

Biostratigraphy and Depositional Facies of the Cretaceous-Tertiary Boundary Strata in Amakusa-Shimojima, Kyushu, Western Japan

M. Tashiro, A. Taira

Department of Geology, Kochi University, Kochi, Japan

and T. Matsumoto

Professor Emeritus, Department of Geology, Kyushu University 33, Fukuoka, Japan

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M. Tashiro, A. Taira and T. Matsumoto. Biostratigraphy and Depositional Facies of the Cretaceous-Tertiary Boundary Strata in Amakusa-Shimojima, Kyushu, Western Japan. *Cretaceous Research* (1980) 1, 13–26. The Upper Himenoura Subgroup exposed in the island of Amakusa-Shimojima, Kyushu, Japan shows an example of the terminal Cretaceous stratigraphic record in the circum Pacific region. This sequence is a part of the Upper Cretaceous intra-arc basins of southwest Japan. Four cycles of upward coarse-graded facies are recognized. Each cycle consists of a basinal mud facies in the lower part and a tide-dominated shallow marine to brackish coarse clastic facies in the upper part. Biostratigraphic correlation chiefly based on ammonites, inocerami and tritoniids indicates that this sequence is Campanian to Maastrichtian in age. The occurrence of the above three fossils decreases upward and is terminated at the top of the sequence, being replaced by a molluscan assemblage similar to the Danian. This suggests that the sedimentation may have continued to the very end of the Cretaceous period and possibly to the beginning of the Tertiary.

Department of Geology, Kochi University, Kochi, Japan.
Department of Geology, Kyushu University, Fukuoka, Japan.

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1. Introduction

Mass extinction of many organisms at the end of the Cretaceous period has long been considered one of the major events in the geological history of the earth (Newell, 1962). However, the main causes of this mass extinction are still debated as is the case for many other stratigraphic boundaries. One of the main obstacles for solving this problem is that a continuous Cretaceous-Tertiary boundary record has been difficult to obtain because of the world-wide unconformity in many stratigraphic sections. Many deep-sea cores have shown biostratigraphic hiatuses, indicating possible occurrence of some oceanographic events such as a drastic rise of CCD level (Worsley, 1974) or major climatic changes (Saito & van Donk, 1974). Therefore, a section which records the continuous deposition across the boundary is of particular value. An essentially complete section of Upper Cretaceous to Palaeocene pelagic calcareous sediments exposed at Gubbio, Italy (Alvarez *et al.*, 1977) is considered one of such rare examples.

The nature of the boundary events should be evaluated on a world-wide scale, especially in different environmental and geographic settings. We have investigated possible Cretaceous-Tertiary boundary strata exposed on the island of Amakusa-Shimojima, Kyushu, Japan. This section represents an intra-arc clastic sequence

of the circum Pacific orogenic belts, the setting of which is quite different from the cratonic North American and northern European sections and pelagic Tethyan sections.

2. Geologic setting

2.1. Cretaceous intra-arc basins

During much of the Cretaceous and Palaeogene period, south-western Japan was an arc-trench system (Figure 1). An extensive rhyolitic and andesitic volcanic belt accompanied by granitic intrusives was situated along the inner side of SW Japan during late Cretaceous and early Palaeogene time. This belt represents a volcanic arc. Along the outer side of SW Japan, a belt of non-depositional uplift composed of pre-Cretaceous rocks is inferred, representing a non-volcanic frontal arc. Outside the frontal arc lies an elongate belt of flysch-mélange terrain, the Shimanto belt, representing a fore-arc basin and subduction complex. Between the volcanic and non-volcanic frontal arc, a series of elongated, narrow and rapidly subsiding troughs was developed representing intra-arc basins.



Figure 1. Geological sketch map of the Cretaceous and Palaeogene rocks in south-west Japan (excluding granitic intrusions). (1) Palaeogene sediments; (2) Cretaceous and Palaeogene volcanics; (3) Cretaceous terrestrial deposits; (4) Cretaceous intra-arc basin deposits; (5) Cretaceous fore-arc shelf deposits; (6) Cretaceous and Palaeogene fore-arc basin deposits and subduction complex (Shimanto Belt). (A) Mifune basin; (B) Goshonoura basin; (C) Ohno-gawa basin; (D) Lower Himenoura basin; (E) Upper Himenoura basin; (F) Izumi basin. Enclosed area is enlarged in Figure 2.

The Late Cretaceous epoch in SW Japan represents a major phase of intra-arc basin formation such as the Goshonoura basin (Albian–Cenomanian), Mifune basin (Cenomanian–Turonian), Ohno-gawa basin (Turonian–Santonian), Lower Himenoura basin (Santonian–Lower Campanian), Upper Himenoura basin (Campanian–Maastrichtian) and Izumi basin (Campanian–Maastrichtian) (Figure 1). This Late Cretaceous event was followed by more extensive intra-arc and back-arc basin formation of Eocene and Oligocene, especially in the western part of SW Japan.

Within these intra-arc basins, thick sequences of brackish to marine clastic sediments were accumulated with high rate of sedimentation. The Ohno-gawa and Izumi basins show especially higher rate of sediment accumulation, reaching up 4 m per 1000 years of turbidite filling. It is suspected that sedimentation may have continued across the Cretaceous–Tertiary boundary in the Izumi and Upper Himenoura basins.

2.2. Geology of Amakusa area

There are two large islands situated west of central Kyushu; Amakusa-Kamishima and Amakusa-Shimojima (Figure 2). On the island of Amakusa-Kamishima and vicinity of the Uto Peninsula, Upper Cretaceous clastic sediments, the Himenoura Group, is exposed. The Himenoura Group is overlain unconformably by the Palaeogene Akasaki Formation which includes red beds. The main part of Himenoura Group yielded an abundant molluscan fauna, including ammonites, inocerami and tritoniids. Among these, *Texanites oliveti* (Blankenhorn) (in the sense of Collignon, 1948), *Protexanites (Aratexanites) fukazawai* (Yabe & Shimizu), *Inoceramus (Platyceramus) amakusensis* (Nagao & Matsumoto) and *I. (Platyc.) japonicus* (Nagao & Matsumoto) indicate Santonian. The upper part of the group, which shows an upward coarse-graded turbidite sequence, is relatively unfossiliferous. *Inoceramus (Sphenoceramus) orientalis* (Sokolow) obtained from this part indicates Lower Campanian and simultaneous occurrence of *Glyptoxoceras* sp. and *Diplomoceras* sp. supports this conclusion.

Similar clastic sequence of Cretaceous age exposed at Amakusa-Shimojima, which is overlain by *Nummulite*-bearing strata, the Miroku Group, has been correlated to the type Himenoura Group. However, recent detailed mapping and extensive search for fossils revealed that the Cretaceous strata exposed on Amakusa-Shimojima are Campanian and Maastrichtian and the uppermost part may extend to Palaeocene. Sedimentary facies analysis also indicates that, although the cyclic pattern of sedimentation is a characteristic of the Himenoura Group, there are differences in depositional facies between the two islands. Shallow marine sand deposits, followed by basin-plain mud facies and later upward coarse-graded turbidite filling, characterize the Lower Campanian section at Amakusa-Kamishima, while cyclic pattern of alternating shallow-marine and supratidal coarse clastic facies and basin-plain mud facies predominate the Upper Campanian–Maastrichtian sequence at Amakusa-Shimojima. Because of these differences in age and lithofacies, the Himenoura Group was divided into two subgroups: the Lower Himenoura and Upper Himenoura (Tashiro & Noda, 1973).

We have examined the Upper Himenoura Subgroup from the biostratigraphical and sedimentological points of view. The main objectives of the study are to reconstruct the depositional environments and to evaluate the faunal changes within this framework. In this study, the authors were unable to identify and place the Cretaceous–Tertiary boundary but were able to show general trends of faunal changes at the close of the Cretaceous period.

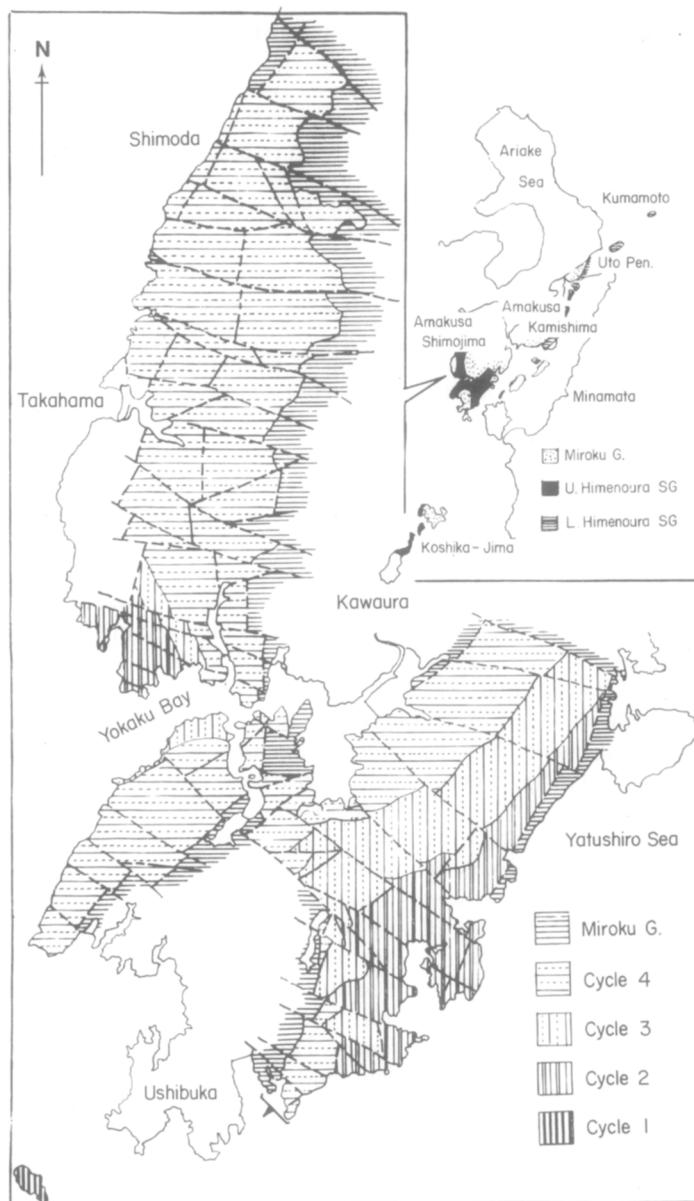


Figure 2. Geological map of the Amakusa area (above right) and of Amakusa-shimojima. The location where the section shown in Figure 4 is measured.

3. Depositional facies of the Upper Himenoura Subgroup

The Upper Himenoura Subgroup exhibits a distinctive cyclic pattern of sedimentation (Figure 3). Four major cycles (Cycles 1, 2, 3, and 4) are recognized, but the nature of the cycles is different between the eastern and the western sides of the island, possibly representing the difference in depositional history in the eastern and the western margins of the basin.

Each sedimentary cycle consists of four parts: fining upward facies (A), mud facies (B), upward coarse-graded facies (C), coarse facies (D) in ascending order.

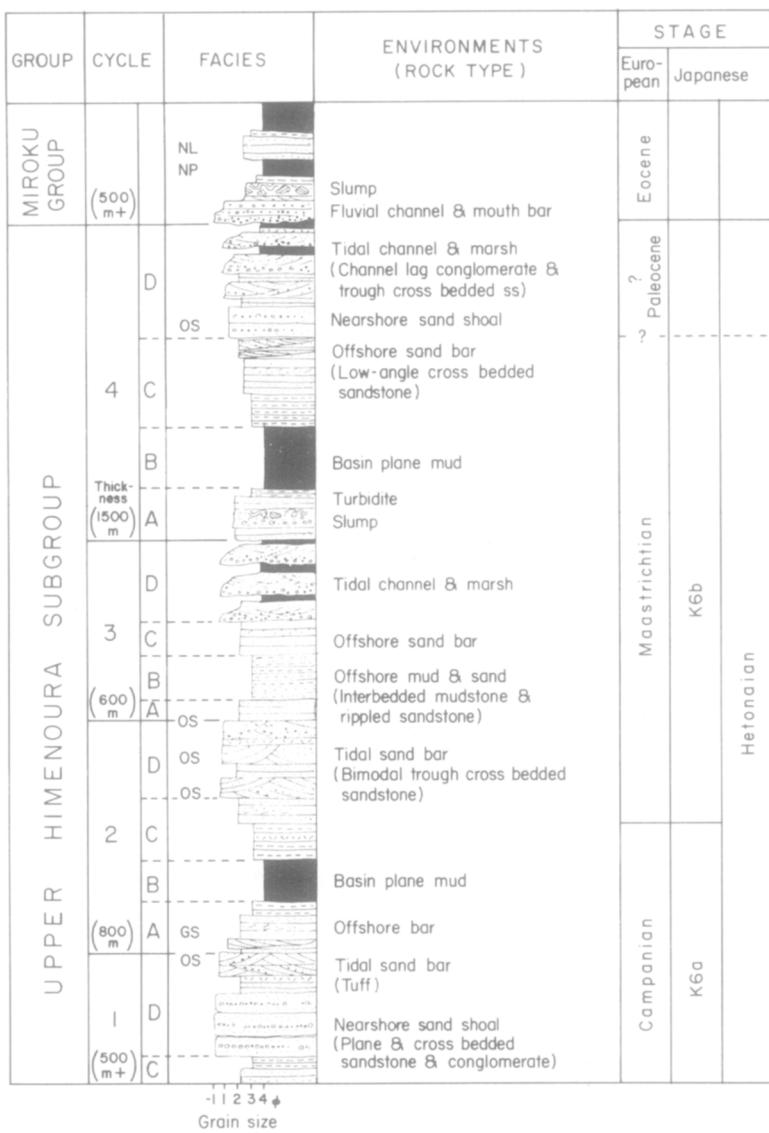
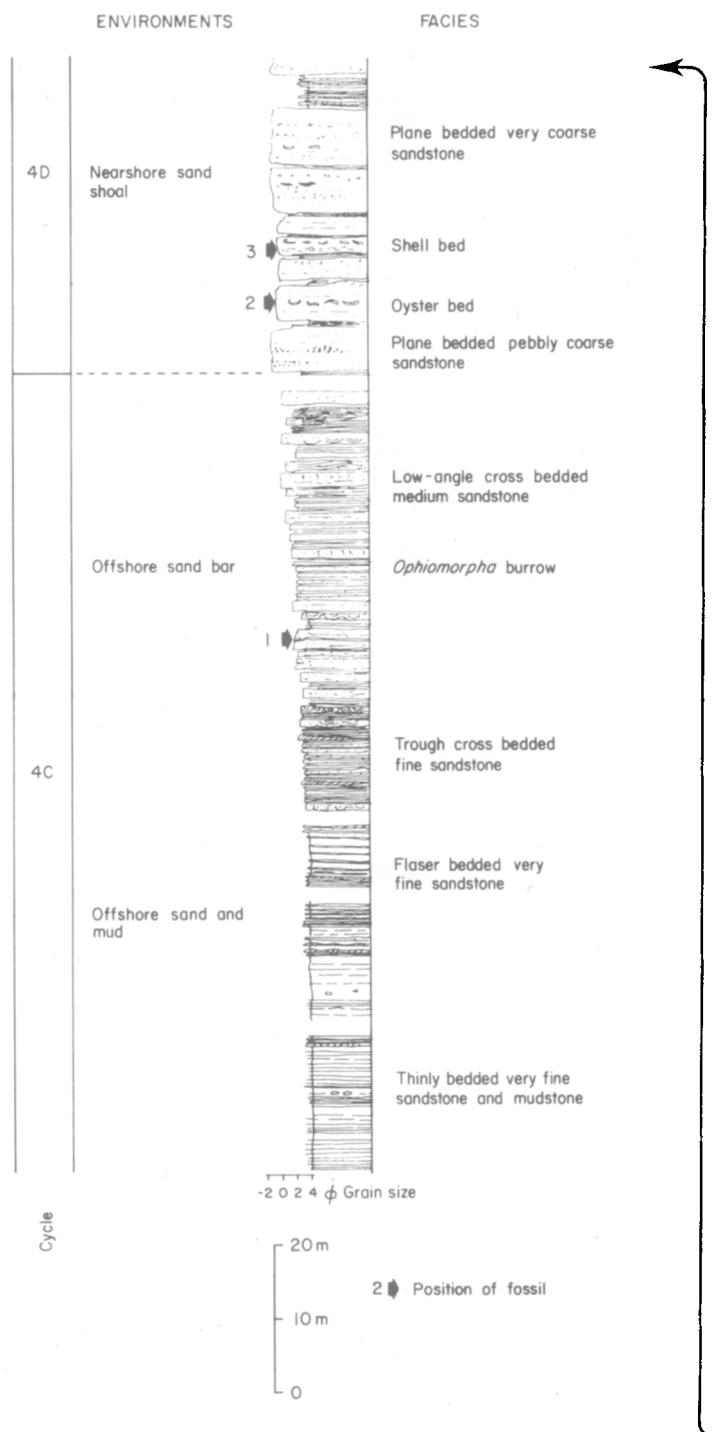


Figure 3. Generalized columnar section of the Upper Himenoura Subgroup. OS = Oyster shell bed; GS = *Glycymeris* shell bed; NP = Middle Eocene nannofossils; NL = *Nummulites* bed.

The fine upward facies is usually thinner than upward coarse-graded facies. Lines of evidence for rapid subsidence of the basin, such as the presence of pebbly mudstone and slump deposits, are present within the fine upward facies. These cycles range from several hundred to more than one thousand meters in thickness.

3.1. Cycle 1

Cycle 1 consists of incomplete parts. No detailed sedimentological examination was undertaken because, except for the coarse facies, the lower parts of the cycle are only exposed on a few isolated islets. *Inoceramus (Sphenoceramus) orientalis* (Sokolow) obtained from this cycle indicates Lower Campanian.



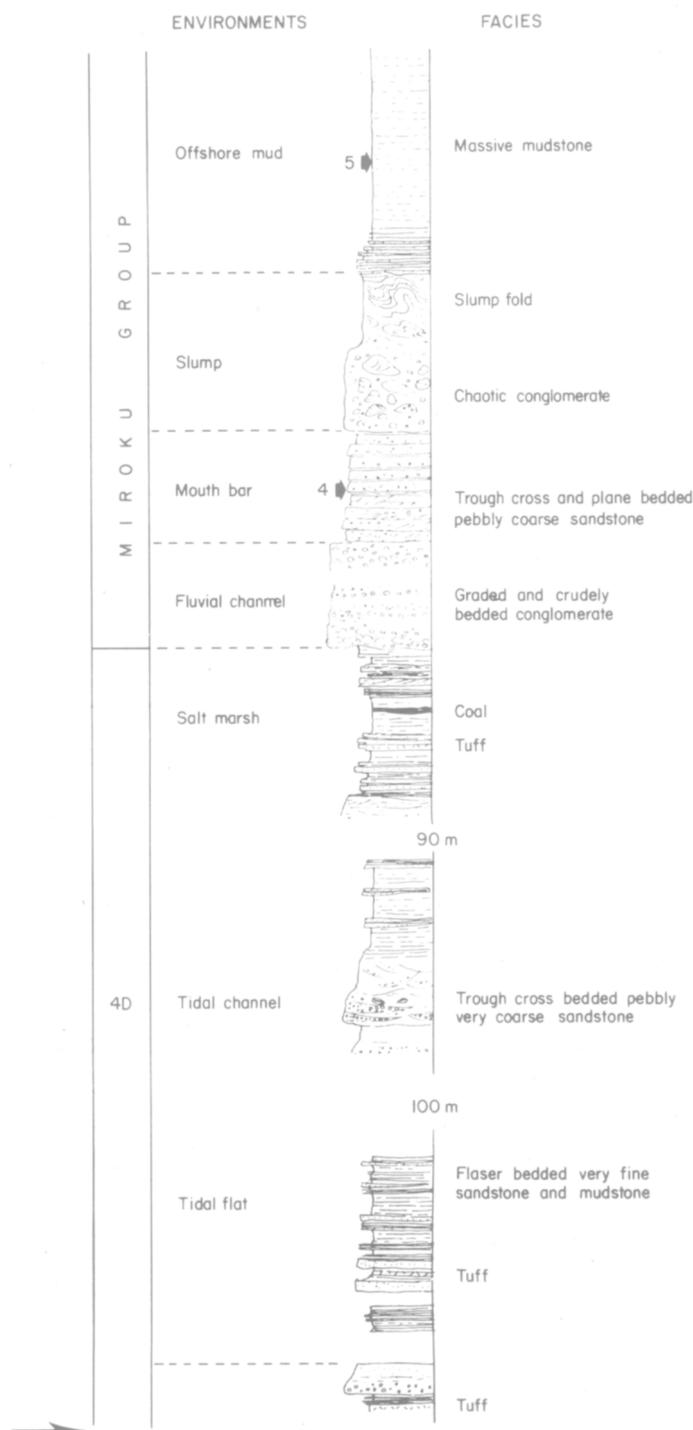


Figure 4. Stratigraphic section showing depositional environments and facies near the Cretaceous and Tertiary boundary in the Himenoura Subgroup and Miroku Group. See Figure 2 for location of measured section.

The coarse facies (1D) is predominated by medium to coarse-grained sandstone, locally conglomeratic, intercalated with minor amount of mudstone. A sandstone bed of up to 4 m thick is present, which includes a basal conglomeratic part with oyster shell fragments and low-angle cross-bedding stratification. Sandstone beds of less than 1 m thickness are common. They show bimodal troughs of cross-bedding and plane-bedding. Several *Glycymeris* shell beds are also present. Overall faunal characteristics and stratification types indicate that this facies consists of nearshore sand shoal and tidal sand bar deposits.

3.2. Cycle 2

Cycle 2 starts with a fining-upward cycle (2A). Sandstone beds are usually less than 1 m thick and composed of medium to fine-grained sandstone. Trough cross-bedding and plane-bedding are common sedimentary structures of sandstone beds which are intercalated with mudstone showing flaser-wavy lamination. *Glycymeris* shell beds are again common. This facies yields an abundant molluscan assemblage, the age of which was interpreted as Late Campanian (Tashiro, 1976).

This facies is covered by black mud facies (2B) which is about 300 m thick. The mud facies is unfossiliferous both in body and trace fossils, possibly representing less oxygenated basin-floor mud deposition.

The mudstone facies (2B) is overlain by coarse-graded upward cycle (2C). Trough cross-bedding and plane-bedding are common sedimentary structures in sandstone beds. A thick sequence of coarse to very coarse-grained sandstone bed which exhibits large-scale bimodal cross beds with oyster shells overlies the coarse-graded upward facies, representing coarse facies (2D). The coarse facies of this cycle resembles that of Cycle 1 and is interpreted as tidal sand bar deposits. The rock unit of this facies yields abundant molluscan fauna, however, occurrence of inocerami and ammonites is rather scarce. The age of this part is interpreted as Campanian to Maastrichtian.

The cyclicity of Cycle 2 is conspicuous at the eastern part of the basin, but less conspicuous in the western part. Correlation using tuff key beds and molluscan fauna indicates that the middle mud facies (2B) is poorly developed in the western part suggesting eastward titling of the basin.

3.3. Cycle 3

Cycle 3 starts with fining-upward facies (3A) in which trough cross-bedded sandstone, locally intensively burrowed, are common with intercalation of thin-bedded mudstone. Oyster shell beds are found in the lower part of this facies. The fining-upward facies grades upward into unfossiliferous mud facies (3B). At the western margin, sandstone beds are very common, again indicating west-shallow and east-deep basin configurations. The mud facies grades upward into the upward coarse-graded facies (3C) and then to the coarse facies (3D).

The coarse facies of this cycle is different from underlying cycles, being composed of a repeated sequence of a fining-upward channel complex. The channel lag conglomerate, large-scale trough cross stratification and the plane-bedded upper part, comprise of channel deposits and mudstone, locally lignitic, over-bank deposits. The bimodal trend of trough cross-bedding observed in some channels indicates that this facies represents intertidal and supratidal channel and over-bank deposits. No fossils have so far been obtained from this facies.

3.4. Cycle 4

The fining-upward cycle of Cycle 4 (4A) contains pebbly mudstone, broken beds and intraformational folding, indicating slump deposits. The slump beds are

overlain by interbedded sandstone and mudstone. The sandstone bed shows characteristic features common to turbidites. This slump-turbidite association suggests rapid deepening of the basin. The fining-upward facies is overlain by mud facies (4B). At the western margin, the mud facies interfingers with shallow marine and tidal sand facies. This again indicates west-shallow and east-deep relationships.

The upward coarse-graded facies is best developed in Cycle 4 (Figure 4). The gradual increase in sandstone intercalation and upward thickening of the sandstone bed are well observed. Plane and low-angle cross stratifications are the predominant internal sedimentary structures. The sandstone bed shapes are more or less lenticular. *Ophiomorpha* burrows are quite common in the upper part of the facies. This facies (4C) is interpreted as a progradational shallow marine sand-bar deposit. The molluscan fauna include small inoceramids, ammonites and tritoniids. However, scarce *Inoceramus* specimens indicate Maastrichtian.

Sand-bar deposits are overlain by thick, plain-bedded, very coarse-grained sandstone beds with thin conglomeratic layers (4D). This part is interpreted as nearshore sand shoal deposits. This part is overlain by intertidal-supratidal channel complex (4D) which is very much similar to the coarse facies of Cycle 3. A "Danian" type molluscan assemblage was found at the basal part of this coarse facies (position 3 in Figure 4) indicating a possibility of the Cretaceous-Tertiary chronological boundary lying within this facies.

3.5. The Tertiary Miroku Group

The Palaeogene Miroku Group begins with fluvial channel conglomerates which cut into the over-bank facies of Cycle 4 (Figure 4). The channel conglomerate is overlain by cross-bedded conglomerate and very coarse-grained sandstone inferred as mouth bar deposits, which yield turritellids (position 4 in Figure 4). This is followed by slump deposits and mudstone. The mudstone bed yields nannofossils (position 5 in Figure 4) which is assigned to the lower Middle Eocene (Okada, H., personal communication).

The basal part of the Miroku Group, therefore, represents a Middle Eocene transgression unconformably overlying the Upper Himenoura Subgroup.

4. Biostratigraphy

Biostratigraphic correlation of the Upper Himenoura Subgroup is chiefly based on molluscs (Table 1, Figure 5) aided by nannoplankton fossils which occur at limited horizons.

Inoceramus (Sphenoceramus) orientalis (Sokolow) and *I. (S.) cfr. patootensiformis* (Seitz) were obtained from Cycle 1 indicating Lower Campanian. Nannofossils of Campanian to Maastrichtian age were also obtained therefore supporting the *Inoceramus* correlation.

Cycle 2 is characterized by ammonites (*Glyptoxoceras* sp.) and *Inoceramus (Endocostea) balticus* (Böhm), *I. (S.) sachalinensis* Schmidt and *Yadzia japonica* (Yehara). *I. (E.) balticus* is an index fossil for Campanian in Europe. The type locality of *I. (S.) sachalinensis* is Sakhalin, U.S.S.R. and the same species is reported from the zone of *I. (S.) orientalis* and of *I. (S.) schmidti* (Michael), i.e., the Lower to Middle Campanian of Hokkaido and British Columbia. These lines of evidence indicate that the lower part of this cycle is probably Middle Campanian (for international correlation; Muller & Jeletzky, 1970; Matsumoto, 1977; Ward, 1978).

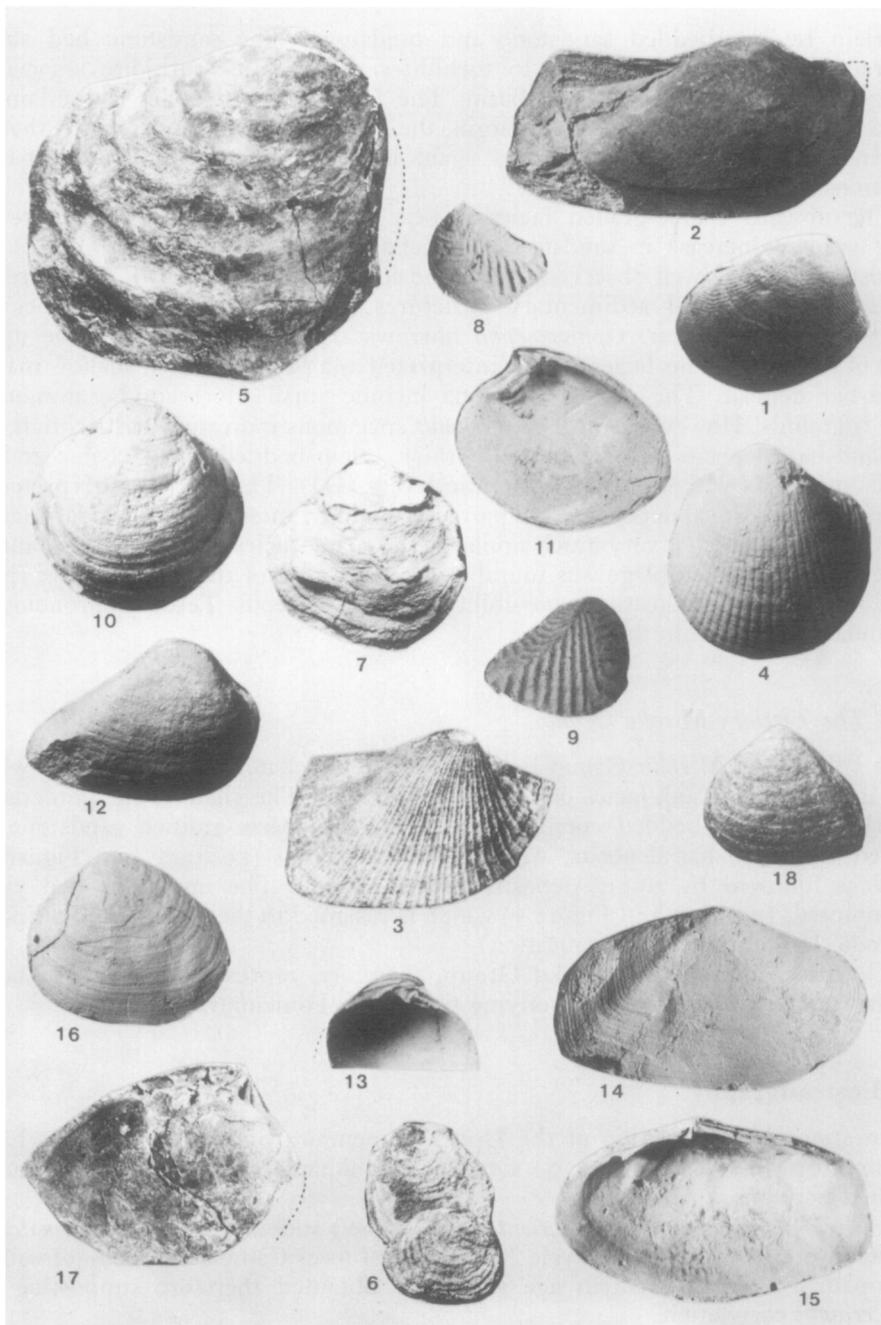


Figure 5. (1) *Acila (Truncacila) shimojimensis* (Tashiro). Left valve, $\times 0.96$; Occurrence: Cycle 1D to Cycle 4C; Upper Campanian and Maastrichtian. (2) *Nanonavis elongatus* (Nagao & Otatume). Right valve, $\times 0.85$; Occurrence: Cycle 4C; Maastrichtian. (3) *Nanonavis sachalinensis* (Schmidt). Right valve, $\times 1.2$; Occurrence: Cycle 1C; Lower Campanian. (4) *Glycymeris (Glycymerita) japonica* (Tashiro). Right valve, $\times 0.85$; Occurrence: Cycle 2C to Cycle 4C; Uppermost Campanian and Maastrichtian. (5) *Inoceramus (Endocostea) goldfussianus* (d'Orbigny). Right valve, $\times 0.85$; Occurrence: Cycle 4B; Maastrichtian. (6) *Dimya* sp. Right valve (lower) and left valve (upper), $\times 1.6$; Occurrence: NP Zone of the Miroku Group; lower part of the Middle Eocene. (7) *Anomia (Paraplacuna)* sp. Left valve, $\times 0.85$; Occurrence: Cycle 4D; Maastrichtian or Danian. (8) *Apotrigonia dubia* (Tashiro). Left valve, $\times 1.6$; Occurrence:

The coarse facies of Cycle 2 (2D) yielded abundant bivalve fossils, however, ammonites and inoceramids are quite rare. The bivalves include genera common to the Campanian and Maastrichtian of California like *Agnomyax*, *Clisoculus*, *Granocardium*, *Loxo* and *Glycymerita*. The only ammonite species so far obtained, *Baculites* cfr. *subanceps* (Matsumoto & Obata) suggests Upper Campanian.

Fossils useful for correlation were not obtained from Cycle 3. The mud facies and upward coarse-graded facies of Cycle 4 (4B and 4C) yielded scarce ammonites, inoceramids and tritoniids, however, *Baculites rex* (Anderson) and *Inoceramus (Endocostea) goldfussianus* (d'Orbigny) are useful for correlation. *Baculites rex* is known from the Upper Campanian and Maastrichtian of California, British Columbia and Hokkaido. *Inoceramus (Endocostea) goldfussianus* (Noda, personal communication) is reported from the Maastrichtian of Europe and India. These occurrences indicate that 4B and 4C are Maastrichtian.

Abundant bivalves were recovered from the upward coarse-graded facies of Cycle 4 (4C). Among these, *Tenea*, *Glycymerita*, *Clisoculus*, *Agnomyax*, *Fleistarte*, *Cyclolisma*, large *Nanonavis* and *Crassatella*(?) are known from California, the Southern Interior of North America, Mexico and Madagascar. *Glycymerita*, *Tenea*, *Fleistarte* and *Crassatella*(?) are known to have existed during the period from the Cretaceous to Palaeogene (Stephenson, 1923, 1941; Stewart, 1930; Collignon, 1951; Anderson, 1958; Dailay & Popenoe, 1964; Speden, 1970; Wolleben, 1977 and Tashiro, 1978).

It is noted that ammonites, inoceramids and tritoniids (*Apotrigonia Microtrigonia* and *Yaadia*) are quite rare in the 4A, 4B and 4C of Cycle 4 but other Bivalvia, like *Acila*, *Glycymerita*, *Portlandia* and *Nanonavis*, which are often associated with the above three in the lower cycles, occur abundantly. This observation together with the fact that the "Danian type" molluscs, i.e., *Crassatella*(?), *Glycymerita*, *Fleistarte*, *Palumicorbula* and *Varicorbula*, are mixed with the Maastrichtian type, i.e., *Agnomyax*, *Clisoculus*, *Cyclolisma*, *Tenea*, *Izumea* and *Loxo*, at these locations, suggest that the molluscan fauna in the 4B and 4C facies can be placed in the terminal Cretaceous assemblage.

The coarse facies of Cycle 4 (4D) yielded *Septifer* sp., *Paraplaguna* sp., *Pycnodonte* sp. and *Lingula* sp. Although they are not useful for dating, *Paraplaguna* is known as Eocene in Europe. Although no conclusive evidence has been obtained so far, this part of Cycle 4 (4D) may extend to the Palaeocene.

Nannofossil assemblages from the basal part of the Miroku Group (position 5 in Figure 4) are assigned to the *Discoaster sublodoensis* Zone (48 to 49.5 ma) (Table 2). Tertiary Bivalvia, *Dimya* sp. and *Colpospira* sp., were found in the same horizon.

5. Discussion and conclusion

The cyclic pattern of sedimentation in the Upper Himenoura Subgroup can be interpreted as a transgressive-regressive sequence chiefly induced by tectonic

Cycle 4c; Maastrichtian. (9) *Apotrigonia (Microtrigonia) postonodosa* (Nakano). Right valve, $\times 1.2$; Occurrence: Cycle 2C to Cycle 2D; Uppermost Campanian and lower part of the Lower Maastrichtian. (10) *Clisoculus* sp. Left valve, $\times 0.85$; Occurrence: Cycle 1C to Cycle 4C; Campanian and Maastrichtian. (11) *Fleistarte* sp. Internal view of right valve, $\times 0.85$; Occurrence: Cycle 4C; Maastrichtian. (12) "Crassatella", aff. *C. (?) protracta* (Collignon). Right valve, $\times 0.85$; Occurrence: Cycle 4C; Maastrichtian. (13) *Tenea japonica* (Ichikawa & Maeda). Internal view of left valve, $\times 1.2$; Occurrence: Cycle 2C to Cycle 4C; Upper Campanian and Maastrichtian. (14 and 15) *Agnomyax elegans* (Tashiro). Right valve (14: external view; 15: internal view), $\times 0.96$; Occurrence: Cycle 2C to Cycle 4C; Uppermost Campanian and Maastrichtian. (16 and 17) "Cyclolisma" sp. (16) Left valve, $\times 0.85$; (17) Internal mould of right valve, $\times 0.85$; Occurrence: Cycle 4C; Maastrichtian. (18) *Mesochione trigonalis* (Tashiro). Left valve, $\times 0.85$; Occurrence: Cycle 2D to Cycle 4B; Uppermost Campanian and Maastrichtian.

Table 1. Distribution of molluscs in the Upper Himenoura Subgroup and Miroku Group.
M=Miroku Group

Bivalvia	Cycle 1				Cycle 2				Cycle 3				Cycle 4				M
	C		D		A	B	C	D	A	B	C	D	A	B	C	D	
	C'	D	C	D													
<i>Acila (Truncacila) shimojimensis</i>		x						x								x	
<i>A. (T.) n. sp.</i>						x	x									x	
<i>Nucula (Nucula) amanoi</i>	x				x												
<i>Ezonuculana mactraeformis obsoleta</i>					x												
<i>E. dubia</i>							x										
<i>Portlandia obliquicostata</i>	x	x			x												
<i>P. cuneistriata</i>													x				
<i>Nanonavis sachalinensis</i>	x																
<i>N. brevis</i>		x	x	x													
<i>N. awajianus</i>									x								
<i>N. turgida</i>													x				
<i>N. elongatus</i>												x					
<i>Glycymeris (Glycymeris) amakusensis</i>	x	x	x	x													
<i>Glycymeris (Glycymerita) japonica</i>								x					x				
<i>Limopsis kogata</i>									x								
<i>Brachiodontes nankoi</i>						x	x	x									
<i>Septifer n. sp.</i>													x				
<i>Lycetta</i> sp.	x																
<i>Inoperna</i> sp.									x								
<i>Pinna</i> sp.							x	x									
<i>Electroma shiranuiensis</i>	x																
<i>Inoceramus (Platyceramus) ezoensis</i>	x				x												
<i>I. (Endocosteal) balticus balticus</i>			x	x	x												
<i>I. (E.) balticus toyajoanus</i>	x																
<i>I. (E.) balticus kunimiensis</i>	x																
<i>I. (E.) cfr. goldfussianus</i>													x				
<i>I. (Sphenoceramus) cfr. patootensiformis</i>	x																
<i>I. (S.) orientalis orientalis</i>	x																
<i>I. (S.) sachalinensis</i>			x														
<i>I. (S.) aff. schmidti</i>				x													
<i>Parvamussium</i> n. sp.						x							x				
<i>Chlamys (s. l.) tamurai</i>					x												
<i>Anomia hataei</i>						x				x							
<i>A. (Paraplaguna) n. sp.</i>							x							x			
<i>Dimya</i> n. sp.								x							x		
" <i>Crassostrea</i> " sp.		x						x	x	x							
<i>Lopha</i> sp.					x	x											
" <i>Pycnodonte</i> " sp.							x						x				
<i>Apotrigonia crassoradiata</i>	x	x						x	x								
<i>A. postonodosa</i>						x			x	x				x			
<i>A. n. sp.</i>							x										
<i>Microtrigonia amanoi</i>		x	x	x	x												
<i>M. imutensis</i>	x	x	x	x	x												
<i>Yaadia japonica japonica</i>	x	x					x			x	x						
<i>Y. japonica obsoleta</i>								x	x								
<i>Clisoculus</i> n. sp.	x						x			x				x			
<i>Fenestricardita densigranulata</i>					x												
<i>Freiastarte</i> n. sp.						x								x			
" <i>Crassatella</i> " sp., aff. C. (?) <i>protracta</i>													x				
<i>Izumia trapezoidalis</i>													x				
<i>Eriphylla japonica</i>							x		x								
<i>Leptosolen japonica</i>								x	x					x			
<i>Agnomyax elegans</i>								x						x			
<i>Tenea japonica</i>					x									x			
<i>Mesocallista</i> sp.		x	x	x	x			x	x						x		
<i>Loxo japonica</i>		x	x	x	x			x						x			
" <i>Cyclolisma</i> " n. sp.						x			x				x				
<i>Mesochione trigonalis</i>							x	x	x					x			
<i>Corbula (Caryocorbula)</i> sp.		x	x	x	x			x	x						x		
<i>Variocorbula</i> n. sp.						x	x	x	x					x			
<i>Palumicorbula</i> n. sp.							x							x			
<i>Panopea matsumotoi</i>							x										
	Campanian				Maastrichtian								?	Eoc.			

Table 1 *continued*

	Cycle 1		Cycle 2		Cycle 3		Cycle 4		M	
	C	D	A	B	C	D	A	B	C	D
<i>Bivalvia</i>										
<i>Periplomya</i> sp.	x		x							
<i>Periploma ambigua</i>					x				x	
<i>Cephalopoda</i>										
<i>Glyptoxoceras</i> aff. <i>indicum</i>			x	x						
<i>Baculites</i> cfr. <i>subanceps</i>					x					
<i>B. rex</i>						x				
<i>Hoploscaphites</i> sp.								x		
<i>Canadoceras</i> cfr. <i>mysticum</i>				x						
<i>Heminautilus</i> (?) sp.					x					
	Campanian					Maastrichtian				

Table 2. List of calcareous nannofossils from the Miroku Group. See Figure 4 for sampled position (position 5). Identification was made by H. Okada (Yamagata University, Japan)

Braarudosphaera bigelowii (Gran & Braarud)
Chiasmolithus grandis (Bramlette & Riedel)
Chiasmolithus solitus (Bramlette & Sullivan)
Coccolithus pelagicus (Wallich)
Cyclocargolithus floridanus (Roth & Hay)
Cyclococcolithus formosus (Kamptner)
Cyclococcolithus gammation (Bramlette & Sullivan)
Discoaster barbadiensis (Tan Sin Hok)
Discoaster binodosus (Martini)
Discoaster lodoensis (Bramlette & Riedel)
Discoaster saipanensis (Bramlette & Riedel)
Discoaster sublodoensis (Bramlette & Sullivan)
Discoasteroides kuepperi (Stradner)
Helicosphaera lophota (Bramlette & Sullivan)
Helicosphaera semilulum (Bramlette & Sullivan)
Neochiastozygus concinnus (Martini)
Neococcolithus dubius (Deflandre)
Reticulofenestra dictyoda (Deflandre & Fert)
Reticulofenestra samodurovii (Hay, Mohler & Wade)
Sphenolithus radians (Deflandre)
Thoracosphaera deflandrei (Kamptner)
Zygrhablithus bijugatus (Deflandre)

movement. A rapid deepening of the basin and fast transgressions resulted in relatively thin fining-upward facies sometimes associated with slump deposits. The deepened basin was then covered by unfossiliferous basin-plane mud facies which show rather euxinic conditions.

A gradual progradation and ordering of a clastic wedge resulted in the upward coarse-graded facies. Then, the basin was filled with coarse clastic material of nearshore to supratidal origin, the following stage of rapid subsidence started the next depositional cycle.

The rapid subsidence of the basin may be related to the genesis of the Cretaceous intra-arc basins. We interpreted the intra-arc basin as having formed during the major tensional phase of tectonic movement, as is the case for modern back-arc and inter-arc basins (Karig, 1974). A periodic tensional breakdown of the crust, possibly in the 1 to 2 Ma period, caused rapid subsidence of the basin resulting in a cyclic pattern of deposition.

This cyclic sedimentation continued through the Campanian to Maastrichtian. Cycle 4 may represent the terminal Cretaceous period. The "mixed" Danian and

Maastrichtian molluscan fauna and the rarity of ammonites, inoceramids and tritoniids may be characteristic of terminal Cretaceous molluscan assemblage. The "brackish" fauna of the coarse facies of Cycle 4 (4D) show characteristics common to European basal Tertiary fauna like the large oysters *Pycnodonte* and *Paraplaguna*. However, with the limitation of the available data, the authors were unable to demonstrate the presence of Palaeocene fauna.

The marine Tertiary in south-western Japan started from the Middle Eocene transgression after a long period of possible non-deposition. However, the absence of a stratigraphic record hinders the interpretation of the causes of this non-depositional period.

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