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Holocene Diatom Flora and Sedimentary Environment of the Echigo Plain, Central Honshu, Japan
– Part 1 The Analysis of Fukushima-gata Well Core –

by

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Abstract

Based on ecological spectra, diatoms of the Fukushima-gata well core are grouped into five diatom assemblages, namely marine, marine-brackish, brackish, fresh-brackish and fresh water diatom assemblages. The change of these assemblages is divided into six diatom divisions in ascending order: (1) Fresh water diatom division 1 (FD1) is characterized by a fresh water diatom assemblage. (2) Transitional division 1 (Tr1) is characterized by the alternation of marine and fresh water diatom assemblages. (3) Marine diatom division 1 (MD1) is dominated by a marine diatom assemblage reflecting Holocene transgression. (4) Transitional division 2 (Tr2) which composes of marine and fresh water diatom assemblages indicates a regression after the culmination of the maximum Holocene transgression. (5) Marine diatom division 2 (MD2) indicating a small transgression is dominated by marine diatoms. (6) Fresh water diatom division 2 (FD2) is dominated by fresh water diatoms. It is probably that each diatom division closely related to the development of sedimentation was caused by Holocene sea level and geomorphological changes.

Key words : Holocene, Diatom, Sedimentary Environment, Echigo Plain, Niigata

I. Introduction

The latest Pleistocene and Holocene deposits are well distributed under all of Japanese alluvial plains. The Echigo Plain is one of wide alluvial plains in Japan and located in the coast along the Sea of Japan. The formative history of the plain is continuously recorded in subsurface deposits. The latest Pleistocene and Holocene deposits of the Echigo Plain are 100 to 150 m in thickness

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(Kobayashi *et al*., 1976). Since 1956, hazards of land subsidence have widely occurred in and around Niigata city. The environmental studies of Holocene deposits have been done by Niigata Quaternary Research Group (1972) under a link of researches as a countermeasure. One of them is a diatom floral study for an analysis of depositional environment (Niigata Diatom Research Group,1976). Moreover, Ohira (1992) reported on the formative history of the northern part of the Echigo Plain. Diatom fossils of boring wells were well used for an environmental analysis. Diatom fossils have played an important role to clarify the change of sedimentary environments caused by Holocene sea level changes in Japan (Sato and Kumano, 1985, 1986, 1990; Kashima *et al*., 1988, 1990,1992; Saito *et al*., 1989; Kumano *et al*., 1990, 1992).

Y. Kamoi, I. Kobayashi and colleagues have been continuing a research of palaeogeographical and palaeontological problems in the Niigata Plain since 1970 (Kamoi *et al*., 1990, 1995). The author's study is one of these fundamental works of the Holocene Niigata sedimentary basin.

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II. Locality and geological outline

The Fukushima-gata well site (No. 61-1) is located near the Fukushima-gata Lake, Toyosaka City, Niigata Prefecture, Central Honshu (Fig. 1). It is in the northern part of the Echigo Plain and inside the New Sand Dune I-1 (Niigata Ancient Dune Research Group, 1974) that is the oldest sand dune in the Echigo Plain.

The latest Pleistocene and Holocene deposits in the Echigo Plain are mainly divided into two formations, namely Shirone and Kurotori Formations in ascending order (Aoki and Nakagawa,1980). The sedimentary sequence of this well mainly belongs to the Shirone Formation. Kamoi *et al*. (1990, 1995) reported the geological section and ^{14}C datings of alluvial strata around the Fukushima-gata Lake (Fig.2).

The geologic column of the well is examined 82.4 m in length and divided into four units, namely Unit I to Unit IV in ascending order. Unit I (-82.4 to -58.6m) composes of three sedimentary cycles (Ia - Ic) from medium sand to sandy silt or silty fine sand with top peat except cycle Ib. The thickness of one cycle is about 6 to 10 m. Unit II (-58.6 to -33.2 m) composes of the alternative beds of sandy silt and fine sand with humus matters. They form five sedimentary cycles (IIa - IIe) from sandy silt to fine sand beds. Unit III (-33.2 to -12.4 m) composes of a lower sandy silt bed with rare humus matters

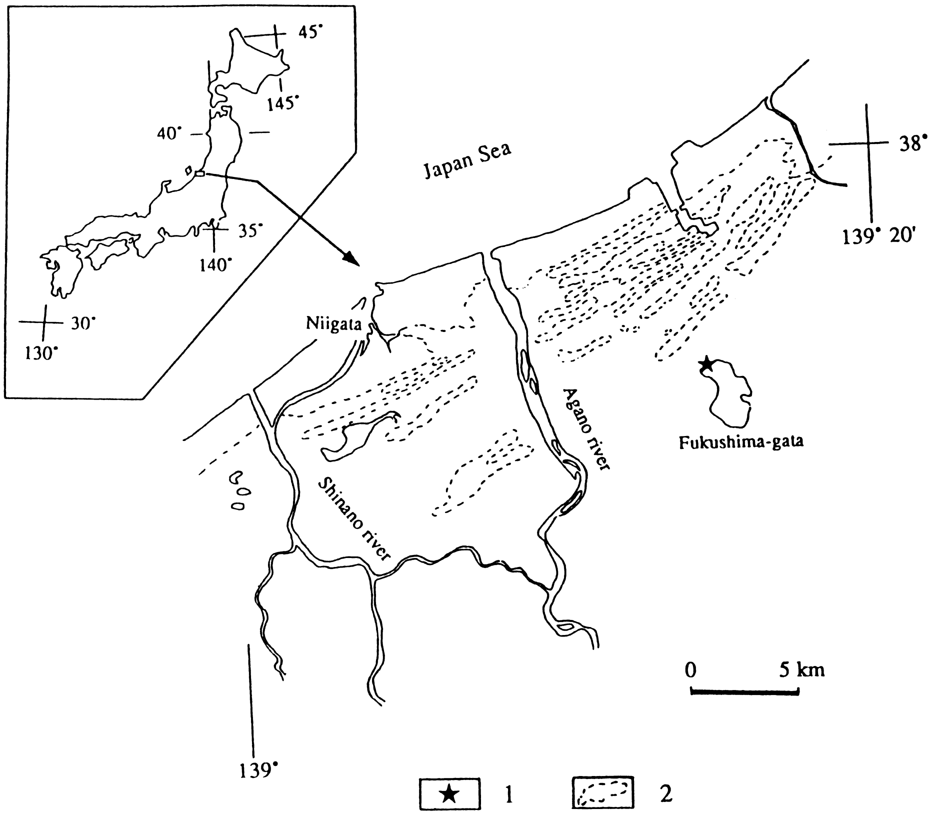

Fig. 1. The index map. 1. Location of Fukushima-gata well, 2. Sand dune.

(IIIa) and an upper massive clayey silt bed with shell fragments (IIIb). Unit IV (-12.4 to 0 m) composes of a lower fine sand bed (Ia) and an upper silt bed (Ib).

The ages of carbon datings are about 30,000 yr.B P. at near -60 m and about 5,000 yr.B P. at near -12 m. Due to these data, the strata of the Fukushima-gata well are in Late Pleistocene and Holocene times. There is the Late Pleistocene and Holocene boundary between Unit I and II. It is inferred that Unit I is unconformably covered by Unit II. There is a long time-interval between two units.

The Fukushima-gata core gave a good chance to estimate the period from transgression to regression in Holocene on the basis of diatom assemblages.

III. Material and method

The samples for several kinds of analyses were collected by our research group, and 63 sampling points for diatom analysis were obtained from -1.7 to -79.6 m. Each sampling point is shown in Fig.2.

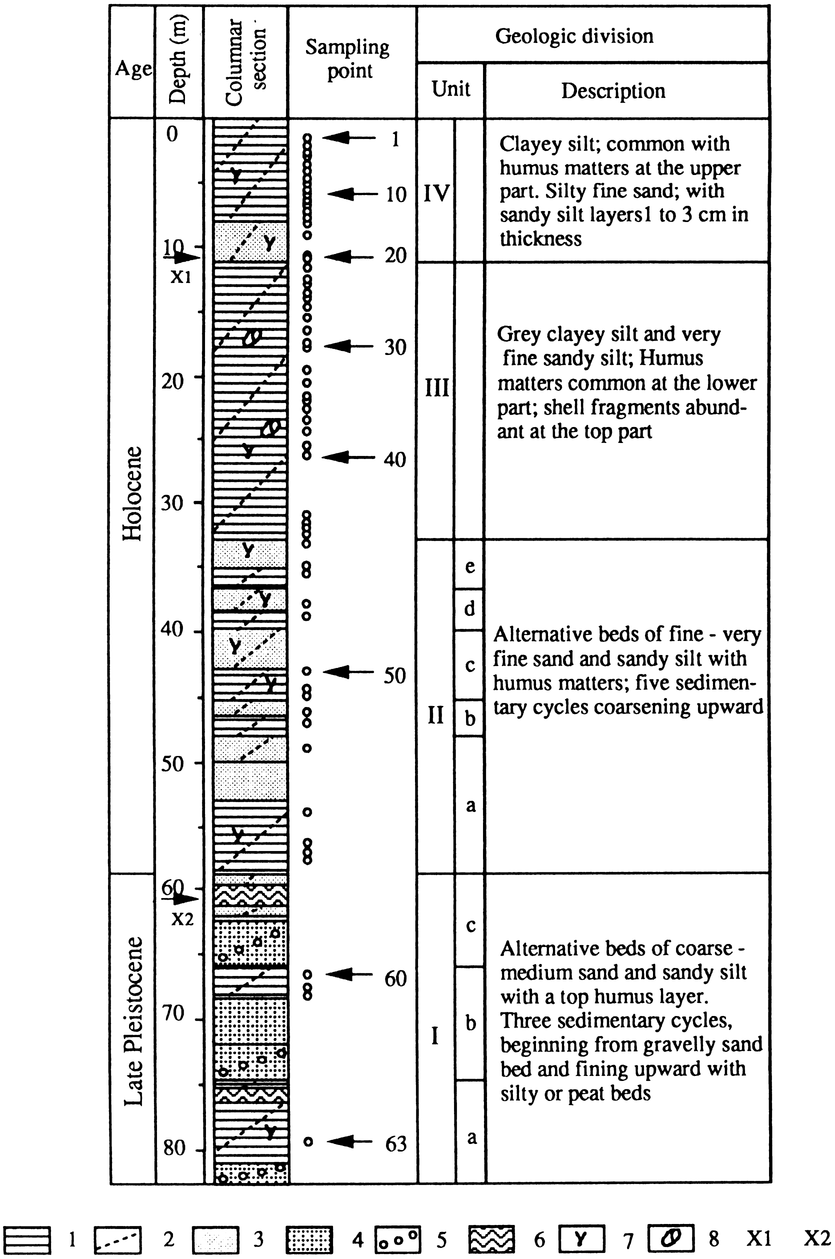

Fig. 2 . The geologic column of a well core and sampling points.
1. Clay, 2. Silt, 3. Fine sand, 4. Medium-coarse sand, 5. Gravel, 6. Peat, 7. Plant fragment, 8. Shell fragment. X1 and X2 show the location of ^{14}C datings 5,000 and 30,000 yr.BP. respectively.

Each sample of approximately 5 g weight was boiled with 15% hydrogen peroxide to remove organic matter, and then dispersed in 250 ml of distilled water. After repeated decanting and settling to remove clay-sized particles, the solution was brought to near neutral pH. An appropriate amount of the cleaned materials was dried on a glass slide and mounted in Pleurax which is commercially named Mountmedia. 200-300 frustules of diatoms in each sample were counted and identified by the use of an optical microscope.

Kashima's reports (1985-1986) are mainly taken for diatom identifications.

IV. Result of analysis

15 genera and 54 species are discriminated in this study. The list of diatom flora is shown in Table 1. The change of individual number of frustule is drawn in Fig.3. On the basis of ecological spectra, these diatoms are grouped into five assemblages, namely marine, marine-brackich, brackich, fresh-brackish and fresh water assemblages.

1. The vertical change of individual number

Unit I is very rare except a few horizons. Diatom frustules are not found in each top humus bed. Sandy beds contain rarely frustules, but the sandy silt bed at -67.6m shows its high number of frustules (569 frustules). Sandy silt beds of Unit II also contain common frustules. Unit III comprises very abundant frustules in all beds except samples of -27 to -29 m in which diatom is absent. The curved line of individual number has a broad abundant section at -22.0 to -13.6 m (510 to 527 frustules). Unit IV contains abundant of frustules and the number of frustules gets the highest at -6.8 m (573 frustules). The individual number gradually increases towards an upper horizon.

2. Characteristic species of each assemblage

Marine diatom assemblage includes two different groups of marine planktonic and benthic diatoms. The former is representative of *Actinocyclus* sp., *Thalassiosira* spp. and *Thalassionema nitzschioides*, and the latter is of *Amphora* spp., *Diploneis suborbicularis*, *Nitzschia constrista*, *N. granulata*, *N. pauduriformis* and *Navicula marina*.

Marine-brackish benthic diatom assemblage mainly comprises *Achnanthes brevipes, Diploneis smithii* and *Cocconeis scutelum*.

Brackish water diatom assemblage mainly comprises *Cyclotella caspia* and *Diploneis pseudovalis*.

Fresh-brackish water diatom assemblage comprises *Gyrosigma distortum, Rhopalodia gibberula, Roicosphenia curvata, Navicula* cf. *peregrina* and *N. levidensis*.

Fresh water diatom assemblage comprises *Cymbella* spp., *Pinnularia* spp., *Synedra ulna, Eunotia flexuosa, E. pectinalis, Gomphonema acuminatum* and *G. constrictum*.

Table 1. The list of diatom flora.

Habitat	Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Habitat	Species name / Depth (m)	1.7	2.5	2.8	3.0	3.6	4.0	4.7	5.0	5.5	5.8	6.0	6.5	6.7	6.8	7.0	7.5	7.8	8.5	9.5	10.5	11.0	11.8	12.6	12.8	13.6	14.0	14.8	15.8	16.8	17.6	18.0
Marine planktonic	*Actinocyclus* sp.	-%	-	-	-	0.4	0.3	0.6	0.3	2.8	3.5	4.3	6.1	6.6	6.6	2.7	2.8	3.2	0.6	2.0	0.9	0.8	1.8	0.9	0.9	2.0	3.9	5.6	5.3	0.5	0.7	0.8
	Actinoptychus serarius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	0.9	0.2	0.5	-	0.4	0.5	0.4	0.4
	Thalassionema nitzschioides	0.2	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.9	3.0	1.4	2.4	2.5	2.7	1.0
	Thalassiosira spp.	-	0.6	-	-	5.2	4.0	2.1	1.5	1.6	1.9	1.4	2.7	1.4	0.5	2.4	1.4	5.1	1.5	6.8	10.7	2.3	3.6	4.4	4.7	3.1	10.3	2.3	4.1	9.9	5.6	7.8
Marine benthic	*Amphora* spp.	0.2	0.3	-	-		1.0	0.9	0.5	0.8	-	2.0	-	0.6	1.9	2.1	1.9	1.6	1.2	2.0	2.7	0.8	2.2	4.0	3.8	5.7	5.0	10.1	6.3	6.1	5.3	7.2
	Caloneis liber	-	0.3	-	-	0.8	1.0	0.3	0.3	0.3	-	-	-	-	0.4	0.3	0.3	-	-	0.3	-	0.8	0.4	0.4	0.6	0.6	0.9	0.9	1.4	1.0	0.9	0.6
	Dimeregramma minor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	0.9	1.0
	Diploneis suborbicularis	-	-	-	-	0.8	-	-	-	1.8	3.2	10.3	5.1	16.5	19.2	7.2	11.1	22.9	0.3	0.3	-	-	3.3	1.3	6.8	6.8	6.9	2.5	2.0	1.8	2.4	2.0
	Grammatophora oceanica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.4	-	-	-	-	-	-
	Navicula spp.	-	-	-	-	-	-	-	-	-	-	-	-	0.6	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-
	Navicula liroides	-	-	-	-	-	-	-	-	-	0.6	-	-	0.3	0.4	-	-	-	-	-	-	-	-	-	1.2	1.6	1.1	0.3	0.8	1.0	0.7	0.8
	Navicula marina	-	-	-	-	-	-	-	-	1.6	0.3	4.6	1.4	4.3	0.7	0.5	1.1	0.8	-	-	-	-	-	0.4	1.2	2.1	1.1	3.9	2.0	0.5	-	3.9
	Nitzschia coarctata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2	2.5	0.3	2.2	0.5	1.6	1.0
	Nitzschia constricta	-	-	-	-	-	-	-	-	-	-	-	-	-	3.0	-	-	-	-	-	-	-	-	-	-	4.3	2.5	0.9	8.0	3.5	1.1	2.3
	Nitzschia granulata	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	-	-	0.8	0.7	0.6	-	-	5.8	3.9
Marine-brackish benthic	*Nitzschia lanceola*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
	Nitzschia pauduriformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6	6.2	-	0.6	-	0.4	1.0
	Nitzschia sp.	0.2	0.3	0.4	-	-	0.3	-	-	5.4	1.9	2.0	0.7	3.4	0.4	2.1	2.8	1.6	0.6	0.7	-	0.3	2.2	0.4	0.3	1.6	2.1	0.9	4.3	0.5	1.6	2.0
	Plagiogramma sp.	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	1.1	-	-	-	-	-
	Surirella fatuosa	-	-	-	-	0.4	-	-	-	7.7	4.8	5.1	5.4	8.0	2.4	3.2	5.8	1.6	-	-	-	-	0.4	-	-	1.0		0.6	2.4	0.3		0.2
	Achnanthes brevipes	-	1.2	0.2		0.4		0.9	0.3	1.0	0.6	0.3	1.0	1.1	0.9	2.9	1.4	2.4	2.7	2.7	6.7	1.5	5.8	4.9	6.8	4.7	10.5	4.5	3.9	3.8	2.2	3.3
	Achnanthes hauckiana	-	-	-	-	-	-	-	-	-	-	-	-	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.8	0.5	-	-
	Cocconeis scutellum	-	-	-	-	-	-	-	0.3	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-	2.5	2.7	-	0.6	0.3	-	-
	Diploneis smithii	-	0.3			0.4			0.8	5.2	0.6	8.0	0.7	6.8	11.0	0.8	3.9	0.8	1.2	1.0	1.8	0.3	1.1	8.8	5.3	5.5	3.7	6.8	4.7	5.1	7.8	8.0
Brackish water	*Cyclotella caspia*	0.2	0.9	0.2	0.3	0.4	1.7	0.6	1.3	1.0	1.0	0.9	1.7	0.6	4.7	0.5	0.6	1.2	0.6	1.4	2.7	0.5	2.2	0.9	0.6	2.0	1.1	1.1	2.2	1.8	0.7	1.2
	Diploneis pseudovalis	-	-	-	-	0.4	0.3	-	0.8	5.9	1.3	4.6	2.7	4.3	4.4	-	2.5	1.2	0.6	0.3	0.9	0.5	1.8	2.2	0.9	1.8	1.4	2.5	1.2	1.3	2.4	2.5
	Synedra pulchella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.9	0.6	-	-	-
Fresh-brackish water	*Bacillaria paradoxa*	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	0.6	2.3	1.4	0.3	1.4	0.5	0.9	0.4
	Epithemia sorex	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	0.3	-	-	0.3	-	-	-	-
	Gyrosigma strigile	1.4	2.1	0.2	2.1	3.0	4.7	3.6	1.5	2.6	0.6	0.9	0.3	0.6	0.2	0.5	1.1	-	1.2	-	-	-	0.4	-	0.3	0.2	0.7	0.6	-	0.3	1.1	1.2
	Gyrosigma distortum	-	2.7	0.4	0.3	2.6	6.6	6.8	7.5	2.6	0.6	2.6	0.3	0.6	0.9	-	2.2	-	-	0.3	0.9	0.8	-	-	0.3	0.8	-	-	1.4	1.5	-	0.8
	Navicula cf. *peregrima*	-	-	-	-	-	-	0.3	1.3	7.0	3.9	4.8	3.1	5.7	3.8	1.1	3.6	1.2	0.9	-	-	-	-	1.3	-	0.4	-	-	0.4	-	0.4	0.2
	Navicula pusilla	-	-	-	-	-	-	-	-	-	0.6	-	-	-	0.9	-	0.6	-	0.6	-	-	-	-	0.4	-	0.6	0.2	1.1	0.6	0.3	0.2	1.2
	Nitzschia levidensis	-	-	-	0.3	0.4	-	-	0.8	0.3	0.3	-	-	0.3	-	-	-	-	-	-	-	-	0.4	0.9	0.3	3.3	3.0	0.9	9.2	3.0	3.8	1.2
	Nitzschia parvula	5.1	0.9	0.7	2.8	1.9	0.3	-	0.5	0.5	-	1.1	-	0.6	-	1.1	0.6	-	0.6	0.7	0.5	0.5	0.7	-	0.3	1.8	0.7	0.3	0.8	-	0.4	2.5
	Rhopalodia gibberula	-	1.5	1.3	-	-	0.7	-	2.3	0.5	-	-	-	-	0.9	-	0.8	-	0.9	1.0		1.0	1.1	0.4	0.9	9.0	8.5	1.4	3.3	1.0	1.3	3.9
	Roicosphenia curvata	-	2.7	0.7	2.5	4.9	10.0	13.9	7.5	2.8	5.1	3.7	6.8	3.7	1.2	3.7	4.2	1.2	3.5	8.8	8.9	3.3	5.5	4.0	2.7	3.5	1.4	0.9	2.9	3.5	2.9	2.1
	Achnanthes lanceolata	-	-	-	-	-	-	0.9	-	-	-	-	-	-	0.7	-	-	0.4	-	-	-	-	-	-	-	0.8	-	-	-	0.3	-	0.2
	Achnanthes spp.	4.7	5.5	6.2	4.3	3.4	5.3	3.0	1.3	1.0	0.6	0.6	0.7	0.3	1.1	1.3	0.3	-	1.5	1.7	1.3	-	2.2	2.2	0.9	1.2	0.2	0.6	1.0	1.0	0.4	0.4
	Actinella sp.	5.1	0.9	1.6	3.7	-	0.3	1.5	1.3	1.3	4.2	0.9	1.7	0.3	1.8	0.8	1.4	4.0	-	1.0	1.3	2.0	0.4	1.8	0.6	0.4	0.2	-	0.4	0.5	-	0.8

Fresh water	*Amphora lybica*	0.4		0.4	0.6	1.5	1.0	0.6	0.5	1.3	0.3	0.3	0.3	_	0.4	_	0.6	0.4	4.4	_	_	0.5	0.7	0.4	_	_	_	_	0.4	0.3	0.7	0.4
	Aulacoseira granulata	0.4	0.9	0.7	0.6	0.8	2.0	5.3	5.8	2.3	1.6	3.7	2.4	2.3	5.6	0.8	2.8	0.8	_	0.7	0.9	2.0	1.1	0.9	0.6	1.8	2.3	1.7	2.2	1.8	0.9	1.8
	Caloneis silicula	1.2	1.5	0.7	0.9	0.4	0.3	0.3	0.3	0.5	_	_	_	_	_	0.3	0.3	_	_	_	_	0.3	_	0.4	_	_	_	_	_	_	_	_
	Cocconeis placentula	2.9	4.9	3.1	3.4	1.9	2.0	1.5	0.8	2.1	1.3	0.9	0.3	0.9	1.2	3.7	1.4	0.8	4.7	6.8	4.5	5.3	3.6	4.9	2.1	1.6	0.7	1.1	1.2	2.0	1.3	0.8
	Cymbella cuspidata	0.2	0.9	0.4	1.2	1.9	1.0	0.6	1.5	1.3	4.2	0.6	0.7	0.6	0.2	1.3	0.8	0.8	0.9	0.3	0.9		1.1	0.9	0.9	0.4	0.5	0.6	0.2	_	0.2	_
	Cymbella minuta	3.1	0.9	1.6	1.2	1.1	1.0	_	0.5	0.3	_	_	_	_	_	_	0.3	_	0.3	0.3	_	0.8	0.4	0.4	0.6	_	_	_	_	0.3	_	_
	Cymbella sp.	11.9	5.2	5.3	5.2	2.6	3.7	5.3	3.0	2.6	3.2	2.3	3.1	2.6	0.5	4.6	_	1.6	3.8	4.8	3.1	2.8	1.5	2.2	3.0	0.4	0.5	1.7	0.6	3.5	4.0	0.6
	Cymbella turgidula	_	3.7	4.4	4.6	1.9	0.7	_	1.5	0.5	0.6	_	_	_	_	6.7	4.2	3.6	16.2	11.5	4.0	9.0	4.7	5.3	3.0	0.6	0.9	0.3	0.4	5.6	5.3	1.4
	Diploneis ovalis	_	0.3	_	_	_	0.3	_	0.3	2.6	0.6	2.3	1.7	1.1	0.5	0.3	0.6	0.4	_	0.3	0.5	0.3	0.7	0.9	0.3	0.2	0.2	0.6	0.2	0.3	0.2	0.4
	Epithemia adnata	15.0	4.9	3.8	7.7	4.5	5.3	1.2	1.0	2.6	3.2	3.1	4.4	3.1	1.4	3.7	1.9	1.6	3.5	4.1	3.1	7.5	2.9	6.6	5.6	3.3	1.4	3.7	1.2	1.3	4.4	3.7
	Eunotia flexuosa	1.2	4.0	1.1	0.6	0.4	1.0	0.6	1.8	0.3	0.3	0.3	_	0.9	_	2.4	1.1	_	4.7	3.4	1.3	1.0	4.7	1.3	3.0	0.2	_	1.4	0.6	4.8	4.7	2.7
	Eunotia pectinalis	2.1	4.0	0.7	2.8	1.9	2.7	1.8	0.8	2.1	2.6	1.4	3.1	0.9	1.2	1.3	0.6	1.6	_	1.4	1.3	2.0	1.5	2.6	0.3	_	0.5	0.3	_	1.0	1.1	_
	Eunotia praerupta	_	_	_	0.9	3.0	0.7	2.1	1.0	_	_	_	0.7	0.6	_	1.3	0.3	_	0.9	0.7	0.5	_	0.4	0.9	0.9	_	0.2	_	0.2	0.3	_	_
	Eunotia spp.	1.0	0.9	6.4	4.3	3.0	0.3	0.3	1.0	0.5	1.6	0.9	0.7	0.3	0.5	2.4	0.8	1.6	1.8	1.4	0.5	0.5	1.8	2.2	1.5	0.2	_	1.7	0.2	1.3	1.6	0.6
	Frustulia rhomboides	0.4	2.4	4.9	2.8	1.5	2.3	7.4	1.8	1.6	_	0.3	_	0.6	_	1.1	0.6	0.8	2.7	1.7	0.5	0.5	1.1	0.4	0.6	0.6	0.5	1.4	0.2	1.0	2.2	1.2
	Gomphonema spp.	13.3	8.8	14.4	11.9	15.7	6.6	3.6	2.3	2.8	4.8	2.3	3.1	3.7	1.8	3.5	7.5	2.8	5.9	3.4	6.3	1.0	2.9	6.6	2.4	0.6	0.2	1.7	1.6	2.0	1.1	1.6
	Gyrosigma scalproides	_	1.8	_	0.3	2.3	4.3	5.6	4.5	1.3	2.6	1.1	2.0	0.6	_	0.3	1.1	_	_	_	_	1.0	1.1	_	0.6	0.4	_	0.6	0.2	0.8	0.9	1.0
	Hantzschia sp.	_	_	_	0.3	0.4	0.3	0.6	0.3	0.3	0.6	1.1	2.0	0.3	0.5	_	1.4	2.0	_	0.3	_	0.5	_	_	_	_	0.5	1.4	0.2	0.8	_	0.2
	Melosira italica	_	_	0.4	_	_	_	_	15.0	3.1	1.9	4.6	4.1	1.4	0.5	3.7	5.6	2.8	_	2.4	2.7	1.0	5.8	1.3	3.8	0.8	0.5	18.3	0.8	_	0.4	5.8
	Meridion circulare	_	0.6	0.7	_	_	_	0.3	0.3	0.5	_	0.3	_	_	0.4	_	_	_	_	_	_	_	0.4	0.4	0.6	_	_	0.3	0.2	0.3	0.2	0.2
	Navicula americana	0.6	_	0.2	0.6	0.8	0.3	_	0.3	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
	Navicula radiosa	5.7	5.8	0.9	0.9	1.1	3.3	1.8	1.8	5.2	4.2	3.7	0.7	1.7	3.5	0.5	3.6	0.8	1.8	1.0	1.8	2.0	0.4	1.3	0.9	1.4	1.1	1.7	2.5	0.5	0.9	1.4
	Navicula sp.	4.9	3.0	5.8	4.0	2.6	2.0	3.6	5.0	2.6	2.2	1.4	1.7	1.4	3.5	0.8	1.4	3.6	2.4	0.7	0.5	5.0	2.9	1.8	1.2	2.1	1.1	0.9	1.4	2.3	1.8	1.2
	Neidium iridis	0.8	1.8	1.3	0.3	1.1	0.7	1.2	0.8	0.5	_	_	_	_	0.4	0.3	0.3	_	0.6	_	_	1.0	_	_	_	_	_	_	_	_	_	_
	Nitzschia palea	1.4	1.5	4.9	2.5	0.8	1.0	0.9	0.5	_	0.6	_	1.0	_	_	0.3	_	_	_	0.3	_	1.3	0.4	2.6	0.6	0.8	0.7	0.6	1.2	1.3	0.2	0.4
	Pinnularia spp.	6.4	7.3	12.8	11.0	12.4	7.6	7.7	6.5	4.1	16.0	4.8	12.5	1.7	1.1	5.6	6.1	5.5	3.8	4.8	5.8	3.5	4.7	4.4	6.5	1.8	0.9	2.3	1.4	2.5	3.8	1.4
	Synedra ulna	1.8	0.6	_	1.2	1.5	0.3	1.5	0.8	0.3	0.3	0.3	0.3	0.6	_	1.1	_	_	_	0.3	_	_	_	0.9	1.2	0.6	_	_	0.2	0.8	_	0.4
	Tabellaria flocculosa	3.3	10.3	2.9	4.6	5.6	8.6	5.6	4.8	2.8	7.1	1.4	7.8	2.3	1.8	14.2	2.2	9.5	18.8	14.9	18.8	31.6	16.4	7.1	12.4	2.0	1.4	1.4	2.7	8.9	7.8	3.3
	Tabellaria fenestrata	2.7	1.2	6.6	3.4	0.4	0.3	0.9	0.5	_	_	0.6	_	_	_	0.3	_	_	_	_	_	_	_	_	_	_	0.2	0.3	_	_	_	0.2
	unknown	2.1	1.5	3.5	5.8	3.4	3.3	4.7	5.5	2.3	3.2	4.6	4.1	5.7	3.3	5.9	4.4	7.9	4.7	3.1	4.0	4.3	3.6	3.5	5.6	3.9	2.1	4.2	2.9	2.8	1.3	3.9
Percentage	Marine planktonic diatoms	0.2	0.9	_	_	5.6	4.3	2.7	1.8	4.4	5.5	5.7	8.8	8.0	7.2	5.1	4.2	8.7	2.1	8.8	11.6	3.0	5.5	5.3	6.5	8.2	17.6	9.3	12.1	13.4	9.3	9.9
	Marine benthic d.	0.4	1.2	0.4	_	1.9	2.3	1.2	0.8	17.5	10.9	23.9	12.5	33.6	30.0	15.5	23.1	28.9	2.1	3.4	2.7	2.3	8.4	6.6	14.5	27.9	30.1	20.9	29.9	15.2	20.7	26.1
	Marine-brackish benthic d.	_	1.5	0.2	_	0.8	_	0.9	1.3	6.2	1.3	8.3	1.7	8.6	12.4	3.7	5.3	3.2	3.8	3.7	8.5	1.8	6.9	13.7	12.1	12.7	16.9	11.3	10.0	9.6	10.0	11.3
	Brackish water d.	0.2	0.9	0.2	0.3	0.8	2.0	0.6	2.0	7.0	2.2	5.4	4.4	4.8	9.1	0.5	3.1	2.4	1.2	1.7	3.6	1.0	4.0	3.1	1.5	3.7	3.0	4.5	3.9	3.0	3.1	3.7
	Fresh-brackish water d.	6.6	10.0	3.3	8.0	12.7	22.3	24.6	21.3	16.5	11.2	13.1	10.5	11.4	8.4	6.7	13.1	2.4	7.7	10.9	10.3	5.5	8.0	7.1	5.6	21.8	15.8	5.6	20.0	10.1	11.1	13.4
	Fresh water d.	90.6	83.9	92.3	85.9	74.9	65.8	64.5	67.5	46.1	65.7	39.0	58.0	27.9	29.0	62.6	46.9	46.3	78.5	68.5	59.4	82.2	63.6	60.8	54.3	21.1	14.6	44.2	21.1	45.6	44.4	31.5

Habitat	Sample number	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
	Species name / Depth (m)	19.6	20.6	21.8	22.0	22.6	23.6	24.6	25.6	26.0	30.8	31.6	32.0	32.7	33.0	35.0	35.6	38.0	38.6	43.0	44.8	45.0	46.6	47.0	49.0	54.0	56.6	57.0	57.6	66.6	67.6	68.0	79.6
Marine planktonic	*Actinocyclus* sp.	1.7	0.9	1.7	1.3	3.2	1.2	2.0	4.3	4.6	4.8	2.1	–	0.9	0.6	–	–	–	–	1.1	0.2	0.3	1.1	1.1	0.8	1.4	2.2	–	1.8	0.9	0.2	–	–
	Actinoptychus serarius	0.5	0.5	0.7	0.2	1.0	1.0	1.1	0.9	0.5	1.2	0.5	–	–	–	–	–	0.3	–	1.1	–	–	–	–	–	–	0.2	–	0.6	–	–	–	–
	Thalassionema nitzschioides	1.9	0.5	1.2	2.5	1.0	1.0	0.9	0.4	1.0	–	1.1	0.5	–	–	–	–	–	–	–	–	–	–	–	–	0.2	0.7	–	–	–	–	–	–
	Thalassiosira spp.	9.1	6.7	54.0	7.0	15.4	10.6	14.2	12.8	18.6	36.7	12.0	2.1	10.5	5.2	2.9	2.6	7.0	3.9	12.4		1.3	7.3	13.4	12.2	3.9	1.8	2.8	4.7	5.4	1.6	–	–
Marine benthic	*Amphora* spp.	3.1	2.2	2.2	3.4	5.8	2.0	2.0	3.8	2.6	0.0	1.3	0.2	1.2	0.3	0.3		0.6	–	0.3	0.2	0.3	–	–	–	1.2	1.1	0.2	0.6	–	0.4	–	–
	Caloneis liber	0.7	0.7	0.7	0.6	0.3	0.7	2.3	–	1.6	1.6	0.3	–	0.5	1.5	0.6	0.5	–	–	–	–	1.0	–	–	–	–	1.8	0.4	–	–	0.2	–	–
	Dimeregramma minor	1.2	0.9	0.7	0.2	–	1.7	0.6	–	1.0	0.4	–	–	–	–	–	–	–	–	–	–	0.0	–	–	–	–	–	–	–	–	–	–	–
	Diploneis suborbicularis	1.9	1.8	1.7	1.3	2.6	6.7	6.0	12.8	5.2	2.0	0.5	0.2	0.5	–	0.3	0.9	0.6	19.9	0.6	–	0.7	–	–	–	20.3	15.7	–	1.5	0.3	–	–	–
	Grammatophora oceanica	0.2	–	–	–	–	–	0.6	–	1.0	1.2	1.3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Navicula spp.	0.7	0.5	–	–	–	–	–	3.4	1.6	0.4	0.5	–	–	–	–	0.9	0.3	–	–	1.0	–	–	–	–	0.7	–	–	–	–	–	–	–
	Navicula liroides	2.6	1.6	1.0	0.8	2.2	2.0	2.0	1.7	0.5	0.8	0.3	–	–	–	–	–	0.9	–	–	–	–	–	0.3	–	0.2	–	–	–	–	–	–	–
	Navicula marina	0.7	1.4	0.5	0.4	2.2	0.7	0.9	1.3	1.0	0.4	0.8	–	–	–	–	–	1.2	–	–	–	–	–	–	–	0.7	0.9	–	0.6	–	–	–	–
	Nitzschia coarctata	1.4	0.5	–	2.9	1.0	–	–	–	0.5	–	0.3	0.2		–	–	–	–	–	–	–	–	–	–	–	–	0.7	–	–	–	–	–	–
	Nitzschia constricta	3.8	1.1	1.2	5.1	0.6	0.7	0.6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.4	0.7	0.4	–	–	–	–	–
	Nitzschia granulata	4.1	6.7	1.4	0.8	9.0	17.5	9.9	–	2.6	2.0	0.3	–	–	–	–	0.7	–	–	–	–	–	–	–	0.4	1.6	1.8	–	1.8	–	–	–	–
Marine-brackish benthic	*Nitzschia lanceola*	1.2	1.4	0.5	0.4	–	–	–	–	–	0.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.4	–	–	–	–	–	–	–
	Nitzschia pauduriformis	2.9	6.7	2.2	6.6	–	0.5	0.3	0.4	1.0	–	–	–	–	0.3	–	–	–	2.6	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Nitzschia sp.	2.4	3.8	0.2	3.6	–	1.0	1.1	0.9	1.0	0.8	2.7	1.2	–	0.9	0.3	0.2	0.6	–	0.8	0.8	0.7	–	1.3	–	0.9	0.7	0.6	–	1.8	–	0.4	–
	Plagiogramma sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.8	–	–	–	–	–	–
	Surirella fatuosa	1.0	0.9	0.2	1.3	2.2	0.5	1.4	2.1	2.6	0.8	3.2	–	–	0.3	–	0.5	–	–	–	–	–	–	–	–	1.4	–	–	–	–	–	–	–
	Achnanthes brevipes	2.4	1.4	1.0	0.4	1.9	1.5	0.9	0.9	0.5	2.0	0.8	–	0.7	0.9	–	0.5	–	0.7	0.3	–	–	–	0.8	0.4	1.9	4.3	–	1.5	1.2	0.2	–	–
	Achnanthes hauckiana	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Cocconeis scutellum	1.2	0.9	–	0.4	–	0.3	0.3	–	–	–	–	–	–	–	–	0.2	–	–	–	–	–	–	–	0.4	0.5	0.2	–	–	–	–	–	–
	Diploneis smithii	13.7	20.2	9.6	15.8	16.0	24.9	11.7	9.8	4.1	1.6	4.8	0.2	1.2	2.1	0.3	1.6	2.3	2.9	0.8	–	0.3	2.1	0.8	0.4	17.5	9.0	0.2	5.3	–	0.2	–	–
Brackish water	*Cyclotella caspia*	1.0	4.3	0.7	4.4	0.3	1.0	1.1	2.1	4.1	6.1	3.7	1.2	0.9	1.8	0.6	0.9	2.1	1.3	1.7	0.6	–	–	2.4	3.2	1.4	2.9	0.4	3.2	3.6	0.5	0.9	2.1
	Diploneis pseudovalis	3.6	4.5	2.2	2.5	2.2	5.4	4.0	3.8	3.6	0.8	2.9	0.9	1.4	3.1	0.9	2.8	2.6	1.3	0.6	0.6	1.0	1.1	1.1	1.2	5.3	3.8	1.6	2.1	–	0.5	0.4	–
	Synedra pulchella	–	0.5	–	–	–	1.7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	0.5	–	–
Fresh-brackish water	*Bacillaria paradoxa*	0.7	0.7	–	1.5	–	0.3	0.6	–	–	–	–	–	1.2	–	–	0.2	0.9	–	–	–	–	–	–	0.4	0.7	–	0.4	–	0.6	–	–	0.3
	Epithemia sorex	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Gyrosigma strigile	2.4	3.1	–	1.3	0.6	0.7	3.1	–	1.6	0.4	2.9	1.2	–	1.8	1.2	4.4	2.1	–	–	0.2	–	–	–	–	0.2	–	–	–	–	–	–	–
	Gyrosigma distortum	0.7	–	0.7	3.0	–	–	0.3	0.9	1.0	–	–	0.2	0.9	1.5	2.9	0.2	0.3	0.3	–	0.4	0.7	0.2	0.3	–	–	–	1.2	–	–	0.7	–	–
	Navicula cf. *peregrima*	–	–	–	–	–	0.5	0.6	–	–	–	0.3	0.5	–	–	–	–	–	–	–	0.6	0.7	–	–	–	2.1	0.2	–	–	–	–	–	–
	Navicula pusilla	1.0	–	–	–	1.6	0.3	–	0.9	–	–	–	0.2	0.9	–	–	1.2	–	–	0.3	0.6	1.0	0.4	0.5	–	0.7	1.4	0.4	–	–	–	–	–
	Nitzschia levidensis	1.0	1.1	–	4.7	–	–	–	–	–	–	–	0.5	0.5	0.6	–	–	–	–	–	–	–	–	–	–	–	4.0	–	–	–	–	–	–
	Nitzschia parvula	0.7	1.1	0.7	0.6	–	–	1.4	–	–	–	1.1	1.7	–	–	1.4	1.2	1.2	0.7	2.8	2.5	2.0	–	–	–	–	0.9	0.4	0.6	–	7.0	0.9	–
	Rhopalodia gibberula	3.1	1.4	2.4	–	0.6	1.2	0.9	1.3	1.0	–	0.8	0.2	1.2	0.3	0.9	5.1	0.9	1.0	0.3	1.9	1.0	1.3	0.5	2.0	12.0	14.8	2.2	4.7	5.4	13.2	2.4	0.6
	Roicosphenia curvata	2.9	2.5	1.2	1.9	0.3	0.7	0.6	2.6	2.6	0.8	0.8	2.8	2.3	2.4	3.7	0.7	1.8	0.3	2.2	0.4	0.7	3.8	2.1	1.6	0.5	–	2.4	0.9	1.8	3.3	1.1	–
	Achnanthes lanceolata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.6	–	–	–	–
	Achnanthes spp.	1.0	0.7	0.2	0.4	–	–	0.6	–	0.5	–	0.3	0.7	0.7	2.4	–	0.2	0.9	1.6	0.8	0.4	0.7	0.2	1.3	0.8		0.5	0.4	0.6	0.9	0.9	0.6	
	Actinella sp.	–	0.2	–	0.2	0.6	0.3	0.9	2.6	1.6	2.0	1.9	0.9	3.0	1.5	1.4	–	1.2	1.6	0.6	3.7	–	0.6	1.3	–	0.9	1.1	1.2	0.9	0.9	1.8	0.4	0.3

Fresh water	*Amphora lybica*	0.5	0.5	–	–	–	–	–	–	–	–	1.9	2.8	1.9	4.9	0.3	2.6	2.6	1.3	0.6	2.3	–	0.6	–	–	1.2	0.7	0.4	–	–	1.1	0.6	0.3
	Aulacoseira granulata	2.2	0.9	0.7	2.3	1.3	1.2	1.4	3.8	2.1	0.8	2.9	0.9	0.7	1.2	0.6	4.9	–	2.6	1.4	3.7	1.0	0.4	2.4	5.3	3.5	6.3	1.6	3.0	4.8	1.1	0.6	–
	Caloneis silicula	–	–	–	–	–	–	–	–	–	0.4	0.3	–	0.2	0.3	–	–	–	–	0.6	0.2	–	–	–	–	–	–	–	–	–	0.4	–	–
	Cocconeis placentula	1.4	1.1	0.2	0.6	1.0	0.3	1.4	–	2.1	2.4	2.1	1.4	4.0	8.2	3.7	3.7	3.5	2.6	1.9	0.4	1.3	2.1	4.0	1.6	1.4	0.9	0.6	0.6	2.1	4.4	1.3	1.5
	Cymbella cuspidata	–	0.5	–	0.2	0.6	–	0.3	–	0.5	0.4	0.8	0.2	0.2	0.3	–	1.4	0.3	–	–	0.8	–	–	–	–	–	–	0.8	–	–	0.2	0.2	0.9
	Cymbella minuta	–	–	–	–	–	–	–	0.4	–	–	–	0.9	1.4	–	–	0.5	0.3	2.3	0.6	2.5	1.0	0.4	1.1	0.8	0.2	–	3.7	0.6	2.4	4.4	1.3	0.6
	Cymbella sp.	1.0	0.5	0.2	0.6	1.3	1.0	1.1	2.6	0.5	2.4	1.3	3.8	3.3	1.2	3.2	5.6	3.5	2.0	4.1	0.4	2.6	7.0	2.1	3.6	1.1	0.2	6.3	–	1.2	3.3	8.9	10.5
	Cymbella turgidula	1.4	1.1	0.5	1.3	1.0	0.3	0.6	–	1.0	0.8	0.8	11.1	5.6	5.8	7.8	1.4	5.9	3.6	3.9	–	1.0	4.1	3.7	6.9	0.7	–	8.1	4.4	0.6	7.7	18.7	1.2
	Diploneis ovalis	0.2	0.2	0.2	0.4	0.3	0.3	0.6	0.4	–	–	0.8	0.2	–	0.6	–	0.7	0.6	–	–	0.2	–	–	–	0.4	1.9	–	0.2	–	0.3	–	–	–
	Epithemia adnata	2.2	1.8	1.0	1.7	2.2	1.0	1.1	0.9	0.5	0.4	2.7	2.1	1.4	2.1	1.2	3.3	3.5	2.9	4.4	1.2	0.7	4.5	4.6	0.8	0.5	2.0	0.2	1.5	6.6	2.6	3.5	1.2
	Eunotia flexuosa	2.2	2.2	0.5	2.9	2.2	0.3	2.0	1.3	3.1	4.4	4.5	11.3	2.1	7.0	15.2	3.3	12.9	2.6	5.2	1.6	3.6	2.8	1.3	11.3	–	0.5	0.8	2.7	1.5	0.2	0.7	0.9
	Eunotia pectinalis	–	0.2	0.7	–	1.3	–	–	–	–	–	1.1	–	0.9	–	–	–	–	–	–	–	–	–	0.8	0.8	0.2	0.2	2.0	0.3	1.5	1.6	2.0	6.0
	Eunotia praerupta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Eunotia spp.	0.5	–	–	–	1.9	0.5	0.9	–	1.0	0.8	2.1	4.7	0.2	2.7	0.9	1.2	–	4.9	4.7	1.9	1.6	0.6	2.7	2.0	0.5	–	0.2	0.6	1.2	1.4	2.2	3.3
	Frustulia rhomboides	1.2	0.5	–	0.8	1.0	0.3	1.4	–	–	0.4	1.1	0.7	0.7	0.9	0.9	0.5	0.3	–	0.6	0.4	0.7	0.2	–	–	–	1.1	1.8	0.3		2.3	1.1	0.3
	Gomphonema spp.	0.7	0.2	–	1.5	0.3	–	0.9	1.3	0.5	1.6	3.2	2.6	1.9	2.7	4.6	1.9	1.8	3.9	3.3	7.8	1.3	1.9	0.8	2.4	0.7	0.2	2.8	2.7	1.8	4.9	6.3	2.1
	Gyrosigma scalproides	0.2	0.5	0.2	0.4	–	–	0.6	0.4	–	–	–	–	5.6	0.6	2.9	0.7	0.3	1.0	0.6	5.2	12.8	1.5	0.8	–	0.5	0.9	7.9	0.9	1.5	1.1	0.6	0.9
	Hantzschia sp.	0.2	0.5	–	–	1.6	1.0	2.0	2.1	2.6	1.2	2.7	0.9	–	–	0.6	8.4	–	–	0.3	6.2	10.8	–	–	0.4	0.9	0.7	–	0.3	0.3	–	–	0.3
	Melosira italica	0.5	–	–	1.1	2.2	0.3	0.6	1.3	2.6	2.4	1.6	0.9	0.5	–	1.2	–	1.2	4.3	4.7	1.0	0.7	0.9	2.1	6.1	1.4	0.2	1.0	18.3	2.4	0.5	2.4	2.1
	Meridion circulare	–	–	–	–	–	–	–	–	–	–	–	0.2	–	0.6	0.3	0.5	0.3	1.6	0.8	–	–	–	–	–	–	–	–	0.3	–	–	–	–
	Navicula americana	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5.2	1.3	–	–	–	–	–	–	–	–	–	0.2	–
	Navicula radiosa	0.7	0.2	0.5	1.7	0.6		0.3	0.9	1.0	0.4	4.5	1.9	1.4	1.8	1.7	14.0	1.5	1.0	–	2.7	8.5	0.6	0.8	–	0.5	0.7	2.0		0.3	0.7	1.1	0.3
	Navicula sp.	1.4	0.7	0.7	1.7	1.0	0.7	2.0	1.3	3.1	–	3.2	5.2	4.7	4.9	3.2	3.5	0.9	1.0	1.1	5.8	3.9	1.7	1.6	0.4	1.9	1.4	4.3	2.1	4.8	2.6	3.1	–
	Neidium iridis	–	–	–	–	–	–	–	0.4	–	–	–	0.7	–	0.9	–	0.2	0.3	–	–	2.7	1.0	–	0.3	–	–	–	–	–	1.5	0.5	0.2	0.9
	Nitzschia palea	–	0.2	–	–	–	–	0.3	–	–	–	0.3	1.7	0.2	0.9	0.3	0.5	0.6	0.7	0.6	–	–	–	–	0.4	0.2	–	–	–	4.8	0.4	0.9	0.9
	Pinnularia spp.	1.0	1.1	1.0	0.8	3.5	1.0	2.6	2.1	1.6	–	2.1	9.0	6.7	4.3	3.7	7.7	5.0	4.9	6.0	22.5	18.0	4.5	3.7	9.7	0.4	3.6	6.7	3.8	21.1	7.7	12.0	44.9
	Synedra ulna	–	–	–	0.2	–	–	0.3	–	–	–	0.3	0.5	0.5	0.6	0.6	0.9	0.6	–	0.8	3.1	1.3	0.2	1.1	1.2	–	–	0.2	1.2	1.8	0.4	0.7	12.0
	Tabellaria flocculosa	1.7	1.4	1.2	2.3	1.6	0.5	4.0	5.1	5.7	7.3	8.0	17.0	24.2	12.5	22.4	3.5	20.8	13.1	21.2	2.3	11.4	42.6	33.4	15.4	1.9	2.0	27.9	18.6	11.0	15.6	21.1	0.9
	Tabellaria fenestrata	0.2	–	–	–	–	–	–	–	–	0.4	–	0.2	–	–	–	–	0.3	–	0.6	1.2	0.3	–	–	–	–	–	0.6	–	0.3	–	–	–
	unknown	3.8	4.5	3.6	3.8	4.2	4.9	3.4	6.4	4.6	6.1	4.3	3.1	3.5	5.8	5.8	3.7	5.3	5.2	6.0	4.8	3.3	5.1	5.4	6.5	3.4	3.6	4.7	5.9	3.9	3.9	3.3	4.8
Percentage	Marine planktonic diatoms	13.2	8.5	57.6	11.0	20.5	13.8	18.2	18.3	24.7	42.7	15.7	2.6	11.4	5.8	2.9	2.6	7.3	3.9	14.6	0.2	1.6	8.3	14.4	13.0	5.5	4.9	2.8	7.1	6.3	1.8	–	–
	Marine benthic d.	28.1	30.0	12.5	27.3	26.0	34.1	27.6	26.4	22.2	10.9	11.5	1.9	2.1	3.4	1.4	3.7	4.1	22.6	1.7	1.9	2.6	–	1.6	0.4	27.7	25.1	2.2	4.4	2.1	0.5	0.4	–
	Marine-brackish benthic d.	17.3	22.4	10.6	16.5	18.0	26.7	12.8	10.6	4.6	3.6	5.6	0.2	1.9	3.1	0.3	2.3	2.3	3.6	1.1	–	0.3	2.1	1.6	1.2	19.9	13.5	0.2	6.8	1.2	0.4	–	–
	Brackish water d.	4.6	9.2	2.9	6.8	2.6	8.2	5.1	6.0	7.7	6.9	6.7	2.1	2.3	4.9	1.4	3.7	4.7	2.6	2.2	1.2	1.0	1.1	3.5	4.5	6.7	7.2	2.0	5.3	3.6	1.6	1.3	2.1
	Fresh-brackish water d.	12.5	9.9	5.0	13.1	3.2	3.7	7.4	5.5	6.2	1.2	5.9	7.3	7.0	6.7	10.1	13.1	7.0	2.3	5.5	6.6	5.9	5.8	3.5	4.1	16.2	21.3	6.9	6.2	7.7	24.3	4.4	0.9
	Fresh water d.	20.6	15.5	7.9	21.4	25.6	8.6	25.6	26.8	29.9	28.6	50.4	82.8	71.9	70.4	78.2	70.9	69.3	59.8	69.0	85.3	85.3	77.6	70.1	70.5	20.6	24.4	81.3	63.7	75.3	67.7	90.6	92.2

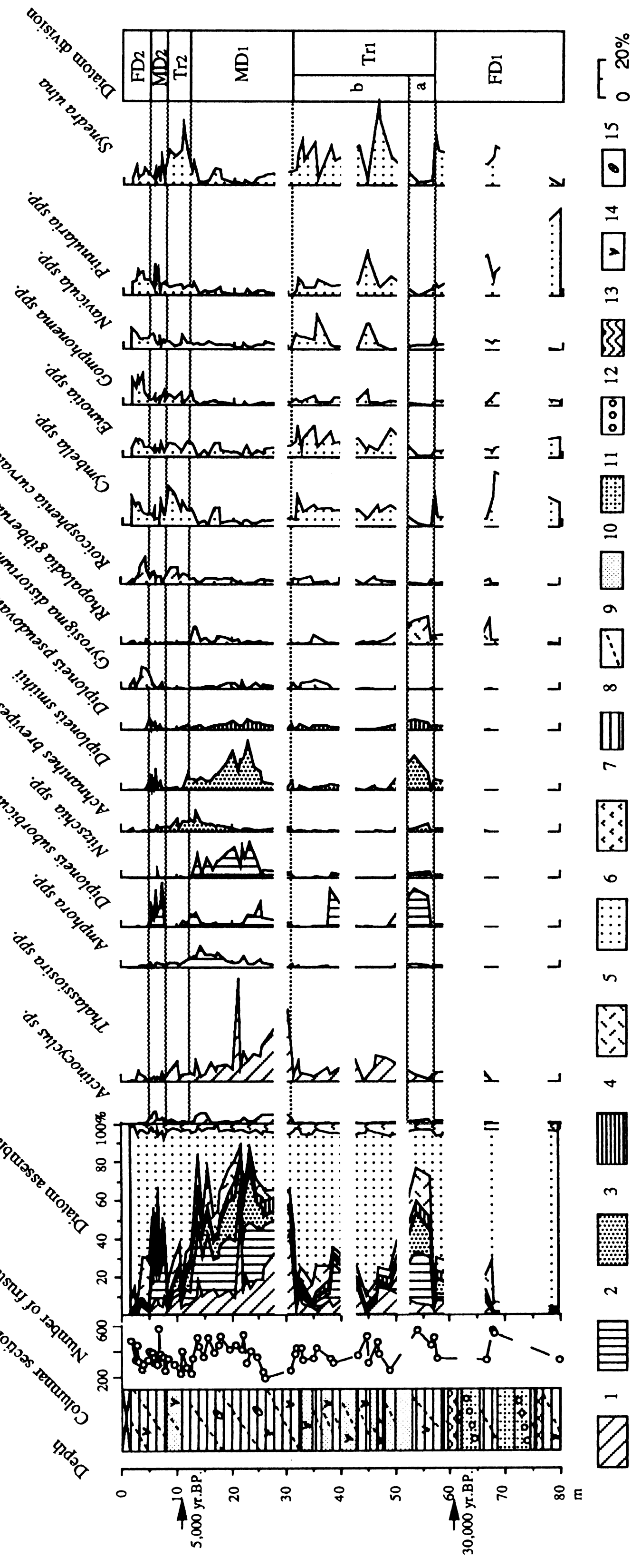

Fig. 3. The diatom floral change.
1. Marine planktonic diatom, 2. Marine benthic diatom, 3. Marine-brackish benthic diatom, 4. Brackish water diatom,
5. Fresh-brackish water diatom, 6. Fresh water diatom, 7. Unidentified diatom, 8. Clay, 9. Silt, 10. Fine sand, 11. Medium - coarse sand,
12. Gravel, 13. Peat, 14. Plant fragment, 15. Shell fragment, FD. Fresh water diatom division, Tr. Transitional division, MD. Marinediatom division.

V. Diatom floral change

On the basis of above-mentioned assemblages, the diatom floral change is divided into six diatom divisions in ascending order, namely FD1, Tr1, MD1, Tr2, MD2 and FD2.

(1) FD1 diatom division (-79.6 to -57.0 m) corresponds nearly to Unit I which yields diatom from two horizons. The beds of these horizons compose of sandy silts. This division comprises 75 to 90% fresh water and 5 to 20% fresh-brackish water diatoms. *Cymbella* spp. and *Pinnularia* spp. are dominant at the lower horizon. *Synedra ulna* is dominant at the upper part. *Rhopalodia gibberula*, *Diploneis smithii* and *Thalassiosira* spp. occur with low frequency.

(2) Tr1 diatom division (-57.0 to -32.3 m) corresponds to Unit II. It alternately occurs marine and fresh water diatoms with high frequency, and is subdivided into two subdivisions, namely Tr1-a and Tr1-b in ascending order. The Tr1-a is dominated by 30% marine, 20% marine-brackish , 5% brackish , 20% fresh-brackish and 23% fresh water diatoms. *Diploneis suborbicularis, Diploneis smithii* and *Rhopalodia gibberula* occur with high frequency (14 to 20% respectively). The Tr1-b is dominated by 60 to 80% fresh water, 10 to 15% marine, 5 to 15% fresh-brackish water and 5% brackish water diatoms. *Cymbella* spp., *Eunotia* spp., *Pinnularia* spp. and *Synedra ulna* are dominant. However, at -38.6 m, *Diploneis suborbicularis* occurs with high frequency (20%) again. Marine species, *Thalassiosira* spp. appears throughout the division with low frequency.

(3) MD1 diatom division (-32.3 to -12.8 m) corresponds almost to Unit III. It comprises 40 to 55% marine and 10 to 25% marine-brackish diatoms. Brackish and fresh water diatoms are diminished. According to the dominant species, this division can be subdivided into lower and upper parts. The lower part is dominated by marine planktonic diatom, 13 to 35% of *Thalassiosira* spp. Apart from -21.8 m, *Thalassiosira* spp. rapidly increases to 54%. In the upper part, *Thalassiosira* spp. decreases to less than 10%, and marine benthic and marine-brackish benthic diatoms are dominant, including *Nitzchia* spp. and *Diploneis smithii* of 15 to 25% respectively.

(4) Tr2 diatom division (-12.8 to -8.5 m) corresponds to the lower part of Unit IV. It is dominated by 60 to 75% fresh water, 8 to 10% fresh-brackish water , 4 to 10% marine-brackish and 5 to 15% marine diatoms. *Cymbella* spp. and *Synedra ulna* occur with high frequency (20 to 25% respectively). *Roicosphenia curvata* increases, and marine and marine-brackish diatoms occur with low frequency.

(5) MD2 diatom division (-8.5 to -5.5 m) corresponds to the middle part of Unit IV. It comprises 20 to 40% marine, 6 to 12% marine-brackish, 5 to 10% brackish water, 5 to 15 fresh-brackish water and 28 to 45% fresh water diatoms. *Diploneis suborbicularis* and *D. smithii* occur with high frequency (10 to 22% and 4 to 10% respectively).

(6) FD2 diatom division (-5.5 to -1.7 m) corresponds to the upper part of Unit IV. Marine diatoms decrease abruptly (less than 6%). Fresh-brackish and fresh water diatoms occur with high frequency

(65 to 90%). This division is characterized by fresh water diatoms including *Cymbella* spp., *Gomphonema* spp., *Pinnularia* spp. and *Eunotia* spp. They are dominated at the upper part of this division. At the lower part of it *Gyrosigma distortum* and *Roicosphenia curvata* of fresh-brackish water diatoms occur with high frequency (10 to 12% respectively).

VI. Sedimentary Environment

According to the result of diatom assemblage analyses, the sedimentary environment of each division is inferred as follows.

(1) FD1 division

On the basis of diatom assemblages, it is assumed that the sedimentation took place under fresh water condition, because haptobenthic aquatic forms such as *Cymbella* spp. and *Eunotia* spp. are very abundant together with aerophilous forms as *Pinnularia* spp. at the upper part. The appearance of haptobenthic and aerophilous species indicates that terrestrial diatoms are probably brought into a depositional site by run off of the surrounding land surface. A radiocarbon age of 30.000 yr.BP. nearly at -63 m indicates that this division was formed in fresh water environment during Late Pleistocene time.

(2) Tr1 division

In this division, marine and fresh water diatoms are intermixed complicately. At the lower part (Tr1-a) of this division, marine and marine-brackish diatoms rapidly increase. In contrast, at the upper part (Tr1-b) the abrupt change of dominant species from marine to fresh water diatoms is clear. Depositional facies were alternative of sandy silt and fine sand. Although sedimentary structure can not be examined, haptobenthic and aerophilous species of fresh water diatoms occur for a long period with high frequency as they were carried out by fresh water distributaries. It seems likely that the sedimentation took place in a pro-delta at the beginning of Holocene transgression. Therefore, a high brackish condition is prevailed at the early stage. After that, the pro-delta deposits are overlaid by fine sand and sandy silt of delta front deposits with five sedimentary cycles.

(3) MD1 division

Marine diatoms are dominant throughout this division. It is considered that the sedimentation took place under marine condition. The course of a transgression is well recognized by the change of individual number. The maximum Holocene transgression (the Jomon transgression) got throughout this division indicating by *Actinocyclus* sp. and *Thalassiosira* spp. of marine planktonic , *Amphora* spp., *Diploneis suborbicularis* and *Nitzschia* spp. of marine benthic , and *Achnanthes brevipes* and *Diploneis smithii* of marine-brackich benthic diatoms. At the top horizon, the increase of fresh and fresh-brackish water diatoms represented the beginning of the next stage toward regression. This

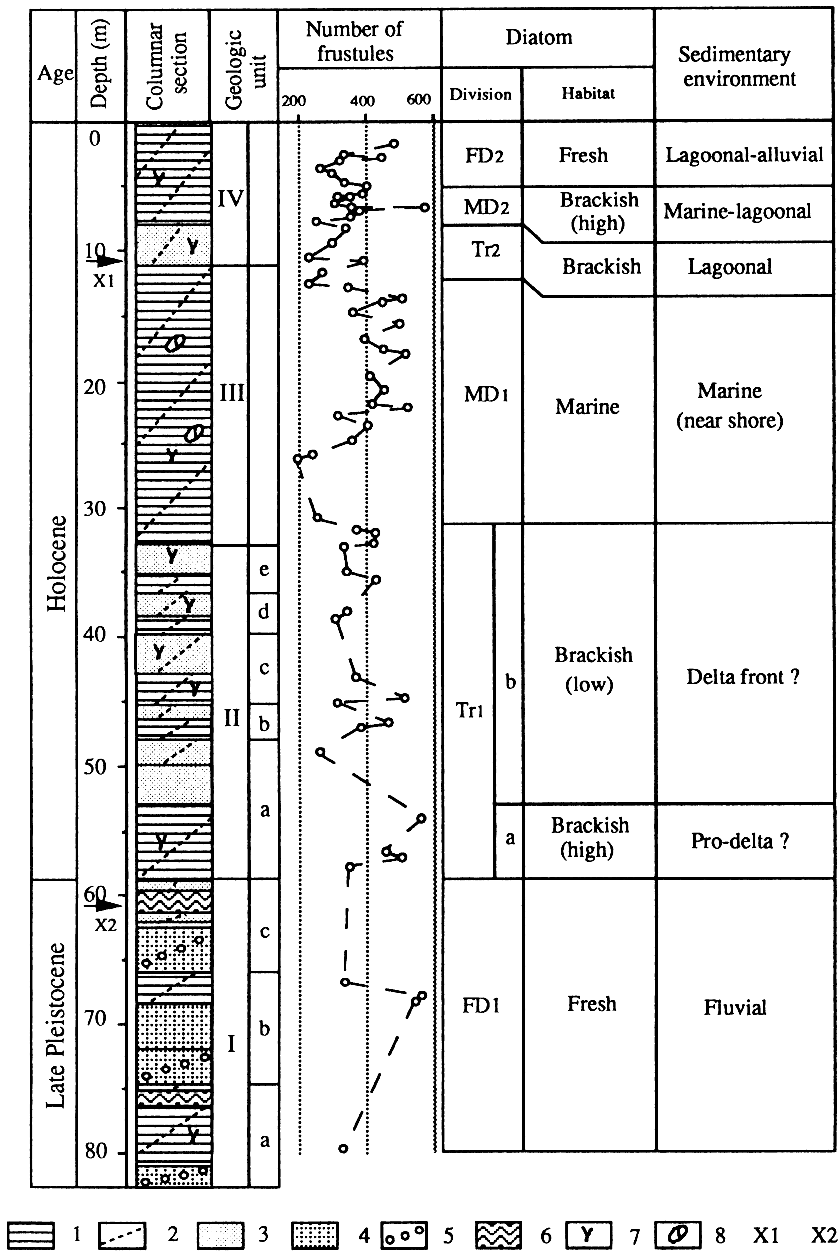

Fig .4. The change of inferred sedimentary environment.
1. Clay, 2. Silt, 3. Fine sand, 4. Medium-coarse sand, 5. Gravel, 6. Peat, 7. Plant fragment, 8. Shell fragment. X1 and X2 show locations of C^{14} dating 5,000 and 30,000 yr.BP. respectively.

division was formed under marine condition. The sea level fell at the top horizon in comparison with the lower part.

(4) Tr2 division

The abrupt increase of fresh water diatoms that intermixed with marine and marine-brackish water diatoms indicates a regression after the culmination of the Holocene transgression. The sedimentation took place under brackish environment such as lagoonal deposit in a regression stage. The age of this division probably is at the Middle Jomon age.

(5) MD2 division

This division is again dominated by a marine benthic diatom, *Diploneis suborbicularis* and a marine-brackish benthic diatom, *Diploneis smithii*. It is suggested that the sea level rose temporaly. Benthic species such as *Diploneis suborbicularis* and *D. smithii* indicate that the sea is shallower with high brackish condition. The division maybe corresponds to a small transgression after the main Jomon transgression, and the sedimentation took place in marine-lagoon.

(6) FD2 division

Fresh water diatoms are dominant throughout this division. *Gyrosigma distortum* and *Roicosphenia curvata* occur with high frequency and marine diatoms with low frequency at the lower part, indicating that this division was formed under brackish environment and changed to fresh water condition toward the upper part.

The Fukushima-gata Lake has the formative history during Holocene as follows: The first stage (the Earliest Jomon age) was under Holocene transgression. The second stage (the Earliest and Early Jomon ages) was the development of sand bars and sand dunes off shore. The third stage (the Early and Middle Jomon ages) was the maximum transgression. The fourth stage (the Middle and Late Jomon ages) was the appearance of the first fresh-brackish water lagoon. The fifth stage (the Late Jomon age) was a small transgression. The sixth stage (the Latest Jomon and Yayoi ages) was the reappearance of the second fresh water lagoon that follows to the recent lake.

This formative history mostly agrees to previous works (Ohira, 1992), but we must make geographical and paleoenvironmental reconstruction in detail.

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Plate I

1~4: *Thalassiosira* sp.

5, 6: *Actinocyclus* sp.

7, 8: *Thalassionema nitzschioides*

9~11: *Amphora* sp.

12, 13: *Diploneis suborbicularis*

14: *Achnanthes hauckiana*

15, 16: *Dimeregramma minor*

17, 18: *Achnanthes brevipes*

19, 20: *Diploneis smithii*

21: *Nitzschia lanceola*

22: *Nitzschia pauduriformis*

23: *Nitzschia constricta*

24: *Nitzschia coarctata*

Plate I

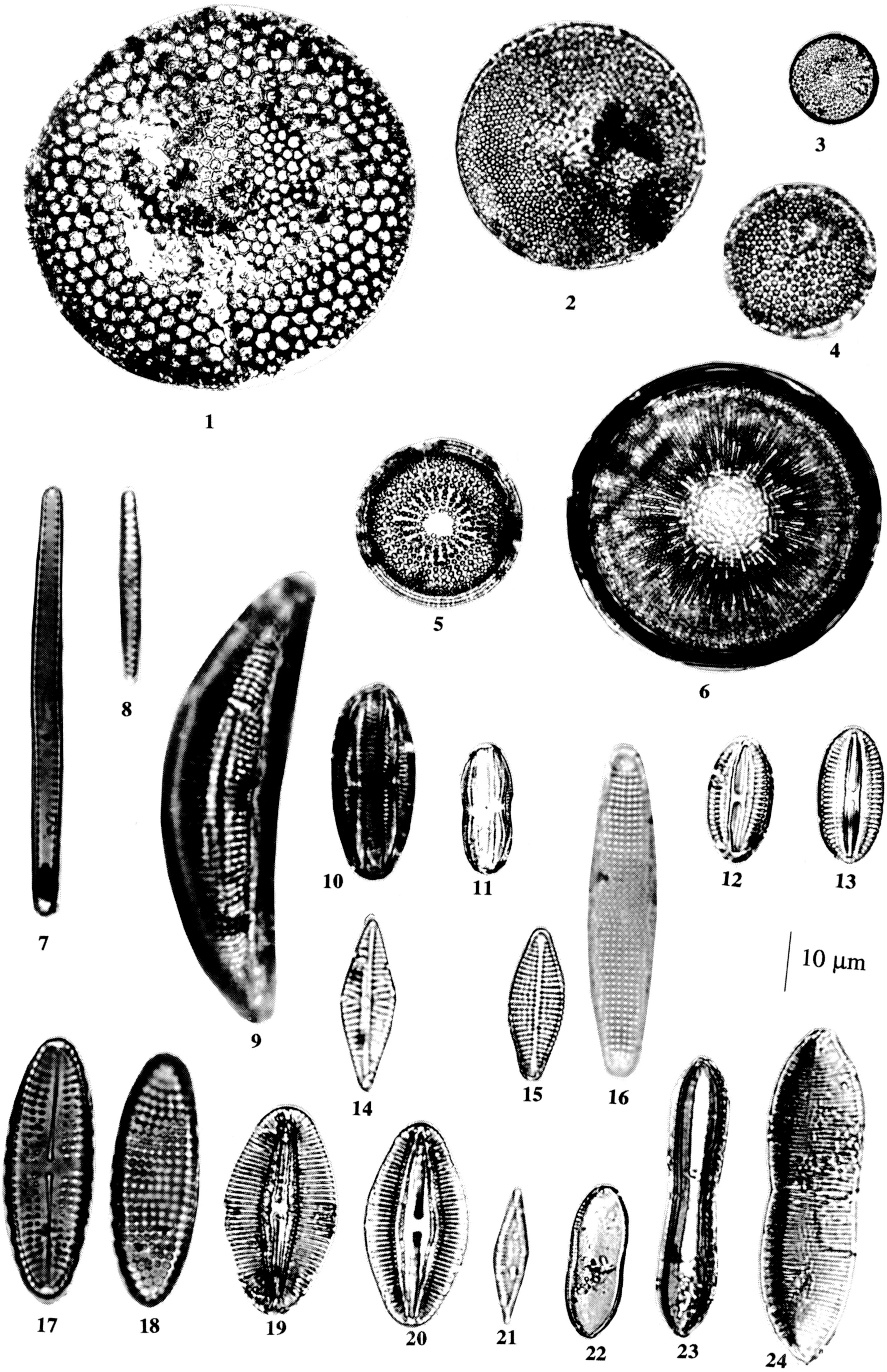


Plate II

1: *Nitzschia granulata*

2, 3: *Cocconeis scutellum*

4: *Diploneis* sp.

5: *Navicula lyroides*

6: *Nitzschia cocconeisformis*

7~11: *Cyclotella caspia*

12, 13: *Synedra ulna*

14: *Nitzschia* sp.

15: *Bacillaria paradosa*

16, 17: *Gyrosigma distortum*

18: *Gyrosigma strigile*

19: *Navicula* sp.

20: *Navicula americana*

21: *Diploneis pseudovalis*

22: *Roicosphenia curvata*

23, 24: *Cocconeis placentula*

25: *Achnanthes lanceolata*

Plate II

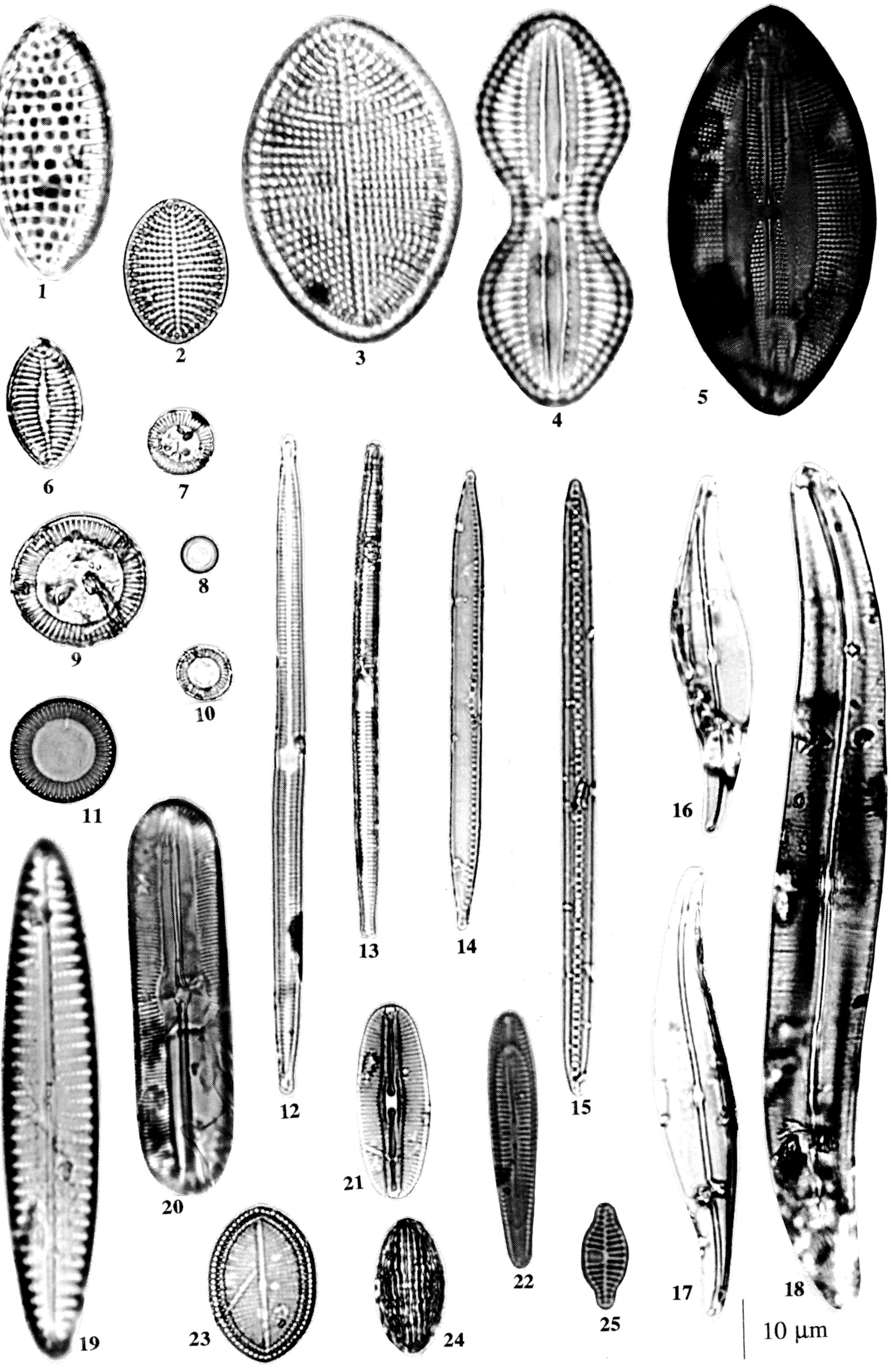


Plate III

1, 2: *Pinnularia viridis*

3: *Pinnularia brevicostata*

4: *Pinnularia cardinalis*

5: *Pinnularia mesolepta*

6: *Cymbella cuspidata*

7: *Cymbella turgidula*

8: *Cymbella tumida*

9: *Cymbella cistula*

10: *Cymbella minuta*

11~14: *Gomphonema acuminatum*

15: *Amphora libica*

16: *Navicula* cf. *peregrima*

17: *Meridium ciculare*

18: *Navicula radiosa*

19: *Cacloneis silicula*

20: *Tabellaria fenestrata*

21: *Eunotia* sp.

22, 23: *Eunotia monodon*

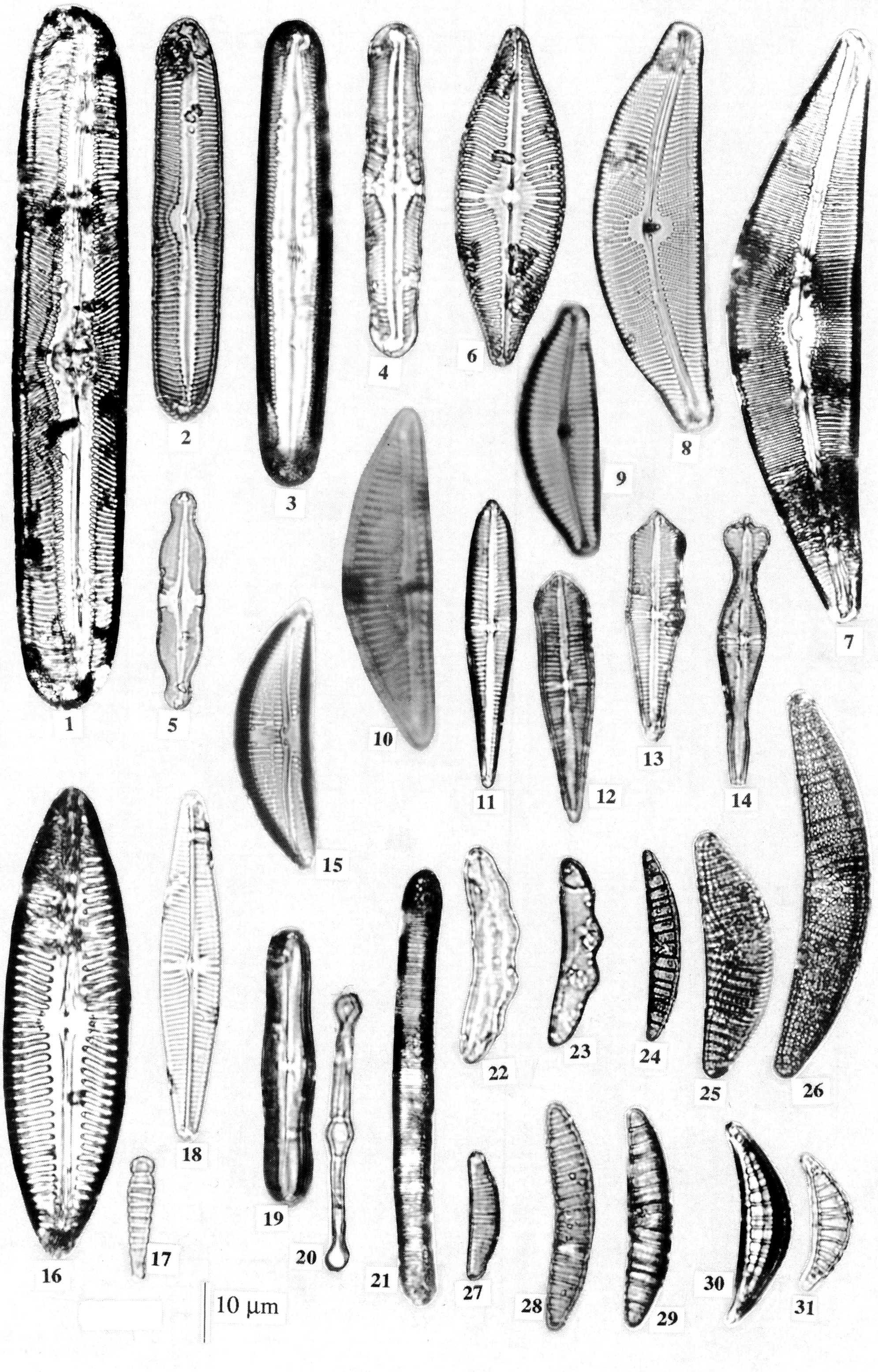
24~26: *Epithemia adnata*

27: *Eunotia veneris*

28, 29: *Eunotia pectinalis*

30, 31: *Rhopalodia gibberula*

Plate III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