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Diatoms in the Holocene Sediments of the Maxwell Bay, King George Island, Antarctica

Won Hyung Kim[1], Mi-Ock Kim[2], and Byong-Kwon Park[3]

1) *Nowon-Ku, Gongneung-Dong, P.O.Box 77, Korea Militry Academy Seoul, 139-799, Korea*
2) *Environment Res. Lab., Rural Research Institute, Rural Development Corporation, Anyang P. O. Box 12, 430-600, Korea*
3) *Korea Ocean Research and Development Institute Ansan P.O.Box 29, 425-600, Seoul, Korea*

Abstract : Diatom floras are analysed in the core sediments collected from Maxwell Bay, King George Island, Antarctica during the austral summer, 1988/89. All sediments contain well preserved and diverse diatoms indicating that the sediments have been deposited during Holocene and the productivity has been very high. The ratios of *N. curta/N. kerguelensis* indicate that middle to lower parts of the core sediments were deposited during the warmer period than today. Based on the core length and warmer period, the sedimentation rate of Maxwell Bay is inferred to 50cm/1,000 yrs.

A genus *Nitzschia* comprises more than 50 % of the diatom populations and increases in proportion toward deeper environments. Dominent species are *N. kerguelensis. N. curta, Thalassiosira antarctica,* and *T. gracilis*

Key words : diatom, holocene sediment, Maxwell Bay, Antarctica

Introduction

Korea Ocean Research and Development Institute (KORDI) has studied natural environments in the area around the Korean Antarctic Station (Sejong Station) on the Barton Peninsula on King George Island, Antarctica since the austral summer, 1988 and published three research reports (KORDI, 1988, 1989, and 1990). In the reports, diatoms have demonstrated usefulness as the simplest and best tool for interpretation on biological production of the water-mass, paleoceanography, stratigraphy, and sedimentation rate of the area.

The purposes of this study are three fold:

1) to analyse characteristics of the diatoms collected from the Maxwell Bay during late January through early February, 1989,
2) to delineate the sediment age and sedimentation rate,
3) to infer the paleoceanographic condition of the area.

These topics will help other researches in this area and serve as a basis for futher studies concerning Antarctica.

Maxwell Bay is a U-shaped typical fjord 18 km long (NW-SE) and 14 km wide (Fig. 1). The average slope of the submarine topography is 16° and maximum depth more than 500m. Several oceanographic parameters observed during the austral summer, 1988/89 represent a water-mass at the southern boundary of the Antarctic Convergence Zone. These parameters are as following. Water-temperature ranges from -0.2 ℃ to 1.5 ℃ and salinity 33.5 ‰ to 34.6 ‰. The chlorophyll-*a* concentrations

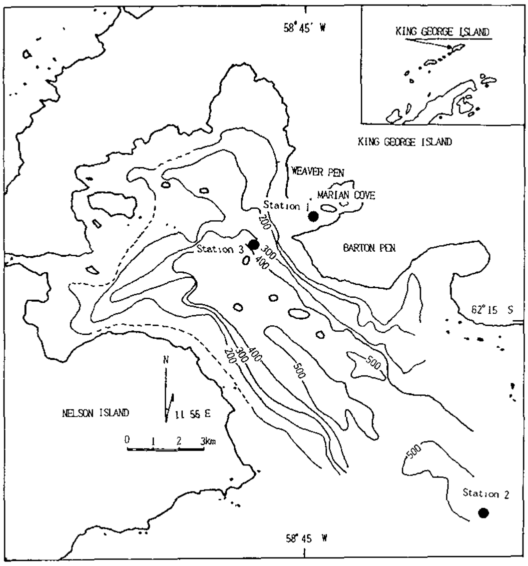

Fig. 1. Coring stations and bathymetric contours (m) of the Maxwell Bay, King George Island, Antarctica.

are 40−65 $\mu g/m^3$ and phytoplanktons in surface water mostly consist of diatoms. The maximum population of diatoms reaches 19−5 cells/cc and occurs from the 0−10 m stratum.

Previous Antarctic Diatom Studies

It is well known that marine diatoms are the most abundant organisms in sea waters and Recent/Cenozoic sediments of the Antarctic region (Krebs, 1983). Especially diatoms constitute 40−60 % of most bottom sediment of the Antarctic Convergence Zone encompassing the region from approximately 55°S to 65°S Lat. (Truesdale and Kellogg, 1979; Ciesielski, 1983). Since Ehrenberg (1844) reported Antarctic diatoms, many diatomists have studied taxonomy, ecology, and the distribution patterns of them (for precise list, see Hasle, 1969; Fenner et al., 1976; Defelice and Wise, 1981). The sensitivity of diatom to environmental parameters demonstrates the usefulness of this region (Defelice and Wise, 1981; Burckle, 1984, 1987; Burckle and Cirilli, 1987; Leventer and Dunbar, 1987). Thus, diatom study is an essential portion of Antarctic Science (Krebs, 1983).

Since Jouse et al. (1963) conducted a biostratigraphic study on a south Indian Ocean core, diatom floras in sediments have been studied vigorously. Recently, the biostratigraphic resolution of diatoms has become as precise as that of planktonic foraminifera (see Bolli et al., 1985). In the Antarctic or related regions, McCollum (1975) proposed middle to late Cenozoic diatom biostratigraphy and many subsequent authors refine and/or discuss this biostratigraphic zonation (Gombos, 1976; Schrader, 1976; Weaver and Gombos, 1981; Ciesielski, 1983; Harwood et al., 1989).

In terms of Quarternary sediments, Donahue (1970) initiated diatom zonation of late Pliocene to Holocene of the Antarctic region with ca. 300,000 yrs resolution. Abbott (1974) and Akiba (1982) tried to refine the Quarternary zonation with ca. 200,000 yrs interval. However, Ciesielski (1983) lumped the refined zones into 600,000 yrs considering reliability. Recently, Burckle (1984) distinguished interglacial sediments from glacial sediments in the Antarctic area based on the ecologic data of the diatom floras. To date, diatoms have been the best stratigraphic and paleoenvironmental tool in the Antarctic region because of their high diversity and dominance (Kellogg and Kellogg, 1986; Burckle and Cirilli, 1987).

Materials and Methods

The diatom floras were extracted from 33 strata of the 3 cores (Station 1, 2, 3) collected by KORDI during January 20 to February 14, 1989 (Fig. 1). The sampling strata are as follows from surface to bottom.

Station 1 : 10 cm, 30 cm, 50 cm, 70 cm, 90 cm, 110 cm, 130 cm, 150 cm, 170 cm,
Station 2 : 10 cm, 30 cm, 50 cm, 70 cm, 90 cm,

110 cm, 130 cm, 150 cm, 170 cm, 190 cm, 230 cm, 260 cm,

Station 3 : 0 cm (surface), 30 cm, 50 cm, 70 cm, 90 cm, 110 cm, 130 cm, 150 cm, 170 cm, 190 cm, 230 cm, 260 cm,

Station 1 core was collected from the central Marian Cove (ca. 100 m in depth). The cove is a silled basin with stratified sediments (KORDI, 1988). Thus, all sediments may be kept in order. The sediment of the core is composed of three parts: lower till facies, middle alternating facies between gravel beds and mud beds, and upper mud facies including gravels (Fig. 2). Station 2 core was recovered from the entrance of Maxwell Bay (> 500 m deep). The sediment was composed of homogenous sandy facies but partly turbidites. Station 3 core was collected from the steep slope environment (ca. 350 m deep) of Maxwell Bay. The sediment was composed of sandy muds partly showing horizontal stratification. Most sediments have the same pale gray color, but show a difference in organic matter content: the most at station 3 (3.0 −4.1 %) and the least at station 2 (1.9−2.5 %).

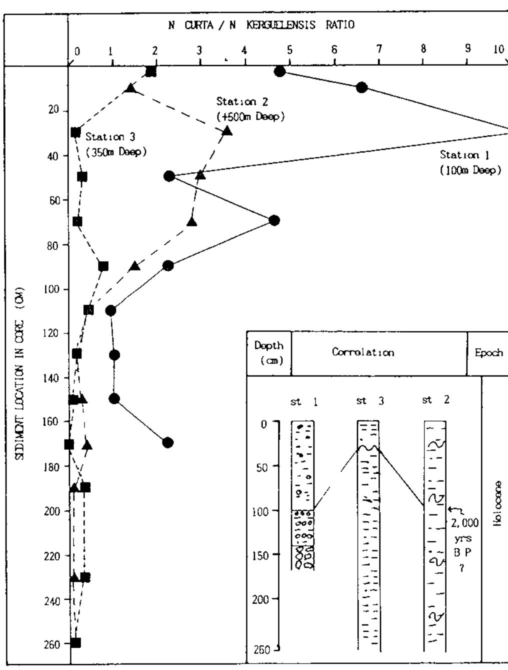

Fig. 2. *N. curta/N. kerguelensis* ratios and correlation of the cores from Stations 1, 2, 3, Maxwell Bay, King George Island, Antarctica.

To make strewn slides, the standard diatom preparation technique described by Barron (1976) was used. Approximately 3 to 5 gram of each sediment sample was placed in a 400 ml beaker. Distilled water was added until the sample was barely coved, then 30 % or 10 % hydrogen peroxide was added in accordance with reaction. Hydrochloric acid was slowly added and the beaker was left on a hot plate and filled with distilled water, and the excess liquid was decanted. The later step was repeated until the sample was neutralized. The sample was stored in a vial (liquid to sample ratio 5−10 to 1). One or two drops of the residue was placed on a glass slide and a cover glass was attached with the mounting medium "Hyrax".

One strewn slide per sample was traversed in its entirety under a light microscope at 600 X. Identification was made at 1,500 X and 600 X and micrographs were taken. More than 200 specimens were counted on each slide (Tables 1, 2, 3). Only diatoms with more than one half of the valve intact were counted to avoid counting the same specimen twice. For *Rhizosolenia* and *Thalassiothrix*, only the ends were counted because the long forms were commonly broken into small fragments. The attained values were then halved to approximate the number of specimens of *Thalassiothrix*. The counts were converted to percent of total sample.

Results and Discussions

1. Preservation and Diversity

The studied sediment samples contain abundant well preserved diatoms comprising 54 species in total. Each sediment contains 26 to 37

Table 1. Occurrence of diatom taxa in the Holocene sediments from the Maxwell Bay, King George Island (Station 1), Antarctica.

Species \ Depth	10cm		30cm		50cm		70cm		90cm		110cm		130cm		150cm		170cm	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Achnanthes groenlandica	1	0.3			4	1.1	3	1.2	3	0.9								
A. spp.	11	2.9	4	1.4	10	2.7	11	4.4	13	3.8	10	3.4	4	1.1	1	0.3	2	0.6
Actinocyclus actinochilus	1	0.3	4	1.4	2	0.5	1	0.4	5	1.5	2	0.7	2	0.5	4	1.1	1	0.3
Amphora spp.	2	0.5	2	0.7	8	2.2	2	0.8			3	1.0						
Asteromphalus parvulus	1	0.3			3	0.8			1	0.3	4	1.4	4	1.1				
Chaetoceros spp.															8	2.3		
Cocconeis californica	2	0.5					2	0.8										
C. costata	12	3.2	2	0.7	32	8.6	9	3.6	13	3.8	10	3.4	15	4.0	4	1.1	1	0.3
C. disculoides							1	0.4	4	1.2								
C. spp.	1	0.3			4	1.1	2	0.8	1	0.3	4	1.4	1	0.3			3	0.9
Corethron criophilum									3	0.9	2	0.7			3	0.9		
Coscinodiscus marginatus	6	1.6			5	1.3	2	0.8	1	0.3	1	0.3			5	1.4		
C. stellaris															1	0.3		
C. spp.	1	0.3	1	0.4	3	0.8	4	1.6	2	0.6	5	1.7			3	0.9	4	1.2
Eucampia antarctica	1	0.3			1	0.3	1	0.4	4	1.2			3	0.8	5	1.4	6	1.8
Gyrosigma spp.															1	0.3		
Licmophora spp.	3	0.8			4	1.1	1	0.4			1	0.3						
Navicula directa	12	3.2	3	1.1	6	1.6	15	6.0	13	3.8	4	1.4	4	1.1	8	2.3	1	0.3
N. radiosa	7	1.9	13	4.7			3	1.2	3	0.9					1	0.3		
N. spp.	30	8.0	23	8.3														
Nitzschia angulata	20	5.4	10	3.6	14	3.8	11	4.4	27	7.9	6	2.1	10	3.0	11	3.1	26	7.6
N. curta	93	24.9	63	22.7	64	17.2	56	22.4	69	20.3	54	18.4	129	34.5	95	26.8	153	45.0
N. cylindra	2	0.5			3	0.8	2	0.8	1	0.3	1	0.3	6	1.6	4	1.1	11	3.2
N. kerguelensis	14	3.7	3	1.1	28	7.5	12	4.8	32	9.4	63	21.5	131	35.0	99	28.0	71	20.9
N. obliquecostata	3	0.8	2	0.7	7	1.9	1	0.4	4	1.2	1	0.3	3	0.8			1	0.3
N. ritscheri	9	2.4	10	3.6	7	1.9	3	1.2	6	1.8	12	4.1	2	0.5	18	5.1	2	0.6

(continued)

Species \ Depth	10cm		30cm		50cm		70cm		90cm		110cm		130cm		150cm		170cm	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
N. separanda	14	3.7	13	4.7	11	3.0	9	3.6	3	0.9	3	1.0	1	0.3	2	0.6	1	0.3
N. sublinearis	3	0.8	2	0.7			1	0.4	3	0.9	3	1.0	2	0.5	10	2.8	6	1.8
N. spp.	2	0.5	3	1.1	11	3.0	5	2.0	1	0.3	2	0.7	9	2.4	17	4.8	9	2.7
Odontella aurita									1	0.3								
O. weissflogii													1	0.3	2	0.6		
Pleurosigma spp.					1	0.3	1	0.4	1	0.3								
Pseudogomphonema groenlandicum	31	8.3	16	5.8	41	11.0	15	6.0	27	7.9	16	5.5	8	2.1	1	0.3	10	2.9
Rhizosolenia alata	2	0.5	1	0.4	2	0.5	1	0.4								1	0.3	
R. alata f. inermis	13	3.5	1	0.4	3	0.8	1	0.4	2	0.6								
R. hebetata f. hiemalis	1	0.3	1	0.4	1	0.3			1	0.3			3	0.8			1	0.3
R. hebetata f. semispina	1	0.3																
R. styliformis					1	0.3	2	0.8	1	0.3			1	0.3				
Rhoicosphaenia spp.									2	0.6	1	0.3	1	0.3				
Roperia tesselata					1	0.3	1	0.4	1	0.3	4	1.4	3	0.8				
Thalassionema nitzschioides					2	0.5	1	0.4	5	1.5	2	0.7	2	0.7	1	0.3	1	0.3
Thalassiosira antarctica	12	3.2	13	4.7	50	13.4	14	5.6	19	5.6	10	3.4	8	2.1	2	0.6	10	2.9
T. gracilis	17	4.5	27	9.7	21	5.6	26	10.4	11	3.2	35	11.9	7	1.9	2	0.6	2	0.6
T. gracilis var expecta	25	6.7	53	19.1	12	3.2	19	7.6	29	8.5	20	6.8	6	1.6	1	0.3	11	3.2
T. lentiginosa	17	4.6	3	1.1	9	2.4	3	1.2	19	5.6	7	2.4	2	0.7	2	0.6	3	0.9
T. leptopus											1	0.3						0.9
T. spp.	3	0.8	1	0.4	1	0.3	7	2.8	8	2.4	5	1.7	5	1.7	43	12.1	2	0.6
Thalassiothrix spp.			1	0.4	1	0.3	2	0.8	1	0.3	1	0.3	1	0.3			1	0.3
Species No.	34		27		34		36		37		31		29		28		26	
Total Individual No.	374		277		373		250		340		293		374		354		340	

Table 2. Occurrence of diatom taxa in the Holocene sediments from the Maxwell Bay, King George Island(Station 2), Antarctica.

Depth / Species	10cm		30cm		50cm		70cm		90cm		110cm		130cm		150cm		170cm		190cm		230cm		260cm	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Achnanthes groenlandica	3	1.5	1	0.3	1	0.4																		
A. spp.	3	1.5									2	0.7	3	0.9	2	0.4	2	0.7	2	0.8			3	1.2
Actinocyclus actinochilus	4	1.9	2	0.7	2	0.9	6	2.1	3	1.0	1	0.3	3	0.9	4	0.9	5	1.8	3	1.2	4	1.4	5	2.0
Actinocyclus curvatulus																					2	0.7		
A. spp.			1	0.3																				
Amphora spp.	2	1.0			2	0.9			2	0.7	3	1.0	2	0.6	2	0.4			3	1.2			2	0.8
Asteromphalus parvulus	2	1.0	2	0.7	2	0.9	2	0.7	3	1.0	3	1.0	3	0.9	4	0.9	2	0.7	3	1.2	5	1.7	1	0.4
Cocconeis californica																	1	0.4			1	0.3		
C. costata	6	2.9	10	3.3	5	2.2	9	3.2	11	3.8	19	6.5	11	3.1	12	2.6	11	4.0	9	3.6	21	7.2	7	2.7
C. disculoides							1	0.4	1	0.4	1	0.3	2	0.6	9	1.9					1	0.3		
C. disculoides							1	0.4	1	0.4	1	0.3	2	0.6	9	1.9					1	0.3		
C. spp.	1	0.5	2	0.7							3	1.0	4	1.1	3	0.6			2	0.8	3	1.0	1	0.4
Corethron criophilum	2	1.0	1	0.3	1	0.4	1	0.4	3	1.0	1	0.3	1	0.3					1	0.4	1	0.3	1	0.4
Coscinodiscus marginatus	1	0.5							1	0.4			5	1.4	3	0.6	2	0.7	6	2.4	2	0.7		
C. stellaris	1	0.5	1	0.3	3	1.3					1	0.3	1	0.3	3	0.6	3	1.1	2	0.8	2	0.7	2	0.8
C. spp.	3	1.5	29	9.6	2	0.9			3	1.0	4	1.4	1	0.3	6	1.3	10	3.6	3	1.2	10	3.4	6	2.3
Diploneis spp.									1	0.4														
Eucampia antarctica																	1	0.4	2	0.8			1	0.4
Licmophora spp.													2	0.6			2	0.7					2	0.8
Navicula directa	7	3.4	7	2.3	4	1.7	2	0.7	4	1.4			1	0.3	1	0.2	1	0.4					2	0.8
N. directa var. javanica			2	0.7	1	0.4	4	1.4	1	0.4														
N. radiosa							1	0.4																
N. spp.			6	2.0	4	1.7			2	0.7			2	0.6	1	0.2	2	0.7						
Nitzschia angulata	7	3.4	16	5.3	6	2.6	25	8.9	22	7.6	11	3.8	19	5.4	9	1.9	14	5.1	9	3.6	4	1.4	10	3.8
N. curta	42	20.3	91	30.1	96	41.7	121	42.3	94	32.5	47	16.0	35	10.0	25	5.3	33	12.0	8	3.2	6	2.1	15	5.8
N. kerguelensis	31	15.0	25	8.3	32	13.9	43	15.0	61	21.1	107	36.5	146	41.6	93	19.9	87	31.5	96	38.1	94	32.2	125	48.1
N. obliquecostata									7	2.4	3	1.0	1	0.3	4	0.9	2	0.7	2	0.8	9	3.1	4	1.5

(continued)

Species \ Depth	10cm		30cm		50cm		70cm		90cm		110cm		130cm		150cm		170cm		190cm		230cm		260cm	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
N. ritscheri	10	4.9																			1	0.3		
N. separanda	1	0.5	9	3.0	6	2.6	15	5.3	5	1.7			5	1.4	12	2.6	4	1.4	7	2.8	4	1.4	3	1.2
N. sublinearis	13	6.3	40	13.3	28	12.2	18	6.3	15	5.2	10	3.4	7	2.0	2	0.4	4	1.4	2	0.8	2	0.7	13	5.0
N. spp.	12	5.8	19	6.3	20	8.7	11	3.9	5	1.7	7	2.4	5	1.4	4	0.9	3	1.1	3	1.2	4	1.4	6	2.3
Odontella weissflogii	2	1.0	1	0.3			2	0.7	2	0.7	1	0.3					2	0.7	3	1.2	2	0.7		
Pseudogomphonema groenlandicum	2	1.0	2	0.7	2	0.9	6	2.1	3	1.0	4	1.4	5	1.4	5	1.1	2	0.7			1	0.3	3	1.2
Rhizosolenia alata			1	0.3	1	0.4			1	0.4	1	0.3	2	0.6	3	0.6			1	0.4				
R. alata f. inermis									1	0.4	2	0.7	4	1.1	27	5.8	7	2.5	5	2.0	3	1.0		
R. hebetata f. hiemalis													2	0.6			1	0.4						
R. hebetata f. semispina	1	0.5	1	0.3									2	0.6	9	1.9	1	0.4	1	0.4	3	1.0		
R. styliformis	1	0.5	1	0.3			1	0.4	4	1.4	4	1.4	2	0.6	36	7.7	7	2.5	2	0.8	11	3.8	4	1.5
Roperia tesselata											2	0.7	4	1.1	12	2.6	1	0.4	3	1.2	1	0.3		
Thalassionema nitzschioides	2	1.0			2	0.9					1	0.3	2	0.6	3	0.6	5	1.8	3	1.2				
Thalassiosira antarctica	10	4.9	3	1.0	3	1.3	3	1.0	6	2.1	11	3.8	11	3.1	92	19.7	21	7.6	24	9.5	43	14.7	22	8.5
T. frenguelliopsis									5	1.7	1	0.3	2	0.6	1	0.2			2	0.8	1	0.3		
T. gracilis	14	6.8	6	2.0	5	2.2	4	1.4	7	2.4	15	5.1	30	8.5	36	7.7	18	6.5	24	9.5	29	9.9	14	5.4
T. gracilis var. expecta	20	9.7	16	5.3	1	0.4	4	1.4	2	0.7	2	0.7	6	1.7	9	1.9	4	1.4	3	1.2				
T. lentiginosa	7	3.4	1	0.3					2	0.7	11	3.8	11	3.1	27	5.8	9	3.3	11	4.4	11	3.8	4	1.5
T. leptopus	1	0.5	2	0.7	1	0.4											1	0.4	1	0.4	2	0.7	2	0.8
T. spp.	3	1.5	4	1.3			7	2.5	2	0.7	15	5.1	7	2.0	16	3.4	8	2.9	6	2.4	8	2.7	2	0.8
Thalassiothrix spp.	1	0.5											1	0.3	3	0.6					1	0.3		
Trachyneis spp.	1	0.5																						
Species No.	32		29		24		21		30		29		36		33		33		32		32		26	
Total Individual No.	206		302		230		286		289		293		351		468		276		252		292		260	

Table 3. Ocurrence of diatom taxa in the Holocene sediments from the Maxwell Bay, King George Island(Station 3), Antarctica.

Depth / Species	100cm		30cm		50cm		70cm		90cm		110cm		130cm		150cm		170cm		190cm		230cm		260cm	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Achnanthes groenlandica													4	1.3										
A. spp.	4	1.0	1	0.4	4	0.8	3	0.7	3	0.8	2	0.6	1	0.3	4	1.3	4	1.3	4	1.2	1	0.3		
Actinocyclus actinochilus	3	0.8	6	2.2	5	1.2	6	1.5	5	1.4	3	0.9	8	2.6	4	1.3	6	1.9	3	0.9	3	1.0	10	3.1
Amphora spp.			2	0.7	4	0.8									2	0.7	1	0.3	2	0.6	1	0.3		
Asteromphalus parvulus					1	0.2			2	0.6	1	0.3	2	0.7	3	1.0			1	0.3				
Bacillaria paxillifer					1	0.2	1	0.2													1	0.3		
Chaetoceros spp.			2	0.7																				
Cocconeis californica			1	0.4															1	0.3			2	0.6
C. costata	9	2.3	22	7.9	26	5.0	26	6.5	7	2.0	16	4.7	24	7.9	·10	3.3	22	7.0	8	2.3	27	8.6	21	6.7
C. disculoides					8	1.5	2	0.5	1	0.3			1	0.3	3	1.0	1	0.3	1	0.3	2	0.6	3	0.9
C. spp.					11	2.1	1	0.2			1	0.3	3	1.0	1	0.3	2	0.6					3	0.9
Corethron criophilum	3	0.8					1	0.2	2	0.6	3	0.9	2	0.7			6	1.9			1	0.3	1	0.3
Coscinodiscus marginatus			1	0.4	4	0.8	1	0.2	1	0.3	1	0.3			1	0.3			1	0.3				
C. stellaris	3	0.8	1	0.4	1	0.2					4	1.2					1	0.3						
C. stellaris	3	0.8	1	0.4	1	0.2					4	1.2					1	0.3						
C. spp.	1	0.3	2	0.7	4	0.8	2	0.5	1	0.3			15	4.9	3	1.0	35	11.3	14	4.0	6	1.9	11	3.5
Eucampia antarctica											2	0.6	1	0.3			4	1.3	1	0.3				
Grammatophora spp.					1	0.2	2	0.5																
Licmophora spp.	6	1.5	6	2.2	2	0.4											1	0.3			1	0.3		
Navicula direca	5	1.3	2	0.7	1	0.2	1	0.2	3	0.8					3	1.0					3	1.0		
N. direca var. javanica			2	0.7																				
N. radiosa																					1	0.3		
N. spp.	5	1.3			15	2.9	3	0.7	4	1.1	3	0.9	1	0.3	4	1.3	5	1.6	6	1.7	5	1.6	1	0.3
Nizschia angulata	15	3.9	8	2.9	5	1.0	7	2.0	15	4.2	5	1.5	12	3.9	11	3.7	2	0.6	10	2.9	8	2.6	1	0.3
N. curta	148	38.1	6	2.2	41	7.9	28	7.0	92	25.8	43	12.6	13	4.3	88	29.2	1	0.3	45	13.0	34	10.9	12	3.7
N. cylindra	7	1.8	1	0.4			1	0.2			5	1.5	2	0.7	2	0.7			2	0.6				
N. kerguelensis	78	20.1	109	39.2	155	29.9	174	43.4	114	32.0	121	35.6	130	42.6	87	28.9	110	34.9	159	45.8	130	41.5	164	50.8

(continued)

Depth / Species	100cm		30cm		50cm		70cm		90cm		110cm		130cm		150cm		170cm		190cm		230cm		260cm	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
N. obliquecostata	1	0.3	1	0.4	19	3.7	8	2.0	10	2.8	3	0.9	6	2.0	5	1.7			7	2.0	7	2.2	20	6.2
N. rischeri					2	0.4			20	5.6	6	1.8	5	1.6	15	5.0	5	1.6	3	0.9	4	1.3	10	3.1
N. separanda	1	0.3	1	0.4	2	0.4	11	2.7	9	2.5	2	0.6	1	0.3	4	1.3			4	1.2	6	1.9	4	1.3
N. sublineraris	1	0.3	6	2.2	8	1.5					5	1.5			2	0.7			3	0.9			1	0.3
N. spp.	5	1.3	5	1.8	3	0.6	2	0.5	2	0.6	1	0.3	1	0.3			3	1.0	1	0.3	2	0.6		
Odontella weissflogii			3	1.1			1	0.2	2	0.6	3	0.9	13	4.3			14	4.4						
Pleurosigma spp.					1	0.2															1	0.3		
Pseudogomphonema groenlandicum	18	4.6	2	0.7	25	4.8	19	4.7	5	1.4	10	2.9			12	4.0	1	0.3	6	1.7	20	6.4	3	0.9
Rhizosolenia alata					3	0.6			1	0.3	5	1.5					1	0.3			2	0.6	1	0.3
R. alata f. inermis	4	1.1			15	2.9	1	0.2	2	0.6	14	4.1	2	0.7	2	0.7	3	1.0	2	0.6			5	1.5
R. hebetata f. hiemalis	2	0.5	1	0.4											2	0.7	2	0.6	2	0.6			3	0.9
R. hebetata f. semispina	1	0.3	2	0.7	1	0.2	3	0.7	2	0.6	10	2.9	5	1.6			4	1.3	5	1.4			1	0.3
R. styliformis	1	0.3	6	2.2	8	1.5	3	0.7	3	0.8	10	2.9	4	1.3	1	0.3	9	2.9	8	2.3			2	0.6
Rhoicosphaenia spp.					1	0.2	2	0.5									1	0.3						
Roperia tesselata	1	0.3	1	0.4	20	3.9	15	3.7	4	1.1	3	0.9	1	0.3	3	1.0	4	1.3	4	1.2			1	0.3
Thalassionema nitzschioides	4	1.1			7	1.4			1	0.3	1	0.3	1	0.3			1	0.3			2	0.6	1	0.3
Thalassiosira antarctica	3	0.8	44	15.8	35	6.8	28	7.0	16	4.5	19	5.6	26	8.5	7	2.3	36	11.4	21	6.1	4	1.3	21	6.5
T. gracilis	15	3.9	16	5.8	45	8.7	34	8.5	15	4.2	19	5.6	10	3.3	16	5.3	20	6.3	12	3.5	20	6.4	12	3.7
T. gracilis var. expecta	29	7.5	6	2.2	18	3.5	8	2.0	7	2.0	3	0.9	2	0.7	14	4.7	3	1.0	5	1.4	14	4.5	5	1.5
T. lentiginosa	6	1.5	5	1.8	14	2.7	4	1.0	4	1.1	11	3.2	5	1.6	1	0.3	4	1.3	1	0.3	1	0.3	3	0.9
T. leptopus			1	0.4			1	0.2			1	0.3					2	0.6			1	0.3		
T. spp.	8	2.1	6	2.2	2	0.4	1	0.2	2	0.6	2	0.6	2	0.7	1	0.3	1	0.3	3	0.9	3	1.0	1	0.3
Thalassiothrix spp.	1	0.3					1	0.2	1	0.3	2	0.6							1	0.3	2	0.6		
Trachyneis spp.													2	0.7										
Species No.	30		32		37		33		31		34		31		29		33		33		30		28	
Total Individual No.	388		278		518		401		356		340		305		301		315		347		313		323	

species showing high diversity (Tables 1, 2, 3). This abundance and high diversity of the diatom floras represent high productivity of the studied area during the austral summer. Diatom preservation and abundance in sediments are an accurate reflection of annual productivity of phytoplankton in surface waters and diatom distribution in the underlying surface sediments (Burckle, 1984). In other words, the high productivity of diatoms causes heavy sedimentation of their frustles on the underlying sedimentary environment. The number of species in a sediment sample may also represent the productivity of overlying water because less diatomaceous sediments generally include less diverse flora (Akiba, 1982) due to diatom's easy dissolution. Several authors noted that diatom flora containing more than twenty species in a sediment sample indicates high diversity even in the Antarctic region (Saar and Wolf, 1973; Defelice and Wise, 1981).

The dominance of dissolution prone species *Nitzschia kerguelensis* over dissolution resistant species such as *Actinocyclus (=Charcotia) actinochilus* and *Eucampia antarctica(=E. balaustium)* (Defelice and Wise, 1981) in the studied sediments also indicates very good preservation of the diatom floras, and these diatom assembleges may well represent the oceanographic conditions of overlying waters. Many authors reported that recent sediments even in the Antarctic region commonly contain poorly preserved diatoms because of diatom's opaline silica dissolution during their descent through the water column (Saar and Wolf, 1973; Brewster, 1980). Recently Leventer and Dunbar (1987) found that more than 80 % of the diatom frustules produced in near surface waters dissolve by 100 m descent and preferential dissolution of weakly silicified frustles and dilution by resuspension influence the thanatocoenosis of diatoms in sediments. Barron (1987) noted that only 1–5 % of diatoms lived in the overlying water and were eventually kept in sediments.

2. Correlation, Paleoceanography, and Sedimentation

The continuously abundant diatom floras suggest that all core sediments are deposited during Holocene. Burckle (1987) noted that the sediments in Antarctic Peninsula area between 60°S and 65°S contain abundant diatom floras in the interglacial sediments while barren to poor floras in the glacial sediments because the area has been covered with thick ice through the whole year during the glacial periods and uncovered in the austral summer during the interglacial periods. If an Antarctic area were covered with thick ice, sunlight could not reach in the sea water and it resulted in very poor diatom production in the area and deposition to the underlying sedimentary environment. If the area were uncovered during the interglacial period, it resulted in diatom bloom in the water and vigorous deposition of diatom frustules to the sedimentary environment. Akiba (1982) also suggested a similar pattern from the Bellingshausen Sea sediment. This kind of phenomenon is reported from Authur Harbor through the ice covered seasons and uncovered austral summer by Krebs (1983). Ferreyra and Tomo (1978) note total diatom counts in the water column in Paradise Bay as low as 21 cells per liter during the winter compared with values in excess of two million cells per liter during the summer. Thus, the continuously abundant diatom floras in the studied core sediments imply that there are no glacial sediments in the cores. The negligible occurrence of *E. antarctica* also indicates that the studied sediments belong to Holocene because the species occurs abundantly from the glacial sediments while rarely from the Holocene or interglacial sediments (Burckle, 1984). No occurrence of extinct species also supports that the sediments were deposited during Holocene.

Nitzschia curta/N. kerguelensis ratios also indicate that all the cores are Holocene sediments. *N. kerguelensis* is a Subantarctic species living in waters between 8℃ and 0℃ (Jacques, 1983; Burckle et al., 1987) and sometimes comprises more than 70 % of the diatom population between 70° S to 60° S Lat. *N. curta* is a dominant form south of 0℃ isotherm (Burckle et al., 1987) and increases in abundance toward the Antarctic continent (Fenner et al., 1976; Truesdale and Kellogg, 1979). Thus, the ratio of *N. curta/N. kerguelensis* is a very important indicator for water temperature (Burckle et al., 1987). In Figure 2, the ratio of these two species in the upper parts of cores are much higher than those of the rest of the portions of the three cores. This means that the middle to lower parts of cores were deposited under warmer seawater than today. Kellogg et al. (1979) also note similar phenomenon from the downcore analysis in the northern part of the continental shelf of the Ross Sea, although they interprete the warmer flora as a seasonal basis "at least" and call their interpretation tentative and somewhat speculative.

Assuming that Fairbridge's (1961) late Quarternary sea-level change curve and age-control is reasonable, the sediments below the 100 cm horizon at Stations 1 and 2, and 20 cm horizon at Station 3 were deposited between 2,000 yrs B.P. and 6,000 yrs B.P. when the sea level was inferred higher than today, in other words, the climate was warmer than today. Considering the sediment thickness (100cm) deposited after 2,000 yrs B.P. in Stations 1 and 2, the sedimentation rate can be tentatively calculated as 50 cm/1,000 yrs. The relatively low sedimentation rate at Station 3 after 2,000 yrs B.P. (20 cm) seems to be the result of slumping after deposition. The steep slope of the sampling site at Station 3 (Fig. 1) and turbidite facies and higher sedimentation rate at Station 2 located in a deeper environment support the inferrence. Many authors also report that sediment gravity flow undoubtedly plays a key role in the redistribution of sediments in the Maxwell Bay (see KORDI, 1988).

There are controversies about the timing of events and their relative sea levels in the late Quarternary and published curves of the late Quarternary sea levels including the Fairbridge's (1961) curve seem to reflect local rather than global (Kennett, 1982)levels. However, several diatom studies imply the Fairbridge's curve is worth more than others in the Antarctic region. In addition to this study and Kellogg et al. (1979), Defelice and Wise (1981) suggest the Polar Front was farther south at least 15,000 yrs B.P. The higher sea level during Holocene transgression in Australia, based on C-14 dating (Shepard, 1960), may be in accordance with this assumption. Holocene diatom flora should be further studied in terms of Holocene paleoceanography/paleoclimate.

The negligible occurrence of heavily silicified species, *Eucampia antarctica(=E. balaustium)*, also indicates that there has been no winnowing of sediments deposited. It is common in Antarctic regions that *E. antarctica* constitute a significant proportion in sediment in contrast to much less proportion in water due to its stronger test to winnowing by bottom currents (Truesdale and Kellogg, 1979). Comparing to the Quarternary sedimentation rate in the Antarctic region (4cm/1000 yr : Brewster, 1980), the high sedimentation rate of the study area is explained by no winnowing, bay environment mechanism and high production.

3. Characteristics of the Diatom Flora

Nitzschia is the dominant genus and comprises approximately 55 % of the diatom flora in the Maxwell Bay. Figure 3 shows that the genus increases in proportion toward deeper environment. For example, Station 1 (100 m deep) contains less than 50 %, Station 3 (350 m deep) approximately 55 %, and Station 2 (> 500 m deep) more than 60 %. The assumption is supported by the decrease of bottom dwelling species *Pseudogomphonema groenlandicum* toward deeper environments. Thus, the genus *Nitzschia* can be a candidate for quick assessment of the

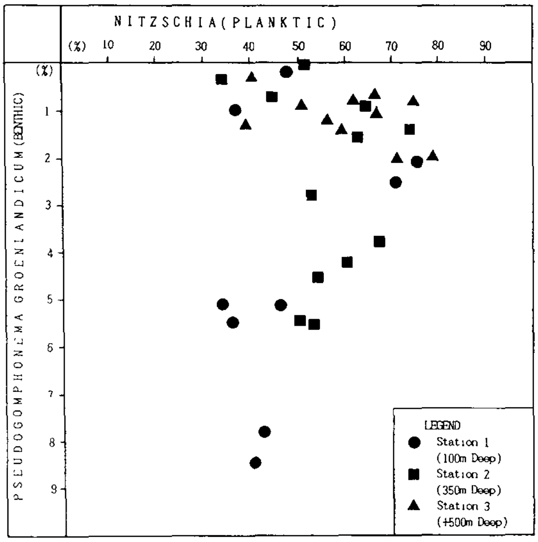

Fig. 3. Content of *Nitzschia* (planktic diatom) and *Pseudogomphonema groenlandicum* (benthic diatom) in the three different sedimentary environments (100m, 350m, +500m in depths).

depth of a sedimentary environment in Antarctic region even though it needs futher studies. The dominent species are *Nitzschia kerguelensis*, *N. curta*, *Thalassiosira antarctica*, and *T. gracilis* which comprise ca. 25 %, 18 %, 6 %, and 6 % respectively.

Conclusion

1. Every sediment contains well preserved and diverse diatom floras. These floras indicate that the sediments were deposited during Holocene and the productivity has been very high.
2. Middle to lower portion of the sediment cores were deposited during a warmer period than today. Assuming Fairbridge's (1961) sea level change curve is reasonable, sedimentation rate is inferred to 50 cm/1,000 yrs in the Maxwell Bay.
3. The genus *Nitzschia* comprises more than 50 % and increases in proportion toward deeper environment.
4. Dominant species are *Nitzschia kerguelensis*, *N. curta*, *Thalassiosira antarctica*, and *T. gracilis*.

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SPECIES REFERENCE LIST OF DIATOM TAXA OBSERVED

Achnanthes groenlandica (Cleve) Grunow : Hustedt, 1959, p.422, fig.874; Schmidt, 1874−1959, pl.418, figs.16−24; Kim and Park, 1988, p.141, pl.2, figs.4−6.

A. spp.

Actinocyclus actinochilus (Ehr.) Simonsen : Simonsen 1982, as *Charcotia actinohilus* (Ehr). Hustedt, p.771, pl.5, fig.5; Krebs, 1983, p.285, pl.1, fig.6; Kim and Park, 1988, p.141, pl.4, fig.4, pl.1, figs.14,15.

A. curvatulus Janish: Hustedt, 1930, p.538, fig. 307; Sancetta, 1982, p.222−224, pl.1, figs.1−3.

A. spp.

Amphora spp.

Asteromphalus parvulus Karsten: Hustedt, 1959, p.128, fig.91; Fenner et al., 1976, p.769, pl.4, figs.20,21; Kim and Park, 1988, p.143−144, pl.4, fig.5, pl.1, fig.13.

Bacillaria paxillifer (Müller) Hendey : Hendey, 1964, p.274; Germain, 1981, p.326.

Chaetoceros spp.

Cocconeis californica Grunow; Krebs, 1983, p. 285, pl.1, fig.7; Kim and Park, 1988, p.145, pl.3, fig.10.

C. costata Gregory: Hustedt, 1959, p.294–295, fig.785; Schmidt, 1874–1959, pl.189, fig.6,7; Kim and Park, 1988, p. 145, pl. 3, figs. 7, 8, 13, 14.

Remarks : Planktonic species (Fenner et al., 1976). Littoral on the coast of Europe from the Meditterranean to the Arctic Ocean (Hustedt, 1959).

C. disculoides Hustedt: Hendey, 1964, p.178, pl. 28, figs.21,22; Kim and Park, 1988, p.145, pl. 3, fig.11.

C. spp.

Corethron criophilum Castracane: Hendey, 1937, p.325; Manguin, 1960, p.259–261, pl.4, figs. 47–48, pl.26, figs.314–315, pl.30, fig.376.

Coscinodiscus marginatus Ehrenberg: Hustedt, 1959, p.416, fig.223; Kim and Barron, 1986, p.177, pl.3, figs.3,5.

C. stellaris Roper : Sancetta, 1982, p. 229, pl. 2, fig.12; Hustedt, 1959, p.396, fig.207; Kim and Park, 1988, p.147, pl.5, figs.1,2.

C. spp.

Diploneis spp.

Eucampia antarctica (Castracane) Manguin: Hendey, 1937, p.285–286, pl.13, figs.8–10; Priddle and Fryxell, 1985, p.66, figs.A–D; Fenner et al., 1976, as *E. balaustium* Castr., pl. 5, figs.7–9; Krebs, 1983, p.285, pl.3, figs.3a, b.

Grammatophora spp.

Gyrosigma spp.

Licmophora spp.

Navicula directa (Smith) Ralfs: Hendey, 1964, p.202; Fenner et al., 1976, p.774, pl.14, fig.7; Kim and Park, 1988, p.149, pl.3, fig.1.

N. directa var. *javanica* Cleve: Schmidt et al., 1874–1979, pl.25, figs.9–16.

N. radiosa Kützing: Germain, 1981, pl.70, figs.1–5; Schmidt, 1874–1959, pl.47, figs.50–52; Kim and Park, 1988, p.151, pl.3, fig.2.

N. spp.

Nitzschia angulata (O'Meara) Hasle: Hasle, 1972; Hasle, 1965 as *Fragilariopsis rhombica* Hustedt, p.24–26, pl.1, fig.6, pl.4, fig.19, pl.9, figs.1–6; Kim and Park, 1988, p.151, pl.1, figs.22,23, pl.1, figs.6,7,8.

N. curta (Van Heurck) Hasle: Hasle, 1972; Hasle, 1965, as *Fragilariopsis curta*, p.32–33, pl. 12, figs. 2–5, as *N. linearis* (Castr.) Hasle, p. 37–39, pl. 12, fig. 17, pl. 15, figs. 9–11, Kim and Park, 1988, p. 151–152, pl. 1, figs. 1–4, pl. 1, figs. 2, 3.

Remarks : Vertical terminal striae distinguish this species form *N. sublinearis*, the striae of which are all horizontal. *N. curta* has curved horizontal striae in the margin while *N. cylindrus* has straight striae.

N. cylindra (Grunow) Hasle: Hasle, 1972; Sancetta, 1982, p.232–233, pl.3, figs.6–7; Hasle, 1965. as *Fragilariopsis cylindrus* (Grun.) Krieger, p.34–37, pl.12, figs.6–12; Kim and Park, 1988, p. 152, pl. 1, fig. 12, pl. 1, fig. 1.

Remarks : Sancetts (1982) noted that the most distinctive trait of this species is the outline with parallel sides and very round apex. Defelice and Wise (1981) suggested that this species is probably conspecific with *N. curta*.

N. kerguelensis (O'Meara) Hasle: Hasle, 1972; Hasle, 1965 as *Fragilariopsis kerguelensis* O'Meara, p.14–18, pl.4, figs.11–18, pl.5, figs.1–11, pl.7, fig. 9; Fenner et al., 1976, p.776, pl.2, figs.19–30; Kim and Park, 1988, p.152, pl.1, figs.5–11, pl.1, figs.4,5.

Remarks : The dominant diatom in the Subantarctic region, some times comprising more than 70% of the diatom flora (Fenner et al., 1976; Defelice and Wise, 1981). Jacques (1983) cultured *N. kerguelensis* and found that its optimal growth rate (ca. 0.5 doubling /day) occurred at temperatures slightly above 5℃ and none survived above temperatures of 8–9℃. The northern limit of the Subantarctic boundary and diatomaceous sediments coincide with the 8℃ isotherm (Burckle and Cirilli, 1987; Burckle et al., 1987).

Although several diatomists report that *N. kerguelensis* is common to abundant even in 70°S Lat. (Defelice and Wise, 1981) and eastern Ross Sea (Truesdale and Kellogg, 1979), it seems due to abnormally higher water−temperature (ca. 2.5℃) resulted by polynya in the areas.

N. obliquecostata (Van Heurck) Hasle: Hasle, 1972; Hasle, 1965, as *Fragilariopsis obliquecostata* Van Heurck, p.18−20, pl.7, figs.2−7; Fenner et al., 1976, p.776−777, pl.2, figs.15−18; Kim and Park, 1988, p.152, pl.1, figs.18,19.

N. ritscheri (Hustedt) Hasle: Hasle 1972; Hasle, 1965, as *Fragilariopsis ritscheri* Hustedt, p.20−21, pl.1, fig.20, pl.4, figs.1−7, pl.7, fig.8.

Remarks: Endemic species in Antarctic shallow waters (Saar and Wolf, 1973; Fenner et al., 1976; Defelice and Wise, 1981).

N. separanda (Hustedt) Hasle: Hasle 1972; Hasle, 1965, as *Fragilariopsis separanda* Hustedt, p.26−27, pl.9, figs.7−10; Fenner et al., 1976, p.777, pl.1, figs.1−16, pl.2, figs.23−29; Kim and Park, 1988, p.152, pl.1, figs.14, 21, pl.1, fig.9.

N. sublinearis (Van Heurck) Hasle: Hasle, 1972; Hasle, 1965, p.27−30, pl.7, figs.1−10, pl.12, fig.1, pl.17, fig.1; Kim and Park, 1988, p.153, pl.1, figs.13,20.

N. spp.

Odontella aurita (Lyngbye) Agardh: Hustedt, 1930, p.846, fig.501; Schmidt, 1874−1959, pl. 120, figs.5−10, pl.122, figs.1−8,28.

O. weissflogii (Janish) Grunow: Priddle and Fryxell, 1985, p.68−69, figs.A−H; Schmidt et al., 1874−1959, pl.141, figs.12−46.

Remarks: Vegetative cells almost rectangular in broad−girdle view, with very low mammiform elevations on the valves. The four (usual number) labiate processes have prominent external tubes. Cells often weakly silicified, ornamentation weakly striae. The resting spore is a smooth lozenge shape. The two valves are rotated on the pervalvlar axis. The cell is more heavily silicified, with only two labiate processes which lack external tubes (Priddle and Fryxell, 1985).

Pleurosigma spp.

Pseudogomphonema groenlandicum (Ost.) Medlin: Medlin and Round, 1986, p.218, figs.31−33, 73−80; Schmidt, 1874−1959, as *Gomphonema groenlandicum* Ost. pl.213, fig.43; Kim and Park, 1988, p.153, pl.2, figs.14−17.

Rhizosolenia alata Brightwell: Fenner et al., 1976, p.778, pl.13, fig.1; Hustedt, 1930, p.600−601, fig.344.

R. alata f. *inermis* (Castracane): Fenner et al., 1976, p.778, pl.13, fig.2.

R. hebetata f. *hiemalis* Gran: Hasle, 1974, p.106, pl.2, figs.21−26; Schmidt et al., 1874−1959, pl.319, figs.4−16; Kim and Park, 1988, p. 153, pl.2, fig.9.

R. hebetata f. *semispina* (Hensen): Hustedt, 1930, p.592, fig.338.

R. styliformis Brightwell: Hustedt, 1930, p.584−588, fig.333.

Roperia tesselata (Roper): Fenner et al., 1976, p.779, pl.12, figs.1−14.

Rhoicosphaenia spp.

Thalassiosira antarctica Comber: Villareal and Fryxell, 1983, p.164, figs.1−5; Johansen and Fryxell, 1985, p.158, figs.15−17, 37−39; Sancetta, 1982, p.240, pl.4, figs.14−15, pl.1, fig.10.

T. frenguelliopsis Fryxell and Johansen: Johansen and Fryxell, 1985, p.168, figs.6,67, 68,71,81; Kim and Park, 1988, p.154, pl.5, figs.3−6.

T. gracilis (Karsten) Hustedt: Hustedt, 1958, p. 109−110, figs.4−7; Fryxell and Hasle, 1979, p.382−384, figs.12−22; Kim and Park, 1988, p.154, pl.4, figs.8, 11, 12, pl.1, figs.11, 12.

T. gracilis var. *expecta* Fryxell and Hasle: Fryxell and Hasle, 1979, p.384−386, figs.23−28; Kim and Park, 1988, p.154, pl.4, fig.12.

T. lentigenosa (Janisch) Fryxell: Johansen and Fryxell, 1985, p.170, figs.7, 49,50; Hustedt, 1958, as *Coscinodiscus lentigenosus*, p.116, pl. 4, figs.22－25; Kim and Park, 1988, p.154, pl. 4, figs.6,7.

T. leptopus (Grun.) Hasle: Hasle and Fryxell, 1977, p.20, figs.1－14.

T. spp.

Thalassiothrix spp.

Trachyneis spp.

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Editor reports with sadness that our friend, Dr. Won Hyung Kim left us on summer, 1991 after a battle against cancer. Won Hyung was one of the leading scientists and profoundly influenced on the field of micropalaeontology. Editor's regret is that he will not see his last and great contribution in this journal. We will remember him forever through his work.

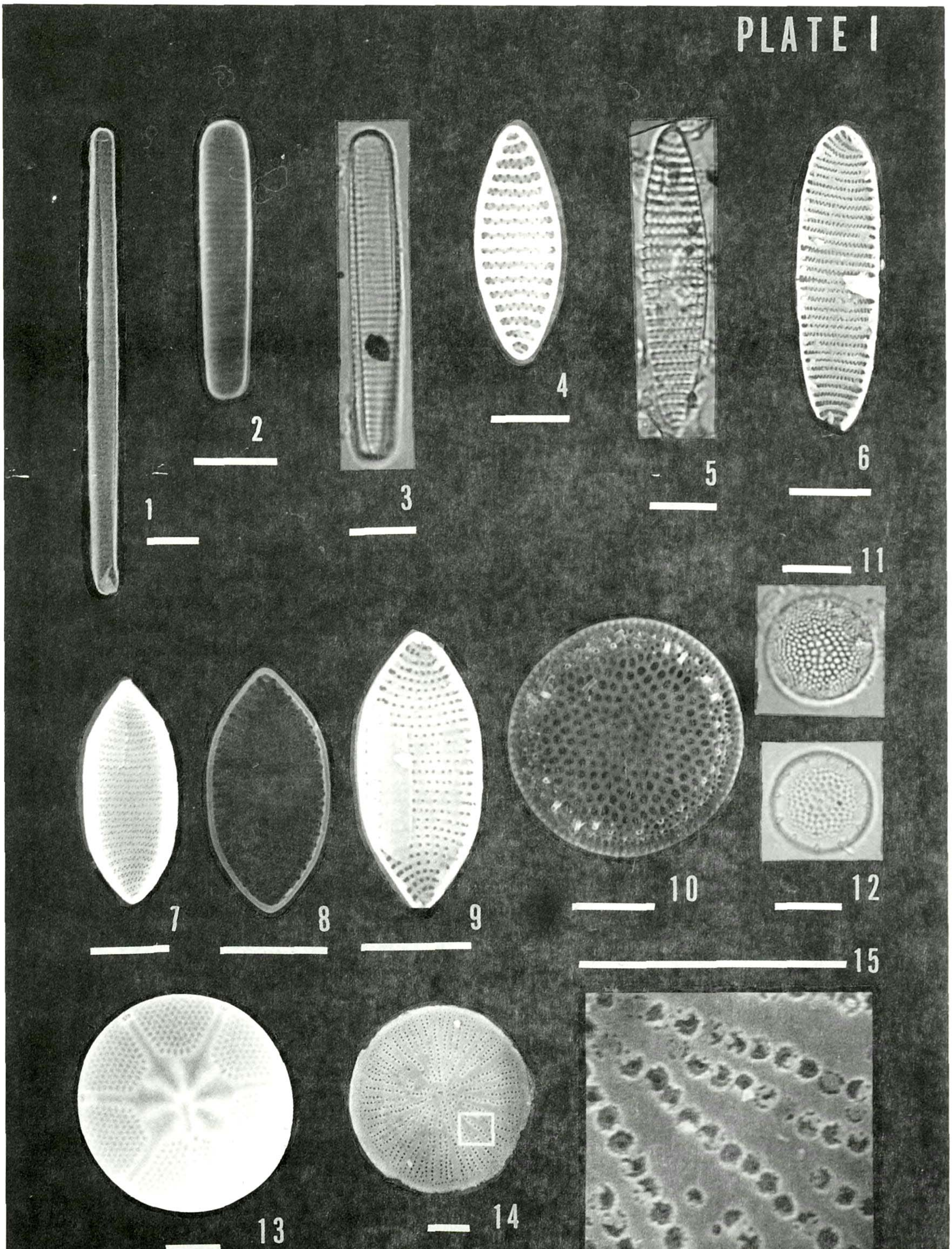
PLATE I
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PLATE I : Diatoms from the Maxwell Bay, King George Island, Antarctica (scale=10μm).

Fig. 1 . *Nitzschia cylindra* (SEM)
Figs. 2, 3. *N. curta* (Fig. 2 : SEM ; Fig. 3 : LM)
Figs. 4, 5. *N. kerguelensis* (Fig. 4 : SEM ; Fig. 5 ; LM)
Figs. 6, 7, 8. *N. angulata* (SEM)
Fig. 9 . *N. separanda* (SEM)
Fig. 10 . *Thalassiosira antarctica* (SEM)
Figs. 11, 12. *T. gracilis* (LM)
Fig. 13 . *Asteromphalus parvulus* (SEM)
Fig. 14 . *Actinocyclus actinochilus* (SEM)
Fig. 15 . Enlarged areolae of Fig. 14 (SEM)