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RADIOCARBON MARINE RESERVOIR AGES IN THE NORTHWESTERN PACIFIC OFF HOKKAIDO ISLAND, JAPAN, DURING THE LAST DEGLACIAL PERIOD

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ABSTRACT. We measured radiocarbon ages of planktic foraminifera in 4 sediment cores from the northwestern Pacific region off northern Japan in order to estimate marine reservoir ages during the Bølling-Allerød period. The ages of deglacial tephra markers from 2 Japanese source volcanoes identified in these sediment cores had been previously estimated from ^{14}C ages of terrestrial charcoal and buried forests. By comparing the foraminiferal and tephra ages, we estimated the surface water reservoir age during the Bølling-Allerød period to be ~1000 yr or more in the region off northern Japan. The deglacial reservoir ages were more than 200 yr higher than the Holocene values of ~800 yr. The older deglacial ages may have been caused by active upwelling of deep water during the last deglaciation and the consequent mixing of "older" deep water with "younger" surface waters.

INTRODUCTION

Radiocarbon dates obtained from material of marine origin are widely used for dating oceanic paleoenvironmental events and as tracers of ocean circulation (Southon et al. 1990; Sikes et al. 2000). However, little is known about past changes in regional marine reservoir ages in the northwestern Pacific. We studied ^{14}C marine reservoir ages in the region off northern Japan during the last deglacial period. Our approach to determine past reservoir ages was based on tephras, dated with terrestrial ^{14}C and used as stratigraphic marker beds, which allowed surface water ^{14}C ages to be related directly to the atmosphere. Many widespread Quaternary tephras have been identified in Japan. To estimate the marine reservoir ages, we compared ^{14}C ages of planktic foraminifera with the ^{14}C ages of 2 tephras (Towada-Hachinohe and Nigorikawa tephras) from Japanese volcanoes (Figure 1). The Towada-Hachinohe (To-H) tephra was erupted from Towada Volcano, which is near the northern end of Honshu Island (Figure 1). Two ^{14}C ages of forests buried in the To-H tephra dated to 12,660 ± 150 BP and 12,640 ± 150 BP (Terada et al. 1994). The ^{14}C ages were calibrated with the CALIB v 5.0 program (Stuiver et al. 2005), using the IntCal04 data set (Reimer et al. 2004). The calendar age was estimated to be 14,580–15,160 cal BP (1 σ).

The Nigorikawa (Ng) tephra was erupted from the Nigorikawa caldera, on the shore of Funka Bay, southwestern Hokkaido Island (Figure 1). The tephra is distributed around the caldera and over a wide area in southwestern Hokkaido. The ^{14}C ages of charcoal and wood fragments buried in the Nigorikawa tephra are 12,020 ± 190 BP and 12,270 ± 190 BP, respectively (Yanai et al. 1992). The calendar age was estimated to be 13,760–14,320 cal BP (1 σ). A study of pollens in terrestrial sediments intercalated by the Ng tephra documented the occurrence of the Bølling-Allerød warming event just after the accumulation of the Ng tephra (Takiya and Hagiwara 1997).

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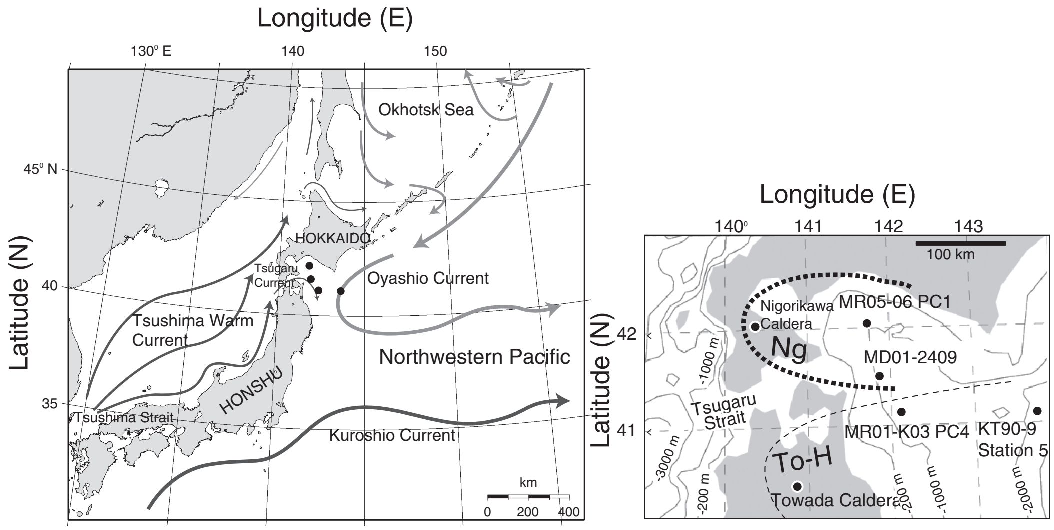

Figure 1 Location map of cores MD01-2409, KT90-9 Station 5, MR01-K03 PC4, MR04-06 PC1, and the study area. The thick dotted line in the right-hand panel shows the distribution of the Nigorikawa tephra, compiled by Yanai et al. (1992). The thin dashed line indicates the distribution of the Towada-Hachinohe tephra, compiled by Hayakawa (1983). Ng = Nigorikawa tephra; To-H = Towada-Hachinohe tephra.

SAMPLES AND METHODS

Four piston core sediment samples used for this study were collected from the northwestern Pacific region off Shimokita Peninsula (Honshu Island) and eastern Hokkaido Island, northern Japan (Figure 1). Core MD01-2409 (41°33′N, 141°52′E) was taken from a water depth of 975 m near the eastern entrance of the Tsugaru Strait, which joins the northwestern Pacific with the Sea of Japan, during the IMAGES VII - WEPAMA (West Pacific Margin) cruise of the research vessel (R/V) *Marion Dufresne*. This core consists mainly of massive mud. Two well-preserved laminated sediment horizons occur in the middle of this core. According to the age model of Kuroyanagi et al. (2006), the upper laminated layer (core depth 694–860 cm) ranges in age from 11,275 to 10,352 cal BP. The lower laminated layer (969–1131 cm depth) ranges from 15,608 to 12,960 cal BP and is intercalated by the Ng tephra (1099–1100 cm depth) (Aoki and Ohkushi 2006). Core MR01-K03 PC4 (41°07′N, 142°24′E) was collected from a water depth of 1363 m off Shimokita Peninsula during the MR01-K03 cruise of the R/V *Mirai*. This core consists of massive mud intercalated by the To-H tephra (419–423 cm depth). Core KT90-9 Station 5 (41°06′N, 143°30′E) was collected from a water depth of 2048 m south of Cape Erimo, Hokkaido, during the KT 90-9 cruise of the R/V *Tansei-Maru*. This core consists of massive mud intercalated by the To-H tephra (300–308 cm depth). Another core, MR04-06 PC1 (42°09′N, 141°42′E), was taken from a water depth of 788 m off Tomakomai, southeastern Hokkaido, during the MR04-06 cruise of the R/V *Mirai*. This core consists of massive mud intercalated by the Ng tephra (1242–1265 cm depth).

For accelerator mass spectrometry (AMS) ^{14}C analysis, specimens of the planktic foraminifer *Neogloboquadrina pachyderma* were picked from sediment samples around tephra layers. These specimens were cleaned ultrasonically in H_2O_2 (30%) and subsequently dissolved in 100% phosphoric acid within evacuated glass vessels at 25 °C. The graphitization of samples was carried out according to the procedure described by Uchida et al. (2004). The ^{14}C analyses were conducted at the AMS facility at the National Institute for Environmental Studies (NIES-TERRA, Tsukuba, Japan) (Tanaka et al. 2000). The results are listed in Table 1.

Table 1 Planktic foraminiferal ^{14}C age data from cores MD01-2409, KT90-9 Station 5, MR01-K03 PC4, and MR04-06 PC1.

Sample #	Species of planktic foraminifer	Tephra[a]	Depth in core (cm)	^{14}C age (^{14}C yr)	Error (yr)	Calendar age (cal BP)	Age differences between foraminifera and terrestrial materials (yr)	AMS facility or accession nr[b]
Core MD01-2409 by giant piston corer								
7-52~54	Mixed species		1016	12,430	80			JAEA (Kuroyanagi et al. 2006)
8-18, 19	Mixed species		1089	13,360	80			JAEA (Kuroyanagi et al. 2006)
8-20	*Neogloboquadrina pachyderma*		1093	13,330	100		1180	NIES (this study)
8-22, 23		Ng	1097	12,150	190	14,040 ± 280		I-16131, -16132 (Yanai et al. 1992)
8-24	*N. pachyderma*		1102	13,430	90		1280	NIES (this study)
8-36	Mixed species		1128	13,840	130			JAEA (Kuroyanagi et al. 2006)
10-26, 27	Mixed species		1387	16,690	90			JAEA (Kuroyanagi et al. 2006)
Core MR04-06 PC1 by piston corer								
7-21	*N. pachyderma*		603	8810	50			NIES (this study)
8-21	*N. pachyderma*		704	9560	70			NIES (this study)
10-21	*N. pachyderma*		903	10,510	90			NIES (this study)
14-16	*N. pachyderma*		1238	13,260	90		1110	NIES (this study)
14-18~28		Ng	1242–1265	12,150	190	14,040 ± 280		I-16131, -16132 (Yanai et al. 1992)
15-2	*N. pachyderma*		1308	13,190	80		1040	NIES (this study)
16-2	*N. pachyderma*		1409	13,800	90			NIES (this study)
17-2	*N. pachyderma*		1507	14,220	70			NIES (this study)
Core KT90-9 Station 5 by piston corer								
	Mixed species		274–280	13,670	190			NUTA-4630 (Ohkushi et al. 2003)
	N. pachyderma		286–288	13,730	100		1080	NIES (this study)
		To-HP	300–308	12,650	150	14,870 ± 290		NUTA-2260, -2261 (Terada et al. 1994)
	N. pachyderma		311–313	15,680	120		3030	NIES (this study)
	Mixed species		444–450	20,910	200			NUTA-4910 (Ohkushi et al. 2003)
Core MR01-K03 PC4 by piston corer								
3-30	Mixed species		262–264	10,900	60			NOSAMS (Ohkushi et al. 2004)
4-29	Mixed species		363–365	13,450	90			NOSAMS (Ohkushi et al. 2004)
5-1	Mixed species		405–407	14,150	60		1500	NOSAMS (Ohkushi et al. 2004)
5-7, 8		To-HP	419–423	12,650	150	14,870 ± 290		NUTA-2260, 2261 (Terada et al. 1994)
5-9	*N. pachyderma*		423–426	14,480	90		1830	NIES (this study)
6-15	Mixed species		540–542	16,450	110			NOSAMS (Ohkushi et al. 2004)

[a]Ng, Nigorikawa; To-H, Towada-Hachinohe. Radiocarbon analysis in this study was conducted at the AMS facility of the National Institute for Environmental Studies (NIES-TERRA), Tsukuba, Japan.

[b]JAEA, Japan Atomic Energy Agency at Mutsu; NOSAMS, National Ocean Sciences Accelerator Mass Spectrometry facility, Woods Hole Oceanographic Institution, USA. Errors are ±1 σ.

RESULTS AND DISCUSSION

Planktic foraminiferal ^{14}C ages are listed in Table 1 and are shown in Figure 2. In core MD01-2409, the ^{14}C age difference between the foraminifera and the Ng tephra was 1180 yr at 4 cm above the Ng tephra, and 1280 yr at 5 cm below the tephra. In core MR04-06 PC1, the ^{14}C age difference with the Ng tephra was 1110 yr at 4 cm above the tephra and 1040 yr at 43 cm below the tephra. Thus, we estimated the difference between the foraminiferal and the Ng tephra ages to be 1040 yr or more. In core KT90-9 Station 5, the age difference between the foraminifera and the To-H tephra was 1080 yr at 12 cm above the To-H tephra and 3030 yr at 3 cm below the tephra. In core MR01-K03 PC4, the age difference between the foraminifera and the To-H tephra was 1500 yr at 12 cm above To-H and 1830 yr just below To-H. Thus, we estimated the age difference between the foraminifera and the To-H tephra to be 1080 yr or more.

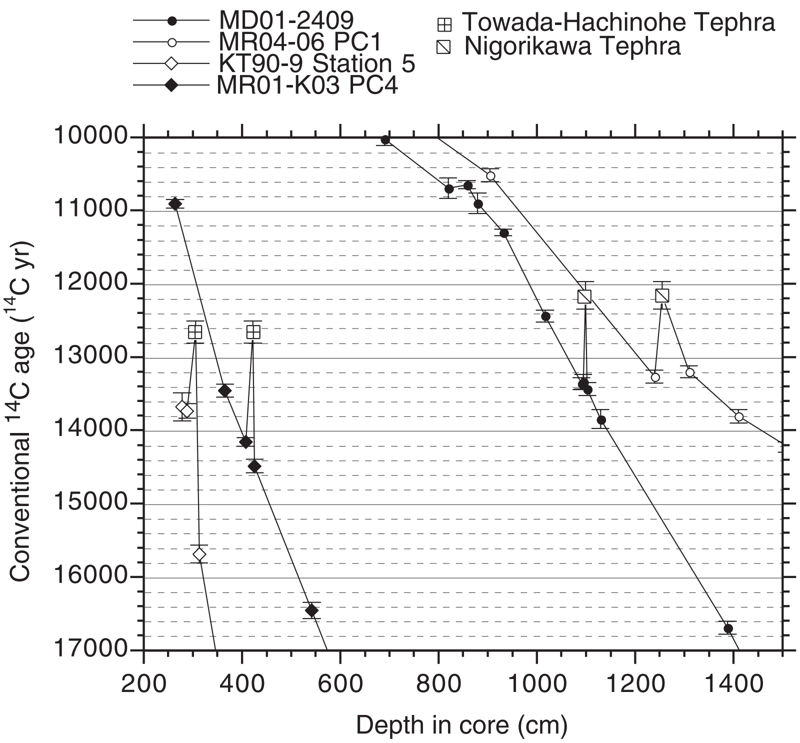

Figure 2 Depth-^{14}C age plots of planktic foraminifera and tephra layers

In this way, we estimated reservoir ages in the northwestern Pacific during the Bølling-Allerød period to be 1000 yr or more, based on the ^{14}C age differences between the ages of the 2 tephras and those of the foraminifera. On the other hand, ^{14}C data from archaeological deposits suggest that in the middle Holocene, the reservoir age was about 800 yr around Hokkaido Island (Yoneda et al. 2001). Similarly, ^{14}C data from mollusk shells from pre-bomb shell middens yield a reservoir age of 710 yr for the northwestern Pacific near the southern Kurile Islands (Kuzmin et al. 2001). Our results indicate that the deglacial reservoir ages were more than 200 yr higher than Holocene reservoir ages. These results suggest active upwelling of deep water during the last deglaciation, leading to mixing of older deep water with younger surface waters.

The northwestern Pacific off northern Japan is the site of confluence of the cold Oyashio Current and the warm Kuroshio Current, with additional influence from the warm Tsugaru Current, which flows from the marginal Sea of Japan through the shallow Tsugaru Strait (sill depth ~130 m). These oceanographic features drastically changed from the last glacial to the Holocene. Glacio-eustatic sea-level lowering isolated the Sea of Japan, resulting in restricted outflow of the warm Tsugaru Current (Oba et al. 1991; Takei et al. 2002). When the sea level rose during the deglaciation, a branch of the Oyashio Current began to flow into the Sea of Japan via the Tsugaru Strait (Oba et al. 1991; Takei et al. 2002). Thus, the large reservoir ages in this study indicate the deglacial values of the Oyashio Current, reflecting strong depletion of ^{14}C in the subarctic North Pacific. Moreover, benthic-planktic foraminiferal ^{14}C age differences in the PC4 core indicate that ventilation ages during the Bølling-Allerød period were 500–1000 yr larger than modern seawater ^{14}C ventilation ages at mid-depths (Ahagon et al. 2003). On the other hand, the benthic-planktic ^{14}C age differences indicate during the H1 cold event, 500–1000 yr smaller ventilation ages than during the Bølling-Allerød period, reflecting active production of the North Pacific Intermediate Water in the subarctic Pacific (Ohkushi et al. 2003, 2004). At the onset of the Bølling-Allerød period, active upwelling of deep water probably started because of restricted intermediate water production. In addition, the active upwelling of deep water in the North Pacific may be related to the formation of the North Atlantic Deep Water during the Bølling-Allerød period.

CONCLUSION

We obtained ^{14}C marine reservoir ages for the region off northern Japan during the last deglacial period. The surface water reservoir ages during the Bølling-Allerød period were estimated to be 1000 yr or more. The deglacial reservoir ages were more than 200 yr higher than the Holocene values of about 800 yr. The results suggest active upwelling of deep water during the last deglaciation and the mixture of older deep water with younger surface waters.

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