Jour. Geol. Soc. Japan, Vol. 101, No. 1, p. 2–12, January 1995

Correlation of the Cenomanian/Turonian boundary between Japan and Western Interior of the United States

*Takashi Hasegawa**

Received June 20, 1994.
Accepted October 16, 1994.
* Department of Geoenvironmental Science, Faculty of Science, Tohoku University, Aoba-ku, Sendai 980–77, Japan

Abstract

Biostratigraphy and carbon isotope stratigraphy afford a precise correlation of the interval across the Cenomanian/Turonian boundary between Japan and the Western Interior of the United States. The last appearance of the planktonic foraminiferal *Rotalipora cushmani* conjoined with that of *Rotalipora greenhornensis* and the first appearance of *Marginotruncana schneegansi* bracket the Cenomanian/Turonian boundary. The upper limit of the Japanese equivalent of the *Whiteinella archaeocretacea* Zone, recognized in the Pueblo section in the Western Interior, is also recognizable by using the first appearances of *M. schneegansi* and *Pseudaspidoceras flexuosum* (an ammonoid). The Japanese Cenomanian/Turonian boundary is drawn just above the upper of the twin positive carbon isotope excursion peaks, taking it as the equivalent of the first appearance of *Watinoceras devonense* in the Pueblo section. Carbon isotope stratigraphy is a powerful tool in determining the Cenomanian/Turonian boundary where important boundary indicators are not available. The lithofacies across the Cenomanian/Turonian boundary indicate that dysaerobic conditions, related to the Cenomanian/Turonian Oceanic Anoxic Event, existed around the northwestern Pacific as well as elsewhere. Remarkably low sedimentation rates just below the Cenomanian/Turonian boundary in the studied area suggest a dramatic decrease in terrigenous input and/or the temporary distal migration of the sedimentary basin, induced by global high-stands of sea level during the time of carbon isotope anomaly events and the Cenomanian/Turonian Oceanic Anoxic Event. The Oyubari section contains enough stratigraphic indicators to allow precise correlations with well-studied Cenomanian/Turonian boundary sections around the world and represents an important regional reference section of the Cenomanian/Turonian boundary around the northwestern Pacific.

Key words: Cenomanian/Turonian (C/T) boundary, Oceanic Anoxic Event (OAE), Oyubari section, Pueblo section, $\delta^{13}C$ spike, planktonic foraminifera, Whiteinella archaeocretacea Zone

Introduction

During the mid-Cretaceous, more than half of the source rocks of the world's giant oil fields were deposited (Irving et al., 1974). Black, organic carbon rich sediments, potential source rocks of petroleum, are globally found to characterize the Cenomanian/Turonian (C/T) boundary interval. These phenomena are interpreted to have been induced by a contemporaneous global event named "Oceanic Anoxic Event (OAE)" (Schlanger and Jenkyns, 1976). During the OAE across the C/T boundary, it is believed that widespread oxygen-depleted water masses gave rise to rapid burial of huge amounts of organic carbon at the seafloors of various oceanographic settings. This is just an inversion of the process of the rapid emission of inorganic carbon (CO_2) by combustion of fossil fuel (i.e. organic carbon) in the present earth. Therefore, a better understanding of the influence of the OAE on paleoenvironments should offer important information on how to assess changing environments of the earth at present and even in future.

Although the OAE at the C/T boundary has been interpreted as a global phenomenon, only a little evidence for its occurrence has been reported from the borders of northwestern Pacific Ocean (Hirano et al., 1991, Hasegawa, 1992; Hirano, 1993; Hasegawa and Saito, 1993; Kaiho and Hasegawa, 1994). The Yezo Group yields abundant ammonoids and inoceramids and various authors have attempted a global correlation of the group based on the macrofossils (see Hirano, 1995). On the other hand, there are few available biostratigraphical studies concerning calcareous microfossils of the Yezo Group. Recently, Hasegawa and Saito (1993) reported the occurrence of important age indicative planktonic foraminiferal species in the Cenomanian～Turonian section of the Oyubari area, Hokkaido and showed the availability of planktonic foraminifera for precise correlation with other well-studied C/T boundary sections of the world. The stratigraphic distributions of planktonic foraminifera across the C/T boundary were precisely described by Eicher and Diner (1985) and Leckie (1985) in the Pueblo section in Colorado and by Jarvis et al. (1988 a) and Hart and Leary (1989) in the Dover section of England. The present author first establishes a detailed biostratigraphy based on planktonic foraminifera which occur more continuously than macrofossils. Moreover the recognition of the planktonic foraminiferal *Whiteinella archaeocretacea* Zone (KS20 of Sliter's (1989) zonal notation) is required to determine the C/T-OAE interval in the northwestern Pacific region precisely because the stratigraphic interval of C/T-OAE elsewhere in the world (e.g., Schlanger et al., 1987) nearly corresponds to this planktonic foraminiferal zone.

During rapid accumulations of the organic carbon-rich sediments across the C/T boundary, the biased exclusion of ^{12}C-rich carbons from the ocean gave rise to ^{13}C-rich global sea water in the world ocean (Schlanger et al., 1987 and Arthur et al., 1987, 1988). This global carbon isotope event has well been documented by virtue of positive anomalies of $\delta^{13}C$ in organic carbon and carbonate across the C/T boundary observed in various areas including the Tethys region, Atlantic Ocean, and the Western Interior of the United States (e.g., Scholle and Arthur, 1980; Pratt, 1985; Hilbrecht et al., 1986; Schlanger et al., 1987; Arthur et al., 1988; Jarvis et al., 1988 b; Hayes et al., 1989; Leary et al., 1989; Shahin, 1991; Hilbrecht et al., 1992; Uličný et al., 1993; Gale et al., 1993; Peryt and Wyrwicka, 1993 and Jenkyns et al., 1994). Therefore, carbon isotopic study can be commonly employed as a supplemental tool to define the stratigraphic position of the C/T boundary.

Hasegawa and Saito (1993) preliminarily discussed the stratigraphic position of the C/T boundary in two Hokkaido sections, but more detailed information is required to discuss the boundary and so-called C/T-OAE in the Hokkaido section on a global scale. In this paper, the author correlates the Japanese C/T boundary sequence with the well studied Pueblo section and discusses the detailed stratigraphic position of the boundary on the basis of carbon isotope stratigraphy and combined biostratigraphical data of planktonic foraminifera and macrofossils.

Geologic settings

Samples were collected from the Cretaceous Yezo Group exposed along the Shirakin (=Hakkinzawa) River in the Oyubari area, Hokkaido, Japan (Fig. 1). The Yezo Group is interpreted as a fore-arc basin facies (Okada, 1979, 1983). The Cenomanian/Turonian boundary sequence of the Yezo Group is represented by the Takinosawa Formation defined by Motoyama et al. (1991). Along the course of the Shirakin River, the Takinosawa Formation is nearly continuously exposed, striking meridionally with a vertical dip, and is composed predominantly of dark gray mudstone with either occasional intercalations of turbiditic sandstone layers of less than 10 cm in thickness or rhythmically alternating layers of turbiditic sandstone and siltstone. Some characteristic lithofacies (OY-a～d, OY for lithologic unit of the Oyubari section) are observable near the C/T boundary as shown in Fig. 2. One is a conspicuous greenish-gray silty, very fine-grained sandstone (33 m in thickness), named "radiolarian sandstone" by Hasegawa and Saito (1993). Common intercalations of bentonite layers of 20-50 cm in thickness are observed in and above the radiolarian sandstone. The other is a dark gray to blackish-gray, pyrite-rich clayey siltstone overlain by the radiolarian sandstone. These lithologic units are traceable throughout the Oyubari area.

Material and method

About 100 samples were collected at < 2.5 m intervals near the C/T boundary and processed for extracting planktonic foraminiferal specimens. Samples of about 240 g were disaggregated using sodium sulfate, naphtha solution, and sodium tetraphenylborate plus NaCl (Hanken, 1979), washed through a 63-μm screen and dried. All specimens larger than 180-μm were then picked from the processed samples and identified. In addition, the author analyzed larger samples (500-800 g) from the boundary sequence from 7 m below to 40 m above the boundary. The present analyses are based on foraminifera from 31 planktonic foraminifer-bearing samples taken from fine-grained sediments (mainly siltstone).

The samples subjected to isotope analyses and total organic carbon (TOC) measurements were prepared and processed through the same procedure that

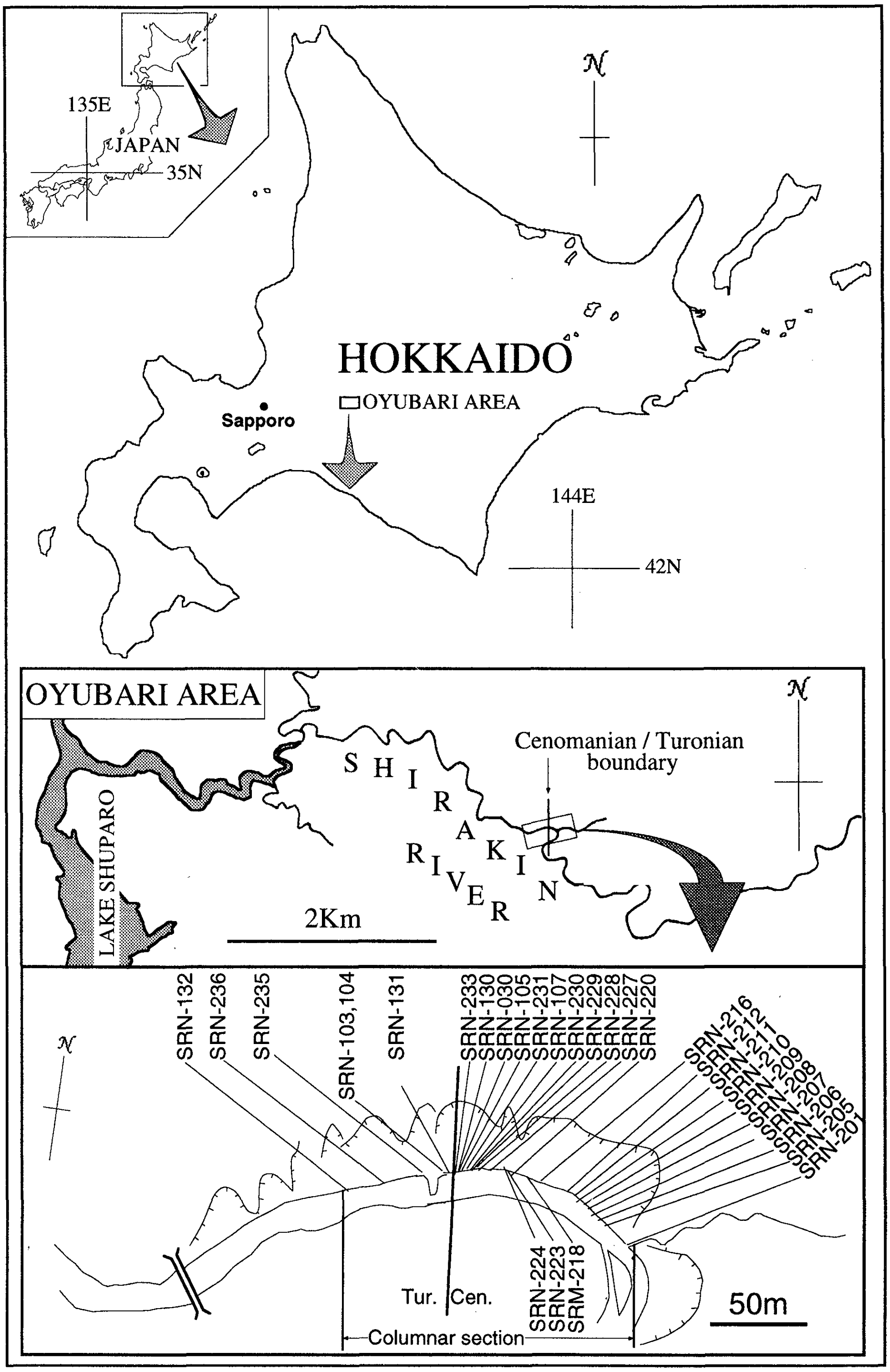

Fig. 1. Index map showing localities of samples along the Shirakin River in the Oyubari area, Hokkaido, Japan.

Hasegawa and Saito (1993) used, then $\delta^{13}C$ analyses were performed with a Finnigan MAT 250 mass spectrometer at the Shizuoka University. The results reported herein are expressed by standard per mil deviations from the PDB standard, with the reproducibility of analyses less than 0.05‰.

Biostratigraphy

The stratigraphic distribution of planktonic foraminifera across the C/T boundary in the Oyubari area is shown in Fig. 3. The stratigraphic interval near the C/T boundary fortunately contains highly diversified assemblages associated with some international zonal marker species. Based on their stratigraphic distributions, the following two important datum planes were recognized.

A: Last appearance datum (LAD) of *Rotalipora cushmani*

Age. Latest Cenomanian

Remarks. The last occurrence of *Rotalipora cushmani*

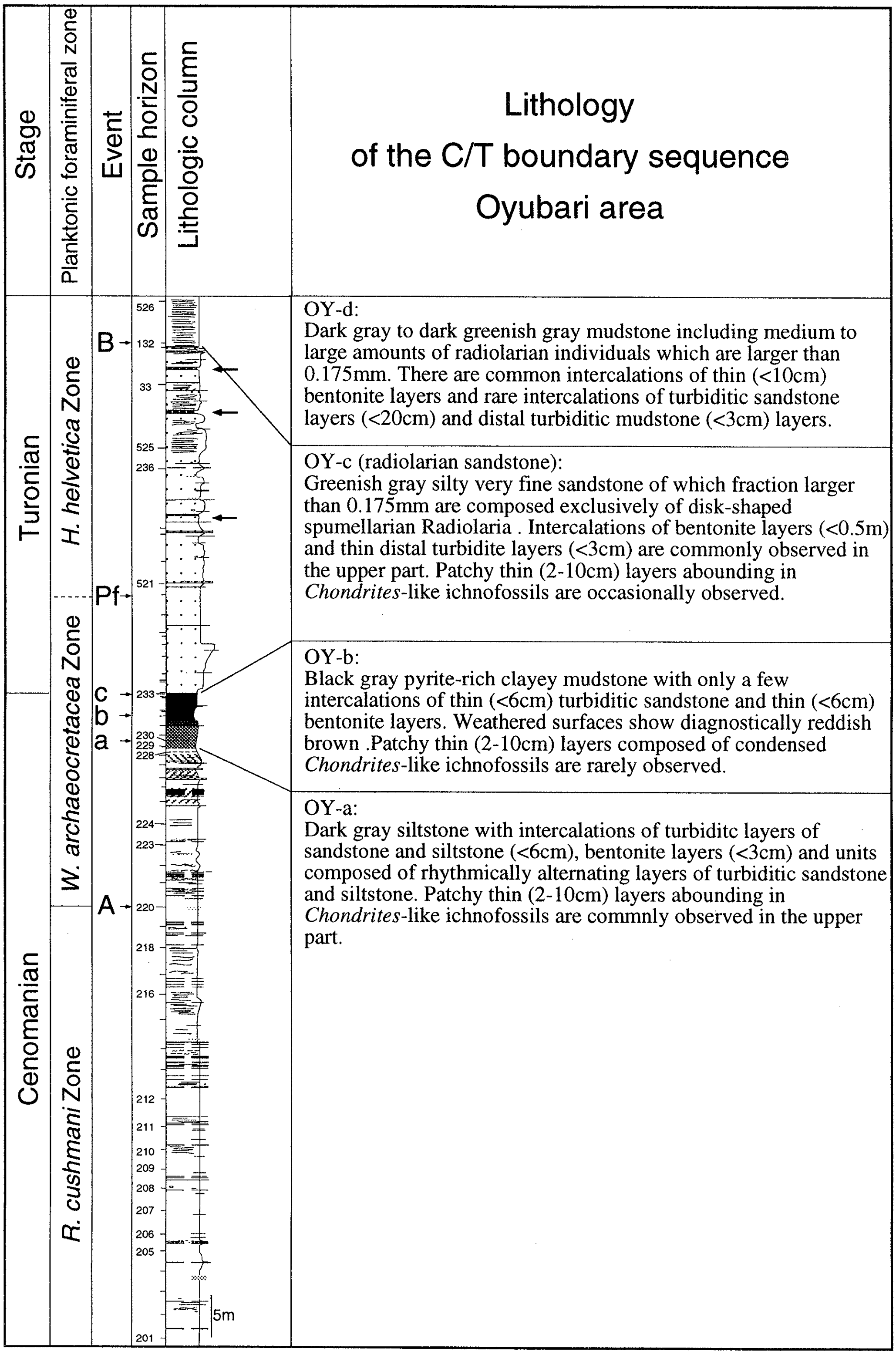

Fig. 2. Lithology and sample horizons across the Cenomanian/Turonian boundary along the Shirakin River, Oyubari area. The boundary sequence is subdivided into four subunits. Arrows show bentonite layers thicker than 20 cm. See Fig. 3 for event notation.

(Morrow) was observed with that of *Rotalipora greenhornensis* (Morrow) in the same horizon. Caron (1985) and Sliter (1989) draw the LAD of *R. greenhornensis* just below the LAD of *R. cushmani*, but recent precise biostratigraphical studies of planktonic foraminifera indicate that these LADs are nearly synchronous within the accuracy of biostratigraphy. Leckie (1985) showed the Cenomanian/Turonian planktonic foraminiferal biostratigraphy in Pueblo, Colorado, where exists the best studied Cenomanian/Turonian boundary section, presenting synchronous last occurrences of *R. cushmani.* and *R. greenhornensis*. The synchronous or nearly synchronous last occurrences of these species were also reported from south-

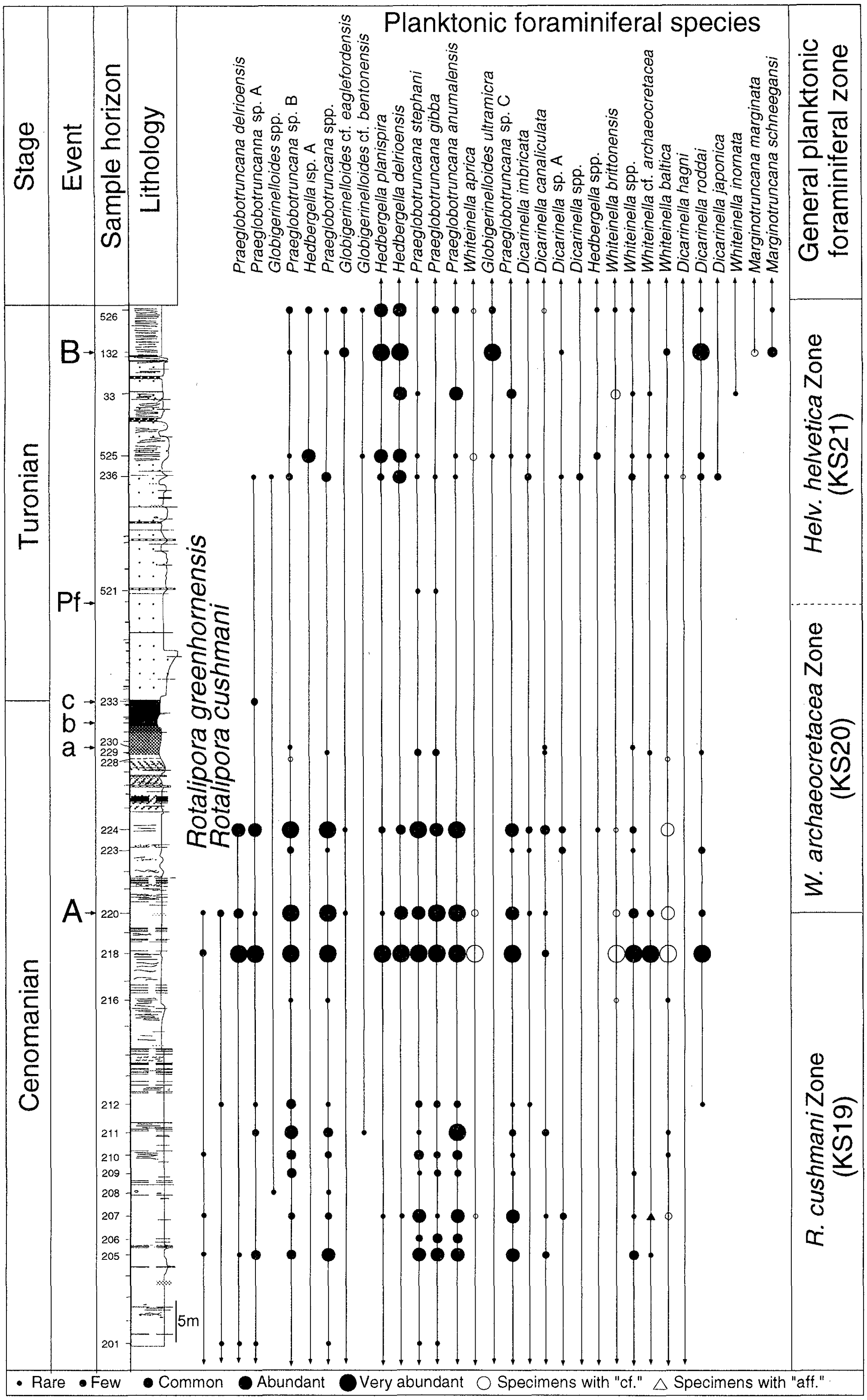

Fig. 3. Stratigraphic distribution of planktonic foraminiferal species crossing the Cenomanian/Turonian boundary along the Shirakin River. A : LAD of *Rotalipora cushmani*, a: horizon of $\delta^{13}C$ peak a, b: horizon of $\delta^{13}C$ notch b, c: horizon of $\delta^{13}C$ peak c (see Fig. 4 for carbon isotope events), Pf: occurrence horizon of *Pseudaspidoceras flexuosum* (an ammonoid) reported by Hirano (1993), B : FAD of *Marginotruncana schneegansi*. Sample horizons with no numbers show horizons where no planktonic foraminifera occurred. The abundance of planktonic foraminifera is determined by the number of individuals included in each rock sample (240 g). Rare : 1-2, Few : 3-5, Common : 6-9, Abundant: 10-20, Very abundant: >21. See text for planktonic foraminiferal zones.

west England (Jarvis et al., 1988 a, b; Hart and Leary, 1989) and central Poland (Peryt and Wyrwicka, 1993). Then the LAD of *R. cushmani* conjoined with the LAD of *R. greenhornensis* observed in Hokkaido is quite a trustworthy datum plane for interregional correlation. The assemblage just below this datum plane shows the highest diversity during the Late Cretaceous in the Oyubari area. The assemblage is pre-

Table 1. Carbon isotopic composition and total organic content-Oyubari area.

Vertical separation	$\delta^{13}C$	TOC
46.5	-23.98	0.26
41	-23.63	0.58
41	-23.63	0.49
41	-23.77	0.50
40	-23.81	0.35
36	-23.40	0.70
26.2	-23.55	0.76
18.6	-23.38	0.13
11.1	-23.50	0.62
7	-23.22	0.42
4.3	-23.12	0.15
2.25	-23.16	0.26
1.6	-23.26	0.47
1.6	-23.20	0.53
0.01	-23.59	0.13
0.01	-22.34	0.15
-0.01	-22.49	0.63
-0.01	-22.35	0.75
-0.1	-22.25	0.60
-2.1	-23.28	1.17
-2.7	-23.61	1.04
-3.9	-22.86	0.65
-5.6	-22.31	1.02
-6.3	-22.19	0.66
-6.9	-23.61	0.97
-7.7	-23.48	0.87
-9.2	-24.33	0.36
-11	-24.22	0.35
-16.2	-24.30	0.74
-22	-24.61	0.59
-26	-24.28	0.88
-30.8	-24.69	0.75
-36.5	-24.21	0.97
-42.8	-24.34	0.63
-51.4	-24.49	0.55
-58.3	-24.40	0.62
-67.5	-24.55	0.54
-77	-24.11	0.91
-77	-24.08	0.72

dominated by *Praeglobotruncana* spp., with common *Whiteinella* spp. and fewer *Rotalipora* and *Dicarinella*.

B: First appearance datum (FAD) of *Marginotruncana schneegansi*

Age. Early Turonian.

Remarks. The FAD of *Marginotruncana schneegansi* is stratigraphically located just above the "radiolarian sandstone". *Helvetoglobotruncana helvetica*, which has been most commonly used as a datum indicator of the early Turonian, occurred above the FAD of *M. schneegansi* (Hasegawa and Saito, 1993). According to Caron (1985) and Sliter (1989), the concurrent range of these two species is quite limited. Therefore, the FAD of *M. schneegansi* is interpreted as a reliable datum plane in Japan. The assemblage in the interval between the LAD of *R. cushmani* and the FAD of *M. schneegansi* is also highly diversified except for the middle. Between SRN-224 and SRN-236, planktonic foraminifers are poorly diversified and less abundant even in stratigraphically densely collected large samples (500-800 g in each). This low diversity event has been recognized equally in other areas of the world. Above the FAD of *M. schneegansi*, a moderately diversified assemblage is observed.

Carbon isotope stratigraphy

The results of $\delta^{13}C$ analyses of organic matter and TOC of the Oyubari section are listed (Table 1), and stratigraphic fluctuations in $\delta^{13}C$ values are shown in Fig. 4a. A distinct positive anomaly of as much as 2‰ occurs within the C/T boundary interval. The organic matter is largely of terrestrial origin as mentioned later, and thus the fluctuation of the $\delta^{13}C$ reflects changes in the global isotopic composition of the atmospheric CO_2. One of the noteworthy observations is that the $\delta^{13}C$ values show no positive correlation with fluctuation of TOC in disagreement with other well studied overseas C/T boundary sequences (e.g., Schlanger et al., 1987), possibly because of the difference of the provenance and accumulating processes of the organic matter (Fig. 4b).

The isotopic ratio below the initial horizon of the positive anomaly is quite stable being around −24.4‰ and includes the lowest value [−24.69‰] of the section. Then it shows a sharp positive shift toward the highest value of the section to form "spikes" composed of two sharp peaks (peak "a" [−22.19‰] and peak "c" [−22.25‰] in Fig. 4) and an intervening brief notch representing a reversal excursion (notch "b" [−23.61‰] in Fig. 4). These remarkable characters of the $\delta^{13}C$ excursion are well seen between the LAD of *R. cushmani* and the FAD of *M. schneegansi*. Above the upper spike (peak c), the ratio also sharply decreases to −23.6∼−23.1‰, and then becomes nearly stable.

Discussion

(1) Recognition of stratigraphic equivalent of *Whiteinella archaeocretacea* Zone (KS20)

As noted above, the recognition of the *W. archaeocretacea* Zone (KS20), whose base is defined by the LAD of *R. cushmani* and the top by the FAD of *Helvetoglobotruncana helvetica*, is a prerequisite to the study of OAE at C/T boundary time. In the Shirakin River section, the LAD of *R. cushmani* was determined at the same horizon as that of *R. greenhornensis*. However, the FAD of *Helvetoglobotruncana helvetica*, which defines the upper limit of the *W. archaeocretacea* Zone, could not be determined with certainty because of its rare occurrence. Its first occurrence in this section was observed 65 m above the FAD of *M. schneegansi* (Hasegawa and Saito, 1993). Based on Sliter (1989) and Kennedy and Cobban (1991), the present author estimated the stratigraphic position of this horizon to be lower than the FAD of *M. schneegansi* and just below the FAD of *Pseudasp-*

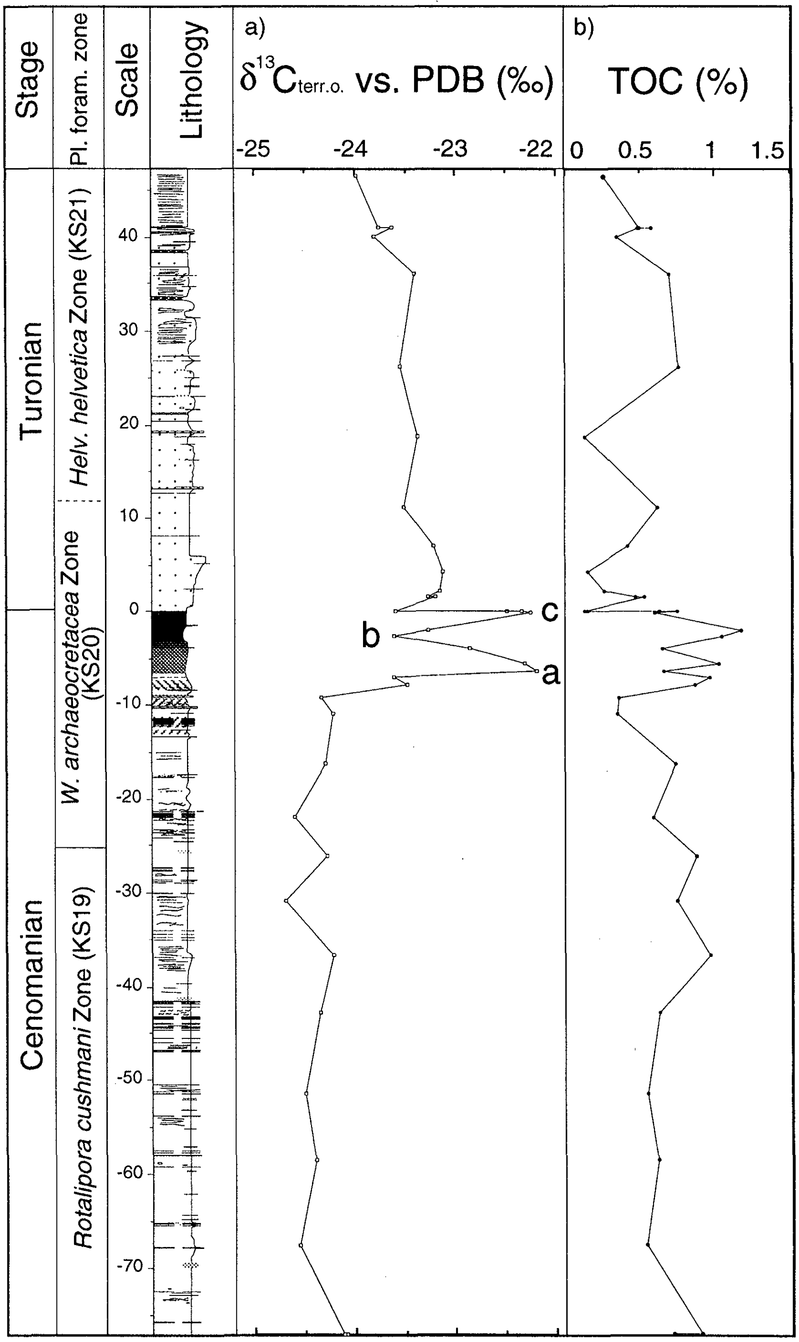

Fig. 4. Carbon isotope profiles and total organic carbon content (TOC) of the Oyubari section across the Cenomanian/Turonian boundary. a) Isotope profiles in organic carbon. Note twin peaks and a brief notch of $\delta^{13}C$ excursion. b) Plots of TOC content obtained during carbon isotope analyses. No TOC increase characterizes the Cenomanian/Turonian boundary interval. Scale in m.

idoceras flexuosum Powell (an ammonoid, whose occurrence reported by Matsumoto et al., 1991; Hirano, 1993; see Fig. 3). Sediments below and above the *W. archaeocretacea* Zone belong to the *Rotalipora cushmani* Zone (KS19) and the *Helvetoglobotruncana helvetica* Zone (KS21) respectively.

(2) **Stratigraphic importance of $\delta^{13}C$ spikes**

Carbon isotope spikes occur within the planktonic foraminiferal *W. archaeocretacea* Zone as mentioned above. Because the origin of organic carbon analyzed here is largely terrestrial (examined by biomarker analyses, Rock Eval pyrolysis and visual observations on selected samples), it is interpreted that the obtained $\delta^{13}C$ curve mainly reflects fluctuations in $\delta^{13}C$ of the atmospheric CO_2.

Well studied C/T boundary sections in the world, including the Pueblo section (e.g. Pratt, 1985; Elder, 1989; Kennedy and Cobban, 1991), Arizona section (Pratt, 1985; Bralower, 1988), South Ferry section (Schlanger et al., 1987), and the Dover section (Jarvis et al., 1988 a, 1988 b; Hart and Leary, 1989; Leary et al., 1989; Corfield et al, 1990; Gale et al., 1993 and Jenkyns et al., 1994), indicate similar $\delta^{13}C$ spikes occurring just below the C/T boundary within the *W. archaeocretacea* Zone. Furthermore, the shape of the $\delta^{13}C$ excursion which consists of two positive peaks and one breaking notch as observed in the Oyubari section shows a remarkable correspondence with that shown in other C/T boundary sections: Pueblo, Arizona (Pratt, 1985), Dover (Gale et al., 1993), and Wüstorf in Germany (Arthur et al., 1988), where high-resolution analyses have been performed in complete sections. This means that all these $\delta^{13}C$ spikes have a same origin and are time-correlative with each other.

(3) Correlation between Oyubari and Pueblo sections

The Pueblo section located in the western part of the Western Interior of the U.S. yields a large quantity of age indicative fossils of different groups (ammonoids, inoceramids, planktonic foraminifera, calcareous nannoplankton) and represents the most important reference section of the C/T boundary of the world. In this section, datum planes of different groups and time slices obtained from carbon isotope stratigraphy can be easily cross-checked. Kennedy and Cobban (1991) conducted an integrated comprehensive zonation of mega- and microfossils and represented precise stratigraphic relationships between zonal boundaries and the carbon isotope curve in the Pueblo section. They drew the C/T boundary at the FAD of *Watinoceras devonense* (=FAD of the genus *Watinoceras*) in that section by precise comparison with many other well-studied C/T boundary sequences. The present author agrees with Kennedy and Cobban's (1991) opinion that the Pueblo section is the best reference section of the C/T boundary in the world. In the Oyubari section, however, *Watinoceras devonense* or any other species belonging to the genus *Watinoceras* have not been recognized. Thus the author draws the C/T boundary just above the upper peak (peak c) position of the $\delta^{13}C$ spike, which can be regarded as time-equivalent to the base of the *W. devonense* Zone by comparison with the Pueblo section (Fig. 5).

The LAD of *R. cushmani* would have been present above the lower peak (peak a) horizon of $\delta^{13}C$ values if the Hokkaido section had mirrored the Pueblo section. Based on a sedimentation rate of about 300 m/m.y. in OY-a (rate calculated from Hasegawa and Saito (1993) based on Sliter's (1989) time scale), a stratigraphic discrepancy of 18 m represents only 0.06 m.y. (Fig. 5), which signifies that datum indicators near the C/T boundary fall within the limits of feasible correlations.

The information on carbon isotopes can be obtained from sediments deposited in various oceanographic settings such as carbonate platforms, oceanic basins, and even fore-arc basins. Therefore, the present author emphasizes that the excursion of carbon isotopes is the most reliable boundary indicator in those sections which rarely yield such biostratigraphic indicative species as *Watinoceras devonense*.

(4) Depositional environment across the Cenomanian/Turonian boundary in Hokkaido

The sedimentary sequence examined for the C/T boundary is subdivided into four lithologic units: OY-a, OY-b, OY-c, and OY-d (Fig. 2). The fact that fine lamination and patchy layers abounding in *Chondrites*-like ichnofossils are occasionally (not fully) observed in unit OY-b suggests the limited activity of benthic organisms, and therefore, low oxygen content of bottom water (e.g. Bromley and Ekdale, 1984; Bromley, 1990). *Chondrites* generally appear as the last (or sole) ichnofossils in many Cretaceous black shales (Bromley and Ekdale, 1984), implying their high tolerance for low oxygen conditions. Layers containing *Chondrites*-like ichnofossils occur more commonly in the uppermost 18 m of unit OY-a, suggesting more oxygen-depleted conditions. Such ichnofossil-condensed layers can be observed in other intervals, but less frequently. Kaiho and Hasegawa (1994) noted two distinct extinction events of benthic foraminifera, associated with low oxygen conditions near the C/T boundary in the same section. The above observations show that the C/T-OAE was a real phenomenon around the northwestern Pacific.

Pratt (1985) calculated the duration of the $\delta^{13}C$ spike about 0.6 m.y. based on Kauffman (1977) and Fischer (1980). This value leads to a sedimentation rate of about 12 m/m.y. for unit OY-b, which is remarkably lower than any other Cretaceous sediments of the Yezo Group (Kaiho and Hasegawa, 1994). This must reflect a dramatic decrease in terrigenous input and/or a temporary shift of the Oyubari sedimentary basin to a more distal setting due to the global rise of sea level during the time of carbon isotope anomaly events and the C/T-OAE.

Conclusion

Based on high-resolution biostratigraphy and carbon isotope stratigraphy of the interval across the Cenomanian/Turonian boundary in the Oyubari area, Hokkaido, Japan, the author came to the following conclusions:

1. Planktonic foraminiferal biostratigraphy gives a reliable clue to determining the Cenomanian/Turonian boundary in Japan. The LAD of *Rotalipora cushmani* and the FAD of *Marginotruncana schneegansi* bracket the C/T boundary. However, the occurrence of *Helvetoglobotruncana helvetica* is too rare in Japan to determine its FAD and to point to the correlative level of the *Whiteinella archaeocretacea* Zone. The upper limit of this zone in Japan is recognizable by using *M. schneegansi* and *Pseudaspidoceras flexuosum*.

2. The Cenomanian/Turonian boundary in the Oyubari section is drawn just above the upper peak of carbon isotope spikes by precise comparison with the Pueblo section. This horizon corresponds to the

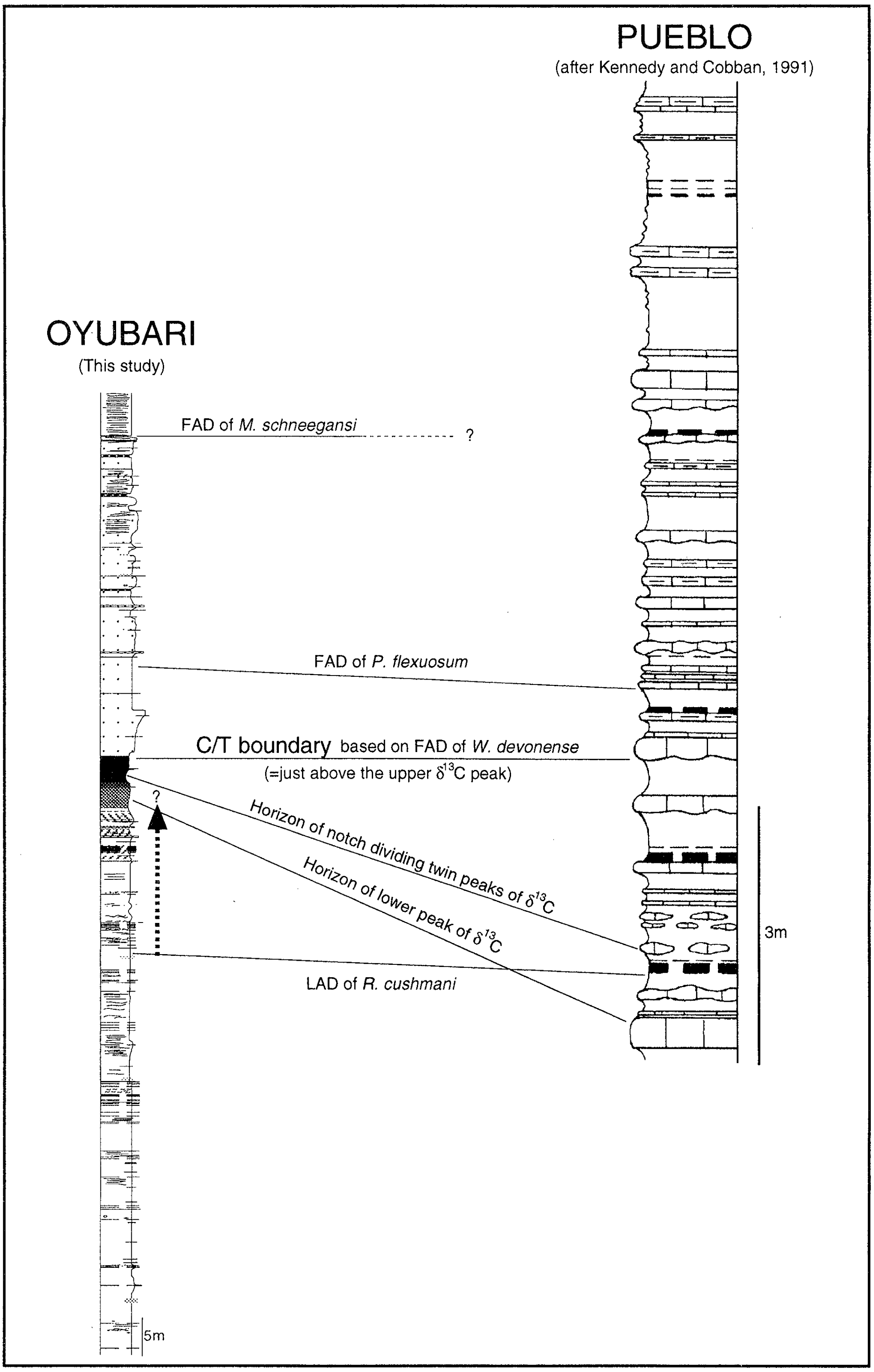

Fig. 5 Correlation of the Cenomanian / Turonian boundary between the Oyubari section, Hokkaido and the Pueblo section, Colorado. LAD of *R. cushmani* should be higher, near the horizon of the lower peak of $\delta^{13}C$ in the Oyubari section. However, this stratigraphic discrepancy is equated with only about 0.06 m.y.

lithologic boundary between OY-b (blackish gray siltstone) and OY-c (Radiolarian sandstone).

3. Carbon isotope stratigraphy is the most powerful tool of determining the C/T boundary where important biostratigraphic indicators are not available.

4. The lithofacies across the Cenomanian/Turonian boundary indicate that dysaerobic conditions, related to C/T-OAE, existed around the northwestern Pacific. Remarkably low sedimentation rates of unit OY-b, just below the C/T boundary, in the Oyubari area suggest a dramatic decrease in terrigenous input and/or the temporary distal migra-

tion of the Oyubari sedimentary basin induced by a global high stand of sea level during the time of carbon isotope anomaly events and the C/T-OAE.

High-resolution biostratigraphy and carbon isotope stratigraphy of the Oyubari section afford enough precision for correlation with well-studied C/T boundary sections of the world, which, in turn, allow us to discuss the Cenomanian/Turonian Oceanic Anoxic Event as a global phenomenon. Therefore, the Oyubari section represents an important regional reference section of the C/T boundary around the northwestern Pacific.

Acknowledgements

The author expresses his deep appreciation to K. Ishizaki of the Tohoku University and H. Hirano of the Waseda University, for their critical readings of the manuscript and T. Saito of the Tohoku University, for his helpful discussions. The author is particularly grateful to H. Wada and N. Niitsuma, both of the Shizuoka University, who assisted the author in the analysis of carbon isotopes at their laboratory. The Rock Eval pyrolysis were kindly performed by W.E. Dean of the U.S. Geological Survey. Observations of the kerogen were kindly done by Y. Suzuki and the biomarker analyses were carried out with the help of M. Yamamoto, both of the Geological Survey of Japan. The author also thanks H. Ando of the Ibaraki University for identifications of megafossils during the course of the fieldwork. Acknowledgements are due to H. Sekiya and his family, and M. Sasaki, for their kind hospitality during the fieldwork.

References

Arthur, M.A., Dean, W.E. and Pratt, L.M., 1988, Geochemical and climatic effects of increased marine organic carbon burial at the Cenomanian/Turonian boundary. *Nature*, **335**, 714-717.

Arthur, M.A., Schlanger, S.O. and Jenkyns, H.C., 1987, The Cenomanian-Turonian oceanic anoxic event, II. Paleoceanographic controls on organic-matter production and preservation. *In* Brooks, J. and Fleet, A.J., eds., *Marine petroleum source rocks, Geological Society Special Publication*. Blackwell Scientific Publications, Oxford, no. 26, 401-420.

Bralower, T.J., 1988, Calcareous nannofossil biostratigraphy and assemblages of the Cenomanian-Turonian boundary interval: Implications for the origin and timing of oceanic anoxia. *Paleoceanogr.*, **3**, 275-316.

Bromley, R.G., 1990, *Trace fossils: Biology and taphonomy*. Unwin Hyman Ltd., London, 280 p.

Bromley, R.G. and Ekdale A.A., 1984, *Chondrites*—A trace fossil indicator of anoxia in sediments. *Science*, **224**, 872-874.

Caron, M., 1985, Cretaceous planktonic foraminifera. *In* Bolli, H.M., Saunders, J.B. and Perch-Nielsen, K., eds., *Plankton Stratigraphy*. Cambridge Univ. Press, Cambridge, 17-86.

Corfield, R.M., Hall, M.A. and Brasier, M.D., 1990, Stable isotope evidence for foraminiferal habitats during the development of the Cenomanian/Turonian oceanic anoxic event. *Geology*, **18**, 175-8.

Eicher, D.L. and Diner, R., 1985, Foraminifera as indicators of water mass in the Cretaceous Greenhorn sea, Western Interior. *In* Pratt, L.M., Kauffman, E.G. and Zelt, F. B., eds., *Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: Evidence of cyclic sedimentary process, Society of Economic Paleontologists and Mineralogists field trip guidebook*. Society of Economic Paleontologists and Mineralogists, Tulsa, **4**, 60-71.

Elder, W.P., 1989, Molluscan extinction pattern across the Cenomanian-Turonian Stage boundary in the western interior of the United States. *Paleobiology*, **15**, 299-320.

Fischer, A.G., 1980, Gilbert-bedding rhythms and geochronology. *Geol. Soc. Amer. Spec. Pap.*, **183**, 93-104.

Gale, A.S., Jenkyns, H.C., Kennedy, W.J. and Corfield, R.M., 1993, Chemostratigraphy versus biostratigraphy: data from around the Cenomanian-Turonian boundary. *Jour. Geol. Soc. London*, **150**, 29-32.

Hanken, N.M., 1979, The use of sodium tetraphenylborate and sodium chloride in the extraction of fossils from shales. *Jour. Paleont.*, **53**, 738-740.

Hart, M.B. and Leary, P.N., 1989, The stratigraphic and palaeogeographic setting of the late Cenomanian 'anoxic' event. *Jour. Geol. Soc. London*, **146**, 305-310.

Hasegawa, T., 1992, Positive excursion of isotopic ratio of organic carbon near the Cenomanian/Turonian boundary in the Upper Cretaceous Yezo Group. *Fossils (Palaeontol. Soc. Japan)*, **53**, 33-37*.

Hasegawa, T. and Saito, T., 1993, Global synchroneity of a positive carbon isotope excursion at the Cenomanian/Turonian boundary: Validation by calcareous microfossil biostratigraphy of the Yezo Group, Hokkaido, Japan. *The Island Arc*, **2** (3), 181-191.

Hayes, J.M., Popp, B.N., Takigiku, R. and Johnson, M.W., 1989, An isotopic study of biogeochemical relationships between carbonates and organic carbon in the Greenhorn Formation. *Geochim. Cosmochim. Acta*, **53**, 2961-2972.

Hilbrecht, H., Arthur, M.A. and Schlanger, S.O., 1986, The Cenomanian-Turonian boundary event: sedimentary, faunal and geochemical criteria developed from stratigraphic studies in NW-Germany. *In* Bhattacharji, S., Friedman, G.M., Neugebauer, H.J. and Seilacher, A., eds. *Lecture Note in Earth Sciences*. Springer-Verlag, Berlin, **8**, 345-351.

Hilbrecht, H., Hubberten, H.-W. and Oberhansli, H., 1992, Biogeography of planktonic foraminifera and regional carbon isotope variations: productivity and water masses in Late Cretaceous Europe. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **92**, 407-421.

Hirano, H., 1993, Phyletic evolution of desmoceratine ammonoids through the Cenomanian-Turonian oceanic anoxic event. *In* House, M.R., ed., *The Ammonoidea: Environment, Ecology, and Evolutionary Change*. Systematics Assoc. Spec. Vol., Clarendon Press, Oxford, no. 47, 267-284.

Hirano, H., 1995, Correlation of the Cenomanian/Turonian boundary between Japan and Western Interior of the United States in relation with oceanic anoxic events *Jour. Geol. Soc. Japan*, **101**, 13-18.

Hirano, H., Nakayama, E. and Hanano, S., 1991, Oceanic anoxic event at the boundary of Cenomanian/Turonian Ages - First report on the Cretaceous Yezo Supergroup, Hokkaido, Japan from the view of biostratigraphy of megafossils, sedimentary-and ichnofacies and geochemistry-. *Bull. Sci. Engineering Res. Lab., Waseda Univ.*, **131**, 52-59.**

Irving, E., North, F.K. and Couillard, R., 1974, Oil, climate

and tectonics. *Canadian Jour. Earth Sci.*, **11**, 1-15.
Jarvis, I., Carson, G. A., Cooper, M. K. E., Hart, M. B., Leary, P. N., Tocher, B. A., Horne, D. and Rosenfeld, A., 1988 a, Microfossil assemblages and the Cenomanian-Turonian (late Cretaceous) oceanic anoxic event. *Cret. Res.*, **9**, 3-103.
Jarvis, I., Carson, G. A., Hart, M. B., Leary, P. N. and Tocher, B. A. 1988 b, The Cenomanian-Turonian (late Cretaceous) anoxic event in SW England: evidence from Hooken Cliffs near Beer, SE Devon. *Newsl. Stratigr.*, **18**, 147-164.
Jenkyns, H. C., Gale, A. S. and Corfield, R. M., 1994, Carbon- and oxygen-isotope stratigraphy of the English Chalk and Italian Scaglia and its palaeoclimatic significance. *Geol. Mag.*, **131**, 1-34.
Kaiho, K. and Hasegawa, T., 1994, End-Cenomanian benthic foraminiferal extinctions and oceanic dysoxic events in the northwestern Pacific Ocean. *Palaeogeogr. Palaeoclimatol. Paleoecol.*, **111**, 29-43.
Kauffman, E. G., 1977, Geological and biological overview: Western Interior Basin. *The Mountain Geologist*, **14**, 75-99.
Kennedy, W. J. and Cobban, W. A., 1991, Stratigraphy and interregional correlation of the Cenomanian-Turonian transition in the Western Interior of the United States near Pueblo, Colorado, a potential stratotype for the base of Turonian stage. *Newsl. Stratigr.*, **24**, 1-33.
Leary, P. N., Carson, G. A., Cooper, M. K. E., Hart, M. B., Horne, D., Jarvis, I., Rosenfeld, A. and Tocher, B. A., 1989, The biotic response to the late Cenomanian oceanic anoxic event; integrated evidence from Dover, SE England. *Jour. Geol. Soc. London*, **146**, 311-317.
Leckie, R. M., 1985, Foraminifera of the Cenomanian-Turonian boundary interval, Greenhorn Formation, Rock Canyon Anticline, Pueblo, Colorado. *In* Pratt, L. M., Kauffman, E. G. and Zelt, F. B., eds. *Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: Evidence of cyclic sedimentary process, Society of Economic Paleontologists and Mineralogists field trip guidebook.* Society of Economic Paleontologists and Mineralogists, Tulsa, **4**, 139-150.
Matsumoto, T., Noda, M. and Maiya, S., 1991, Towards an integrated ammonoid-, inoceramid- and foraminiferal biostratigraphy of the Cenomanian and Turonian (Cretaceous) in Hokkaido. *Jour. Geogr.*, **100**, 378-398**.
Motoyama, I., Fujiwara, O., Kaiho, K. and Murota, T., 1991, Lithostratigraphy and calcareous microfossil biostratigraphy of the Cretaceous strata in the Oyubari area, Hokkaido, Japan. *Jour. Geol. Soc. Japan*, **97**, 507-527.**
Okada, H., 1979, Geology of Hokkaido and plate tectonics. *Earth (Chikyu)*, **1**, 869-877.*
Okada, H., 1983, Collision orogenesis and sedimentation in Hokkaido, Japan. *In* Hashimoto, M. and Uyeda, S., eds., *Accretion tectonics in the circum-Pacific regions*. Terra Scientific Publishing Company, Tokyo, 91-105.
Peryt, D. and Wyrwicka, K., 1993, The Cenomanian/Turonian boundary event in Central Poland. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **104**, 185-197.
Pratt, L. M., 1985, Isotopic studies of organic matter and carbonate in rocks of the Greenhorn marine cycle. *In* Pratt, L. M., Kauffman, E. G. and Zelt, F. B., eds. *Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: Evidence of cyclic sedimentary process, Society of Economic Paleontologists and Mineralogists field trip guidebook*. Society of Economic Paleontologists and Mineralogists, Tulsa, **4**, 38-48.
Schlanger, S. O., Arthur, M. A., Jenkyns, H. C. and Scholle, P. A., 1987, The Cenomanian-Turonian oceanic anoxic event, I. Stratigraphy and distribution of organic carbon-rich beds and the marine δ^{13}C excursion. *In* Brooks, J. and Fleet, A. J., eds., *Marine petroleum source rocks, Geological Society Special Publication*. Blackwell Scientific Publications, Oxford, no. 26, 371-399.
Schlanger, S. O. and Jenkyns, H. C., 1976, Cretaceous oceanic anoxic events: Causes and consequences. *Geol. Mijnbouw*, **55**, 179-184.
Scholle, P. A. and Arthur, M. A., 1980, Carbon Isotope fluctuations in Cretaceous pelagic limestones: Potential stratigraphic and petroleum exploration tool. *Bull. Amer. Assoc. Petrol. Geol.*, **64**, 67-87.
Shahin, A., 1991, Cenomanian-Turonian ostracods from Gebel Nezzazat, southwestern Sinai, Egypt, with observations on δ^{13}C values and the Cenomanian/Turonian boundary. *Jour. Micropalaeontol.*, **10**, 133-150.
Sliter, W. V., 1989, Biostratigraphic zonation for Cretaceous planktonic foraminifers examined in thin section. *Jour. Foram. Res.*, **19**, 1-19.
Uličný, D., Hladíová J. and Hradecká L., 1993, Record of sea-level changes, oxygen depletion and δ^{13}C anomaly across the Cenomanian/Turonian boundary, Bohemian Cretaceous Basin. *Cret. Res.*, **14**, 211-234.
* : in Japnese
** : in Japanese with English abstract

(要　旨)

Hasegawa, T., 1995, Correlation of the Cenomanian/Turonian boundary between Japan and Western Interior of the United States. *Jour. Geol. Soc. Japan*, 101, 2-12. (長谷川卓, 1995, 日本のセノマニアン/チューロニアン階境界の北米ウエスタンインテリアへの対比. 地質雑, **101**, 2-12.)

生層序と炭素同位体比（δ^{13}C）層序を統合し，日本のCenomanian/Turonian（C/T）境界を北米ウエスタンインテリアの同境界に詳細に対比した．北海道大夕張セクションのC/T境界は浮遊性有孔虫の2枚の国際的年代面に挟まれる．アンモナイト層序との総合的考察からKS20帯相当の層位範囲が認識可能である．C/T境界はウエスタンインテリアにおける*Watinoceras devonense*の初出現層準相当層準として，2つのピークを持つδ^{13}C曲線の上位側ピークの直上に対比される．δ^{13}C層序はC/T境界を詳細に決定する上で重要な対比手段となる．大夕張セクションC/T境界付近の岩相は海洋無酸素事変が北西太平洋域にも影響を与えたことを示し，境界直下における著しい堆積速度の低下は海水準上昇と関連する陸源物質供給量の著しい減少を示唆する．大夕張セクションは研究先進地のC/T境界との対比上，十分な層位学的分解能を持っており，北西太平洋域の重要なリファレンスセクションである．