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MARINE FOSSILS OF 30-40 ka IN RAISED BEACH DEPOSITS, AND LATE PLEISTOCENE GLACIAL HISTORY AROUND LÜTZOW-HOLM BAY, EAST ANTARCTICA

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Abstract: Radiocarbon ages of fossil marine organisms in raised beach deposits along the Sôya Coast are clearly classified into two groups of 3-8 ka and 33-42 ka by Tandetron Accelerator Mass Spectrometry (TAMS). The older fossils are recognized on the Ongul Islands and the northernmost part of Langhovde, which are separated from the present ice sheet margin by a drowned glacial trough deeper than 500 m. Some of the older molluscan fossils as well as the younger ones retain their living form *in situ*. These facts together with the deep continental shelf and a small amount of isostatic uplift of the Holocene raised beaches lead to the following conclusions for the region: 1) Marine transgression took place in the last interstadial and in the Holocene. 2) Major deglaciation took place by the last interstadial in the region. 3) Expansion of the ice sheet during the Last Glacial Maximum was slight, although its extent is still unknown. 4) Sea-level during the last interstadial was probably higher than that estimated from foraminiferal $\delta^{18}O$ records in deep-sea sediments.

1. Introduction

It has been known since the early Japanese Antarctic Research Expeditions (JARE) that raised beach deposits along the Sôya Coast include fossil marine organisms whose ^{14}C ages are older than 20 ka as well as younger than 10 ka (MEGURO *et al.*, 1964; YOSHIDA, 1970; MORIWAKI, 1974). YOSHIDA and MORIWAKI (1979) and YOSHIDA (1983) considered that deglaciation in the Sôya Coast region took place by at least 30 ka. However, they also mentioned that the age data of the older raised beach deposits were still insufficient to reconstruct the late Quaternary glacial history in the region more precisely. In the Vestfold Hills east of Prydz Bay, several ^{14}C ages older than 20 ka for fossils in marine sediments at Marine Plain were reported (ADAMSON and PICKARD, 1983; ZHANG *et al.*, 1983). However, these ^{14}C ages were considered to be beyond the range of radiocarbon dating (ADAMSON and PICKARD, 1986). At present, the Marine Plain sediments are regarded as those of the Pliocene on the basis of amino-acid dating and biostratigraphic age of

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marine diatoms (ADAMSON and PICKARD, 1986; PICKARD *et al*., 1988). As described above, some doubts have been cast on the reliability of ^{14}C ages older than 20 ka for the Antarctic region.

Recently, IGARASHI *et al*. (1995) dated twelve units of molluscan shell fossils obtained from raised beach deposits along the Sôya Coast by Tandetron Accelerator Mass Spectrometry (TAMS), and classified their ages into two clearly different groups (younger than 8 ka and older than 33 ka, respectively). We dated fifteen other samples (molluscan shell fossils and benthic foraminiferal fossils) by TAMS at Nagoya University, and confirmed the existence of marine fossils whose ages are 33–42 ka in the raised beach deposits along the Sôya Coast. All samples were processed in the same way, by soaking in dilute hydrochloric acid and cleaning ultrasonically, as those of IGARASHI *et al*. (1995).

In this paper, we discuss fluctuations of the East Antarctic ice sheet and global sea-level changes during the latest Pleistocene, based on the existence of marine fossils of about 30–40 ka in the deposits.

2. ^{14}C Ages of Marine Fossils and their Localities along the Sôya Coast

The raised beach deposits on several ice-free rocks along the Sôya Coast are located below 25 m asl, and fossil marine organisms (mainly molluscs, foraminifers, and serpuloid tubes) in them occur below 20 m asl (*e.g*., HAYASHI and YOSHIDA, 1994; Fig. 1). In the region, TAMS dating has been carried out for 36 fossil samples of 30 localities (Table 1; HAYASHI and YOSHIDA, 1994; IGARASHI *et al*., 1995; this work).

The maximum ^{14}C age detection by the TAMS measurement has been extended to about 60 ka, and the capability largely depends on the ^{14}C background at the measurement (*e.g*., NAKAMURA and NAKAI, 1988). The ^{14}C ages previously reported by IGARASHI *et al*. (1995) were without correction for the ^{14}C background. Therefore, we made the correction for them taking into account the ^{14}C background (43.68 ka in apparent ^{14}C age) at the time of measurement. As a result, they were corrected to be older as shown in Table 1. Among them, the reliability of two ages beyond 40 ka which are close to the ^{14}C background might be somewhat low, with true ages considerably older. On the other hand, newly measured ^{14}C ages (~38 ka) are rather reliable, because ^{14}C backgrounds were calculated as either 50.86 ka or 52.46 ka in apparent ^{14}C age at the time of measurements (Table 1).

The $\delta^{13}C$ correction for isotopic fractionation effect on $^{14}C/^{13}C$ ratio was made for the ^{14}C ages of IGARASHI *et al*. (1995). However, the corrected values were very small, especially for the ^{14}C ages older than 30 ka. Therefore, we treat ^{14}C ages without the $\delta^{13}C$ correction in this work. We also treat ^{14}C ages without the reservoir correction, which involves subtracting about 1000 yr for Holocene marine organisms in the Antarctic region, suggested by many investigators (*e.g*., OMOTO, 1983; STUIVER *et al*., 1986), because we mainly discuss here pre-Holocene ages for which the value of the correction is unknown at present.

According to previous work, it is known that older fossils occur in close proximity to younger fossils in extent and elevation in the beaches on the Ongul Islands and Langhovde (Fig. 1). Furthermore, it is difficult to distinguish the younger fossils from the older ones by their aspects. Such occurrence of fossils suggests that some ^{14}C ages determined by previous works, for which a relatively large amount of fossils were necessary, were probably derived from the mixture of younger and older fossils (HAYASHI and YOSHIDA, 1994; IGARASHI *et al.*, 1995). Therefore, some ages belonging to the previously classified age group of older than 20 ka seem to have become young. On the contrary, only one

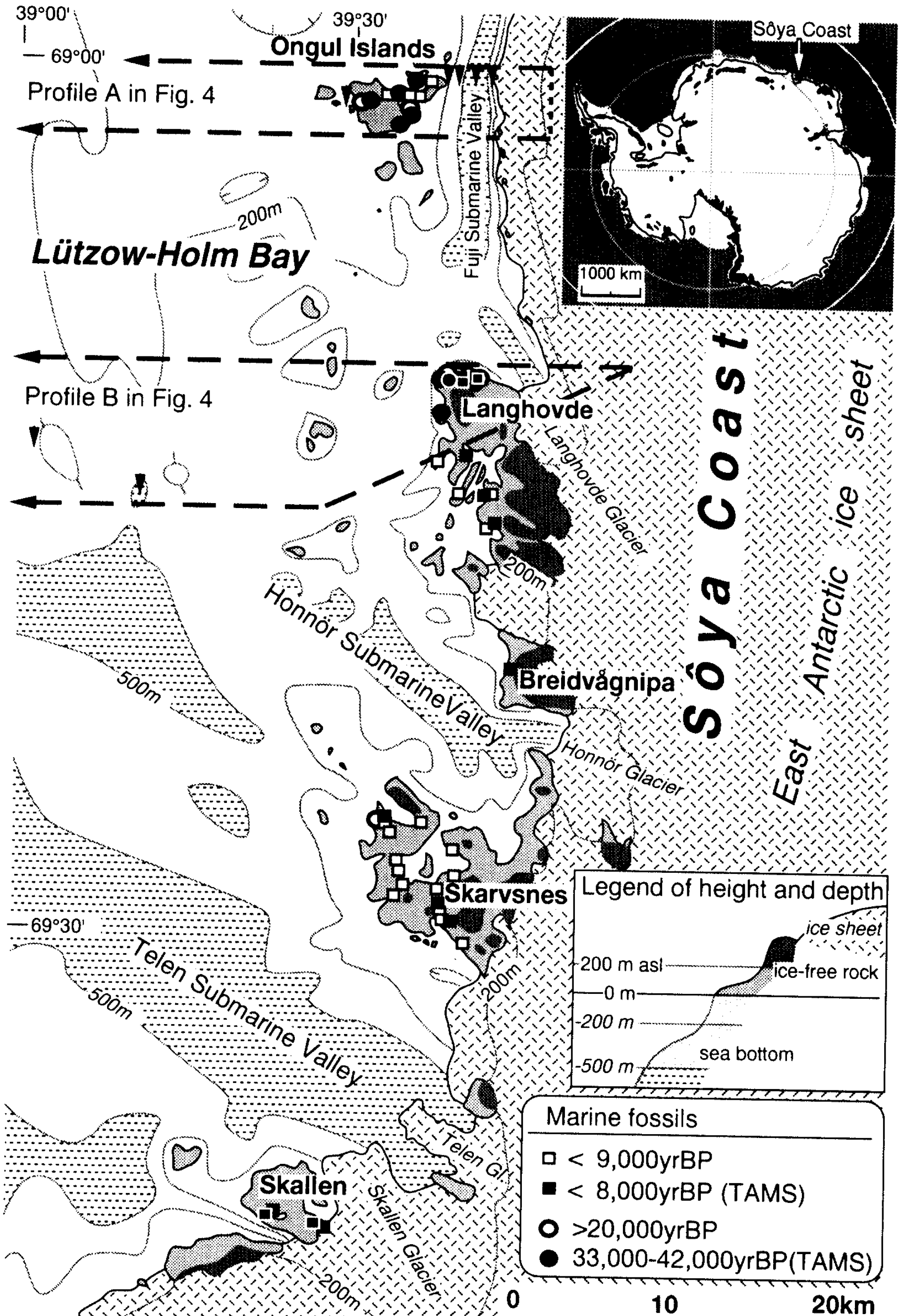

Fig. 1. Localities of ¹⁴*C-dated fossil marine organisms in raised beach deposits along the Sôya Coast (Data sources: Appendix 3 in* HAYASHI *and* YOSHIDA, *1994;* IGARASHI et al., *1995; and this study). A downward wedge shows sampling station of sediment core of sea-bottom. Isobathes of 500 m and 200 m are quoted from* MORIWAKI *and* YOSHIDA *(1990).*

Table 1. Inventory of radiocarbon dates of fossil marine organisms in raised beach deposits on ice-free rocks along the Sôya Coast determined by applying TAMS. Ages published by IGARASHI *et al. (1995) are re-examined with background correction in the present study.*

Locality	Altitude (m)	Material	Age (yr BP) without $\delta^{13}C$ and background corrections	Age (yr BP) with background correction	Background in apparent age (yr BP)	Code	*
East Ongul, NW	1.0	*Adamussium colbecki*	32350 ± 390	33190 ± 390	50860	Nu-1	1
East Ongul, NW	10.0	*Laternula elliptica*	37220 ± 720	42000 ± 720	43680	Nu-2	2
East Ongul, N	13.0	fragment of molluscan shell	33170 ± 630	35710 ± 630	43680	Ar-1	2
East Ongul, W	7.5	*Laternula elliptica*	32960 ± 300	33700 ± 300	52460	Km-7	1
West Ongul, E	12.0	*Laternula elliptica*	33960 ± 520	34810 ± 520	52460	Wo-32	1
West Ongul, N	12.0	*Laternula elliptica*	34070 ± 370	34930 ± 370	52460	Wo-54	1
West Ongul, W	18.0	fragment of molluscan shell	34190 ± 550	37140 ± 550	43680	Wo-28	2
West Ongul, SE	17.0	*Adamussium colbecki*	34880 ± 480	38160 ± 480	43680	Wo-48	2
Langhovde, N	1.5	fragment of molluscan shell	34160 ± 550	35230 ± 550	50860	Ko-27	1
Langhovde, N	8.0	*Adamussium colbecki*	34780 ± 460	38000 ± 460	43680	Ko-21	2
Langhovde, N	0.0	*Laternula elliptica*	37030 ± 910	41650 ± 910	43680	Ko-20	2
Langhovde, N	6.0	*Laternula elliptica*	3490 ± 100	3550 ± 100	43680	Ko-16	2
Langhovde, N	-6.0	*Laternula elliptica*	33280 ± 510	35860 ± 510	43680	Ko-14	2
Langhovde, N	3.0	fragment of molluscan shell	33910 ± 410	34750 ± 410	52460	Ko-5	1
Langhovde, N	5.0	*Laternula elliptica*	5330 ± 080	-	-	NUTA-2993	3
Langhovde, N	5.0	*Laternula elliptica*	5930 ± 090	-	-	NUTA-2994	3
Langhovde, N	5.0	*Laternula elliptica*	5030 ± 090	-	-	NUTA-2995	3
Langhovde, N	3.0	*Laternula elliptica*	3100 ± 070	-	-	NUTA-2996	3
Langhovde, N	3.0	*Laternula elliptica*	3000 ± 070	-	-	NUTA-2997	3
Langhovde, N	3.0	*Laternula elliptica*	4020 ± 070	-	-	NUTA-3024	3
Langhovde, N	1.5	*Laternula elliptica*	35510 ± 540	36790 ± 540	50860	Mk-14	1
Langhovde, C	12.0	*Laternula elliptica*	5370 ± 070	-	-	Ky-9	1
Langhovde, S	2.8	*Laternula elliptica*	4570 ± 160	-	-	Yz-14	1
Langhovde, S	2.4	benthic foraminifera	6040 ± 120	-	-	Yz-20	1
Langhovde, S	5.5	*Laternula elliptica*	6290 ± 060	-	-	NUTA-2984	3
Langhovde, S	5.5	*Laternula elliptica*	5990 ± 070	-	-	NUTA-2985	3
Langhovde, S	5.5	*Laternula elliptica*	5450 ± 070	-	-	NUTA-2986	3
Breidvågnipa	1.0	*Laternula elliptica*	6430 ± 080	-	-	Bn-8	1
Skarvsnes, N	-17.0	*Laternula elliptica*	2340 ± 090	-	-	Fn-17	1
Skarvsnes, S	13.0	benthic foraminifera	5640 ± 120	-	-	Bc-8	1
Skarvsnes, S	16.0	*Laternula elliptica*	4970 ± 080	-	-	Bc-11	1
Skarvsnes, S	13.0	benthic foraminifera	6140 ± 120	-	-	Sb-7	1
Skallen, W	12.0	*Laternula elliptica*	4560 ± 090	4620 ± 090	43680	Ok-1	2
Skallen, W	7.0	*Laternula elliptica*	7630 ± 130	7720 ± 130	43680	Ok-2	2
Skallen, SE	1.0	*Laternula elliptica*	3610 ± 180	3670 ± 180	43680	Mp-12	2
Skallen, SE	5.0	*Laternula elliptica*	3010 ± 090	3060 ± 090	43680	Mp-14	2

* References: 1: present study; 2: IGARASHI *et al.*, 1995; 3: HAYASHI and YOSHIDA, 1994.

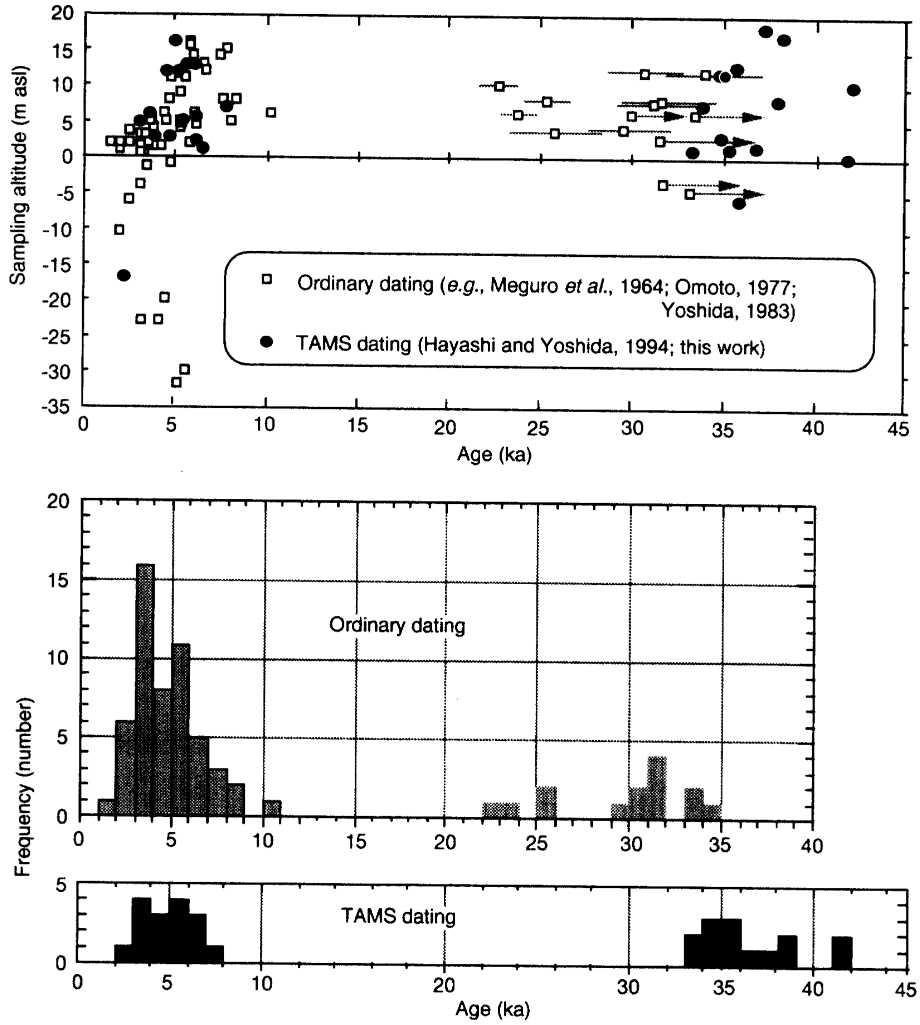

Fig. 2. ^{14}C *ages of fossil marine organisms in raised beach deposits along the Sôya Coast. Data sources: Appendix 3 in* HAYASHI *and* YOSHIDA *(1994), and this study.*

individual shell is sufficient for the necessary amount of each sample in the TAMS dating, which can avoid the above-mentioned problem.

Taking the above matters into consideration, the ages obtained by TAMS dating, which are clearly classified into a group of 33-42 ka and another group of 3-8 ka (Fig. 2), are regarded as having much higher reliability than those determined in previous works by traditional dating methods (*e.g.*, MEGURO *et al.*, 1964; YOSHIDA, 1970; MORIWAKI, 1974). Then, we consider ages of fossils in the raised beach deposits to be in ranges from 33 ka to 42 ka and from 3 ka to 8 ka. However, in the present TAMS system and knowledge, there would be a possibility that a ^{14}C age measured as older than 40 ka has a true age older than the measured age, even if the background correction is taken into account (Prof. T. NAKAMURA of Nagoya University, personal communication). Therefore, older ages over 42 ka might be found in the future.

Almost all localities of the older fossils are confined to the East and West Ongul islands and the northernmost part of Langhovde (MEGURO *et al.*, 1964; YOSHIDA, 1970;

MORIWAKI, 1974; IGARASHI *et al.*, 1995; Fig. 1); however, an age of about 32 ka from the northwestern part of Skarvsnes was reported by YOSHIDA (1970). These ice-free rocks are located on the northern part of the Sôya Coast. On the other hand, the younger fossils are distributed more widely toward the bay head from the Ongul Islands, southward along the Sôya Coast than the older ones (*e.g.*, YOSHIDA, 1970; OMOTO, 1977; IGARASHI *et al.*, 1995; Fig. 1). Among all the younger and older fossils, many molluscan shell fossils retain their living form *in situ* or unbroken shape; some of them were dated as older than 30 ka (Fig. 3; MORIWAKI, 1974).

3. Fluctuations of the Ice Sheet since the Last Interstadial

The fossil marine organisms of 33–42 ka and of 3–8 ka in the raised beach deposits suggest intermittent periods of marine transgression, namely those of deglaciation, that had taken place during the last 42000 years in the vicinity of the Sôya Coast. The ages of fossils ranging from 33 ka to 42 ka probably correspond to the last interstadial during the Last Glacial Stage of the northern hemisphere. On the basis of the above-mentioned geographical distribution of the older fossils, it can be safely said that the ice sheet retreated from at least the present ice-free rocks on the northern part of the Sôya Coast during the last interstadial.

After the last interstadial, sea-level lowering or re-advance of ice sheet is presumed to have taken place on the basis of a hiatus of fossils whose ages are from 8 ka to 33 ka. However, the older fossils still remain on outcrops without being eroded away by movement of the ice sheet, and some of them retain their living form *in situ* without being shattered by the load of the ice sheet (Figs. 1, 3). This fact indicates that the ice sheet had not invaded the raised beaches including the older fossils since 33 ka. YOSHIDA (1983) also recognized that the raised beach topography had not been subjected to ice sheet erosion. GOODWIN (1993) estimated that the margin of the late Pleistocene grounded ice sheet coincides with the location of the 200 m isobath off the Windmill Islands, Wilkes Land. In Lützow-Holm Bay, the sea bottom becomes deeper than 200 m immediately offshore. Especially, the Ongul Islands and the northernmost part of Langhovde, where some raised beach deposits including the older fossils are distributed, are separated from the present ice sheet margin by a drowned glacial trough deeper than 500 m (Figs. 1, 4). Such topographic features must have obstructed grounding and re-advance of the ice sheet induced by sea-level lowering around 100 m during the Last Glacial Maximum (LGM).

These facts suggest that expansion of the ice sheet would have been slight during the LGM, although re-advance of the ice sheet undoubtedly took place at that time. This view disagrees with the CLIMAP model (STUIVER *et al.*, 1981) in which the Antarctic ice sheet is estimated to have expanded to the continental shelf edge during the LGM. Similar conclusions have been presented YOSHIDA (1983), DOMACK *et al.* (1991) and COLHOUN *et al.* (1992).

No evidence, such as a drowned terminal moraine, that can delineate the margin of the ice sheet during the LGM has been discovered in the Lützow-Holm Bay area, even though the evidence exists there. Many core samples recovered from Lützow-Holm Bay reveal that unconsolidated glacio-marine sediments are quite thin, less than several tens of centimeters, or lacking altogether in the Bay, with the exception of sediments that were

Fig. 3. Occurrence of shell fossils in raised beach deposits on the northernmost part of Langhovde. Upper: Laternula elliptica retain their living form in situ. They were dated to be over 33400 yr BP (Moriwaki, 1974). Lower: Adamussium colbecki (Ko-21) retain their unbroken shape. One of them was dated to be 38000±460 yr BP (Table 1).

deposited within depressions such as drowned glacial troughs (Moriwaki, 1977; Moriwaki and Yoshida, 1983; Fig. 4). From the troughs, several cores of glacio-marine sediments, whose lengths are less than 150 cm, have been recovered by gravity- and piston-corers. Harada *et al.* (1995) carried out TAMS dating for organic carbon that was contained within a core of sediments (129 cm in length), which was recovered from a trough about 20 km west of Langhovde (Figs. 1, 4), and the bottom of the core was dated as about 14 ka. This result suggests that the greater part of Lützow-Holm Bay would have been free from the ice sheet since 14 ka. However, further TAMS dating and sedimentological

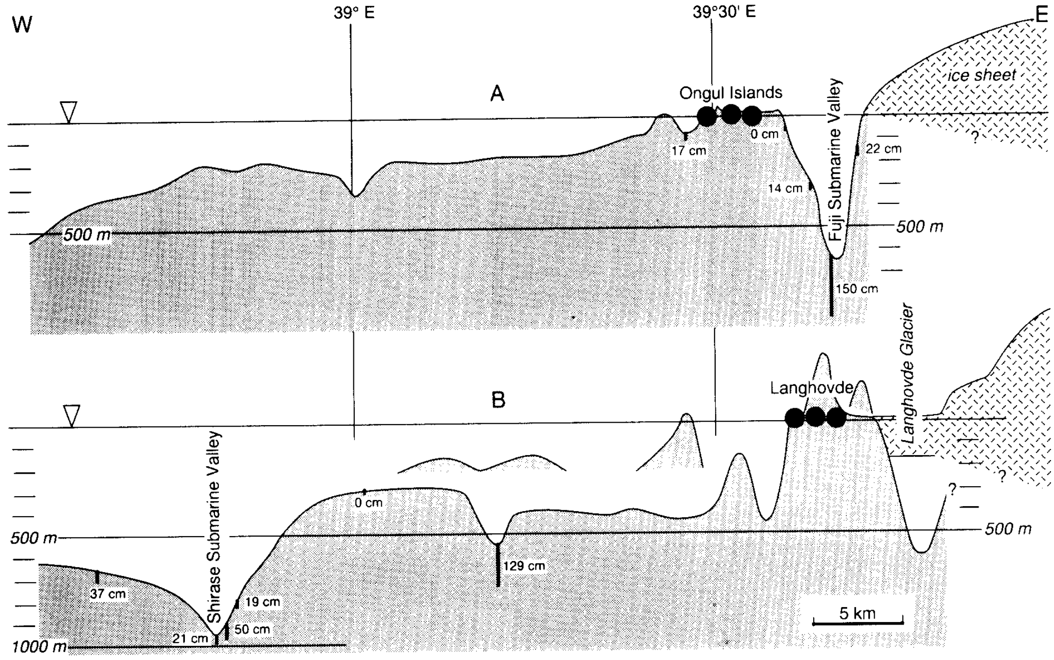

Fig. 4. Topographic profiles roughly perpendicular to the present ice sheet margin of the Sôya Coast, and positions of the older fossils (solid circle) and sediment cores of sea-bottom (thick bar). Positions of the profiles are shown in Fig. 1.

analyses for submarine sediments will be necessary to clarify the environmental change on the Antarctic continental shelf (*e.g.*, DOMACK *et al.*, 1989).

Distribution of the younger fossils posterior to 8 ka suggests that, during the Holocene, the margin of the ice sheet retreated more widely toward inland and southward than that during the last interstadial. This agrees with the conclusion by YOSHIDA (1983), based on the different grade of weathering of rocks, that the northern part of the Sôya Coast became free from the ice sheet earlier than the southern part of the Coast.

4. Sea-level during the Last Interstadial

Late Quaternary sea-level curves estimated from foraminiferal $\delta^{18}O$ records in deep-sea sediments seem to be valuable as serial records. However, they still have some problems (*e.g.*, CHAPPELL and SHACKLETON, 1986; MATTHEWS, 1990). According to the sea-level curve estimated by SHACKLETON (1987) using planktonic and benthic $\delta^{18}O$ data, sea-level during 30–40 ka was about 75 m lower than that of the present. Therefore, the highest and older raised beach (20 m asl; Fig. 2) on the Sôya Coast must have uplifted more than 95 m since that time, if the Shackleton curve is applied.

In this region, it is difficult to estimate sea-level at the last interstadial, because fluctuations of the ice sheet and the magnitude of isostatic movement since the last Interglacial period are still obscure. However, low elevations (maximum height: 25 m asl) of the Holocene raised beaches in the region imply that the isostatic rebound has been quite small, at least during the Holocene (HAYASHI and YOSHIDA, 1994). The Antarctic continental shelf, of which outer margins range from 400 m to 700 m in depth, is deeper than any other continental shelves in the world. Such unusual depth is considered to be caused by the load of the huge ice sheet (JOHNSON *et al.*, 1982), and suggests that the whole of Antarctica has isostatically subsided.

Both the small isostatic rebound during the Holocene and the deep continental shelf imply that the estimate of uplift of more than 95 m of the older beach is an overestimation. Therefore, we infer that sea-level during the last interstadial would have been considerably higher than that estimated from the $\delta^{18}O$ analysis by SHACKLETON (1987). As mentioned by CHAPPELL and SHACKLETON (1986), increase and decrease in volume of isotopically light floating ice, which is regarded as an ice shelf, change the ocean isotopic composition without having any effect on sea-level change. However, the changes in volume and area of the past ice shelf around Antarctica are still unknown. Therefore, the $\delta^{18}O$ change should not be directly connected with the sea-level change according to our present knowledge, because the change in volume of sea water would have been determined not only by the terrestrial ice mass but also by the floating ice mass on the sea (JOHNSON and ANDREWS, 1986). Further detailed geological and geomorphological studies will be necessary to establish sea-level changes during the late Quaternary.

5. Concluding Remarks

By application of the TAMS dating method to fossil marine organisms on the raised beaches along the Sôya Coast, their ^{14}C ages were clearly classified into two groups: 3-8 ka and 33-42 ka. The dating confirmed the existence of marine fossils of about 30-40 ka in the raised beach deposits. Some molluscan fossils of not only the younger ages but also the older ages have retained their living form *in situ*, and their localities are distributed near the present ice sheet margin. The occurrence and distribution of 33-42 ka aged marine fossils together with the existence of deep submarine topography and a small amount of isostatic uplift in the Lützow-Holm Bay region led us to the following conclusions and suggestion:

1) The fossils of 3-8 ka and 33-42 ka indicate two periods of inundation of sea water to presently ice-free coastal areas. The older period probably corresponds to the last interstadial in the northern hemisphere.

2) The ice sheet had retreated from the northern part of the Sôya Coast by the last interstadial, and its subsequent expansion during the LGM was not so large as that shown in the CLIMAP model but rather slight, although its extent is still unknown.

3) Sea-level during the last interstadial is assumed to have been considerably higher than that estimated from the $\delta^{18}O$ analysis for foraminifera in deep sea sediments. We consider that further geological and geomorphological studies are necessary to establish sea-level changes during the late Quaternary.

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