Short Article

Sea Level of the Last Glaciation Maximum Based on In-Place Sediments on the Shelf off Sendai, Northeast Japan¹⁾

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The lowest sea level during the last glaciation maximum is estimated to be 95 ± 3 m below the present level based on the sedimentological, diatom and ^{14}C dating analyses of the in-place sediments of the two cores taken from the shelf off Sendai, Northeast Japan.

Introduction

The lowest sea level during the last glaciation maximum around Japan is estimated to be 80 to 130 m below the present level by morphological analyses of the shelf (OHSHIMA, 1982; SATO and MOGI, 1982). The ^{14}C data and in-place sediments indicating the lowest sea level, however, have not been reported around Japan.

The core samples taken from the shelf off Sendai, Northeast Japan, are dealt with in this paper. The data indicating the lowest sea level during last glaciation maximum were obtained as a result of the sedimentological and diatom analyses and ^{14}C dating of these samples.

Regional Setting

Morphology and surface sediments

The studied area off Sendai is situated on the Pacific shelf of Northeast Japan and it is the widest part of the shelf with a width of about 80 km (Fig. 1). The shelf break is apparent to the south at about $37^{\circ}55'\text{N}$ and is not clear to the north. It is, however, traced through both areas at approximately 145 m of water depth.

The surface sediments on the shelf are divided into Younger Suites, Older Sand A and Older

Fig. 1 Bathymetry of the shelf off Sendai and locations of the coring site
Depth contours in meters.

Sand B by HATTORI (1967). The first is modern sediments and the others are relict sediments deposited during the late Pleistocene to the early Holocene, and the early Holocene, respectively (HATTORI, 1967; SAITO, 1989).

Methods

Field survey was conducted using *R/V Tokai-Nisei* in 1986.

The collected cores were cut vertically, logged, slabbed ($25 \times 5 \times 1$ cm), X-radiographed, and subjected to paleontological, chemical and textural

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analyses.

Carbon radiometric datings were performed at the Geological Survey of Japan with a benzene liquid scintillation method (TOGASHI and MATSUMOTO, 1983) and by Teledyne Isotope (Code No.; I). All dates were calculated using the Libby half-life of 5,570 years, A. D. 1950 reference and one standard deviation.

One to two grams of the samples were taken from the cores and used for diatom analysis. Each sample was treated with hot 15 % hydrogen peroxide to remove organic matters. Then it was treated with an undiluted hydrochloric acid to remove CaCO_3 and washed with H_2O by a centrifugal method. An appropriate amount was then mounted with Pleurax. Generally 150 to 200 frustules were counted in each sample (KASHIMA, 1985, 1986). Ten samples in the P-4 core and five samples in the P-9 core were analyzed with this procedure. According to HUSTEDT (1927~1930, 1931~1937, 1959, 1961~1964), CLEVE-EULER (1951, 1952, 1953a, b, 1955), HENDEY (1964), PATRICK and REIMER (1966, 1975) and GOTO (1979), diatoms which appeared in this study were identified.

Results

Sedimentary facies, molluscan species and ^{14}C dating

1. P-4 core

This core sample was taken from the middle shelf off Sendai with a water depth of 94.5 m. The core length is 248 cm (Fig. 2).

These sediments of this core are divided into three parts. The upper part consists of silt with a few sand layers and is found at 0 to about 85 cm. This silt is deposited at the current rip zone between the coastal water mass and the Oyashio Current behind Ojika Peninsula (HOSHINO, 1958).

A vitric tephra layer is found at the lowest part, 80 to 85 cm, and is zero to a few millimeters thick and white in color. This consists of pumice-type glass shards associated with bubble-walled flakes. The refractive index of glass shards ranges from 1.506 to 1.508. This tephra is probable to be correlated with the Chuseri Pumice erupted from the Towada caldera,

Fig. 2 Lithofacies of the P-4 and P-9 cores with ^{14}C dates and shell assemblage

northern Honshu, at about 5,500 y.B.P., based on these characteristics and those of Chuseri Pumice (HAYAKAWA, 1983).

The middle part is composed of very poorly sorted muddy medium sand and ranges from 85 to 150 cm in depth. Scour-and-fill structures are often found (Fig. 3). This part contains shells and shell fragments, they are particularly abundant in this lower part. The shells are *Dosinia penicillata* (REEVE) at the depths of 38 and 96 cm from the core top, and *Solen strictus* (GOULD), *Mya arenaria oonogai* MAKIYAMA and *Callithaca adamsi* (REEVE) at the depths of 133 to 138 cm. These molluscan assemblages indicate the mixed

Fig. 3 Soft X-radiographs (negative) of the P-4 core

Table 1 List of ^{14}C dates

Code No.	Sample Core:Depth (cm)	^{14}C Date y.B.P.	Materials
JGS-344	P-4:133~138	$10,060 \pm 230$	<i>Solen strictus</i> , <i>Mya arenaria</i> <i>oonogai</i> , <i>Callithaca adamsi</i>
I-15126	P-4:232~248	$16,950 \pm 2,300$	Sandy mud (plant frag. rich)
JGS-331	P-9:60~69	$13,980 \pm 200$	Peaty mud (carbon content: 1.9%)

environments, that is, from intertidal zone to less than about 20 m in a water depth. The base of this shell layer is sharp. The ^{14}C date of these shells, taken from 133 to 138 cm, is $10,060 \pm 230$ y.B.P. (JGS-344, Table 1).

The lower part is comprised of sandy silt to silty sand with plant fragments, and ranges from 150 to 248 cm is depth. A fining upward

sequence is found. In the lowest part of this part, volcanic glass shards and fine pumices are abundant. Contents of plant fragments increase to downward. The ^{14}C date of this lowest part, organic materials in the sediments, is $16,950 \pm 2,300$ y.B.P. (I-15126, Table 1).

2. P-9 core

This core was collected from the middle shelf

Fig. 4 Diatom diagrams of the P-4 and P-9 cores, showing the occurrence of the significant marine, estuary and fresh taxa

off Sendai with a water depth of 97 m. It is 82 cm long (Fig. 2).

The core is divided into two parts. The upper part is made of very poorly sorted, muddy medium sand to sandy gravel with shell fragments. This part is 42 cm long. Scour-and-fill structures are well recognized. The lower part consists of alternating layers of sandy silt and peaty mud, and found at 42 to 82 cm. The boundary of both parts is sharp. The ^{14}C date of the peaty mud, from 60 to 69 cm, is $13,980 \pm 200$ y.B.P. (JGS-331, Table 1).

Diatom assemblages

The sediments of these cores can be divided into four zones in the P-4 core and two zones in the P-9 core (Fig. 4).

1. P-4 core

Four diatom assemblage zones are recognized in this core, these are P-4-1, -2, -3 and -4 zones in ascending order.

P-4-1 (depth: 180 to 230 cm) :

This zone is characterized by fresh water diatoms which constitute 40 to 50 % of the total diatomaceous flora. They are *Fragilaria construens* (EHRENBERG) GRUNOW, *F. pinnata* EHRENBERG, *F. brevistriata* GRUNOW, *Synedira rumpens* KÜTZING, and *Cocconeis placentula* EHRENBERG. Marine and brackish water diatoms are commonly found, particularly *Nitzschia tryblionella* HANTSCH, living in river-mouth environment (HUSTEDT, 1937~1930; HENDEY, 1964), is abundant.

Sedimentary environment of this zone is inferred to be river-mouth or brackish water, including tidal river area, because fresh-water and marine diatoms are mixed and *Nitzschia tryblionella* is abundant in this zone.

P-4-2 (140 to 180 cm) :

This zone is characterized by marine benthic diatoms. *Cocconeis scutellum* EHRENBERG constitutes 40 % of the diatomaceous flora. Marine planktonic diatoms, fresh-brackish water diatoms and fresh-water diatoms are commonly recognized.

Sedimentary environment of this zone is inferred to be very shallow marine, less than about 10 m deep, and close to shoreline, because *C. scutellum* is growing on seaweeds (KOSUGI, 1988) and sea bottom at depths of less than about 10 meters.

P-4-3 (80 to 140 cm) :

This zone is mostly composed of marine planktonic diatoms. *Paralia sulcata* (EHRENBERG) CLEVE, *Thalassionema nitzschioides* HUSTEDT and *Thalassiosira* spp. constitute 20 to 30 % of the diatomaceous flora, respectively.

Sedimentary environment of this zone is inferred to be inner bay, lower than open sea in salinity. Because *Paralia sulcata* is living in polyhaline brackish lagoons, about 15‰ in salinity, and inner bay areas (KASHIMA, 1987).

P-4-4 (0 to 80 cm) :

This zone is mostly composed of marine planktonic diatoms. *Thalassionema nitzschioides* and *Thalassiosira* spp. constitute 30 to 40 %, respectively, and the content of *P. sulcata* is less than 10 %.

Sedimentary environment of this zone is inferred to be bay and open shelf strongly

influenced by an open sea water mass. This is because the ratio of *P. sulcata* in this zone is lower than that of the P-4-3 zone, and modern diatom assemblages in this location are the same.

2. P-9 core

Two zones are recognized in this core and these are P-9-1 and -2 zones in ascending order.

P-9-1 (50 to 70 cm) :

Fresh water diatoms, *Fragilaria construens*, *F. pinnata*, *Melosira granulate* (EHRENBERG) RALFS etc., occupy 50 to 60 % of this zone, with marine and brackish-fresh water diatoms. Sample below 80 cm do not yield diatoms.

Sedimentary environment of this zone is inferred to be tidal-river area, river-mouth, or ephemeral lagoon, e.g., located in inter-beach ridges. This is based on the fact that the fresh water diatoms occupy the majority, and that marine and brackish diatoms are mixed with them.

P-9-2 (less than 50 cm) :

This zone is characterized by marine planktonic diatoms, contents of *Paralia sulcata*, *Thalassionema nitzschioides* and *Thalassiosira* spp. are 20 to 30 %, respectively.

Sedimentary environment of this zone is inferred to be inner bay area. This diatom assemblage resembles that of the P-4-3.

Discussions and Conclusions

Depositional unit

Core samples are divided into three units based on the lithofacies, shell and diatom assemblages, and ^{14}C dating results.

The first unit is modern sediments deposited under the present environment, found at 0 to 85 cm in the P-4 core. This unit is correlated with Younger Suites of HATTORI (1967) and is deposited at the current rip zone between the coastal water mass and the Oyashio Current behind Ojika Peninsula (HOSHINO, 1958).

The second unit is recognized at 85 to 140 (or 180) cm in the P-4 core and at 0 to 42 cm in the P-9 core. This unit is inferred to contain redeposited sediments, because fossil assemblages indicate wide range of sedimentary environment. Moreover, the shells from the lowest part of this

unit are not in-situ and are transported from the original locations in-place to deeper area of this stations. This is inferred from the fact that the sea level estimated from these samples at about 10,060 y.B.P. is too deep in comparison with the sea level around Japan at the same age. Because the sea level estimated from the samples is the coring depths of 94.5 m and 97 m minus the depths of the sedimentary environment, intertidal to very shallow marine, that is, about 70 to 95 m. Whereas the sea level around Japan is 30 to 50 m at about 10,000 y.B.P. (OTA *et al.*, 1982). And scour-and-fill structures are commonly recognized in this unit. These facts indicate that this unit contain the sediments deposited under high shear stress, that is, it is possible to be deposited by bottom currents with offshore directions.

The third unit, found at 180 to 248 cm in the P-4 core and at 42 to 82 cm in the P-9 core, was deposited ranging from 17,000 to 14,000 y.B.P., that is during the lowest sea level in the last glaciation maximum (DUPLESSY *et al.*, 1981, 1986; BERGER *et al.*, 1987). Diatom assemblages from this unit of two cores indicate river-mouth or ephemeral lagoon environment.

Changes in diatom assemblages in the P-4 core show transition from river-mouth to very shallow marine environment and then to inner bay and to bay or shelf environment in ascending order. These changes indicate that the P-4 station has gradually deepened. Changes of depositional environment observed in the P-9 core are mostly the same as those in the P-4 core. These are, however, not smooth in its changes and the P-4-2 and P-4-4 horizons are lacking compared with the P-4 core.

Estimated sea level

The relative sea level during the last glaciation maximum in this area is concluded to be about 95 ± 3 meters below the present level from sedimentological and diatom analyses. The bases are as follows (Table 2).

The estimated sea level from two cores ranges from 88 to 97 m below the present level, because the sample in the P-4 core was taken from water depth of 94.5 m and the position of the third unit is 1.8 to 2.48 m beneath the sea bottom (P-4-1 zone) and the sedimentary environment

Table 2 Estimated lowest sea level

	Water depth	Subbottom depth	Sedimentary environment	Estimated sea level	Age y.B.P.
P-4 core	94.5 m	1.80~2.48 m	0 to ca.-10 m	97~86 m	ca. 17 k
P-9 core	97 m	0.42~0.82 m	0 to ca.-10 m	98~87 m	ca. 14 k

inferred from diatom assemblages is intertidal zone to river-mouth which is shallower than about 10 m of water. On the other hand, the sample in the P-9 core was taken from water depth of 97 m and the second unit is located 0.42 to 0.82 m beneath the sea bottom. And the sedimentary environment inferred from diatom assemblages is intertidal zone to river-mouth which is shallower than about 10 m of water, or ephemeral lagoon located in inter-beach ridges, less than 5 to 6 m of water depth.

The minimum sea level of these estimations corresponds to the maximum depth of river-mouth environment. This maximum depth, however, is not applied. If the samples were deposited in a depression of 10 m deep in a river-mouth, this depression will be buried during the following transgression and thick deposits will be formed. But post-glaciation sediments in the P-4 core are only about 2 m thick and changes of diatom assemblages is smooth. Moreover topographical depressions have not been recognized at the coring station. This means that the environment of the third unit in the P-4 core is not deep and nearly intertidal or a few meters deep.

Moreover as the third unit does not contain characteristic sedimentary structure formed in an intertidal zone, such as flaser bedding formed by tidal currents in tidal flat, or swash cross stratification formed by waves at beachface, it is highly possible that the sedimentary environment is a few meters deep. The relative sea level in this area is concluded to be about 95 m below present sea level. This conclusion is supported by peaty sediments, estimated to be deposited in a flood plain, from 92 m of water depth off Sendai (HONZA *et al.*, 1982).

Correlation

Sediments on the shelf off the Pacific coast of Northeast Japan deposited during the last

glaciation have been reported as follows. These are Older Sand A off Sendai (HATTORI, 1967) and ancient coastal sediments off Kuji River (KAGAMI and NASU, 1964). The former is correlated with the second unit, and it is strongly possible that the latter is correlated with the third unit.

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仙台沖の陸棚域から採取した柱状試料から推定される最終氷期極寒期の海水準

斎藤文紀・松本英二・鹿島薫

仙台沖の陸棚域から採取した P-4 と P-9 の 2 本の柱状試料について、堆積学的分析と珪藻分析、含有する貝片と有機物の ^{14}C 年代測定を行った結果、両柱状試料

の下部は、最終氷期極寒期の低海水準期の汀線近くの堆積物であり、これから推定される海水準は、 $-95 \pm 3 \text{ m}$ である。

Plate I Typical diatoms

1. *Thalassiosira* sp.
2. *Actinocyclus* sp.
- 3~4. *Paralia sulcata* (EHRENBERG) KÜTZING
- 5~6. *Thalassionema nitzschioides* GRUNOW
- 7~8. *Cocconeis scutellum* EHRENBERG
9. *Diploneis smithii* (BRÉBISSE) CLEVE
10. *Rhaphoneis surirella* (EHRENBERG) GRUNOW *ex* VAN HEURUCK
11. *Nitzschia acuminata* (W. SMITH) GRUNOW
- 12~13. *Nitzschia tryblionella* HANTZSCH
14. *Rhopalodia gibberula* (EHRENBERG) O. MÜLLER
15. *Synedra pulchella* KÜTZING
16. *Navicula radiosa* KÜTZING
17. *Eunotia veneris* (KÜTZING) O. MÜLLER
18. *Cocconeis placentula* EHRENBERG
19. *Pinnularia viridis* (NITZSCH) EHRENBERG
- 1~6. Marine (plankton)
- 7~11. Marine (benthos)
- 12~15. Estuary
- 16~19. Fresh water