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MARINE SEDIMENT CORES FROM THE CONTINENTAL SHELF AROUND ANVERS ISLAND, ANTARCTIC PENINSULA REGION

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Abstract: Sediment core samples are described from the area adjacent to Anvers Island north of the Antarctic Peninsula. The sequence is divided into three lithologic units, siliceous mud, alternation sandy silt and siliceous mud, and sandy silt with gravel, in descending order. These units suggest sedimentary environmental changes from under the ice sheet, to marine with highly influenced by fluctuation of the ice sheet, and finally to open marine. These major environmental changes are dated to *ca.* 16 ka BP and *ca.* 11.5 ka BP, respectively, based on uncorrected radiocarbon ages of organic carbon.

key words: late Quaternary, AMS radiocarbon ages, sea bottom sediments, Antarctic Peninsula

1. Introduction

The sedimentary sequences around Antarctica record long-term sedimentary environmental changes influenced by development of continental ice sheet, sea ice, and productivity of marine plankton. Our previous work on sediments in and around the Ross Sea area (NISHIMURA *et al.*, 1996, 1998; TOKUHASHI *et al.*, 1996) has revealed that the sedimentary environmental changes were accompanied by a retreating ice sheet, shelf ice formation and considerable production of marine organisms in the open ocean.

In the area north of the Antarctic Peninsula, a geological and geophysical survey, TH96 Cruise by R/V HAKUREI-MARU, was conducted by Technology Research Center, Japan National Oil Corporation (JNOC) (TANAHASHI *et al.*, 1998). In this paper, are described first, the results of analysis of sediment core samples around Anvers Island off the northern part of the Antarctic Peninsula, and second, the sedimentary processes and sedimentary environments.

2. Geological Setting

The continental shelf in this area is developed along the coast in the NE-SW direction and has ca. 150 km width and a deep shelf break *ca.* 400 m deep. A trough with a maximum depth exceeding 1000 m is located south of Anvers Island on this shelf (Fig. 1).

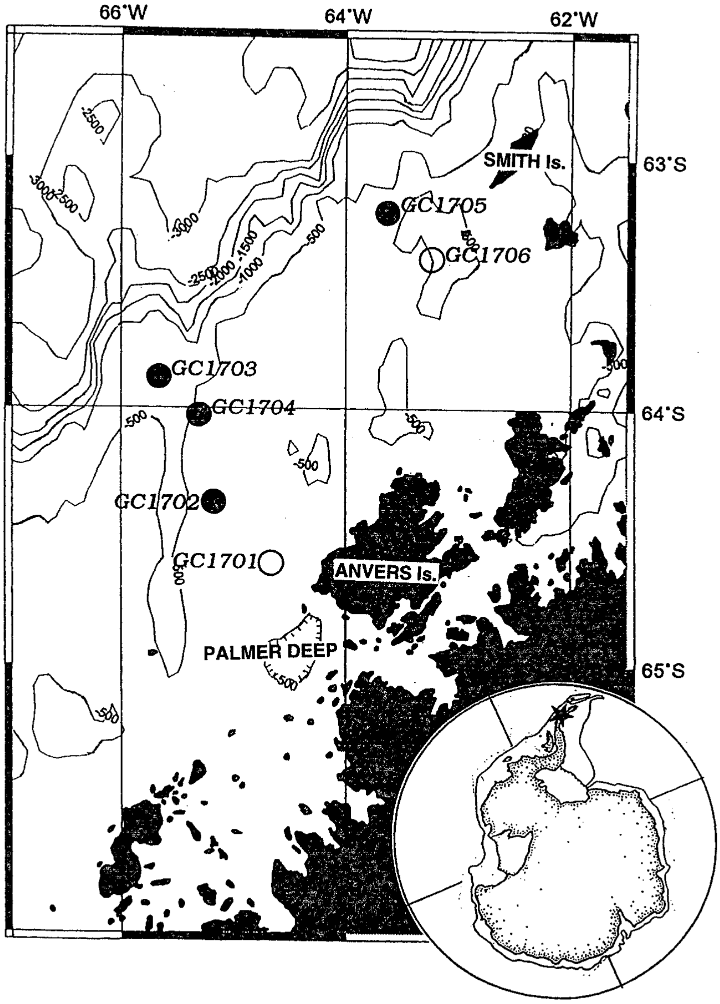

Fig. 1. Study area showing the sampling locations.
Closed circles show locations with a sediment core sample, and open circles ones with no available sediment sample.

According to MCCOY (1991), the continental shelf and the deeper continental slope are covered by biosiliceous muddy sediments. Coarse gravely sediments distribute around the continental slope and the topographic highs on the continental shelf. A high resolution record showing Holocene environmental change with 200–300 year cycles, is reported based on the lithology and composition of a piston core sample, from the Palmer Deep southwest of Anvers Island (LEVENTER *et al.*, 1996). In 1988, three sites and two sites were drilled along the traverse of the continental slope northwest of Anvers Island and in the Palmer Deep, respectively, during ODP Leg 178 (BAKER *et al.*, 1998). In the same area, an advance of the ice sheet on the continental shelf in the Last Glacial Maximum and the sedimentary process in the Holocene have been discussed based on side-scan sonar mapping, deep-tow seismic survey and sediment core sampling (PUDSEY *et al.*, 1994; VANNESTE and LARTER, 1995). No precise sediment records through the last glacial cycle has been reported in this area.

3. Samples and Analytical Methods

We tried to collect the sediment core samples using a gravity corer with 11 cm diameter and 5.4 m length at 6 sites around Anvers Island during the TH96 Cruise (Fig. 1 and Table 1), but no core section was taken at two sites (GC1701 and GC1706). Four core sequences, the maximum being 3.14 m long, were available for this study (Fig. 2).

The samples were processed as follows through on-board and shore-based work:

(1) Sediment lithologies and structures were described based on visual observation, soft X-ray photos, and smear slide observations.

(2) Water content (weight percent water), dry bulk density and sand content (weight percentage of grains larger than 63 μm) were measured for syringe samples (4–5 cc) at 10-cm stratigraphic intervals. Sand fractions were subdivided into five grain size classes

Table 1. Location data for core samples.

Sample No.	Location (Latitude)	Location (Longitude)	Water depth (m)
GC1701	64°35'55"S	64°40'59"W	310
GC1702	64°22'13"S	65°11'58"W	522
GC1703	63°52'16"S	65°39'14"W	451
GC1704	64°01'25"S	65°17'58"W	470
GC1705	63°12'16"S	63°36'33"W	368
GC1706	63°24'02"S	63°13'02"W	190

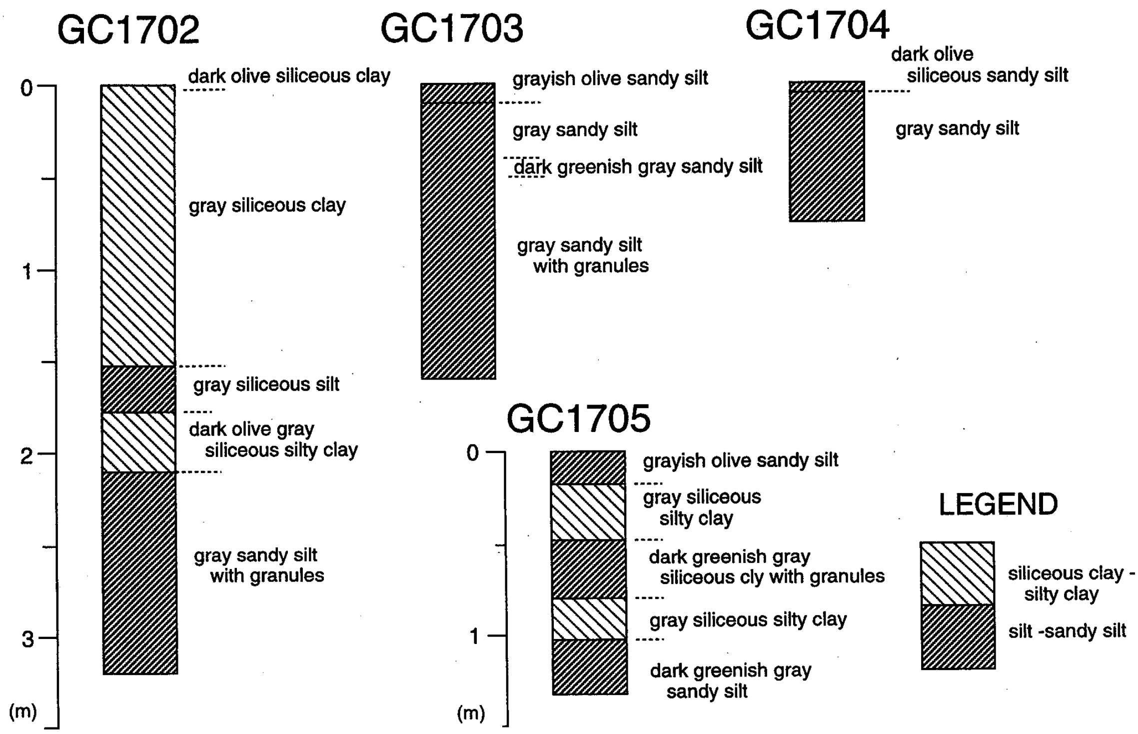

Fig. 2. Simplified lithology columns of the sediment cores.

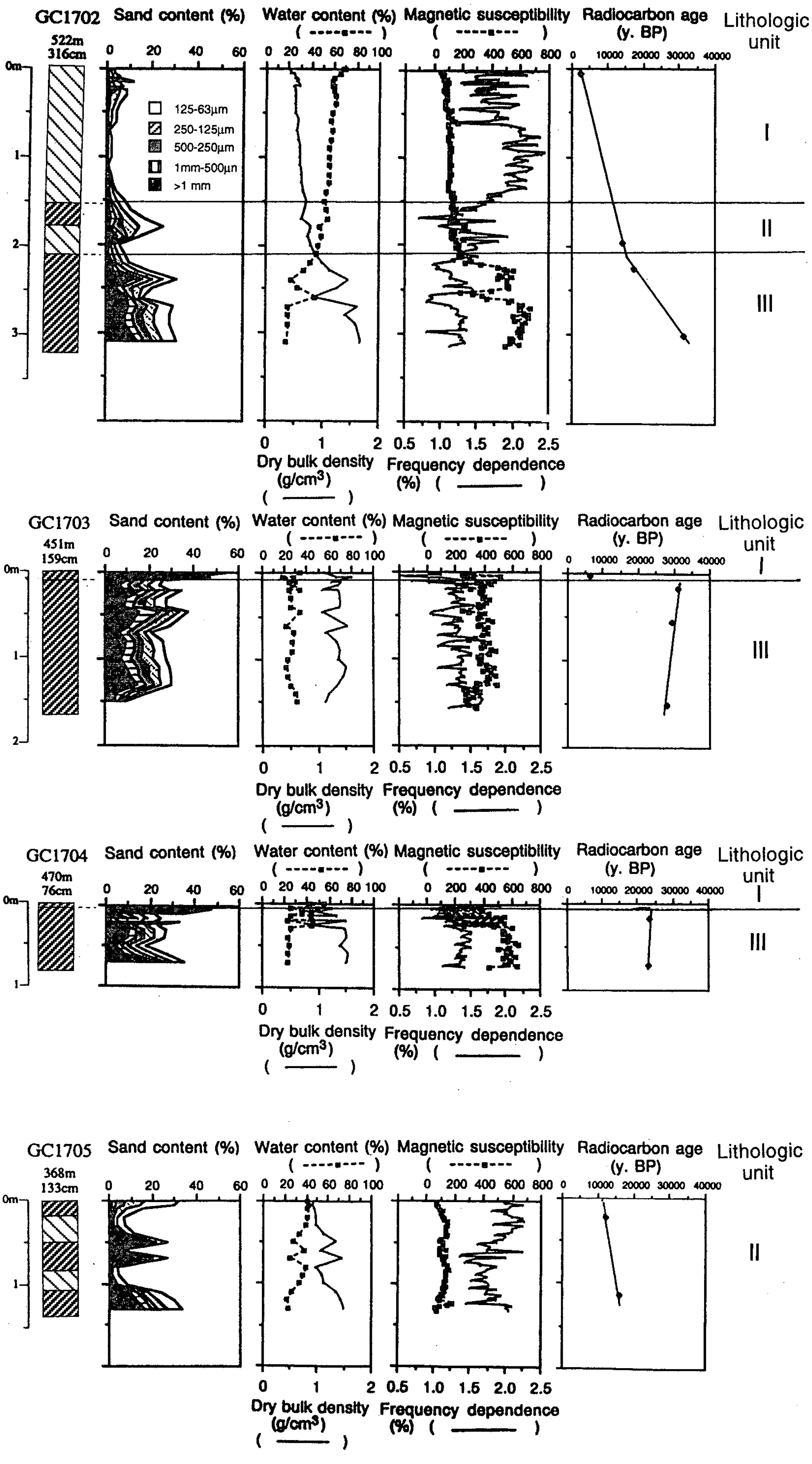

Fig. 3. Lithologies, sand contents, physical properties and AMS ^{14}C ages of the core samples.

as shown in Fig. 3.

(3) Magnetic susceptibilities were measured for one-cubic inch samples at every inch using a Martison Type-2 apparatus in 0.47 kHz and 4.7 kHz frequency modes. Magnetic susceptibility shows the amount of magnetic minerals, most of which are supposed to have terrigenous origin in this region, and its profiles in the core sequence may be used to infer the content of terrigenous materials in the sediments. Larger values of frequency dependence suggest that the grain sizes of magnetic minerals are relatively small (YAMAZAKI and KATSURA, 1990). The frequency dependence was calculated from the differences of measured susceptibility values between the two modes using the equation:

$$\chi_{FD}=(\chi_L-\chi_H)/\chi_L\times 100\ (\%),$$

where χ_{FD} indicates frequency dependence, χ_L magnetic susceptibility of 0.47 kHz frequency, and χ_H that of 4.7 kHz frequency.

(4) Organic carbon, inorganic carbon, and nitrogen content were measured on all core sequences at 10 to 20 cm intervals. Samples were stored frozen before drying at 50°C. Inorganic carbon content was converted to calcium carbonate content by multiplying by 8.33, the atomic weight ratio of calcium carbonate to carbon. Organic carbon content of sediment depends on biogenic productivity and supply of terrigenous materials.

(5) Opal content was measured on the same sample for carbon and nitrogen analysis of Core GC1702, using a modified method for the rapid determination of biogenic opal (MORTLOCK and FROELICH, 1989). Silica was extracted into 2M-Na_2CO_3 at 85°C for 5 hours by shaking. Dissolved silica was determined by molybdate-yellow spectrophotometry using a Spectrophotometer Model-6C; Hirama Laboratories. Opal contents of sediments also depend on biogenic productivity and supply of terrigenous materials.

(6) Acid-insoluble organic carbon of the sediment samples was used for AMS ^{14}C dating, because carbonates were almost totally lacking in the sediments. The sediment samples for dating were taken at 2 to 3 cm stratigraphic intervals on board (Table 2) and stored frozen before drying at 50°C in the shore-based laboratory. The AMS measurements were performed at Groningen University (Netherlands) after preparation at Beta

Table 2. AMS radiocarbon age data of the organic carbon in Cores GC1702, GC1703, GC1704, and GC1705.

Core No.	depth (cm)	measured ^{14}C age (y BP)	$\delta^{13}C$ (‰)	Conventional ^{14}C age (y BP)	Lab. Sample No.
GC1702	5–8	2360±50	−25.8	2340±50	Beta-109032
	195–198	14320±50	−25.1	14320±50	Beta-109033
	225–228	17500±60	−23.9	17520±60	Beta-109034
	300–302	31250±280	−24.6	31250±280	Beta-109035
GC1703	3–7	6210±50	−26.0	6190±50	Beta-109036
	16–18	31240±270	−24.7	31240±270	Beta-109037
	55–58	29380±270	−24.9	29380±270	Beta-109038
	151–154	28090±160	−24.8	28090±160	Beta-109039
GC1704	16–19	23410±100	−25.1	23410±100	Beta-109040
	70–73	22870±90	−25.1	22870±90	Beta-109041
GC1705	22–25	12120±60	−26.2	12100±60	Beta-109042
	112–115	16130±60	−25.8	16110±60	Beta-109043

Analytic Inc. (USA). ^{14}C ages were determined and corrected for isotopic fractionation based on $^{13}C/^{12}C$ ratios, using a half-life of 5568 years. These ^{14}C ages are called the uncorrected ages in this paper, which means that radiocarbon ages are not corrected for the reservoir effect.

4. Description of Sediment Cores

The simplified core lithologies are shown in Fig. 2; the results for sand content, physical properties, and radiocarbon ages are shown in Fig. 3; and results of chemical analysis are shown in Fig. 4.

GC1702: This core was taken from the middle of the continental shelf west of Anvers Island. This core is divided into three parts, upper, middle, and lower parts, based on its lithology. The upper part (0–153 cm) is dark olive to gray siliceous clay, which is characterized by low sand content of less than 10%, high water content, low magnetic susceptibility, and high contents of organic carbon and opal. The C/N ratio shows a gradual downward increase from 6 to 8. The middle part (153–210 cm) is gray siliceous silt with high sand content and silty clay with low sand content, which shows downward decreases of water content and organic carbon content. The C/N ratio is around 7. The lower part (210–316 cm) is gray sandy silt with high sand content exceeding 30%; and low water content, high magnetic susceptibility, and low contents of organic carbon and opal. The C/N ratio is generally high with large variation.

Four radiocarbon age data from this core imply continuous sedimentation from the top to the bottom. The boundary between the lower and middle parts and that between the middle and the upper parts are calculated to be ca. 16 ka BP and 11.5 ka BP, respectively. The sedimentation rate of the upper and the middle parts is 15.9 cm kyr^{-1} and that of the lower part is 5.5 cm kyr^{-1}. The core top age extrapolated from the upper two ages is 1.93 ka BP.

GC1703: This core was taken from the mouth of a canyon incising into the continental shelf. This core comprises grayish olive to gray sandy silt through the whole sequences of the main core. The sediments are characterized by high sand content, low water content, high magnetic susceptibility, and low organic carbon content. The X-ray photos show high contents of pebble to granule-sized angular rock fragments and flexure structures formed by sediment mixing in several parts. One radiocarbon age of 3–7 cm in the upper part is 6.19 ka BP. Three radiocarbon ages of the lower part of this core show reversed stratigraphic order from 31 ka BP to 28 ka BP. The age data suggest that a hiatus with a large time lack is present at 9 cm with a sharp color change from grayish olive to gray.

GC1704: This core was taken from adjacent to the GC1703 site, the continental shelf edge northwest of Anvers Island. This core is composed of dark olive siliceous sandy silt in the top 4 cm and olive gray to gray sandy silt elsewhere. The top part of the sediment shows high sand content and moderately high organic carbon content. The rest shows low water content, high magnetic susceptibility, and low organic carbon content. The X-ray photos show no sedimentary structure or inclusions of angular rock fragments. Two radiocarbon ages of the lower lithology are reversed in stratigraphic order with similar values around 23 ka BP. The topmost part of the core (0–4 cm) is possibly

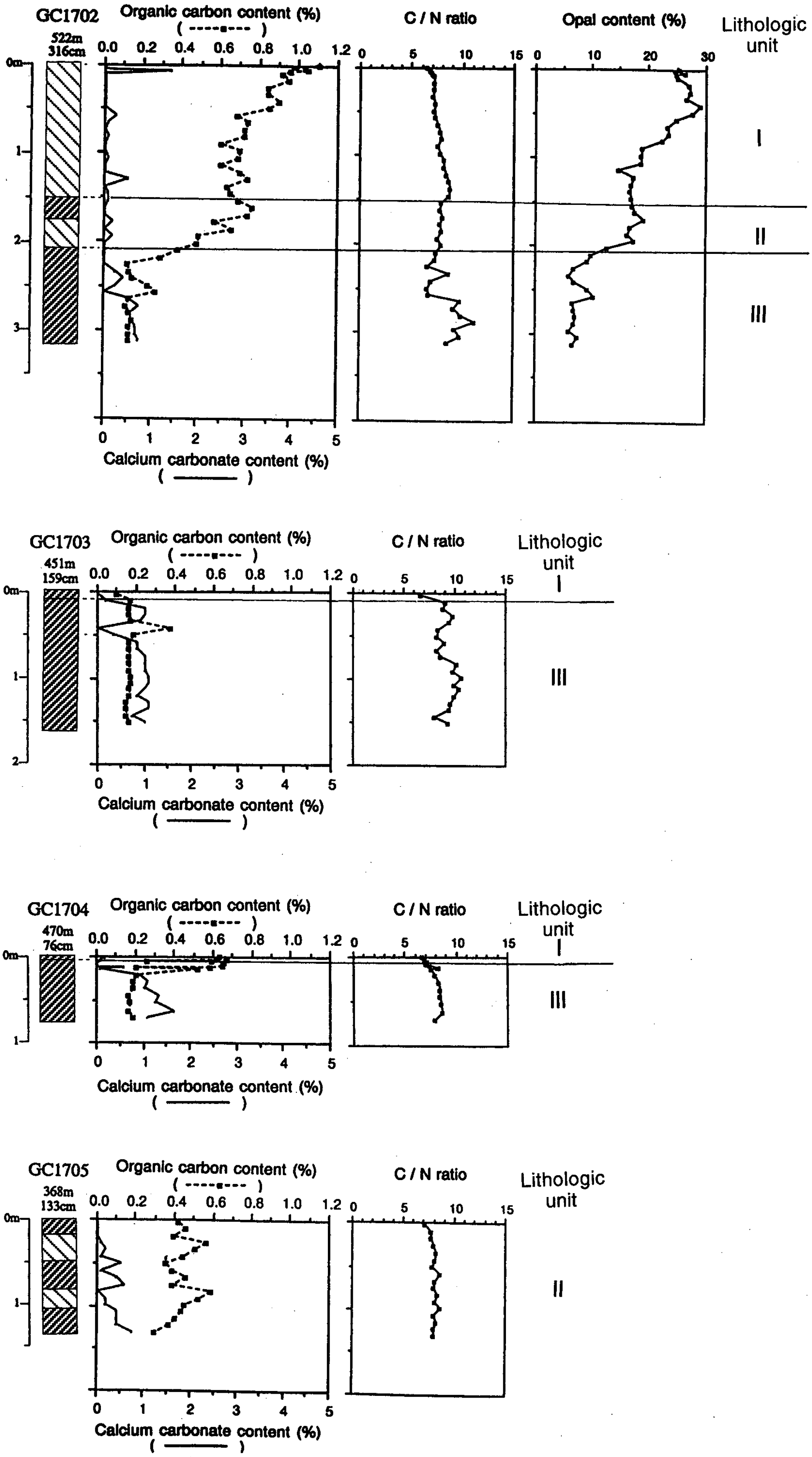

Fig. 4. Lithologies, carbon and nitrogen contents, carbon/nitrogen ratios, and opal contents of the core samples.

younger sediment correlated to the upper part of GC1702, considering the water content and organic carbon content.

GC1705: This core was taken from the continental shelf near the shelf edge west of Smith Island. This core comprises alternation of grayish olive to dark greenish gray sandy silt and gray siliceous silty clay. Sand content is highly variable and water content decreases downward from 40% at the top to 20% at the bottom. Organic carbon content is *ca.* 0.4%, moderate in this area. Two radiocarbon ages of this core implies that the sediments had deposited from *ca.* 16 ka BP to 12 ka BP with a high sedimentation rate of 22.4 cm kyr^{-1}.

5. Lithologic Units

Based on the core lithology and characteristics, we can divide the core sequences into three lithologic units, Units I, II, and III, in descending order. All these units are recognized in GC1702 and correspond to the units mentioned in the former section. Their characteristics and ages are as follows.

Unit I: This unit is dark olive to gray siliceous clay and corresponds to 0–153 cm in GC1702. This unit also includes 0–9 cm in GC1703, and 0–4 cm in GC1704, and those lithologies are siliceous clay and sandy silt. This unit yields abundant diatom tests. High water content, low sand content, low value of magnetic susceptibility, and high organic carbon content characterize this unit.

Unit II: This unit shows two lithologies of siliceous mud and sandy silt and includes 153–210 cm in GC1702 and 0–133 cm in GC1705. The upper boundary of this unit to Unit I is a gradual transition with a color change in GC1702. This unit is characterized by medium value of water content and contents of organic carbon and opal, between those of Units I and III. The magnetic susceptibilities are moderately stable but frequency dependencies are large and highly variable.

Unit III: This unit is sandy silt and includes 210–316 cm in GC1702, 9–159 cm in GC1703, and 4–76 cm in GC1704. This unit comprises gravel bearing sandy silt with high sand content and low water content. The characteristics of this unit are low contents of organic carbon and opal. Moreover, high values of magnetic susceptibility and low values of frequency dependence are characteristic of this unit. C/N ratios are large between 7 and 10. The age data of this unit in GC1703 and GC1704 show reversed stratigraphic orders and/or homogenous age values.

The ages of these units are defined based on the ages of the boundaries of the parts of GC1702. Unit I corresponds to 11.5 ka to present, Unit II 16 ka to 11.5 ka, and Unit III before 16 ka. Age data of unit boundaries are consistent with other core age data.

6. Discussions

6.1. Proxy of productivity

Organic carbon and inorganic carbon are produced by marine planktonic organisms in an open ocean environment. The organic carbon content of sediments is usually used as a proxy for productivity and can be used for quantitative reconstruction of primary productivity combined with data of sedimentation rate, dry bulk density, and water depth.

Around Antarctica, organic carbon content is sometimes used as one of the criteria of classification of sedimentary environments (LICHT *et al.*, 1996; NISHIMURA *et al.*, 1998). The organic carbon content changes depending on the lithology and is used as a proxy for the open marine environment. The C/N ratios range between 6 and 10, which implies that most organic carbon materials in sediments are originated from marine organisms. In the Antarctic seas, planktonic siliceous organisms, such as diatoms, are major primary producers. In this study, the opal content of GC1702 was measured. The relation between the contents of organic carbon and opal shows good correlation as shown in Fig. 5. This result suggests that the siliceous planktons contribute to the primary production, and opal content has a potential to be used as production.

Calcium carbonate is also produced by marine organisms. Carbonate contents of sediments are small, less than 2%, in the sediments of this area. The contents show

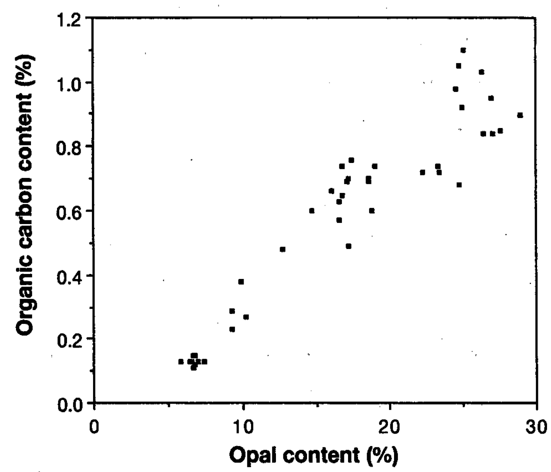

Fig. 5. Relation between organic carbon and opal contents in Core GC1702.

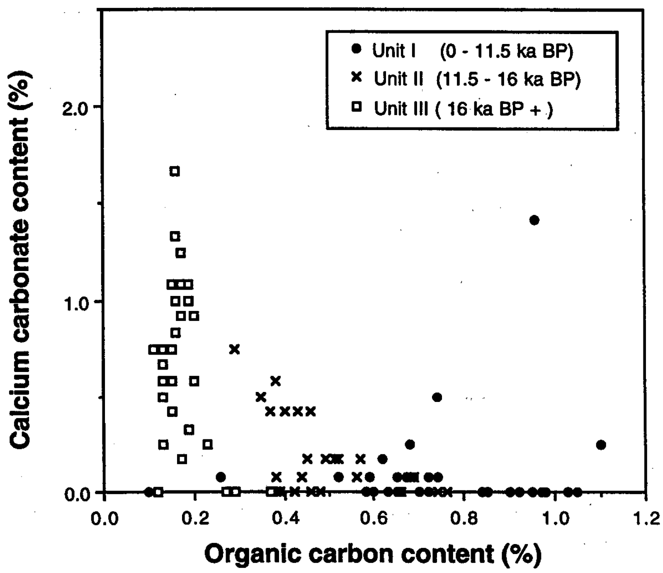

Fig. 6. Relation between organic carbon and calcium carbonate contents in all core sequences.

extremely low values in Unit I with a trend to downward increase on average, as shown in Fig. 6. The calcium carbonate preservation state highly depends on the characteristics of ambient water of sediments; in Antarctic seas, preservation of carbonate is generally poor. In the core sequences of this area, there is no positive relation between the carbonate content and contents of organic carbon and opal. It is concluded that carbonate content of the sediment in this area cannot be not a proxy of production of marine organisms. A small amount of reworked Cretaceous calcareous microfossils are found in these cores (JNOC, unpublished data), which possibly contributes to carbonate content. The origin and cause of the carbonate content need more works including the components of carbonate materials in sediments.

6.2. Sedimentary environments

The sedimentary environments are discussed based on the lithologies and characteristics of cores mentioned above. In the Antarctic area, sedimentation on the continental shelves is highly influenced by the ice sheet, sea ice, and shelf ice (ANDERSON *et al.*, 1991). On the Ross Sea continental shelf, the lithologic unit of consolidated gravely coarser sediment with low water content is distributed widely. Those sediments have been interpreted as sediments affected by a grounded ice sheet on the Ross Sea continental shelf (EDWARDS *et al.*, 1987; NISHIMURA *et al.*, 1996, 1998), especially in the Last Glacial Maximum (DENTON *et al.*, 1989). LICHT *et al.* (1999) distinguish subglacial till and glacial marine diamictons based on their sedimentary structures, carbon contents, and fossil occurrence. They reveal that glacial marine diamictons include the tephra layers and several sediment layers with sedimentary structures and that no normal sedimentary structure is present in the subglacial till with relatively homogeneous lithology formed by mixing.

Unit III, which shows mixing sedimentary structures and relatively homogenous characteristics, low water content, and low organic carbon content, possibly corresponds to subglacial till, and Unit II, which shows sedimentary structures, lithologic changes with sand content variation, and medium organic carbon content, to the glacial marine diamictons defined by LICHT *et al.* (1999). Units II and III are characterized by high contents of gravel and sand. Large magnetic susceptibilities and low values of frequency dependencies in Unit III suggest high contents of coarse terrigenous materials had been transported into the sediments.

The sedimentary environment of Unit I, sediments with high diatom content, is the same as that at present. The large productivity of planktonic organisms is suggested by large organic carbon and opal contents.

6.3. Sedimentary history

The sedimentary history, based on the sedimentary environments inferred from the lithologies, is as follows.

The ice sheet advanced and covered the continental shelf, and deposited subglacial tills, composed of both gravely coarse sediments transported by the ice sheet and sediments already deposited there, mixed and deformed by the moving ice sheet. The subglacial tills had been deposited before 16 ka BP, which is the boundary age between Units II and III in GC1702. After retreat of the ice sheet, biogenic siliceous sediments have been deposited under an open ocean environment. The establishment of an open marine environment in the whole part of this area is 11.5 ka BP, which is suggested by the boundary age between Units I and II. Transitional facies of the upper two sedimentary environments, coarse gravely sandy sediments and fine muddy sediments were deposited, probably depending on the advance and retreat of the ice sheet.

Marine sediments around Antarctica show a large and regionally variable reservoir effect on radiocarbon age (OMOTO, 1983; DOMACK *et al.*, 1989; GORDON and HARKNESS, 1992). The extrapolated core top age of GC1702 implies that the reservoir effect of this area is *ca.* 2 ka. Assuming that the reservoir effect for radiocarbon dating in this area is *ca.* 2 ka, the sedimentary environmental changes mentioned above are dated *ca.* 14 ka BP and 0.95 ka BP, respectively.

7. Concluding Remarks

We analyzed four core sequences from the area adjacent to Anvers Island, the northwestern margin of the Antarctic Peninsula. Three lithologic units were recognized in the core sequences and radiocarbon ages of organic carbon were dated by the AMS method. The continental shelf of this area was covered by an ice sheet and subglacial till was deposited before 16 ka BP. After 16 ka BP, the sediments were highly influenced by retreat and advance of the ice sheet. Diatomaceous siliceous mud has been constantly deposited since *ca.* 11.5 ka BP of radiocarbon age with high productivity. Assuming that the reservoir effect for radiocarbon dating in this area is *ca.* 2 ka, the sedimentary environmental changes are dated *ca.* 14 ka BP and 0.95 ka BP for release from ice sheet and transition to open marine, respectively.

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