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Oligocene shallow marine foraminifera from the subsurface of southern Hokkaido

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Abstract. Foraminiferal faunas from the Upper Oligocene Minaminaganuma Formation recovered from boreholes of the Yufutsu Oil and Gas Field and MITI Umaoi located in southern Hokkaido are characterized exclusively by the large elphidiids *Elphidium mabutii* and *Cribroelphidium ombetsuense*. They indicate cold water temperatures and an inner to middle sublittoral paleobathymetry. The total organic carbon (TOC) content and hydrogen index (HI) values obtained by CHN Corder and Rock-Eval pyrolysis indicate the significant deposition of organic carbon of phytoplankton origin in the inner sublittoral condition. *Elphidium mabutii* and *C. ombetsuense* show ubiquitous distribution suggesting high tolerance of these two species against environmental stresses such as fluctuations in primary productivity (nutritional condition). This newly recognized shallow marine fauna is located between the Eocene-Oligocene Poronai-Momijiyama fauna (agglutinated foraminifera dominant) and the Miocene Takinoue fauna (*Ammonia* dominant). A comparison between the thickness of strata and the range of paleobathymetric changes in the study area suggests that an equilibrium between basin subsidence and sediment accumulation existed to keep this area under shallow marine conditions during a certain period in the Late Oligocene, which preceded the rifting of the Japan Sea during the Early Miocene.

Key words: Foraminifera, Hokkaido, Oligocene, Paleoenvironment, basin evolution

Introduction

Information on Late Oligocene foraminifera in the northwestern Pacific region is fragmentary due to the lack of a continuous marine sequence across the Oligocene-Miocene transition, and also due to an absence of age-diagnostic planktonic microfossils in the region. These gaps have arisen mainly because the Oligocene was a period of low sea level coinciding with the formation of major unconformities and hiatuses (Pomerol and Premoli-Silva, 1986; Haq *et al.*, 1987).

A similar observation has been made in Hokkaido, Japan, where thick Paleogene and Neogene sequences were formed, and several important stratigraphic and paleontologic studies have been performed (e.g., Asano, 1952a, 1953; Kaiho, 1984a, b). Kurita and Yokoi (2000) recently described the Minaminaganuma Formation in southern central Hokkaido. They determined the age of the formation, previously believed to be Neogene, to be Late Oligocene based on diatom and palynologic (dinoflagellate and pollen) biostratigraphy (Figure 1). The formation intercalates fossiliferous marine strata in the nonmarine strata; therefore, the foraminiferal fauna

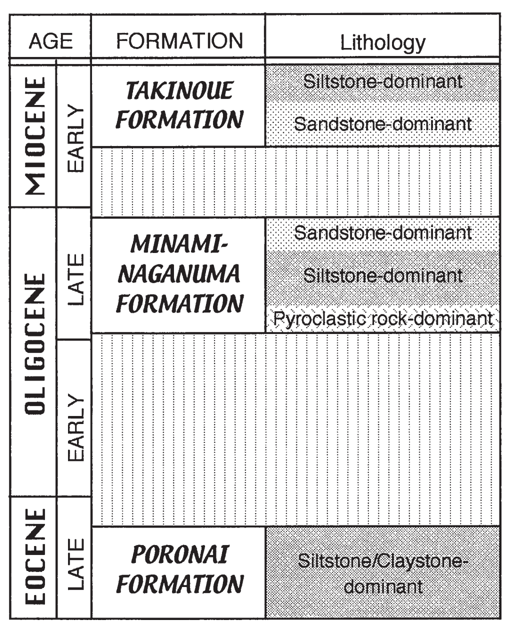


Figure 1. Age distribution of the Minaminaganuma Formation and its adjoining formations in the Yufutsu-Umaoi region after Kurita and Yokoi (2000).

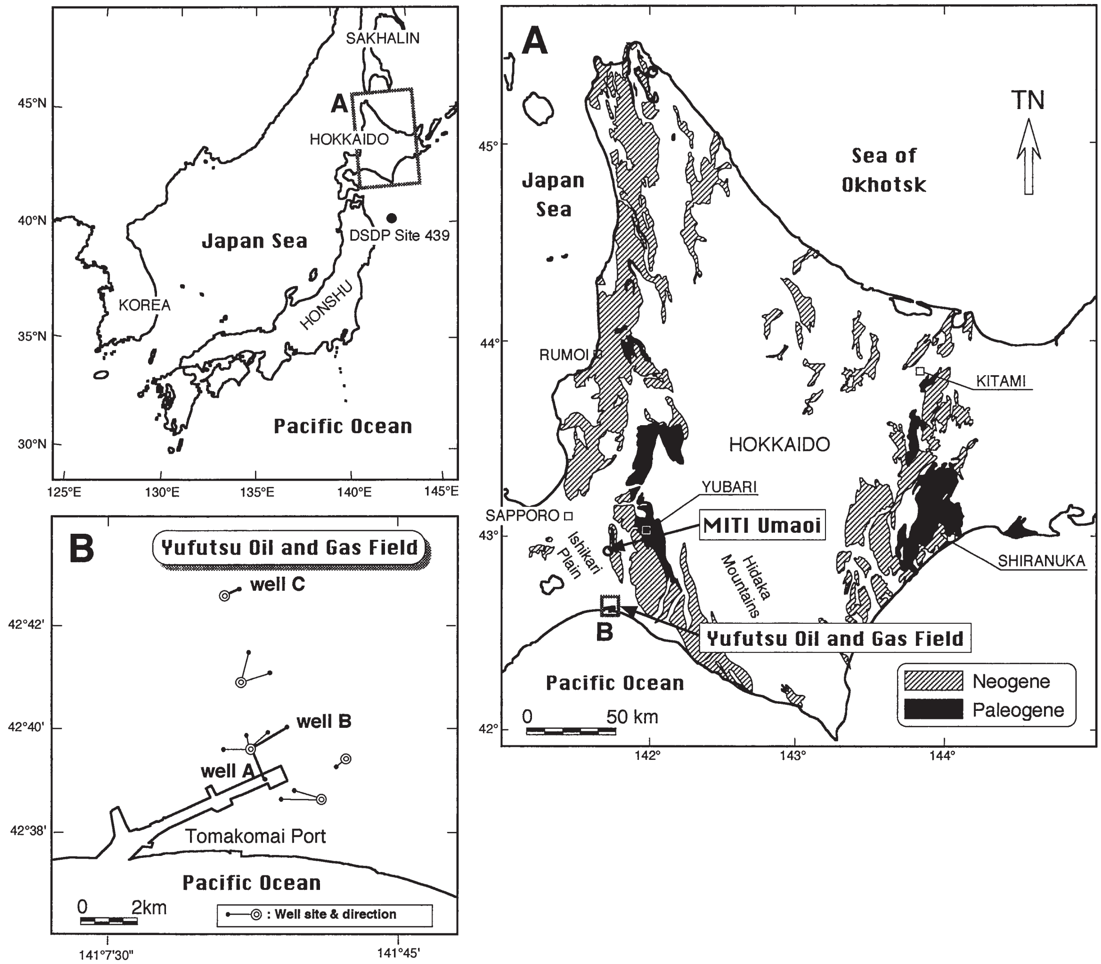


Figure 2. Index map of the study borehole sections. Distribution of the Paleogene and Neogene formations based on the compilation of Kato (1990) with slight modifications.

from the formation is expected to provide fundamental information on paleoceanography, tectonics, and other paleoenvironmental factors in the Oligocene of the northwestern Pacific realm.

The Paleogene and Neogene sedimentary rocks in southwestern Hokkaido are generally distributed in ascending order from east to west on the western side of the central axis of the Hidaka Mountains (Figure 2). The Paleogene and Neogene sequences extend further westward into the subsurface of the Ishikari Plain, as revealed by many boreholes including the present ones. The upper part of the Minaminaganuma Formation is exposed at the surface of Umaoi Hill, a topographic feature that resides along an axial part of an anticline accompanying a fault system (Kurita and Yokoi, 2000), whereas its lower part, which is more fossiliferous, is restricted to the subsurface and inaccessible at any surface section. Therefore, rock samples of the lower part of the Minaminaganuma Formation are presently available only as ditch cuttings and cores from boreholes drilled for petroleum exploration.

This study reports on the foraminiferal fauna obtained from four borehole sections. Three of the sections are in the Yufutsu Oil and Gas Field, east of Tomakomai City, along the Pacific coast of southern Hokkaido, drilled by Japan Petroleum Exploration Co. Ltd. (JAPEX), and the fourth section is the MITI Umaoi borehole drilled by Japan National Oil Corporation approximately 25 km north of the Yufutsu Field. The study sections from the Yufutsu Field are hereafter referred to as the wells A, B, and C.

In addition, geochemical data obtained by Rock-Eval pyrolysis and CHN Corder analyses that were conducted for the MITI Umaoi samples are used for interpretations of the paleoenvironment.

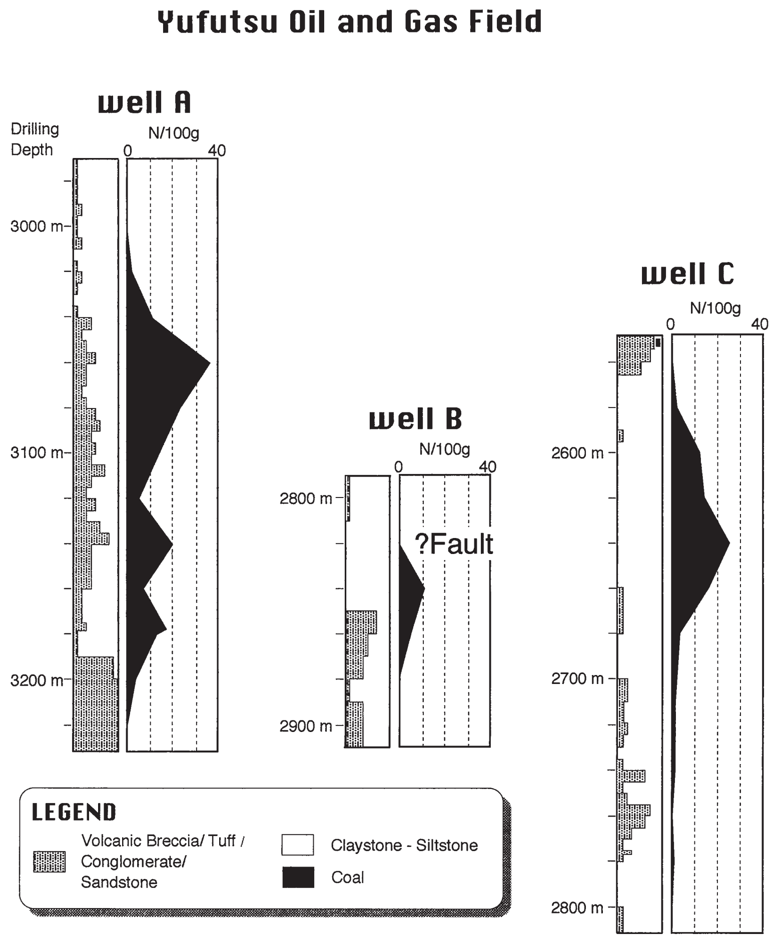


Figure 3. Lithologic columns and the occurrence of foraminifera (N/100 g) in the sections of the Yufutsu Field. Each column is arranged at the base horizon of the marine strata.

Geologic setting and lithostratigraphy of study sections

The formations in the Yufutsu-Umaoi region in ascending order are as follows: (1) the Cretaceous granitoids (basement); (2) conglomeratic and coal-bearing formations of the Ishikari Group; (3) the Eocene Poronai Formation; (4) the Oligocene Minaminaganuma Formation; (5) the Miocene Takinoue Formation (= Unit IV of Hanagata and Hiramatsu, 2005); and (6) other Neogene formations (= Units III–I of Hanagata and Hiramatsu, 2005). The foraminiferal fauna both above and below the Minaminaganuma Formation in the Yufutsu-Umaoi region and their paleoenvironmental implications have previously been reported by the author and a coworker (Hanagata, 2002; Hanagata and Hiramatsu, 2005).

The upper part of the Minaminaganuma Formation at Umaoi Hill is exposed to the surface (the MITI Umaoi well is located in the western fringe of the hill) at the axial part of the anticline that extends toward the north and south. On the other hand, the lower part is restricted to the subsurface and remains inaccessible from surface sections. The extension of the formation is broadly recognized in the subsurface of the southern Ishikari Plain (Kurita and Yokoi, 2000). The upper sequence of the surface section is dominated by terrestrial coarse-grained sediments with alternations of sandstone and carbon-bearing mudstone beds, sandstone, and acidic tuff beds. It is occasionally intercalated with marine siltstone beds, which yield the large (> 1 mm) benthic foraminifer *Elphidium mabutii* Asano (Kurita and Yokoi, 2000). In contrast, the lower sequences composed mainly of bedded or massive siltstone strata have yielded diverse foraminifers as reported below.

The geologic ages obtained from the upper section of the formation are based on diatom and palynologic biostratigraphies present in the surface section of Umaoi Hill (Kurita and Yokoi, 2000). An occurrence of the dia-

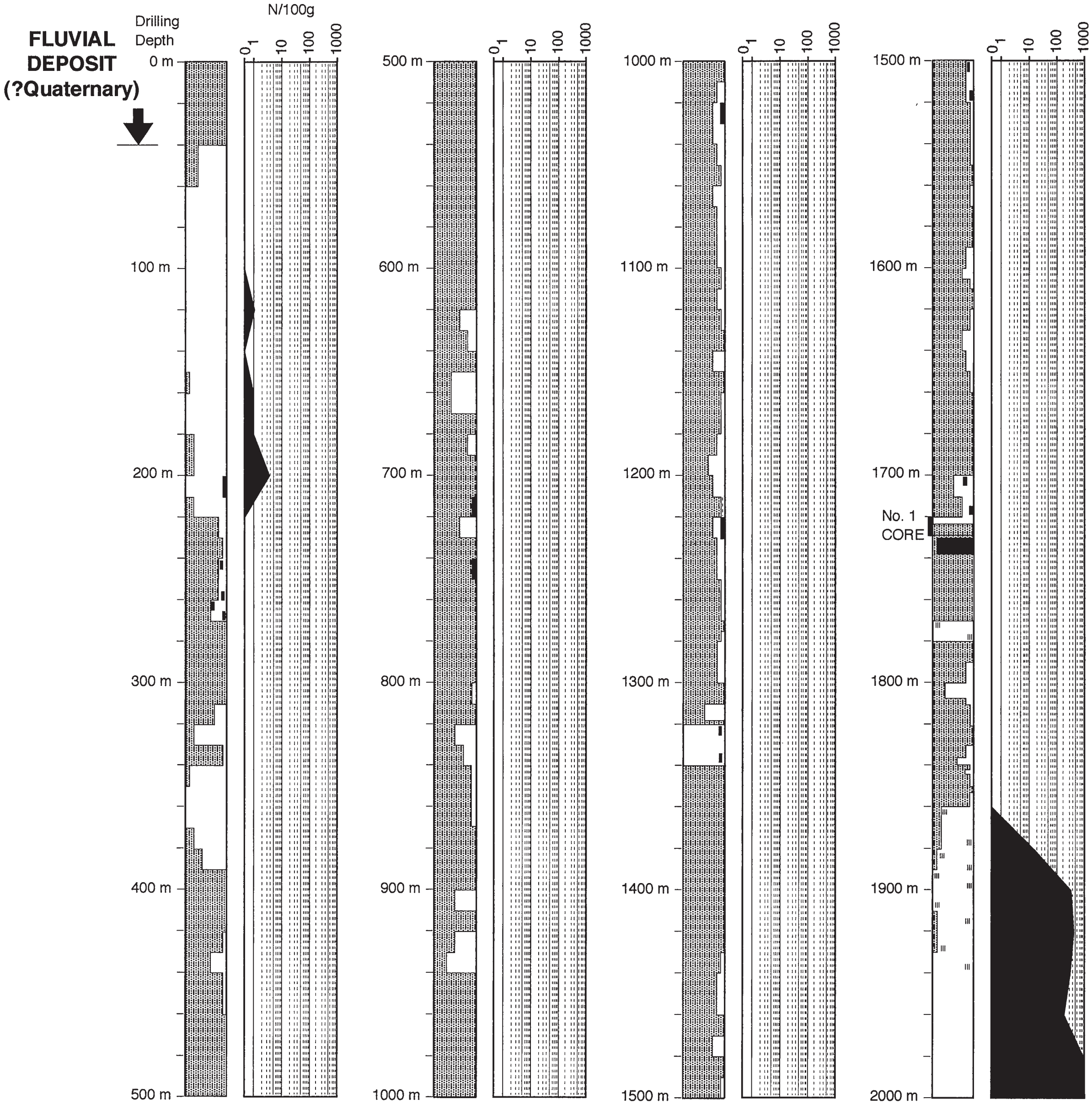
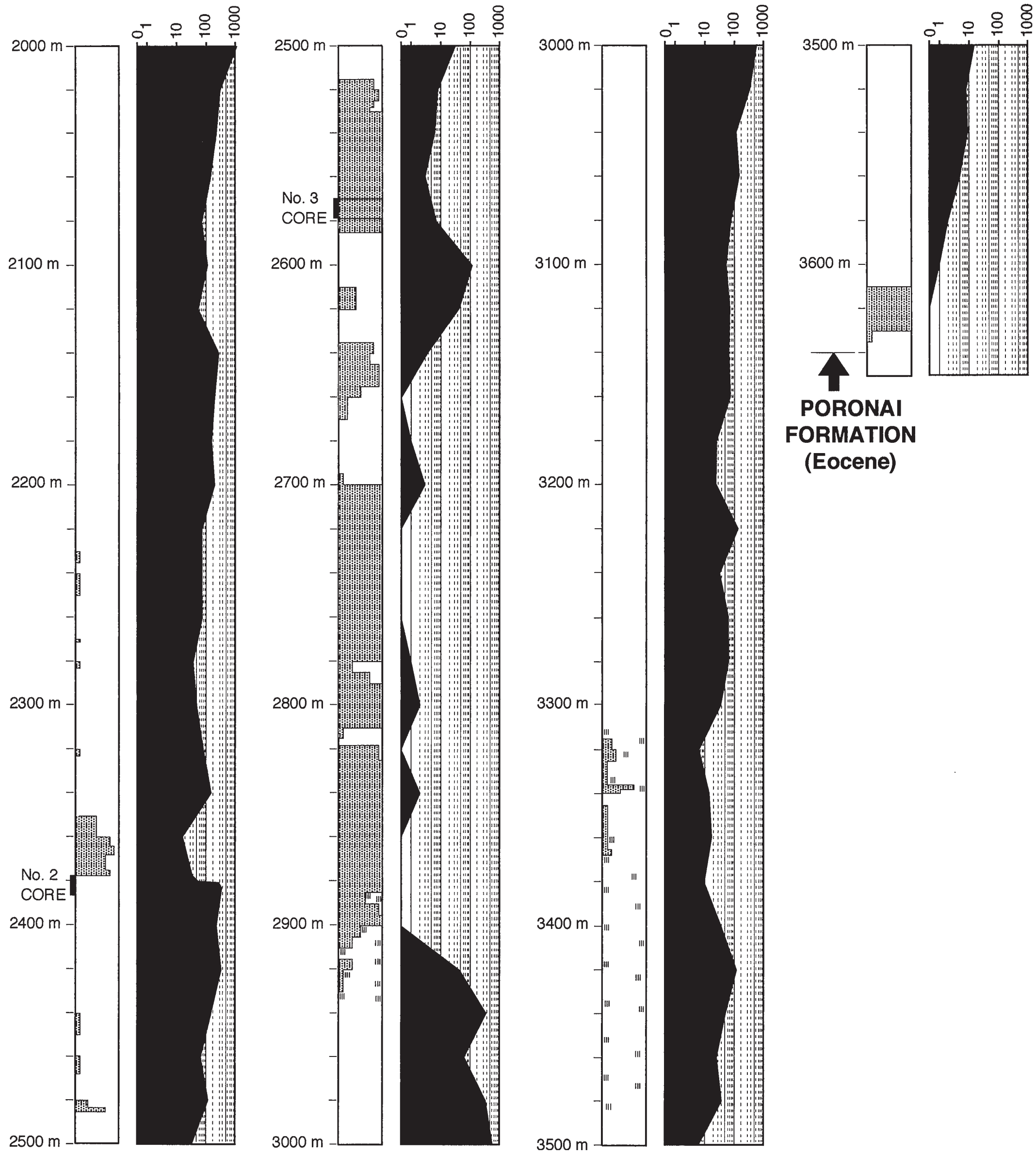


Figure 4. Lithologic column and N/100 g of foraminifera from the MITI Umaoi borehole. N/100 g is shown on a logarithmic scale except for numbers 0–1. For legend of lithology, see Figure 3.

tom *Lisitzinina ornata* Jouse is particularly age diagnostic and restricts the age of the horizon to within the Late Oligocene, ca. 28 to 24 Ma (Gladenkov and Barron, 1995; Morita *et al.*, 1996). No Miocene species have been found from the formation.

The lithology of the subsurface sections has been described by wellsite geologists based on observations of ditch cuttings and cores (Figures 3, 4). The basal part of the formation is characterized by alternations of conglomerate, sandstone, and tuff beds, which cover the underlying Eocene Poronai Formation disconformably. The middle section of the formation is composed of olive-gray to olive-black siltstone and yields abundant foraminifers. It also intercalates light-gray acidic tuff beds, tuffaceous sandstone beds, and tuff breccia. The upper sequence is composed mainly of alternating sandstone and tuff beds; further, it intercalates tuffaceous sandstone, mudstone, and thin coal beds similar to the lithofacies of surface outcrops. In a wider sense, the Minaminaganuma Formation exhibits a single cycle of transgression followed by regression.

The formation thickness is approximately 300 to 700



m in the Yufutsu Field expanding to approximately 1900 m in the Umaoi area. Kurita and Yokoi (2000) indicated that such a difference in formation thickness is attributable to the pull-apart/transtensional tectonics in the Late Oligocene to Early Miocene in southern Hokkaido.

A major fault exists at the top of the Minaminaganuma Formation in well B, which is confirmed by the correlation of physical borehole loggings (see geologic section of Fujii and Moritani, 1998). On the other hand, three low-angle faults have been proposed for the formation of the MITI Umaoi as shown in the geologic section by Kurita and Yokoi (2000). A lack of repetition of the strata indicates that these faults are minor and do not affect the conclusions of this report.

Materials and methods

The three well sections of the Yufutsu Field are drilled with deviations. Therefore, the term "depth" used in this study neither means thickness of the formation nor level but rather the uncorrected drilling length from the surface measured by drill pipes. The MITI Umaoi borehole is drilled vertically, and its depth is close to the level from the ground. All the samples and specimens are stored in the collection of JAPEX Research Center, Mihama-ku Hamada 1-2-1, Chiba City, Chiba 261-0025, Japan.

Foraminiferal analysis

Ditch cuttings and cores were used for the analysis of foraminifers. Ditch cuttings were taken at every 20 m with some extra ones. The cores of the Minaminaganuma Formation were taken from the three horizons of the MITI Umaoi as shown in the columnar section (Figure 4). Although the cuttings may contain cavings from the upper horizons, the borehole conditions while drilling were good; therefore, for the purpose of this study, possible downhole contamination can be considered negligible.

All the samples were oven dried. Subsamples of approximately 100 g were then soaked in a hot supersaturated solution of sodium sulfate for approximately three hours. After removing the excess solution, the soaked samples were maintained in the same condition for more than three days. The samples were then wet sieved through an opening screen of 125 μm. All the specimens in the residues were collected and identified.

This study employed two indices of diversity; species richness (SR) and Simpson's index of diversity (SID). SID is the reciprocal of $\lambda = (\sum(n_i/N))^2$, where n_i = number of species *i*, and N = total number of specimens; the concentration index of Simpson, 1949).

Geochemical analysis

Forty-five samples obtained from the MITI Umaoi borehole were used for Rock-Eval and CHN Corder analyses. The ditch cuttings, cores, and samples taken from borehole walls using a wireline tool (Chronological Sample Taker; ©Schlumberger Ltd.) were utilized for the analysis.

Approximately 10–15 mg of rocks were pulverized for analysis. The samples were analyzed using an automatic pyrolysis analyzer, Rock-Eval 6 (VINCI Technologies, France) and CHN Corder (Yanaco Analytical Instruments Co., Tokyo), both presently installed in JAPEX Research Center. Figure 5 illustrates the principles of the Rock-Eval analysis (after Espitalié *et al.*, 1977). These apparatuses provide various data such as residual total organic carbon (TOC), Tmax, hydrogen index (HI), and oxygen index (OI) based on the volume of gas generated through heating of the materials and their peak temperatures (see examples of Japanese materials: Takeda, 1980; Watanabe and Akiyama, 1998). Tmax is an indicator of organic maturity and the HI-OI diagram is used to classify kerogen types, specifically type I (algal organic matter), type II (marine organic matter), and type III (terrigenous organic matter).

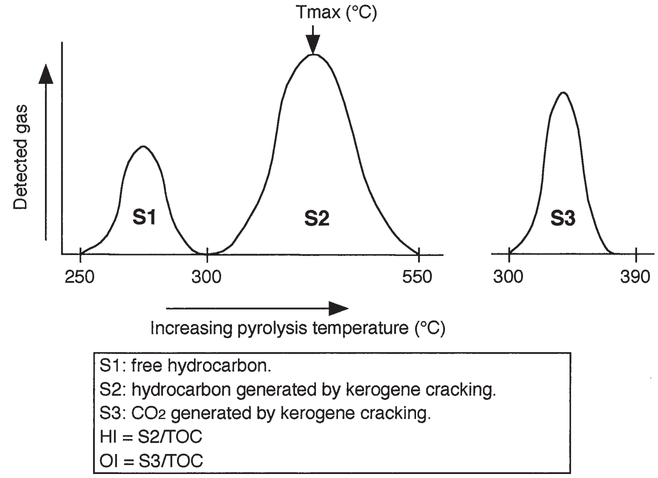


Figure 5. Principle of the Rock-Eval analysis. The apparatus detects pyrolytically generated gas volumes (S1, S2, and S3) with increasing temperature. The hydrogen index (HI = S2/TOC) is a proxy of the hydrogen/carbon ratio (H/C) and the oxygen index (OI = S3/TOC) is a proxy of the oxygen/carbon ratio (O/C). Organic matter of phytoplanktonic origin tends to have a higher H/C than that of terrestrial (higher plants) origin, whereas terrestrial organic matter tends to have a higher O/C. Such a character is applied to the HI-OI diagram (Figure 6) and used to distinguish the kerogen types. Note that Tmax is an empirical index of organic maturation obtained at the peak temperature of S2, and this does not mean that the sample was geothermally heated to the indicated temperature at any time in its history.

Results

In the three well sections of the Yufutsu Field, four foraminiferal species from four genera were identified in 22 samples (Table 1). In the MITI Umaoi section, on the other hand, 13 species of 13 genera were distinguished from 86 samples, and 43 samples were devoid of foraminifera (Table 2). The abundance of foraminifera in 100 g rock samples (N/100 g) is shown with lithologic columns in Figures 3 and 4. Most samples devoid of foraminifera are from the upper interval of the MITI Umaoi section between 20 m and 1860 m.

Benthic assemblages are quite monotonous (average SR = 3.57, SID = 1.98) and are dominated by two species–*Elphidium mabutii* Asano and *Cribroelphidium ombetsuense* (Asano)–in all sections. *Buccella oregonensis* (Cushman, Stewart, and Stewart) is third in abundance after the two elphidiids. Relatively diverse foraminiferal assemblages in the MITI Umaoi, including *Bolivina* sp. 1, *Bulimina* sp. 1, *Globocassidulina* sp. 1, and *Pullenia* aff. *Pullenia apertula* Cushman, are found at 1920 m, 2420 m, and 3000 m with peak N/100 g (N/100 g = 441 at 1920 m; 370 at 2420 m; 614 at 3000 m). Maximum diversities also exist around these horizons (SR = 8 at 1940 m and 1980 m; SID = 3.54 at 1900 m). Planktonic foraminifera were absent in the whole sequence of the formation.

Table 1. List of foraminifera from three well sections in the Yufutsu Oil and Gas Field.

	well A											well B		well C								
Sample depth (m)	3020	3040	3060	3080	3100	3120	3140	3160	3178	3180	3200	2840	2850	2580	2600	2620	2640	2660	2680	2705	2720	2780
Buccella sp.				1										1	1	3	3	3				
Bulimina sp. indet.																1						
Elphidium mabutii	2	8	12	11	6	4	3	7	7	7	4	7	5	1	9	5	18	7	1	1		1
Cribroelphidium ombetsuense			1	4								4			1		2	1			1	
Cribroelphidium sp. 1 (8ch)			9	2														3				
Cribroelphidium sp. indet.		3		5		1			1	6					1	3		2	2			
Calcareous Miscellaneous			14		8		17		9							2	2					
Total Foraminifera	2	11	36	23	14	5	20	7	17	13	4	11	5	2	12	14	25	16	3	1	1	1
Diversity (SR)	1	1	3	4	1	1	1	1	1	1	1	2	1	2	3	3	3	4	1	1	1	1
Diversity (SID)	1.0	1.0	2.1	2.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.9	1.0	2.0	1.5	2.3	1.6	2.9	1.0	1.0	1.0	1.0

The results of the Rock-Eval and CHN Corder analyses are present in Table 3. Tmax indicates temperatures less than 435°C excluding one sample (1720.55 m) that exhibits 436°C. Since a Tmax of approximately 435°C is believed to be an oil-generating level (Tissot *et al.*, 1974), I regard the data obtained in this study to be indicative of depositional geochemical facies without significant dispersion by organic maturation with the exception of the sample at 1720.55 m that did not yield foraminifera. Two samples in the lower horizon (3300 m and 2700 m) have a relatively high TOC, while most of the remaining samples exhibit a TOC of less than 1%. The averages for the TOC, HI, and OI of the marine (fossiliferous) sediments are 0.76%, 90 mg/g, and 52 mg/g, respectively.

Paleoenvironment

Paleobathymetry

The extinct elphidiids *Elphidium mabutii* and *Cribroelphidium ombetsuense* dominate the foraminiferal fauna of the Minaminaganuma Formation. These species are believed to be indicative of shallow marine conditions since, with the exception of the bathyal species *Elphidium batialis* (Saidova, 1961; = *Elphidium abyssicola* Ishiwada, 1962), many modern elphidiids live in shallow marine environments (e.g., *Elphidium bartletti* of Loeblich and Tappan, 1953; *Elphidium clavatum* of Buzas, 1966 and Lagoe, 1979).

The occurrences of *Bolivina*, *Bulimina*, and *Globocassidulina* in the MITI Umaoi section indicate a relatively deeper paleobathymetry than the inner sublittoral zone in comparison with the modern species of the same genera in the northwest Pacific Ocean (after compilation of Akimoto and Hasegawa, 1989). These genera are also reported from the middle sublittoral and deeper depositional conditions of the Eocene of Hokkaido (Hanagata, 2002). Conversely, there is no reason to suspect deeper paleobathymetry than the middle sublittoral zone. Moreover, it should be mentioned that diversity is generally higher in the middle than in the inner sublittoral assemblages that are dominated by *Elphidium mabutii* and *Cribroelphidium ombetsuense*. An absence of planktonic foraminifera also suggests a coastal (neritic) condition (Lipps and Warme, 1966; Lipps, 1979).

Consequently, the paleobathymetry inferred for most of the marine sequences of the Minaminaganuma Formation is the inner sublittoral zone in most of the Yufutsu Field, whereas the maximum water depth extended to the middle sublittoral zone in the Umaoi area.

Paleotemperature

The foraminiferal fauna of the Minaminaganuma Formation is unique, and a comparable Paleogene assemblage could not be detected in the course of study. However, this fauna is presumed to be one of the boreal/cold water faunas of the northwestern Pacific region since similar faunas dominated by large elphidiids are known from the modern Arctic region (Loeblich and Tappan, 1953).

Ammonia, *Pararotalia*, and other rotaliids occur abundantly in the Recent as well as the Early to Middle Miocene coastal areas of northern Japan (Akimoto and Hasegawa, 1989; Hasegawa *et al.*, 1989), which indicates a warm temperate climate. An *Ammonia yubariensis* (Asano)-dominant fauna has also been reported from the Miocene strata overlying the Minaminaganuma Formation in the Yufutsu Field (Unit IV of Hanagata and Hiramatsu, 2005), which are correlative to the surface Takinoue Formation. Asano (1952a) described a similar *A. yubariensis* [= *Rotalia yubariensis*]-dominant fauna from the Takinoue Formation in the Momijiyama district, northeast of the Yufutsu Field. The present study describes this Miocene *Ammonia*-dominant fauna as the Takinoue fauna. The absence of rotaliids or related/ancestral taxa in the present material also indicates colder water conditions at shallow marine depths. The Late Oligocene was an overall cold and low sea level period (Haq *et al.*, 1987); therefore, this faunal change in southern Hokkaido is considered to mirror the global climate shift between the Oligocene and the Miocene.

Table 2. List of foraminifera from the well MITI Umaoi.

continue

Sample depth (m)	120	160	180	200	1880	1900	1920	1940	1960	1980	2000	2020	2040	2060	2080	2100	2120	2140	2160	2180	2200	2220	2240	2260	2280	2300	2320	2340	2360	2377.90-2378.00	2380	2380.50-2380.65	2383.90-2384.00	2400	2420	2440	2460	2480	2500	2520	2540	2560	2580
Haplophragmoides sp. 1				1																																							
Haplophragmoides sp. indet.																						1																					
Agglutinated indeterminables							1	1																																1			
Pyrgo sp.																																			1								
Quinqueloculina cf. *Q. seminula*									1																													1					
Quinqueloculina sp. indet.													1																														
Bolivina sp. 1										1																								1	1								
Buccella oregonensis						42	46	28	43	61	313	29	19	19	5	3	5	4	8		8	1	1	3	3	1		2			3	5	3	3	5	3							
Bulimina sp.1							8	1	2	2											2	1		1																			
Globocassidulina sp. 1											2	1						12	3	1	1	1	1					1															
Cribroelphidium ombetsuense					3	135	163	175	100	728	766	223	149	85	35	31	26	103	75	119	139	35	21	25	16	16	49	135	1	2	26	192	79	91	248	104	25	43	14			1	
Cribroelphidium ombetsuense var.1					3	86	41	16	8	38	31	31	29	24	13	12	10	9	11				1					4		1	5	25	1	3	4	7							
Cribroelphidium sp. indet.			1	1			15																																				
Elphidium mabutii					5	92	155	84	44	115	211	27	49	42	17	63	17	166	116	69	59	32	47	44	21	33	35	39	12	35	20	60	273	48	100	69	35	74	21	6	6	2	7
Globobulimina sp.																			1																								
Nonionella miocenica								2		1																																	
Protoglobobulimina pupoides								1																																			
Pullenia aff. *P. apertula*						1	12	4	3	2			1								1							1	1					1	11	1	2	1		1			
Calcareous indeterminables	1	1		2	3							1	1		1					3						1																	
Total Foraminifera	1	1	1	4	14	356	441	312	201	948	1323	312	249	170	71	109	58	294	214	192	210	71	71	73	40	51	84	182	14	38	54	282	356	147	370	184	62	119	35	8	6	3	7
Diversity (SR)	0	0	0	1	3	5	6	8	7	8	5	5	5	4	4	4	4	5	6	3	6	5	5	4	3	3	2	6	3	3	4	4	4	6	7	5	3	4	2	2	1	2	1
Diversity (SID)	-	-	-	1.0	2.8	3.5	3.3	2.5	2.9	1.6	2.4	1.9	2.4	2.9	2.9	2.3	3.1	2.3	2.4	1.9	1.9	2.2	1.9	2.1	2.3	1.9	1.9	1.7	1.3	1.2	2.6	1.9	1.6	2.0	1.9	2.2	2.1	1.9	1.9	1.3	1.0	1.8	1.0

Sample depth (m)	2600	2620	2640	2680	2700	2780	2800	2840	2920	2940	2960	2980	3000	3020	3040	3060	3080	3100	3120	3140	3160	3180	3200	3220	3240	3260	3280	3300	3320	3340	3360	3380	3400	3420	3440	3460	3480	3500	3520	3540	3560	3580	3600
?*Silicosigmoilina* sp.											1																																
Agglutinated indeterminable															1																												
Quinqueloculina cf. *Q. seminula*													1																														
Buccella oregonensis	1								1	5	2	36	58	93	19	19	4	4	2	1	1	1			2	2								1			1			1			
Bulimina sp.1												1	1																														
Globocassidulina sp. 1																									1	1																	
Cassidulina sp. indet.																										1																	
Cribroelphidium ombetsuense	69	24	2				2	1	15	202	37	163	390	162	58	83	36	16	31	28	30	13	9	16	14	10	25	9		7	2	5	7	49	25	13	4	5	2		2		
Cribroelphidium ombetsuense var.1	1	4							5	50	1	13	17	2	4	11	3	1	5	2	4				3	1	2			1					2								
Elphidium mabutii	36	16	2	1	3	1		1	25	36	18	135	147	108	31	43	29	26	35	35	42	14	5	120	19	47	38	28	6	7	17	4	33	70	24	15	23	11	3	8	3	2	1
Nonionella cf. *N. miocenica*											1																																
Pullenia aff. *P. apertula*												3		2		6	1																										
Calcareous indeterminables										3						3	1	4										2									2		3				
Total Foraminifera	107	44	4	1	3	1	2	2	46	296	60	351	614	367	113	165	74	51	73	66	77	28	14	136	39	62	65	39	6	15	19	9	40	120	51	28	30	16	8	9	5	2	1
Diversity (SR)	4	3	2	1	1	1	1	2	4	4	5	6	6	5	4	5	5	4	4	4	4	3	2	2	5	5	3	2	1	3	2	2	2	3	3	2	3	2	2	2	2	1	1
Diversity (SID)	1.9	2.3	2.0	1.0	1.0	1.0	1.0	2.0	2.4	1.9	2.0	2.7	2.1	2.9	2.7	2.8	2.5	2.3	2.4	2.2	2.2	2.1	1.8	1.3	2.7	1.6	2.0	1.6	1.0	2.3	1.2	2.0	1.4	2.0	2.2	2.0	1.4	1.8	1.9	1.2	1.9	1.0	1.0

Samples barren of foraminifers: 20m, 40m, 60m, 80m, 100m, 140m, 220m, 240m, 260m, 280m, 300m, 320m, 360m, 380m, 640m, 660m, 720m, 1200m, 1240m, 1320m, 1400m, 1420m, 1440m, 1460m, 1600m, 1620m, 1640m, 1720.20-1720.25m (Core), 1720.55-1720.65m (Core), 1721.00-1721.05m (Core), 1721.95-1722.00m (Core), 1722.95-1723.00m (Core), 1780m, 1800m, 1860m, 2660m, 2720m, 2740m, 2760m, 2820m, 2860m, 2880m, 2900m.

Table 3. Result of the Rock-Eval and CHN Corder analyses. CT = Ditch cuttings, CST = Chronological Sample Taker (wireline tool).

	Depth (m)	Sample Spec.	Tmax (℃)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	TOC (%)	IH (mg/g)	IO (mg/g)
1	100	CT	427	0.03	0.33	0.58	0.73	45	79
2	200	CT	426	0.02	0.18	0.48	0.53	34	91
3	665.0	CST	416	0.03	0.19	0.65	0.50	38	130
4	760.0	CST	360	0.03	0.08	0.24	0.18	44	133
5	905.0	CST	431	0.06	1.25	1.21	1.60	78	76
6	910.0	CST	425	0.01	0.09	0.41	0.37	24	111
7	937.2	CST	426	0.03	0.41	0.66	0.83	49	80
8	1025.5	CST	404	0.04	0.16	0.32	0.29	55	110
9	1033.0	CST	424	2.00	53.33	10.06	28.34	188	35
10	1100	CT	430	0.06	0.53	0.59	0.89	60	66
11	1130.0	CST	430	0.07	0.24	0.44	0.37	65	119
12	1182.4	CST	421	0.29	0.18	0.52	0.37	49	141
13	1200	CT	426	0.02	0.16	0.31	0.43	37	72
14	1256.2	CST	426	0.04	0.29	0.43	0.51	57	84
15	1262.5	CST	425	0.05	0.43	1.13	0.84	51	135
16	1300	CT	431	0.02	0.38	0.44	0.66	58	67
17	1328.0	CST	426	0.50	2.04	0.93	1.27	161	73
18	1500	CT	427	0.10	2.45	0.67	1.68	146	40
19	1600	CT	428	0.03	0.38	0.49	0.67	57	73
20	1643.0	CST	388	0.12	0.17	0.25	0.32	53	78
21	1720.55	CORE	436	0.16	9.84	0.30	3.43	287	9
22	1721.95	CORE	429	0.07	0.28	0.28	0.64	44	44
23	1722.95	CORE	436	0.03	0.61	0.21	1.13	54	19
24	1800	CT	415	0.18	0.11	0.15	0.28	39	54
25	1867.5	CST		0.01	0.00	0.04	0.56	0	7
26	1900	CT	426	0.39	0.50	0.34	0.57	88	60
27	1962.0	CST	424	0.02	0.27	0.41	0.56	48	73
28	2000	CT	425	0.21	0.70	0.41	0.78	90	53
29	2100	CT	423	0.32	0.88	0.36	0.78	113	46
30	2200	CT	430	0.06	0.60	0.34	0.65	92	52
31	2300	CT	422	0.17	0.67	0.39	0.68	99	57
32	2331.5	CST	413	0.13	0.59	0.34	0.63	94	54
33	2378.40	CORE	427	0.04	0.47	0.17	0.55	85	31
34	2382.85	CORE	430	0.04	0.34	0.13	0.52	65	25
35	2400	CT	426	0.09	0.44	0.27	0.56	79	48
36	2500	CT	423	0.22	0.54	0.35	0.57	95	61
37	2600	CT	425	0.21	0.88	0.38	0.86	102	44
38	2700	CT	433	0.15	1.25	0.42	1.02	123	41
39	3000	CT	424	0.23	0.43	0.35	0.58	74	60
40	3037.5	CST	427	0.46	1.39	0.32	0.97	143	33
41	3100	CT	424	0.12	0.65	0.37	0.81	80	46
42	3200	CT	423	0.17	0.53	0.32	0.65	82	49
43	3300	CT	419	0.77	3.54	0.46	1.42	249	32
44	3500	CT	423	0.62	1.42	0.36	0.95	149	38
45	3600	CT	431	0.12	1.69	0.19	0.95	178	20

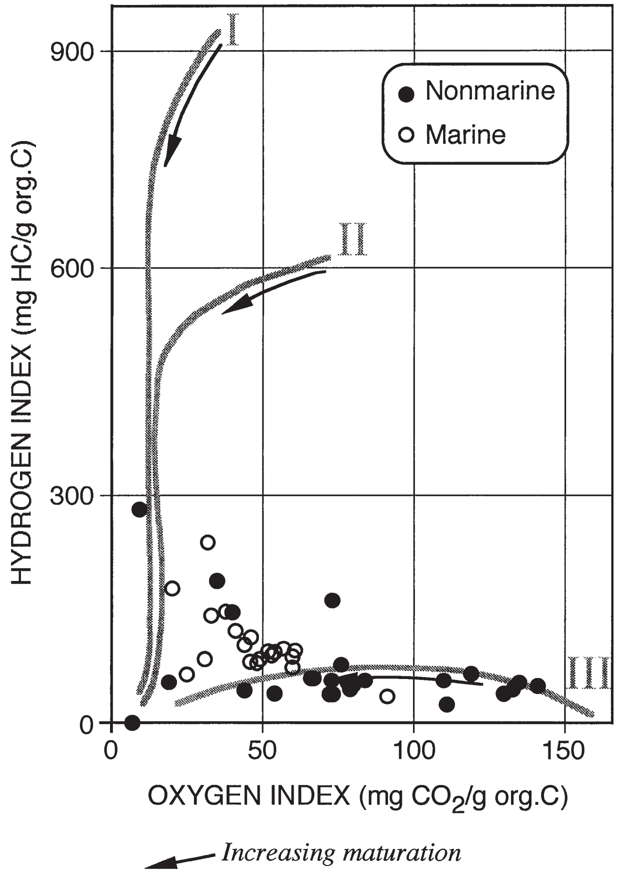


Figure 6. Hydrogen index–oxygen index diagram. See explanation provided in Figure 5. Marine and nonmarine samples are distinguished based on the occurrence of foraminifera.

Primary productivity/nutritional environment and dissolved oxygen

This section discusses the further paleoenvironmental implications of the foraminiferal assemblages based on the correlations between foraminiferal proxies and geochemical data obtained by Rock-Eval and CHN Corder analyses. The values of TOC, HI, and OI are basic indicators of organic facies closely related to primary productivity and the oxygenation of the sea bed (Espitalié *et al.*, 1977).

As a premise to the consideration, marine and nonmarine samples are distinguished based on the occurrences of foraminifers. The HI-OI diagram (Figure 6) indicates that most terrestrial samples are plotted on the trend curve of type III kerogen that indicates organic matter of terrestrial origin, while many marine rocks exhibit higher HI values and are plotted near the trend curves of type I–II kerogen. In addition, the TOC and HI exhibit high correlation (Figure 7). This data suggests a significant accumulation of organic matter that originated predominantly from marine phytoplankton and/or the oxygen-depleted conditions that are conducive to the preservation of organic matter.

The foraminiferal numbers per gram of rock (N/g) are expected to indicate the standing stocks of foraminiferal assemblages and to be positively correlated with the TOC in many cases of modern deep-sea foraminifera (e.g., Altenbach *et al.*, 1999). The N/g, however, increases to a TOC of approximately 0.7%, but it then decreases with increasing TOC (Figure 8A). The N/g also exhibits a peak at 75 mg/g HI (Figure 8B). The relationships between organic facies (TOC and HI) and diversities (SR and SID) also exhibit peaks at 0.7% TOC and 80 mg/g HI (Figure 8C–F). These peaks of TOC and HI are indistinct but are considered to indicate favorable conditions, i.e., environmental optima for many benthic species. Assemblages of the middle sublittoral zone (samples of 2000 m, 2200 m, 2400 m, and 3000 m),

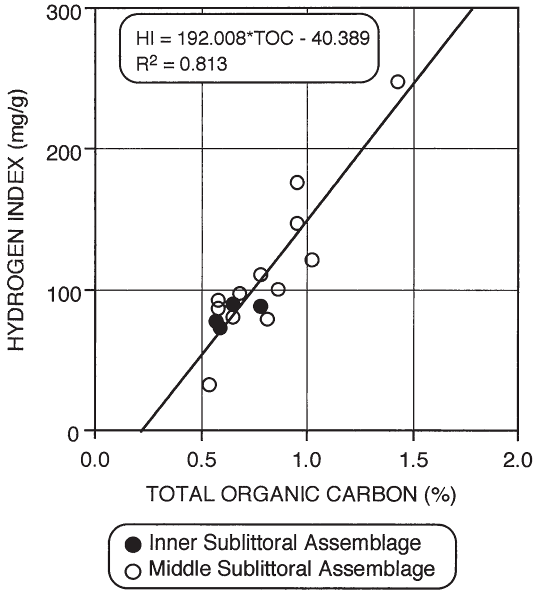


Figure 7. Correlation between hydrogen index and total organic carbon.

which indicate high diversity, appear in the middle of the peak. This suggests that the environmental stress due to fluctuation of primary productivity (unstable nutrient supply for foraminifers) and/or oxygen depletion is greater in shallower marine environments than in deeper marine environments. Moreover, the ubiquitous occurrence of *Elphidium mabutii* and *Cribroelphidium ombetsuense* in most of the inner sublittoral samples suggests a high tolerance of these two species to environmental stresses.

Considering oxygen depletion in the sea bed to be a main cause of high TOC (> 0.7%) and HI (> 80 mg/g), an essential requirement is the stratification of the water mass in a shallow sea, which prevents vertical circulation and induces oxygen depletion near the sea bed (see summary of Tyson and Pearson, 1991). However, it is difficult to infer such stratified conditions that are caused solely by fresh water input (density stratification) from foraminiferal assemblages; the foraminiferal assemblages of the Minaminaganuma Formation do not contain agglutinated taxa that might suggest a decrease in carbonate saturation similar to modern brackish conditions (see summary of Sen Gupta, 1999). Seasonal temperature change, on the other hand, could be a cause of the stratification (thermal stratification) and resultant oxygen depletion. However, the success of large-sized elphidiids, which implies a high rate of dissolved oxygen consumption and slower cycles of generation change (Phleger and Soutar, 1973), tends to suggest stable oxic conditions. Consequently, fluctuation of primary production (unstable nutritional conditions) is considered to have been the primary factor facilitating the high TOC/HI that determined foraminiferal distribution. Oxygen depletion, if it occurred, is likely to have been a minor contributory factor.

Compared with deep-sea foraminifera (summarized by Loubere and Fariduddin, 1999), the contribution of primary productivity toward the distribution of benthic foraminifers in shallow coastal seas has been comparatively little studied. The results presented here might provide an example of how the deposition of organic matter acted as a primary factor in controlling the distribution of shallow marine benthic foraminifera during the Late Oligocene. However, it must be borne in mind that the distribution of shallow marine benthic foraminifera is not only controlled by nutritional conditions and oxygen levels but also by various additional factors including substrate conditions and predator-prey interactions (e.g., Kaminski and Wetzel, 2004). Moreover, geochemical data inevitably include somewhat (biologically or chemically) degraded residual organic carbon; hence there is no guarantee that they mirror the original depositional conditions.

Comparison with the other Oligocene faunas in the adjacent regions

In order to position the foraminiferal fauna of the Minaminaganuma Formation in the context of paleoceanographic and faunal evolution in Hokkaido and adjacent areas, this section compares it with faunas in adjacent regions. In order to avoid taxonomic confusion, Hanagata's (2002) taxonomic view is applied in the following discussion.

Momijiyama Formation in southern Hokkaido

Several workers have described the Oligocene foraminiferal faunas of Hokkaido (e.g., Maiya *et al.*, 1982; Takayanagi *et al.*, 1982; Kaiho, 1984a, b; Kaiho and Hasegawa, 1984). Kaiho (1984a) described the fauna of the Momijiyama Formation from southern central Hokkaido. Kurita and Miwa (1998) indicated the geologic age of the upper section of the formation to be Early Oligocene based on palynologic data. In addition, the Momijiyama Formation is presumed to have a conformable contact with the underlying Eocene Poronai Formation, an extension of which exists in the subsurface of the Yufutsu Oil and Gas Field. Consequently, the foraminiferal fauna of the Momijiyama Formation is positioned historically between that of the Poronai Formation and that of the Minaminaganuma Formation (Figure 9).

The foraminiferal fauna of the Momijiyama For-

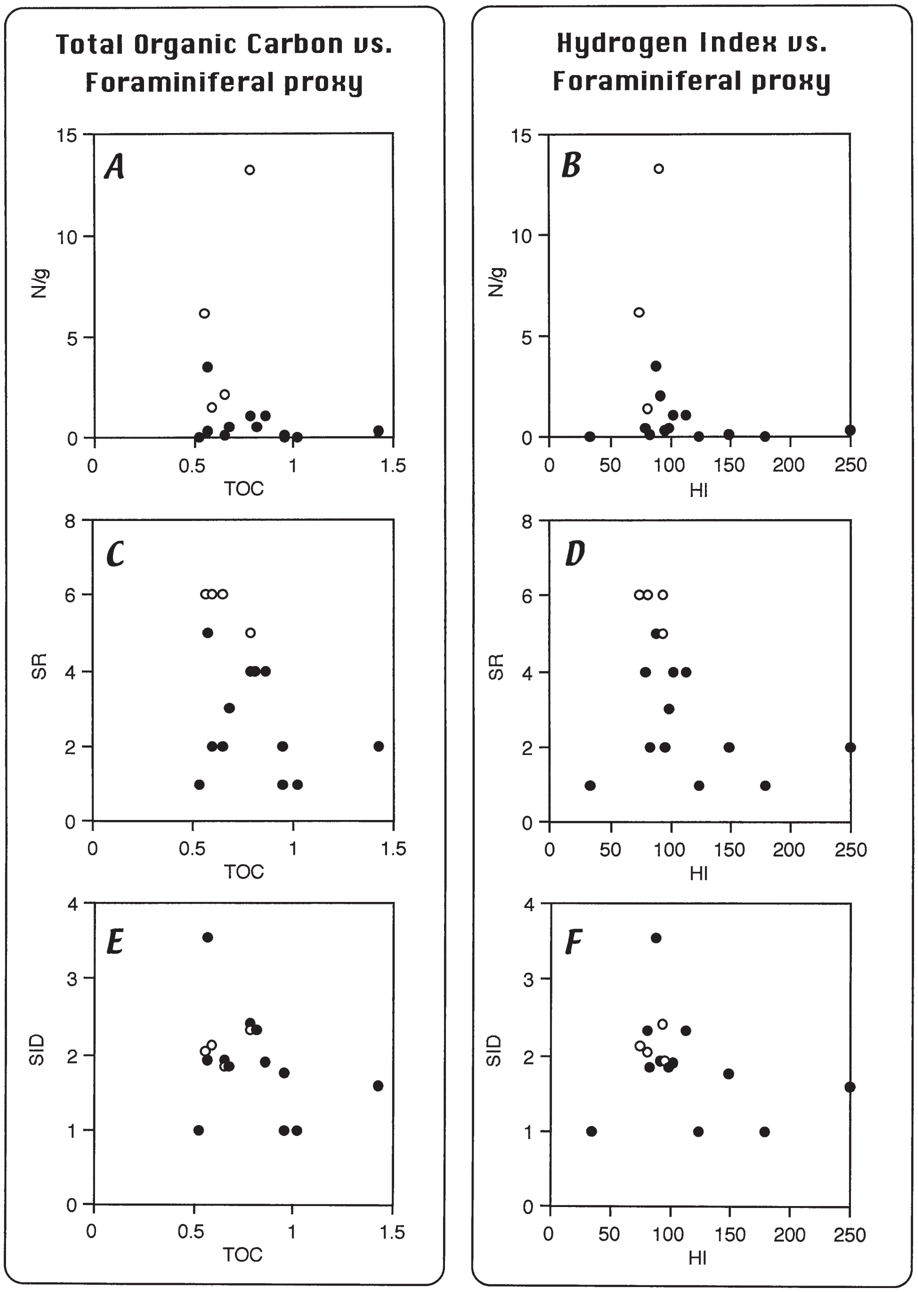


Figure 8. Relationship between organic facies and foraminiferal proxies. TOC: Total organic carbon content (%). HI: Hydrogen index (mg-HC/g-Org.C). N/g: Number of specimens in one gram of rock. SR: Species richness. SID: Diversity index of Simpson (1949; 1/λ). See Figure 7 for legend of open and solid circles.

mation contains abundant agglutinated foraminifera, including *Evolutinella subamakusaensis* (Fukuta) and *Cyclammina pacifica* Beck, exhibiting high similarity to those of the underlying Poronai Formation. This agglutinated foraminifera-dominant fauna, referred to henceforth as the Poronai-Momijiyama fauna, indicate shallow marine/brackish conditions (Hanagata, 2003). This older fauna is evidently different from those of the Minaminaganuma Formation described in this study; consequently, the paleoceanographic conditions in the region are assumed to have changed between the times of deposition of the Momijiyama and Minaminaganuma formations.

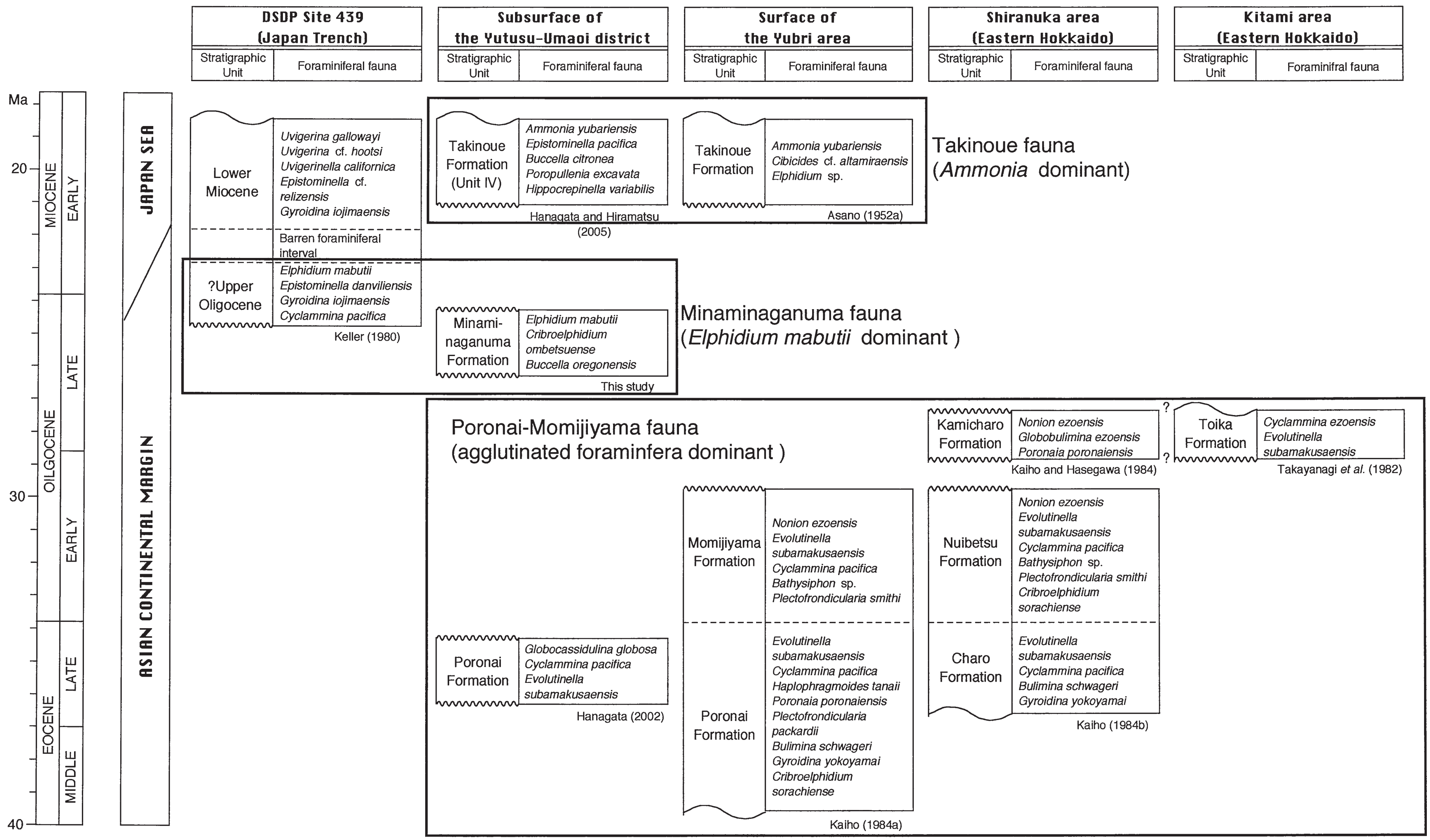


Figure 9. Correlation between the major Oligocene-Miocene formations and their foraminiferal fauna representing shallow marine conditions in southern Hokkaido and DSDP Site 439. Abundant and representative species are listed in the column "foraminiferal fauna."

Eastern Hokkaido

The Oligocene foraminiferal fauna in eastern Hokkaido was extensively described from the Charo, Nuibetsu and Kamicharo formations in the Shiranuka area, and the Tatsukobu, Tsubetsu, and Toika formations in the Kitami area.

Kaiho (1983) described the planktonic foraminifera *Globorotalia opima opima* Bolli [= *Paragloborotalia opima opima*] from the upper horizon of the Kamicharo Formation in the Shiranuka area. The last occurrence of *G. opima opima* is estimated to have been the early Late Oligocene (27.1 Ma; Berggren *et al.*, 1995).

Benthic foraminiferal faunas of the Charo, Nuibetsu, and Kamicharo formations are diverse and are assigned to the Poronai-Momijiyama fauna based on abundant agglutinated foraminifera including *E. subamakusaensis*, *Haplophragmoides yokoyamai* Kaiho, and *Poronaia poronaiensis* (Asano), and also characteristic calcareous species such as *Bulimina schwageri* Yokoyama, *Plectofrondicularia smithi* Kaiho, *Gyroidina yokoyamai* Ujiié, and *Nonion ezoensis* (Kaiho) (Maiya *et al.*, 1981; Kaiho and Hasegawa, 1984; Kaiho, 1984b).

Takayanagi *et al.* (1982) reported foraminiferal faunas from the Toika Formation of the Kitami area. They estimated the geologic age of the formation as middle P. 22 to upper N. 7 following Blow's (1969) zonation, Late Oligocene to Early Miocene based on the cooccurrence of the planktonic species *Catapsydrax* spp. and *Globoquadrina* cf. *venezuelana* (Hedberg) [cf. *Globigerina venezuelana*]. However, the stratigraphic overlap of *G. venezuelana* and *Catapsydrax* was revised by later workers (Toumarkine and Luterbacher, 1985; Bolli and Saunders, 1985), indicating an interval from P. 13 to N. 7 in Blow's (1969) zonation, Middle Eocene to Early Miocene. Therefore, the estimated range of the geologic age of the Toika Formation has an older lower limit and overlaps with that of the Poronai and Momijiyama formations in southern Hokkaido.

Benthic foraminiferal faunas of the Tatsukobu, Tsubetsu, and Toika formations resemble each other and are composed of abundant agglutinated foraminifera similar to the Poronai-Momijiyama fauna such as *C. pacifica*, *E. subamakusaensis*, *H. yokoyamai*, and *P. poronaiensis* (Takayanagi *et al.*, 1982).

Consequently, the Oligocene foraminiferal faunas of eastern Hokkaido exhibit high similarity with those of the Poronai and Momijiyama Formations in southern Hokkaido but are different from that of the Minaminaganuma Formation. Although information on the geologic age is insufficient to draw a conclusion and requires further study, and the coexistence of two different types of fauna is undeniable, the difference in fauna suggests historical paleoceanographic changes such as an increase in the carbonate saturation between the ages of the Kamicharo and Minaminaganuma formations.

DSDP Japan Trench

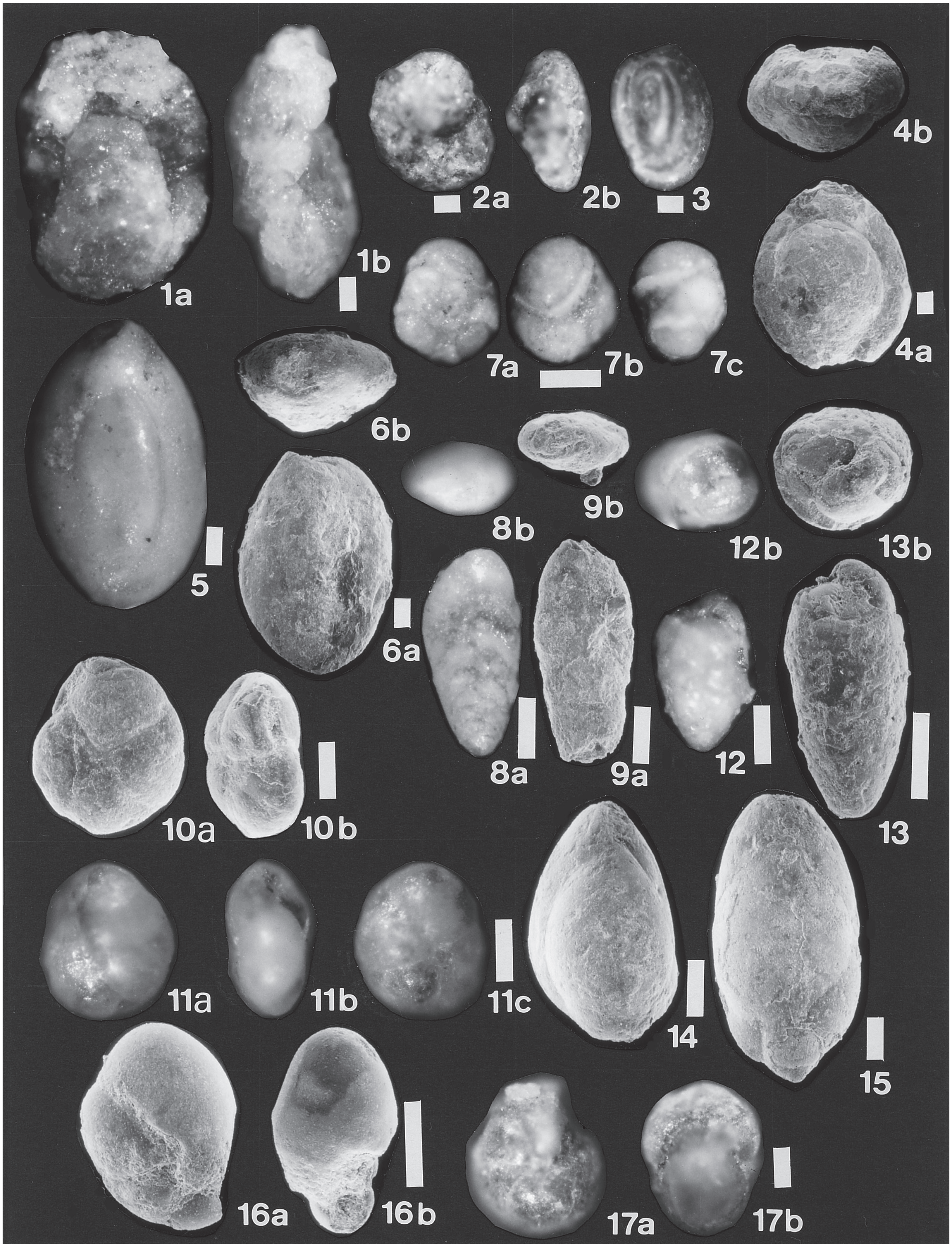
Keller (1980) described an "Upper Oligocene" foraminiferal fauna that bears *Elphidium mabutii* and other calcareous benthic species including *Bolivina substriatula* Asano, *Cassidulina laevigata* d'Orbigny, and *Epistominella danvillensis* Howe and Wallace from Deep Sea Drilling Project (DSDP) Leg 57, Site 439. This site is located 1656 meters below sea level on the inner trench slope of the Japan Trench, approximately 140 km offshore from northern Honshu (Figure 2). This *E. mabutii*-bearing stratum overlies the Cretaceous at this site. The $^{40}Ar/^{39}Ar$ ages were obtained from a boulder of volcanic rock obtained from the conglomerate bed underlying the *E. mabutii*-bearing strata. The $^{40}Ar/^{39}Ar$ ages were indicated as 23.4 ± 5.5 Ma (Moore and Fujioka, 1980) and 21.2 ± 0.7 Ma (Yanagisawa *et al.*, 1980), respectively. The report of Yanagisawa *et al.* (1980), in particular, applied the stepheating dating method for three rock samples, and each sample indicates close geologic ages suggesting that the alteration after deposition is negligible. The data from both sources indicate a younger age than the Oligocene-Miocene boundary (23.8 Ma; Steininger, 1994, after Berggren *et al.*, 1995). The diatom biostratigraphy of this site was reexamined by Akiba (1985). Diatoms were not obtained from the horizon that yielded *E. mabutii*, although they were reported in the overlying horizons of the Early Miocene *Thalassiosira fraga* Zone (20.3–18.4 Ma; Yanagisawa and Akiba, 1998).

Based on the above-mentioned geologic ages, I conclude that the age of the *E. mabutii*-bearing strata of DSDP Site 439 is not Late Oligocene but rather Early Miocene, which is approximately 21 Ma, and therefore younger than the Minaminaganuma Formation. In other words, as far as geologic ages presently available for these horizons indicate, the *E. mabutii*-dominant fauna appears to have originated in the Late Oligocene and thrived until the Early Miocene in the shallow marine environment of the northwest Pacific region.

Tectonic implications

Significant differences exist in the thickness of the Minaminaganuma Formation between the Yufutsu Field and the Umaoi area. This implies that subsidence was faster in the Umaoi area than in the Yufutsu Field. This is consistent with the paleobathymetric interpretation that greater depths existed in a northward direction.

The foraminiferal fauna of the Minaminaganuma Formation indicates inner sublittoral or middle sublittoral paleobathymetry. The water depth of these paleobathy-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metric zones in the modern Pacific coast off northern Japan is approximately 70 m shallower (Akimoto and Hasegawa, 1989). In contrast, the thickness of the marine deposit exceeds 500 m at the location of the MITI Umaoi borehole even after consideration of stratigraphic repetitions by faults (refer to the geologic section of Kurita and Yokoi, 2000). These facts indicate that the sedimentary basin had subsided, maintaining shallow marine conditions during a certain period of the Late Oligocene. This means that the subsidence and sediment supply was balanced in this particular basin. Moreover, the marine sediments of the formation are dominated by siltstone, which was supposedly supplied under low-energy conditions and distal to the hinterland. A similar subsidence-sediment supply balanced condition is reported from the underlying Eocene Poronai Formation distributed in the Yufutsu-Umaoi area and adjacent region of southern Hokkaido (Hanagata, 2003). The Poronai Formation also has siltstone/claystone facies. This suggests that similar tectonics had controlled southern Hokkaido from the Eocene through Oligocene periods.

Kurita and Yokoi (2000) and Kuniyasu and Yamada (2004) explained the tectonics of the Minaminaganuma Formation in terms of a pull-apart basin model. The results of the present study provide an additional factor for the consideration of the basin history; i.e., the intermittent basin-subsidence is in equilibrium with the sediment accumulation.

Western Hokkaido is assumed to have been a part of the Asian continental margin in the Oligocene until the beginning of the rift leading to the formation of the Japan Sea in the Early Miocene that strongly affected the tectonics of Hokkaido (Kimura and Tamaki, 1986; Iijima and Tada, 1990; Takahashi, 1994; Hoshi and Takahashi, 1999; Hanagata and Hiramatsu, 2005). Therefore, a significant shift in the tectonic setting is thought to have occurred during or just after the deposition of the Minaminaganuma Formation.

Summary

1) The foraminiferal fauna of the Minaminaganuma Formation is dominated by the large elphidiids *Elphidium mabutii* and *Cribroelphidium ombetsuense*. Foraminiferal assemblages indicate cold and shallow marine conditions that are not deeper than the middle sublittoral zone.

2) A comparison of the foraminiferal fauna with geochemical data demonstrates that primary productivity in the shallow seas controlled the distribution of benthic foraminifera. *Elphidium mabutii* and *C. ombetsuense* exhibit particularly high tolerance to environmental stress such as fluctuations in the nutrition supply.

3) The foraminiferal fauna of the Minaminaganuma Formation from southern Hokkaido is placed stratigraphically between the Eocene-Oligocene Poronai-Momijiyama fauna (agglutinated foraminifera-dominant) and the Miocene Takinoue fauna (*Ammonia*-dominant).

4) An equilibrium between subsidence and sediment accumulation is inferred to have been existed at least since the Eocene until the Late Oligocene in southern Hokkaido. Such tectonics imply that the historical change of the tectonic setting related to the origin of the Japan Sea occurred during or after the deposition of the marine sequence of the Minaminaganuma Formation.

The foraminiferal faunas and tectonics of Hokkaido in the Late Oligocene remain poorly understood in many aspects mainly due to a paucity of stratigraphic information; therefore, the results of the present study provide some basis for future studies.

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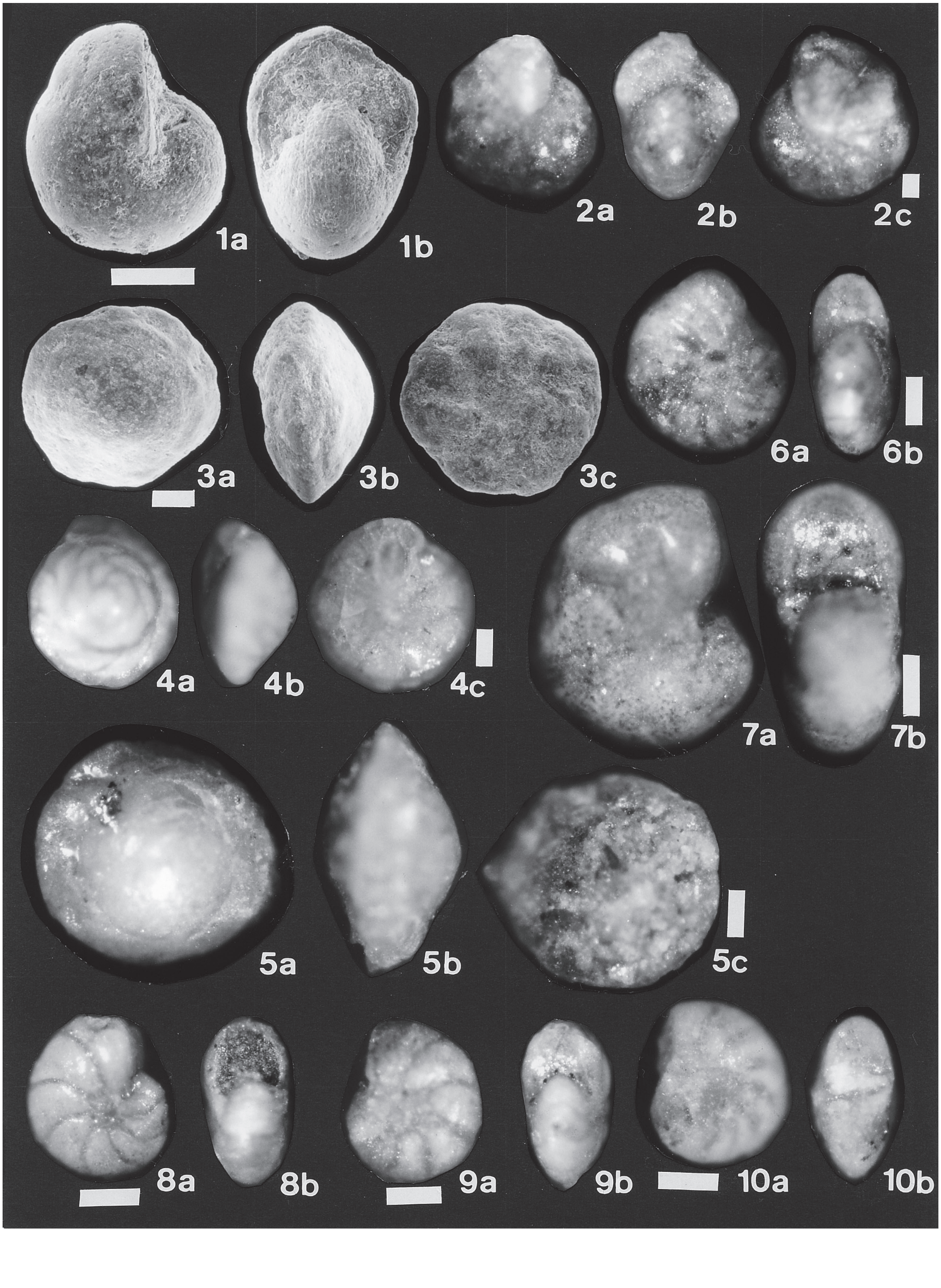
⬅ **Figure 10.** Foraminifera from the Minaminaganuma Formation. All figured specimens from the well MITI Umaoi. All scale bars = 0.1 mm. **1.** *Haplophragmoides* sp. 1. Sample depth 200 m. **2.** *Haplophragmoides* sp., Sample depth 2320 m. **3.** ?*Glomospira* sp. Sample depth 2760 m. **4.** *Pyrgo* sp. Sample depth 2420 m. **5, 6.** *Quinqueloculina* cf. *Q. seminula* (Linné). Sample depth of 5: 1960 m, of 6: 2480 m. **7.** Indeterminable calcareous foraminifer (? planktonic foraminifer). Sample depth 2020 m. **8, 9.** *Bolivina* sp. 1. Sample depth of 8: 1980 m, of 9: 2420 m. **10, 11.** *Globocassidulina* sp. 1., both specimens from depth of 2140 m. **12, 13.** *Bulimina* sp. 1., both specimens from depth of 1920 m. **14.** *Globobulimina* sp. Sample depth 2160 m. **15.** *Protoglobobulimina pupoides* (d'Orbigny). Sample depth 1940 m. **16.** *Nonionella miocenica* Cushman. Sample depth 1940 m. **17.** *Pullenia* aff. *P. apertula* Cushman. Sample depth 2360 m.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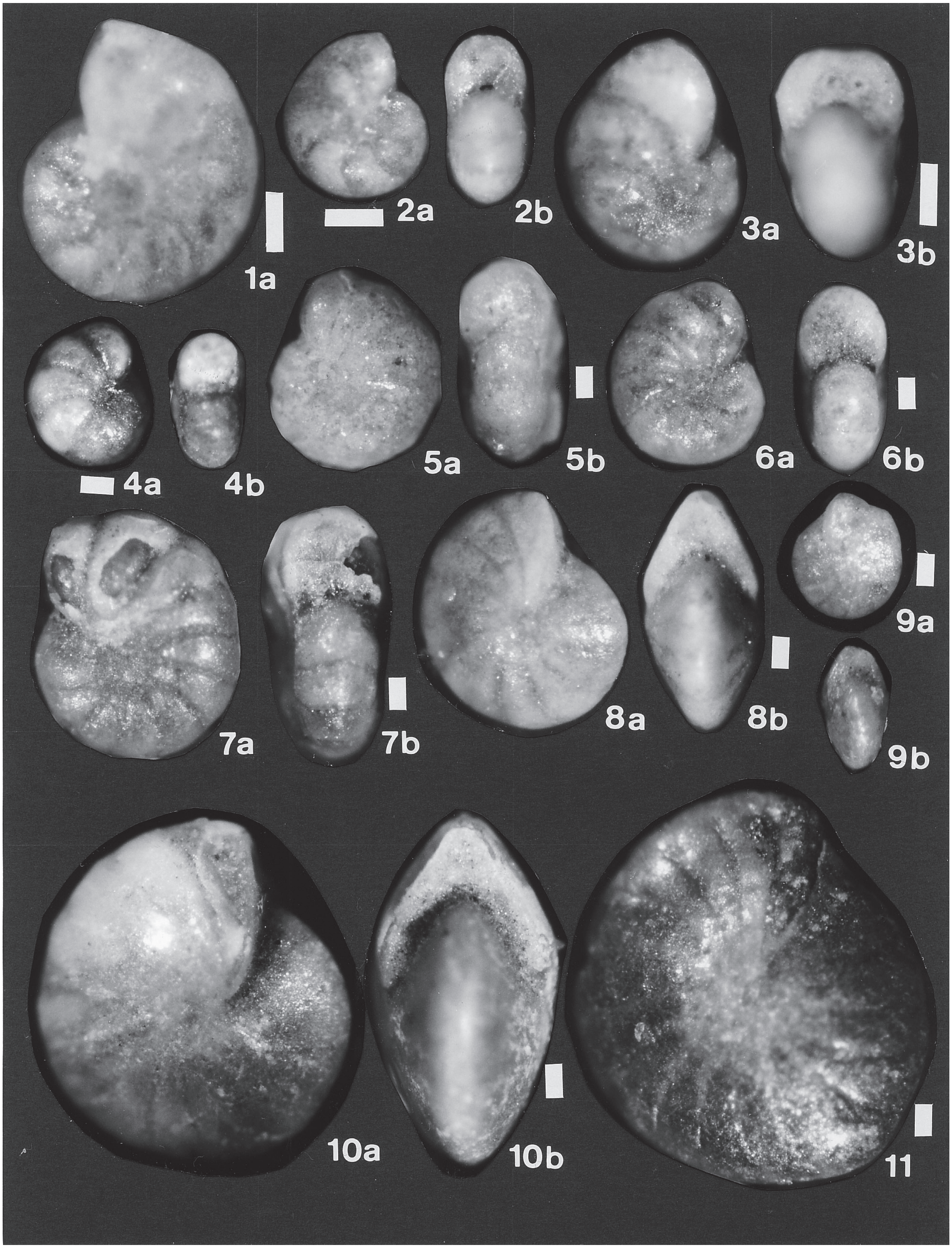
⬅ **Figure 11.** Foraminifera from the Minaminaganuma Formation. All figured specimens from the well MITI Umaoi. All scale bars = 0.1 mm. **1–2.** *Pullenia* aff. *apertula* Cushman. Sample depth of 1 = 1960 m; of 2 = 1900 m. **3–5.** *Buccella oregonensis* (Cushman, Stewart and Stewart). Sample depth of 3 and 4 = 3000 m; of 5 = 1940 m. **7–10.** *Cribroelphidium ombetsuense* (Asano). Sample depth of 6 and 10 = 1940 m; of 7 = 2000 m; of 8 and 9 = 1900 m. Specimens of 7 and 8 are descriminated as var. 1.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⬅ **Figure 12.** Foraminifera from the Minaminaganuma Formation. All figured specimens from the well MITI Umaoi. All scale bars = 0.1 mm. **1–7.** *Cribroelphidium ombetsuense* (Asano). Sample depth of 1 = 1900 m; of 2 = 1940 m; of 3–7 = 2000 m. Specimens of 1 and 2 are descriminated as var. 1. **8–11.** *Elphidium mabutii* Asano. Sample depth of all specimens, 2000 m. Note that the number of chambers in the final whorl increases with growth: juvenile specimen (9) has 11, 8 has 13, 10 has 15, and 11, the largest, has 18 chambers in the final whorl, respectively.

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Appendix: Taxonomic notes. Foraminifera identified in this study are listed below in taxonomic order of Loeblich and Tappan (1987, 1992).

***Haplophragmoides* sp. 1** (Figure 10.1)
Diagnosis.— *Haplophragmoides* species with a test of medium size, coarsely agglutinating surface and biumbilicate coiling.
Remarks.— Single specimen occurred from depth of 200 m of MITI Umaoi borehole. It occurred with indeterminable *Cribroelphidium* species and probably is a shallow marine species.

Quinqueloculina* cf. *Q. seminula (Linné) (Figures 10. 5, 6)
Compared with *Serpula seminulum* Linné, 1758, p. 786.
Remarks.— This species occurred in two samples from MITI Umaoi borehole. This study tentatively treats this species with “cf.” because of the unobservable aperture filled with sediment and worn surface.

***Bolivina* sp. 1** (Figures 10. 8, 9)
Diagnosis.— Small-sized *Bolivina* species with short and slender test without ornamentation.
Remarks.— This rather simple species of *Bolivina* occurred only in two samples of MITI Umaoi borehole.

***Globocassidulina* sp. 1** (Figures 10. 10, 11)
Diagnosis.— *Globocassidulina* species with a compressed test of small to medium size, aperture is near rounded periphery.
Remarks.— Preservation of specimens is always too poor to observe the structure of the aperture and other features, and consequently it is difficult to make an exact identification.

***Bulimina* sp. 1** (Figures 10. 12, 13)
Diagnosis.— Small *Bulimina* species with cylindrical shape, obscure sutures without ornamentation and slitlike aperture on the apertural face.
Remarks.— Almost all specimens are poorly preserved. Slower growth rate and indistinct sutures characterize this species. It is probably a distinct species to be described as new.

Protoglobobulimina pupoides (d’Orbigny) (Figure 10. 15)
Bulimina pupoides d’Orbigny, 1846, p. 185, pl. 11, figs. 11–12.
Remarks.— This species is commonly found in the Eocene through Miocene of Hokkaido (Asano, 1952b; Kaiho, 1992).

Nonionella miocenica Cushman (Figure 10. 16)
Nonionella miocenica Cushman, 1926, p. 64, fig. 4a–c.
Remarks.— Three specimens occurred from depths of 1940 m, 1980 m and 2960 m (cf.) of MITI Umaoi borehole. It has been commonly found in the Miocene of Hokkaido (Asano, 1953), but its range is found here to be older.

Pullenia* aff. *P. apertula Cushman (Figures 10. 17; 11. 1, 2)
Compared with *Pullenia apertula* Cushman, 1927, p. 171, pl. 6, fig. 10.
Remarks.— This species is distinguished from typical *P. apertula* in having seven chambers in the final whorl instead of six. Most specimens are distorted and observation of the aperture is difficult for exact identification.

Buccella oregonensis (Cushman, Stewart and Stewart) (Figures 11. 3–5)
Eponides mansfieldi var. *oregonensis* Cushman, Stewart and Stewart, 1948, p. 48, pl. 6, figs. a–c.

Cribroelphidium ombetsuense (Asano) (Figures 11. 7–10; 12. 1–7)
Elphidium ombetsuense Asano, 1962, p. 32, pl. 1, fig. 7a, b.
Remarks.— This species occur abundantly from whole sections. It was originally described from the Eocene Omagari Formation with *Elphidium mabutii*. This species resembles *Cribroelphidium yumotoense* Asano (1949) described from the Paleogene Asagai Formation in northern Honshu, but is distinguishable in having a broader test and more chambers than the latter species. Specimens with small test and less inflated chambers are distinguished as *C. ombetsuense* var. 1 in this study (Figures 11.8–10, 12.1, 2).

Elphidium mabutii Asano (Figures 12. 8–11)
Elphidium mabutii Asano, 1962, p. 31–32, pl. 1, figs. 4a, b; 6a, b.; Kaiho, 1984b, p. 70, pl. 6, fig. 11a, b.
Remarks.— This species occurred abundantly from whole sections of the Minaminaganuma Formation. In this study, 3,744 specimens were counted, and the range of the variation of this species in terms of its test size and number of chambers was clarified. In the original description of Asano (1962) from the Eocene Omagari Formation in eastern Hokkaido, the number of chambers in the last whorl is 13 to 15, the suture is distinct, and the periphery is subacute. But in this study, the number of chambers in the last whorl in the largest specimens is up to 18, while immature specimens have as few as 11 chambers. Most adult forms have smooth lamellae on the test surface, which cover the sutures.
Elphidium iojimaense Asano and Murata resembles the adult form of *E. mabutii*, but the former has a relatively acute periphery.