPHY OF THE BIRAFU FORMATION

The Birafu Formation is exposed in Central Shikoku, east of Tosamyamada (Kochi Prefecture), striking generally ENE-WSW and dipping steeply south. The type section of the Birafu Formation is located at Ogawa along the Nishinokawa River, where a thickness of 725 m was measured (Fig. 2). The formation is subdivided into six members (Fig. 3).

Member A1 is composed of alternating beds of dark gray mudstone and sandstone. In the lower part of the member, 1 cm to 10 cm thick sandstone layers are well graded. Parallel and current ripple laminations are also observed. In the upper part of the member, the sandstone beds become thicker. The total thickness of the unit A1 is approximately 40 m.

Member A2 contains medium-grained massive sandstone, muddy sandstone, sandy mudstone, mudstone and tuff. The muddy sandstone bed of unit A2 contains fragments of bivalves. The Kimmeridgian ammonite *Ataxioceras kurisakense* Kobayashi and Fukada was described from this member by Kobayashi and Fukada (1947). The member is topped by a mudstone (32601R) with tuff intercalation. The mudstone yields Oxfordian radiolarians. This unit is approximately 80 m thick.

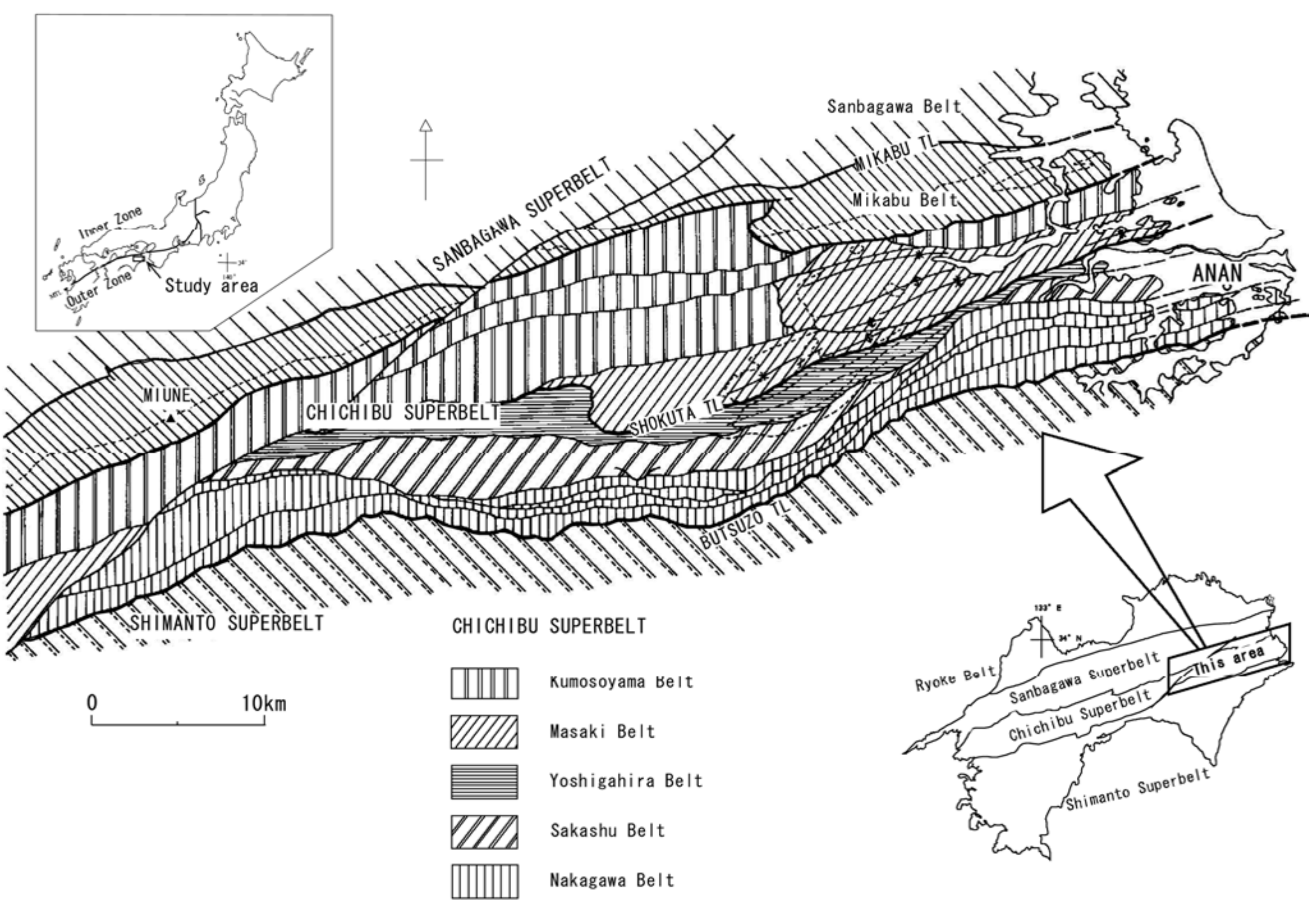

Fig. 1. Tectonic subdivision of the Chichibu Superbelt in East Shikoku (modified after Ishida and Kozai, 2003; Kozai and Ishida, 2003).

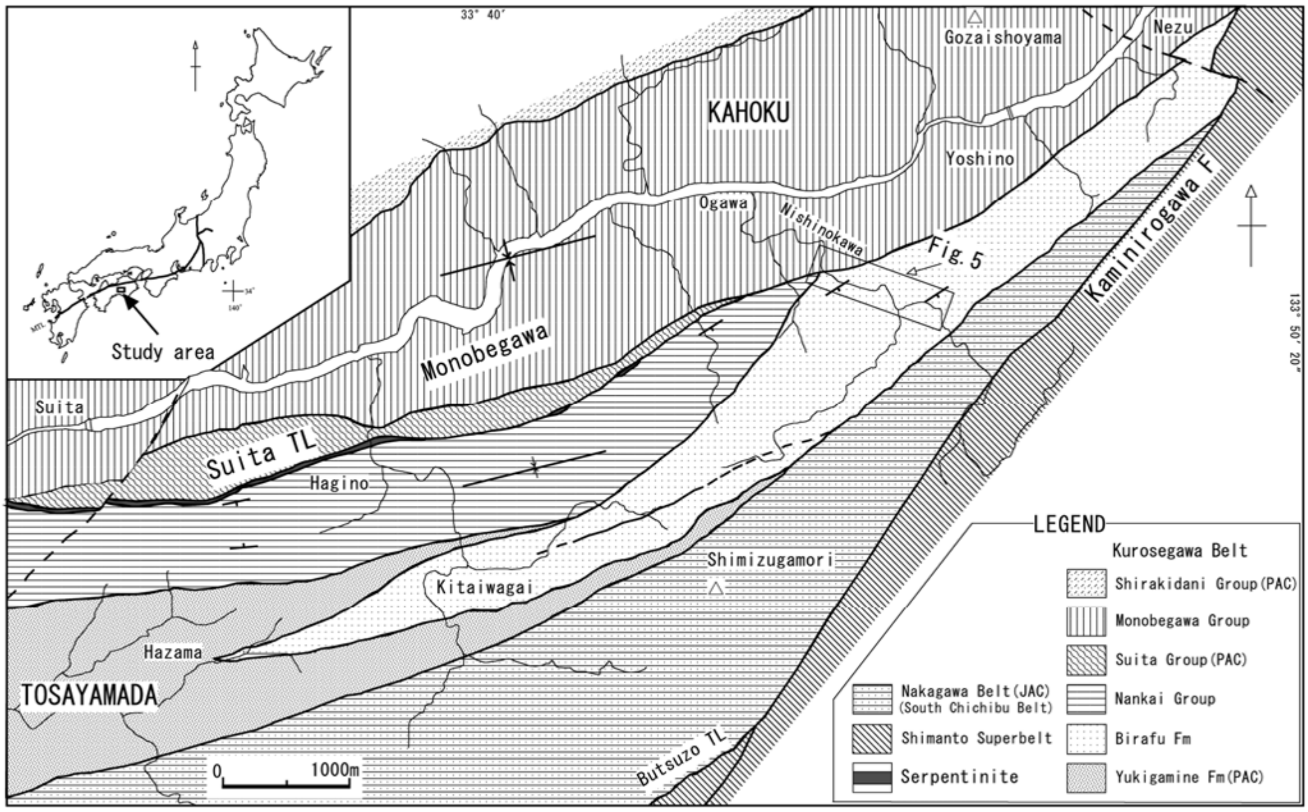

Fig. 2. Map showing the distribution of the Birafu Formation in Central Shikoku (modified after Kozai et al., 2004).

Member A3 is characterized by sandy mudstone and mudstone. The upper part of the member is again intercalated with tuff and the mudstone yields rare bivalves and Tithonian radiolarians (32602R). This unit is approximately 40 m thick.

The bivalve yielding Member B1 consists of conglomerate, sandstone, mudstone, limestone and alternating beds of sandstone and mudstone. The conglomerate contains chert, shale and granite pebbles. The medium grained poorly sorted sandstone beds contain coaly inclusions and abundant nonmarine and marine mollusks. Limestone beds are oolitic-peloidal and bioclastic grainstones (Morino, 1993). This unit is approximately 170 m thick.

Member B2 is composed of alternating sandstone, mudstone and limestone beds. The well-sorted, fine- to medium-grained sandstone is arkosic. The mudstone is intercalated with tuff and yields Berriasian radiolarians (32604R, 32605R). The limestone is sandy and laminated. This unit is approximately 115 m thick.

Member C is composed of sandstone, mudstone, tuff and alternating beds of sandstone and mudstone. The sandstone is medium-grained, graded and ranging from 1 cm to 10 cm in thickness. Parallel and current ripple laminations are observed. The mudstone yielded radiolarians (32606R, 32607R, 32608R, 32609R). This unit is approximately 280 m thick.

4. RADIOLARIAN BIOSTRATIGRAPHY AND GEOLOGICAL AGE OF THE BIRAFU FORMATION

The Late Jurassic–Early Cretaceous radiolarian biostratigraphy in Japan was established by Matsuoka and Yao (1986). In the type section of the Birafu Formation, three assemblage zones were found in ascending order: the *Kilinora spiralis* Assemblage Zone, the *Loopus primitivus* Assemblage Zone and the *Pseudodictyomitra carpatica* Assemblage Zone. The *Kilinora spiralis* Assemblage Zone is found near the top of Member A2 (32601R). The *Loopus primitivus* Assemblage Zone occurs in the uppermost part of Member A3 (32602R). The *Pseudodictyomitra carpatica* Assemblage Zone ranges from the base of Member B2 (32604-5R) and throughout Member C (32606-9R). The presence of Late Jurassic beds in the Nishinokawa section was first established by the occurrence of *Ataxioceras kurisakense,* a Lower Kimmeridgian ammonite (Kobayashi and Fukada, 1947).

4.1. *Kilinora spiralis* Assemblage Zone

Although the details of the top and base of this zone have not yet been determined, the *Kilinora spiralis* Assemblage Zone is characterized by *Kilinora spiralis* (Matsuoka) and the common occurrence of *Hsuum maxwelli* Pessagno, *Sti-*

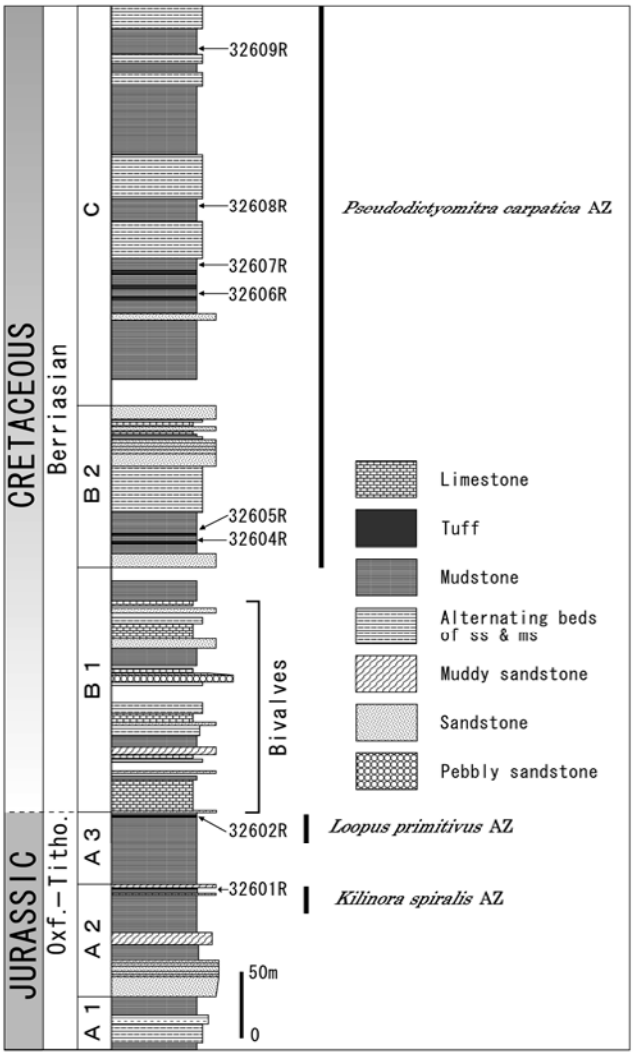

Fig. 3. Lithological section of the Birafu Formation with location of Radiolarian assemblage zones.

chocapsa robusta Matsuoka, *Tethysetta dhimenaensis* (Baumgartner), *Tricolocapsa conexa* Matsuoka, *Tricolocapsa* sp. cf. *T. parvipora* Tan, *Archaeodictyomitra amabilis* Aita, *Eucyrtidiellum nodosum* Wakita, *Ristola procera* (Pessagno), *Stylocapsa tecta* Matsuoka, and *Tricolocapsa plicarum* Yao (Fig. 4). *Cinguloturris carpatica* Dumitrica and *Mirifusus guadalupensis* Pessagno are rare.

Correlation and Age: The present radiolarian assemblage corresponds to the *Kilinora spiralis* Zone (Matsuoka and Yao, 1986) of Oxfordian age (Late Jurassic). Based on the co-occurrence of *Eucyrtidiellum ptyctum* (Riedel and Sanfilippo) with *Kilinora spiralis* (Matsuoka), the top horizon (32601R) of Member A2 corresponds to Subzone 2γ (Middle Oxfordian) of Hull (1997) at Stanley Mountain, California. Baumgartner et al. (1995) considered *Kilinora spiralis* (Matsuoka) to range from Middle Bathonian to Early Callovian (Unitary Association zones 6 and 7).

4.2. *Loopus primitivus* Assemblage Zone

Although the details of the top and base of this zone have not yet been determined, the *Loopus primitivus* Assemblage Zone is characterized by the common occurrence of *Loopus primitivus* (Matsuoka and Yao) associated with *Cinguloturris carpatica* Dumitrica, *Protunuma japonicus* Matsuoka and Yao, *Ristola altissima* (Rüst), *Svinitzium depressum* (Baumgartner), *Svinitzium mizutanii* Dumitrica, *Svinitzium pseudopuga* Dumitrica, and *Xitus gifuensis* Mizutani. *Archaeodictyomitra apiarium* (Rüst), *Archaeodictyomitra brouweri* (Tan), *Archeodictyomitra minoensis* (Mizutani), *Loopus doliolum* Dumitrica, *Loopus primitivus* Matsuoka and Yao, *Loopus yangi* Dumitrica, *Neorelumbra kiesslingi* Dumitrica, *Pantanellium lanceola* (Parona), *Protunuma japonicus* Matsuoka and Yao, *Solenotryma* (?) *ichikawai* Matsuoka and Yao, *Svinitzium mizutanii* Dumitrica, *Svinitzium pseudopuga* Dumitrica, *Tethysetta boesii* (Parona), *Tethysetta pygmaea* Dumitrica, and *Xitus gifuensis* Mizutani appear first in this zone (Fig. 4). *Eucyrtidiellum ptyctum* (Riedel and Sanfilippo) is rare, whereas *Hsuum maxwelli* Pessagno and *Pseudodictyomitra carpatica* (Lozyniak) are absent in the *Loopus primitivus* Assemblage Zone.

Correlation and Age: The *Loopus primitivus* Assemblage Zone corresponds to the *Loopus primitivus* Zone of Matsuoka (1995b), and the age is regarded Tithonian (Late Jurassic). In Japan and western Pacific region (ODP Site 801), the *Loopus primitivus* Zone is recognized by the abundant occurrence of *Loopus primitivus* (Matsuoka & Yao), above the last appearance of *Hsuum maxwelli* Pessagno and below the first appearance of *Pseudodictyomitra carpatica* (Matsuoka, 1995a).

4.3. *Pseudodictyomitra carpatica* Assemblage Zone

Although the top and base of this zone have not yet been determined, the assemblage found in the Nishinokawa section near the base of Member B2 can be attributed to the *Pseudodictyomitra carpatica* Assemblage, characterized by the common occurrence of *Pseudodictyomitra carpatica* (Lozyniak). The first appearance of *Pseudodictyomitra carpatica* (Lozyniak) accompanied by *Archaeodictyomitra mitra* Dumitrica, *Archaeodictyomitra pseudomulticostata* (Tan), *Sethocapsa kaminogoensis* Aita, *Sethocapsa pseudouterculus* Aita, and *Tethysetta columna* (Rüst). *Archaeodictyomitra apiarium* (Rüst), *Archaeodictyomitra mitra* Dumitrica, *Loopus doliolum* Dumitrica, *Loopus yangi* Dumitrica, *Neorelumbra kiesslingi* Dumitrica, *Pantanellium lanceola* (Parona), *Svinitzium depressum* (Baumgartner), *Svinitzium mizutanii* Dumitrica, and *Svinitzium pseudopuga* Dumitrica are relatively common in the zone. *Archaeodictyomitra brouweri* (Tan), *Archeodictyomitra minoensis* (Mizutani), *Mirifusus mediodilalatus* (Rüst),

JURASSIC		CRETACEOUS						PERIOD
OXFORDIAN	TITHONIAN	BERRIASIAN						AGE
Ks	*Lp*	*Pseudodictyomitra carpatica*						ZONE
LOWER BIRAFU	BIRAFU	MIDDLE BIRAFU		UPPER BIRAFU				LITHOSTRATIGRAPHY
A2	A3	B2		C				
32601R	32602R	32604R	32605R	32606R	32607R	32608R	32609R	HORIZON / SPECIFIC NAME
R								*Archaeodictyomitra amabilis* Aita
	C	C	C		C			*Archaeodictyomitra apiarium* (Rüst)
	C	R						*Archaeodictyomitra brouweri* (Tan)
	R	R						*Archeodictyomitra minoensis* (Mizutani)
		C	C	C	C	C		*Archaeodictyomitra mitra* Dumitrica
		R			C			*Archaeodictyomitra pseudomulticostata* (Tan)
					R	C		*Archaeodictyomitra tumandae* Dumitrica
R								*Archaeodictyomitra* sp. aff. *A. pseudoscalaris* (Tan)
					C			*Becus rotula* Dumitrica
R	C		C					*Cinguloturris carpatica* Dumitrica
	R	R						*Cinguloturris* sp. aff. *S. carpatica* Dumitrica
				C	C			*Cinguloturris cylindra* Kemkin & Rudenko
					C			*Cinguloturris* sp. aff. *S. cylindra* Kemkin & Rudenko
C	R							*Dictyomitrella* (?) sp. aff. *D. kamoensis* Mizutani & Kido
C								*Eucyrtidiellum nodosum* Wakita
R	R	R						*Eucyrtidiellum ptyctum* (Riedel & Sanfilippo)
				R				*Eucyrtidiellum pyramis* Aita
C								*Hsuum maxwelli* Pessagno
C								*Hsuum* spp.
R								*Kilinora spiralis* (Matsuoka)
	R	R	R	C	C			*Loopus doliolum* Dumitrica
	C	R	R		R			*Loopus primitivus* (Matsuoka & Yao)
	R	R	C				C	*Loopus yangi* Dumitrica
R		R						*Mirifusus cheodes* (Renz)
R								*Mirifusus guadalupensis* Pessagno
				R				*Mirifusus mediodilatatus* (Rüst)
	R				C		C	*Neorelumbra kiesslingi* Dumitrica
	R	R		R				*Obesacapsula rotunda* (Hinde)
	R	R		R	R			*Pantanellium lanceola* (Parona)
					R			*Praecaneta cosmoconica* (Foreman)
	C							*Protunuma japonicus* Matsuoka & Yao
					C		C	*Pseudodictyomitra altiturris* Dumitrica
		C	R	C	C	C	C	*Pseudodictyomitra carpatica* (Lozyniak)
				R				*Pseudodictyomitra* sp. aff. *P. thurowi* Dumitrica
					C			*Pseudoxitus* sp. aff. *P. seriola* Dumitrica
	C							*Ristola altissima* (Rüst)
C								*Ristola procera* (Pessagno)
					R			*Ristola* sp. aff. *R. cretacea* (Baumgartner)
		R		R			C	*Sethocapsa kaminogoensis* Aita
		C			C			*Sethocapsa pseudouterculus* Aita
					R			*Sethocapsa* (?) *subcrassitestata* Aita
	C	R						*Solenotryma* (?) *ichikawai* Matsuoka & Yao
C								*Stichocapsa* sp. aff. *S. naradaniensis* Matsuoka
C								*Stichocapsa robusta* Matsuoka
R								*Stylocapsa tecta* Matsuoka
	C	R		C	C		C	*Svinitzium depressum* (Baumgartner)
	C	R	R		C			*Svinitzium mizutanii* Dumitrica
	C		R		C	C		*Svinitzium pseudopuga* Dumitrica
	R		R					*Svinitzium* sp.
	R	R		R				*Tethysetta boesii* (Parona)
		R		R				*Tethysetta columna* (Rüst)

Fig. 4. Occurrence and inferred range of radiolarians in the type section of the Birafu Formation. *Ks*: *Kilinora spiralis* Assemblage Zone; *Lp*: *Loopus primitivus* assemblage Zone; *Pseudodictyomitra carpatica* Assemblage Zone; R: rare (< 1%); C: common (1-5%); A: abundant (5%<) in total number of counted specimens; gray bar showing the inferred range of species in the section.

Tethysetta boesii (Parona), *Tethysetta pygmaea* Dumitrica, and *Tethysetta usotanensis* (Tumanda) are relatively few in the zone. The lower part of the zone (Member B2) still yields *Cinguloturris carpatica* Dumitrica, *Eucyrtidiellum* *ptyctum* (Riedel and Sanfilippo), *Loopus primitivus*ÅiMatsuoka and Yao, and *Solenotryma* (?) *ichikawai* Matsuoka and Yao (Fig. 4). The younger part of the zone (in Member C) is characterized by the first occurrence of *Archaeodictyomitra tumandae* Dumitrica, *Becus rotula* Dumitrica, *Cinguloturris cylindra* Kemkin and Rudenko, *Eucyrtidiellum pyramis* Aita, *Pseudodictyomitra altiturris* Dumitrica, *Pseudodictyomitra* sp. aff. *P. thurowi* Dumitrica, *Pseudoxitus* sp. aff. *P. seriola* Dumitrica, *Ristola* sp. aff. *R. cretacea* (Baumgartner), *Sethocapsa* (?) *subcrassitestata* Aita, and *Xitus robustus* Wu (Fig. 4).

Correlation and Age: In general, the *Pseudodictyomitra carpatica* Assemblage Zone corresponds well with the *Pseudodictyomitra carpatica* Zone (Matsuoka, 1995b) and the *Ditrabs sansalvadorensis* Zone (Aita and Okada, 1986), the ages of which are regarded as latest Tithonian to earliest Cretaceous (Berriasian–Early Valanginian). In the Nishinokawa section, *Sethocapsa pseudouterculus* (Aita) and *S. kaminogoensis* (Aita) appear with *Pseudodictyomitra carpatica* (Lozyniak) nearly at the base of the zone. In terms of UA (unitary associations), Jud (1994) established for *Pseudodictyomitra carpatica* (Lozyniak) a Tithonian to Barremian range, or more precisely Late Kimmeridgian/Early Tithonian to Early Barremian as established by Baumgartner et al. (1995). Matsuoka (1995b) estimated that the first appearance of *Pseudodictyomitra carpatica* (Lozyniak) took place slightly below the J/K boundary. In the Breggia Gorge (Switzerland) *Sethocapsa pseudouterculus* (Aita) appears according to Aita and Okada (1986), near the base of the *Ditrabs sansalvadorensis* Zone, the base of which is also slightly below the J/K boundary. *S. kaminogoensis* appears however above the J/K boundary. In addition, Dumitrica *et al*. (1997) reported the occurrences of *Archaeodictyomitra mitra* Dumitrica, *Archaeodictyomitra pseudomulticostata* (Tan), and *Tethysetta columna* (Rüst) from Berriasian and younger samples from Mashirah Ophiolite sections in Oman. Therefore, we regard the base of the present *Pseudodictyomitra carpatica* Assemblage Zone to be Berriasian, and that the J/K boundary is probably below the base of Member B2.

Concerning the younger age of the zone, Dumitrica *et al*. (1997) reported the occurrences of *Archaeodictyomitra tumandae* Dumitrica, *Becus rotula* Dumitrica, *Cinguloturris cylindra* Kemkin and Rudenko, *Pseudodictyomitra altiturris* Dumitrica from Berriasian–Valanginian samples of the Mashirah Ophiolite sections in Oman. According to Matsuoka and Yang (2000), the first appearance of *Cecrops septemporatus* (Parona) is situated near the base of the *Cecrops septemporatus* Zone, and is Valanginian. We have not found *Cecrops septemporatus* (Parona) in our section. As such, we still consider the uppermost part of Member C as part of the *Pseudodictyomitra carpatica* Assemblage Zone, the age of which can be regarded to be older than Late Valanginian.

5. DEPOSITIONAL ENVIRONMENT OF THE BERRIASIAN MEMBER B1

Member B1 is well exposed along the banks of the Nishinokawa River, where it yields abundant bivalves, gastropods and corals. It consists of alternating beds of limestone and muddy sediments (Fig. 4). Although faults are present in the area, the exposed sequence seems mostly continuous. The upper contact of the limestone beds with the overlying muddy deposits are sharp. This contrasts with the gradual nature of the lower contact of the limestone beds. We have subdivided member B1 into seven cycles (sub-units I-VII) based on lithofacies.

The lower three consist of the regular cyclic recurrence of mudstone at base, followed by fossiliferous muddy sandstone, calcareous sandstone with nerineacean gastropods and ooid-bearing limestone at top. In each of the three lower sub-units, the proportion of clastic particles decreases upward. While the base of sub-unit I is still part of Member A3, containing the *L. primitivus* radiolarian AZ (Tithonian), the base of Member B1 corresponds to the base of the fossiliferous sandy mudstone that contains disarticulated and poorly preserved bivalves. The other layers are fossiliferous calcareous sandstone bed with undeterminable nerineacean gastropods, ooid-peloid-grainstone, calcareous ooid-grainstone, sandstone, ooid-grainstone/packstone and thin limy mudstone containing algal-coated grains. Within sub-units II and III, the stratigraphy becomes unclear due to faulting, but the observed lithologic succession appears similar to that of sub-unit I. The limestone beds of sub-unit III along the river, probably correspond to the limestone that Morino (1993) described in a cliff about 20 m above the southern riverbank.

In the middle part of member B1, sub-units IV and V are thinner than the lower sub-units. Detailed stratigraphy of the limestone is unclear, although similar lithofacies to that in the lower sub-units.

In the upper part of member B1, Sub-unit VI consists of alternating beds of sandy mudstone and thin- and very fine-grained sandstone, calcareous sandstone and pisolite. Sub-unit VII consists of a 50 m thick sequence of muddy and sandy sediments, showing upward coarsening of the sequence. Higher up, the base of Member B2 is exposed, consisting of a basal sandstone, overlain by calcareous fine-grained sandstone and boundstone.

6. BIVALVE FAUNA

Bivalves are rare in members A2, A3 and B2, and only Member B1 yields abundant bivalves. As such the geological age discussion will center on the bivalves from Member B1.

Members A2 and A3 are well dated as Jurassic by radiolarians and Member B1 starts immediately above the horizon yielding Tithonian radiolarians. Member B1 is overlain

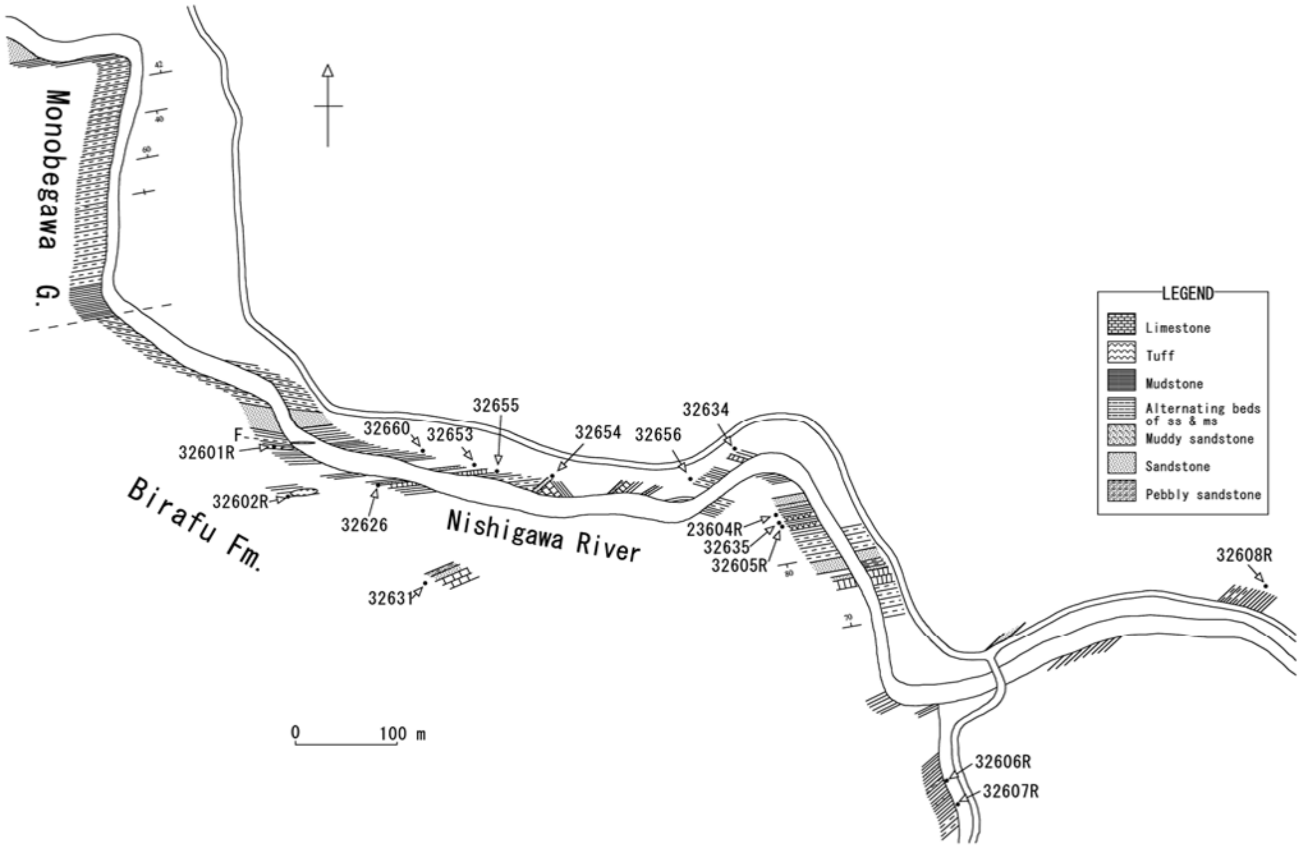

Fig. 5. Route map along the type section of the Birafu Formation, Nishinokara River in Kahoku. Also shown are the Micro- and Mega fossil localities.

by member B2 that contains a Berriasian radiolarian fauna. This indicates that the J/K boundary must be within Member B1. Abundant bivalves are mostly found in the sandstone beds that underlie the limestones in most of the cycles of Member B1. Bivalves are rarely found in the mudstone beds. Bivalve distribution occurs in the six sub-units of Member B1 (Fig. 5).

6.1. Sub-unit I

The sandstone yielded abundant but generally poorly preserved forms of *Grammatodon takiensis* Kimura, *Cucullaea* sp. aff. *C. Acuticarinata* Nagao, *Arcomytilus* sp. aff. *A. Laitmairensis* (de Loriol), *Aguilerella nagatoensis* (Ohta), *Ctenoides tosanus* (Kurata and Kimura), *Pterotrigonia toyamai* (Yehara), *Miltha japonica* Tashiro, *Protocardia* sp. cf. *P. tosensis* Kimura and *Isocyprina japonica* Tashiro and Kozai. *Grammatodon takiensis* Kimura and *Ctenoides tosanus* (Kurata and Kimura) occur in the Jurassic to the Lowest Cretaceous formations of Japan, e.g. the Torinosu Group in Shikoku, Nakanosawa and Koyamada formations of the Somanakamura Group and Isokusa Formation of the Karakuwa Group in NE Japan (Kimura, 1951; Tamura, 1960a; Masatani and Tamura, 1959; Hayami *et al*., 1960). *Pterotrigonia toyamai* (Yehara) was originally described from the Birafu Formation by Yehara (1923). It was also found in the Oxfordian - Kimmeridgian formations of the Torinosu Group in Shikoku, as well as in the Kurosaki and Ebirase formations in Kyushu (Tamura, 1960a, 1984; Tamura and Murakami, 1986). The Cretaceous is represented by the species *Aguilerella nagatoensis* (Ohta), *Miltha japonica* Tashiro and *Isocyprina japonica* Tashiro and Kozai that occur in the non-marine and marine formations (Tashiro and Kozai, 1988, 1989).

6.2. Sub-unit II

The sandstone bed of this sub-unit yielded *Grammatodon takiensis* Kimura, *Isocyprina japonica* Tashiro, *Corbula globosa* Tamura, *C. imamurae* Hase and *Caestocorbula morinoi* Tashiro and Kozai. *Corbula globos*a Tamura occurs in the Upper Jurassic Sakamoto Formation in Kyushu (Tamura, 1959a, 1959b) and in the Torinosu Group in Shikoku (Tamura, 1960a) as well as in Upper Jurassic to Berriasian formations, like the Nakanosawa and Koyamada formations in NE Japan. *C. imamurae* Hase was described from the Lower Cretaceous Yoshimo Formation in Chugoku (Hase, 1960).

6.3. Sub-unit III

The sandstone yielded *Eomiodon nipponicus* Ohta and *Corbula imamurae* Hase that occur in Lower Cretaceous non-marine formations (Hase, 1960; Ohta, 1973; Kozai *et al.*, 2005).

6.4. Sub-unit IV

The fossiliferous sandstone is overlain by limestone along the river bed. It contains the *Aguilerella nagatoensis*-*Corbula imamurae* Association, a highly diversified brackish-water molluscan association. The horizon is identical with the one described by Morino (1993). This sub-unit yields *Parallelodon* sp. cf. *P. koikensis* Tamura, *Aguilerella nagatoensis* (Ohta), *Parvamussium habunokawense* (Kimura), *Ctenoides tosanus* (Kurata and Kimura), *Miltha japonica* Tashiro, *Protocardia* sp. cf. *P. tosensis* Kimura, *Isocyprina japonica* Tashiro and Kozai, *Linearia* sp. aff. *L. nankaiana* Tashiro and Kozai, *Eomiodon nipponicus* Ohta, *Eomiodon kumamotoensis* Tamura, *Crenotrapezium kitakamiense* Hayami, *Corbula globosa* Tamura and *Caestocorbula morinoi* Tashiro and Kozai. *Eomiodon kumamotoensis* Tamura was described from the Upper Jurassic Sakamoto Formation in Kyushu by Tamura (1959c). *Crenotrapezium kitakamiense* was described from the Lower Cretaceous in the Jusanhama Group in NE Japan by Hayami (1960).

6.5. Sub-unit V

The sub-unit yields *Pterotrigonia* sp., *Isocyprina japonica* Tashiro *and Ostrea* sp.

6.6. Sub-unit VI

The sub-unit yields *Aguilerella nagatoensis* (Ohta), *Protocardia* sp. cf. *P. tosensis* Kimura, *Eomiodon nipponicus* Ohta, *Eomiodon kumamotoensis* Tamura, *Crenotrapezium kitakamiense* Hayami and *Corbula imamurae* Hase. While four species, *Aguilerella nagatoensis* (Ohta), *Eomiodon nipponicus* Ohta, *Crenotrapezium kitakamiense* Hayami and *Corbula imamurae* Hase are Lower Cretaceous, two species, *Protocardia* sp. cf. *P. tosensis* Kimura and *Eomiodon kumamotoensis* Tamura are still Jurassic.

7. THE J/K BOUNDARY BIVALVE FAUNAL TURNOVER

The bivalves found in Member B1 are characteristically mixed Jurassic marine and Cretaceous marine and non-marine (Fig. 6). Hayami (1961) summarizing Jurassic marine bivalve faunas in Japan, included *Grammatodon takiensis Kimura*, *Arcomytilus* sp. cf. *A. laitmairensis* (de Loriol), *Ctenoides tosanus* (Kurata and Kimura), *Pterotrigonia toyamai* (Yehara), *Protocardia tosensis* Kimura, *Eomiodon kumamotoensis* Tamura, *Corbula globosa* Tamura, *Parvamussium habunokawense* (Kimura). With exception of *Pterotrigonia toyamai* (Yehara), all these marine species also occur in the Berriasian formations. Furthermore, the marine *Isocyprina japonica* Tashiro and Kozai and *Miltha japonica* Tashiro, as well as the brackish *Eomiodon nipponicus* Ohta, *Crenotrapezium kitakamiense* Hayami, *Aguilerella nagatoensis* (Ohta) and *Corbula imamurae* Hase are exclusively Early Cretaceous in Japan. The presence of both the marine and brackish Cretaceous forms from the very base of member B1 strongly suggests that the member can be regarded as Berriasian. Since Hayami (1961, 1975) pointed out that some Upper Jurassic marine bivalves survived until the Berriasian, the concurrent range of Jurassic and Lower Cretaceous bivalves is not surprising. Although Although Ohta and Moji (1976) assigned on Early Cretaceous age to the Uminoura Formation based on *Pulsidis globosa* Tamura and *Eomiodon kumamotoensis* Tamura (Late Jurassic–Berriasian) and *Eomiodon matsumotoi* Ohta and *Pulsidis nagatoensis* Ota (Early Cretaceous), regarding this formation as Early Cretaceous, Ohta and Sakai (2003) refers to this Formation as Middle or Late Jurassic. Therefore the Birafu Formation is a key to the understanding of the J/K bivalve faunal turnover.

Some important ecological and taxonomic changes can be recognized for the faunal turnover across the J/K boundary as inferred from Member B1. The most important change is the occurrence of *Linearia* sp. aff. *nankaiana* Tashiro and Kozai. Until now, the first occurrence of the family Tellinidae was considered as Early Hauterivian based on *Linearia subhercynica* from Hannover, Germany and *Linearia subconcentrica* from Paris Basin, France, (Skelton and Benton, 1993). As discussed in this paper, *Linearia* sp. aff. *L. nankaiana* Tashiro and Kozai occurred on Member B1, which is considered as Berriasian. Therefore this is the oldest fossil record of the Tellinidae. In contrast to the labial-palp deposit feeders protobranchians, which appeared in early Paleozoic, the Tellinidae are new deposit-feeders using siphon for feeding.

The occurrence of *Caestocorbula morinoi* (Yehara), is also important because this is probably the first record of the subfamily Caestocorbulinae, as well as being first of the genus *Caestocorbula*. This species is also paleoecologically important, because this may be one of the first heterodont bivalves that developed deep pallial sinus.

Also, there are several genera which are considered to have occurred first here, such as *Isocyprina* spp. and *Linearia* spp.

The first appearance of these modern-type life habits in the bivalves in the Member B1 suggests new environmental conditions prevailing in this age, which facilitated such evolutionary diversification. However, further detailed study is needed to reveal the environmental and biotic changes that occurred around the J/K boundary.

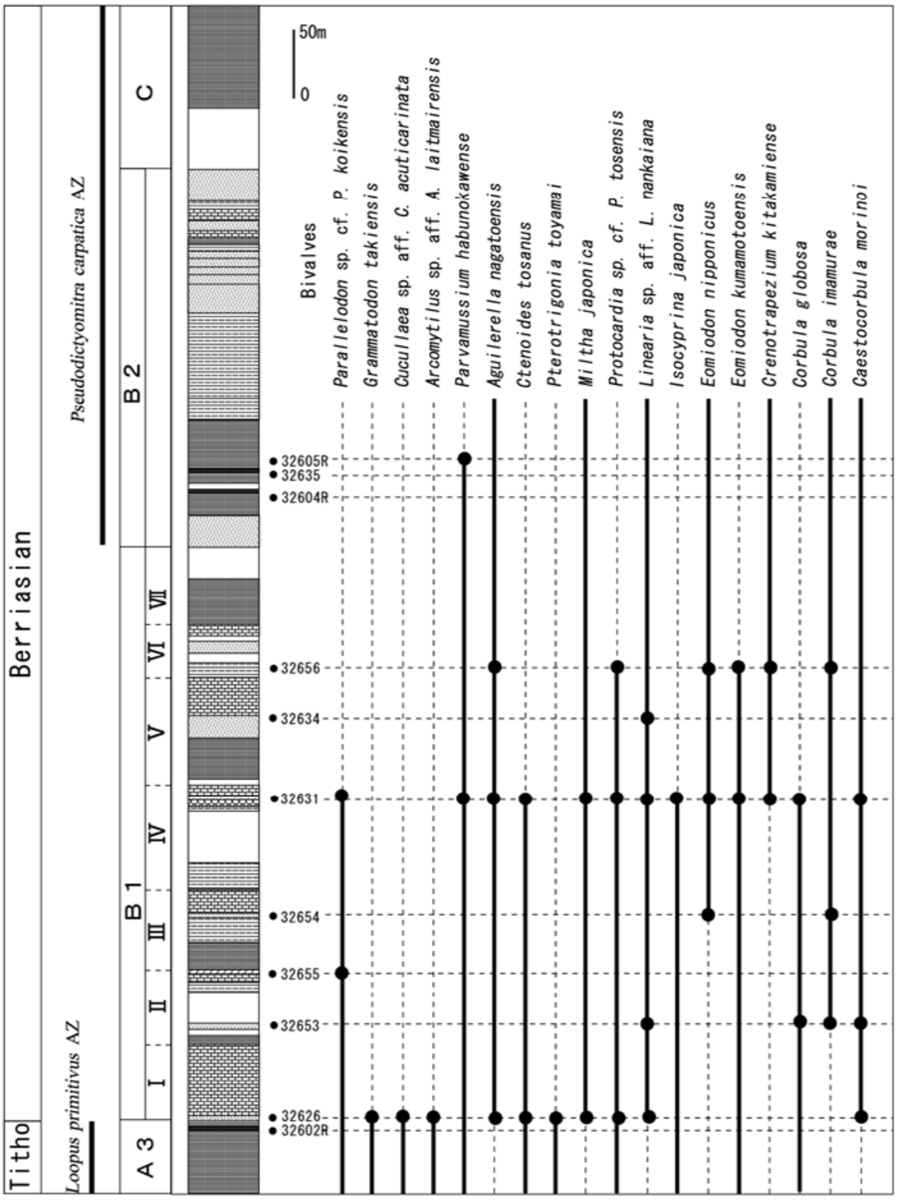

Fig. 6. Lithological section of the Members B1 and B2 and occurrence list of bivalves (modified after Kozai et al., 2004).

8. CONCLUSIONS

1. Oxfordian to Berriasian radiolarian assemblages provide biostratigraphic constraints for the Birafu Formation.

2. Cretaceous forms from the base of Member B1 strongly suggests that this member can be regarded as Berriasian and that the J/K boundary can be placed at base B1.

3. Very different Lower Cretaceous and Upper Jurassic bivalves co-occur in the Berriasian of the Birafu Formation. Hence, the Berriasian is regarded as a transitional zone of Jurassic to Cretaceous bivalve taxa.

4. The bivalve fauna of Member B1 suggests a Lower Cretaceous (Berriasian) shallow marine environment in which brackish forms have been transported, probably by floods.

5. The concurrence of Jurassic and Cretaceous marine taxa suggests that the survival of the Jurassic marine taxa in the Lower Berriasian is a feature related to the Jurassic-Cretaceous turnover and that the Berriasian is a transitional zone in Jurassic - Cretaceous bivalve evolution.

6. First appearance of some modern life habits in bivalves are recorded in the B1 member of the Birafu Formation, such as siphonate deposit-feeding heterodont (Tellinidae) and siphonate suspension-feeding heterodont with deep pallial sinus (Caestocorbulinae). These suggest a widespread new environment near J/K boundary. This new environment facilitated the evolution of new life habit groups in Bivalves.

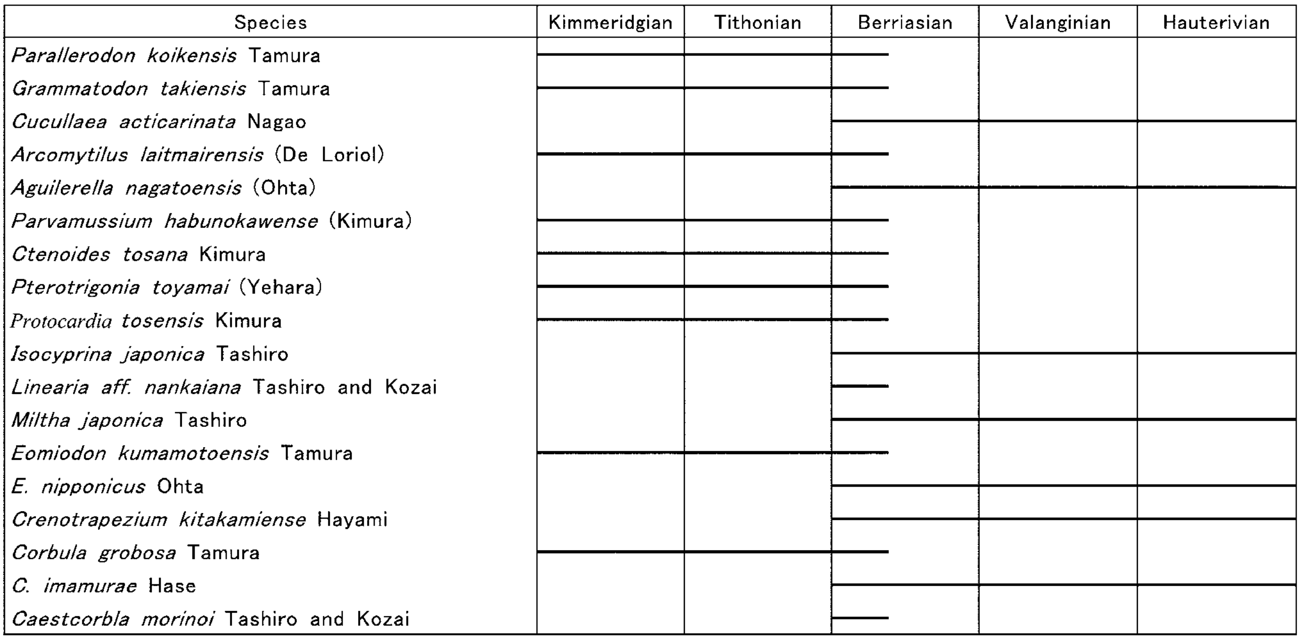

Fig. 7. Kimmeridgian to Hauterivian range-chart of the Birafu Bivalve fauna, SW Japan.

ACKNOWLEDGMENTS: We thank Masahiro Ohno, Hiroshi Endo, Makoto Saito for their help during field research. The authors also thank the reviewers, Luis O'Dogherty (Universidad de Cádiz) and E. J. Marquez (University of the Philippines) for comments that improved our manuscript. We are indebted to Graciano Yumul Jr. and Carla Dimalanta (University of the Philippines) for their efficient editorial work.

REFERENCES

Aita, Y. and Okaka, H., 1986, Radiolarians and calcareous nannofossils from the uppermost Jurassic and Lower Cretaceous strata of Japan and Tethyan regions. Micropaleontology, 32, 97–128.

Baumgartner, P. O., O'dogherty, L., Gorican, S., Jud, R. D., Dumitrica, P. Pillevuit, A., Urquhart, E., Matsuoka, A., Danelian, T., Bartolini, A., Carter, E. S., De Wever, P., Kito, N., Marcucci, M. and Steiger, T., 1995, Radiolarian catalogue and systematics of Middle Jurassic to Early Cretaceous Tethyan genera and species. In: Baumgartner, P. O., O'dogherty, L., Gorican, S., Urquhart, E., Pillevuit, A. and De Wever, P. (eds.), Middle Jurassic to Lower Cretaceous radiolarians of Tethys: Occurrences, systematics, biochronology, Memoires de Geologie (Lausanne), 23, 48–685.

Dumitrica, P., Immenhauser, R. and Dumitrica-Jud, R., 1997, Mesozoic Radiolarian Biostratigraphy from Masirah Ophiolite, Sultanate of Oman Part I: Middle Triassic, uppermost Jurassic and Lower Cretaceous Spumellarians and multisegmented Nassellarians. Bulliten of the National Museum of National Science, 9, 1–106.

Hase, A., 1960, The Late Mesozoic formations and their molluscan fossils in West Chugoku and North Kyushu, Japan. Journal of Science of the Hiroshima University, 3, 238–338.

Hayami, I., 1960, Pelecypods of the Jusanhama Group (Purbeckian or Wealden) in Hashiura Area, Northeast Japan. Japanese Jounal of Geology and Geography, 31, 13–21.

Hayami, I., 1961, On the Jurassic pelecypods faunas in Japan. Journal of the Faculty of Science, University of Tokyo, 13, 243–343.

Hayami, I., 1965a, Lower Cretaceous Marine Pelecypods of Japan, part 1. Memoirs of the Faculty of Science, Kyushu University, 15, 221v349.

Hayami, I., 1965b, Lower Cretaceous Marine Pelecypods of Japan, part 2. Memoirs of the Faculty of Science, Kyushu University, 17, 73–150.

Hayami, I., 1975, A systematic survey of the Mesozoic bivalvia from Japan. University Museum, University of Tokyo, Bulletin, 10, 1–249.

Hayami, I. Sugita, M. and Nagumo, Y., 1960, Pelecypods of the Upper Jurassic and Lowest Cretaceous Shishiori group in northeast Japan. Japanese Jounal of Geology and Geography, 31, 85–98.

Hirano, H.,1971, Biostratigraphic study of the Jurassic Toyora Group, Part 1. Memoirs of the Faculty of Science, Kyushu University, 21, 93–128.

Hull, D. Meyerhoff, 1997, Upper Jurassic Tethyan and southern Boreal radiolarians from western North America. Micropaleontology, 43, 1–202.

Ishida, K. and Kozai, T., 2003, Stratigraphy and tectonic subdivision of the Chichibu Superbelt in East Shikoku. Faculty of Integrated Arts, University of Tokushima, Science Research. 16, 11–41. (In Japanese with English abstract)

Ishida, K. and Kozai, T., 2004, Stratigraphy and Radiolarian ages of the Kurisaka and Hirose (new name) formations, southern Kurosegawa Terrane (Sakashu Belt) in East Shikoku. News of Osaka Micropaleontokogists, Special Volume, 13, 135–148. (In Japanese with English abstract)

Jud, R., 1994, Biochronology and systematics of Early Cretaceous Radiolaria of the Western Tethys. Memoires de Geologie (Lausanne), 19, 1–147.

Kimura, T., 1951, Some Pectinids and a Limid from the Jurassic Torinosu Group in Japan. Journal of Faculty of Science, Univer-

sity of Tokyo, 7, 337–350.
Kimura, T., 1956, Some pelecypods from the Upper Jurassic Torinosu group in Japan. Journal of Earth Sciences, Nagoya University, 4, 80–90.
Kobayashi, T., 1954, Studies on the Jurassic trogonians in Japan. Part 1. Preliminary notes. Japanese Jounal of Geology and Geography, 25, 61–80.
Kobayashi, T., 1956, Studies on the Jurassic trogonians in Japan. Part 5. Some Jurassic trigonians from central and west Japan. Japanese Jounal of Geology and Geography, 27, 1–8.
Kobayashi, T. and Fukada, A., 1947, A new species of Ataxioceras in Nippon. Japanese Jounal of Geology and Geography, 20, 45–48.
Kobayashi, T. and Suzuki, K., 1939, The brackish Wealden Fauna of the Yoshimo Beds, in Prov. Nagato, Japan. Japanese Jounal of Geology and Geography, 21, 213–224.
Kozai, T. and Ishida, K., 2003, Early Cretaceous non-marine bivalve faunal groups from Central and East Shikoku, Japan. Memoir of the Fukui Dinosaur Museum, 2, 133–148.
Kozai, T., Ishida, K., Hirsch, F., Park, S. O. and Chang K. H., 2005, Early Cretaceous non-marine mollusk faunas of Japan and Korea. Cretaceous Research, 26, 97–112.
Kozai, T. Ishida, K. and Kondo, Y., 2004, Radiolarian ages and bivalve fauna of the Birafu Formation, Central Shikoku. News of Osaka Micropaleontologists, Special Volume, 13, 149–165. (In Japanese with English abstract)
Masatani, K. and Tamura, M., 1959, A stratigraphic study on the Jurassic Soma Group in the eastern foot of the Abukuma Mountains, Northeast Japan. Japanese Jounal of Geology and Geography, 30, 245–257.
Matsuoka, A., 1995a, Radiolaria-based Jurassic/Cretaceous boundary in Japan. Proceedings of the 15th Symposium of Kyungpook National University, 219–232.
Matsuoka, A., 1995b, Jurassic and Lower Cretaceous radiolarian zonation in Japan and in the western Pacific. The Island Arc, 4, 140–153.
Matsuoka, A. and Yang, Q., 2000, A Direct Correlation between North American and Japan-Pacific Radiolarian Zonal Schemes for the Upper Jurassic. GeoResearch Forum, 6, 119–128.
Matsuoka, A. and Yao, A., 1986, A newly proposed radiolarian zonation for the Jurassic of Japan. Marine Micropaleontology, 11, 91–105.
Morino, Y. Kozai, T. Wada, T. and Tashiro, M., 1989, On the Lower Cretaceous Birafu Formation including the Torinosu type limestone in the Monobe area, kochi Prefecture. Research Reports of the Kochi University, 38, 73–83. (In Japanese with English abstract)
Morino, Y., 1993, Depositional environments of the Lower Cretaceous Torinosu type limestone in the Monobe area, Kochi Prefecture. Journal of Geological Society of Japan, 99, 173–183. (In Japanese with English abstract)
Ohta, T. and Sakai, T., 2003, Revised stratigraphy of the Paleozoic and Mesozoic successions and proposal of the Jurassic Ashikita Group in the Uminoura area of the Kurosegawa Tectonic Belt, western Kyushu, SW Japan. Journal of Geological Society of Japan, 109, 671–688. (In Japanese with English abstract)
Ohta, Y., 1973, Pelecypod Family Neomiodontidae from the Lower Neocomian of Japan. Bulletin of Fukuoka University of Education, 22, 245–273.
Ohta, Y., 1974, A new Bakevellid (Bivalvia) from the Lower Cretaceous of Southwest Japan. Bulletin of Fukuoka University of Education, 23, 79–89.
Ohta, Y. and Moji, N., 1976, On the lower Cretaceous Uminoura Formation in Kyushu. Bulletin of Fukuoka University of Education, 26, 117–136. (In Japanese with English abstract)
Sato, T., 1958, Presence du Berriasien dans La stratigraphie de plateu de Kitakami (Japon septentrional). Le Bulletin de la Société Géologique de France, 8, 585–599.
Skelton, P. W. and Benton, M. J., 1993, Mollusca: Rostroconchia, Scaphopoda and Bivalvia. In: Benton, M. J. (Ed.), The fossil record 2, Chapman and Hall, London, 237–263.
Takahashi, H., 1973, The Isokusa Formation and its late Upper Jurassic and early Lower Cretaceous ammonite fauna. Science Reports of the Tohoku University, Special Volume, 6, 319–336.
Tamura, M., 1959a, Torigoniidae, Ostreidae, Bakevelliidae, Pteriidae, Cardiidae and Astartidae from the Upper Jurassic Sakamoto Formation in Central Kyushu, Japan. Transactions and Proceedings of the Palaeontological Society of Japan, N.S., 33, 23–32.
Tamura, M., 1959b, Taxodonta and Isodonta from the Upper Jurassic Sakamoto Formation in Central Kyushu, Japan. Transactions and Proceedings of the Palaeontological Society of Japan, N.S., 34, 53–65.
Tamura, M., 1959c, Some pelecypods from the Upper Jurassic Sakamoto Formation in Central Kyushu, Japan. Transactions and Proceedings of the Palaeontological Society of Japan, N.S., 35, 113–120.
Tamura, M., 1959d, Taxodonta and Isodonta from the Jurassic Soma Group in North Japan. Transactions and Proceedings of the Palaeontological Society of Japan, N.S., 36, 168–180.
Tamura, M., 1960a, Upper Jurassic pelecypods from the Torinosu group in Shikoku, Japan. Memoirs of the Faculty of Education, Kumamoto University, 8, 227–244.
Tamura, M., 1960b, Heterodont and other pelecypods from the Upper Jurassic Soma Group, Japan. Transactions and Proceedings of the Palaeontological Society of Japan, N.S., 39, 285–292.
Tamura, M., 1960c, Upper Jurassic Pteriacea from the Soma Group in north Japan. Transactions and Proceedings of the Palaeontological Society of Japan, N.S., 37, 223–229.
Tamura, M., 1984, Upper Jurassic Bivalve fauna from the Ebirase Formation, Middle Kyushu, with a note on the Haidaia species (Trigoniid) in the Torinosu fauna. Memoirs of the Faculty of Education, Kumamoto University, 33, 23–33.
Tamura, M. and Murakami, K., 1986, Upper Jurassic Kurosaki Formation discovered at Kurosaki, Tanoura Town, Kumamoto Prefecture, Japan. Memoirs of the Faculty of Education, Kumamoto University, 35, 47–55.
Tamura, M. and Murakami, K., 1987, Uminoura Formation (Lower Cretaceous) in the area West of Uminoura. Memoirs of the Faculty of Education, Kumamoto University, 36, 19–27. (In Japanese with English abstract)
Tanaka, H., 1989, Mesozoic Formations and their Molluscan Faunas in the Haidateyama Area, Oita Prefecture, Southwest Japan. Journal of Science of the Hiroshima University, 9, 1–45.
Tashiro, M., 1987, Cretaceous Eomiodon and Costocyrena (Bivalvia) from Southwest Japan. Transactions and Proceedings of the Palaeontological Society of Japan, N.S., 147, 91–108.
Tashiro, M., 1990, Bivalve fauna from the Kesado Formation of Yatsushiro Mountains in Kyushu. Memoirs of the Faculty of Science, Kochi University, 11, 1–22.
Tashiro M., 1992, A handbook of illustrated fossils, Cretaceous bivalves in Japan. Shirono Press, 307 p. (In Japanese).
Tashiro, M. and Katto, J., 1986, Upper Jurassic molluscan fauna of the Shimanto Belt in Shikoku. Research Reports of Kochi Uni-

versity, 34, 121–127 (In Japanese with English abstract).
Tashiro, M. and Kozai, T., 1984, Bivalve from the type Monobegawa Group (Part 1). Research Reports of Kochi University, 32, 259–293.
Tashiro, M. and Kozai, T., 1986, Bivalve from the type Monobegawa Group (Part 2). Research Reports of Kochi University, 35, 23–54.
Tashiro, M. and Kozai, T., 1988, Bivalve from the type Monobegawa Group (Part 3). Research Reports of Kochi University, 37, 33–64, 1–4.
Tashiro, M. and Kozai, T., 1989, Bivalve from the type Monobegawa Group (Part 4). Research Reports of Kochi University, 38, 113–144.
Tashiro, M. and Kozai, T., 1991, Bivalve from the type Monobegawa Group (Part 5). Research Reports of Kochi University, 40, 189–204.
Tashiro, M. and Kozai, T., 1994, Bivalve from the type Monobegawa Group (Part 6). Research Reports of Kochi University, 43, 55–68.
Yehara, S., 1923, Cretaceous Trigoniae from southwest Japan. Japanese Journal of Geology and Geography, 2, 59–84.

TAXONOMIC NOTES OF BIVALVES

The studied bivalve specimens are kept in Naruto University of Education (NU) and radiolarian specimens are deposited in Tokushima University.

Subclass PTERIOMORPHIA Beurlen, 1944
Order ARCOIDA Stoliczka, 1871
Family PARALLELODONTIDAE Dall, 1898
Genus *Parallerodon* Meek and Worthen, 1866
Parallelodon sp. cf. *P. koikensis* Tamura, 1959
Pl. 2, fig. 12

Material.- NU39-0085, internal mold of left valve from loc. 32631.

Remarks.- The poorly preserved specimen from the Birafu Formation is similar to *Parallelodon koikensis* described by Tamura (1959d) from the Nakanosawa Formation, Soma Group of Northeast Japan. It has an elongate outline and a distinct posterior carina.

Occurrence.- Loc. 32631.

Range.- Kimmeridgian to Berriasian.

Genus *Grammatodon* Meek and Hayden, 1861
Grammatodon takiensis Kimura, 1956
Pl. 2, figs. 4-5

Grammatodon takiensis Kimura, 1956, p. 82, pl. 1, figs. 5,6; Tamura, 1959b, p. 54, pl.6, figs. 1,2; Tamura, 1959d, p. 172, pl. 19, figs. 4-6; Hayami, Sugita and Nagumo, 1960, p. 91, pl. 8, figs. 6,7; Hayami, 1975, p. 29.

Material.- NU39-0038a,b, right valves from Loc.32655 and NU39-0039, left valve from Loc. 32626.

Remarks.- The specimens are identical with *Grammatodon takiensis* in the subrectangular outline with fairly distinct posterior carina.

Occurrence.- Loc. 32626, 32655.

Range.- Kimmeridgian to Berriasian.

Family CUCULLAEIDAE Stewart, 1930
Genus *Cucullaea* Lamarck, 1801
Cucullaea sp. aff. *C. acuticarinata* Nagao
Pl. 2, fig. 33

Material.- NUE39-0040, left valve from 32626.

Remarks.- This specimen is characterized by the strongly inflated valve and the sharp posterior carina. These features are similar to *Cucullaea acuticarinata* Nagao from the Miyako Group in NE Japan and the Hagino Formation of the Nankai Group in Shikoku. However, the umbo of this specimen situates near the center of shell-length and is smaller than that of C. *acuticarinata* Nagao.

Occurrence.- Loc.32626.

Range.- Berriasian.

Order MYTILOIDA Férussac, 1822
Family MYTILIDAE Rafinesque, 1815
Genus *Arcomytilus* Agassiz, 1842
Arcomytilus sp. aff. *A. laitmairensis* (de Loriol)
Pl. 2, figs. 21-22

Material.- NUE39-0086, left valve from 32626; NU39-0087, right valve from loc. 32626; NU39-0088, internal mold of right valve from loc.32626.

Remarks.- The surface of our incomplete specimens has a clear ornamentation. The radial ribs are stronger than those of *Arcomytilus laitmairensis* (de Loriol). The Birafu specimens are similar to Tamura's specimens from the Soma Group in Northeast Japan and Torinosu Group in Shikoku.

Occurrence.- Loc.32626.

Range.- Kimmeridgian to Berriasian.

Order PTERIOIDA Newell, 1965
Family BAKEVELLIDAE King, 1850
Genus *Aguilerella* Chavan, 1951
Aguilerella (*Yoshimopsis*) *nagatoensis* (Ohta)
Pl. 2, figs. 34-35

Gervillia shinanoensis Yabe and Nagao. Kobayashi and Suzuki 1939, p. 217, pl. 13, figs. 20-22, pl. 14, figs. 16-19.

Bakevelloides (*Yoshimopsis*) *nagatoensis*Ohta, 1974, p. 81, text-figs. 1-4, pl. 1, figs. 1-11.

Balevellia (*Yoshimopsis*) *nagatoensis* (Ohta), Hayami 1975, p. 46, pl. 9, fig. 2.

Aguilerella (*Yoshimopsis*) *nagatoensis* (Ohta), Tashiro 1992, p. 72, pl. 18, fig. 6; Tanaka *et al.* 2000, fig. 4, 8-10.

Material.- NU39-0050 and 0051, left valves from loc. 32631; MU39-0052, left valve from loc.32656.

Remarks.- The specimens from the Birafu Formation are poorly preserved, but can be referred to *Aguilerella* (*Yoshi-*

mopsis) *nagatoensis* (Ohta) by their trapezoidal to subtrigonal outline and ligamental characters. Specimens from the Birafu Formation show changes in their morphological character. They include one-to-three-ligament pits. We have 20 specimens but all of the specimens are left valves and are worn out. This fact shows that they are allochthonous.

Occurrence.- Locs. 32626, 32631, 32656.

Range. - Berriasian to Hauterivian.

Family PROPEAMUSSIIDAE Abbott, 1954
Genus *Parvamussium* Sacco,1897
Parvamussium habunokawense (Kimura)
Pl. 2, fig. 23

Propeamussium habunokawensis Kimura, 1951, p. 344, pl. 1, figs. 14-15; *Variamussium habunokawense* (Kimura), Tamura 1959b, p. 60, pl. 6, figs. 20-22; Tamura 1960a, p. 236; *Variamussium* cf. *habunokawense* (Kimura), Hayami, Sugita and Nagumo 1960, p. 92, pl. 8, figs. 11-13; *Parvamussium habunokawense* (Kimura), Hayami 1975, p. 83; *Parvamussium* cf. *habunokawense* (Kimura), Tamura and Murakami 1987, pl. 1, figs. 3-5.

Material.- NU39-0062, external mold of left valve from 32631.

Remarks.- The specimen from the Birafu Formation is an imperfect external mold, but the surface ornamentation is clearly preserved. Ribs include 9 strong internal radial ribs and 10 secondary radial ribs. Though the radial ribs seem more irregular than those of *P. habunokawense*, our specimen shares the essential characters of *Parvamussium habunokawense* (Kimura) from the Torinosu Group in Shikoku. In this respect, our specimen is also similar to a specimen from the Kogoshiro Formation in NW Japan.

Occurrence.- Locs. 32631, 32635.

Range. - Kimmeridgian to Berriasian

Family LIMIDAE Rafihesque, 1815
Genus *Ctenoides* Mörch, 1853
Ctenoides tosanus (Kurata and Kimura)
Pl. 2, figs. 13-14

Lima (*Ctenoides*) *tosana* Kurata and Kimura, *in* Kimura, 1951, p. 349, pl. 1, fig. 22; Tamura 1959b. p. 62, pl. 6, figs. 44-47; Tamura 1959d. p. 177; Tamura 1960a. p. 238.

Ctenoides tosanus (Kurata and Kimura). Hayami, 1975, p. 87.

Material.- NU39-0041 and 0042, right valves from loc. 32626; NU39-0043, left valve from loc.32626.

Remarks.- This species is usually small, but the specimens from the Birafu Formation are relatively large, 39.1 mm in height and 22.4 mm in length. The surface ornamentation consists of numerous fine radial ribs.

Occurrence.- Locs. 32626, 32631.

Range. - Kimmeridgian to Berriasian.

Subclass PALAEOHETERODONTA Newell, 1965
Order TRIGONIOIDA Dall, 1889
Family TRIGONIIDAE Lamarck,1819
Genus Pterotrigonia van Hoepen, 1929
Pterotrigonia toyamai (Yehara)
Pl. 2, figs. 28-29

Torigonia toyamai Yehara, 1923, p. 78, pl. 9, figs. 4,5; Yehara 1927, p. 35, pl. 3, fig. 9; *Linotrigonia toyamai* (Yehara), Kobayashi 1954, p. 77; Kobayashi 1956, p. 6, pl. 1, figs. 10-12; Tamura 1960, p. 234; Hayami 1975, p. 112; Tamura 1984, pl. 2, figs. 18-22; Tamura and Murakami 1986, Pl. 2, figs. 8-13; *Pterotrigonia* (*Pterotrigonia*) *toyamai* (Yehara), Tashiro 1992, p. 160, pl. 43, figs. 7,11.

Material.- NU39-0064-0067, left valves from loc.32626; NU39-0068, right valve from 32626.

Remarks.- All the specimens from the Birafu Formation are poorly preserved, but surface ornamentation can be observed. They have a few oblique costae on the area near carina, a feature that is characteristic of the Genus *Pterotrigonia*.

Occurrence.-Loc. 32626.

Range.- Oxfordian to Berriasian.

Subclass HETERODONTA Neumayr, 1884
Order Veneroida Adamus and Adamus, 1856
Family LUCINIDAE Fleming, 1828
Genus *Miltha* Adamus and Adamus, 1857
Miltha japonica Tashiro
Pl. 2, fig. 32

Miltha japonica Tashiro, 1990, p. 13-14, text-fig. 8, pl. 3, figs. 7-9.

Material.- NU39-0063, left valve from loc. 32631.

Remarks.- The specimen from the Birafu Formation is relatively small, but it is similar in surface ornamentation and outline to the *Miltha japonica* Tashiro that was described from the Kesado Formation in Kyushu. The surface is marked with narrow concentric ribs, which are regular and usually much narrower than their interspaces.

Occurrence.- Locs. 32626, 23631.

Range. - Berriasian to Barremian.

Family CARDIIDAE Lamarck, 1809
Genus *Protocardia* von Beyrich, 1845
Protocardia sp. cf. *P. tosensis* Kimura
Pl. 2, figs. 15-16

Material.- NU39-0069, right valve from loc. 23656; NU39-0070, left valve from loc.32656.

Remarks.- The outline of the specimens from the Birafu Formation resembles that of *Protocardia tosensis* Kimura from the Torinosu Group in Shikoku. But the poor preservation and deformation of these specimens makes accurate comparison difficult.

Occurrence.- Locs. 32626, 32631, 32656.

Range. - Kimmeridgian to Berriasian.

Family ARCTICIDAE Newton, 1891

Genus *Isocyprina* Roeder, 1882

Isocyprina japonica Tashiro and Kozai

Pl. 2, figs. 9-11

Isocyprina aliquantula (Amano), Hayami 1965b, p. 137, pl. 19, figs. 8-9; *Isocyprina japonica* Tashiro and Kozai, 1989, p. 118-119, pl. 2, text-fig. 2A, figs. 3-9.

Material.- NU39-0076, 0077 and 0081, from loc. 23631, internal molds of right valves; NU39-0078 from loc. 32653 and NU39-0079 and 0080 from loc. 32626, internal molds of left valves; NU39-0082 from loc. 32631, external mold of right valve.

Remarks.- The specimens from Birafu Formation are similar to the species *Isocyprina japonica* Tashiro and Kozai. The test of this species is thin, hence detailed hinge structure can not be observed in these specimens.

Occurrence.- Locs. 32626, 32653, 32631.

Range.- Berriasian to Aptian.

Family TELLINIDAE de Blainville, 1814

Genus *Linearia* Conrad, 1860

Linearia sp. aff. *L. nankaiana* Tashiro and Kozai

Pl. 2, figs. 19-20

Material.- NU39-0083, internal mold of right valve from loc. 32631; NU-39-0084, external mold of right valve from loc. 32631.

Remarks.- Our specimen from the Birafu Formation is compared with *Linearia nankaiana* Tashiro and Kozai. The complete specimen (NU39-0083) is characterized by large size (length 30.8 mm, height 15.2 mm), nearly flat outline and smooth surface. The outline of *Linearia nankaiana* Tashiro and Kozai from the Igenoki Formation in Shikoku is weakly inflated and smaller than this specimen. The surface of this species is covered with very fine radial striae with distinct posterior carina. In this respect, the Birafu specimens differ to *Linearia nankaiana* Tashiro and Kozai. Detail hinge structure can not be observed in these specimens.

Occurrence.- Loc. 32631.

Range. - Berriasian.

Family NEOMIODONTIDAE Casey, 1955

Genus *Eomiodon* Cox, 1935

Eomiodon nipponicus Ohta

Pl. 2, figs. 26-27

Astarte sakawana Kobayashi and Suzuki, 1939, p. 219, pl. 13, figs. 12-13.

Eomiodon nipponicus Ohta, 1973, p.252, pl.1. figs. 15-22, pl. 2. figs. 14-19; Hayami 1975, p. 138; Kozai *et al.* 2001, pl. 1, figs. 1-2.

Material.- NU39-0060, left valve from loc.32631; NU39-0061, external mold of right valve from loc.32631.

Remarks.- These specimens are identical with *Eomiodon nipponicus* Ohta from the Yoshimo Formation of Chugoku, in position of umbo, concentric ribs and shape.

Occurrence.- Locs. 32654, 32631, 32656.

Range. - Berriasian to Hauterivian.

Eomiodon kumamotoensis Tamura

Pl. 2, figs. 17-18

Eomiodon kumamotoensis Tamura, 1959c, p. 115, pl. 12, figs. 17, 18; Tamura 1960a, p. 240; Tashiro and Katto 1986, pl. 1, figs. 15-17; Tashiro 1987, p. 93.

Astarte ? *kumamotoensis* (Tamura). Hayami 1975, p. 128.

Material.- One complete right valve, NU39-0058, internal mold of right valve from loc.32631; NU39-0059, external mold of right valve from loc.32631.

Remarks.- These specimens are similar to *Eomiodon kumamotoensis* Tamura, its strongly inflated valve, small size and regularly disposed concentric ribs. However, it has more regular concentric ribs.

Occurrence.- Locs. 32631, 32656.

Range. - Kimmeridgian to Berriasian.

Genus *Crenotrapezium* Hayami, 1958

Crenotrapezium kitakamiense Hayami

Pl. 2, figs. 30-31

Crenotrapezium kitakamiense Hayami, 1960, p.17, text-fig. 2, figs. 8-10; Hayami 1975, p. 141; Tashiro and Kozai, 1989, p. 126, pl. 2, figs. 11-13.

Material.- NU39-0071, left valves from loc. 32656; NU-39-0072–0074, left valves from loc. 32631; NU39-0075, right valve from loc.32656.

Remarks.- These specimens are identical with *Crenotrapezium kitakamiense* Hayami in having a distinct posterior carina and subtrigonal outline. They are also similar to *C. kitakamiense kurumense* Hayami, but the posterior extremity of *C. kitakamisense kitakamiense* is more elongated.

Occurrence.- Locs. 32631, 32656.

Range. - Berriasian to Barremian.

Order MYOIDA Striczka, 1870

Family Corbulidae Lamarck, 1818

Genus *Corbula* Bruguière, 1797

Corbula grobosa Tamura

Pl. 2, figs. 6-8

Corbula globosa Tamura, 1959c, p.114, pl.12, figs. 1-4; Tamura 1960a, p. 242; Tamura 1960b, p. 290-291, pl. 33, figs. 8-10; Hayami 1975, p. 145; Ohta and Moji 1976, pl. 1. figs. 8-10; Tashiro and Katto 1986, pl. 1, fig. 18.

Material.- NU39-0046-0047, right valve from loc. 32653; NU-0048–0049, internal mold of right valve from loc. 32631.

Remarks.- The specimens are similar in size, shape and surface ornamentation to *Corbula globosa* Tamura. This species is small and strongly inflated. Surface is ornamented with fine concentric ribs. The species differs from *Corbula imamurae* Hase from the Toyonishi Group in its smaller and more inflated valve.

Occurrence.- Locs. 32653, 32631.

Range. - Oxfordian to Berriasian.

Corbula imamurae Hase
Pl. 2, figs. 24-25

Corbula(?) *imamurae* Hase, 1960, p. 324, pl. 37, figs. 16-21, pl. 39, figs. 2-4; Kozai 1989, p. 43-44, Fig. 4, nos. 23–25.

Material.- NU39-0044, internal mold of left valve from loc.32653; NU39-0045, internal mold of left valve from 32654.

Remarks.- The specimens from the Birafu Formation are internal mold of left valves, so surface ornamentation is not preserved, however the outline of these specimens are similar to *Corbula imamurae* Hase.

Occurrence.- Locs. 32653, 32654, 32656.

Range. - Berriasian to Hauterivian.

Genus *Caestocorbla* Vincent, 1910
Caestocorbula morinoi Tashiro and Kozai
Pl. 2, figs. 1-3

Caestocorbula morinoi Tashiro and Kozai, 1991, p.193-194, text-fig. 5, pl. 1, figs. 12-18.

Material.- NU39-0053 and 0054, internal molds of right valve, loc.23653; NU390055 and 0057, internal molds of .right valve, loc.32631; NU39-0056, external mold of right valve, loc.32631.

Remarks.- This species is distinguished from other species of Genus *Caestocorbula* by much narrowly elongated area.

Occurrence.- Locs.32653 and 32631.

Range.- Berriasian.

Manuscript received September 13, 2005
Manuscript accepted July 24, 2006

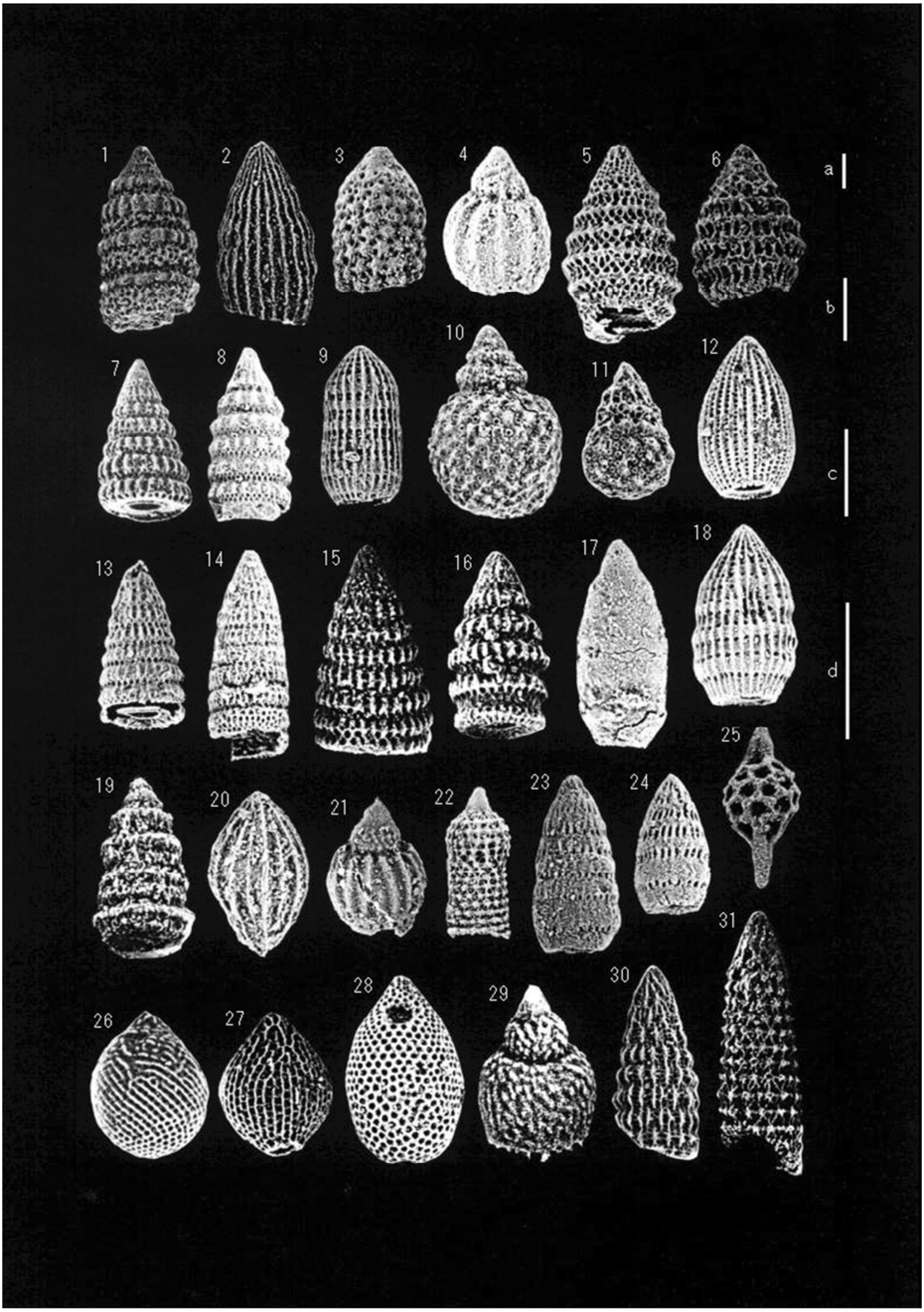
1
2
3
4
5
6
a
b
7
8
9
10
11
12
c
13
14
15
16
17
18
d
19
20
21
22
23
24
25
26
27
28
29
30
31

Plate 1. Upper Jurassic and Lower Cretaceous radiolarians from the Birafu Formation. Scale bars: 100 μm; a: 22; b: 1, 3, 5, 7, 9, 25, 30, 31; c: 2, 4, 6, 8, 10–24, 26–28; d: 29. Fig. 1, *Cinguloturris cylindra* Kemkin and Rudenko, from 32607R in C. Fig. 2, *Archaeodictyomitra tumandae* Dumitrica, from 32607R in C. Fig. 3, *Ristola* aff. *cretacea* (Baumgartner), from 32607R in C. Fig. 4, *Eucyrtidiellum pyramis* Aita, from 32606R in C. Fig. 5, *Tethysetta boesii* (Parona), from 32604R in B2. Fig. 6, *Tethysetta pygmaea* Dumitrica, from 32607R in C. Fig. 7-8, *Pseudodictyomitra carpatica* (Lozyniak), from 32604R in B2. Fig. 9, *Archaeodictyomitra apiarium* (Rüst), from 32604R in B2. Fig. 10, *Sethocapsa pseudouterculus* Aita, from 32604R in B2. Fig. 11, *Sethocapsa kaminogoensis* Aita, from 32604R in B2. Fig. 12, *Archaeodictyomitra mitra* Dumitrica, from 32604R in B2. Fig. 13, *Loopus primitivus* (Matsuoka and Yao), from 32604R in B2. Fig. 14, *Loopus primitivus* (Matsuoka and Yao), from 32602R in A3. Fig. 15, *Svinitzium pseudopuga* Dumitrica, from 32602R in A3. Fig. 16, *Svinitzium depressum* (Baumgartner), from 32607R in C. Fig. 17, *Solenotrima* (?) *ichikawai* Matsuoka and Yao, from 32602R in A3. Fig. 18, *Archeodictyomitra minoensis* (Mizutani), from 32602R in A3. Fig. 19, *Cinguloturris carpatica* Dumitrica, from 32602R in A3. Fig. 20, *Protunuma japonicus* Matsuoka and Yao, from 32602R in A3. Fig. 21, *Eucyrtidiellum ptyctum* (Riedel and Sanfilippo), from 32602R in A3. Fig. 22, *Ristola altissima* (Rüst), from 32602R in A3. Fig. 23, *Loopus yangi* Dumitrica, from 32602R in A3. Fig. 24, *Loopus doliolum* Dumitrica, from 32602R inA3. Fig. 25, *Pantanellium lanceola* (Parona), from 32607R in C. Fig. 26, *Kilinora spiralis* (Matsuoka), from 32601R in A2. Fig. 27, *Tricolocapsa conexa* Matsuoka, from 32601R in A2. Fig. 28, *Stichocapsa robusta* Matsuoka, from 32601R in A2. Fig. 29, *Eucyrtidiellum nodosum* Wakita, from 32601R in A2. Fig. 30, *Hsuum maxwelli* Pessagno, from 32601R in A2. Fig. 31, *Ristola procera* (Pessagno), from 32601R in A2.

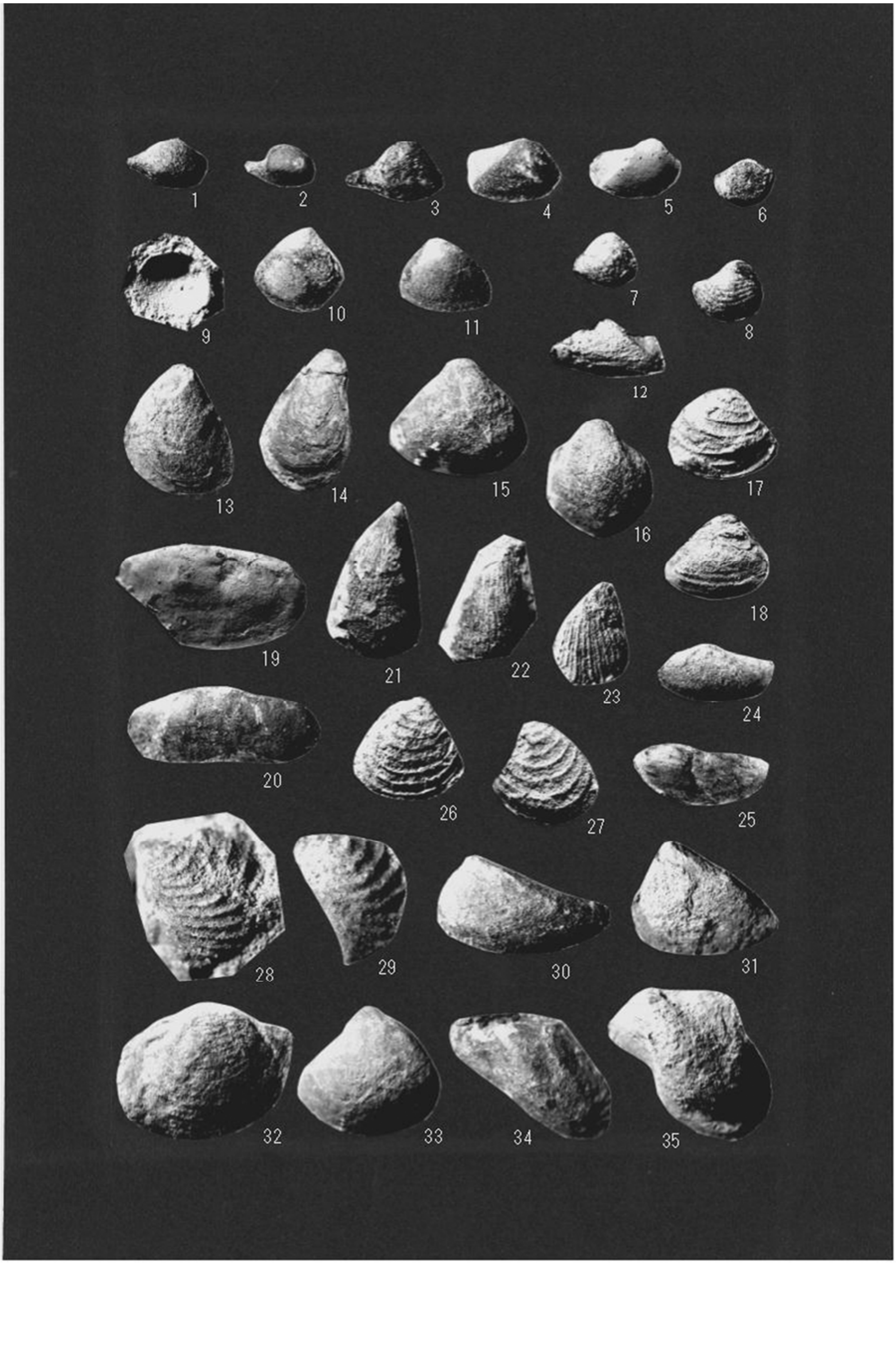
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35

Plate 2. Berriasian bivalves from the Birafu Formation. Figs. 1-3, *Caestocorbula morinoi* Tashiro and Kozai. 1: NU39-0054, from 32631, ×2.5, 2: NU39-0053, from 32631, ×2, 3: NU39-0057, from 32631, ×2.5. Figs. 4-5, *Grammatodon takiensis* Kimura. 4: NU39-0038a, from 32655, ×2. 5: NU39-0038b, from32655, ×2. 6-8, Corbula *globosa* Tamura. Fig. 6: NU39-0049, from 32631, ×3. Fig. 7: NU39-0048, from 32631, ×3. Fig. 8: NU39-0047, from 32653, ×4. Figs. 9-11, *Isocyprina japonica* Tashiro andÅ@Kozai. 9: NU39-0081, from 32631, ×2. 10: NU39-0076, from 32631, ×2.5. 11: NU39-0078, from 32653, ×3. Fig. 12, *Parallelodon* sp. cf. *P. koikensis* Tamura, NU39-0085, from 32631, ×4. Figs. 13-14, *Ctenoides tosana* (Kurata and Kimura). 13: NU39-0041, from 32626, ×1.5. 14: NU39-0042,from 32626, ×1.5. Figs. 15-16, *Protocardia* sp. cf. *P. tosensis* Kimura. Fig. 15: NU39-0069, from 32656, ×1, Fig. 16: NU39-0070, from 32656, ×1. Figs. 17-18, *Eomiodon kumamotoensis* Tamura. 17: NU39-0059, from 32631, ×2. 18: NU39-0058, from 32631, ×2. Figs. 19-20, *Linearia* sp. aff. *L. nankaiana* Tashiro and Kozai. 19: NU39-0084, from 32631, ×1. 20: NU39-0083, from 32631, ×1. Figs. 21-22, *Arcomytilus* sp. cf. *A. laitmairensis* (de Loriol). 21: NU39-0087, from 32626, ×1.5. 22: NU39-0086, from 32626, ×2. Fig. 23, *Parvamussium habunokawense* (Kimura), NU39-0062, from 23631, ×2. Figs. 24-25, *Corbula imamurae* Hase. Fig. 24: NU39-0044, from 32653, ×2. Fig. 25: NU39-0045, from 32654, ×2. Figs. 26-27, *Eomiodon nipponicus* Ohta. Fig. 26: NU39-0026, from 32631, ×2. Fig. 27: NU39-0061, from 32631, ×2. Figs. 28-29, *Pterotrigonia toyamai* (Yehara). Fig. 28: NU39-0069, from 32626, ×1.5. Figs. 29: NU39-0065, from 32626, ×1.5. Figs. 30-31, *Crenotrapezium kitakamiense* Hayami. 30: NU39-0073, from 32631, ×1. 31: NU39-0074, from 32631, ×1. Fig. 32, *Miltha japonica* Tashiro, NU39-0063, from 32631, ×1. Fig. 33, *Cucullaea* sp. aff. *C. acuticarinata* Nagao, NU39-0040, from 32626, ×1.5. Figs. 34-35, *Agillerella nagatoensis* (Ohta). 34: NU39-0050a, from 32631, ×0.5. 35: NU39-0050b, from 32631, ×0.5.