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# Oligocene ostracode assemblages from the Itanoura Formation, Nishisonogi Group, Nagasaki Prefecture, southwestern Japan

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**Abstract.** At least thirty-three ostracode species are reported for the first time from the Oligocene Itanoura Formation, Nishisonogi Group. This is also the first report of Oligocene ostracodes from the Japanese Islands. Fifteen samples bearing fossil ostracodes were grouped into three biofacies (A to C). Three biofacies have characteristics as follows: Biofacies A is dominated by *Acanthocythereis volubilis* (Liu) and *Eopaijenborchella sinensis* (Liu); Biofacies B is dominated by *Krithe* sp. associated with *Palmoconcha oujiangensis* (Liu) and *A. volubilis*; Biofacies C dominantly includes *P. oujiangensis*. The lithofacies, fossil molluscan assemblages and planktonic/total foraminifers ratios suggest the following habitats for the ostracodes: all ostracode species from the formation inhabited a shelf influenced by coastal water; dominant species of Biofacies A flourished in environments shallower than those of Biofacies B. Fossil ostracode assemblages from the Itanoura Formation have lower numbers of species and lower species diversity indices than other such assemblages from shelf habitats through the Neogene to Recent. These results also suggest that some genera such as *Cytherella*, *Eopaijenborchella* and *Palmoconcha* may differ from their Recent counterparts in their habitats, and that shallow-marine ostracodes in the northwestern Pacific might have diversified after the early Oligocene.

**Key words:** depositional environments, habitat, Itanoura Formation, Nishisonogi Group, Oligocene, Ostracoda

## Introduction

Only a few studies on Paleogene shallow-marine ostracodes in the northwestern Pacific have been made, although many studies on Neogene ostracodes have been carried out. Among those few studies, Hanai (1970) reported the genus *Eopaijenborchella* from the Eocene in Hokkaido, northern Japan. Liu (1989) and Yang *et al.* (1990) reported Paleocene and Eocene ostracodes from drilling cores off Taiwan and described 27 and six new species, respectively. However, these studies were qualitative in nature and Paleogene ostracode assemblages have until now not been quantitatively evaluated. Moreover, Oligocene ostracodes have never been studied in Japan. One of the aims of this study is to clarify the Oligocene ostracode assemblages in the northwestern Pacific on the basis of quantitative examination.

Ostracodes are considered to be useful indicators of paleoenvironments, such as in studies of the depo-

sitional environments of upper Cenozoic strata (e.g., Irizuki and Matsubara, 1994; Irizuki *et al.*, 1998; Yamada *et al.*, 2001). Many discussions on depositional environments using late Cenozoic ostracodes are based on the modern geographical distributions of extant species. Because all Eocene ostracode species are extinct, Yang *et al.* (1990) discussed the depositional environments of the Eocene Wenzhou Formation on the basis of the modern geographical distribution of extant genera. Yang *et al.* (1990) thought that the lower part and the upper part of the Wenzhou Formation had been deposited in a shallow sea and an alternate environment between a shallow and a deep sea, respectively. However, calcareous nannofossils both from the lower and the upper part of the Wenzhou Formation suggested deposition in coastal environments on the basis of the Paleogene geographical distribution of the genera (Zhong, 1990). Generally the deep sea is considered not a coastal but an offshore environment. Hence, the geographical

distribution of Paleogene ostracode genera could be different from those of their Recent counterparts. In order to discuss depositional environments using Paleogene ostracodes clearly, the relationship between Paleogene ostracode species and depositional environments needs to be revealed. Therefore, another aim of this study is to examine the habitats of extinct species. The depositional environments of the Itanoura Formation, the study strata, were previously discussed on the basis of fossil molluscs, benthic foraminifers and sedimentary facies analysis (Inoue, 1964; New Energy Development Organization (NEDO), 1985, 1986, 1987; Hattori *et al.*, 1993; Kurita *et al.*, 2003). Inoue (1964) and Hattori *et al.* (1993) mentioned that the Itanoura Formation included near-shore and offshore deposits on the basis of the modern geographical distribution of extant molluscan genera. NEDO (1985, 1986, 1987), which reported the *Nonion-Elphidium* benthic foraminiferal assemblage from drilling cores off the Nishisonogi Peninsula, considered that the formation was deposited in the near-shore zone. On the other hand, Kurita *et al.* (2003) analyzed sedimentary facies and thought that the formation was deposited in an estuary. To determine the depositional environments in which the ostracodes had lived, I examined the lithofacies, foraminifers and reinterpreted the molluscan data of Inoue (1964) and Hattori *et al.* (1993).

### Geological outlines

The Itanoura Formation is distributed in the Nishisonogi Peninsula and adjacent areas, western part of Nagasaki Prefecture, southwestern Japan. The geology there is summarized by Nagahama and Matsui (1958) and Hattori *et al.* (1993). In this study, the division of the Paleogene sequence follows that of Hattori *et al.* (1993). The Itanoura Formation is included in the Nishisonogi Group. The group dips in a northwestern to west direction at less than 30 degrees and is divided by faults in the study area (Figure 1).

The Itanoura Formation, which is 90 to 170 m thick, consists chiefly of sandstone. It is divided into three parts on the basis of lithofacies: The basement part consists of conglomerate with abundant *Ostrea* shells less than 2 m thick; the main part consists of alternating sandstone and muddy sandstone with abundant molluscan fossils and is 60 to 100 m thick; the uppermost part, 10 to 30 m thick, consists mainly of sandstone with mud pipes. The lithofacies of the formation changes laterally. The formation conformably overlies the Sakito Formation, which consists chiefly of sandstone intercalated by lignite layers, and is conformably

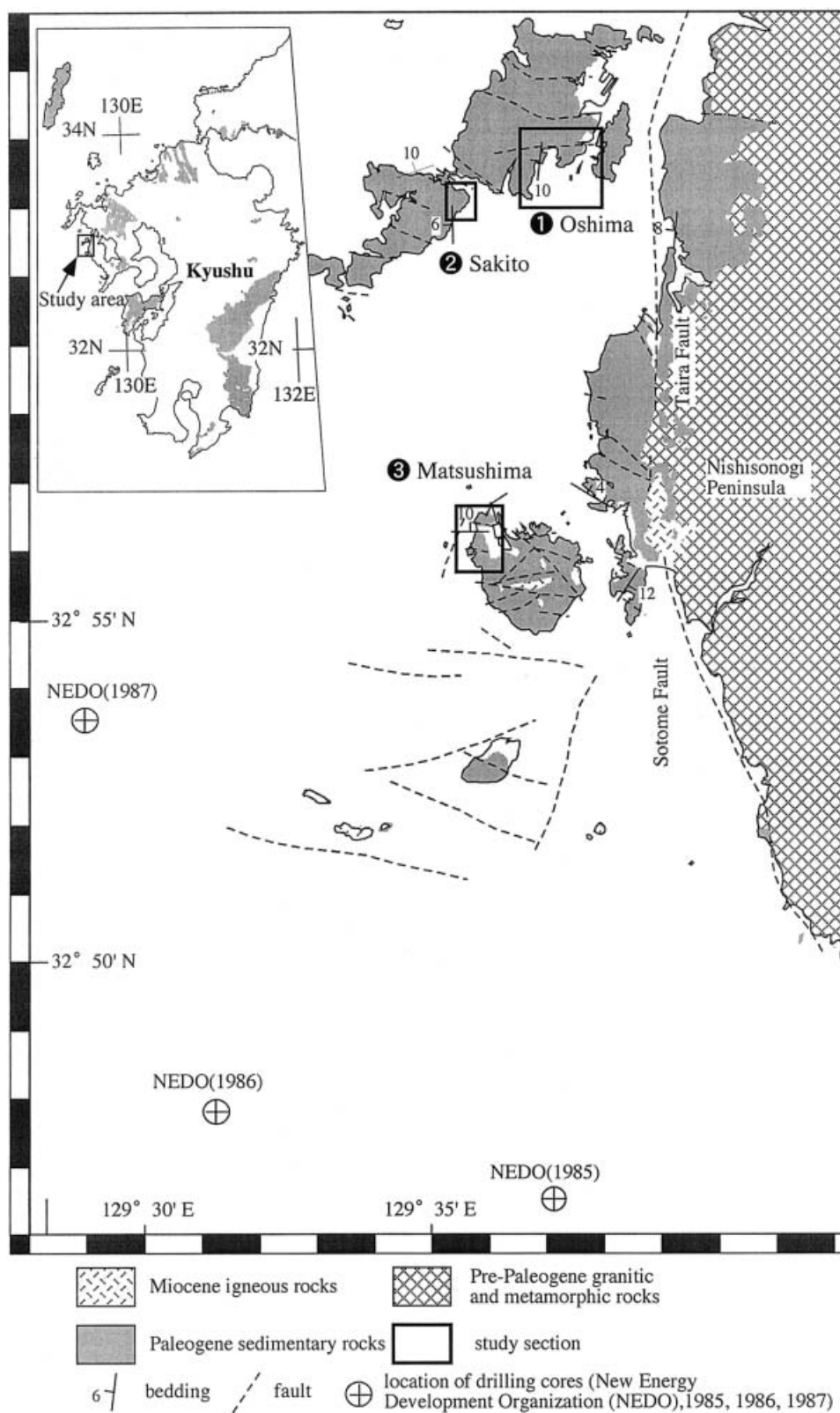
overlain by the Kakinoura Formation, which is composed of sandstone and calcareous sandstone.

The geological age of the Itanoura Formation has been examined on the basis of the dating of the tuff layer with the fission-track method and calcareous nannofossils by Miyachi and Sakai (1991) and Okada (1992), respectively. Calcareous nannofossils date the formation as 33.3 to 32.8 Ma (Berggren *et al.*, 1995), because the formation is correlated with calcareous nannofossil Zone CP16b of Okada and Bukry (1980) (Okada, 1992). The fission-track ages of zircons from the andesitic tuff layer in the Sakito section, which are  $37.8 \pm 4.0$  and  $37.9 \pm 3.6$  Ma ( $2\sigma$  error) (Miyachi and Sakai, 1991), suggest an age older than that indicated by the calcareous nannofossils. The zircons are interpreted as having been reworked, because the tuff layer, which includes gravels and represents upward-fining, is regarded as a reworked deposit. Therefore, the formation is thought to be of early Oligocene age.

### Materials and methods

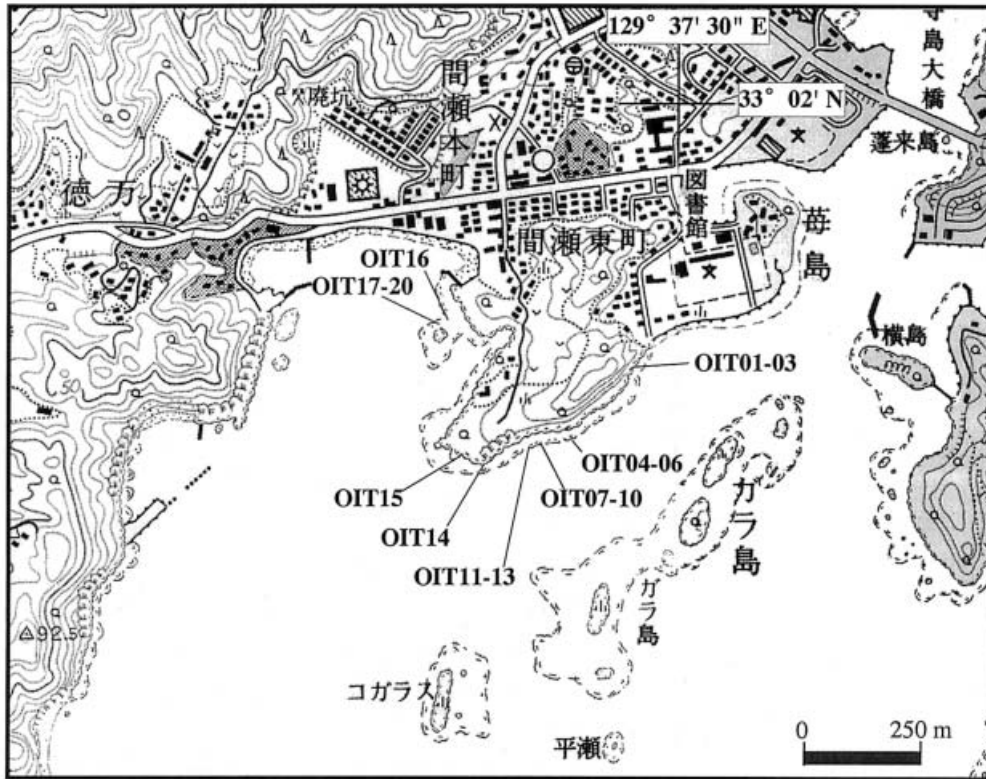
Thirty-six rock samples for examination of microfossils (ostracodes and foraminifers) were collected from outcrops exposed in the Oshima, Sakito and Matsushima sections (Figures 2 and 3). All samples except for sample MIT01 were gathered from the main part of the Itanoura Formation. Sample MIT01 was collected from the basement part of the formation in the Matsushima section. The Itanoura Formation in these sections cannot be clearly correlated with each other, because these sections are divided by faults and key beds could not be recognized.

In laboratory procedures, 160 to 400 g rock samples were disaggregated in a saturated sodium sulfate solution and naphtha. The disaggregated samples were washed through 63  $\mu\text{m}$  mesh sieve and dried. Ostracode specimens were picked from fractions coarser than 125  $\mu\text{m}$  in samples. Photographs of the specimens of dominant species were taken with a scanning electron microscope (SEM) to identify species. In order to observe the internal view of the carapaces of some dominant species, photographs of the thin sections of carapaces were taken with a transmitted light microscope. The total number of ostracode individuals was reckoned as the sum of the number of carapaces and the larger number of either left or right valves (Table 1). To recognize ostracode biofacies, samples with more than 50 individuals were subjected to Q-mode cluster analysis. The analysis was performed with the cosine theta index of Imbry and Purdy (1962) as the similarity measure and the weighted pair

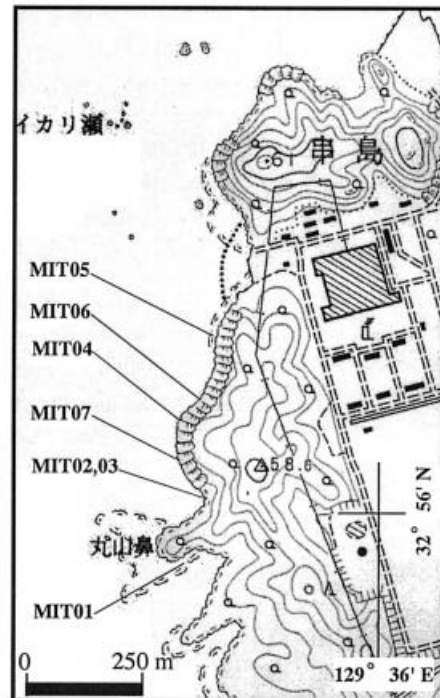


**Figure 1.** Geological map of the study area. Partly modified after Nagahama and Matsui (1958) and Hattori *et al.* (1993).

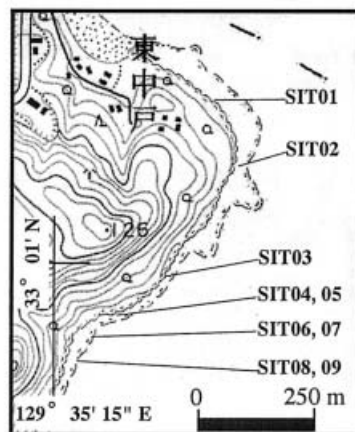
## ① Oshima section



## ③ Matsushima section



## ② Sakito section



**Figure 2.** Locality maps of the samples (parts of 1:25,000 “Omodaka”, “Kakinoura” and “Kamanoura” sheets published by the Geographical Survey Institute of Japan).

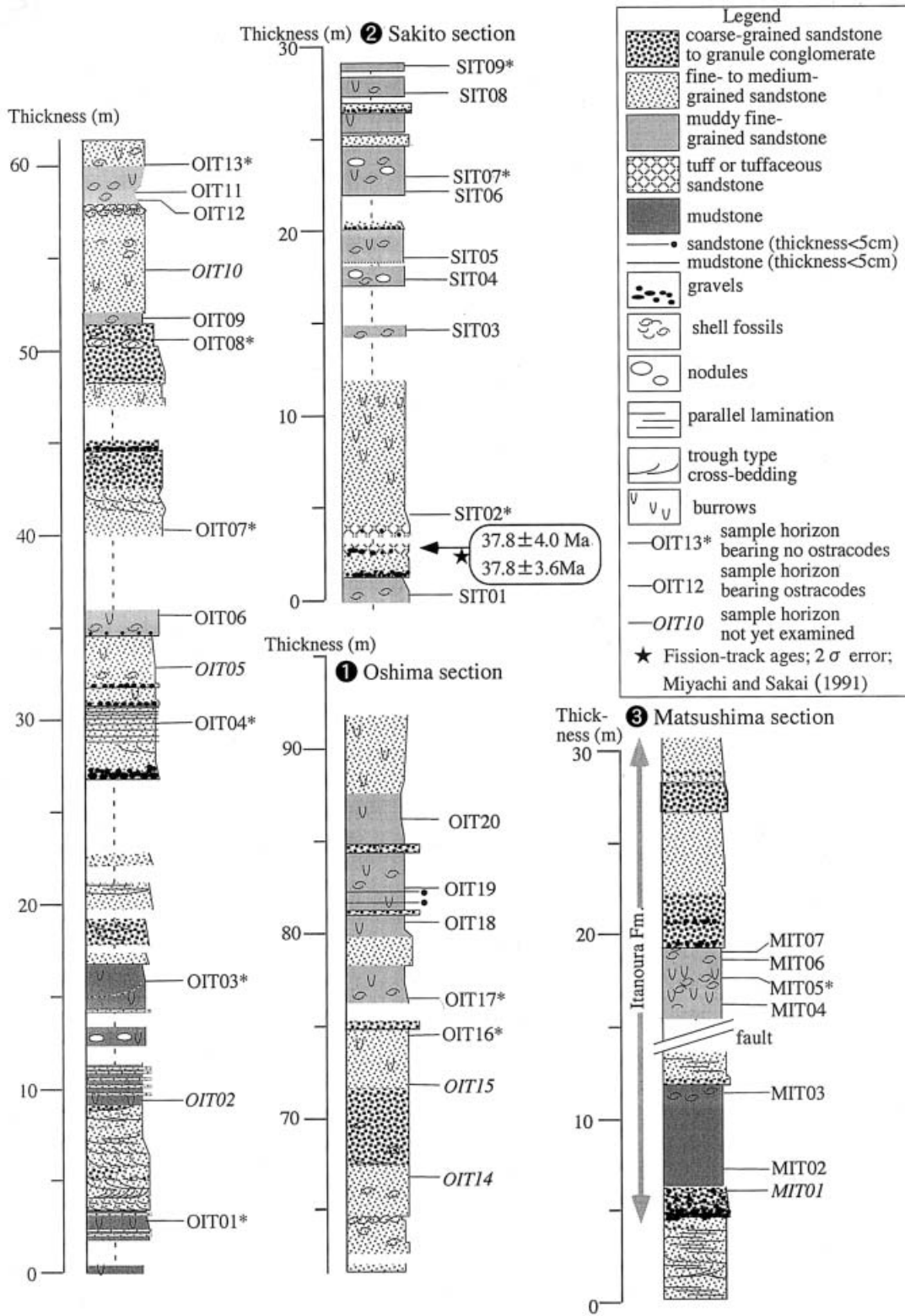


Figure 3. Columns of the study sections.

**Table 1.** List of ostracode species from the Itanoura Formation. Ind = individuals, C = carapaces, L = left valves, R = right valves

sample	OIT06		OIT09		OIT11		OIT12		OIT18		OIT19		OIT20		SIT01		SIT03			
	Ind	C	L	R	Ind	C	L	R	Ind	C	L	R	Ind	C	L	R	Ind	C	L	R
<i>Abrocythereis</i> aff. <i>acromadalis</i> (Liu, 1989)	24	24			12	12			18	18			14	14			23	23		
<i>Acanthocythereis volabillis</i> (Liu, 1989)	33	33			19	19			25	25			87	87			53	53		
<i>Acanthocythereis</i> spp.																				
<i>Caudites</i> sp.	2	2											1	1						
<i>Cytherella</i> sp. 1	25	25			5	5			6	6			8	8			9	9		
<i>Cytherella</i> sp. 2																				
<i>Cytheredoloides wendongensis</i> Liu, 1989	2	2																		
<i>Cytheropteron</i> sp. 1	10	10							1	1			3	3			6	6		
<i>Cytheropteron</i> sp. 2	2	2																		
<i>Cytherura</i> sp.																				
<i>Eopaijenborchella sinensis</i> (Liu, 1989)	57	57			18	18			12	12			1	1			29	29		20
<i>Eopaijenborchella</i> sp.																				
<i>Hanaiborchella alata</i> (Liu, 1989)	2	2			1	1			1	1										
<i>Hanaiborchella cavernosa</i> (Liu, 1989)																				
<i>Hanaiborchella</i> sp.																				
<i>Hanaiborchella</i> spp.																				
<i>Hernanites?</i> sp.	1	1											1	1						
<i>Kribia</i> sp.	4	4			10	10			3	3			3	2	1	3	3	3	3	
<i>Munseyella simplex</i> Chen, 1990																				
<i>Neononoceratina</i> sp.																				
<i>Neonesidea</i> sp.																				
<i>Pacanbocythere</i> sp.																				
<i>Palmocochlea oujiangensis</i> (Liu, 1989)																				
<i>Paracytheridea</i> sp.	1	1											33	33						
<i>Pontocythere</i> sp.																				
<i>Propontocypris</i> sp.																				
<i>Schizocythere</i> sp.																				
<i>Schizocythere?</i> spp.	2	2																		
<i>Xestoleberis</i> sp.	1	1																		
gen. et sp. 1 indet.	1	1																		
gen. et sp. 2 indet.																				
gen. et sp. 3 indet.																				
gen. et sp. 4 indet.	2	2																		
Total individuals	146				66				67				63				163			132
No. of species	6				13			6	8			5	10			8	7			7
Sample weight (g)	160				400			160	320			160	240			160	160			160

Table 1. Continued

sample	SIT04			SIT05			SIT06			SIT08			MIT02			MIT03			MIT04			MIT06			MIT07					
	Ind	C	L R	Ind	C	L R	Ind	C	L R	Ind	C	L R	Ind	C	L R	Ind	C	L R	Ind	C	L R	Ind	C	L R	Ind	C	L R			
species																														
<i>Abrocyclytheris</i> aff. <i>acrocaudalis</i> (Liu, 1989)	12	30	42	30	42	42							3	3	3	1	1	1	4	4	4	4	4	4	10	10	10	7	6	1
<i>Acanthocyclytheris volatilis</i> (Liu, 1989)	29	46	58	46	58	58							2	2	2	2	2	2	1	1	1	50	50	50	19	19	19	15	15	15
<i>Acanthocyclytheris</i> spp.																														
<i>Caudites</i> sp.																														
<i>Cytherella</i> sp. 1	1	4	15	4	15	15	2	2	2	6	4	1 2	4	2	2	4	2	2	4	4	4	9	8	1	5	4	1			
<i>Cytherella</i> sp. 2										1	1	1	1	1	1															
<i>Cytherelloidea wendongensis</i> Liu, 1989																														
<i>Cytheropteron</i> sp. 1	2	3	11	3	11	11				1	1	1	1	1	1	2	2	2	2	2	2	2	2	2				4	4	4
<i>Cytheropteron</i> sp. 2										4	2	2																		
<i>Cytherura</i> sp.																														
<i>Eopaijenborchella sinensis</i> (Liu, 1989)	3	14	26	14	26	26	3	3	3	2	2	2	2	2	2	2	2	2	3	3	3	30	29	1	6	6	6			
<i>Eopaijenborchella</i> sp.																														
<i>Hanaiborchella alata</i> (Liu, 1989)	2		3		3	3	5	5	5	1	1	1	1	1	1	4	4	4	4	4	4									
<i>Hanaiborchella cavernosa</i> (Liu, 1989)																														
<i>Hanaiborchella</i> sp.																														
<i>Hanaiborchella</i> spp.																														
<i>Hermanites?</i> sp.																														
<i>Kribia</i> sp.																														
<i>Manseylla simplex</i> Chen, 1990	1	10	23	10	23	23	20	20	20	15	15	15	31	31	31	3	3	3	5	4	1	5	4	1	25	22	2	3		
<i>Neomonoceratina</i> sp.																														
<i>Neonesidea</i> sp.																														
<i>Pacambocythere</i> sp.																														
<i>Palmocochia oujiangensis</i> (Liu, 1989)																														
<i>Paracytheridea</i> sp.																														
<i>Pontocythere</i> sp.	1	1	12	1	12	12	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
<i>Propontocypris</i> sp.																														
<i>Schizocythere</i> sp.																														
<i>Schizocythere?</i> spp.																														
<i>Xestoleberis</i> sp.																														
gen. et sp. 1 indet.																														
gen. et sp. 2 indet.																														
gen. et sp. 3 indet.																														
gen. et sp. 4 indet.																														
Total	51	108	205	108	205	205	36	36	36	52	52	52	54	54	54	67	67	67	80	80	80	67	67	67	80	80	80	70	70	70
No. of species	7	7	12	7	12	12	9	9	9	10	10	10	8	8	8	6	6	6	10	10	10	6	6	6	10	10	10	11	11	11
Sample weight (g)	160	160	200	160	200	200	400	400	400	400	400	400	200	200	200	160	160	160	240	240	240	160	160	160	240	240	240	240	240	240



**Table 2.** List of foraminifer groups from the Itanoura Formation

group/sample	OIT06	OIT09	OIT11	OIT12	OIT18	OIT19	OIT20	SIT01	SIT03	SIT04	SIT05	SIT06	SIT08	MIT02	MIT03	MIT04	MIT06	MIT07
Planktonic	0	1	1	0	1	1	0	1	0	0	0	0	0	1	2	0	2	1
Benthic	112	117	151	368	119	342	297	165	227	292	144	199	191	156	150	117	155	166
Total foraminifers	112	118	152	368	120	343	297	166	227	292	144	199	191	157	152	117	157	167
P/T ratio (%)	0	0.847	0.658	0	0.833	0.292	0	0.602	0	0	0	0	0	0.637	1.316	0	1.274	0.599
sample weight (g)	10	25	10	10	15	10	10	15	5	5	5	5	10	5	37.5	10	2.5	5

group arithmetic average method as the linkage strategy. Relative abundance of species, the number of species and species diversity index in assemblages were also calculated for the samples with more than 50 individuals. Species diversity index ( $H(S)$ ) was expressed by the Shannon-Wiener index:

$$H(S) = -\sum Pi \ln(Pi)$$

where  $Pi$  and  $S$  are the relative abundance of the  $i$ -th species and the number of species, respectively.

Molluscan data in the sections were based on Inoue (1964), Hattori *et al.* (1993) and supplemental data by the observation in this study. Fossil foraminifers were picked from fractions coarser than 125  $\mu\text{m}$  in samples sieved for examination of ostracodes. I divided foraminifers into planktonic and benthic groups and calculated planktonic/total foraminifers ratios (P/T ratios) (Table 2).

## Results

### 1) Description of lithofacies and molluscs data

The lithofacies containing fossil ostracodes are divided into two units: muddy fine-grained sandstone (Unit 1) and massive mudstone (Unit 2) (Figures 4 and 5).

#### 1-1) Unit 1 (muddy fine-grained sandstone)

*Description.*—The unit is distributed in the Oshima, Sakito and Matsushima sections. It consists of muddy fine-grained sandstone, which is gray to bluish-gray in color and 1 to 15 m in thickness, representing bioturbation. The unit contains mica, mud pipes, fossil molluscs, and plant fossils. The unit is intercalated with fine- to medium-grained sandstones, which include little mud.

*Molluscan fossils.*—The unit yields the *Turritella* and “*Cardium*”-*Pitar* assemblages (Inoue, 1964; Hattori *et al.*, 1993). In the Oshima and Sakito sections, *Turritella* occurs abundantly and forms the

*Turritella* assemblage (Inoue, 1964; this study). In the Matsushima section the *Turritella* assemblage changes into the “*Cardium*”-*Pitar* assemblage stratigraphically within the unit (Inoue, 1964; Hattori *et al.*, 1993; the horizons of the samples MIT04 to MIT07 in this study).

#### 1-2) Unit 2 (massive mudstone)

*Description.*—The unit is distributed in the Matsushima section. It consists of massive mudstone, which is dark gray in color and 7 m in thickness, and does not show any evidence of bioturbation or primary sedimentary structures.

*Molluscan fossils.*—The unit yields the “*Cardium*”-*Pitar* assemblage (Hattori *et al.*, 1993).

### 2) P/T ratios

P/T ratios of examined samples show values of less than 1.5% (Table 2; Figures 4 and 5). There is little difference among the samples.

### 3) Ostracode biofacies

Ostracodes occur in 18 samples. Most ostracode specimens were carapaces and were not well preserved (Figures 6 and 7). At least thirty-three species were identified (Table 1). Fifteen out of 18 samples contained more than 50 individuals and three samples included less than 50 individuals. Three ostracode biofacies were identified at the 0.6 level of the cosine theta index based on the Q-mode cluster analysis (Figure 8). Three biofacies have their own characters in species components, the number of species and  $H(S)$  as follows.

*Biofacies A.*—The biofacies occur in Unit 1. It is characterized by dominance of *Acanthocythereis volubilis* (Liu) and *Eopaijenborchella sinensis* (Liu), accounting for about 40 to 70%. These dominant species are associated with *Abrocythereis* aff. *acrocaudalis* (Liu), *Munseyella simplex* Chen and *Cytheropteron* sp. 1. The number of species and  $H(S)$  are 6 to 13 and

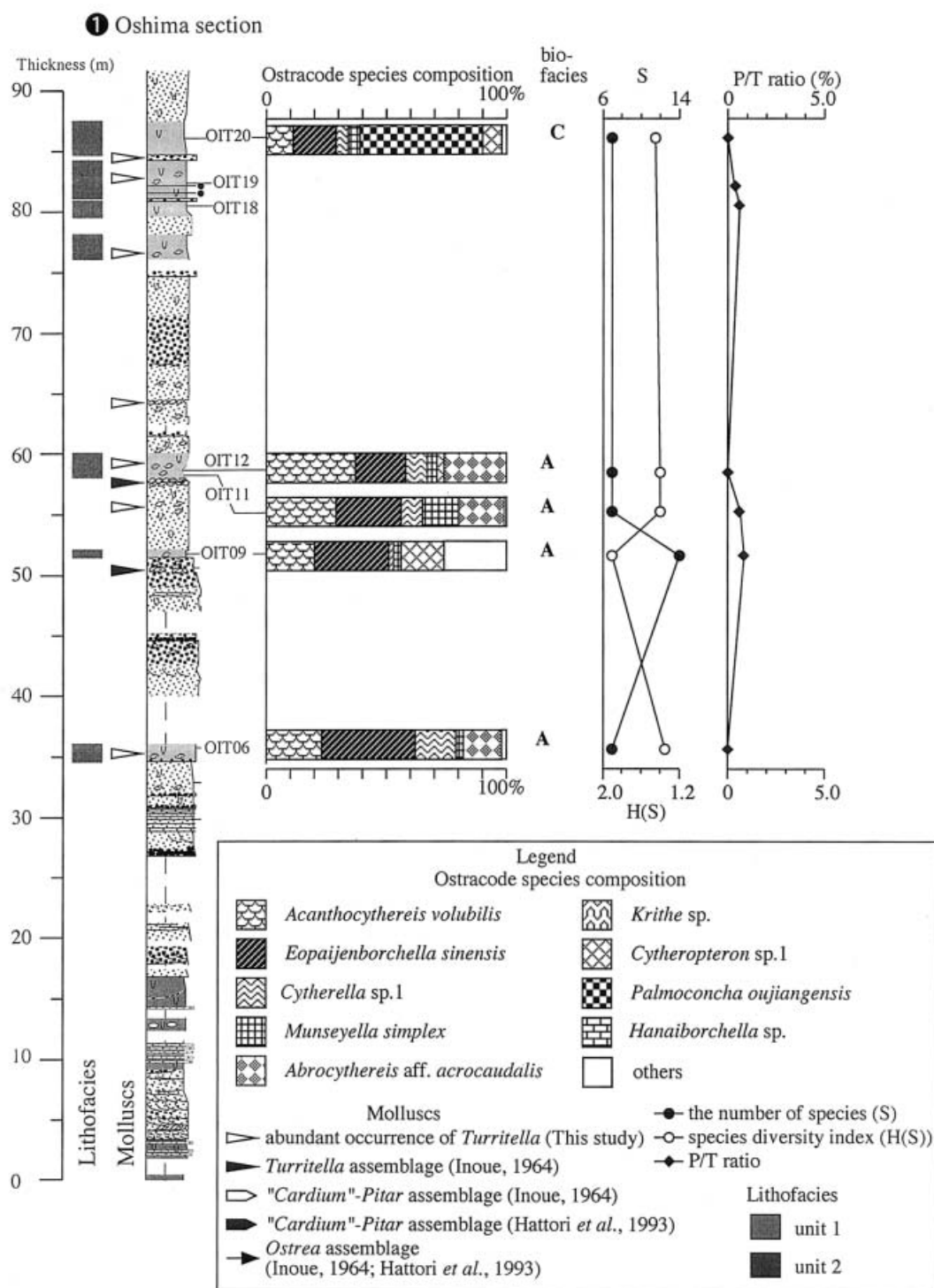


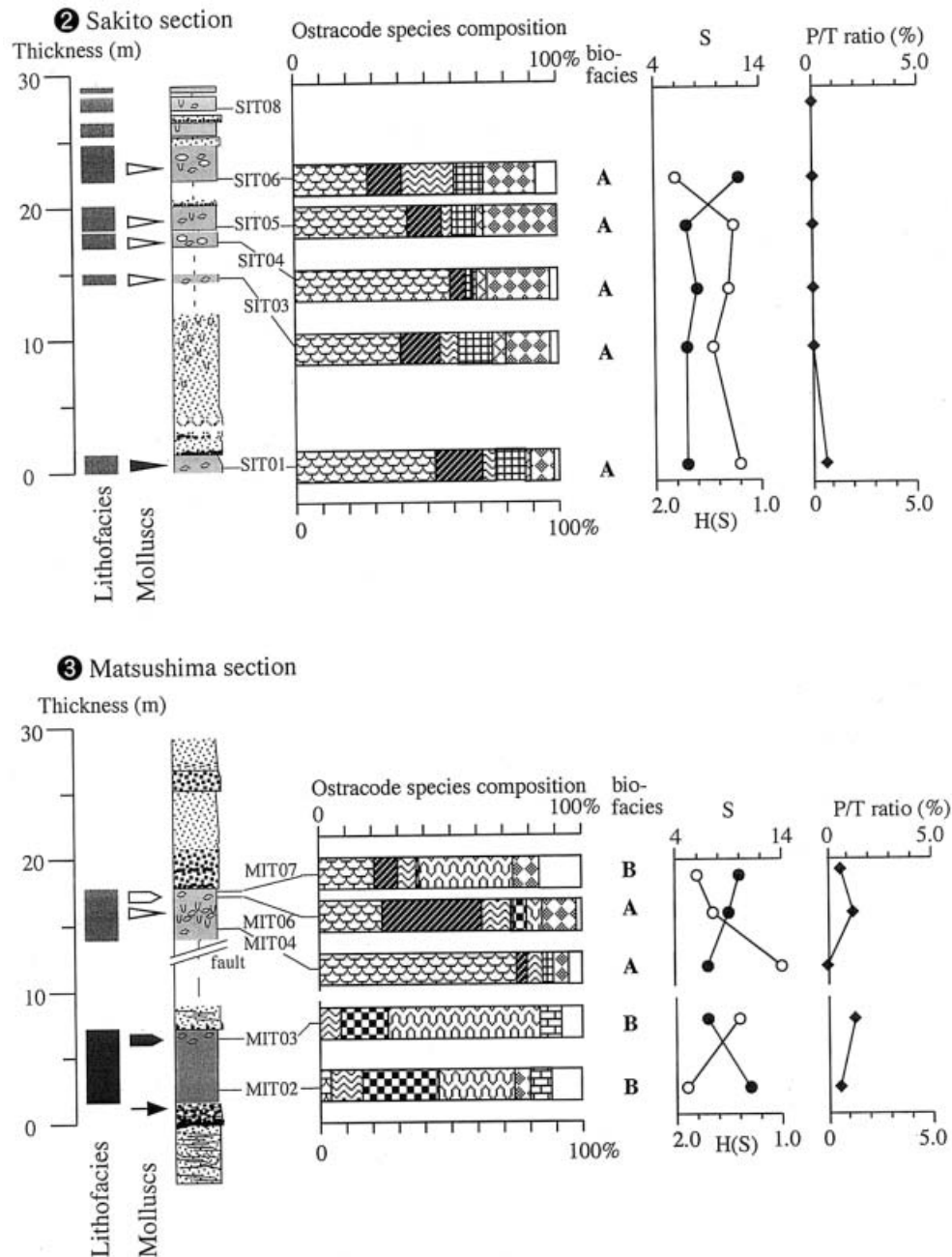
Figure 4. Stratigraphic distribution of ostracodes, lithofacies, P/T ratios and fossil molluscan assemblages in the Oshima section.

1.31 to 2.11, respectively.

**Biofacies B.**—The biofacies occurs from Units 1 and 2. It is characterized by predominance of *Krithe* sp. associated with *A. volubilis* and *Cytherella* sp. 1.

*Hanaiborchella* sp. is also a characteristic species. The number of species and  $H(S)$  are 6 to 10 and 1.39 to 1.93, respectively.

**Biofacies C.**—The biofacies occurs from Unit 1. It is



**Figure 5.** Stratigraphic distribution of ostracodes, lithofacies, P/T ratios and fossil molluscan assemblages in the Sakito and Matsushima sections. Legend is the same as Figure 4.

characterized by *Palmoconcha oujiangensis* (Liu), accounting for about 50%. The dominant species is associated with *A. volubilis* and *E. sinensis*. The number of species and  $H(S)$  are 8 and 1.65, respectively.

Biofacies A and B contain the *Turritella* and the “*Cardium*”-*Pitar* assemblage, respectively (Figures 4 and 5), although Biofacies C does not have concurrent fossil molluscan assemblages.

## Discussion

### 1) The depositional environment of the Itanoura Formation

The lithofacies, P/T ratios of foraminifers and fossil molluscan assemblages suggest that Units 1 and 2 were deposited on a shelf. P/T ratios in Units 1 and 2 indicate the continental shelf at depths shallower than

around 100 m influenced by coastal water on the basis of recent data (e.g., Gibson, 1989). Unit 1 is thought to have been deposited under little influence of wave and tide because there is no sign of wave- or tide-influenced sedimentary structures. The *Turritella* assemblage contains *Turritella karatsuensis* (Inoue, 1964; Hattori *et al.*, 1993). The species was reported from depositional facies representative of the outer shelf below the storm wave base in the lower Oligocene Waita Formation, Ashiya Group (Sakakura, 2002). Hence, Unit 1 is regarded as a shelf deposit formed below the storm wave base. Unit 2 also shows no sign of wave- or tide-influenced sedimentary structures. This unit is finer-grained than Unit 1. The “*Cardium*”-*Pitar* assemblage from this unit indicates environments deeper than the *Turritella* assemblage (Inoue, 1964; Hattori *et al.*, 1993). Stratigraphic changes from the *Turritella* to the “*Cardium*”-*Pitar* assemblage in the Matsushima section represent increasing of paleo-water depth. Therefore, Unit 2 was deposited on the shelf but deeper than Unit 1 was. Consequently, Units 1 and 2 were deposited on the shelf in waters shallower than about 100 m at a depth influenced by coastal water. This is consistent with the views of NEDO (1985, 1986, 1987), which analyzed the benthic foraminifers. Okada (1992) reported calcareous nannofossils, which seldom occur from estuaries, from sandy siltstone of the Itanoura Formation at the core site of NEDO (1985) and outcrops of the Nishisonogi Peninsula (Figure 1). Thus, the fossil data suggest a shelf environment, not an estuarine one as represented by Kurita *et al.* (2003).

## 2) The habitats of fossil ostracodes

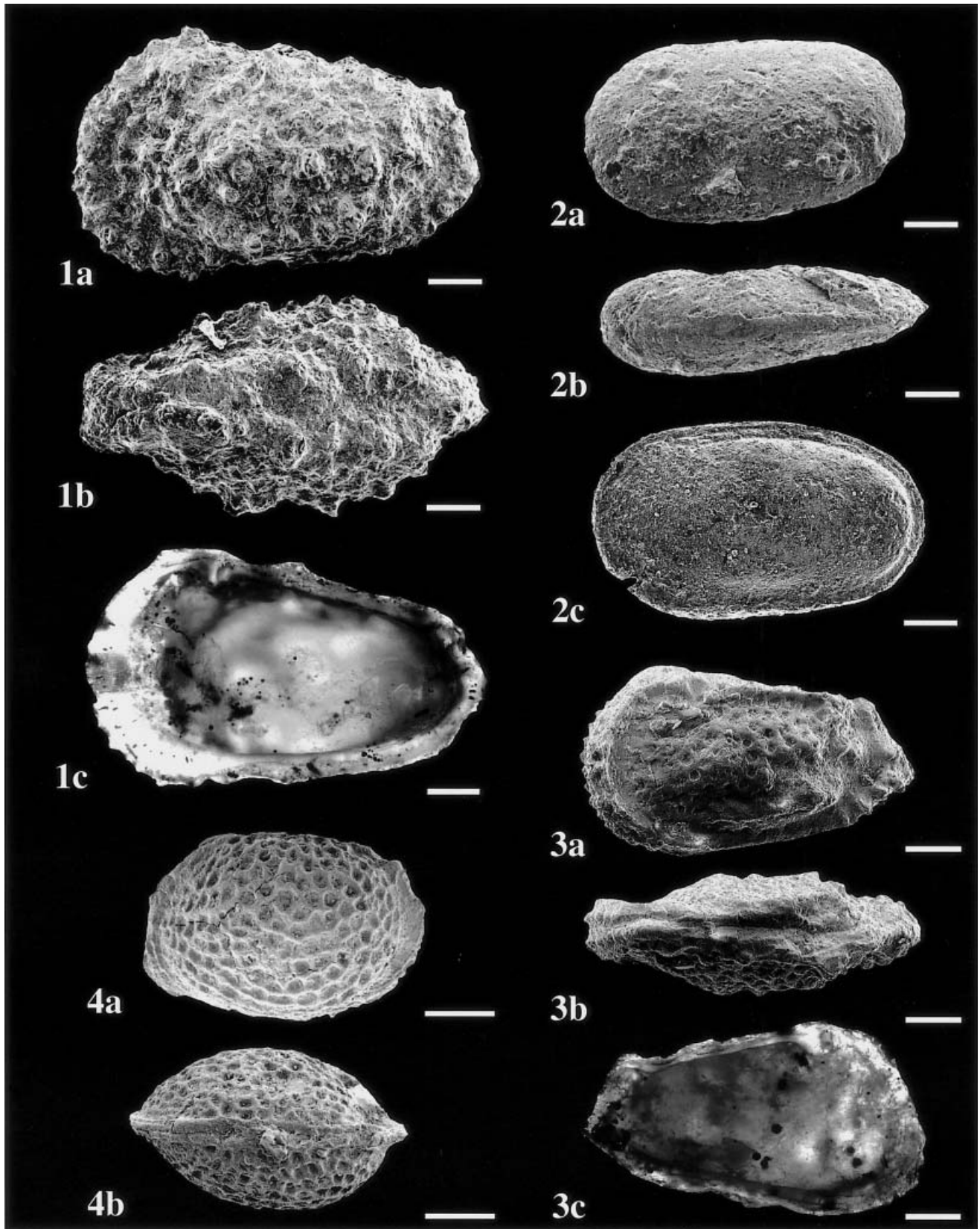
The correlation among ostracode biofacies, lithofacies and fossil molluscan assemblages indicates that Biofacies A was deposited in a shelf shallower than Biofacies B (Figure 9). It is not clear whether the depositional environment of Biofacies C was shallower or deeper than Biofacies A.

*Acanthocythereis volubilis*, *Eopaijenborchella sinensis*, *Munseyella simplex* and *Cytheropteron* sp. 1 are believed to have flourished on the muddy sand bottom in a shallower shelf. Their relative abundances decrease in deeper-water environments. On the other hand, *Kriithe* sp. inhabited a deeper shelf environment, as did *Hanaiborchella* sp. It is not clear whether the relative abundances of *Palmoconcha oujiangensis*, *Cytherella* sp. 1 and *Abrocythereis* aff. *acrocaudalis* were dependent on water depths or not. The genera *Acanthocythereis*, *Abrocythereis*, *Cytheropteron*, *Hanaiborchella* and *Munseyella* are commonly reported from the continental shelf in the Recent East

China Sea and off southwestern Japan (e.g. Ishizaki, 1981; Wang and Zhao, 1985; Zhao and Wang, 1988; Zhou, 1995). The genus *Kriithe* occurs in the deeper shelf to deep sea (e.g. Hanai *et al.*, 1980; Ishizaki, 1981; Wang and Zhao, 1985; Zhao and Wang, 1988; Zhou and Ikeya, 1992). The habitats of these six genera in the Recent are generally consistent with those of their counterparts from the Oligocene Itanoura Formation. Meanwhile, the genus *Eopaijenborchella* occurs from the deep sea in the South China Sea but not in the seas around the Japanese Islands (e.g. Hanai *et al.*, 1980; Zhou, 1995). The genera *Cytherella* and *Palmoconcha* from the Itanoura Formation inhabited shallower environments than their Recent counterparts, because they are reported from the Recent shelf edge and slope at water depths of about 100 to 800 m around the Japanese Islands (e.g. Zhou, 1995). Nakao *et al.* (2001) reported the genus *Cytherella* from the Pleistocene Ukari and Hijikata Formations of the Kakegawa Group in central Japan, which comprise outer shelf and slope facies, respectively (Sakai and Masuda, 1995). Irizuki and Matsu- bara (1994) represented the abundant occurrence of the genus *Palmoconcha* from middle Miocene deposits containing fossil shallow-marine molluscs of the Kadonosawa Formation, Shiratorigawa Group in northeastern Japan. These data suggest that *Cytherella* and *Palmoconcha* may have changed habitats during the Cenozoic around the Japanese Islands. The depositional environment of the upper part of the Wenzhou Formation including *Eopaijenborchella sinensis* and the genus *Cytherella* can be reinterpreted as a shallow sea rather than the deep sea. This interpretation agrees with the view that the Wenzhou Formation was deposited in coastal areas on the basis of calcareous nannofossil assemblages (Zhong, 1990). Thus, it is noteworthy that careful examination is required when we apply Recent geographical distribution of certain ostracode genera to Paleogene environmental analysis.

## 3) Low species diversity of ostracode assemblages

The number of species and  $H(S)$  of fossil ostracode assemblages from the Itanoura Formation are 5 to 13 and 1.31 to 2.11, respectively. These values differ little between the three biofacies (Figures 4 and 5). The number of species and  $H(S)$  of Recent ostracode assemblages are related to the depositional environment. Generally, Recent ostracode assemblages living on the open shelf have higher numbers of species and higher  $H(S)$  than those in brackish enclosed bays (e.g., Ishizaki, 1979; Ikeya and Shiozaki, 1993). For example, Recent ostracode assemblages from a shelf area shallower than 100 m depth in the East China Sea



have from 17 to 44 species and values of  $H(S)$  of 2.28 to 3.37 (Ishizaki, 1981). The enclosed-bay ostracode assemblages reported from Lake Nakanoumi, Shimane Prefecture, western Japan, have from 3 to 19 species and values of  $H(S)$  of 0.34 to 2.56 (Ishizaki, 1969). Fossil ostracode assemblages from the Itanoura Formation have low numbers of species and low  $H(S)$  in spite of having lived on the shelf. On the other hand, early Miocene ostracode assemblages from the Arakida Formation in central Japan, whose paleo-water depth was estimated to be 20 to 100 m by fossil molluscan assemblages, have from 28 to 37 species and values of  $H(S)$  of 2.76 to 3.08 (Yamada *et al.*, 2001). Oligocene ostracodes from the Itanoura Formation have lower numbers of species and lower  $H(S)$  than both Miocene and Recent assemblages. The Eocene ostracode assemblage from the lower part of the Wenzhou Formation consists of 14 species, a low number (Yang *et al.*, 1990). Thus, the number of species and  $H(S)$  of Paleogene shallow-marine ostracode assemblages in the northwestern Pacific are apparently lower than shallow-marine ostracode assemblages of the Neogene and Quaternary. Low species diversity of ostracode assemblages from the Itanoura Formation can be explained in at least two ways: 1) Taphonomic bias such as the dissolution of ostracode carapaces decreased species diversity and 2) ostracode assemblages from the formation represent a low original species diversity. The many poorly preserved specimens from the Itanoura Formation suggest the dissolution of carapaces. Meanwhile, some genera from the Miocene of the Japanese Islands, which have carapaces as thick as the genera from the Itanoura Formation, do not occur in the formation but do occur in Paleogene deposits overseas (e.g. Irizuki and Matsumura, 1994; Irizuki *et al.*, 1998; Yamada *et al.*, 2001). For example, the genera *Callistocythere*, *Hemicythere* and *Loxoconcha* are reported from the Eocene of Tanzania and New Zealand as well as the Miocene of Japan (e.g. Ahmad *et al.*, 1991; Ayress, 1995). Therefore, the Oligocene ostracode assemblages might have originally been less diverse than the Miocene ones. The low species diversity of ostracodes from the formation suggests shallow-marine ostracode diversification

occurred after the early Oligocene in the northwestern Pacific.

### Summary

1) Thirty-three ostracode species occurred from the Oligocene Itanoura Formation, Nishisonogi Group. This report is the first quantitative description of the Japanese Paleogene marine ostracodes. Rock samples containing fossil ostracodes are divided into three biofacies.

2) On the basis of the lithofacies, fossil molluscan assemblages and planktonic/total foraminifers ratios, all ostracode biofacies are thought to represent a shelf environment in waters less than about 100 m deep and influenced by coastal water. The dominant species of Biofacies A flourished in environments shallower than those of Biofacies B.

3) Some genera such as *Cytherella*, *Eopaijenborchella* and *Palmoconcha* from the Itanoura Formation are thought to have inhabited the shallower shelf, thus differing from their Recent counterparts.

4) Fossil ostracode assemblages from the Oligocene Itanoura Formation have lower species diversity than those living in the shelf environment through the Neogene to Recent.

### Taxonomic notes

The illustrated ostracode specimens are presently deposited in University Museum, University of Tokyo (UMUT-CA28605 to UMUT-CA28617). UMUT-CA28608, UMUT-CA28610 and UMUT-CA28613 of the specimens are thin sections of carapaces.

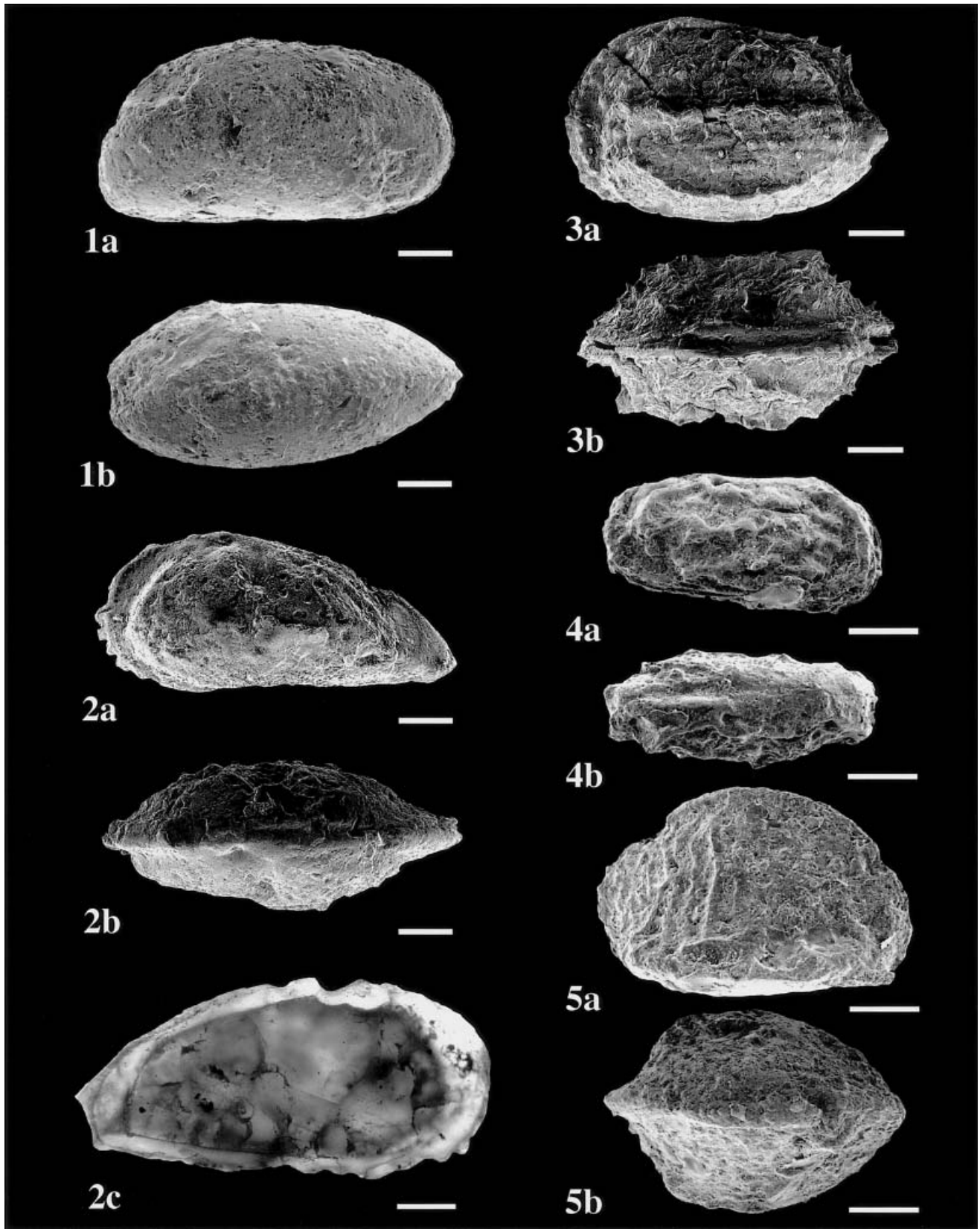
Order Platycopida Sars, 1866  
 Family Cytherellidae Sars, 1866  
 Genus *Cytherella* Jones, 1849  
*Cytherella* sp. 1

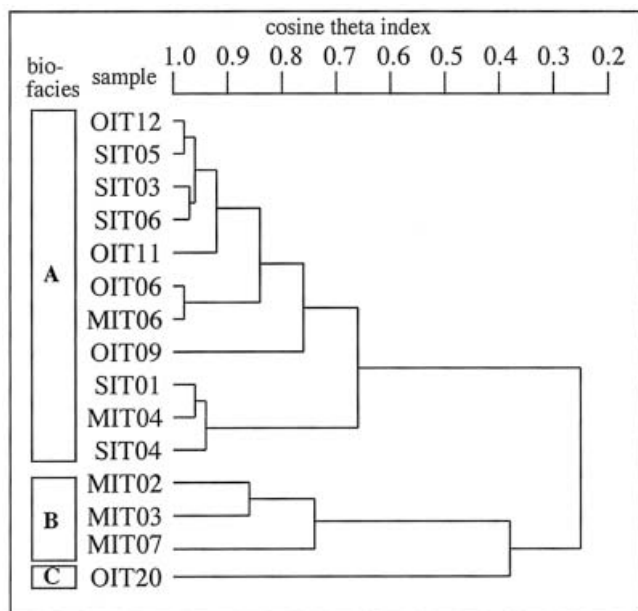
Figure 6.2a–c

*Illustrated specimens.*—Carapace, UMUT-CA28605 (Figure 6.2a, b) from sample MIT07 and right valve,

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◆ **Figure 6.** Photographs of dominant species, all taken by scanning electron microscope (SEM) except for 1c and 3c, for which a transmitted-light microscope was used. All scale bars indicate 100  $\mu\text{m}$ . **1:** *Acanthocythereis volubilis* (Liu, 1989), a: left lateral view of carapace, UMUT-CA28607, SIT03, b: dorsal view of carapace, UMUT-CA28607, SIT03, c: internal view of right valve, UMUT-CA28608, SIT03, **2:** *Cytherella* sp. 1, a: right lateral view of carapace, UMUT-CA28605, MIT07, b: dorsal view of carapace, UMUT-CA28605, MIT07, c: internal view of right valve, UMUT-CA28606, MIT03, **3:** *Abrocythereis* aff. *acrocaudalis* (Liu, 1989), a: right lateral view of carapace, UMUT-CA28609, OIT11, b: dorsal view of carapace, UMUT-CA28609, OIT11, c: internal view of left valve, UMUT-CA28610, SIT06, **4:** *Palmoconcha oujiangensis* (Liu, 1989), a: left lateral view of carapace, UMUT-CA28615, MIT02, b: dorsal view of carapace, UMUT-CA28615, MIT02.





**Figure 8.** Diagram showing the dendrogram of the cluster analysis and biofacies.

UMUT-CA28606 (Figure 6.2c) from sample MIT03.

**Remarks.**—The species resembles *C. lepida* Liu, 1989 and *C. rotunda* Liu, 1989 in its dorsal margin parallel to the ventral margin in lateral view and subtriangular outline in dorsal view. However, poor preservation makes its surface ornament obscure, and the species cannot be identified.

Order Podocopida Sars, 1866

Family Trachyleberididae Sylvester-Bradley, 1948

Genus *Acanthocythereis* Howe, 1963

*Acanthocythereis volubilis* (Liu, 1989)

Figure 6.1a–c

*Trachyleberis volubilis* Liu, 1989, p. 154, pl. 168, figs. 12–16; Yang *et al.*, 1990, p. 377, pl. 2, figs. 1–3.

**Illustrated specimens.**—Carapace, UMUT-CA28607 (Figure 6.1a, b) and thin section of carapace, UMUT-CA28608 (Figure 6.1c) from sample SIT03.

**Remarks.**—Subtriangular outline, surface ornamented with tubercles, tubercles along anterior margin in lateral view and amphidont hinge indicate that this species belongs to the genus *Acanthocythereis*. It resembles *A. munechikai* Ishizaki, 1981 in the tubercles along the anterior and dorsal margins but differs from the latter in its wide anterior cardinal angle, and indistinct tubercles along the posterior ventral margin.

Genus *Abrocythereis* Gou, 1983

*Abrocythereis* aff. *acrocaudalis* (Liu, 1989)

Figure 6.3a–c

Cf. *Trachyleberidea acrocaudalis* Liu, 1989, p. 156, pl. 169, figs. 7–10; *Caudites? acrocaudalis* (Liu, 1989), Yang *et al.*, 1990, p. 373, pl. 2, figs. 12, 15.

**Illustrated specimens.**—Carapace, UMUT-CA28609 (Figure 6.3a, b) from sample OIT11 and thin section of carapace, UMUT-CA28610 (Figure 6.3c) from sample SIT06.

**Remarks.**—Subquadrangular outline with tapering posterior margin, distinct anterior marginal ridge, short lateral ridge parallel to ventral margin, surface ornamented with punctae, three tubercles along dorsal margin in lateral view and amphidont hinge in interior view indicate that this species belongs to the genus *Abrocythereis*. The specimens from the Itanoura Formation differs from *A. acrocaudalis* (Liu, 1989) in lacking a spine at the anterior dorsal corner and not having a sharp tapering caudal process.

Family Krithidae Mandelstam, 1958

Genus *Krithe* Brady, Crosskey and Robertson, 1874

*Krithe* sp.

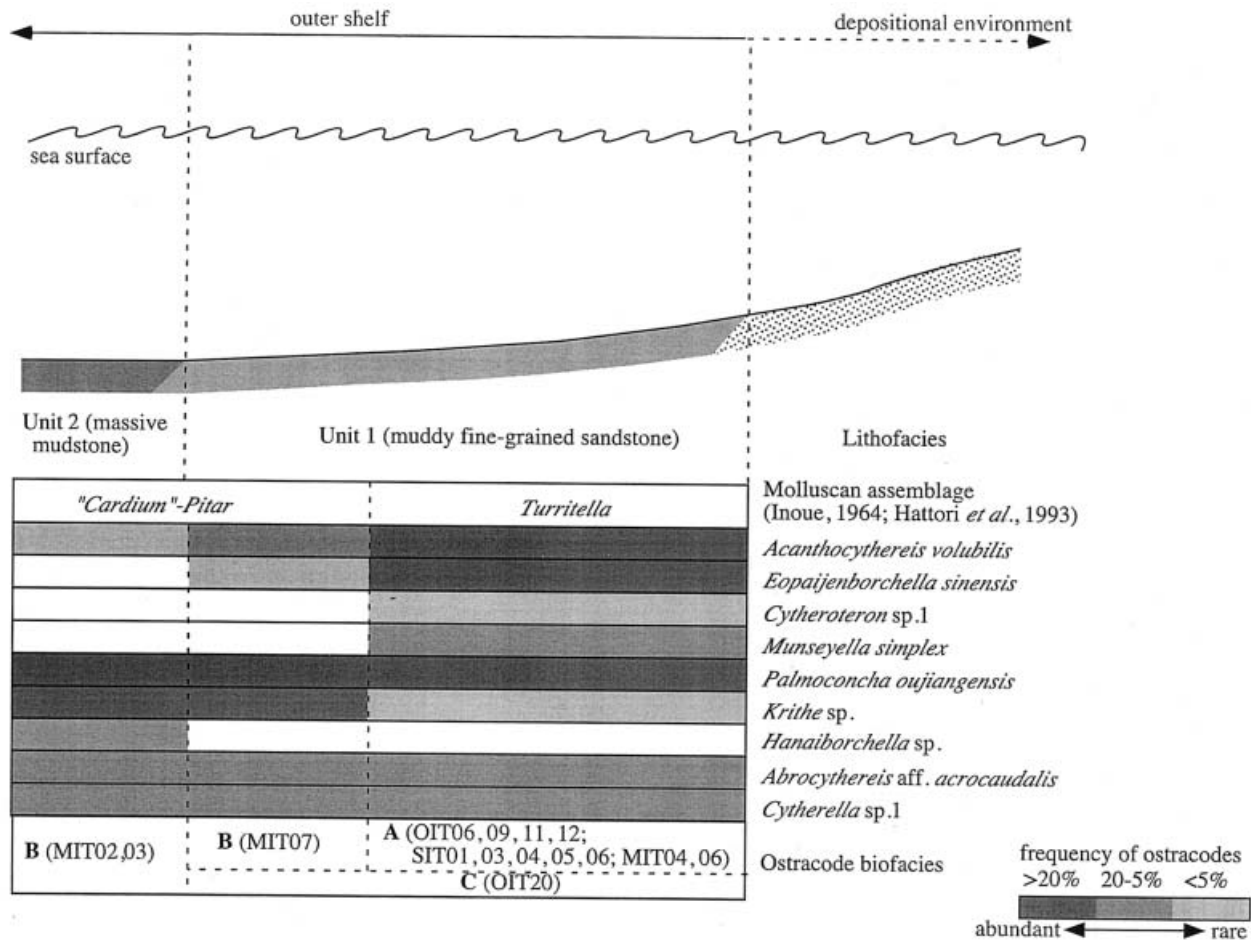
Figure 7.1a–b

**Illustrated specimen.**—Carapace, UMUT-CA28611 (Figure 7.1a, b) from sample MIT07.

**Remarks.**—Subtrapezoidal outline, smooth surface ornaments in lateral view and indented posterior end in dorsal views indicate that this species belongs to the genus *Krithe*.

◀ **Figure 7.** Photographs of dominant species, all taken by scanning electron microscope (SEM) except for 2c, for which a transmitted-light microscope was used. All scale bars indicate 100  $\mu$ m. **1:** *Krithe* sp., a: left lateral view of carapace, UMUT-CA28611, MIT07, b: dorsal view of carapace, UMUT-CA28611, MIT07, **2:** *Eopaijenborchella sinensis* (Liu, 1989), a: right lateral view of carapace, UMUT-CA28612, OIT11, b: dorsal view of carapace, UMUT-CA28612, OIT11, c: internal view of left valve, UMUT-CA28613, MIT07, **3:** *Hanaiborchella* sp., a: right lateral view of carapace, UMUT-CA28614, MIT02, b: dorsal view of carapace, UMUT-CA28614, MIT02, **4:** *Munseyella simplex* Chen, 1990, a: left lateral view of carapace, UMUT-CA28617, OIT12, b: dorsal view of carapace, UMUT-CA28617, OIT12, **5:** *Cytheropteron* sp. 1, a: left lateral view of carapace, UMUT-CA28616, SIT06, b: dorsal view of carapace, UMUT-CA28616, SIT06.





**Figure 9.** Relationship between depositional environments and ostracodes from the Itanoura Formation. The frequencies of ostracode species are the average values in each biofacies.

Family Cytheridae Baird, 1850  
Genus *Eopaijenborchella* Keij, 1966  
*Eopaijenborchella sinensis* (Liu, 1989)

Figure 7.2a–c

*Paijenborchella sinensis* Liu, 1989, p. 151, pl. 167, figs 1, 2.  
*Paijenborchella* (*Eopaijenborchella*) *sinensis* Liu, 1989,  
Yang *et al.*, 1990, p. 374, 375, pl. 3, figs. 1–5.

*Illustrated specimens.*—Carapace, UMUT-CA28612 (Figure 7.2a, b) from sample OIT11 and thin section of carapace, UMUT-CA28613 (Figure 7.2c) from sample MIT07.

*Remarks.*—Ovate outline, dorsomedian sulcus which is cut off by two longitudinal ridges medianly, developed caudal process and surface ornamented with punctae in lateral view indicate that this species belongs to the genus *Eopaijenborchella*.

Genus *Hanaiborchella* Gruendel, 1976  
*Hanaiborchella* sp.

Figure 7.3a–b

*Illustrated specimen.*—Carapace, UMUT-CA28614 (Figure 7.3a, b) from sample MIT02.

*Remarks.*—Subrectangular outline, dorsomedian sulcus which is cut off by two longitudinal ridges medianly area and undeveloped caudal process in lateral view indicate that the species belongs to the genus *Hanaiborchella*. It resembles *H. wendongensis* (Liu, 1989) in its lateral outline and the median longitudinal ridges. Poor preservation makes the surface ornamentation obscure.

Family Loxoconchidae Sars, 1925  
Genus *Palmoconcha* Swain and Gilby, 1974  
*Palmoconcha oujiangensis* (Liu, 1989)

Figure 6.4a–b

*Loxococoncha oujiangensis* Liu, 1989, p. 148, pl. 165, figs. 12–15; Yang *et al.*, 1990, p. 373, 374, pl. 2, figs. 6–8.

*Illustrated specimen.*—Carapace, UMUT-CA28615 (Figure 6.4a, b) from sample MIT02.

*Remarks.*—Subquadrangular outline, flat areas along anterior and posterior margins and surface ornamented with reticulation in lateral view indicate that this species belongs to the genus *Palmoconcha*.

Family Cytheruridae G.W. Mueller, 1894

Genus *Cytheropteron* Sars, 1866

*Cytheropteron* sp. 1

Figure 7.5a–b

*Illustrated specimen.*—Carapace, UMUT-CA28616 (Figure 7.5a, b) from sample SIT06.

*Remarks.*—This species differs from the Miocene species *C. sendaiense* Ishizaki, 1966 (Ishizaki, 1966; Irizuki *et al.*, 1998) in its undeveloped caudal process and feeble vertical ridges in the posterior half of the carapace.

Family Eucytheridae Puri, 1954

Genus *Munseyella* van den Bold, 1957

*Munseyella simplex* Chen, 1990

Figure 7.4a–b

*Munseyella simplex* Chen, 1990, Yang *et al.*, 1990, p. 374, 385, 386, pl. 1, figs. 7, 8.

*Illustrated specimen.*—Carapace, UMUT-CA28617 (Figure 7.4a,b) from sample OIT12.

*Remarks.*—This species resembles *Munseyella* sp. of Yajima (1992) in the ridge pattern of its surface ornamentation and the size of the carapace but differs from the latter in having an indistinct ridge and shallow hollow within the anterior marginal rim.

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