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SEDIMENTOLOGICAL STUDY OF THE SEA BOTTOM SEDIMENTS IN AND AROUND THE ROSS SEA CONTINENTAL SHELF, ANTARCTICA

Akira NISHIMURA[1], Makoto YUASA[1], Toru NAKASONE[2],
Masaki NAKAHARA[2] and Noboru IOKA[3]

[1]*Geological Survey of Japan, 1–3, Higashi 1-chome, Tsukuba 305*
[2]*Kawasaki Chishitsu Co. Ltd., 23–17, Omori-minami 3-chome, Ota-ku, Tokyo 143*
[3]*Kansai Environmental Engineering Center Co. Ltd., 3–39, Nakasaki-nishi 2-chome, Kita-ku, Osaka 530*

Abstract: Sediment cores collected in and around the Ross Sea, Antarctica, are described and discussed based on sedimentological data, such as visual descriptions, sedimentary structures, magnetic susceptibility, sand contents, and water content. On the Ross Sea Continental Shelf, the core sequences contain two lithologic units, soft diatomaceous mud in the upper and compound glacio-marine sediments in the lower. The lower lithologic unit suggests that highly ice-sheet influenced sedimentation existed in glacial times in the Ross Sea. The core sequences on the continental slope and deep-sea basins off the Ross Sea comprise foraminiferal ooze, siliceous mud, and terrigenous mud, sometimes with laminated parts. The laminated parts of the core sequences suggest that strengthened bottom water influenced sedimentation, probably in glacial times. The sedimentary environment in the Late Quaternary is reconstructed based on the core data.

key words: Ross Sea, Dumont D'Urville Sea, Late Quaternary, sea bottom sediments

1. Introduction

Sediments and sedimentary processes of the sea bottom sediments around Antarctica are very different from those around other continents and are influenced more or less by the actions of ice sheets, glaciers, icebergs, and sea ice. In several glacial times, continental ice sheet and sea ice-covered areas were conspicuously extended. The sedimentary sequences around Antarctica record long-term sedimentary environmental changes. The Ross Sea is situated south of the Pacific Ocean; it is one of the major inlets of the Antarctic Continent and is bordered on the south by the largest ice shelf in the world, the Ross Ice Shelf. Characteristics of sediments and sedimentation in the Ross Sea were studied and discussed by several authors based on the sedimentological, oceanographical and micro-paleontological data (STETSON and UPSON, 1937; JACOBS *et al.*, 1970; CHRISS and FRAKES, 1972; KELLOGG *et al.*, 1979; ANDERSON, 1980, 1991; ANDERSON *et al.*, 1984; EDWARDS *et al.*, 1987; DEMASTER *et al.*, 1992; BRAMBATI *et al.*, 1994). In these studies, EDWARDS *et al.* (1987) described sediment core samples in the western Ross Sea in detail, and ANDERSON *et al.* (1984) discussed the sediment samples in the whole area of the Ross Sea.

In this paper, first the results of sedimentological analysis on core sediment samples in and around the Ross Sea are shown; next, the sedimentary processes and sedimentary environment are discussed based on these data. As to the same samples of this study, the heavy mineral provenances and their relation to sea surface currents have already been discussed in separate papers (Agyingi *et al.*, 1995; Tokuhashi *et al.*, 1996).

2. Geomorphology and Bottom Sediments in and around the Ross Sea

The continental shelf of the Ross Sea is deep, up to 500 to 600 m deep on average, and several banks and troughs are developed generally with a NNE-SSW trend. These topographic features result from geologic structures of sedimentary basins and glacial erosion in the Quaternary (Davey *et al.*, 1987). The shelf break of the Ross Sea occurs at relatively great depth (approximately 800 m); the greatest depths on the shelf occur in its landward rather than seaward part (Chriss and Frakes, 1972).

According to Anderson *et al.* (1984) and McCoy (1991), the deeper (greater than approximately 300 m) portions or basin floors of the Ross Sea Continental Shelf are covered by muddy sediments (compound glacial marine sediments), whereas shallower (above approximately 300 m) portions or bank areas of the shelf are floored by coarser (sand and gravel) deposits (residual glacial marine sediments), reflecting effective sediment sorting by bottom currents to a depth of up to nearly 300 m. The muddy sediments in the deeper portions consist of terrigenous fine silt and clay, and siliceous biogenic material containing poorly sorted ice-rafted debris. The continental slope and deep-sea basins from the area off of the Ross Sea to the Dumont D'Urville Sea are covered by hemipelagic muddy sediments, such as silt and clay.

3. Materials and Analytical Methods

The sediment samples in the Ross Sea Continental Shelf were collected during TH91 and TH92 Antarctic Cruises conducted by the Technology Research Center, Japan National Oil Corporation (JNOC), using R/V Hakurei-Maru. The core samples were taken by a gravity corer with an 11 cm diameter and a 5.4 m length. Fourteen core samples are available for this study. Localities of samples are shown in Fig. 1 and their location data are shown in Table 1.

On board, visual core description and smear slide observation, and brief analysis of sand-size fraction were performed. Soft X-ray photography, magnetic susceptibility measurement, determination of water content and sand grain content were done in the shore-based laboratory.

Soft X-ray photographs were taken on the one centimeter sliced sediment samples. Magnetic susceptibilities were measured on one inch cubic samples continuously throughout the core sequences using a Martison Type-2 susceptibility apparatus in 0.47 kHz frequency mode. Water contents were measured for samples of several cubic centimeters with a 10 cm stratigraphic interval using a syringe (Oba, 1983). Water contents, bulk wet density, and bulk dry density were calculated. Sand contents were measured on the same samples as those for water content measure-

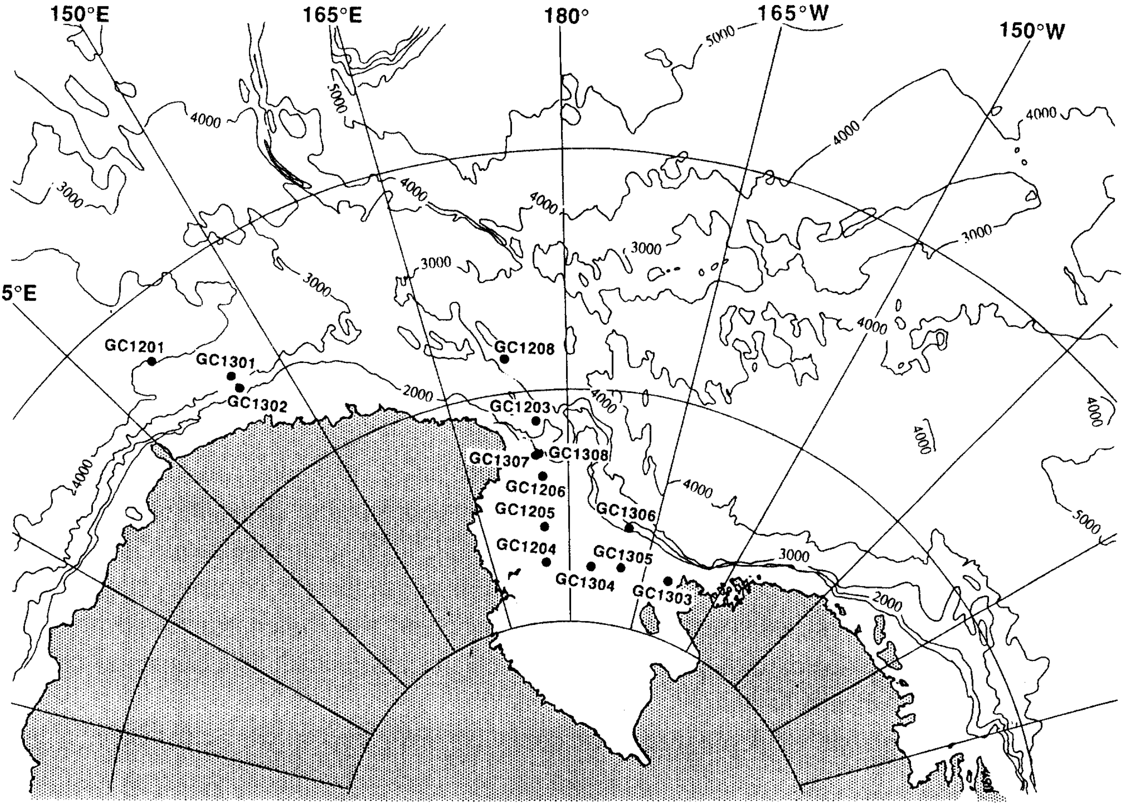

Fig. 1. Sampling locations in and around the Ross Sea, Antarctica.

Table 1. Location data of the core samples in and around the Ross Sea, Antarctica.

Sample No.	Location (Latitude)	Location (Longitude)	Water depth (m)	Topography
GC1201	62°41'41"S	139°52'48"E	4058	Basin floor of the Dumont D'Urville Sea
GC1203	71°20'10"S	175°30'18"E	2224	Upper continental rise north of the Ross Sea
GC1204	77°25'15"S	175°28'12"E	662	Basin floor in the Ross Sea
GC1205	75°55'55"S	175°29'35"E	543	Basin floor in the Ross Sea
GC1206	73°44'33"S	175°30'48"E	580	Basin floor in the Ross Sea
GC1208	68°29'32"S	172°27'36"E	3405	Lower continental rise north of the Ross Sea
GC1301	64°49'45"S	145°01'00"E	3341	Basin floor of the Dumont D'Urville Sea
GC1302	62°29'07"S	144°59'30"E	2537	Lower continental slope of the Dumont D'Urville Sea
GC1303	77°26'46"S	161°11'03"W	672	Basin floor in the Ross Sea
GC1304	77°26'26"S	175°54'30"W	571	Basin floor in the Ross Sea
GC1305	77°26'23"S	169°46'28"W	570	Basin floor in the Ross Sea
GC1306	75°46'11"S	169°59'36"W	1450	Continental slope north of the Ross Sea
GC1307	72°31'04"S	175°27'54"E	527	Bank slope at the shelf break of the Ross Sea
GC1308	72°27'38"S	175°37'54"E	643	Bank slope at the shelf break of the Ross Sea

ments.

Micropaleontological and paleomagnetic analysis were performed on these core samples (JNOC, unpublished data).

4. Features of Surface Sediments in and around Ross Sea

Simplified lithologies of the core samples are summarized in Fig. 2. Core penetration in the Ross Sea is very poor, because of consolidated sediments in most of the sea bottom. The lithologies of the studied core sequences can be grouped into three types based on the bathymetric features of sampling sites. They are the continental slope—deep-sea basin type, continental shelf break type, and continental shelf type. The first type includes Cores GC1201, GC1301, GC1302, GC1208, GC1203 and GC1306; its core sequence is composed of pelagic and/or hemipelagic sediments throughout the core. The second type includes Cores GC1307 and GC1308 and the sediments are characterized by the coarse sediments, such as coarse sandy sediments with shell fragments. The third type includes Cores GC1204, GC1303, GC1304 and GC1305, and contains two lithologic units, siliceous muddy sediments in the upper and silty sediments with pebbles sometimes characterized by high consolidation in the lower. Cores GC1205 and GC1206 are transitions between the second and third types and the upper part of their sequences is composed of siliceous mud, the same as those of continental shelf type, and the lower part is composed of sandy silt and silty sand with pebbles and shelly coarse sand, the same as those of continental shelf break type.

Brief descriptions of representative cores of three types are as follows (Fig. 3).

GC1302 (continental slope—deep-sea basin type)

This core is composed of silty clay throughout the sequence with sandy silt in the upper and lower parts. Laminations are developed in several parts of the core. The laminations are observed as one millimeter to several millimeter thick bands on soft X-ray photographs (Fig. 4E) and the grain sizes of the laminated parts are silt. Sand contents are less than five percent except for the top and lower parts of the core, and water contents are variable, between 30 and 120%. The terrigenous sand grains in the core are thought to be ice-rafted debris because of their dispersed occurrence. The age of this core is middle to late Quaternary because the lower part of this core (deeper than 180 cm from the core top) is assigned to *Rouxia isopolica* Zone (0.66–0.35 Ma) of the diatom zone of AKIBA (1982) (JNOC, unpublished data).

GC1307 (continental shelf break type)

This core consists of sandy sediment. Shell fragments, barnacles, bryozoans, foraminifers, and ostracods occur in the sediments. The sand content is high and water content is low throughout the core. Silty sediments include pebble gravel and are semiconsolidated. The preliminary result shows that the AMS ^{14}C age of foraminifers at 40–42 cm from the top is *ca.* 34000 yrs. B. P. (MURAYAMA, personal communication).

GC1305 (continental shelf type)

This core is composed of two lithologic units. The boundary exists at 90 cm from the core top. The upper unit is siliceous clay and contains many diatoms. The lower unit is semiconsolidated silt with pebble gravel, with remarkably low water content.

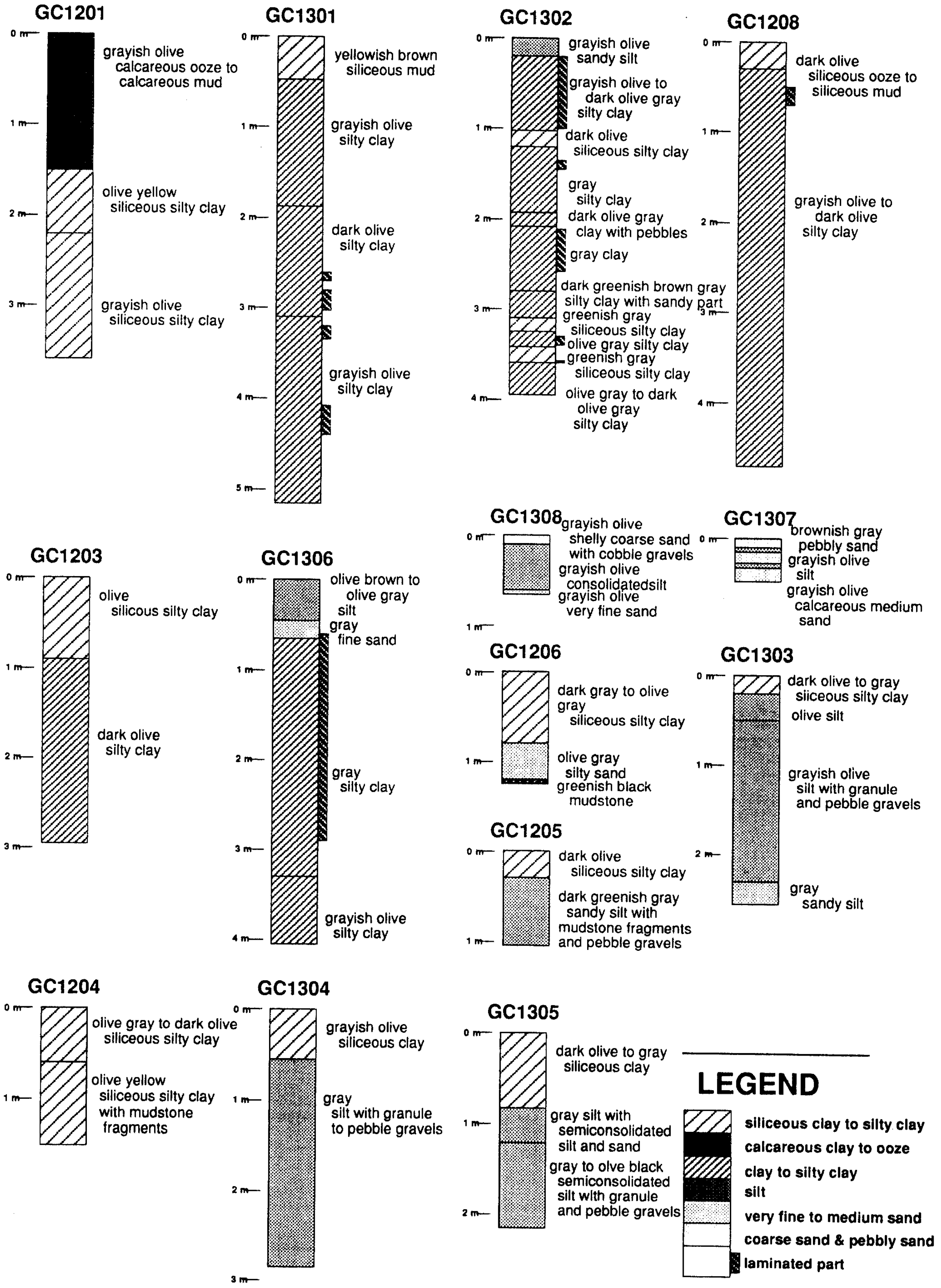

Fig. 2. Simplified lithologic columns of core samples in and around the Ross Sea, Antarctica.

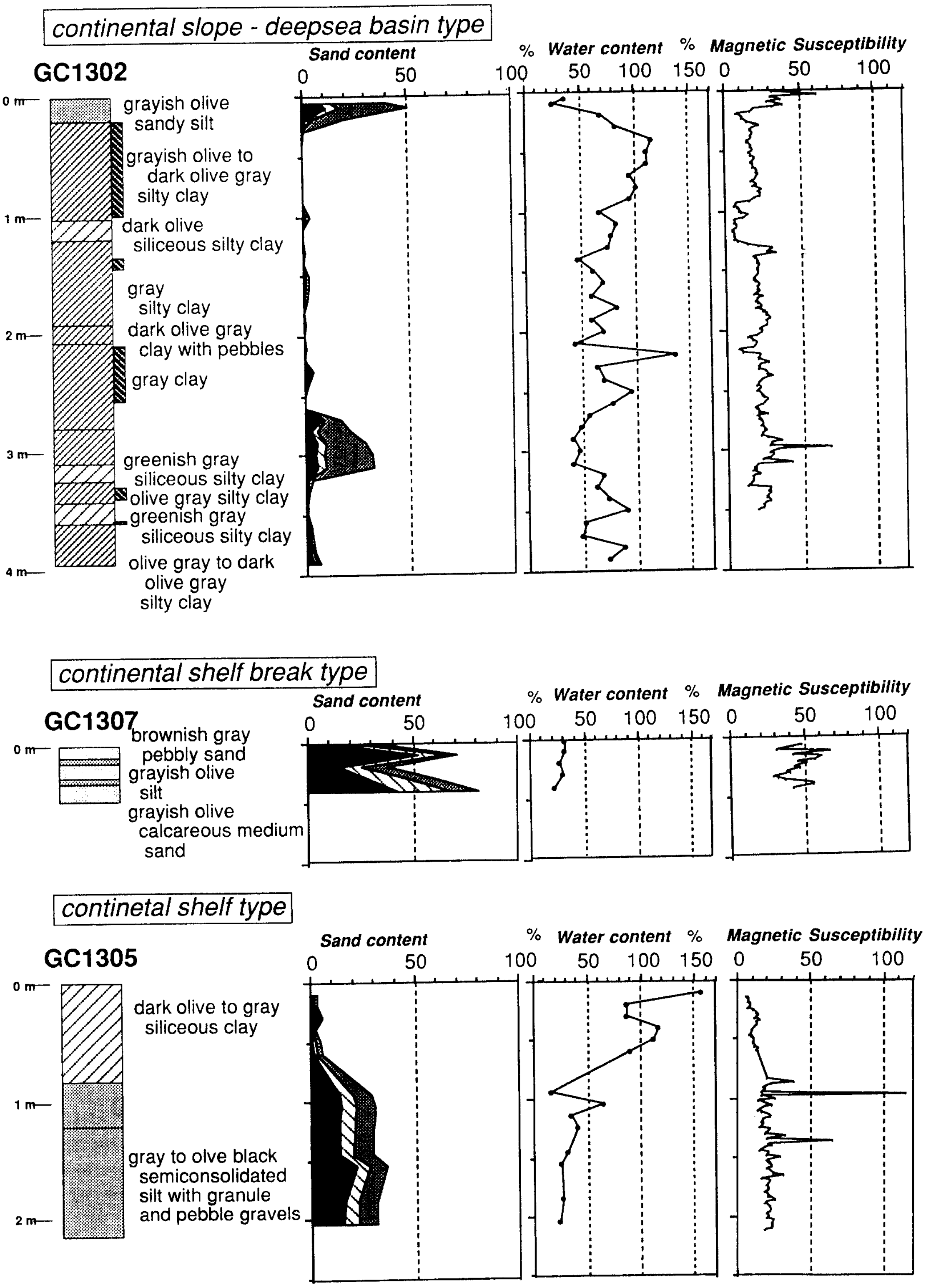

Fig. 3. Three representative core sequences in and around the Ross Sea, Antarctica. Deep-sea basin off Antarctic (GC1302), continental shelf edge of the Ross Sea (GC1307), and inner part of the Ross Sea (GC1305). The legend of the lithologic columns is the same as that of Fig. 2. In the sand content diagrams, black parts show >250 μm grains, oblique lined ones 250–125 μm grains, and dotted ones 125–63 μm grains.

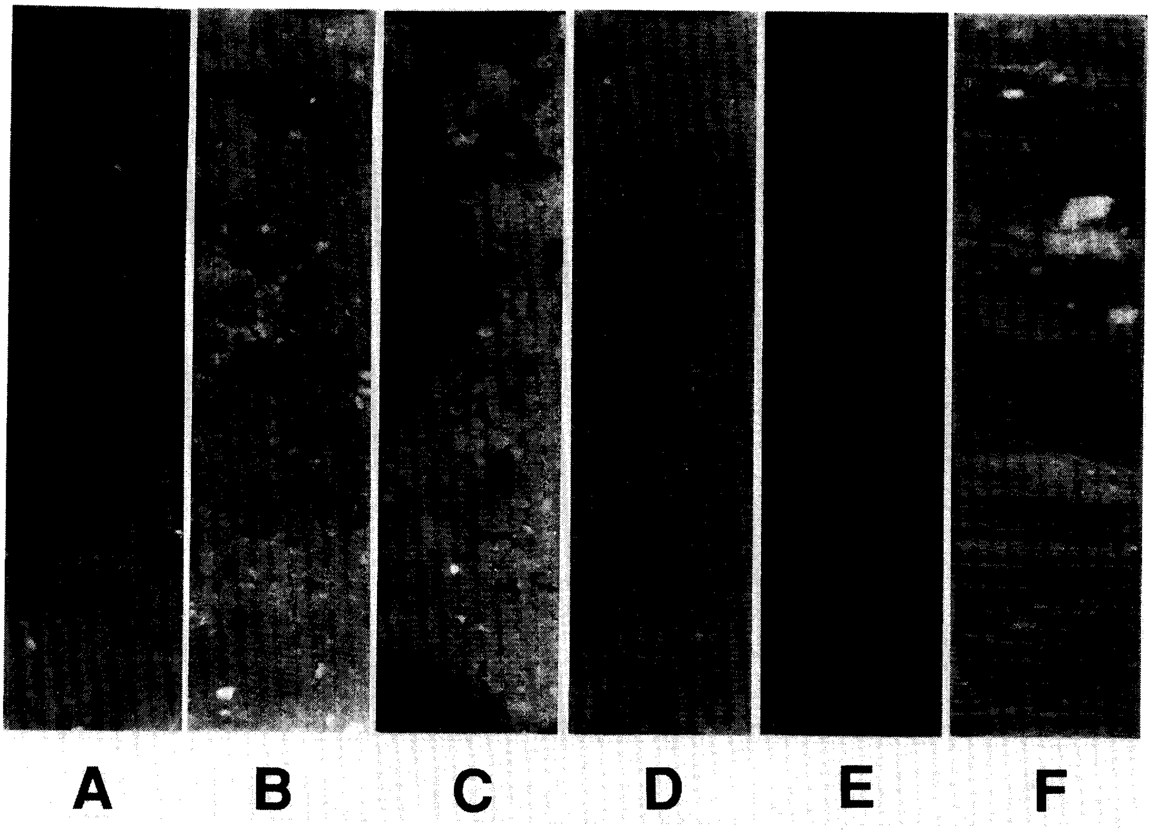

Fig. 4. Soft X-ray photographs of representative samples. A; Homogeneous part of GC1204 (0–20 cm), B; Homogeneous part with coarse sands of GC1206 (65–85 cm), C; Muddy part with consolidated silt fragments of GC1305 (104–124 cm), D; Highly bioturbated part of GC1203 (100–120 cm), E; Laminated part of GC1302 (58–78 cm), and F; Laminated part with coarse sands of GC1306 (225–245 cm). Vertical lengths of photographs are 20 cm.

The sand content of the upper unit is low and that of the lower unit is high. Magnetic susceptibilities are correlated with sand content. The age of the upper unit is assigned to *Nitzschia kerguelensis* Zone (0–0.2 Ma) of AKIBA (1982); that of the lower unit cannot be judged based on biostratigraphy because of the assemblage composed of probable reworked diatoms (JNOC, unpublished data).

5. Sedimentary Environmental Change in the Late Quaternary

The sequences of the core samples in and around the Ross Sea show lithologic changes. The lithology of the top of the sequences is considered to have been deposited in the same sedimentary environment as the present.

In the Ross Sea, KELLOGG *et al.* (1979) recognized lithologic units in the sedimentary sequence; the upper unit composed of diatomaceous mud is thought to be of Holocene age based on the ^{14}C dating of organic carbon. Moreover, DEMASTER *et al.* (1992) recognized variable thickness and sedimentation rate of the upper unit on account of the organic productivity and Holocene age for it. The lower unit is thought to be the glacio-marine sediments in the last glacial time without precise age data (KELLOGG *et al.*, 1979; ANDERSON *et al.*, 1991). We have no precise data as to the age of the lower unit of sediments in the Ross Sea, so we adopt the last glacial time for its age estimated by KELLOGG *et al.* (1979), because the lower unit exists just below the Holocene upper unit with no suggestion of an age gap. The upper unit consists of the sediments deposited under high organic productivity of diatoms; small content of coarse sand grains in the upper unit shows the contribution of iceberg transportation of sand grains to the whole area from the continent, controlled by a surface current in the Ross Sea (AGYINGI *et al.*, 1995). The lithologies of the lower unit are variable and complex in some places and they show generally high gravel content and consolidation. These may include basal till and glacio-marine sediments under the ice sheet covering most of the Ross Sea Continental Shelf in the last glacial time.

The sediments of the shelf break show coarser sediments, such as shelly gravelly sands, and suggest sedimentation sorted by inflow currents into the Ross Sea. The age

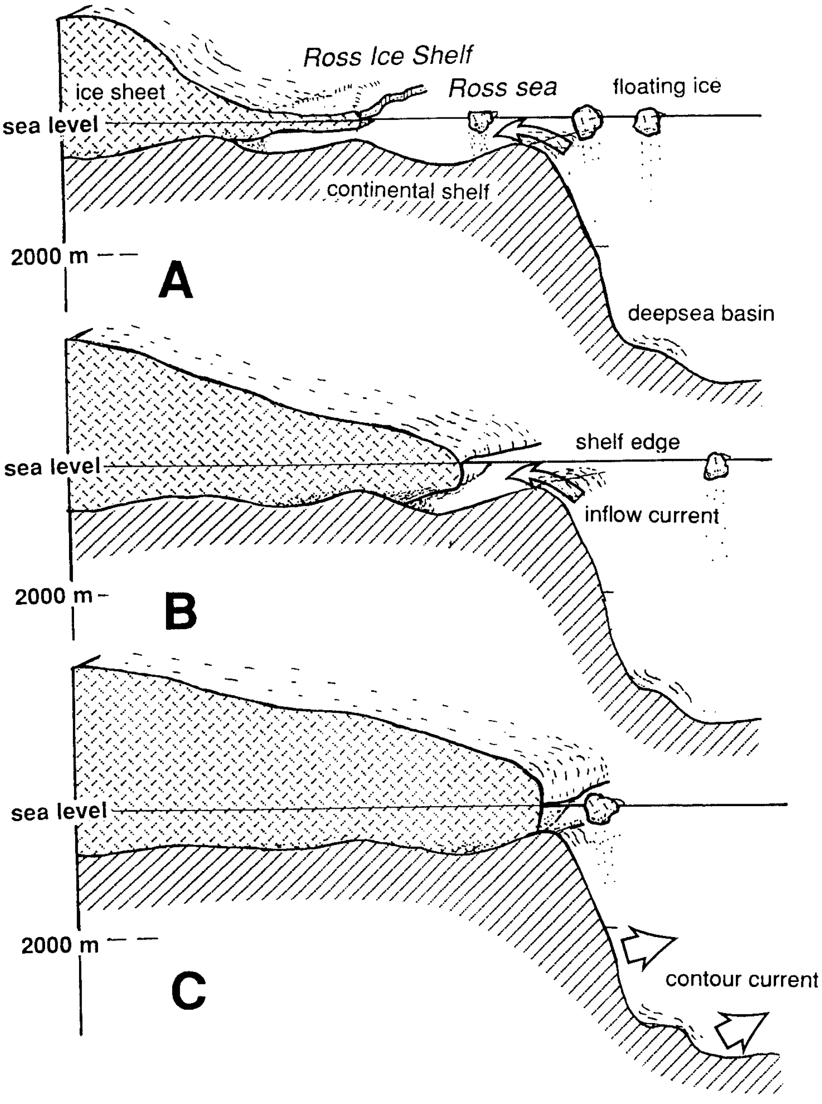

Fig. 5. Cartoon of sedimentary history of the Ross Sea area. A; Recent, B; Retreating stage of ice sheet (early Holocene), and C; The last glacial time.

(*ca.* 34000 yrs. B.P.) of the foraminiferal tests and the presence of semiconsolidated silt in the lower part of Core GC1307 suggest the presence of both of an open marine environment and strong influence of the ice sheet in the last glacial time.

The sediments of the continental slope—deep-sea basin are characterized by hemipelagic muddy sediments with a variable amount of biogenic grains and ice-rafted debris. The continental slope and deep-sea basin environmental change in the Late Quaternary was discussed based on the nearby Weddell Sea by BONN *et al.* (1994). The contour current was strengthened in the last glacial time. The laminated silty clay in the core sequences of the deeper part of the studied area is thought to consist of contourites formed by strengthened bottom currents in glacial times as in the nearby Weddell Sea.

We show a cartoon of the sedimentary environments in the last glacial stage, retreating stage of glacier, and the recent period, estimated based on the sediment samples mentioned above (Fig. 5).

6. Concluding Remarks

The studied sediment core samples in and around the Ross Sea can be grouped into three types, continental slope—deep-sea basin type, shelf break type, and continental shelf type. In the sequences of all types, we can recognize lithologic changes reflecting the sedimentary environment. On the assumption that the core top lithology reflects the present sedimentary condition after the retreat of glaciers after the last glacial time and that another distinct lithology below the core top lithology shows the sedimentary environment of the glacial stage, we reconstruct the sedimentary environmental change after the last glacier. At present, high biogenic productivity, especially siliceous organism, is present and iceberg transportation of terrigenous coarse sediments is also present in and around the Ross Sea. In the last glacial time, most of the Ross Continental Shelf was covered by an ice sheet continued from the continental ice sheet, and the sediments of deep-sea basins were modified by strengthened bottom currents in some places.

We show the roughly estimated history of the sedimentary environment, and propose a cartoon of the sedimentary environmental change from the last glacial stage to Recent in Fig. 5. Precise age data of the sedimentary sequences are needed for the further discussion of the sedimentary history of this area.

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