JAMSTEC Report of Research and Development, Volume 5, March 2007, 1– 8

Paleohydrography of the Kuroshio-Kuroshio Extension off Sanriku Coast based on fossil diatoms

Itaru Koizumi[1] and Hirofumi Yamamoto[2]

Abstract The high-resolution analyses of fossil diatom assemblages in four cores recovered from the area off Sanriku Coast revealed the most complicated hydrographic history in this area. The fossil diatom assemblages changed in responding to the expansion of the warm-water eddies detached from the Kuroshio Extension and of the southward Oyashio Intrusion. Diatom abundances are higher in the cores from near shore than in the area off shore. The diatom assemblages were affected more seriously by the environmental changes in the cores from near shore. The diatom assemblages were also changed by the fluctuations at the intervals of ~40-kyr corresponding to the obliquity (tilt) band variations among the Earth's orbital parameters and ~60-kyr intervals suggesting changes in the sea level due to glacial/interglacial phases, with secondary and smaller fluctuations at ~20-kyr intervals corresponding to the precessional changes. Diatom assemblages in the southern margin of the Perturbed Area have been controlled mainly by the Kuroshio-Kuroshio Extension, but in the northern margin they changed in responding to the mixing of warm-water eddies and Oyashio Intrusion.

Keywords: diatoms, extinct diatoms, *Td´* values, orbital-obliquity (tilt), Kuroshio-Kuroshio Extinction, Perturbed Area, Oyashio

1. Introduction

The R/V "Mirai" belonging to Japan Agency for Marine-Earth Science and Technology (JAMSTEC) systematically collected many piston cores in order to understand the changing Kuroshio-Kuroshio Extension system in the Tohoku Area from 1997 to 2002.

We previously reconstructed the hydrographic history of the Kuroshio- Kuroshio Extension system off Joban coast from Inubo-zaki to about 38ºN based on high-resolution records of fossil diatoms in three cores recovered from the area beneath the Kuroshio Warm Core (Koizumi and Yamamoto, 2005).

This study is the second one in series to obtain paleohydrographic records in the area off Sanriku coast located the Pacific coast of the northern Tohoku District of about 38ºN (Fig. 1). The most complicated hydrographic conditions are encountered in the northern margin of the Perturbed Area, where numerous eddies and thermohaline fronts are irregularly distributed (Kawai, 1972). This is due to the transitional wide space from the Kuroshio Extension to the southern limit of the Oyashio Intrusion. Several warm tongues protrude northward along the Kuroshio Extension and a big tongue meandering convex

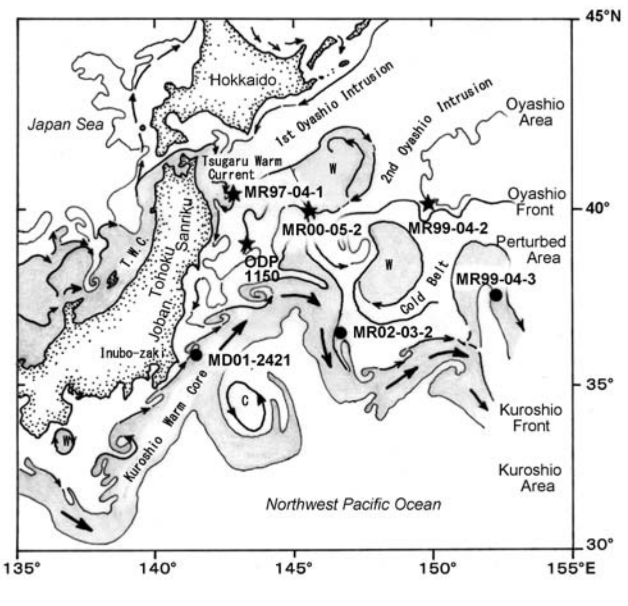

Figure 1: Locations of four cores in this report (black stars). Black circles indicate cores previously studied by Koizumi and Yamamoto (2005). Arrows show the currents and contour intervals show the boundary between water masses (Kawai, 1991). T.W.C.=Tsushima Warm Current, W=warm-water eddy, C=cold-water eddy.

1 Ocean Research Department, Visiting Researcher in 2000 (Emeritus Professor of Hokkaido University)
2 Japan Agency for Marine-Earth Science and Technology, Safety Control Office

to the north at 146ºE is sometimes called the secondary Kuroshio Front. The large-scale anti-cyclonic eddies with a diameter greater than 100 nautical miles are characteristically detached from the Kuroshio Extension. At the northern margin of the Perturbed Area, two southward intrusions of Oyashio water are found. The Tsugaru Warm Current occasionally comes in contact with the first Oyashio Intrusion in the seas south of Erimo-misaki and east of the Sanriku coast, and it may produce a faster current between the two waters.

2. Core materials and sediment age model

The fossil diatoms were previously analyzed in the sediment core recovered from the upper 2700 cm below seafloor (cmbsf) in Ocean Drilling Program (ODP) Hole 1150A at 39º11´N, 143º20´E, 2681m deep. There are no other useful age assignments than the last occurrence of diatom *Proboscia* (=*Rhizosolenia*) *curvirostris*, which is assigned to 0.3 million years ago, at 5103 cmbsf (Koizumi and Sakamoto, 2003). After that, Motoyama et al. (2004) reported Aso-4 tephra is assigned to 87.00 cal ka (kyr BP) at 2681 cmbsf, Shikotsu Daiichi (Spfa-1) tephra to 39.80 cal ka at 1507 cmbsf and Towada-Hachinohe (To-H) tephra to 14.83 cal ka at 505 cmbsf in the Peistocene sequence at ODP Hole 1150A (Table 1).

Three piston cores were recovered by R/V "Mirai" along the transverse running East-West at about 40ºN. The fossil diatoms in the core MR97-04-1 were previously analyzed (Koizumi et al., 2006). The marine isotope chronology based on the benthic $\delta^{18}O$ record suggested that the sediment of 25.16 cm thick corresponding to 7.8 kyr was lost at the topmost sediment of main piston core (Oba et al., 1999; Yamamoto et al., 1999; Koizumi et al., 2006).

The core MR00-05-2 was recovered at 40º00´N, 146º00´E, 5177m deep, and is composed of gray olive colored siliceous clay, mottled with abundant glassy ash layers. Such composition is recognized in Kutcharo-Haboro (Kc-Hb) tephra at 1237.5 cmbsf, Aso-4 tephra at 1151.5 cmbsf, Spfa-l tephra at 661 cmbsf, To-Of tephra at 540.5 cmbsf and To-H tephra at 221 cmbsf (Yamamoto and Kanamatsu, 2001; Yamamoto and Aoki, 2002).

The core MR99-04-2 was recovered at 40º05´N, 149º51´E, 5608m deep, and is mainly composed of dark olive gray colored clay with abundant glassy ash layers as recognized in Aso-4 tephra at 679 cmbsf, Spfa-1 tephra at 392 cmbsf, To-Of tephra at 297 cmbsf and To-H tephra at 775 cmbsf (Yamamoto et al., 2000; Aoki et al., 2000).

The age model (depth vs. calendar age) for four cores is shown in Table 1. In the interval from 679.0 cmbsf to 950.0 cmbsf of the core MR99-04-2, the sedimentation rate (depth vs. calendar age) were taken an average both the extrapolation between 39.8 cal ka of Spfa-1 tephra at 392 cmbsf and 87.0 cal ka of Aso-4 tephra at 1151.5 cmbsf, and 87.0 cal ka of Aso-4 tephra at 1151.5 cmbsf and 300.0 cal ka of the last occurrence of *P. curvirostris* at

Table 1: Chronostratigraphic framework (depth vs. calendar age) in four cores recovered from the northern margin of the Perturbed Area.

Age controls	Age (cal kyr BP)	ODP Hole 1150A (cm)	MR97-04-1 (cm)	MR00-05-2 (cm)	MR99-04-2 (cm)
MI Event 2.0	12.05		38.2		
To-H tephra	14.83	505.0		221.0	77.5
MI Event 2.2	17.85		54.4		
MI Event 3.0	24.11		64.7		
To-Of tephra	31.27			540.5	297.0
Spfa-1 tephra	39.80	1507.0		661.0	392.0
MI Event 3.3	50.21		247.7		
MI Event 4.0	58.96		267.7		
MI Event 5.0	73.91		344.7		
MI Event 5.1	79.25		365.7		
Aso-4 tephra	87.00	2681.0		1151.5	679.0
MI Event 5.2	90.94		410.4		
MI Event 5.3	99.38		448.4		
Kc-Hb	110.73			1237.5	
MI Event 5.4	110.79		491.4		
MI Event 5.51	122.56		552.7		
MI Event 6.0	129.84		598.8		
MI Event 6.2	135.10		634.0		
MI Event 6.4	152.58		674.0		
MI Event 6.41	161.34		698.0		
Top *P. curvirostris*	300.00				1575.0

1575.0 cmbsf (Fig. 2). The sediment cores recovered from the area off Tohoku District include abundant glassy ash layers, which were derived from the Japanese Island Arc. These tephras contribute much to construct the chronology for hemipelagic deep-sea sediments have not good carbonate components in the northwest Pacific Ocean.

3. Method of Study

The average sampling interval in ODP Hole 1150A is 30 cm corresponding to 0.95 kyr, and in MR00-05-2 10 cm corresponding to 1.40 kyr throughout the core. The sampling interval during the Holocene sequence in both MR97-04-1 and MR99-04-2 is 5 cm corresponding to 3.10 kyr due to the high sedimentation rate and 0.95 kyr, respectively. Below this interval, the average sampling interval in both cores is 10 cm corresponding to 2.10 kyr and 1.07 kyr, respectively.

The procedures of slide preparation, microscopic examination, and paleoceanographic analyses follow Koizumi and Yamamoto (2005).

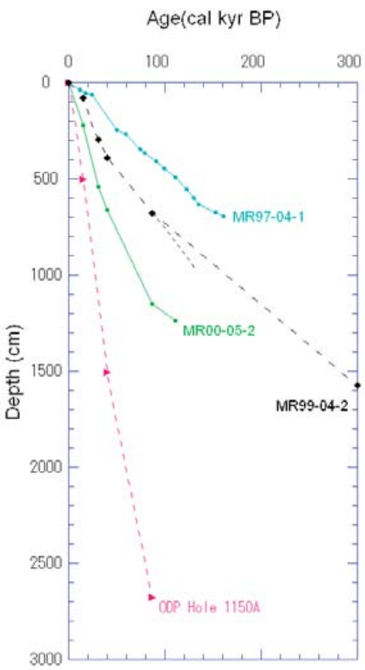

Figure 2: Sedimentation rates (depth vs. age) in four cores. The lower sedimentation rate in the core MR99-04-2 is based on the extrapolation between Spfa-1 tephra at 392 cmbsf and Aso-4 tephra at 1151.5 cmbsf, and higher rate on the rate between Aso-4 tephra at 1151.5 cmbsf and the last occurrence of *Proboscia curvirostris* at 1575.0 cmbsf.

4. Results and Discussion

The fragments of big diatom *Coscinodiscus wailesii* occur abundant to common exclusively at ~140-130 cal ka in MR99-04-2. The abundances of freshwater and littoral diatom species occupy less than 10% of the total diatoms.

4.1 Diatom abundance

Diatom abundances (10^7 valves/1 g of dried sediment) decrease as the location of the core becomes far from near shore, with exceptions of spike-like increases at the horizons 135.10 cal ka, 93.38 cal ka and 41.15 cal ka in MR97-04-1 (Fig. 3). Diatom abundances fluctuate largely in the cores from near shore than off shore, where affected more serious environmental changing near shore than off shore. Large fluctuations occur at the intervals of ~40-kyr, which corresponds to the obliquity (tilt) band variations of 41-54-kyr, with secondary and smaller fluctuations at intervals of ~20-kyr corresponding to precessional of 19-23-kyr, changes in distribution of insolation. The peaks of high abundances, therefore, are correlated with each other in the interglacial stages throughout four cores.

4.2 Extinct diatoms

The relative abundances of extinct diatoms occupy less than 10 % of the total diatoms in MR99-04-2 located off shore, but they are dominant in three cores of near shore

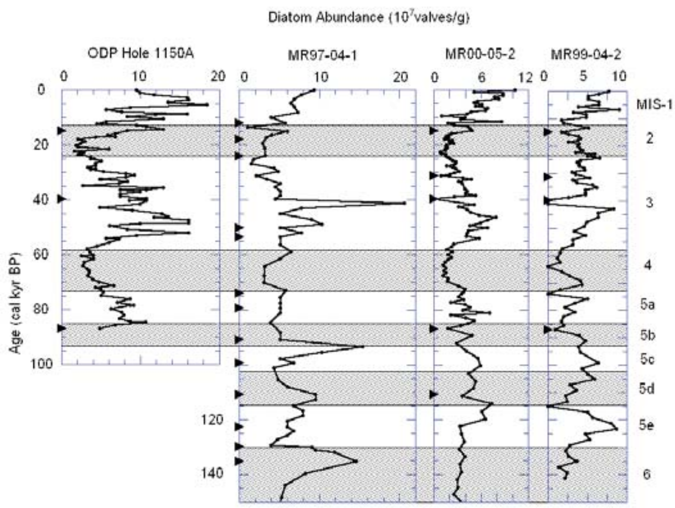

Figure 3: Chronostratigraphic variations of diatom abundance (10^7 valves/1 g of dried sediment) in four cores. High diatom abundances are correlated within the interglacial phase of each core among four cores. Black triangles on the left side of each column indicate the age control points for age model. The stage boundaries of the marine isotope stage (Martinson et al., 1987) are indicated.

(Fig. 3). Large fluctuations with secondary and smaller fluctuations are correlated with each other throughout four cores, and the peaks of high abundances occur at 135 cal ka, 115 cal ka, 75-85 cal ka, 35-40 cal ka and 25 cal ka. The abundances of extinct species was increased during the lowered sea-level phase, which indicate contribution of reworked and displaced diatoms derived from sea bottom, since freshwater and littoral diatoms rarely occur. The relative abundances decrease since 20 cal ka due to the deglaciation.

The predominant occurrences of *Melosira albicans* are accompanied with that of *Pseudopodosira elegans* throughout four cores. *Melosira albicans* and Pseudopodosira elegans were described originally at the Pliocene in Sakhalin and Kamchatica (Sheshukova-Porentzkaya, 1964), and found on land sections in the Pliocene Tatsunokuchi Formation in Fukushima and Miyagi Prefectures (Koizumi, 1972, 1973b). On the other hand, their last occurrences are at the *Pleistocene Proboscia (=Rhizosolenia) curvirostris* Zone by the diatom biostratigraphy in the Deep Sea Drilling Project (Koizumi, 1973a) and Ocean Drilling Program (Koizumi, 1992). They occur regularly, however, throughout the Pleistocene to Holocene sediments recovered by piston coring in the North Pacific Ocean (Koizumi et al., 2001, 2004; Shimada and Hasegawa, 2001). Those species need to be checked taxonomically.

4.3 Littoral-neritic and oceanic diatoms

Stephanopyxis turris s.l. and *Thalassionema nitzschioides* dominate in littoral-neritic association in four cores. The relative abundances of littoral-neritic association gradually decrease from 150 cal ka to 15 cal ka with gentle undulations made of the rapid and short cyclicities of several kyr duration. The abundances of littoral-neritic association increase during the Holocene interval (Fig. 5).

Large fluctuations in the relative abundance of oceanic diatoms occur at the intervals of ~40-kyr following secondary and smaller fluctuations at ~20-kyr intervals throughout four cores.

4.4 Cold-water and warm-water species in littoral-neritic association

The relative abundances of cold-water and warm-water species in littoral-neritic association are almost equal in three cores with the exception of MR99-04-2 since 8 cal ka (Fig. 6). In MR99-04-2, the relative abundances of such warm-water species as *Hemiaulus sinensis, Odontella reticulum* and *Thalassionema nitzschioides* var. *parva* dominate over those of cold-water ones. Sudden

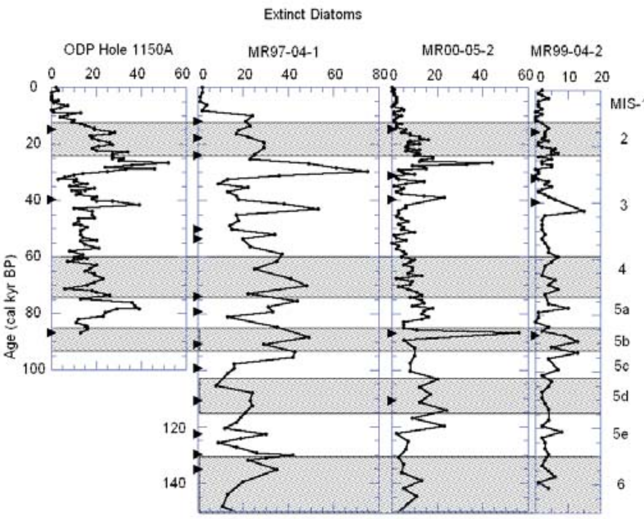

Figure 4: Chronostratigraphic variations of extinct diatoms (valves/200 valves) in four cores. High relative abundances are correlated within the lowered sea level phase estimated from normalized δ^{18}O curve by Martinson et al. (1987) of each core among four cores. Black triangles on the left side of each column indicate the age control points for age model. The stage boundaries of the marine isotope stage (Martinson et al., 1987) are indicated.

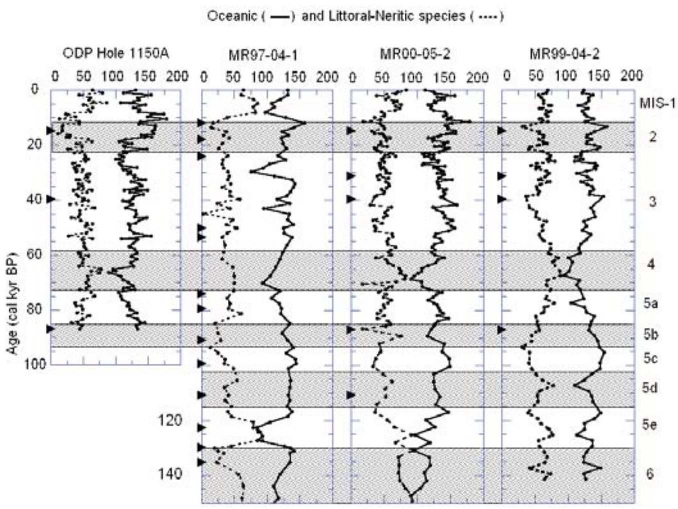

Figure 5: Chronostratigraphic variations of littoral-neritic and oceanic diatoms (valves/200 valves) in four cores. High relative abundances of oceanic diatoms are correlated each other among four cores. Black triangles on the left side of each column indicate the age control points for age model. The stage boundaries of the marine isotope stage (Martinson et al., 1987) are indicated.

increases in the relative abundance of exclusive cold-water species *Odontella aurita* in littoral-neritic association occur from ~8 cal ka in four cores, and at ~125cal ka in MR97-04-1. The relative abundances of *O. aurita* in three cores recovered near shore are two times as much that in MR99-04-2 from off shore. *O. aurita* widely distributes but most abundant in arctic and boreal seas (Cupp, 1943), and sometimes found free but usually in long chains attached to a substratum (Hendey, 1964).

4.5 Cold-water and warm-water species in oceanic association

The relative abundances of cold-water species in oceanic association dominate over those of warm-water ones throughout four cores. The fluctuations at ~40-kyr intervals in the relative abundances of cold-water species lead to correlate each other among four cores. Remarkable decreases in the relative abundances of cold-water species are recognized at ~125 cal ka, ~70 cal ka, ~25 cal ka and ~7.5 cal ka in four cores. In these levels, the relative abundances of such cold-water as *Fragilariopsis cyclindrus*, *Fragilariopsis oceanicus* and *Thalassiosira gravida* decrease and those of warm-water such as *Azpetia nodulifer*, *Azpetia tabularis*, *Fragilariopsis doliolus* and *Roperia tesselata* generally increase.

The relative abundances of warm-water species in both MR99-04-2 and MR00-05-2 recovered from off shore are larger than those in both MR97-04-1 and ODP Hole 1150A from near shore (Fig. 6). It suggests that the area near shore is exactly located within the 1st Oyashio Intrusion, but off shore cores were affected by the warm-water eddies detached from Kuroshio Extension (Fig. 1).

4.6 Diatom temperature (*Td´*) values in the oceanic association

The *Td´* values in the cores from near shore are smaller than those from off shore (Fig. 7). It might be caused that ODP Hole 1150A located in the 1st Oyashio Intrusion and MR97-04-1 is at the outer margin of the Tsugaru Warm Current, and both MR00-05-2 and MR99-04-2 are under the influence of the warm-water eddies and particularly the latter is considered to have lesser influence of the cold-water.

Large fluctuations occur at 50-60-kyr intervals with secondary and smaller fluctuations at ~20-kyr intervals throughout four cores. The cyclicities at ~60-kyr intervals

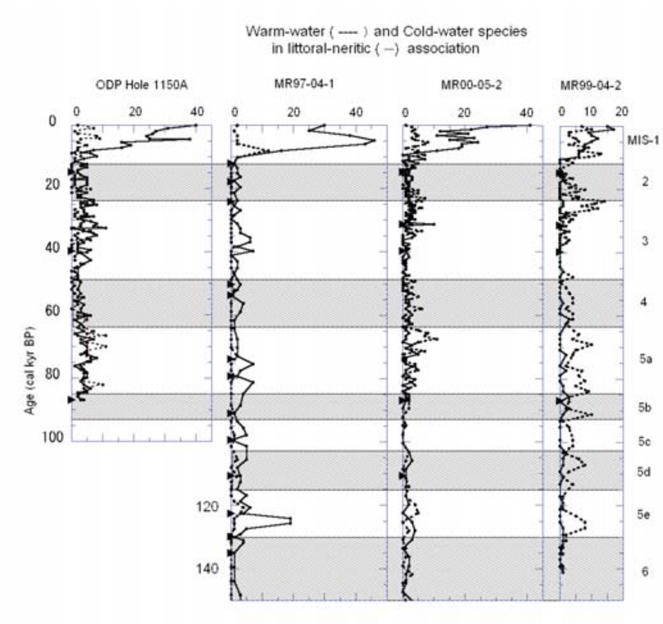

Figure 6: Chronostratigraphic variations of cold-water and warm-water species (valves/200 valves) in littoral-neritic association in four cores. High relative abundances of cold-water species increase suddenly from 8 cal ka in four cores. Black triangles on the left side of each column indicate the age control points for age model. The stage boundaries of the marine isotope stage (Martinson et al., 1987) are indicated.

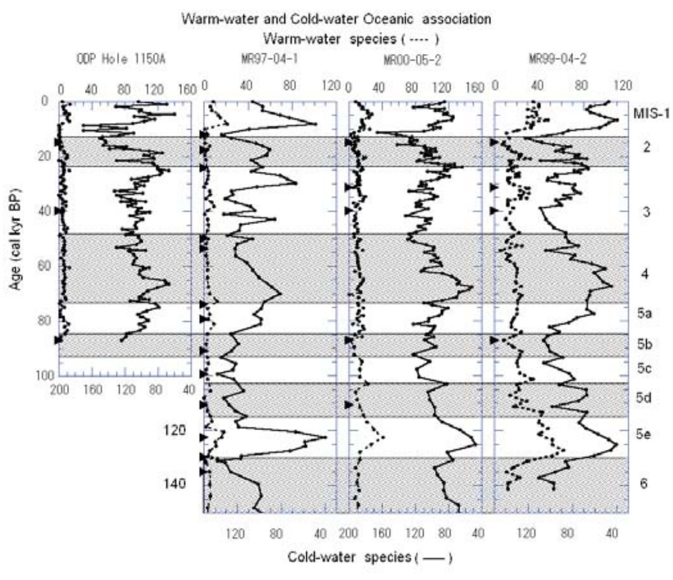

Figure 7: Chronostratigraphic variations of cold-water and warm-water species (valves/200 valves) in oceanic association in four cores. High relative abundances of cold-water species are correlated each other among four cores. Black triangles on the left side of each column indicate the age control points for age model. The stage boundaries of the marine isotope stage (Martinson et al., 1987) are indicated.

recognize in the variation of isostatic balance between the crust and advance retreat of continental ice sheet on Northern Hemisphere (Birchfield and Gurmbine, 1985). The cross-spectral analysis of the *Td´* values in MD01-2421 recovered from off Inubo-zaki shows that sea surface temperature (SST) at the core site indicated by *Td´* values is controlled by the intensity of the Kuroshio transport at 50-62 and 17-kyr bands, and also affected by global ice volume as the proxy for climate at 23-kyr band (Koizumi et al., 2004). The glacio-eustatic sea level changes associated with the combination of high obliquity and seasonal temperature changes could have caused the changes in species composition of diatom assemblages (De Bore and Smith, 1994; Koizumi et al., 2004).

The first high *Td´* values occur at ~125 cal ka in the interglacial phase (Fig. 8). Second high *Td´* values occur 75 cal ka in the core MR97-04-1 and ~65 cal ka, and third occur 7-8 cal ka throughout four cores.

5. Comparison with the previous results off Joban coast

Diatom abundances are generally higher in the area near shore than in the area off shore because diatom production depends on the degree of mixing of seawaters between cold-water and warm-water under the control of the variations in the Earth's orbital parameters and isostatic balance. In the northern margin of the Perturbed Area, diatom abundances are twice as high as those beneath the stream axis of the Kuroshio Extension because streaky structures due to mixing of Oyashio Intrusions and warm-water eddies along the Kuroshio Extension develops in the northern margin area.

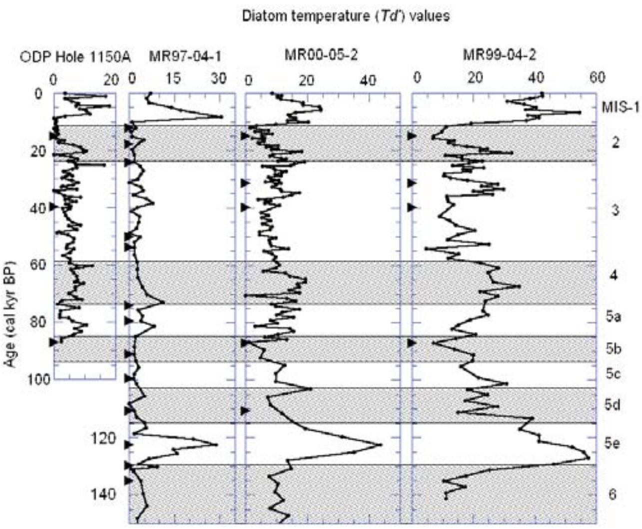

Figure 8: Chronostratigraphic variations of *Td´* values in four cores. Remarkably high *Td´* values are correlated within the limits of age indicating by markers on the left side of each core among four cores. Black triangles on the left side of each column indicate the age control points for age model. The stage boundaries of the marine isotope stage (Martinson et al., 1987) are indicated.

The abundances of extinct diatoms increase in the cores from near shore than those off shore. In the northern area of the Perturbed Area, reworked and/or displaced derived from extinct diatoms dominantly occur than those beneath the track of the Kuroshio Extension when the lowered sea-level times during the glacial phase.

The relative abundances of littoral-neritic diatoms, particularly warm-water species, are higher in the cores beneath the Kuroshio Extension than in the cores in the northern margin of the Perturbed Area, because the Kuroshio Current flowing northeast along the near shore of southwest Japan transports littoral-neritic diatoms into the southern margin of the Perturbed Area.

The littoral-neritic cold-water species *Odontella aurita* increases suddenly since ~8 cal ka in five cores, except MR02-03-2 and MR99-04-3 located off shore area of the Kuroshio Extension, and at 9.5 cal ka in MD01-2409 off the Shimokita Peninsula (Koizumi et al., 2006). The increased abundances of *O. aurita* in Holocene interval may represent the increased productivity occurring in the area along the frontal zone at the northern margin of the Perturbed Area, because this species flourishes most in arctic and boreal seas during April and May.

The relative abundances of cold-water species in oceanic association dominate over those of warm-water species throughout the cores recovered from the Perturbed Area. However, the abundances of oceanic warm-water species increase in MR99-04-3 and MR99-04-2 located in the warm-water tongue and eddies along the Kuroshio Extension. The *Td´* values are higher in the cores recovered the southern margin in the Perturbed Area than those in the northern margin, as expected.

6. Conclusion

The complicated hydrographic records in the northern area of the Kuroshio-Kuroshio Extension system were reconstructed based on high- resolution analyses of fossil diatom assemblages in four cores recovered from the northern margin of the Perturbed Area.

Freshwater and littoral diatoms occupied less than 10% of the total 200 valves counted. Extinct diatom *Melosira albicans* and *Pseudopodosira elegans* occurred commonly in the cores from near shore than off shore. The relative abundances of the extinct diatoms cyclically fluctuated at the intervals of ~40-kyr and ~20-kyr corresponding to the Earth's orbital parameters, and the abundances was increased in the lowered sea-level phase during the glacial time. The extinct diatoms should be derived from sea bottom, since freshwater and littoral diatoms rarely occur.

The fragments of *Coscinodiscus wailesii* are dominant exclusively at 140-130 cal ka corresponding to the upper part of the MIS 6 in MR99-04-2.

Diatom abundances and the fluctuations are larger in the cores from near shore than off shore. Large fluctuations occur at ~40-kyr intervals with secondary and smaller fluctuations at ~20-kyr intervals.

The littoral-neritic cold-water species *Odontella aurita* occurs abundantly since ~8 cal ka in four cores, because productivity increases in the area along the frontal zone at the northern margin of the Perturbed Area.

The relative abundances of oceanic cold-water species dominate over those of warm-water species throughout the cores recovered in the northern margin of the Perturbed Area. However, warm-water species increase in MR99-04-2 located near warm-water eddy detached from the Kuroshio Extension.

The *Td´* values in the cores from near shore area smaller than those from off shore. Locations of the cored sites account for this; ODP Hole 1150A locates in the first Oyashio Intrusion, and MR97-04-1 is the outer margin of the Tsugaru Warm Current, Both MR00-05-2 and MR99-04-2 are under the influence of the warm-water eddies and particularly the latter is thought to have lesser influence of the cold-water.

6. Acknowledgements

We thank Dr. Kaori Aoki of the Japan Science and Technology Corporation for the advice of volcanostratigraphy and Dr. John Barron of the U.S. Geological Survey for reviews and suggestions for improving the manuscript.

References

1) K. Aoki, H. Yamamoto, and M. Yamauchi, "Late Quaternary tephrostratigraphy of marine cores collected during "Mirai" MR98-03 and MR99-K04 cruises". JAMSTECR **41**, 49-56 (2000) (Japanese with English abstract).

2) G.E. Birchfield, and R.W. Gurmbine, ""Slow" physics of large continental ice sheets, the underlying bedrock and the Pleistocene Ice Age". J. Geophys. Res. **90**, 11294-11302 (1985).

3) E.E. Cupp, "Marine Plankton Diatoms of the West Coast of North America". Univ. Calif. Press, Berkely, 237p (1943).

4) P.L. De Bore, and D.G. Smith, "Orbital forcing and cyclic sequences". In: De Bore, P.L., Smith, D.G. (Eds.) Oribital Forcing and Cyclic Sequences. Spec. Pub. No.19, IAS, Blackwell, London, pp. 1-14 (1994).

5) N.I. Hendey, "An Introductory Account of the Smaller Alage of British Coastal Waters". Part V. Her Majesty's Stationery Office, London. 317p (1964).

6) H. Kawai, "Hydrography of the Kuroshio Extension". In: Stommel, H., and Yoshida, K. (Eds.), Kuroshio-Its Physical Aspect. Univ. of Tokyo Press, Tokyo, pp. 235-352 (1972).

7) H. Kawai (Ed.), Currents and Life–Special Lecture on Fishery Biology–. Kyoto Univ. Press, Kyoto, 410p (1991).

8) I. Koizumi, "Marine diatom flora of the Pliocene Tatsunokuchi Formation in Fukushima Prefecture, northeast Japan". Trans. Proc. Paleontol. Soc. Jpn., No. 86, 340-359 (1972).

9) I. Koizumi, "The late Cenozoic diatoms of Sites 183-193, Leg 19 Deep Sea Drilling Project". In: Creager, J.S., Scholl, D.W., et al. (Eds.) Init. Repts. DSDP 19, Washington (U.S. Govt. Printing Office), 805-855 (1973a).

10) I. Koizumi, "Marine diatom flora of the Pliocene Tatsunokuchi Formation in Miyagi Prefecture". Trans. Proc. Paleontol. Soc. Jpn., N.S., No. 79, 126-136 (1973b).

11) I. Koizumi, "Diatom biostratigraphy of the Japan Sea: Leg 127". In: Ingle J.C., Jr., von Breymann, M.T., Barron, J., et al. (Eds.) Proc. ODP, Sci. Res. 127/128, Pt.1, College Station, TX (Ocean Drilling Program), 249-289 (1992).

12) I. Koizumi, and T. Sakamoto, "Paleoceanography off Sanriku, northeast Japan, based on diatom flora". In: Suyehiro, K., Sacks, I.S., Acton, G.D. , and M. Oda (Eds.), Proc. ODP, Sci. Results 186 [Online]. Available from World Wide Web: http://www-odp.tamu.edu/publications/186_SR/110/110. htm> [Cited YYYY-MM-DD] (2003).

13) I. Koizumi, and H. Yamamoto, "Paleohydrography of the Kuroshio- Kuroshio Extension based on fossil diatoms". JAMSTEC Rep. Res. Dev. **1**, 57-68 (2005).

14) I. Koizumi, T. Irino, and H. Yamamoto, "Changes in the warm water Kuroshio Current system from the ending period of the last glacial to the present interglacial based on diatom fossils in the western North Pacific Ocean sampled on the R/V Mirai cruise [MR00-K05]". JAMSTECR **44**, 29-40.

15) I. Koizumi, T. Irino, and T. Oba, "Paleoceanography during the last 150 kyr off central Japan based on diatom floras". Mar. Micropaleontology **53**, 293-365 (2004).

16) I. Koizumi, R. Tada, H. Narita, T. Irino, T. Aramaki, T. Oba, and H. Yamamoto, "Paleoceanographic history around the Tsugaru Strait between the Japan Sea and the Northwest Pacific Ocean since 30 cal kyr BP". Palaeogeogr. Palaeoclimatol. Palaeoecol. **232**, 36-52 (2006).

17) D.G. Martinson, N.G. Pisias, J.D. Hays, J. Imbrie, T.C. Moore Jr., and N.J. Shackleton, "Age dating and the orbital theory of the Ice Ages: development of a high-resolution 0 to 300,000-year chronostratigraphy". Quat. Res. **1**, 1-29 (1987).

18) I. Motoyama, N. Niitsuma, T. Maruyama, H. Hayashi, S. Kamikuri, M. Shiono, T. Kanamatsu, K. Aoki, C. Morishita, K. Hagino, H. Nishi, and M. Oda, “Middle Miocene to Pleistocene magneto-biostratigraphy of ODP Sites 1150 and 1151, northwest Pacific: Sedimentation rate and updated regional geological timescale”. The Island Arc **13**, 289-305 (2004).
19) V.S. Sheshukova-Poretzkaya, “New and rare marine diatoms in the Neogene of Sakhalin and Kamchatka”. Akad. Nauk SSSR, Bot. Inst., Novitates Systematicae Plantaru non Vascularum 10, 69-72 (1964) (in Russian with English abstract).
20) C. Shimada, and S. Hasegawa, “Paleoceanographic implications of a 90,000 year long diatom record in piston core KH94-3, LM-8 off NE Japan”. Mar. Micropaleontol. **41**, 153-166 (2001).
21) H. Yamamoto, M. Yamauchi, K. Aoki, M. Horii, and T. Sugawara, “Lithology of piston cores recovered from the deep sea floor in the western North Pacific during the R/V Mirai cruise [MR99-K04]”. JAMSTEC **41**, 37-48 (2000) (Japanese with English abstract).
22) H. Yamamoto, and T. Kanamatsu, “Lithology of piston cores recovered from the northwestern Pacific Ocean on R/V Mirai cruise [MR00-K05]”. JAMSTECR **44**, 55-72 (2001) (Japanese with English abstract).
23) H. Yamamoto, and K. Aoki, “Late Quaternary tephrostratigraphy in piston cores collected during “Mirai” MR00-K05 cruise”. JAMSTECR **46**, 29-37 (2002) (Japanese with English abstract).

(Received November 17, 2006)