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Litho- and Biofacies of Mudstone in the Pliocene-Pleistocene Kazusa Group, Boso Peninsula, Central Japan

By

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Contents

Abstract

The Pliocene-Pleistocene Kazusa Group, deep- to shallow-marine clastic deposits attaining 3,000 m thick, exposed in the Boso Peninsula, central Japan, is predominated by apparently monotonous mudstone. Based on the sedimentary structure, nature and intensity of bioturbation, and containing mega-fossils, the mudstone can be divided into following five different facies;

(1) Greenish gray massive fine-grained mudstone facies (facies A). Moderately bioturbated, fine-grained mudstone, in which small, horizontal tube burrows are quite common. Benthic assemblages indicate the bathyal environments.

(2) Bluish gray mottled coarse-grained mudstone facies (facies B). Intensely bioturbated, coarse-grained mudstone containing large vertical tube burrows. Lower-neritic environments are suggested from benthic assemblages.

(3) Light gray massive fine-grained mudstone facies (facies C). Intensely bioturbated, fine-grained mudstone, in which large vertical tube burrows are abundant. Benthic assemblages indicate environments from outer shelf to uppermost bathyal.

(4) Facies composed of alternating beds of greenish gray fine-grained mudstone and bluish gray fine-grained mudstone (facies D). This is the low-density turbidite facies; the bluish bed is a layer formed by muddy turbidity current and intercalated in the greenish gray massive fine-grained mudstone similar to the facies A.

(5) Greenish gray laminated fine-grained mudstone facies (facies E). Parallel and narrowly spaced lamination is distinct in this fine-grained mudstone. Degree of bioturbation is low, and benthic mega-

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fossils are quite rare.

The distribution of facies types changes stratigraphically, the facies A is seen in the lower part of the group, and is replaced upward by the facies B, and C, successively. In general, grain size and degree of bioturbation increase upward. The succession probably reflect the shallowing upward environmental change of the group. The facies D, the muddy turbidite, is found locally within the distribution of the facies A.

Thin parallel laminated mudstone of the facies E suggests an oxygen-deficient environment. The *in situ* bed of the facies E is distributed in a restricted western part of the Yoro area, while they occur commonly as allochthonous blocks of the slump deposits in the facies A of the eastern area. The facies E might originally be deposited in the shallower western area, and most part of the facies might be slumped eastward, and preserved as allochthonous blocks.

Introduction

The Kazusa Group, Upper Pliocene to Lower Pleistocene offshore deposits, is widely distributed in the middle part of the Boso Peninsula, central Japan. It consists largely of massive bluish- to greenish-gray mudstone intercalated with light-colored sandstone beds and many traceable tuff beds, and yields numerous well-preserved mega- and microfossils.

Many studies from various points of view have been made for the group since the last century. Detailed litho- and chronostratigraphy of the group have been established by MITSUNASHI (1954), MITSUNASHI *et al.* (1959, 1961, 1976), ISHIWADA *et al.* (1971), NIITSUMA (1976), and ODA (1977). Many paleontological data of the group have been accumulated (*e.g.*, OYAMA, 1959; ISHIWADA, 1964; BABA, 1990). Bathymetric study using benthic foraminifers indicates that the group was deposited in the depths from lower continental slope to shelf upward (AOKI, 1968). In addition, there are sedimentological studies focused on the sandstone beds in the group. Some sandy turbidite beds in the group were traced and observed over 38 km (HIRAYAMA and SUZUKI, 1968). KATSURA (1984) recognized twenty-five sandstone facies in the group, and reconstructed their depositional processes. Cyclic change in thickness of the turbiditic sandstone layer was regarded to reflect the "Milankovitch cycle" by MASUDA *et al.* (1989).

In contrast, sedimentary features of mudstone have remained largely to be explored, although mudstone is dominant throughout the Kazusa Group. Mudstone may yield many important information on offshore litho- and bio-event, and may reflect sedimentary environments at that time.

I made detailed observation on the mudstone of the Kazusa Group, focusing on lithology, sedimentary structures, fossil associations, and mode of their occurrences in mudstone. Some different types of mudstone facies have been recognized. In this paper, I will describe sedimentary and biological features of the mudstone facies, and try to reconstruct depositional environments in the Kazusa Group.

Offshore mudstone facies are predominant in the Kazusa Group except the uppermost part (Mandano and Kasamori Formations). Therefore, the discussion will be concentrated mainly on sedimentary and biological features of the lower 10 formations of the group, namely, the Kurotaki, Katsuura, Namihana, Ohara, Kiwada, Otadai, Umegase, Kokumoto, Kakinokidai, and Chonan Formations, all of which are composed mainly of muddy deposits, and are well-exposed in the Yoro area, the study area in the central part

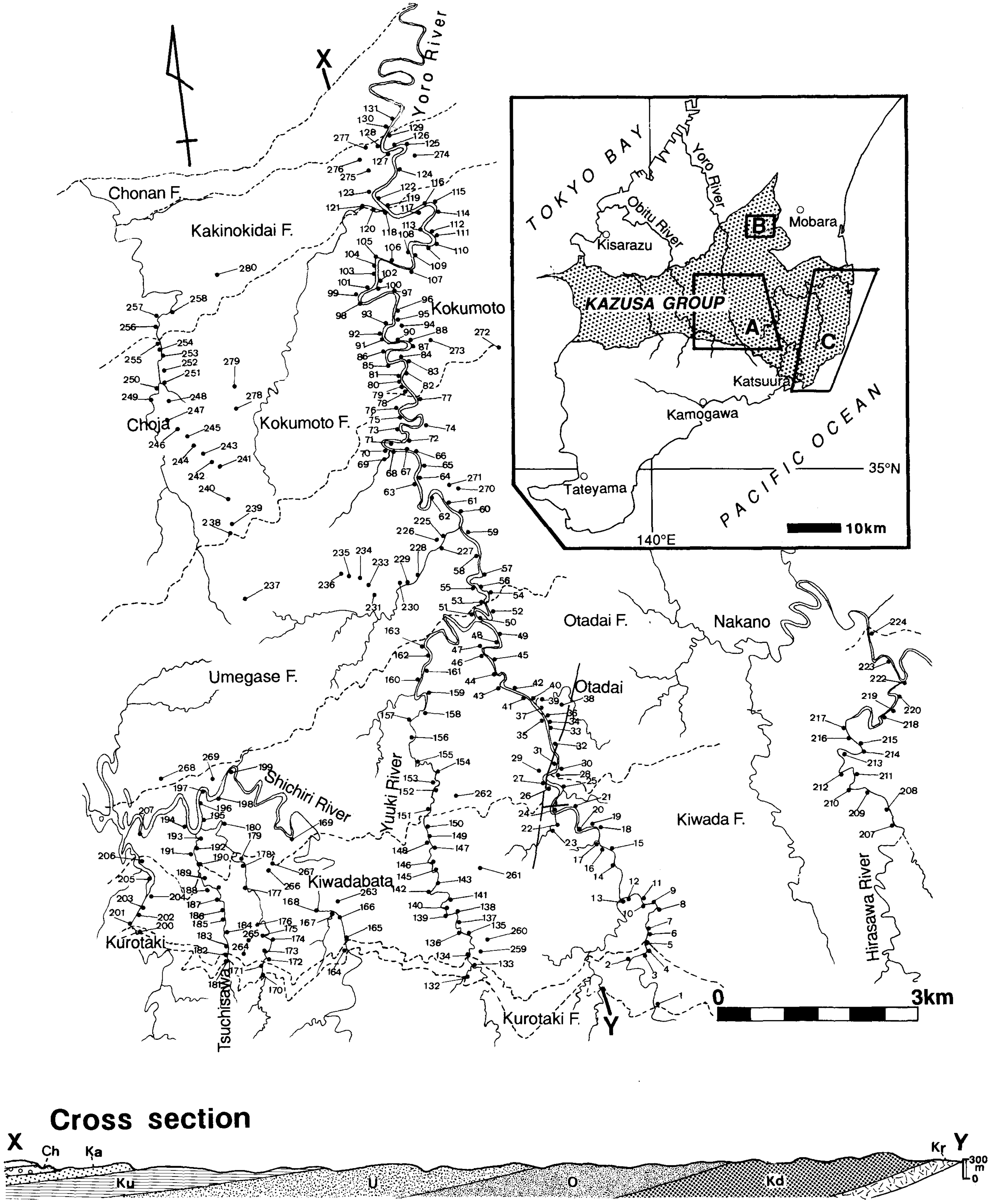


Fig. 1. Index- and locality-maps of the Yoro area. A, B and C in the index map show the location of the Yoro, Chonan, and Katsuura-Ohara areas respectively.

of the Peninsula, and the Katsuura-Ohara area in the eastern part of the Peninsula (Fig. 1; Table 1).

As the distinction of claystone and siltstone is difficult without precise grain size analysis, I divide the mudstone into fine-grained and coarse-grained based mainly on the observation with binocular microscope.

Geological setting

The Boso Peninsula is situated in the southern part of northeast Japan near the triple junction of the Philippine sea, Pacific, and North American Plates. The Neogene and Quaternary sediments deposited in the forearc slope and basin, ranging from deep- to shallow-marine environments, are widely distributed in the Peninsula. The sediments have been divided into the Lower Miocene to Lower Pliocene Miura Group, the Upper Pliocene to Lower Pleistocene Kazusa Group, and the Middle to Upper Pleistocene Shimosa Group. The Kazusa Group is exposed in the middle and northern parts of the Peninsula, showing northwestward-dipping homoclinal structure with dips of 20° in the lower part, and 5° in the upper part in general. There are many normal faults of N-S strike in the eastern part of the distribution area. Main part of the group is well exposed in the Yoro, Chonan, and Katsuura-Ohara areas (Figs. 1–3).

Stratigraphy of the Pliocene-Pleistocene Kazusa Group

The Kazusa Group is characterized by thick, clastic sequence attaining 3,000 m in maximum thickness. It overlies unconformably the Miura Group, with the Kurotaki Unconformity, and unconformably overlain by the Shimosa Group.

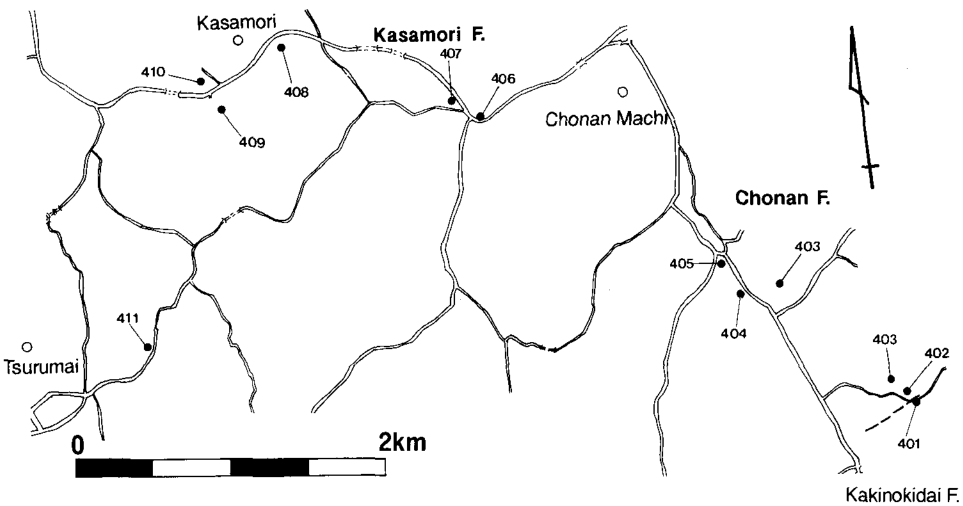


Fig. 2. Locality map of the Chonan area (B in Fig. 1).

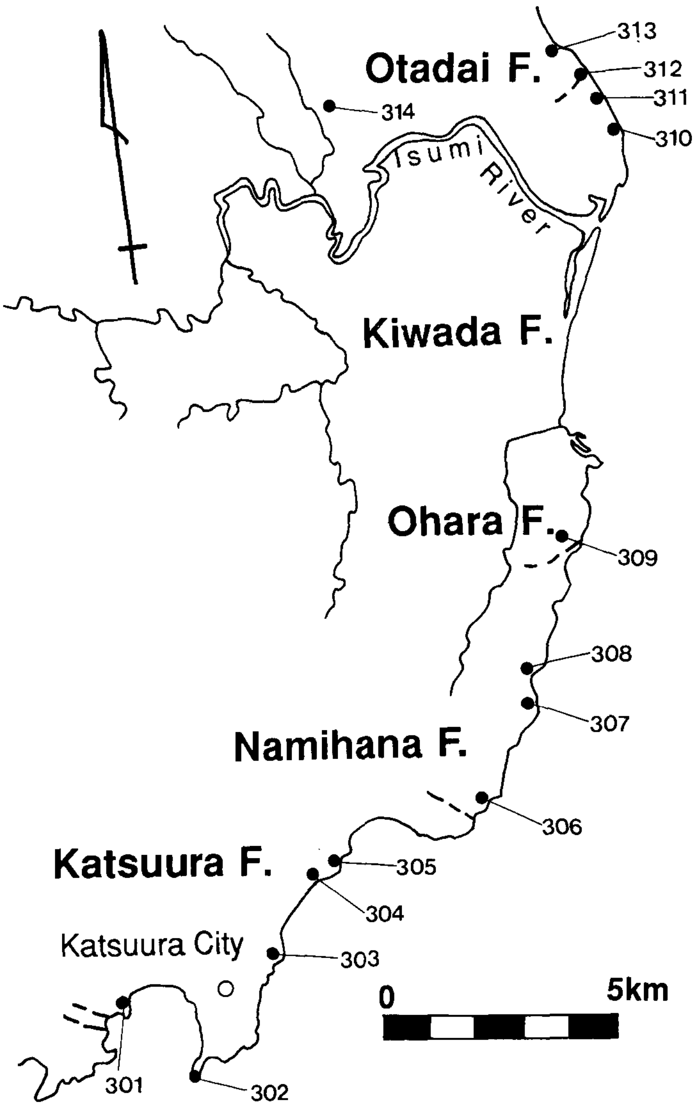
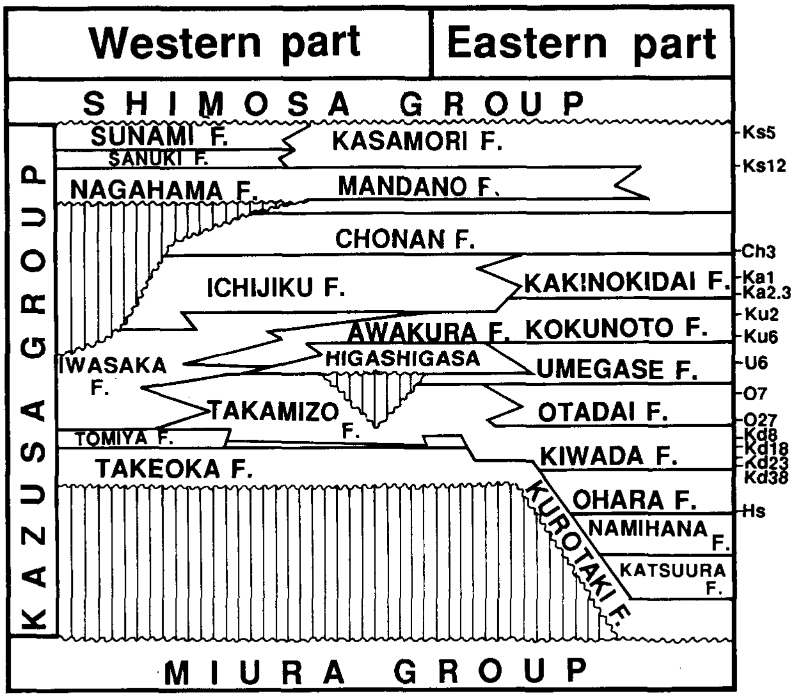


Fig. 3. Locality map of the Katsuura-Ohara area (C in Fig. 1).

Stratigraphic subdivision of the Kazusa Group differs in places because the group shows remarkable lithologic change laterally from west to east. In the western area, sandy deposits predominate, and are partly interrupted by small-scale unconformities, while muddy deposits are widely distributed in the central to eastern parts of the Peninsula. In the latter parts, the Kazusa Group is about 3,000 m thick and is subdivided into 9 formations, namely the Kurotaki, Kiwada, Otadai, Umegase, Kokumoto, Kakinokidai, Chonan, Mandano, and Kasamori Formations in ascending order (MITSUNASHI *et al.*, 1959, 1961, 1979). They are conformable with each other. Among them, the lower 6 formations, from Kurotaki to Kakinokidai Formations, are well-exposed in the

Yoro area, where is the chief area studied (A in Fig. 1). The Chonan Formation is well-exposed in the Chonan area, located at 9 km northeast of the Yoro area (Fig. 2; B in Fig. 1). In the Katsuura-Ohara area of the eastern coast, located 25 km east of the Yoro area (Fig. 3; C in Fig. 1), the beds synchronous with the Kurotaki Formation become very thick, and are further subdivided into 3 formations, namely Katsuura, Namihana, and Ohara Formations in upward sequence. Summary of stratigraphic subdivisions and correlation is shown in Table 1.

Table 1. Stratigraphic summary of the Kazusa Group in the Boso Peninsula. (Modified from MITSUNASHI, 1979).



The uppermost parts of the group, the Mandano and Kasamori Formations, are composed of sandy deposits. Therefore they are out of the scope of the this study. Thicknesses of the formations shown below are mainly measured along the Yoro River route. The columnar sections in the Yoro and Katsuura-Ohara areas are shown in Figs. 4–6.

Kurotaki Formation [UEDA, 1930]

Stratotype: Kurotaki, east of the Kameyama Lake, Kimitsu City, about 6 km west of the Yoro area.

Thickness: 280 m along the Yoro River.

The formation is composed of basal conglomerate of 5 m thick in the western area (Locs. 181, 200), being succeeded by brownish gray, bedded tuffaceous sandstone of

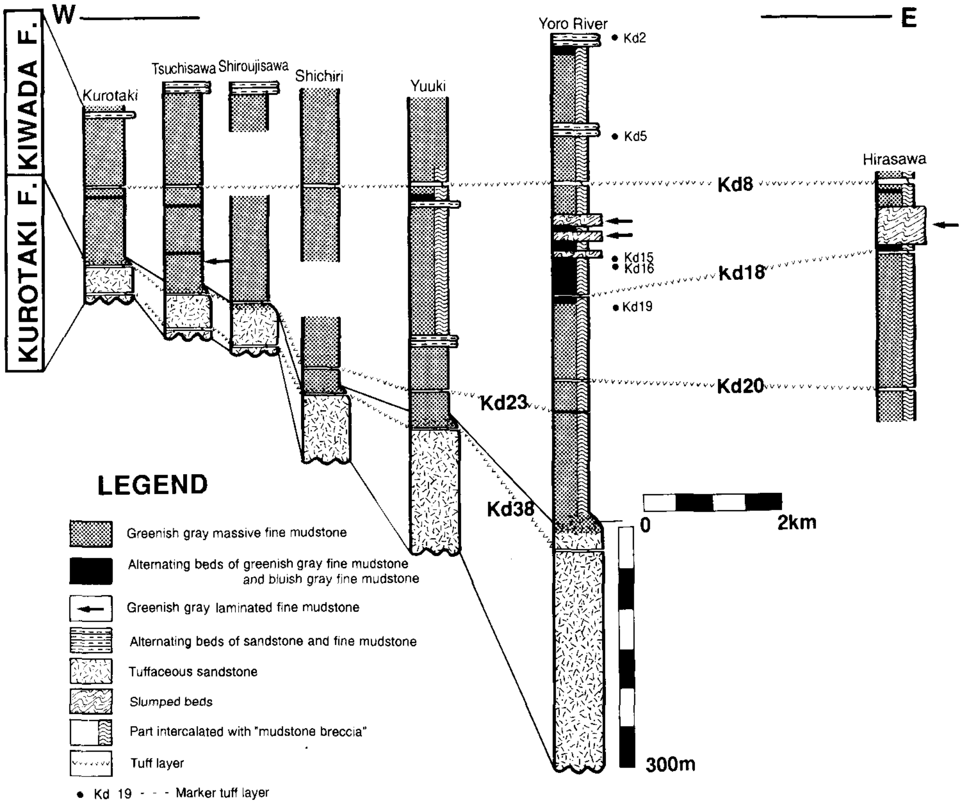


Fig. 4. Columnar section of the Kurotaki and Kiwada Formations in the Yoro area. Deposits thicken in the eastern part, in which mass-gravity flow deposits originated from slump and turbidity current are frequently intercalated in the mudstone.

various grain size, 270 m thick, which becomes finer upward, and muddy tuff of 10 m thick at the top.

Katsuura Formation [SAWADA, 1939]

Stratotype: Katsuura Coast, Katsuura City, about 20 km east of the Yoro area.

Thickness: 250 m in the Katsuura City.

The formation is composed of bedded mudstone, alternating beds of fine- to coarse-grained turbiditic sandstone of 30–200 cm thick and bedded mudstone of 10–30 cm thick. There are frequent intercalations of slumped beds of 1–20 m thick.

Namihana Formation [KOIKE, 1949]

Stratotype: Misone Coast, Ohara, about 25 km east of the Yoro area.

Thickness: 220 m in Ohara.

The formation consists of bedded fine-grained mudstone, 30–100 cm thick, and intercalated fine-grained sandstone beds, 5 to 30 cm thick, with frequent intercalations of slumped beds of 50–100 cm thick.

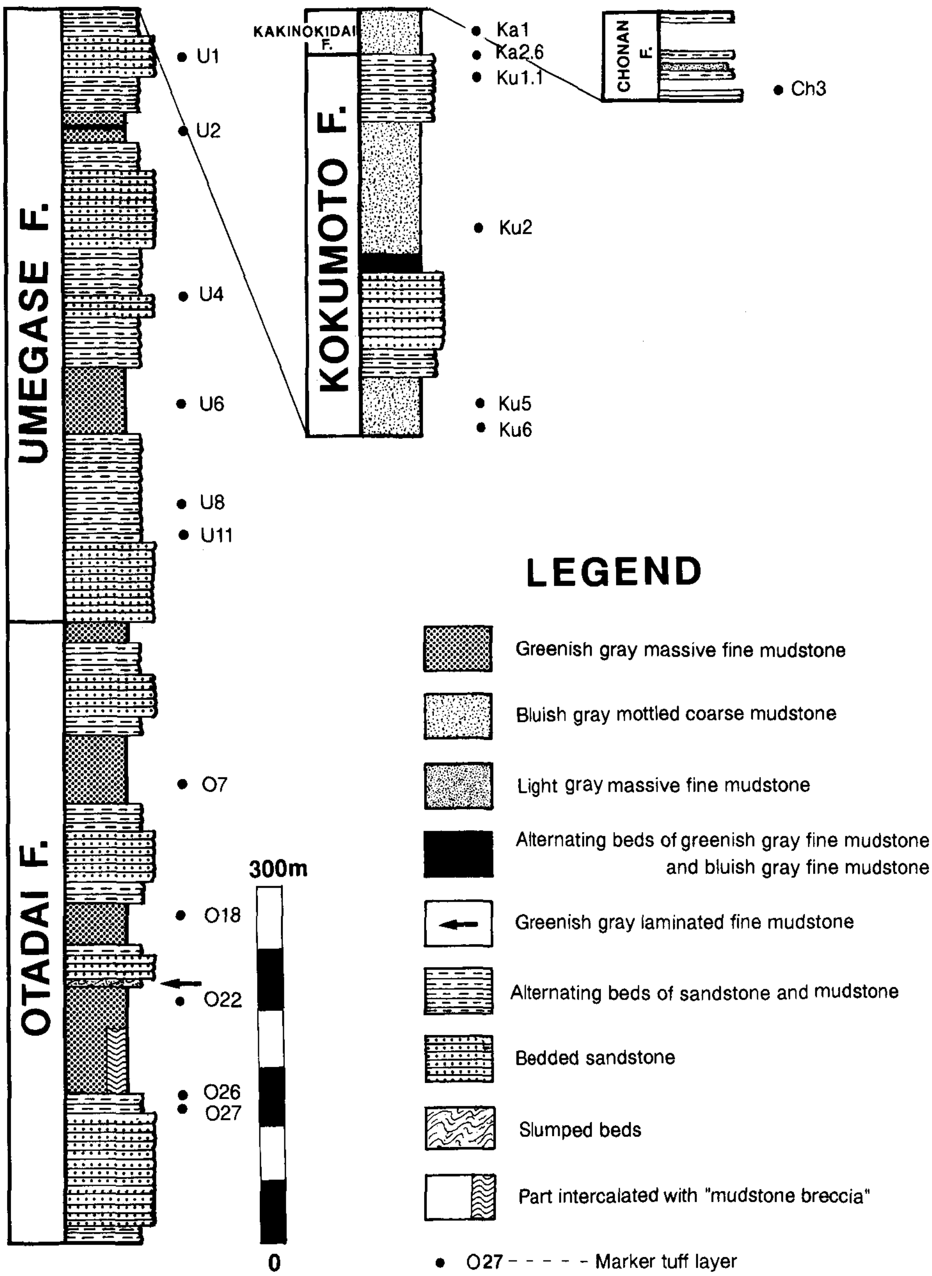


Fig. 5. Columnar sections of the Otadai to Chonan Formations along the Yoro River.

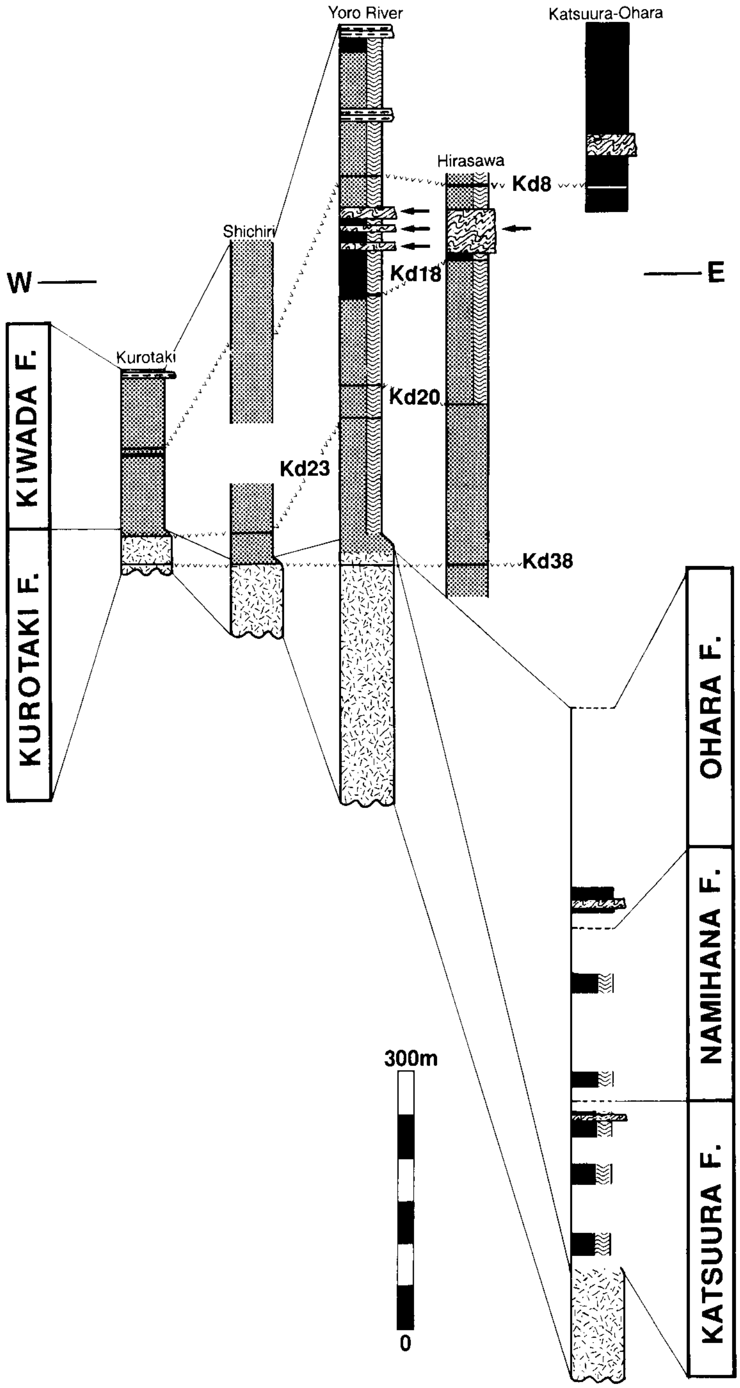


Fig. 6. Columnar sections of the Kurotaki to Kiwada Formations in the Yoro and Katsuura-Ohara area. Symbols are same with Fig. 4.

Ohara Formation [MITSUCHI, 1933]

Stratotype: Ohara Coast, Ohara, about 28 km east of the Yoro area.

Thickness: 200 m in the Ohara town.

The formation is characterized by frequent intercalation of sandstone beds. It consists of alternating beds of bedded fine-grained mudstone, 30–200 m thick, and sandstone of 10–100 cm thick with slumped beds of 5–20 m thick.

Kiwada Formation [UEDA, 1933]

Stratotype: Kiwada, Kimitsu City, about 3.5 km west of the Yoro area.

Thickness: 600 m along the Yoro River.

The formation is characterized by dominance of bedded fine-grained mudstone, 50–100 cm thick. The mudstone is intercalated with sandstone of 5–30 cm thick at the east of the Yuuki River, and slumped beds of 5–35 m thick in the middle part of the Yoro area.

Otadai Formation [MITSUCHI, 1933]

Stratotype: Otadai, the Yoro area.

Thickness: 540 m along the Yoro River.

This is characterized by frequent intercalation of sandstone beds in mudstone. It consists of bedded fine-grained mudstone, 30–80 m thick, and alternating beds of fine-grained mudstone, 1–50 cm thick, and sandstone of 30–300 cm thick, and slump beds of 30–300 cm thick intercalated at several stratigraphic levels.

Umegase Formation [MITSUCHI, 1933]

Stratotype: Umegase, west of Asobara, Ichihara City, about 2.2 km west of the Yoro area.

Thickness: 530 m along the Yoro River.

The formation is characterized by more frequent intercalation of sandstone beds than the Otadai Formation. The formation consists of alternating beds of fine-graned mudstone, 1–50 cm thick, and turbiditic sandstone of 50–200 cm thick, and bedded fine-grained mudstone, 30–60 cm thick, with intercalated several slump beds of 2–3 m thick. Mudstone becomes coarser in the upper part of the formation.

Kokumoto Formation [MITSUCHI, 1933]

Stratotype: Kokumoto, Ichihara City, Yoro area.

Thickness: 300 m along the Yoro River.

The formation consists of bedded coarser-grained mudstone, 50–200 cm thick, and alternating beds of sandstone, 30–300 cm thick, and coarser-grained mudstone, 5–50 cm thick.

Kakinokidai Formation [MITSUCHI, 1933]

Stratotype: Kakinokidai, Ichihara City, about 2 km east of the Yoro area.

Thickness: 65 m along the Yoro River.

The formation is composed of coarse-grained mudstone, in the lower 35 m, and sandy mudstone, 30 m thick, in the upper part.

Chonan Formation [MITSUCHI, 1933]

Stratotype: Chonan Town, about 9 km northeast of the Yoro area. The lower boundary of the Chonan Formation is demarcated here according to TOKUHASHI and ENDO (1984).
Thickness: 85 m along the Yoro River.

The formation is characterized by frequent intercalation of sandstone beds. It consists of alternating beds of fine-grained mudstone, 5–50 cm thick, and fine- to coarse-grained turbiditic sandstone of 30–300 cm thick.

Geological age of the Kazusa Group

The age of the Kazusa Group ranges from Late Pliocene to Early Pleistocene. According to the magnetostratigraphic correlation (NIITSUMA, 1976), the boundary between Pliocene and Pleistocene lies at the lower part of the Kiwada Formation, near the Kd38 tuff. ODA (1977) indicated that the boundary between the Matsuyama Reversed Epoch and the Brunhes Normal Epoch, based on the planktonic foraminiferal assemblages, lies in the middle part of the Kokumoto Formation. He also reported that the Jaramillo Event lies at the uppermost part of the Otadai Formation. The LAD of *Discoaster brouweri*, 1.91 Ma, is known at the middle part of the Ohara Formation, and the Kasamori Formation is older than the FAD *Helicosphaera inversa*, 0.48 Ma, both of calcareous nannofossils (SATO *et al.*, 1988).

Sedimentological features of mudstone and benthic faunas

Apparently monotonous muddy deposits predominate throughout the Kazusa Group of the study area. However, detailed observation of stratification, grain size, color, degree of bioturbation, and other features of mudstone revealed that the mudstone vary stratigraphically and geographically. Following five mudstone facies can be distinguished in the main part of the Kazusa Group: (1) greenish gray massive fine-grained mudstone facies (facies A), (2) bluish gray mottled coarse-grained mudstone facies (facies B), (3) light gray massive fine-grained mudstone facies (facies C), (4) facies of alternating beds of greenish gray fine-grained mudstone and bluish gray fine-grained mudstone (facies D), and (5) greenish gray laminated fine-grained mudstone facies (facies E). The facies A is widely distributed in the lower part of the group, the facies B is mainly distributed in the upper part of the group, and the facies C is restricted to the uppermost part, the Chonan Formation. On the other hand, the facies D and E is found intercalating in the facies A.

Many well-preserved fossil mollusks and echinoids were obtained from the mudstone. The faunal composition and their modes of occurrence are closely related to the facies types of the mudstone, reflecting the sedimentary environments.

(1) Greenish gray massive fine-grained mudstone facies (facies A)

Distribution: The fine-grained mudstone of the facies A is distributed extensively in the lower part of the group, from the lowermost part of the Kiwada Formation to the uppermost part of the Umegase Formation in the Yoro area. This mudstone is also distributed in the Ohara to Otadai Formations in the Katsuura-Ohara area, at Locs. 309–313.

Type Locality: Loc. 16, along the Yoro River, the middle part of the Kiwada Formation.

Characteristics: Fine-grained mudstone of massive, moderately bioturbated, and greenish gray (5 GY 6/1: wet) in color.

Description: The mudstone is sparsely bedded with 30–200 cm interval intercalated with sandstone beds and slumped beds (described later). The mudstone is greenish gray (5 GY 6/1: wet), fine-grained, containing dark-colored *Planolites* type burrows (unlined horizontal tube of 1 cm in diameter) at places (Plate 2, fig. 1). It is almost massive, but in some cases, thin, lamina-like sandstone layers of 1 mm thick are preserved.

Horizontal burrows predominate in the facies. Among them, *Planolites* type burrows, *Chondrites* of 0.5 mm in diameter, echinoid burrows of 2–4 cm in diameter, and *Anconichnus horizontalis** are quite common. *Anconichnus horizontalis* burrow is a dark-colored, narrow, discontinuous, twisting, muddy fecal string, 0.5–1 mm in diameter, within a light-colored, poorly defined burrow fill, 2–5 mm in diameter, depleted in mud and inertinite (Figs. 7, 8; Plate 2, fig. 5; GOLDRING *et al.*, 1991).

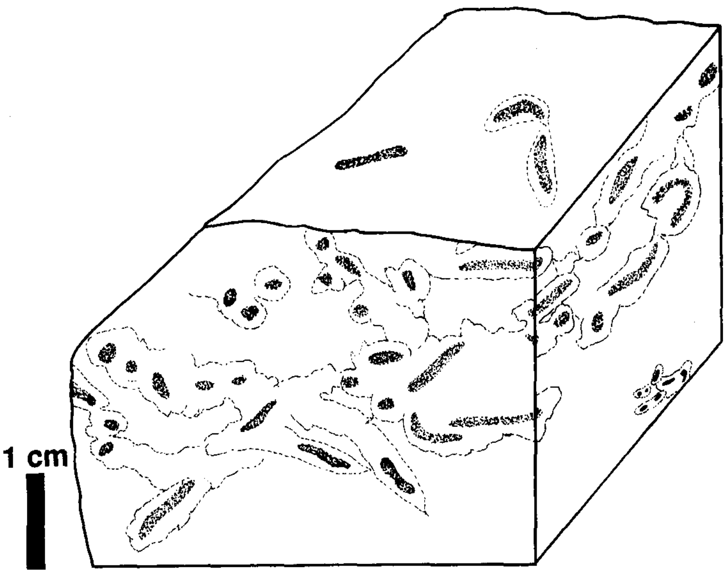


Fig. 7. Schematic diagram showing *Anconichnus horizontalis* burrows.

* The ichnofossil is widespread in muddy deposits of various ages and parts in Japan other than the Kazusa Group. They are known from the Lower Cretaceous Monobegawa Group, Upper Cretaceous Yezo and Himenoura Groups, as well as from the recent sediments recovered from 1,800～4,000 m off Muroto (personal communication of Mr. M. MURAYAMA, Ocean Res. Inst., Univ. Tokyo).

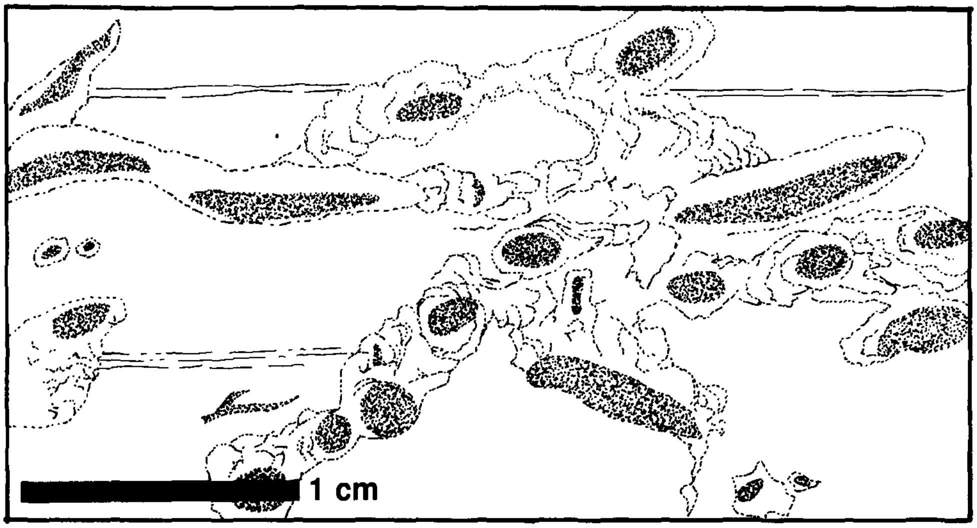


Fig. 8. Vertical profiles of *Anconichnus horizontalis* burrows.

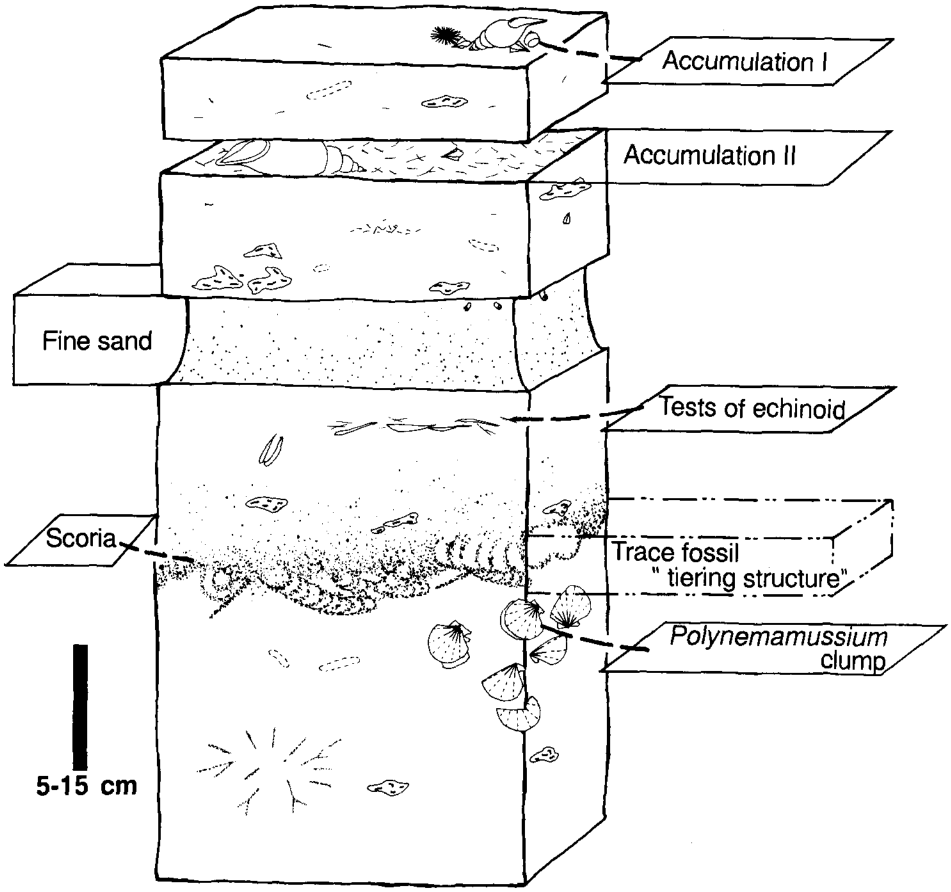


Fig. 9. Schematic diagram showing modes of occurrence of ichno- and benthic assemblages in the greenish gray massive fine-grained mudstone (facies A).

Fine- to coarse-grained scoria beds of 2–5 mm thick are also intercalated. The upper part of scoria beds is, however, usually bioturbated, and scoria grains are mixed with surrounding mudstone. Several types of trace fossils penetrate such scoria beds (Fig. 9). Such traces are sometimes filled with fine scoria grains, and exhibit tiering structure. *Chondrites* (1–2 mm in diameter), echinoid burrows (2–3 cm in diameter) are usually recognized in the upward order. Under the microscope, diatoms, sponge spicules, planktonic and benthic foraminifers, and volcanic glass fragments are quite common.

Turbiditic sandstone showing Bouma sequence of 5–200 cm thick (Fig. 10), and two types of sandy slump deposits of 30–100 cm thick ("mudstone breccia I and II" in Fig. 10) which contain abundant mudstone blocks, are intercalated in the facies A. Mudstone breccia I is composed of three parts, coarse-grained sandstone of 10–30 cm thick showing graded bedding at the base, fine- to coarse-grained poorly-sorted sandstone in the middle part, 10–50 cm thick and containing few to numerous angular mudstone blocks of 1–100 cm in diameter, and parallel laminated, fine-grained sandstone of 1–5 cm thick at the top (Fig. 10).

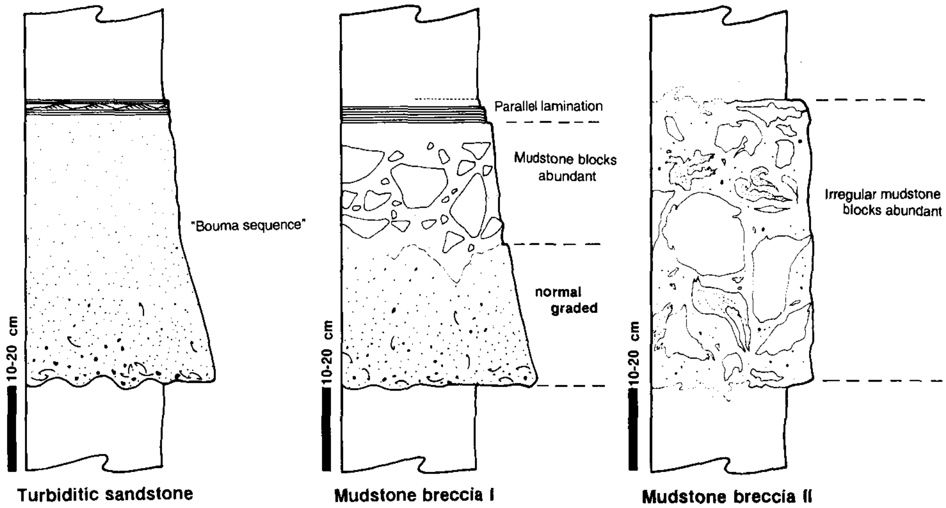


Fig. 10. Sketches of sandy beds intercalated in the mudstone. These are quite common in the eastern part of the area surveyed.

Mudstone breccia II is poorly-sorted, medium-grained sandstone including numerous contorted blocks of mudstone (Fig. 10). These three types of gravity-flow deposits are quite common particularly in the eastern part of the area studied (Fig. 4).

In the upper part of the Umegase Formation, fine-grained mudstone of the facies A grades upward into coarser-grained mudsone (facies B; described later).

Associated fauna: Molluscan fossils are monotonous. A molluscan association of low diversity, the *Portlandia-Neilonella-Ancistrolepis* Association, is recognized in the mudstone of the facies A (Table 2). It is mainly composed of three thin-shelled deposit-feeding bivalves, *Portlandia lischkei* (SMITH), *Neilonella japonica* OKUTANI, and *Nuculana robai* (KURO-

Table 2. Faunal list of the main part of the Kazusa Group. Numbers show individual

Mudstone Facies	A							
Species / Locality	303	13	16	204	18	149	26	311
[Mollusca]								
Machaeroplax delicatus (Dall)				9			9	
Bathybembix argenteonitens hirasei (Taki & Otuka)								
Naticoid spp.		5	3	12		1	4	
Japelion pericochlion (Schrenck)								
Ancistrolepis trochoideus (Dall)				22	2	1	3	1
Neptunea intersculpta (Sowerby)				1				
Parancistrolepis fujitai (Kuroda)				2				
Buccinum isaotakii Kira								
B. sp.								
Fulgoraria prevostiana koshibensis Otuka				1				
F. sp.			1	1				
Aforia diomedea Bartsch								
A. sp.								
Suavodrillia declivis (v. Martens)								
Riuguhdrillia mediocarinata (Yokoyama)			1	15	3	1		
Obestoma sp.				1		1		
Elegantiscala rugosa Kuroda			1	2		1	1	
Antalis rhabdotum (Pilsbry)								
Siphonodentalium isaotakii Habe				1				
Episinophon makiyamai (Kuroda & Kikuchi)				1		1		
Gadila sagamiensis Kuroda & Habe		4				1		
Acharax johnsoni (Dall)								
Acila insignis (Gould)				5				
Ennucula tenuis (Montagu)			2		1			
Neilonella japonica Okutani			3	8	3		10	
N. sp.		5	3		2			2
Nuculana pernula pernuloides (Dunker)		2	2	12	2			
N. yokoyamai Kuroda		2	5	13	7		1	
N. robai (Kuroda)	12							
Tenuileda ikebei (Suzuki & Kanehara)				2				
Portlandia japonica (Adams & Reeve)		2	13(2)	1				
P. lischkei (Smith)		4	4	61(10)	9		6(1)	
Limopsis uwadokoi Oyama								5
L. tajimae Sowerby								
L. obliqua A. Adamus								
Modiolus sp.								
Solamen diaphana (Dall)				3(1)				
S. sp.						1(1)		
Polynemamussium intuscostatum (Yokoyama)		1	5	39(6)	2		4	5
Delectopecten peckhami GABB				6(1)				
Limatula kurodai Oyama								
Lucinoma sp.		2		5				
Conchocele bisecta (Conrad)								
Thyasira sp.		2						
Macoma calcarea (Gmelin)		2						1
Periploma plane Ozaki		2		3		1		1
Cyathodonta granulosa (Adams et Reeve)								
Cardiomya sp.		3	2	13	2			2
[Echinoids]								
Brisaster latifrons (Agassiz)								
Brissopsis luzonica (Gray)								
Linopneustes murrayi (Agassiz)		3	4	2	1	2		2

number, those of disarticulated bivalves is shown in parentheses.

			B									C
37	160	163	79	81	241	242	94	98	251	255	257	403
								3				
					5			2		3		
1	1	6	1	6	2			11		4	5	
											1	
	2		1	3				1				
								1				
										4	10	
											2	
								1				
				1				3				
				2				2		2		
											1	
										2		
				1			1	1				
1												
					1			1		1		
								3				
2	2	3										
									3	2	2	
			4	1	3		3					
2	17			3(2)	3(3)			4		2		
	4(1)		1									
	3											
	2											
		1(1)	8(4)	5(2)						4(4)	5(5)	
1	1(1)						1(1)					
				4(3)	6(4)			6(4)	1(1)		5(5)	
		1(1)		3								
					15(22)			4(5)		26(15)	46(20)	2
							3(1)					
							3(1)				5(5)	
		6(4)	6(3)				1(1)					
		1(1)		4		5(5)		5(4)				
			12(8)	1			3	2(1)				
				2(2)								
			3	6(1)				2				
			1						18(5)			
			1						22(5)	4		
		1	1					1				6(2)
								2				2
		1	1	1				4		2		
1			1							3		
						34	2	7			2	1
						5		1				
1	1	1										

DA). In addition, *Acila insignis* (GOULD), *Polynemamussium intuscostatum* (YOKOYAMA), *Periploma plane* OZAKI, *Cardiomya* sp., and *Ancistrolepis trochoideus* (DALL) are also common. Bivalves mostly occur with conjoined valves or slightly dislocated two valves. *Polynemamussium* occur at places. The species usually forms clump consisting of 5–10 articulated individuals distributed within about 10 cm long of mudstone (Fig. 9). Five to seven individuals of *Neilonella* also occur with conjoined valves, oriented parallel to bedding plane, although they are few in general.

On the other hand, allochtonous shell accumulations are contained in the mudstone as small pathces (accumulation I in Fig. 9; Plate 3, figs. 1, 2). Unbroken shells of above mentioned association including articulated bivalve individuals form the accumulation I, in which planktonic and benthic shells and corals are arranged parallel to the bedding plane, and accumulated as small patches of 0.5–2 cm thick, 1–30 cm wide in cross-section.

Numerous *Makiyama* sp. are sometimes accumulated in 2 to 10 mm thick bed in the fine-grained mudstone. This is the accumulation II in Fig. 9. It is more continuous laterally than the accumulation I. The matrix is same as the surrounding mudstone.

Besides these, *Linopneustes murray* (AGASSIZ), a spatangoid echinoid, is quite common in the mudstone (Table 2). The urchin usually occurs as fragments or as entire individuals. The small fragments are concentrated into thin lenses or layers, mostly arranged parallel to the bedding plane (Plate 3, fig. 2), and are frequently associated with spines, and sometime with other molluscan fossils. On the other hand, the entire shells are found sporadically. The tests are usually collapsed by compaction, but still keeps their living orientation.

(2) Bluish gray mottled coarse-grained mudstone facies (facies B)

Distribution: This facies is distributed in the Kokumoto and the Kakinokidai Formations at Locs. 78–118.

Type Locality: Loc. 98, along the Yoro River, the middle part of the Kokumoto Formation.

Characteristics: Facies characterized by massive, mottled or intensely bioturbated bluish gray (5 B 5/1: wet), coarse-grained mudstone. It sometimes intercalates muddy sandstone beds.

Description: The coarse-grained, and poorly sorted mudstone of bluish gray in color (5 B 5/1: wet), and is sparsely bedded with 30–200 cm interval. The mudstone is mottled or intensely bioturbated, and several kinds of burrow are observable (stated later). Fine sand-size quartz, feldspars and mica grains, plant debris, diatoms, sponge spicules, planktonic and benthic foraminifers are contained in the mudstone, and volcanic glass grains are quite common.

Fine- to coarse-grained turbiditic sandstone beds of 3–300 cm thick are interacalated at the several stratigraphic levels. The coarse-grained mudstone is frequently intercalated, 5–20 cm interval, with sandy mudstone beds of 5–10 cm thick with diffused upper and lower boundaries (Fig. 11; Plate 1, fig. 1). Such sandy mudstone layers are sometimes preserved as patches of 0.5–2 cm thick, 1–15 cm wide in cross-section or mottled in

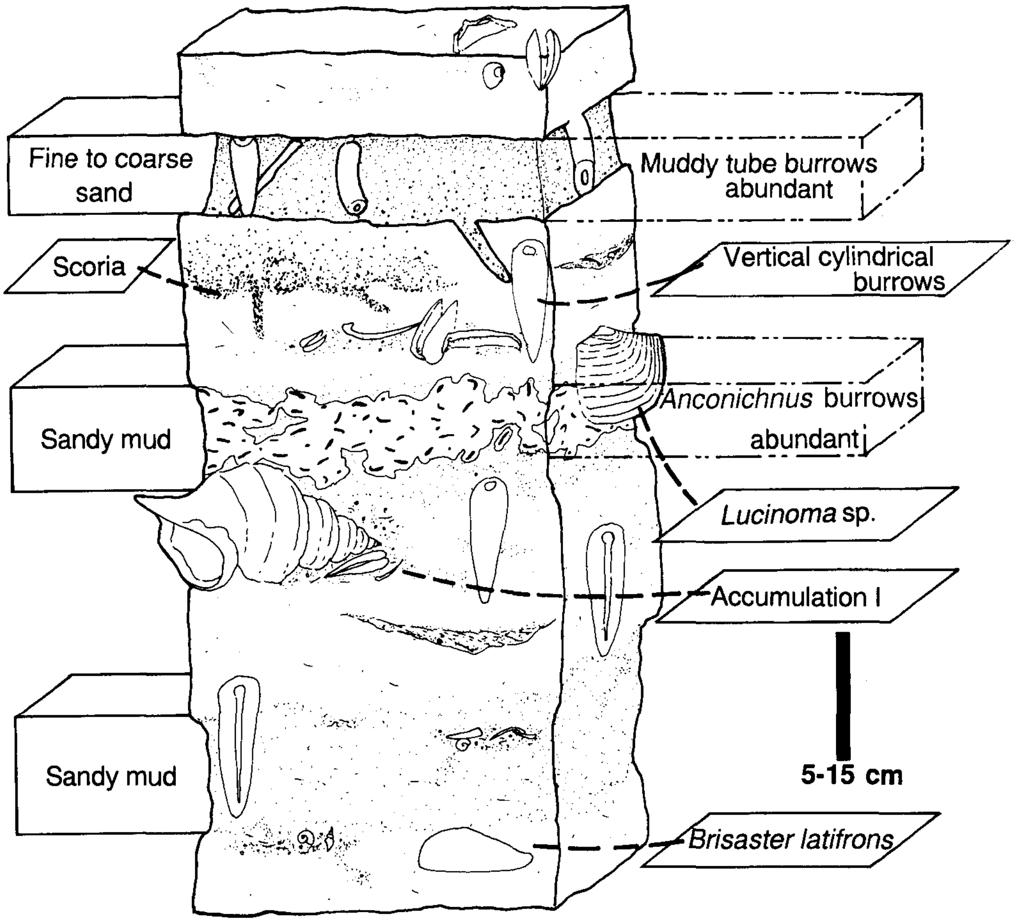


Fig. 11. Schematic diagram showing modes of occurrence of ichno- and benthic assemblages in the bluish gray mottled coarse-grained mudstone (facies B).

surrounding mudstone (Plate 2, fig. 2).

This facies can be distinguished from greenish gray fine-grained mustone of the facies A in coarser grain-size, bluish color, and more intensive bioturbation. Laminations are sometimes preserved in part in the facies A. In contrast, laminations are never preserved, and even thin scoriaceous sandstone beds intercalated are destroyed by bioturbation in the facies B (Fig. 11; Plate 2, fig. 2).

Many trace fossils are found throughout coarse-grained mudstone beds. Three characteristic traces are observed: (1) elliptical pellets, (2) vertical cylindrical burrows, and (3) muddy tube burrows. Both of (1) and (2) are commonly found in the coarse-grained mudstone, while (3) are usually seen in sandstone beds. Elliptical pellets of 0.5 mm in diameter and 1 mm in length are common throughout this facies. Vertical cylindrical burrows (Fig. 11), 2–3 cm in diameter and 5–7 cm long, consist of fine-grained muddy sediments, and usually form concentrated layers of 1–3 m thick. The muddly tube burrows of 0.5–2 cm in diameter and 5–30 cm in length consist of muddy deposits. They densely occur in sandstone beds, orienting vertical to the bedding and penetrating the sandstone beds (Fig. 9). In addition, numerous *Anconichnus horizontalis* burrows in 1 mm in diameter and echinoid burrows of 2–4 cm in diameter are frequently found forming beds of 5–20 cm thick (Fig. 11).

Ichnofossil assemblages differ between the facies A and B. The assemblages in the facies A consist mainly of small horizontal tube burrows, and large tube-burrows, vertical ones in particular, are not found.

The mudstone shows coarsening upward succession within the facies B, and coarse-grained sandy mudstone predominates in the upper part of the Kakinokidai Formation along the Yoro River.

Associated fauna: The following three molluscan associations can be recognized in the facies B (Table 2); the *Limopsis-Tenuileda-Bathybembix* Association, the *Limopsis-Buccinum* Association, and the *Conchocele-Thyasira-Acharax* Association. The former is the most common in this facies. It consists of *Limopsis tajimae* Soweby or *L. uwadokoi* Oyama, *Tenuileda ikebei* (SUZUKI & KANEHARA), *Lucinoma* sp., *Periploma plane* OZAKI, and *Bathybembix hirasei* (TAKI & OTUKA). Two *Limopsis* species are not coexisting and replace with each other. Twenty to thirty individuals of *Limopsis*, articulated or disarticulated, are sometimes aggregated within 1 m×1 m area of a bedding plane (Plate 3, fig. 4). Other bivalves occur sporadically. More than a half of the bivalve individuals occur as conjoined. Most bivalves and gastropods never show preferred orientation, except for *Lucinoma* and *Periploma*. Both species occur in living position: the former is in an upright position (Fig. 11) and the latter species lay horizontally.

Besides these autochthonous mollusks, disarticulated bivalves and gastropods are accumulated as small patches, 0.5–2 cm thick, 1–15 cm wide in cross-section, together with plant debris and fine-grained sand.

In the sandy mudstone of this facies at the upper part of the Kakinokidai Formation, *Limopsis-Buccinum* Association is common. It is predominated with *Limopsis tajimae* SOWERBY and *Buccinum isaotakii* KIRA. *Tenuileda ikebei* (SUZUKI & KANEHARA), and *Modiolus* sp. are also common. *Buccinum*, 5–10 cm in shell-length, is abundant in this association, *e.g.* 5 individuals/m^2 at Loc. 257. Small disarticulated bivalve shells and plant debris show "sheltered preservtion" (MAEDA, 1991) in horizontally laying *Buccinum* shells (accumulation I in Fig. 11). The *Conchocele-Thyasira-Acharax* Association occurs from a restricted horizon of 30–200 cm thick (Loc. 246, 251) in which impure calcareous nodules of 3–10 cm in diameter are common. It is predominated by *Conchocele* sp., *Thyasira* sp., and *Acharax johnsoni* (DALL). The shells are usually found as conjoined valves in upright living position.

Two spatangoid species, *Brisaster latifrons* (AGASSIZ) and *Brissopsis luzonica* (GRAY), are common in the coarse-grained mudstone. *Brisaster* occurs quite commonly, and *Brissopsis* occurs sporadically. Both species are found in good state of preservation; being not fragmented nor collapsed, occasionally associated with spines, and usually keeping their ventral side down (Fig. 11). On the other hand, many individuals of *Brisaster* and

Brissopsis are associated with pumice grains, plant debris, and some other disarticulated bivalves, and concentrated in the upper 3–7 cm thick part of turbiditic sandstone bed of 15–150 cm thick (= accumulation III; Locs. 103, 241; Plate 3, fig. 5). In contrast to the accumulation I in mudstone, the accumulation III is restrictedly found in the top part of turbiditic sandstone beds, in which the test and shells are usually broken.

(3) Light gray massive fine-grained mudstone facies (facies C)

Distribution: The fine-grained mudstone of this facies is in the Chonan Formation at Locs. 130, 131, 402–405.

Type Locality: Loc. 405, Chonan area, the middle part of the Chonan Formation.

Characteristics: The facies characterized by massive, intensely bioturbated, light gray (N 6: wet) to medium light gray (N 5: wet), fine-grained mudstone.

Description: Fine-grained mudstone of 5–100 cm thick is usually alternated with fine- to coarse-grained turbiditic sandstone of 5–200 cm thick. The mudstone is light gray (N 6:

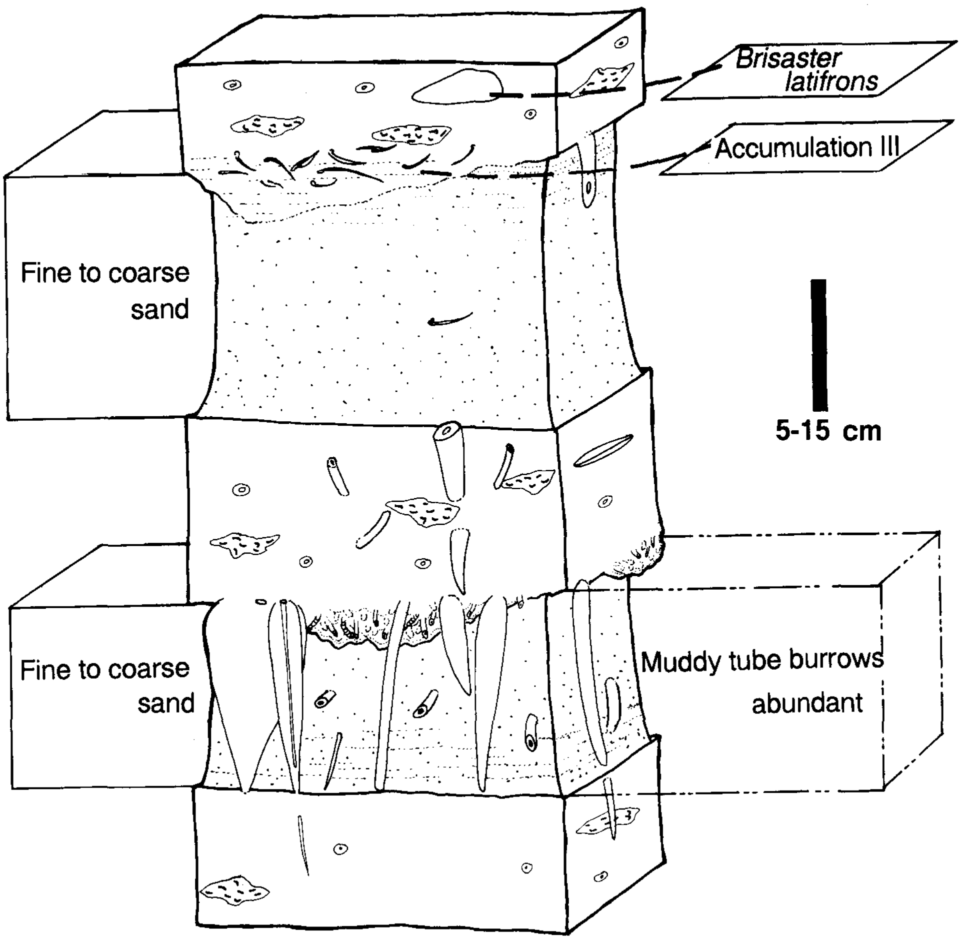


Fig. 12. Schematic sketch of the light gray massive fine-grained mudstone (facies C).

wet) to medium light gray (N 5: wet), well-sorted, and fine-grained. It is almost massive, and it usually contains *Planolites* type, small, horizontal tube burrows (Plate 2, fig. 3).

Under the microscope, diatoms, sponge spicules, and volcanic glass grains are quite common, but in contrast, planktonic and benthic foraminifers are rather rare. The mudstone resembles the facies A in grain size, but laminations are indiscernible in the facies C.

Unlined burrows, *e.g. Anconichnus horizontalis* and *Planolites* type burrows of 0.5–1 cm in diameter, oriented parallel or oblique to the bedding plane are quite common in the fine-grained mudstone. Occasionally, numerous muddy tube burrows, and cylindrical burrows of 0.5–3 cm in diameter and 10 cm long, penetrate vertically the intercalating sandstone beds of 5–200 cm thick (Fig. 12). The feature is similar to those of the facies B. The bottom surface of the fine-grained mudstone bed is sometimes quite irregular by intense bioturbation.

The mudstone becomes coarser upward in the uppermost part of the Chonan Formation in the Chonan area.

Associated fauna: The *Macoma* Association, composed of *Macoma calcarea* (GMELIN), *Limopsis* sp., and *Periploma plane* OZAKI, is characteristic in the Facies C (Table 2). Bivalves mostly occur as conjoined valves, and sporadically, usually lying parallel to the bedding plane. Disarticulated bivalve shells, such as some *Macoma* individuals are accumulated in several sandy layers or patches of 5–10 cm thick. These shells show horizontally to random orientation (accumulation III in Fig. 12).

A spatangoid species, *Brisaster latifrons* (AGASSIZ) is also common in the fine-grained mudstone. Individuals of the species are found sporadically keeping their ventral side down.

(4) Facies of alternating beds of greenish gray fine-grained mudstone and bluish gray fine-grained mudstone (facies D)

Distribution: It is mainly distributed in the lower part of the Kazusa Group, and intercalated with the mudstone of the facies A. The facies D appears in the Kiwada Formation at Locs. 14–17, 25, 26, 149 and the middle part of the Kokumoto Formation at Locs. 93–95 in the Yoro area, and in the Katsuura to Otadai Formations at the Katsuura-Ohara area. Partly, thin blue mudstone units of 1–5 cm thick are also found in other parts of the group from the Kiwada to Chonan Formations.

Type Locality: Loc. 16, along the Yoro River, the middle part of the Kiwada Formation.

Characteristics: Mudstone consisting of bluish gray (5 B 6/2: wet) fine-grained mudstone (blue unit), and greenish gray (5 GY 6/1: wet) moderately bioturbated fine-grained mudstone (green unit), are rhythmically interbedded with each other. The blue unit is most probably turbiditic in origin as described below.

Description: Mudstone is rhythmically bedded with 10–50 cm interval (Fig. 13; Plate 1, fig. 2). Turbiditic sandstone of 5–30 cm thick, and the mudstone breccia I and II (Fig. 10) of 10–50 cm thick, are in some places intercalated in the alternating fine-grained mudstone units.

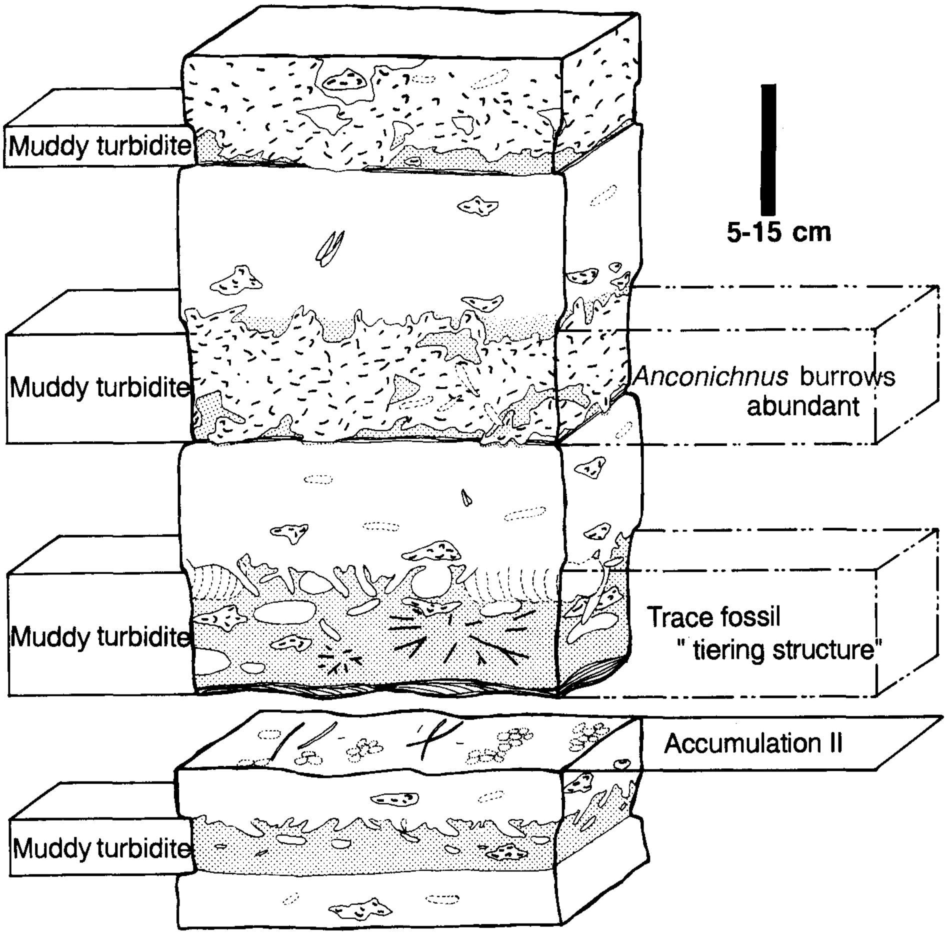


Fig. 13. Schematic sketch of alternating beds of the greenish gray fine-grained mudstone (white parts) and bluish gray fine-grained mudstone (dotted parts) (facies D).

A cycle of mudstone beds consists, in upward sequence, of thin sandstone of 0.1–5 cm thick, blue fine-grained mudstone of 1–10 cm thick, and green fine-grained mustone of 3–50 cm thick (Plate 2, fig. 4). The sandstone is cross- or parallel laminated, very fine-grained, and the base slightly cuts into the lower bed (Fig. 13). The succession of the blue unit, including basal sandstone, is comparable with the uppermost part (D and E) of "Bouma sequence," and may be regarded as muddy turbidite (Griggs *et al.*, 1969; Rupke, 1975). The main part of the blue unit is almost homogeneous or very weakly laminated, and the top grades upward into the green unit. The green unit is almost massive, and quite similar to the fine-grained mudstone of the facies A described above.

Under the microscope, the mudstone contains diatoms, sponge spicules, and volcanic glass fragments. The green units usually contain abundant planktonic and benthic foraminifers. On the other hand, density and diversity of foraminiferal fauna is low in the blue units (Table 3). The blue unit is usually poor in bioclasts.

Table 3. List of fossil formanifers from alternating beds of greenish gray fine-grained mudstone and bluish gray fine-grained mudstone (facies D) at Loc. 95.
blue 1: lower part of the bluish gray fine-grained mudstone (1–3.5 cm thick), blue 2: upper part of the bluish gray fine-grained mudstone (3.5–7 cm thick), green 1: greenish gray massive bioturbated fine-grained mudstone (7–10.5 cm thick), 260: individual number/100 g mudstone.

Species \ Sample	blue. 1	blue. 2	green.1
BENTHONIC FORAMINIFERS			
Bulimina spissa Cushman			2
Pseudononion japonicm Asano			1
Nonion sp.			1
Rotalia inflata (Seguenza)			1
Cibicides cf. *refulgens* (Montfort)			3
Cibicides aknerianus d'Orbigny			2
Cassidulina subglobosa depressa Asano	1	1	20
Cassidulina kasiwazakiensis Husezima & Maruhashi			1
Cassidulina asanoi Uchio		1	1
Fissurima submarginata (Boomgart)			1
PLANKTONIC FORAMINIFERS	15	13	260

Such alternating fine-grained mudstone is more or less bioturbated. While the green units are usually intensely bioturbated and appear to be massive, the blue units are relatively weak in bioturbation. Two types of bioturbation are recognized in the blue units. One is the association of different traces, which exhibit tiering structure, consisting of *Chondrites* (1–2 mm in diameter), *Anconichnus horizontalis* (0.5–1 mm in diameter), echinoid burrows (2–3 cm in diameter) and *Planolites* of 0.5–1 cm in diameter in upward order (Fig. 13; B in Fig. 14; Plate 2, fig. 4). These burrows are filled with greenish gray fine-grained mudstone of the overlying green unit. These features indicate that the deposition of the blue unit were rather rapid, and the benthic organisms burrowed into the blue unit from the top surface after the deposition.

The other type of bioturbation was made by numerous *Anconichnus horizontalis* burrows (Fig. 11; B in Fig. 14; Plate 2, fig. 5). The burrows are densely crowded in the blue unit. The green unit is also bioturbated, but trace fossils are indiscernible. It is probably due to the low color contrast between traces and matrix of the green unit.

Associated fauna: Two types of molluscan association are recognized in the green unit,

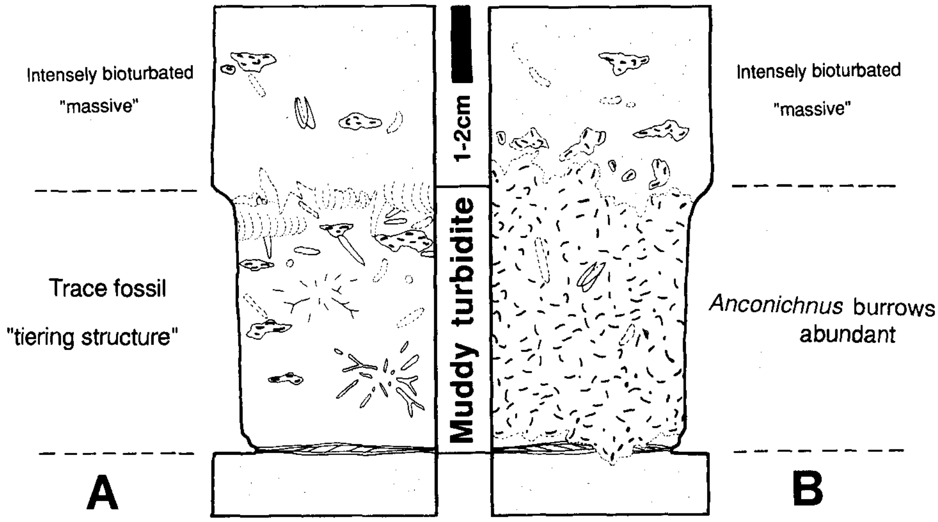


Fig. 14. Two types of bioturbation in alternating beds of greenish gray fine-grained mudstone and bluish gray fine-grained mudstone (facies D).
A: showing "tiering structure" of the trace fossils.
B: showing numerous *Anconichnus horizontalis* burrows.

Portlandia-Neilonella-Ancistrolepis Association and *Nuculana* Association. The former association is known in the facies A. It is also common in the facies D of the Yoro area, and the Ohara to lower part of the Otadai Formations in the Katsuura-Ohara area. Their composition and mode of occurrence are similar to those of the facies A. In addition, *Limopsis uwadokoi* OYAMA is common in the Katsuura-Ohara area. The *Nuculana* Association is restrictedly distributed in the Katsuura and Namihana Formations in the Katsuura-Ohara area, about 25 km east of the Yoro area. It consists only of *Nuculana sagamiensis* OKUTANI.

The individuals occur as conjoined valves, and are scattered in the mudstone. Some shells arranged parallel to the bedding plane (accumulation I).

Echinoid fossils *Linopneustes murray* (AGASSIZ) sporadically occur in the green unit, and their mode of occurrence is similar to that in the facies A. Both of mollusks and echinoids are rare in the blue unit. *Makiyama* sp. are sometimes accumulated immediate or 2 to 10 mm below the thin sandstone, the basal part of the blue unit, in between the underlying green fine-grained mudstone beds (accumulation II in Fig. 13). This type of fossil occurrence is sporadically found in the green mudstone. Numerous trace fossils, *e.g.* muddy horizontal tube of 5 mm in diameter and muddy pellets of 5–10 mm in diameter, also found below the sandstone.

(5) Greenish gray laminated fine-grained mudstone facies (facies E)

Distribution: The facies E is mainly distributed in the lower part of the group from the Kiwada to Umegase Formations, intercalating in the facies A in the western part of the Yoro area at Locs. 17, 19, 20, 38, 39, 40, 214, 218, 219, 184.

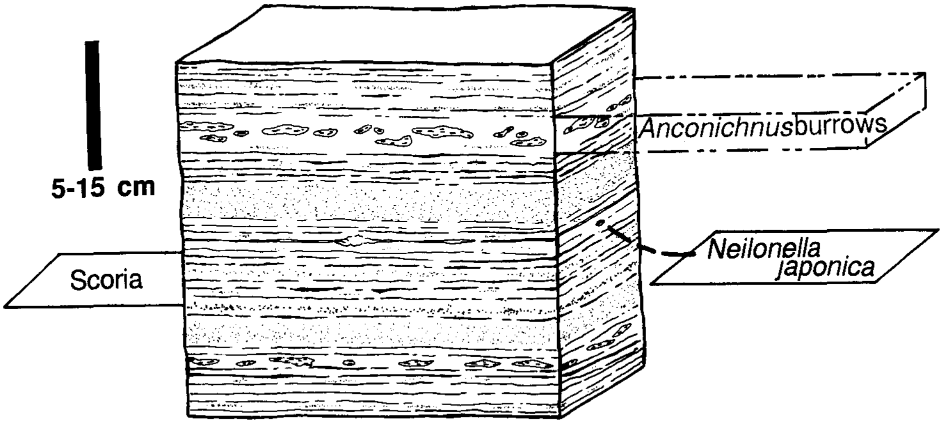


Fig. 15. Schematic sketch of the greenish gray laminated fine-grained mudstone (facies E).

Type Locality: Loc. 184, along the Tsuchisawa River, the lower part of the Kiwada Formation.
Characteristics: The fine-grained mudstone characterized by frequent parallel lamination.
Description: Although the mudstone of the facies E is similar to facies A in grain-size, and in greenish gray (5 GY 6/1: wet) color, it can easily be distinguished from other facies in its thin and parallel lamination (Plate 2, fig. 6). The mudstone is sparsely bedded. The greenish gray fine-grained mudstone is intercalated with intervals of 3–10 mm by fine-grained sand layers of 0.5–2 mm thick. The sand layers are composed of quartz, feldspars, and foraminiferal tests. Laminated sandstone beds of 5–30 cm thick, and fine- to coarse-grained scoria layers of 1–5 mm thick are sometimes intercalated in the mudstone, but are not disturbed by burrows (Fig. 15).

The mudstone contains diatoms, planktonic and benthic foraminifers, sponge spicules, and volcanic glass. Under the microscope, most of calcareous benthic foraminifers are concentrated in thin lamination composed of very fine sand grains. Such foraminifers may not be indigenous but probably transported with sand grains from other places.

Few trace fossils are observed in the fine-grained mudstone. Small *Anconichnus horizontalis* burrows of 0.5 mm in diameter are only contained in the limited layers of 0.5–1 cm thick (Fig. 15; Plate 2, fig. 6). This facies suggest a sedimentary environment in which activities of large benthic organisms are scarce.

Two types of occurrence of the facies E fine-grained mudstone, "autochthonous beds" and "allochthonous blocks," are recognized. The autochthonous bed of facies E has very restricted distribution in the lower part of the Kiwada Formation exposed along the Tsuchisawa River (Loc. 184), in the western part of the Yoro area, where the laminated fine-grained mustone bed of 2 m thick is intercalated in the mudstone of facies A.

In contrast, the autochthonous facies E is not found in the eastern area. The laminated fine-grained mudstone is preserved as allochthonous blocks in the slumped beds and as mudstone rubbles in mudstone breccia I and II. Slumped beds of 5–30 m thick contain numerous blocks of greenish gray laminated fine-grained mudstone of 30–300 cm thick (facies E), and greenish gray massive fine-grained mudstone of 30–300 cm (facies A). The allochthonous occurences of facies E are commonly found in the Kiwada to Umegase Formations in the eastern part of the Yoro area (Locs. 17, 19, 20, 38, 39, 40, 214, 218, 219).

Associated fauna: Fossil mollusks are rarely contained in the laminated fine-grained mudstone. *Neilonella japonica* OKUTANI, rarely occurs with conjoined valves. In addition, *Makiyama* sp. is accumulated in some horizons. All of these fossils are arranged parallel to the bedding plane.

Sedimentary environment of mudstones in the Kazusa Group

A. Stratigraphic change of mudstone facies

The mudstone facies of the Kazusa Group change stratigraphically, through the Kiwada to Chonan Formations in the Yoro area. The succession of the mudstone facies can be summarized as follows; facies A (the Kiwada, Otadai, and Umegase Formations), facies B (the Kokumoto and the Kakinokidai Formations), facies C (the Chonan Formation), in upward sequence (Fig. 16). The facies D, alternating beds of greenish gray fine-grained mudstone and muddy turbidite beds, is intercalating in part of the facies A. Laminated mudstone of the facies E has a limited distribution, intercalating also in the facies A. Roughly speaking, mudstone tend to become coarse upward. The mudstone consists mainly of clay-size material in the facies A, becomes silty in the facies B, and again consists of clay-size material in the facies C in upper part of the Kazusa Group.

The mudstone of the Kazusa Group is usually bioturbated, and degree of bioturbation increases upwards. Thin, lamina-like sandstone layers are sometimes preserved in the facies A (particularly in the Kiwada Formation; Plate 2, fig. 1). Small horizontal tube burrows, such as *Planolites* and *Anconichnus horizontalis*, are predominant in the facies A (Fig. 9; Plate 2, fig. 1), but large vertical tube burrows are almost absent. In contrast, mudstone of the facies B, distributed in the upper part of the group, is much more intensely bioturbated than the underlying facies A. Thin sandy mudstone layers are frequently intercalating in the facies B, however, most of them are severely destroyed by benthic activities. Such layers are only preserved as patches or mottles in surrounding mudstone (Fig. 11; Plate 2, fig. 2). Laminations are not preserved in the mudstone of the facies B. Various types of trace fossils are observed in the facies B. Among them, large vertical tube-burrows are quite common (Fig. 11).

Autochthonous benthic fossils are quite common throughout the Kazusa Group (Table 2). The molluscan assemblages change stratigraphically parallel with the change in lithofacies. The *Portlandia-Neilonella-Ancistrolepis* Association, composed of small thin-shelled mollusks, is quite common in the facies A, while they are few in the facies B and C. The association indicate bathyal environments (BABA, 1990).

The *Limopsis-Nuculana-Bathybembix* Association is dominant in the facies B. Deep-burrowing *Lucinoma* sp. also occurs in this association (Fig. 11). In addition, large, thick-shelled mollusks, such as *Buccinum* appear in the facies B in the upper part of the

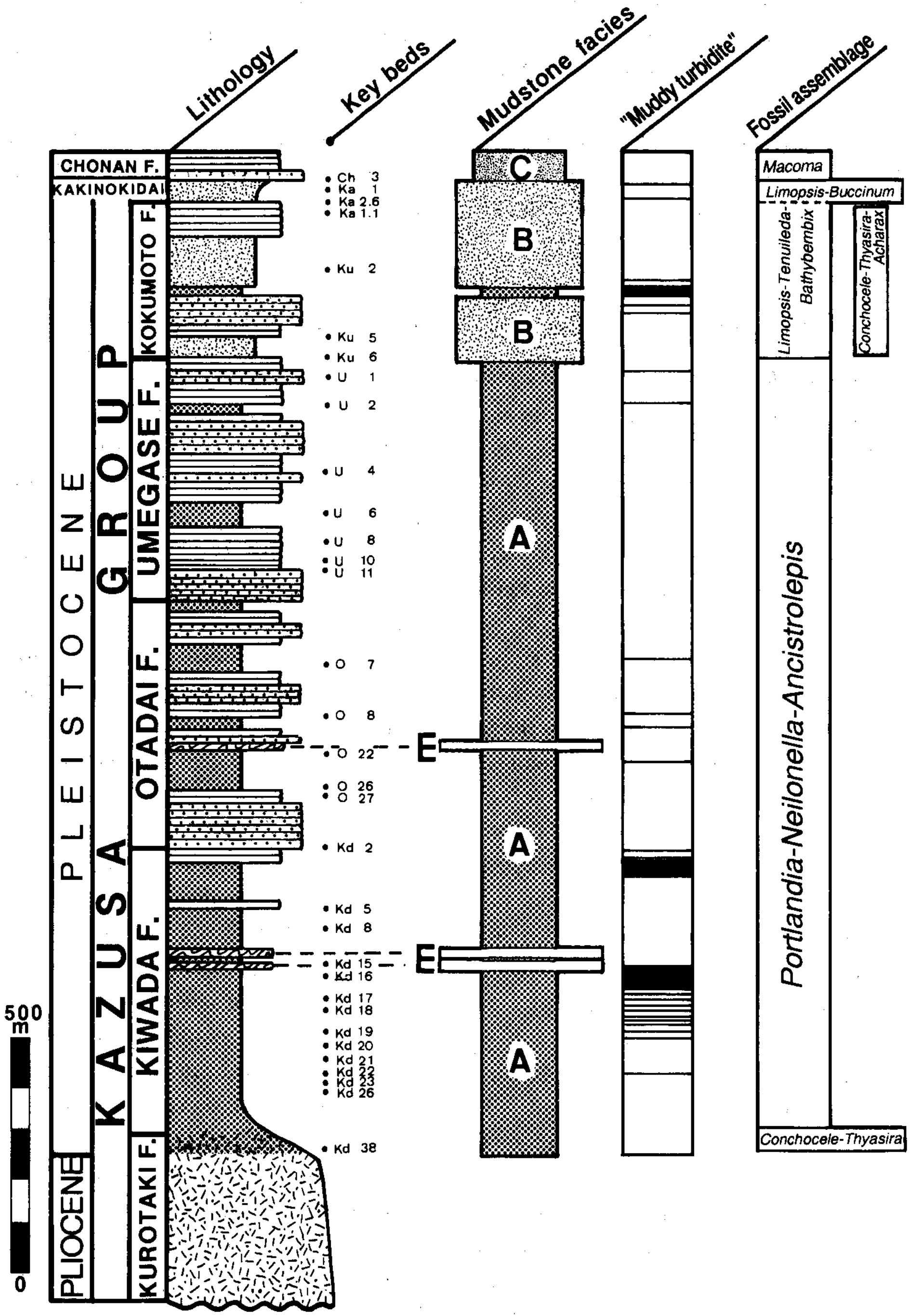


Fig. 16. Generalized columnar section of the Kazusa Group in the Yoro area, showing stratigraphic distributions of mudstone facies and fossil assemblages.

Kakinokidai Formation. The assemblage including *Buccinum isaotakii* Kira is referable to the *Buccinum-Limopsis* Association of BABA (1990), which may be indicative of outer shelf mud bottom.

All of these features suggest the shallowing upward sequence of the Kazusa Group. From the view point of benthic foraminifers, AOKI (1965) presumed bathymetry of the depositional environments of the Kazusa Group. According to him, the lower part of the group, from the Katsuura Formation to the upper part of the Umegase Formation was deposited in the lower to upper continental slope environments, and the upper part of the group, from the uppermost part of the Umegase Formation to the Kasamori Formation was deposited in the outer to middle shelf environments. The sedimentary features of mudstone and molluscan associations may also support AOKI's interpretation.

Massive fine-grained mudstone (facies C) is again predominant in the uppermost part of the Kazusa Group. The facies C is quite similar to the facies A in grain size, however, the former is much more intensely bioturbated than the latter. Ichno- and molluscan assemblages of the facies C are also quite different from the facies A. Many large vertical tube-burrows, which are absent in the facies A, are observed penetrating intercalated sandstone bed in the facies C (Fig. 12). The *Macoma calcarea* (GMELIN) Association, which may be indicative of the outer shelf to uppermost bathyal environments (BABA, 1990), is common in the facies C. The facies C is overlain by the sandstone facies of the shelf environment (OYAMA, 1952; 1959). Therefore, rather shallow and quiet environment, in which sand influx was prevented by the barrier may be considered for the deposition of the facies C.

B. Reconstruction of sedimentary environments of the laminated fine-grained mudstone (facies E)

The greenish gray laminated fine-grained mudstone of the facies E is similar to the facies A in color, grain-size, and grain composition. However, it is different from the latter in the following features.

(1) Well-preserved parallel laminations.

(2) Rare bioturbation. Only small *Anconichnus horizontalis* burrows are partly aggregated in some narrow horizons.

(3) Benthic fossils almost absent.

(4) Calcareous benthic foraminifer concentrated in a laminae surface. They are not indigenous in the facies E but may be transported form the other facies together with sandy materials.

These characteristic features indicate low activity of large benthic animals and suggest dysaerobic condition of the environment in which the laminated fine-grained mudstone was deposited.

The distribution of the laminated fine-grained mudstone facies is characteristic.

(1) It is narrowly distributed in the middle part of the Kiwada Formation in the western part of the area studied (Loc. 184). The laminated mudstone is about 2 m thick intercalating in the greenish gray massive fine-grained mudstone of the facies A.

(2) The mudstone is found as allochthonous blocks in the slump beds of 5–30 m thick, and in two types of the mudstone breccia, both of which are intercalating in the facies A of the Kiwada to Umegase Formations in the eastern area.

It is likely that the laminated fine-graied mudstone was deposited on the slope of the western area, and most part of the facies was transported downslope toward the east by slumping or debris flow, and preserved as allochthonous blocks. The original place of the deposition was thought to be relatively depleted with dissolved oxygen, possibly due to the local bottom topography.

Mass movement from west to east is also supported by following observations. Deformation and thrust structures in the slump beds indicate that the slumps were supplied from west to east or northwest to southeast. The trend is also shown as sole marks and cross-lamination in the turbiditic sandstone beds in the Kiwada to Umegase Formations.

The mudstone breccia are also intercalated limitedly in the eastern area. The breccia is absent in the Kiwada Formation in the western area around Kurotaki, while more than 60 beds are observed along the Yoro River (Fig. 4). Similar trend of distribution is recognized among muddy turbidite beds, particularly those in the middle part of the Kiwada Formation; few around Kurotaki and many along the Yoro River. The thickness of the Kiwada and Otadai Formations in the eastern area is as three times larger than that of the western area; *e.g.* the Kiwada Formation is 185 m around Kurotaki and 600 m along the Yoro River (Fig. 4). HIRAYAMA and SUZUKI (1968) also noted the eastward transportation of sandy turbidite along a datum plane defined with 07 marker tuff in the Otadai Formation.

Fig. 17 shows a reconstruction of the paleoenvironment of mudstone in the Kazusa Group. The series of the facies A to C may reflect the shallowing sequence. The depositional environment of the facies C was probably a silled depression or a part shaded from wave and current action. The muddy turbidite facies appears within the facies A,

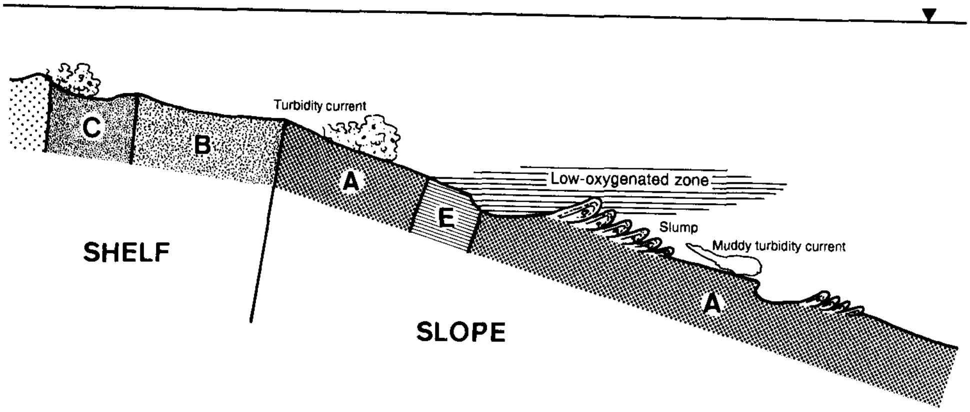


Fig. 17. Schematic reconstruction of sedimentary environments of the main part of the Kazusa Group. The sedimentary basin deepens eastward. Greenish gray laminated mudstone (facies E) might be deposited under dysaerobic condition, such as O_2-minimum zone, and the most part is preserved as allochthonous blocks in slump deposits.

and tend to increase toward the eastern area. The facies E was accumulated within the area of the facies A deposition, but in the low oxygenated condition.

Conclusion

1). Monotonous muddy deposits in the Kazusa Group, distributed in the central to the eastern part of the Boso Peninsula, can be divided into five major facies (A-E), namely greenish gray massive fine-grained mudstone facies (facies A), bluish gray mottled coarse-grained mudstone facies (facies B), light gray massive fine-grained mudstone facies (facies C), facies of alternating beds of greenish gray fine-grained mudstone and bluish gray fine-grained mudstone (facies D), and greenish gray laminated fine-grained mudstone facies (facies E).

2). In the Yoro area, the central part of the Boso Peninsula, the mudstone facies changes stratigraphically upward, from the facies A (from the Kiwada to Umegase Formations) to the facies C (the Chonan Formation) through the facies B (the Kokumoto and Kakinokidai Formations). In general, mudstone of the Kazusa Group shows coarsening upward, and the degree of bioturbation also increases upward.

3). In accordance with the suceessional change of lithofacies, ichno- and molluscan assemblages change stratigraphically. These features of litho- and biofacies suggest shallowing upward sequence of the Kazusa Group.

4). The facies D consists of alternating beds of greenish gray fine-grained mudstone and muddy turbidite layers. The greenish gray fine-grained mudstone is the same as that of the facies A, and the facies D is intercalated in the faces A, particularly in the middle and uppermost part of the Kiwada and lower part of the Kokumoto Formations in the Yoro area, and the Katsuura to the lower part of the Otadai Formations in the Katsuura-Ohara area.

5). The facies E, the laminated fine-grained mudstone, yields few benthic fossils, and is scarcely bioturbated. The feature suggests the deposition under dysaerobic environment. The autochthonous part of the facies E is distributed only in the western area, while they occur as numerous allochthonous blocks contained in the slump deposits in the eastern area. The facies E might originally be deposited in the shallower, upper slope of the western area, and the most part of the facies were thought to be transported eastward by mass-gravity flow, and preserved as allochthonous blocks in the facies A.

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Explanation of Plate 1

Outcrop of the Kazusa Group.

1. Bluish gray mottled coarse-grained mudstone frequently intercalated by sandy mudstone layers (facies B). Loc. 128 (upper part of the Kakinokidai Formation).
2. Alternating beds of bluish gray fine-grained mudstone of 5–6 cm thick and greenish gray fine-grained mudstone of 10–40 cm thick (facies D). Loc. 16 (Middle part of the Kiwada Formation).

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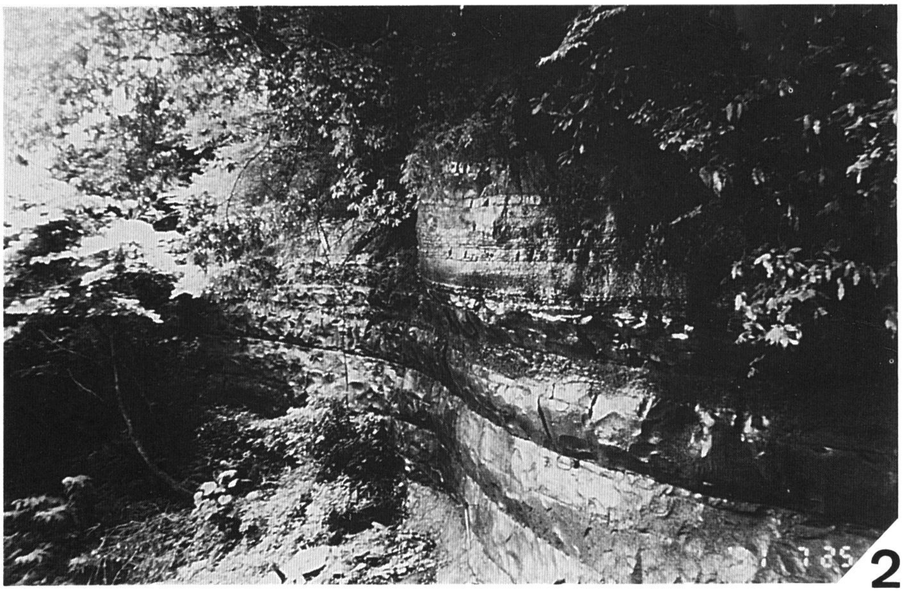

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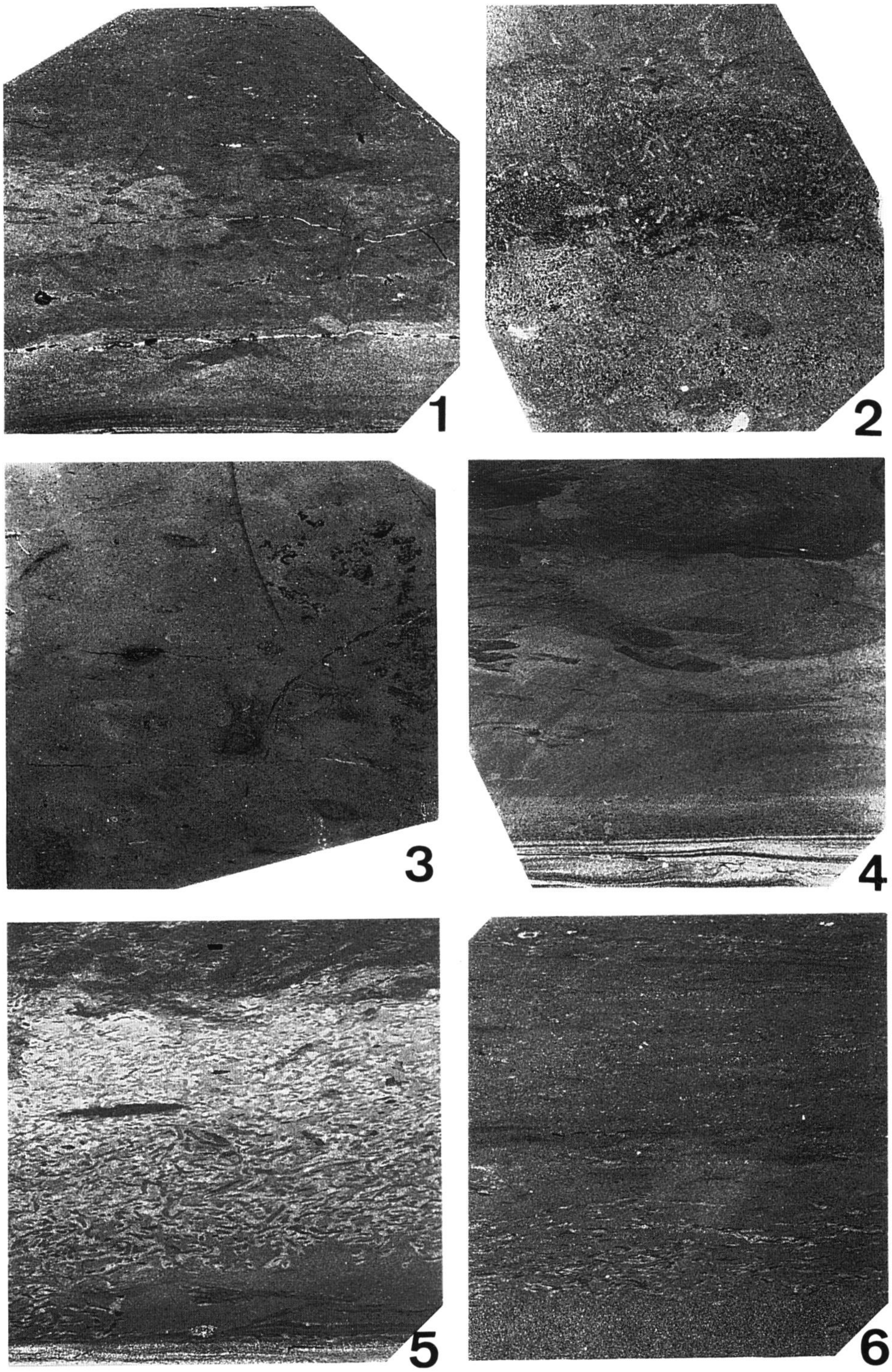
Explanation of Plate 2

Vertical profiles of the rock specimens
(all figures are ×0.6 and of upright position)

1. Greenish gray fine-grained mudstone (facies A) containing *Planolites* and *Ancoichnus horizontalis* burrows. JC9001, Loc. 25 (upper part of the Kiwada Formation).
2. Bluish gray mottled coarse-grained mudstone (facies B). A fine scoria layer (center) is disturbed by burrowing. JC9002, Loc. 98 (middle part of the Kokumoto Formation).
3. Light gray massive fine-grained mudstone (facies C) containing many *Planolites*-type burrows. JC9003, Loc. 403 (lower part of the Chonan Formation).
4. Alternating beds of the facies D consisting three parts. Light gray laminated fine sandstone at the basal part, bluish gray bioturbated fine-grained mudstone in the middle, and greenish gray bioturbated fine-grained mudstone in the upper part. JC9004, Loc. 306 (lower part of the Namihana Formation).
5. Alterating beds of green unit and underlying blue unit (facies D). Numerous *Ancoichnus horizontalis* burrows are observable. JC9005, Loc. 37 (middle part of the Kiwada Formation).
6. Greenish gray laminated fine-grained mudstone (facies E). Thin laminations are frequently intercalated in the fine-grained mudstone. JC9006, Loc. 184 (middle part of the Kiwada Formation).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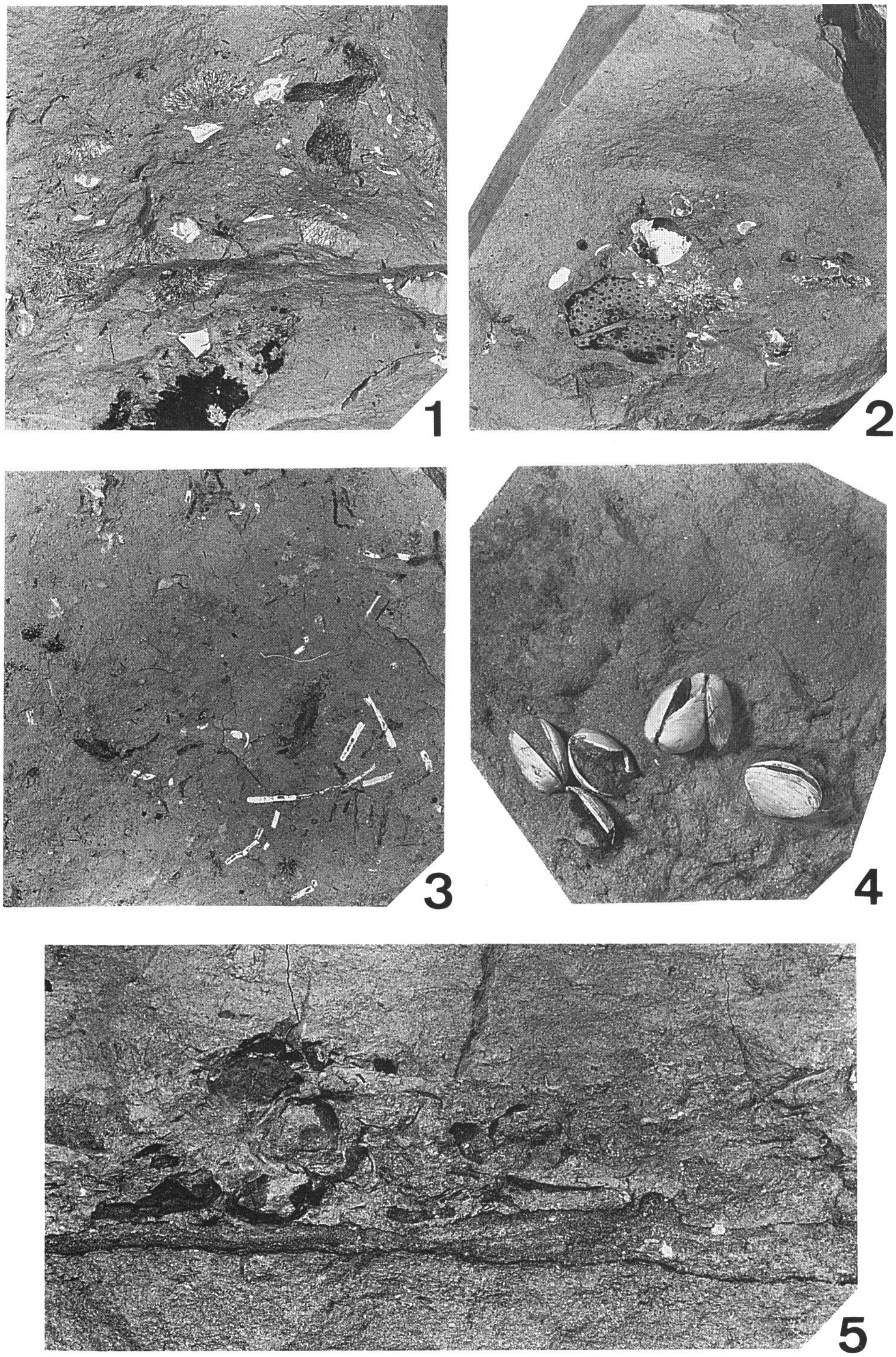
Explanation of Plate 3

Mode of fossil occurrence (all figures are ×0.7)

1. Horizontal profile of mudstone in which many small shells and solitary corals are aggregated (accumulation I). JC9007, Loc. 204 (facies A; middle part of the Kiwada Formation).
2. Shells and an echinoid test accumulated on a bedding plane as a small patch. Horizontal profile of mudstone. JC9008, Loc. 204 (facies A; middle part of the Kiwada Formation).
3. *Makiyama* sp. accumulated on a bedding plane (accumulation II). Horizontal profile of mudstone. JC9009, Loc. 149 (facies D; upper part of the Kiwada Formation).
4. *Limopsis* showing autochthonous occurrence. Five articulated individuals are observable in the vertical profile of mudstone. JC9010, Loc. 256 (facies B; lower part of the Kakinokidai Formation).
5. Vertical profile of sandy layers intercalated in coarse-grained mudstone, which shows accumulation of bivalve shells and echinoid tests (accumulation III). JC9011, Loc. 241 (facies B; middle part of the Kokumoto Formation).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