D-1.3.2 Studies to estimate long-term change of element cycles in ocean based on microfossils and other sediment components

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Southern oceans around Antarctica have been focused as one of the most important areas which control global environmental change through ocean circulation, because Antarctic water is very nutritious and behaves as the source of deep ocean water. Sediment core sequences taken around Antarctica are expected to include a plenty of information of paleoceanographic change.

In this work, we tried to establish quantitative reconstruction of environmental change of the Antarctic seas including surface productivity, deep water circulation, and glacier development. We analyzed cores from the Ross Sea and adjacent regions. Sedimentological analyses of cores in the surface sediments of the Ross Sea revealed two lithologic units, upper pelagic unit of diatomaceous ooze and clay and lower semi-consolidated sandy silt. The lower lithologic unit suggests that the highly ice-sheet influenced sedimentation existed in glacier time and/or the ice sheet retreating in the Ross Sea. In the outer area of the Ross Sea, there are found contourites with highly laminated parts formed by bottom currents probably during glacial time. The sedimentary environment in the Late Quaternary is reconstructed based on the core data.

1. Introduction

Sediments and sedimentary process 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 glacial time, continental ice sheet and sea ice cover areas were conspicuously extended. The sedimentary sequences around Antarctica record long-term sedimentary environmental changes. The Ross Sea is one of the largest inlets of Antarctic Continent and half of the inlet is covered by 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.

In this report, are first shown the results of sedimentological analysis on core sediment samples in and around the Ross Sea and are next discussed the sedimentary process and sedimentary environment based on these data.

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

The Ross sea is situated south of the Pacific Ocean and one of major inlets of the Antarctic Continent and bordered on the south by the largest ice shelf in the world,

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

Sample No.	Location (Lat.)	(Long.)	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 noth 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

the Ross Ice Shelf. The continental shelf is deep up to 500 to 600 meter deep on average and several banks and troughs are developed generally with a NNE-SSW trend. These topographic features result in geologic structures of sedimentary basins and glacier erosion in the Quaternary. The shelf break of the Ross Sea occurs at relatively great depth (approximately 800m) and the greatest depths on the shelf occur in its landward rather than seaward.

The deeper (greater than approximately 300m) portions or basin floors of the Ross Sea Continental Shelf are covered by muddy sediments (compound glacial marine sediments), whereas shallower (above approximately 300m) portions or bank areas of the shelf are floored by coarser (sand and gravel) deposits (residual glacial

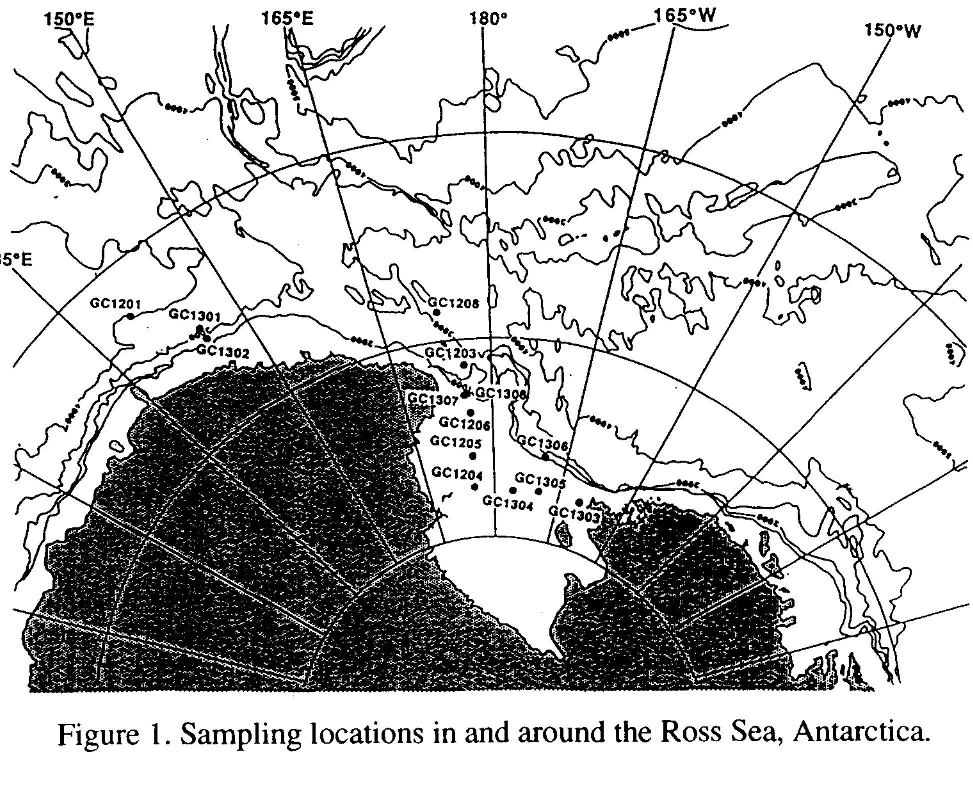

Figure 1. Sampling locations in and around the Ross Sea, Antarctica.

marine sediments), reflecting effective sediment sorting by bottom currents to depth of up to nearly 300m[1), 2)]. 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 offing 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

In the Ross Sea continental shelf, the core samples were taken by a gravity corer with a 11 cm diameter and a 5.4 m length. Fourteen core samples are available for this study. Localities of samples are shown in Figure 1 and their location data are shown in Table 1. Cores GC1303, GC1304, and GC1305 were taken from the basin floors in the eastern and central Ross Sea Continental Shelf and Cores GC1204, GC1205, and GC1206 in the western Ross Sea Continental Shelf. Cores GC1307 and GC1308 were collected from the bank slope at the shelf break of the Ross Sea. Other samples were collected from more deeper portions off the Ross Sea shelf, such as continental slope (GC1306), upper continental rise (GC1203) and lower continental rise (GC1208). Cores GC1201, GC1301, and GC1302 were taken from the continental slope and basin floor of the Dumont D'Urville Sea west of the Ross Sea.

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 made on 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 susceptibility apparatus of Martison Type-2 in 0.47 kHz frequency mode. Water contents were measured on the samples of several cubic centimeter with a 10 cm stratigraphic interval using a syringe. Water contents, bulk wet density, and bulk dry density were calculated. Sand contents were measured on the same samples as those for water content measurements.

Microplaeontological and paleomagnetic analysis were performed on these core samples.

4. Features of Surface Sediments in and around Ross Sea

Simplified lithologies of the core samples are summarized in Figure 2. Core penetration in the Ross Sea are very poor, because consolidated sediments exist several tens centimeters to one meter below the sea bottom. The lithologies of the studied core sequences can be grouped into three types based on the bathymetric features of sampling sites. That are continental slope - deep-sea basin type, shelf break type, and continental shelf type. First type includes Cores GC1201, GC1301, GC1302, GC1208, GC1203, and GC1306 and its core sequence is composed of pelagic and/or hemipelagic sediments throughout the core. Second type includes Cores GC1307, GC1308 and the sediments are characterized by the coarse sediments, such as coarse sandy sediments with shell fragments. 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 second and third types and the upper part of them is composed of siliceous mud as same as those of continental shelf type and the lower of sandy silt and silty sand with pebbles and shelly coarse sand like as those of shelf break type.

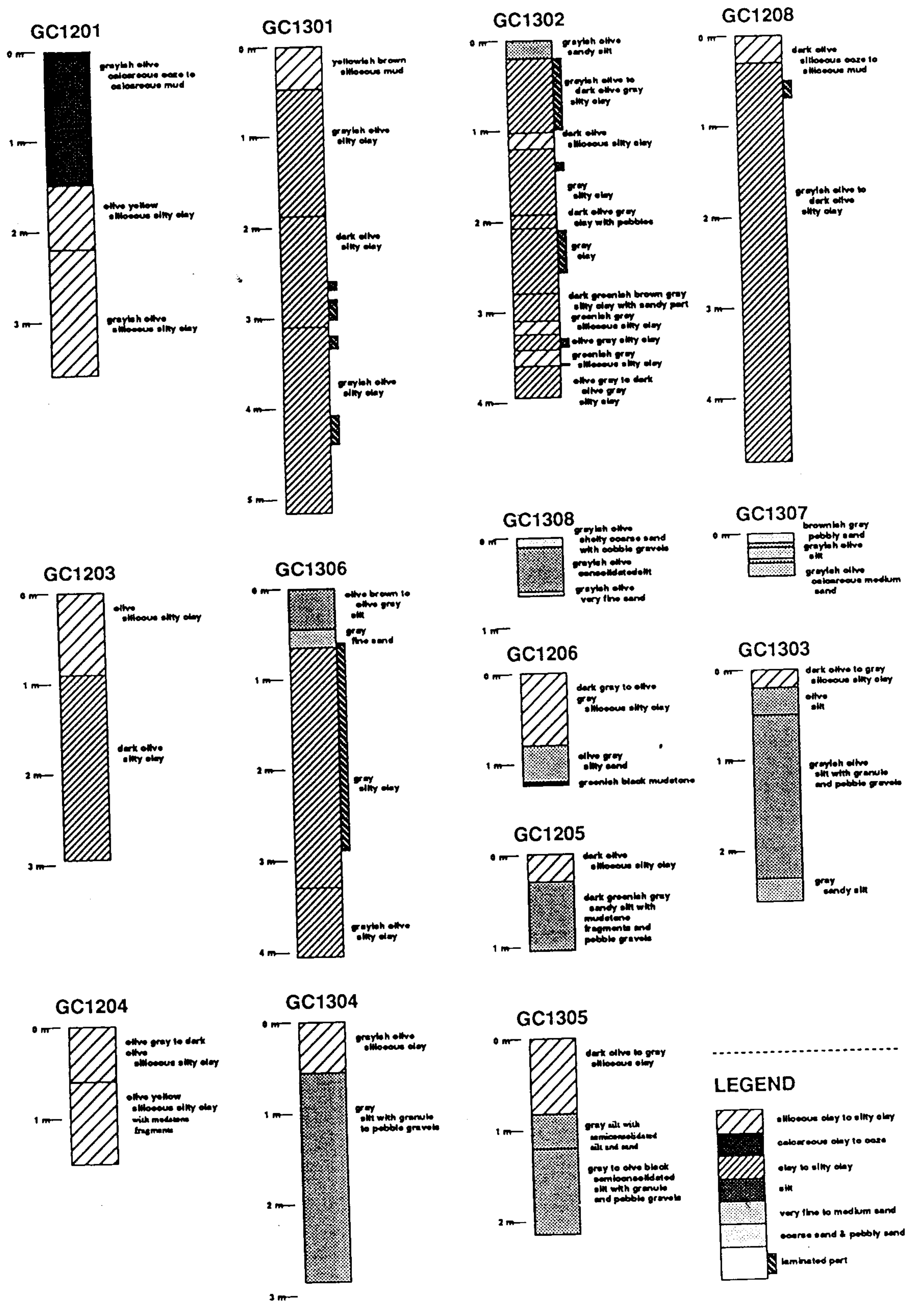

Figure 2. Simplified lithologic columns of core samples in and around the Ross Sea, Antarctica.

Brief description of representative cores of three types are as follows (Figure 3).
GC1302 (continental slope - deep-sea basin type)

This core comprises 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 millimeters thick bands on soft X-ray photographs and the grain sizes of the laminated parts are silt. Sand contents are less than five percent except the top and lower part 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 (IRD) because their occurrence is dispersed. The age of this core is middle to late Quaternary because the lower part of this core is defined into *Rouxia isopolica* Zone (0.66-0.35 Ma) of diatom zone [3].

GC1307 (continental shelf break type)

This core consists of sandy sediment. The shell fragments, barnacles, bryozoans, foraminifers, and ostracods occur in the sediments. The sand content are high and water contents are low throughout of the core. Silty sediments include pebble gravels and are semiconsolidated. The preliminary result shows that AMS ^{14}C age of foraminifers at 40-42 cm from the top is ca.34,000 yrs. B. P. (Murayama of Univ. Hokkaido, personal communications).

GC1305 (continental shelf type)

This core comprises of two lithologic units. The boundary exists at 90 cm from the core top. The upper unit is siliceous clay and contains a lot of diatoms. The lower unit is semiconsolidated silt with pebble gravels with remarkably low water content. The sand content of the upper unit is low and that of the lower unit is high. Magnetic susceptibilities are correlative to sand contents. The age of the upper unit is defined into *Nitzschia kerguelensis* Zone (0-0.2 Ma)[3] and that of the lower unit cannot be defined based on biostratigraphy because of the assemblage composed of probable reworked diatoms.

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, two lithologic units are recognized in the sedimentary sequences and the upper unit composed of diatomaceous mud is thought to be Holocene age based on the ^{14}C dating of organic carbon [4]. Moreover, the lower unit is thought to be the glacio-marine sediments in the last glacial times otherwise they cannot get age data[4, 5]. The thickness and sedimentation rates of the upper unit are variable in the Ross sea on account of the organic productivity and the age data of the upper unit shows Holocene age [6]. We have no data as to age of the sediments in and around the Ross Sea, but we estimate the probable age of the lower part of the sediments. The upper unit is the sediments deposited under the high organic productivity of diatoms and a 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 [7]. The lithologies of the lower unit are variable and complex in some places and they show generally high content of gravels and consolidation. It may include basal till sediments and glacio-marine sediments under the ice sheet cored most of the Ross Continental Shelf area in glacial time.

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

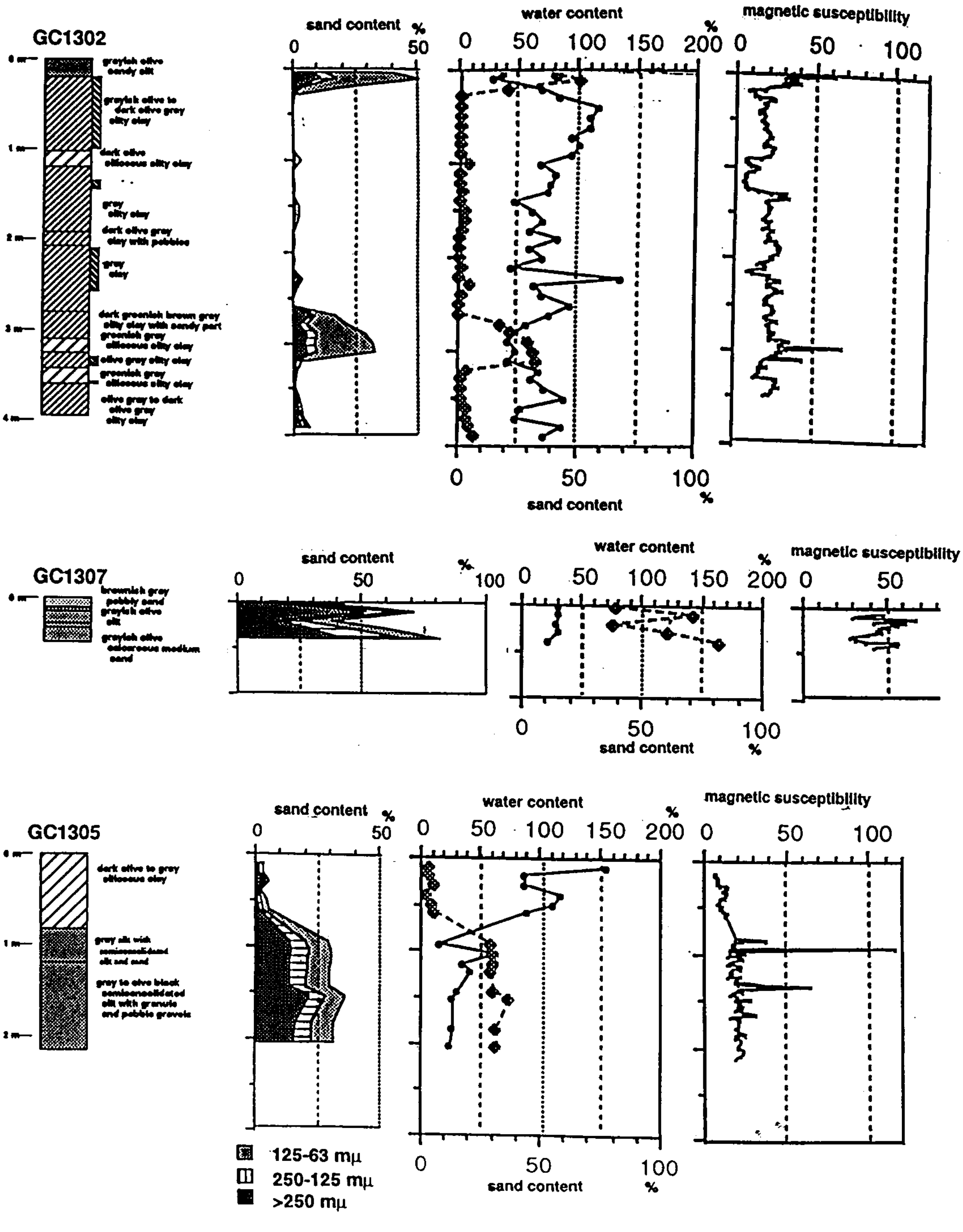

Figure 3. Three representative core sequences in and around the Ross Sea, Antarctica. Deep seabed off Antarctic (GC1302), continental shelf edge of the Ross Sea (GC1307), and inner part of the Ross Sea (GC1305).

semiconsolidated silt in the lower part of Core GC1307 suggest the presence of both of a open marine environment and a high influence of ice sheet in glacial time.

The sediments of 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 Weddel Sea [8]. Contour current was strengthened in the Glacial time. The laminated silty clay in the core sequences of the deeper part of the studied area is thought to be contourites formed by a strengthened bottom currents in glacier times as already pointed out[8].

We show the cartoon of the sedimentary environments in glacial stage, retreating stage of glacier, and recent, estimated based on the sediment samples mentioned above (Figure 4).

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 all types, we can recognize lithologic changes in the sequences. On the assumption that the core top lithology reflects the present sedimentary condition after the retreating of glacier after the last glaciation maximum and that another distinct lithology below the core top lithology reflects the sedimentary environment of the glacier stage, we reconstruct the sedimentary environmental change after the last glacier. At present, the 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 glacial time, almost of the Ross Continental Shelf was covered by ice sheet continued from the continental ice sheet and the sediments were modified by strengthened bottom currents in some places.

We show that the roughly estimated a history of the sedimentary environment, mentioned as above, and propose the cartoon of the

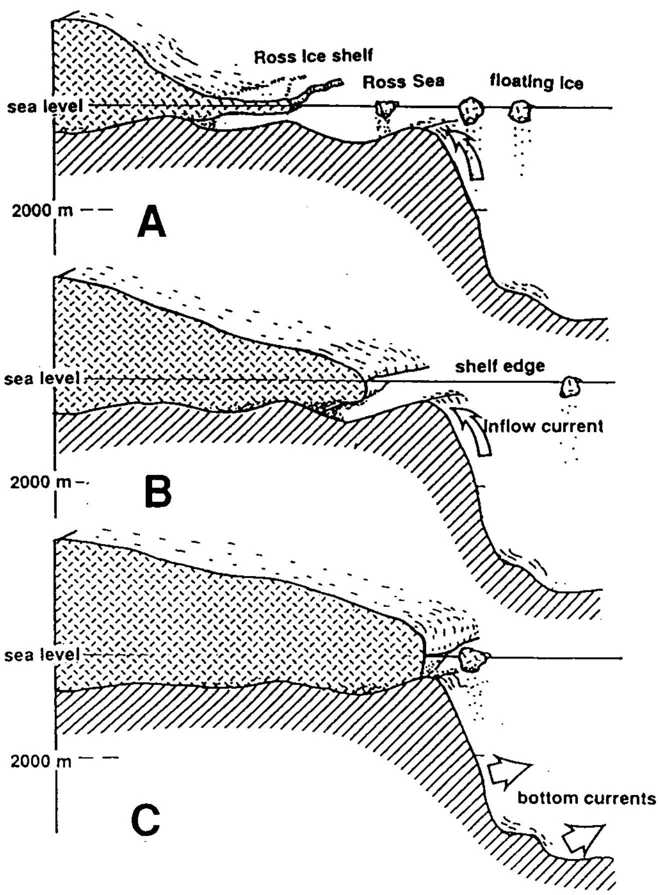

Figure 4. Cartoon of sedimentary history of the Ross Sea area.
A; Recent, B; Retreating stage of continental ice sheet (early Holocene), and C; Last glacial.