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Evidence of cooling during the Younger Dryas in the western North Pacific

Younger Dryas
Oxygen-18
AMS ^{14}C
North Pacific
Paleaoclimatology
Dryas récent
Oxygène-18
AMS ^{14}C
Pacifique Nord
Paléoclimatologie

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ABSTRACT

The isotopic and micropaleontological records from a western North Pacific sediment core, covering the last deglaciation, have been dated by ^{14}C Accelerator Mass Spectrometry. The results show a definite cooling synchronous with the Younger Dryas, as recorded in the North Atlantic. The deglaciation began at $\simeq$14,750 yr BP and the polar front retreat started at about 12,750 yr BP. It reached its northernmost position, during this period, at about 11,450 yr BP. The Younger Dryas type cooling was marked between about 11,000 yr BP and 10,000 yr BP by a more southerly location of the polar front.

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RÉSUMÉ

Un refroidissement synchrone du Dryas récent dans le Pacifique Nord-Ouest

Les enregistrements isotopiques et micropaléontologiques d'une carotte de sédiment prélevée dans le Pacifique Nord-Ouest, couvrant la dernière déglaciation, ont été datés en spectrométrie de masse ^{14}C par accélérateur. Les résultats montrent un refroidissement au milieu de la dernière déglaciation, synchrone de celui enregistré dans l'Atlantique Nord pendant le Dryas récent. L'amorce de la déglaciation apparaît vers 14750 ans BP, suivie du retrait du front polaire vers 12750 ans BP. Le front polaire atteint sa position la plus septentrionale, durant cette période, vers 11450 ans BP. Le refroidissement synchrone du Dryas récent est marqué entre environ 11000 ans BP et 10000 ans BP par une position plus méridionale du front polaire.

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INTRODUCTION

The last deglaciation resulted in the disappearance of the Laurentide and Northern Europe ice sheets and in the reduction of the Arctic and Antarctic ice shelf extension during a short time span (15,000 to 8,000 years BP). It has been associated with the maximum of summer solar radiation in the Northern high latitudes, centred around 11,000 years BP (Berger, 1978).

Extensive studies in the North Atlantic showed that the deglacial warming proceeded in two steps (Termination 1 *a* and Termination 1 *b*), separated by a major cooling and a southward migration of the polar front between 11,000 and 10,000 years BP (Duplessy *et al.*, 1981 *a*; 1986; Ruddiman, McIntyre, 1981; Bard *et al.*, 1987 *a*; Broecker *et al.*, in press *a*). This strong cooling is also observed on the European continent and is referred to as the younger Dryas event. The fact that the last deglaciation was abrupt by comparison with the smooth shape of the associated summer solar radiation maximum, and was marked by the presence of the younger Dryas cold event, indicates that the earth's climate does not respond linearly to the astronomical forcing.

The development of models of the deglaciation dynamics requires a detailed absolute chronology in different oceanic areas. In the western North Pacific, no detailed records are available for the surface circulation change during the last deglaciation. We present here a micropaleontological and isotopic study completed with a ^{14}C Accelerator Mass Spectrometer chronology of the last deglaciation in a high sedimentation rate core from the western North Pacific. Core CH84-14 is at present located in the southern part of the subarctic zone and is thus ideally located to record past shifts in the polar front. Our study demonstrates the synchronism of the events marking the last deglaciation in the North Pacific and in the North Atlantic. In particular, the cooling in the western North Pacific at the time of the younger Dryas was associated with a strong surface circulation change which resulted from a southward migration of the polar front, just as occurred in the North Atlantic.

MATERIAL AND METHODS

Core CH84-14 (41°44′N, 142°33′E) was collected on the continental margin off northern Japan at 978 m water depth (Fig. 1), during the Estase I (1984) cruise of the *Jean-Charcot*.

Two kinds of climatic indicators have been utilized in this study: the coiling ratio of the planktonic foraminifera *Neogloboquadrina pachyderma* as a proxy for variation in the proximity of the polar front in the North Pacific (Thompson, Shackleton, 1980; Thompson, 1981) and the oxygen isotopic composition ($\delta^{18}O$) of the planktonic foraminifera *Globigerina bulloides* and of the benthic foraminifera *Uvigerina akitaensis*.

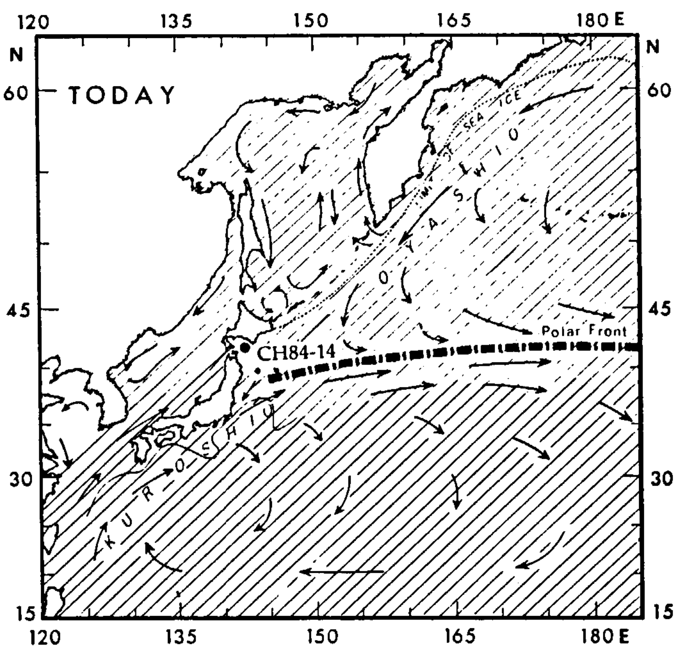

Figure 1

Location of the core CH84-14 and surface hydrology in the western North Pacific (after Thompson, Shackleton, 1980).

Position de la carotte CH84-14 et hydrologie de surface dans l'océan Pacifique Nord-Ouest (d'après Thompson, Shackleton, 1980).

Planktonic and benthic oxygen isotopic records

The oxygen isotopic compositions were measured on a V.G. Micromass 602 D mass spectrometer with a standard deviation of 0.07 ‰ and are expressed in the conventional fashion as δ-values defined by the relationship:

$$\delta = (R_{sample}/R_{standard}-1) \, . \, 1\,000\ ‰$$

where R represents the $^{18}O/^{16}O$ ratio and the standard is the P.D.B. Results are shown in Figure 2.

$\delta^{18}O$ variations measured in foraminiferal shells reflect both the global variations of the ocean water $\delta^{18}O$ due to continental ice volume changes and the isotopic fractionation between calcium carbonate and water, which depends upon the temperature at which foraminifera have formed their tests (Emiliani, 1955; Shackleton, 1974). The ice sheet effect of the last deglaciation was 1.1 ‰ (Labeyrie *et al.*, 1987; Shackleton, 1987), but the surface temperature variations are not easy to calculate because of other effects on $\delta^{18}O$ record of planktonic foraminifera such as changes in depth habitat, seasonality (Williams *et al.*, 1979; 1981; Erez, Honjo, 1981), selective dissolution (Berger, Killingley, 1977; Berger *et al.*, 1978), gametogenic calcification (Duplessy *et al.*, 1981 *b*; 1981 *c*) and possible local surface salinity change.

Surface water hydrology and coiling ratio of *N. pachyderma*

Modern surface circulation in the western North Pacific is characterized by two dominant surface currents: the Kuroshio and the Oyashio (Fig. 1). The first one is a warm high-salinity western boundary current, flows northward from the Philippines Pacific coasts, then eastward at approximately 36°N, off Japan. The Oyashio, a cold low-salinity current forms along the east coast of Kamachatka, flows southward along the Pacific coast of the Northern Japanese islands. Near the northeastern corner of Honshu, the Oyashio is deviated eastward by the Kuroshio along a complex front characterized by numerous eddies (Reid, 1965; Tchernia, 1978; Vastano, Bernstein, 1984).

Under present conditions, the coiling types of *N. pachyderma* in the North Pacific are characteristic of the water masses rather than of the sea surface temperatures. The sinistral coiling form is associated to the subarctic water and the dextral coiling form is associated with the subtropical water (Thompson, Shackleton, 1980). The polar front is overlying sediments containing 10% to 20% of sinistral-to-total *N. pachyderma*.

Down core CH84-14 the sinistral-to-total *N. pachyderma* ratio varies between 72 and 100% (Fig. 2). Thus, through the period covered by the record, the location of the CH84-14 core was always dominated by the subarctic water mass. A decrease of the sinistral-to-total *N. pachyderma* ratio is interpretated as a consequence of the increase in the influence of the polar front water mass.

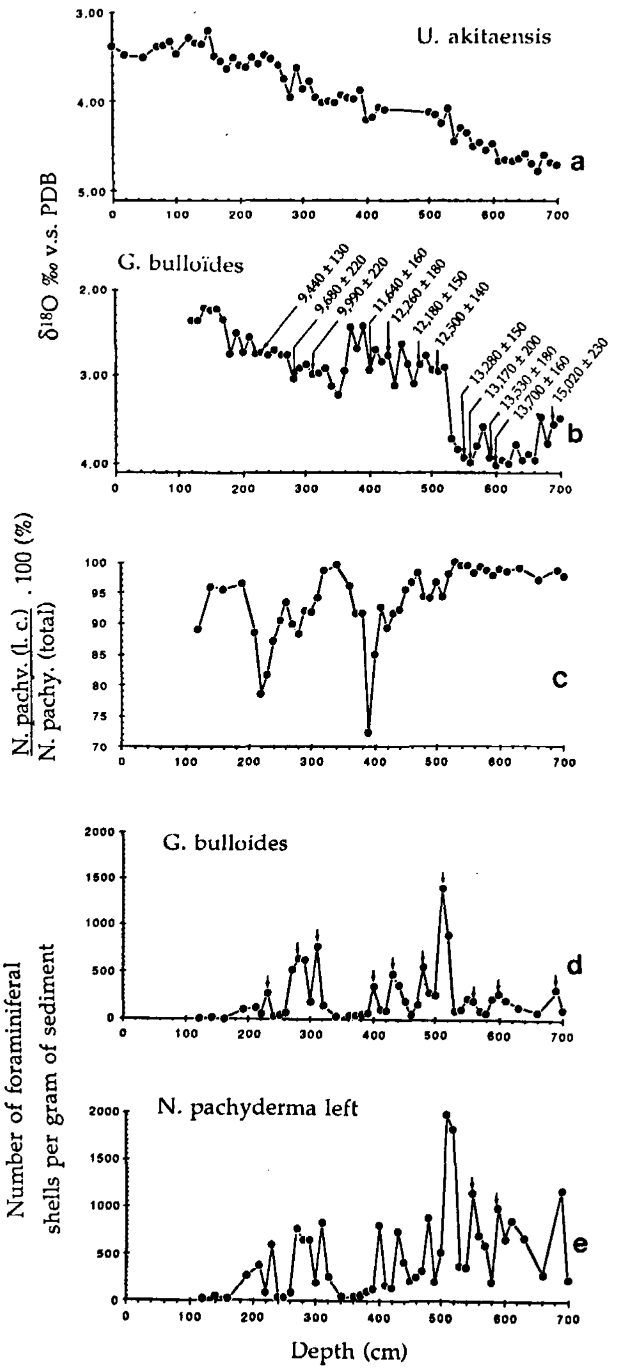

Figure 2

Climatic records of the core CH84-14: a) oxygen isotope of U. akitaensis; *b) oxygen isotope of* G. bulloides *and AMS* ^{14}C *ages obtained on both* G. bulloides *and* N. pachyderma *(l. c.); c) coiling ratio of* N. pachyderma; *d)* G. bulloides *abundances; e)* N. pachyderma *(l. c.) abundances.*

Variations des indicateurs climatiques en fonction de l'âge de la carotte CH84-14 : a) composition isotopique de l'oxygène de *U. akitaensis*; b) composition isotopique de l'oxygène de *G. bulloides* et les âges ^{14}C obtenus en spectrométrie de masse par accélérateur sur *G. bulloides* et *N. pachyderma* senestre; c) rapport *N. pachyderma* senestre/*N. pachyderma* total; d) abondances de *G. bulloides;* e) abondances de *N. pachyderma* senestre.

North Pacific circulation change chronology

The development of a new dating technique, counting of $^{14}C/^{12}C$ ratio by Accelerator Mass Spectrometry (AMS) in only 1 mg of carbon, permits the assignment of precise ages to monospecific foraminiferal samples with an upper limit of $\simeq$41,000 yr BP (Arnold *et al.*, 1987). Our radiocarbon age determinations on the core CH84-14 were carried out on hand-picked foraminifera samples from levels of abundance maxima [to minimize the bioturbation effect (Bard *et al.*, 1987*a*)] of the two planktonic foraminifera species *G. bulloides* and *N. pachyderma* (left coiling). A 560 years correction was made to raw ^{14}C ages to take into account the difference in radiocarbon content between the total dissolved CO_2 in surface waters in the studied region, and the CO_2 of the atmosphere (Broecker, Peng, 1982). For the purpose of this study, the magnitude of this difference is assumed to be time-invariant. Results are reported in Figures 2 and 3. The estimated sedimentation rate varies between 55 cm/kyr and 208 cm/kyr along the core (Fig. 3). This implies that in this particular high sedimentation rate core, the effect of smoothing by bioturbation is negligible for time-scales greater than one or two centuries (Bard *et al.*, 1987 *a*).

RESULTS

Benthic (*U. akitaensis*) $\delta^{18}O$ values show a progressive decrease from glacial to Holocene conditions. The two-step deglaciation described by Duplessy *et al.* (1981 *a*) is indicated only by small changes in the slope of the benthic $\delta^{18}O$ *v.s.* depth diagram (Fig. 2 *a*) between 610 cm and 530 cm (from about 13,850 yr BP to 12,800 yr BP) for Termination 1*a* and between 320 cm and 240 cm (from about 10,150 yr BP to 9,500 yr BP) for Termination 1 *b*. Because of the scarcity or the absence of planktonic foraminifera in the upper 2.20 m of the core, no radiocarbon age is available for these levels. At the top of the core, the $\delta^{18}O$ value of *U. akitaensis* is 3.38 $^0/_{00}$, to be compared with the expected modern equilibrium value, 3.13 $^0/_{00}$, calculated using the hydrological parameters of the modern water at the location and depth of the core CH84-14 and the Shackleton relationship (1974). Typical high resolution benthic $\delta^{18}O$ records show always, in the middle of the Holocene (about 5,500 yr BP) a $\delta^{18}O$

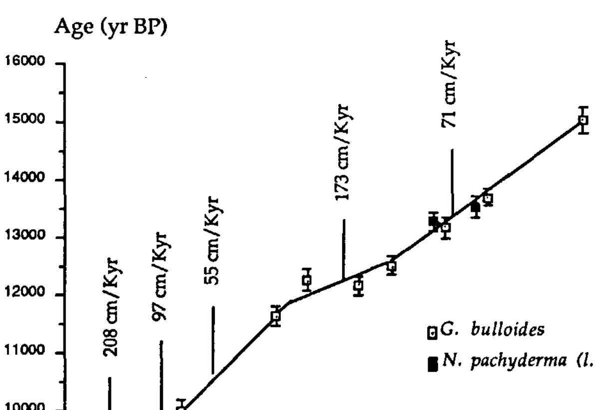

Figure 3

AMS ^{14}C *records* versus *depth in core CH84-14 for the two foraminiferal species* G. bulloides *and* N. pachyderma *(l. c.).*

Variations des âges ^{14}C, obtenus en spectrométrie de masse par accélérateur sur *G. bulloides* et *N. pachyderma* senestre, en fonction de la profondeur dans la carotte CH84-14.

peak 0.2 ‰ to 0.4 ‰ lower than modern values (3.13 ‰ in the case of the core CH84-14). This peak is absent from our record, then indicating an age older than 5,500 yr BP for the top of the core. An age of about 8,350 yr BP may be obtained for the top of the core assuming a uniform sedimentation rate for the upper 280 cm (208 cm/kyr).

The beginning of the last deglaciation, defined on the *U. akitaensis* $\delta^{18}O$ record by the first significant decrease after the glacial conditions is at 670 cm. An interpolated age of $\simeq$14,750 ± 200 yr BP for this event may be obtained by assuming a constant sedimentation rate between the levels 690 cm (15,020 ± 230 yr BP) and 600 cm (13,700 ± 160 yr BP). During the first part of the period of deglaciation (approximately from 14,750 yr BP to 12,800 yr BP), the coiling ratio of *N. pachyderma* (close to 100%) indicates a maximum influence of the subarctic water mass. Between the levels 530 cm and 520 cm (about 12,750 yr BP) the oxygen isotopic composition of *G. bulloides* shows a steep decrease by about 0.8 ‰. Because of possible surface salinity change and thus local variation of the water oxygen isotope composition, we do not attempt to estimate the temperature variation during this transition. Over the next thousand years, the coiling ratio of *N. pachyderma* exhibits a progressive decrease, with a minimum at 390 cm (about 11,450 yr BP), indicating a progressive northward migration of the polar front.

A drastic climatic deterioration is well marked in both climatic records culminating at approximately 10,550 yr BP (340 cm), at the same time as the Younger Dryas in Europe and in the North Atlantic. A southward shift of the polar front, during this period, is indicated by the sinistral-to-total *N. pachyderma* ratio which returns to very near to 100%. The strong $\delta^{18}O$ increase in the planktonic foraminifera record which is not correlated with a $\delta^{18}O$ change of *U. akitaensis* is likely to reflect a sea surface cooling. Support for this conclusion comes also from the presence of ice rafted detritus observed in the size fraction higher than 160 µm of the sediment between 370 cm (about 11,100 yr BP) and 340 cm (about 10,550 yr BP) in the core CH84-14. These ice rafted detritus indicate that the icebergs reached to the south the latitude of our sediment core because of colder sea surface temperatures.

After this cold period, $\delta^{18}O$ values of *G. bulloides* and the coiling ratio of *N. pachyderma* decreased, marking a new northward shift of the polar front. Another cold period between 190 cm and 140 cm is observed, but it is less pronounced than that marking the Younger Dryas type cooling. A time span from 9,250 yr BP to 9,000 yr BP may be obtained for this event, if we assume a sedimentation rate at the top of the record equivalent to that between 230 cm and 280 cm. The age of the two $\delta^{18}O$ minima of the planktonic and benthic records (around 150 cm), estimated by this extrapolation is about 9,000 yr BP, in agreement with that obtained for the same isotopic feature in the Atlantic and Pacific planktonic records (Berger *et al.*, 1985; Bard *et al.*, 1987 *a*). The upper 1.20 m of the sediment are barren of planktonic foraminifera, which prevents the study of the final part of the deglaciation.

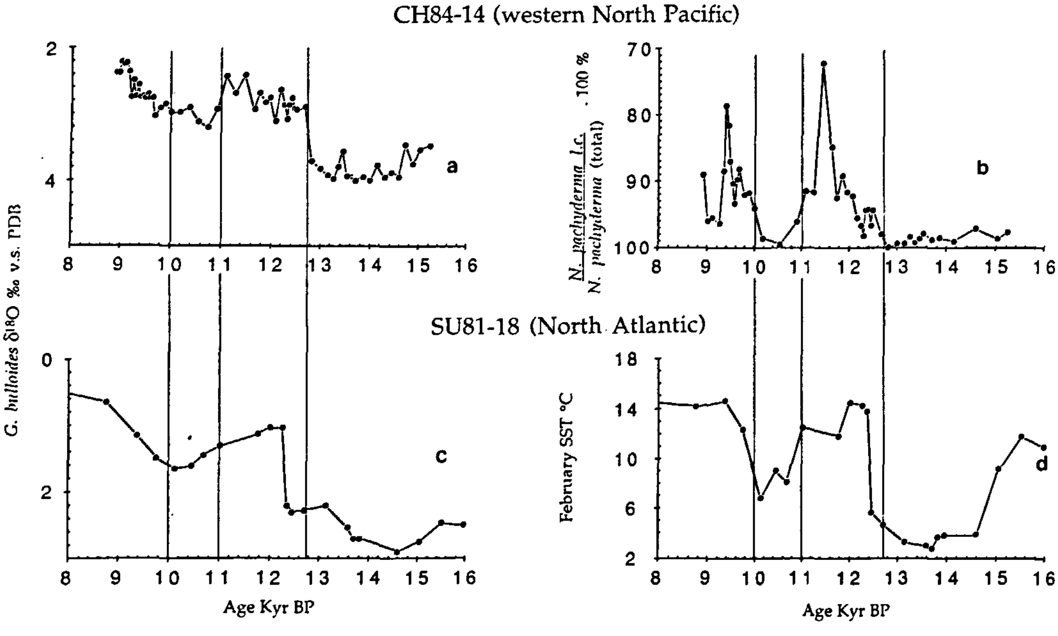

Figure 4

Climatic records versus age for cores CH84-14 and SU81-18 (37°46′N, 10°11′W): a) oxygen isotope of G. bulloides *for the core CH84-14; b) coiling ratio of* N. pachyderma *for the core CH84-14 (as proxy for the polar front oscillations); c) oxygen isotope of* G. bulloides *for the core SU81-18 (west of Portugal); d) February sea surface temperature based on transfer function for the core SU81-18. 12,750 yr BP, 11,000 yr BP and 10,000 yr BP solid lines represent respectively the onset of the polar front northward retreat, the beginning and the close of the Younger Dryas type cooling in the western North Pacific. Data of the core SU81-18 are from Bard* et al. (1987 b).

Variations des paramètres climatiques en fonction de l'âge des carottes CH84-14 et SU81-18 (37°46′N, 10°11′W): a) composition isotopique de l'oxygène de *G. bulloides* de la carotte CH84-14; b) rapport *N. pachyderma* senestre/*N. pachyderma* total (indicateur de la proximité du front polaire) de la carotte CH84-14; c) composition isotopique de l'oxygène de *G. bulloides* de la carotte SU81-18; d) température de surface de février basée sur la fonction de transfert de la carotte SU81-18. Les lignes 12750 ans BP, 11000 ans BP et 10000 ans BP représentent respectivement le début du premier réchauffement post-glaciaire, le début et la fin de la période froide synchrone du Dryas récent dans l'océan Pacifique Nord-Ouest. Les données de la carotte SU81-18 sont d'après Bard *et al.* (1987 *b*).

DISCUSSION

It is clear that the circulation changes during the last deglaciation in the western North Pacific are similar to those in the North Atlantic (Duplessy *et al.*, 1981 *a*; 1986; Ruddiman, McIntyre, 1981; Bard *et al.*, 1987 *a*; Broecker *et al.*, in press *a*). We discuss here the impact of these deglacial events on the climate of land in Japan and in western North America. The comparison of the North Pacific circulation change chronology with that of the North Atlantic permits a better understanding of the mechanisms of the events characterizing the last deglaciation.

Correlation with vegetation changes

Data that might contain evidence for a cooling at the middle of the last deglaciation at the time of the Younger Dryas are scarce around the North Pacific. The Younger Dryas cold event has a strong impact in the Northern Europe, in Greenland and in the maritime province of Canada. Evidence for the return to boreal conditions at the middle of the last deglaciation in Central Japan is shown by the pollen data of Tsubogakure bog (altitude 1,500 m; latitude 36°43′N, longitude 138°30′E) just prior to $9{,}740 \pm 440$ yr BP (Tsukada, 1967). In western North America, a climatic deterioration in coastal Washington between 11,000 yr BP and 10,000 yr BP was pointed out by Heusser (1974; 1977) at approximately the same period than the glacial advance of the Sumas Stade in Washington (Armstrong *et al.*, 1965). This may support the extension of the cooling to the whole high latitudes of the North Pacific during this period.

Correlation with other oceanic records

In order to compare the chronology of surface circulation changes in the North Pacific and in the North Atlantic, we have used the climatic records (planktonic $\delta^{18}O$ values and February sea surface temperatures) of Bard *et al.* (1987 *b*) on the North Atlantic sediment core SU81-18 (37°46′N, 10°11′W).

The last deglaciation began at approximately the same moment (between 15,000 and 14,500 yr BP) in the western North Pacific and in the North Atlantic (Duplessy *et al.*, 1986; Bard *et al.*, 1987 *b*; Broecker *et al.*, in press *a*). In the western North Pacific, the increase of the polar front influence was progressive and started at about 12,750 yr ago. It reached its northernmost position, during this period of climatic amelioration, at about 11,450 yr BP (Fig. 4). The retreat of the polar front associated to the first deglacial warming in the North Atlantic appeared at about 12,500 yr ago off Portugal (Fig. 4; Bard *et al.*, 1987 *b*). The age of this event is also in agreement with that obtained by Broecker *et al.* (in press *a*; 12,280 yr BP) on the North Atlantic core V23-81 (54°15′N, 16°50′W). If we assume that the record of the coiling ratio of *N. pachyderma* at the location of the core CH84-14 was sensitive to the beginning of the polar front retreat, this indicates that, within the measurement precision, polar front displacements were synchronous in the Pacific and Atlantic oceans. In agreement with these Northern Hemisphere data, an abrupt termination of the last glacial period was pointed out in the South China Sea at about 13,100 yr BP by Broecker *et al.* (in press *b*).

The establishment of the conditions associated with the Younger Dryas type cooling (about 11,000 to 10,000 yr BP) and those which followed were almost instantaneous within the North Atlantic (Bard *et al.*, 1987; Broecker *et al.*, in press *a*) and the North Pacific Oceans and synchronous in the two oceans.

CONCLUSION

Data from CH84-14 indicate that as late as about 12,750 yr BP sea surface water at the location of this core was dominated by the subarctic water mass. The increase of the polar front influence started at 12,750 yr BP and culminated at about 11,450 yr BP. An abrupt southward oscillation of the polar front has marked a Younger Dryas type coiling in the western North Pacific between about 11,000 yr BP and 10,000 yr BP. Change in the surface ocean circulation in the western North Pacific concomitantly with the European and the North Atlantic Younger Dryas indicates the general impact that this cold event had in the high latitudes of the Northern hemisphere.

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Core CH84-14, 41°44′N, 142°33′E, 978 m.

Level (cm)	Age (kyr BP)	*U. akitaensis* δ^{18}	*G. bulloides* δ^{18}	Number of foraminifera per gram of sediment: *G. bulloides*	*N. pachy* (*l.c.*)	*N. pachy* (*r. c.*)	*N. pachy* (*l. c.*)/*N. pachy* (*total*) 100
0	8.34	3.38	—	—	—	—	—
10	8.38	—	—	—	—	—	—
20	8.43	3.48	—	—	—	—	—
30	8.48	—	—	—	—	—	—
40	8.53	—	—	—	—	—	—
50	8.58	3.50	—	—	—	—	—
60	8.62	—	—	—	—	—	—
70	8.67	3.39	—	—	—	—	—
80	8.72	3.37	—	—	—	—	—
90	8.77	3.33	—	—	—	—	—
100	8.82	3.46	—	—	—	—	—
110	8.86	—	—	—	—	—	—
120	8.91	3.29	2.37	2	17	2	89
130	8.96	3,35	2.37	—	—	—	—
140	9.01	3.36	2.22	7	44	2	96
150	9.06	3.21	2.24	—	—	—	—
160	9.10	3.50	2.23	1	19	1	96
170	9.15	3.55	2.36	—	—	—	—
180	9.20	3.63	2.75	—	—	—	—
190	9.25	3.51	2.50	97	275	10	96
200	9.30	3.59	2.74	—	—	—	—
210	9.34	3.62	2.56	118	379	49	89
220	9.39	3.51	2.75	48	94	26	79
230	9.44	3.58	2.74	279	605	135	82
240	9.49	3.48	2.76	24	41	6	87
250	9.54	3.52	2.71	37	32	3	90
260	9.58	3.59	2.77	60	95	7	93
270	9.63	3.74	2.77	522	773	87	90
280	9.68	3.95	3.04	637	651	86	88
290	9.78	3.62	2.92	620	658	57	92
300	9.89	3.85	2.87	176	192	17	92
310	9.99	3.78	2.98	776	833	52	94
320	10.17	3.95	2.97	138	259	3	99
330	10.36	4.00	2.91	—	—	—	—
340	10.54	3.99	3.12	24	48	0	100
350	10.72	4.00	3.21	—	—	—	—
360	10.91	3.92	2.94	33	53	2	96
370	11.09	3.94	2.44	34	58	5	92
380	11.27	3.96	2.69	50	100	9	92
390	11.46	3.87	2.42	57	128	49	72
400	11.64	4.19	2.94	345	811	144	85
410	11.75	4.17	2.70	107	172	14	93
420	11.85	4.06	2.84	91	144	17	89
430	11.96	4.08	2.77	481	744	68	92
440	12.06	—	3.10	369	414	34	92
450	12.17	—	2.63	194	225	10	96
460	12.25	—	2.86	45	260	9	97
470	12.30	—	3.08	152	329	6	98
480	12.35	—	2.86	556	893	53	94
490	12.40	—	2.77	280	206	13	94
500	12.45	—	2.92	255	515	18	97
510	12.50	4.15	2.94	1,408	1,974	118	94
520	12.66	4.24	2.90	902	1,814	37	98
530	12.82	4.07	3.71	95	382	0	100
540	12.98	4.44	3.83	100	360	2	99
550	13.14	4.29	3.93	221	1,150	6	99
560	13.27	4.35	3.98	193	705	12	98
570	13.36	4.50	3.79	93	603	5	99
580	13.44	4.46	3.57	67	201	3	99
590	13.53	4.54	3.93	225	996	21	98
600	13.70	4.47	4.01	267	670	8	99
610	13.85	4.66	3.95	204	866	13	99
620	13.99	4.65	3.99	—	—	—	—
630	14.14	4.67	3.77	131	684	6	99
640	14.29	4.64	3.95	—	—	—	—
650	14.43	4.58	3.88	—	—	—	—
660	14.58	4.69	3.95	73	291	9	97
670	14.73	4.78	3.47	—	—	—	—
680	14.87	4.59	3.76	—	—	—	—
690	15.02	4.68	3.54	320	1,171	15	99
700	15.24	4.70	3.48	97	230	5	98

Appendix

Climatic data along the core CH84-14: Oxygen isotopic composition of U. akitaensis *and* G. bulloides; *number of* G. bulloides, N. pachyderma (*l. c.*) *and* N. pachyderma (*r. c.*) *per gram of dry sediment; sinistral-to-total* N. pachyderma *ratio.*

Données climatiques de la carotte CH84-14 : composition isotopique de l'oxygène de *U. akitaensis* et de *G. bulloides*; nombre de *G. bulloides*, *N. pachyderma* senestre et *N. pachyderma* dextre par gramme de sédiment sec; rapport de *N. pachyderma* senestre sur *N. pachyderma* total.

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