Carbon-isotope stratigraphy and its chronostratigraphic significance for the Cretaceous Yezo Group, Kotanbetsu area, Hokkaido, Japan

Paleontological Research, vol. 4, no. 2, pp. 95-106, June 30, 2000

Carbon-isotope stratigraphy and its chronostratigraphic significance for the Cretaceous Yezo Group, Kotanbetsu area, Hokkaido, Japan

TAKASHI HASEGAWA[1] **and TAKAYUKI HATSUGAI**[2]

[1] *Division of Global Environmental Sciences and Engineering, Graduate School of Natural Science and Engineering, Kanazawa University, Kakuma, Kanazawa, 920-1192, Japan; Department of Earth Sciences, Faculty of Science, Kanazawa University, Kakuma, Kanazawa 920-1192 Japan (jh7ujr@kenroku.kanazawa-u.ac.jp)*

[2] *Geoplanning, Ichinazaka, Izumi-ku, Sendai 981-3117 Japan*

Received 14 July 1999; Revised manuscript accepted 21 January 2000

Abstract. A positive carbon isotopic excursion across the Cenomanian/Turonian boundary in the Kotanbetsu area, Hokkaido, Japan provides accurate positioning of the boundary. A microscopic study based on organic petrology reveals that the organic matter included in mudstones of the Kotanbetsu River section is exclusively terrestrial. The results of stratigraphic time-series analysis of stable carbon isotopes from these mudstone samples can be translated as representing an average of a terrestrial plant community signal. The isotopic fluctuation through this time interval records information on the global ocean-atmosphere system. Two internationally recognized events characterize the uppermost Cenomanian through middle Turonian. On the basis of this study the Cenomanian/Turonian boundary can be recognized within a stratigraphic range of ~14 meters. This horizon of the boundary is concordant with that from biostratigraphy (ammonoids, inoceramids and planktonic foraminifers). Above the middle Turonian strata, the isotopic pattern supports the biochronology of planktonic foraminifers rather than that of inoceramids.

Key words: biostratigraphy, carbon isotope, Cenomanian/Turonian boundary, Coniacian, correlation, Cretaceous, Kotanbetsu, terrestrial organic matter, Yezo Group

Introduction

International chronostratigraphic correlation of the Cretaceous Yezo Group, especially the Cenomanian through Turonian has been extensively discussed in this decade mainly with reference to the Oyubari area and by the use of megafossils (e.g. Nishida *et al.*, 1993a; Hirano, 1995) and planktonic foraminifers (Motoyama *et al.*, 1991; Hasegawa, 1995, 1997; Takashima *et al.*, 1997). On the other hand, carbon-isotope stratigraphy through the Cretaceous was first shown by Sholle and Arthur (1980) to be a potential correlational tool in the Tethyian region. After this pioneering study, many carbon-isotopic studies using marine carbonate and marine organic matter across the Cenomanian/Turonian (C/T) boundary were performed for detailed correlation at the same resolution as biostratigraphy (e.g. Pratt, 1985; Gale *et al.*, 1993) . In Japan, Hasegawa (1995, 1997) analyzed the stable carbon-isotope composition of terrestrial organic carbon from the Oyubari section and discussed its isotope stratigraphy against the control of the planktonic foraminiferal biostratigraphy. Hasegawa (1995) identified the well-known positive isotopic event caused by an Oceanic Anoxic Event (Schlanger and Jenkyns, 1976) at the C/T boundary and supported the idea that it was a global signal (e.g. Gale *et al.*, 1993; Jenkyns *et al.*, 1994). This was subsequently compared with the carbon-isotope curve derived from marine carbonate carbon established in southern England (Jenkyns *et al.*, 1994) and Italy (Corfield, 1995; Jenkyns *et al.*, 1994). This led to the identification of three isotopic events as global markers for correlation (Hasegawa, 1997). Even though carbon-isotope stratigraphy can be a powerful tool for international correlation (Hasegawa, 1997, Beerling and Jolley, 1998; Gröcke *et al.*, 1999), it has not been employed for detailed stratigraphic positioning of the C/T boundary in other areas of Hokkaido Island except for a study in the Tappu area by Hasegawa and Saito (1993). Nishida *et al.* (1992, 1993b) performed detailed biostratigraphy of megafossils and foraminifers along the Kotanbetsu River in the Kotanbetsu area, Hokkaido focusing on the positioning of the C/T boundary. Hatsugai *et al.* (1999) also discussed detailed planktonic foraminiferal biostratigraphy using internationally

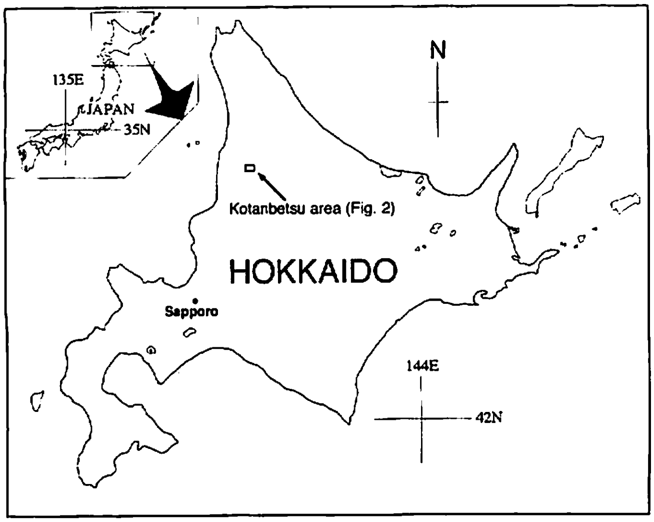

Figure 1. Index map showing the locality of the Kotanbetsu area.

recognized species along the same section.

The purpose of this study is to show how carbon-isotope stratigraphy is a powerful and important tool for correlation. The Kotanbetsu River section was selected as the best section to demonstrate the applicability of carbon-isotope stratigraphy not only for intra-regional but also for inter-regional correlation of the Yezo Group.

Geological setting

The Yezo Group exposed along the Kotanbetsu River in the Kotanbetsu area, Hokkaido, Japan (Figure 1) is interpreted as a forearc basin (Okada, 1979, 1983). The sequence of the Cenomanian through Turonian is represented, in ascending order, by six lithologic units, namely Mf-h, Mi, Mj-o, Ua-b, Uc-e and Uf-g which were originally defined by Igi *et al.* (1958). These lithologic units strike meridionally and dip westward at an angle of ~60°. They are nearly continuously exposed and are composed dominantly of dark gray mudstone with either occasional intercalations of sandstone layers of less than 30 cm in thickness or alternating layers of turbiditic sandstone and siltstone. Frequency of intercalating sandstone layers increases in the Units Mi and Ua-b.

The averaged rate of sedimentation for this succession is inferred as approximately 200 m/m.y. based on planktonic foraminiferal biostratigraphy (Hatsugai *et al.*, 1999) using the first occurrence of *Helvetoglobotruncana helvetica* and the first occurrence of the genus *Archaeoglobigerina* and time scale of Gradstein *et al.* (1995). This is more than ten times as fast as the English Chalk section (Jenkyns *et al.*, 1994).

Based on four K-Ar ages from four different bentonite layers encompassing the Unit Mi (Shibata and Miyata, 1978; Shibata *et al.*, 1997), Shibata *et al.* (1997) concluded that the K-Ar age of C/T boundary in the Tappu area was 93.1 $\pm 1.2 (1\sigma)$. Hirano *et al.* (1997) also obtained similar K-Ar ages from the Tappu and Oyubari sections.

Materials and methodology

Samples were collected along the Kotanbetsu River in the Kotanbetsu area (Figures 1, 2). All samples subjected to isotopic analysis were obtained from the pelagic mudstone unit, whereas turbidite units were ignored. The stratigraphic intervals for samples are between 20–100 m along the section (Figure 2). Powdered mudstones were treated with a 5N solution of HCl for 12 hours to remove carbonate minerals. Each acid-processed sample was then baked in an oven at 850°C for 8 hours in a tube under vacuum together with CuO to convert organic carbon into CO_2 gas. After purification of CO_2 gas on a cryogenic vacuum line, carbon-isotope analyses were performed with a Finnigan MAT

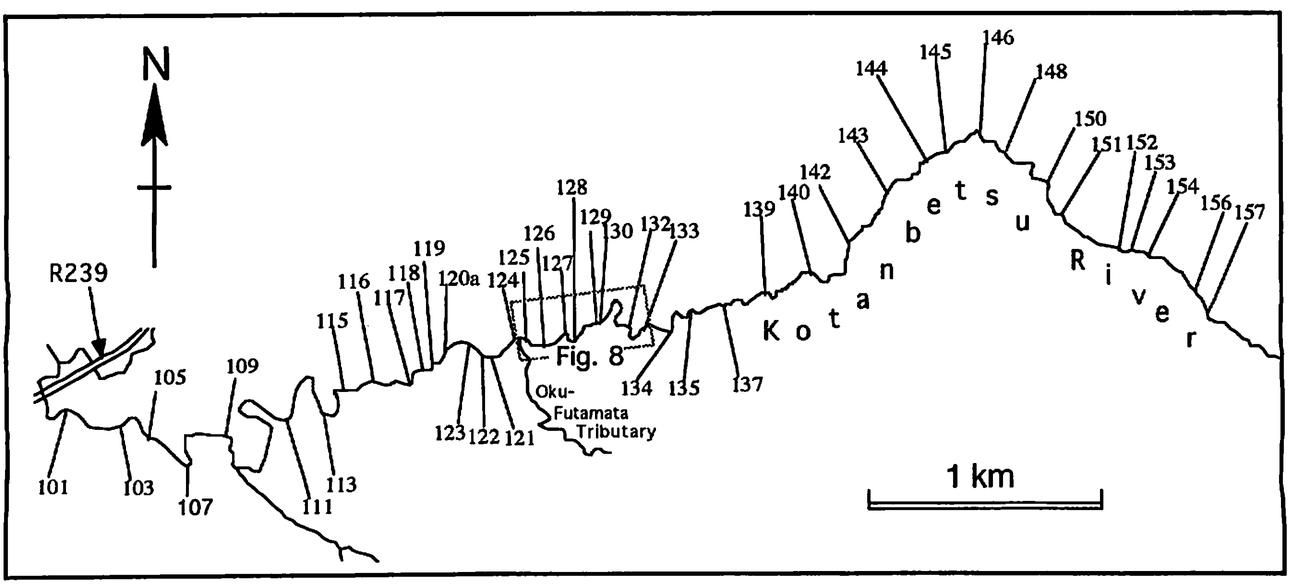

Figure 2. Map showing sampling localities in the Kotanbetsu area.

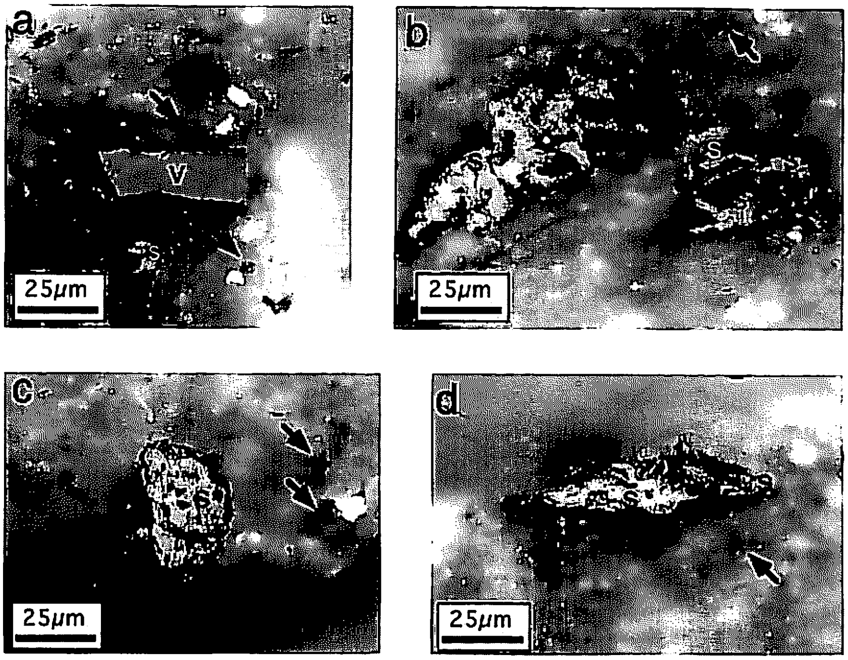

Figure 3. Kerogen observed under microscope with reflected light. Note that most structured particles are identified as semifusinite and vitrinite, which are terrestrial in origin (see text for details). Semifusinites which have obvious lignitic cellular structure in selected samples document vascular plants as their origin. Examples of indeterminable vitrodetrinites and inertodetrinites are also indicated by arrows. **a**. Vitrinite (*v*) with smaller particles of semifusinite (*s*) from KOT-148. **b**. Semifusinites (*s*) with obvious cellular structure from KOT-130. **c**. Semifusinites (*s*) with obvious cellular structure from KOT-129. **d**. Semifusinites (*s*) with obvious cellular structure from KOT-101.

delta-E mass spectrometer at Indiana University. The results reported herein are obtained using reference CO_2 as a working standard calibrated by NBS standards. Carbon-isotope results are expressed in the standard delta notation with respect to the PDB standard, where $\delta^{13}C = \{(^{13}C/^{12}C)_{sample}/(^{13}C/^{12}C)_{standard} - 1\} \times 1000$, with a reproducibility of analyses of $\pm$ 0.1‰. The isotopic values were checked by an isotopically known laboratory standard (triphenylamine). Total organic carbon (TOC) content of whole rock was estimated by CO_2 gas volume with a Baratron pressure transducer.

For visual observation of kerogen, crushed mudstone was made into polished blocks following the standard preparation procedure (Bustin *et al.*, 1983). Polished pellets were examined using a MPV-2 microscope to identify organic particles.

Results

Visual observation of kerogen

Kerogen was analyzed on selected samples optically under reflected light and in fluorescent mode. Microscopic observation was carried out on seven selected samples (KOT-101, 113, 126, 129, 130, 148 and 152) as representative horizons of stratigraphically-important isotopic events (see below) through the Kotanbetsu River section. Kerogen from all selected samples is dominated by semifusinite and vitrinite with a minor amount of particulate vitrodetrinite and inertodetrinite (Figure 3a-d) derived exclusively from cellular lignins of terrestrial vascular plants. Preservation of cell structure in semifusinite indicates its origin as woody plant matter. Organic matter of other than terrestrial woody plant origin (alginite and liptinite) was rarely ($\ll$1%) detected during microscopic examination. Sporinites, resinites and bitumen were the only fluorescent organic matters in the samples. This fluorescent property can be explained by the absence of marine organic matter. Some nonoxidized vitrinite might have incorporated marine organic molecules through the process of condensation during early stage of diagenesis. But in such a case, marine alginite and/or liptinite should have been more conspicuous components under microscope. The result from visual observation of kerogens strongly suggests no significant incorporation of marine organic materials in the kerogens.

Carbon isotopes and total organic carbon (TOC)

A stratigraphic profile with carbon isotope ratios ($\delta^{13}C$) for terrestrial organic matter from the Kotanbetsu area is shown

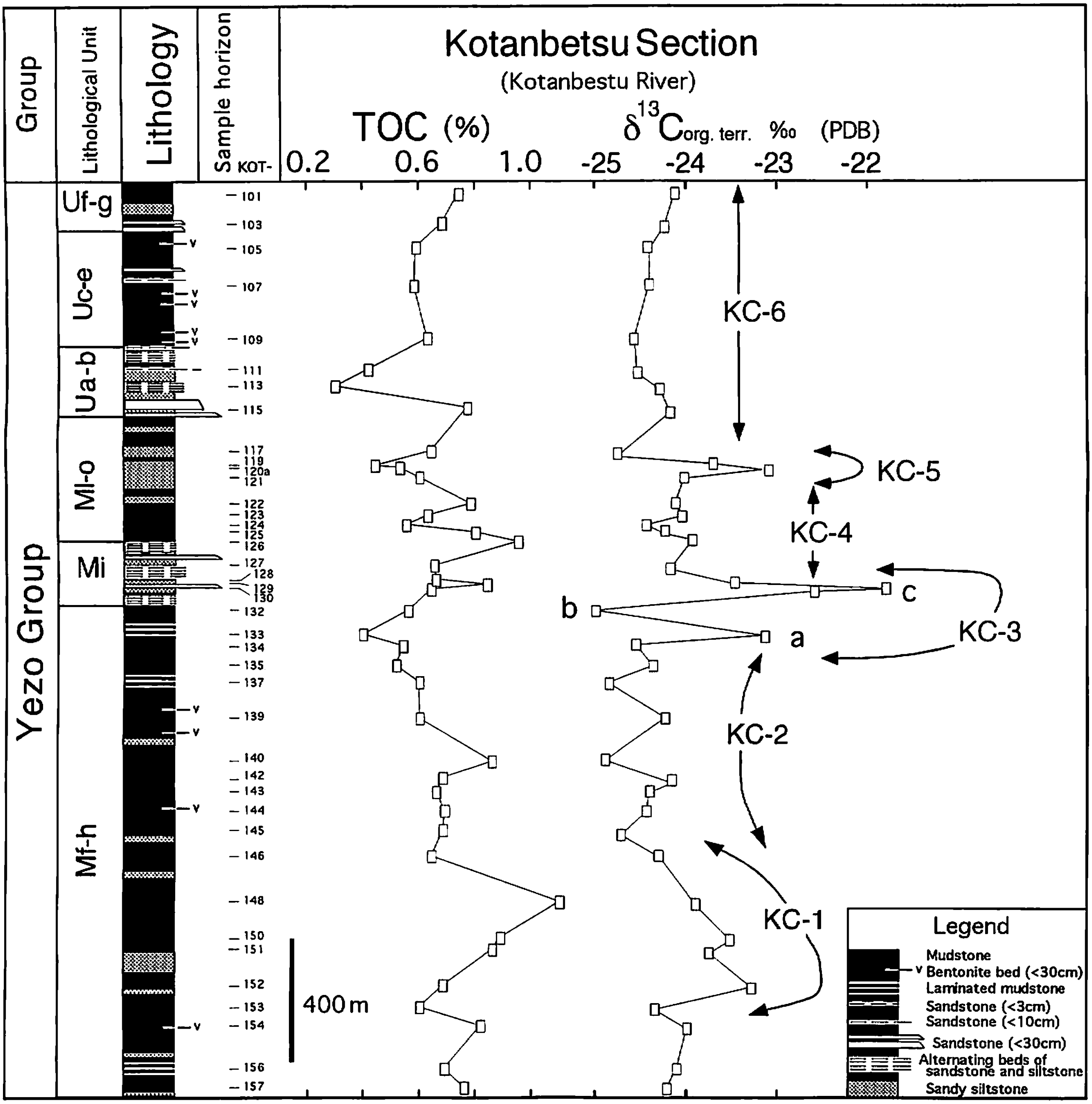

Figure 4. Carbon isotope profile of terrestrial organic matter in the Kotanbetsu River section, Hokkaido, Japan. Labels KC-1 to KC-6 indicate different events on the $\delta^{13}C$ curve discussed in the text. KC-3 is composed of three subevents namely KC-3a, KC-3b and KC-3c. Note a sharp peak of $\delta^{13}C$ values (KC-3c) at the middle of the section and a stepwise negative shift through KC-3c~KC-6.

in Figure 4. The profile is divided into six "events" by characteristics in the isotopic fluctuation and are expressed by a KC-numerical notation (designating Kotanbetsu carbon isotopic event):

KC-1: Characterized by a positive isotopic event (-23.3 ‰) observed in the lower part of Unit Mf-h. Above the peak at KOT-152, $\delta^{13}C$ shows a gradual negative shift toward -24.7‰ at KOT-145.

KC-2: Segment of relatively negative values fluctuating between -24.2 and -24.9‰ through the upper Unit Mf-h.

KC-3: Characterized by two positive excursions. At the top of Unit Mf-h, $\delta^{13}C$ reaches -23.1‰ at the horizon KOT-133 (KC-3a: designated as "a" in Figure 4). However, the value rebounds down to -25.0‰ at KOT-132 just above KOT-133 (KC-3b: designated as "b"). The most prominent feature is a sharp positive excursion of ~2.5~3‰ which occurs in the middle Unit Mi at the horizon KOT-130 and 129 (KC-3c: designated as "c").

Table 1. Carbon isotopic ratio and TOC along the Kotanbetsu section. The Cenomanian/Turonian boundary is expected just above KOT-129 (see text for details).

Sample	$\delta^{13}C$ org. terr. ‰ (PDB)	TOC (%)
KOT-101	-24.1	0.74
KOT-103	-24.2	0.68
KOT-105	-24.4	0.59
KOT-107	-24.4	0.58
KOT-109	-24.6	0.63
KOT-111	-24.5	0.42
KOT-113	-24.3	0.30
KOT-115	-24.2	0.77
KOT-117	-24.8	0.64
KOT-119	-23.7	0.44
KOT-120a	-23.1	0.53
KOT-121	-24.0	0.60
KOT-122	-24.1	0.78
KOT-123	-24.1	0.63
KOT-124	-24.4	0.55
KOT-125	-24.2	0.80
KOT-126	-23.9	0.95
KOT-127	-24.2	0.65
KOT-128	-23.5	0.66
KOT-129	-21.8	0.84
KOT-130	-22.6	0.64
KOT-132	-25.0	0.56
KOT-133	-23.1	0.40
KOT-134	-24.6	0.54
KOT-135	-24.4	0.52
KOT-137	-24.9	0.60
KOT-139	-24.2	0.60
KOT-140	-24.9	0.86
KOT-142	-24.2	0.68
KOT-143	-24.4	0.66
KOT-144	-24.4	0.69
KOT-145	-24.7	0.68
KOT-146	-24.3	0.64
KOT-148	-23.9	1.10
KOT-150	-23.5	0.89
KOT-151	-23.7	0.86
KOT-152	-23.3	0.68
KOT-153	-24.4	0.60
KOT-154	-24.0	0.82
KOT-156	-24.1	0.69
KOT-157	-24.2	0.76

KC-4: Relatively stable isotopic ratios above KC-3c excursion. $\delta^{13}C$ drops rapidly above KOT-129 and stabilizes around -24.0‰ between the middle Unit Mi and the middle Unit Ml-o.

KC-5: Characterized by a minor positive excursion of ~1‰ at KOT-120 followed by a negative shift back to KC-6.

KC-6: Characterized by stable isotopic ratio between -24.8 and -24.1‰. The most negative value is recorded in the lowest part of this interval (-24.8‰).

Values of total organic carbon content (TOC) range between 0.2 and 1.0% with no notable fluctuation in the Kotanbetsu River section.

Discussion

No organic-rich layer across the C/T boundary

In spite of fine parallel laminations in the Mi Unit indicating limited benthic activity and dysaerobia, no TOC spike (extraordinary accumulation of organic matter) at the C/T boundary (=peak horizon of $\delta^{13}C$; see following discussion) was observed (Figure 4) contrary to the case of many carbonate sections around the world (e.g. Schlanger *et al.*, 1987). This is caused by the depositional environment of the Kotanbetsu section, which was far different from that of those sections with an accumulation of organic matter at the boundary. The sedimentation rate of the Kotanbetsu section is about 200 m/m.y. and substantially all materials including organic matter are terrestrial in origin. Most of the organic matter in the mudstone samples are very residual lignitic material. Therefore, the concentration of organic matter across the section was controlled predominantly by the content of organic matter in terrigenous debris and never affected by oceanographic events.

Factors controlling carbon-isotope fluctuations

Kerogen from two samples representing the KC-3 event were optically examined and the results were compared with those from KC-4, KC-6 and KC-1. All visually checked samples are dominated by semifusinite and vitrinite. This means organic matter in the samples is derived from nothing but lignins of terrestrial woody C_3 plants which are exclusively resistant to oxidation. Rare occurrences of small amounts of alginite, sporinite, resinite, and bitumen should not affect the following discussion dealing with differences larger than 0.1‰ of carbon isotopic fluctuation. Since these samples were selected from the intervals of major isotopic events of stratigraphic importance, the isotopic fluctuation of terrestrial organic carbon obtained in this study cannot be ascribed to the composition of kerogens. That the lithological evidence shows no significant change of depositional environment also suggests that the composition of kerogens is a feature of the sedimentary rock through the Kotanbetsu River section.

In Figure 5, $\delta^{13}C$ values are plotted against TOC with no systematic relation revealed between them. This indicates that the $\delta^{13}C$ values are independent of mechanisms of supply and deposition of organic matter; organic matter derived from lignins of terrestrial woody C_3 plants has not been carbon-isotopically biased by these mechanisms and has essentially kept its original isotopic signature. As mentioned above, the isotopic fluctuation of organic carbon in the Kotanbetsu River section can be interpreted as representing the average biomass of woody plants in the provenance area. The isotopic fluctuation of global atmospheric CO_2 is

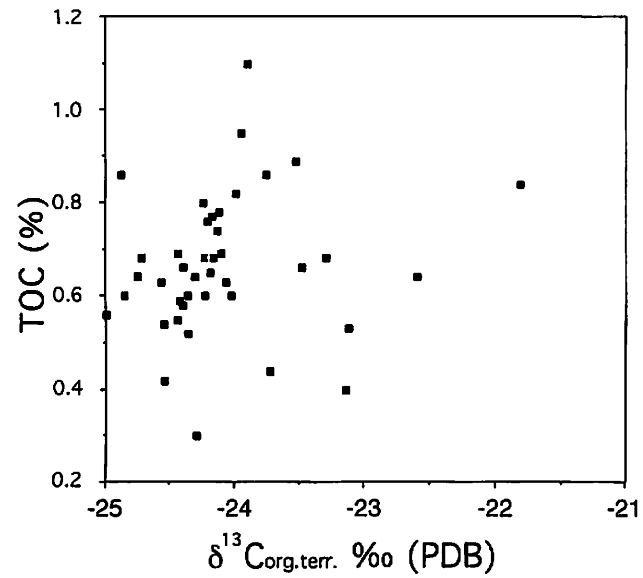

Figure 5. Carbon-isotope ratios of terrestrial organic carbon (δ^{13}Corg.terr.) against total organic carbon content (TOC; dry weight %) along the Kotanbetsu River section.

interpreted to be a primary factor responsible for δ^{13}C fluctuation of the terrestrial biomass as discussed in Hasegawa (1997), Beerling and Jolley (1998) and Gröcke *et al.* (1999). If this assumption is accepted and other environmental and/or ecological factors are negligible, δ^{13}C fluctuation of terrestrial organic matter is essentially parallel to that of carbonates. Arthur *et al.* (1988) ascribed a discrepancy of amplitude observed between marine carbonate and marine organic carbon across the C/T boundary to a marked decrease of partial pressure of CO_2 in the ocean-atmosphere system. Gröcke *et al.* (1999) discussed the possibility that the partial pressure of atmospheric CO_2 may have also affected carbon-isotopic fluctuation of fossil woods as a secondary factor in conjunction with the isotopic composition of CO_2. If δ^{13}C of atmospheric CO_2 during the deposition of the studied sequence exclusively reflects proportion of fluxes of organic and inorganic carbons into/out of the ocean-atmospheric reservoir, changes of partial pressure of atmospheric CO_2 should lead to exaggeration of the δ^{13}C events in terrestrial and marine organic matter against marine carbonates (see also discussion of Popp, *et al.*, 1989; Gröcke *et al.*, 1999). Therefore, even if the δ^{13}C curve obtained in this study was affected by the partial pressure of atmospheric CO_2, it is still plausible to correlate it with δ^{13}C curves derived from marine carbonates as well as those from terrestrial organic matter of other Hokkaido sections. Kuypers *et al.* (1999) discussed a turnover from a C_3 plant community to a C_4-dominated community, which had been derived from a decrease of partial pressure of CO_2, as a factor in an exaggerated δ^{13}C excursion of n-alkanes. This factor could only exaggerate a positive excursion of δ^{13}C. The kerogens examined under the microscope show predominance of lignitic macerals in both samples from the C/T boundary excursion (KOT-129 and 130) and other horizons. This indicates no turnover of C_3/C_4 plant communities was involved with the δ^{13}C excursion at the C/T boundary shown in the present study. Shift of atmospheric humidity and taxonomic turnover in the provenance of organic matter may have affected carbon isotopic fractionation during photosynthesis of the biomass (O'Leary, 1993). These factors could result in some local, regional or sometimes global isotopic disturbance and should be considered during carbon-isotope correlation. Nguyen Tu *et al.* (1999) proposed that environmental stress derived from salinity had affected significantly the carbon isotopic composition of fossil terrestrial plants from Cenomanian strata. However, the organic matter treated in this study is interpreted to have been transported from wide and distant provenance. It should be highly mixed enough to eliminate such a local salt stress discussed in Nguyen Tu *et al.* (1999).

Significance of carbon isotope stratigraphy as a tool for correlation

The Kotanbetsu River section has been subdivided into stages by biostratigraphic studies of megafossils (Nishida *et al.*, 1992, 1993b) and planktonic foraminifera (Nishida *et al.*, 1992; Hatsugai *et al.*, 1999) (Figure 6). No biochronological study of megafossils is available above the middle Turonian along the Kotanbetsu River section. However, Sekine *et al.* (1985) studied the Tappu area next to the Kotanbetsu area and that study was adopted to draw boundaries above the middle Turonian. Planktonic foraminiferal biostratigraphy (Hatsugai *et al.*, 1999) indicates no appreciable diachroneity in lithologies between the Tappu and Kotanbetsu areas.

As Hatsugai *et al.* (1999) noted, stages defined by both megafossils and planktonic foraminifers correspond well with each other below the upper part of Unit Mj-o (Figure 6). There are two conspicuous isotope events (KC-3 and KC-4) in the Kotanbetsu River section which can be correlated internationally (Figure 7). KC-1 is regionally correlated to H1 of the Oyubari section (Figure 7) by its shape and amplitude of isotopic fluctuations as well as by biostratigraphic position (within planktonic foraminiferal *Rotalipora cushmani* Zone). Though this event could be globally correlated, however, it is not conclusive because of low chronological resolution across this event in Japan. KC-2 is the common event of three Hokkaido sections (Oyubari, Tappu and Kotanbetsu; Figure 7) and equivalent to H2 in the Oyubari area (Hasegawa, 1997). This negative isotopic feature of KC-2/H2 cannot be observed in European sequences (Jenkyns *et al.*, 1994). Shift of atmospheric humidity and/or taxonomic turnover in the provenance of organic matter may explain this event, which is specific to terrestrial organic carbon (see O'Leary, 1993). KC-3 is the most prominent feature of the Kotanbetsu River section and is regarded to be the best worldwide stratigraphic marker across the C/T boundary in relation to the Oceanic Anoxic Event II (Schlanger and Jenkyns, 1976; Arthur *et al.*, 1988). KC-3 is composed of a double peak and a trough between (Figure 4). These subevents in KC-3, namely KC-3a, b and c ("a", "b" and "c" in Figure 4) can be correlated with isotopic subevents a, b and c, respectively at the C/T boundary of the Oyubari (Hasegawa, 1995) and Tappu areas (Hasegawa, 1994), al-

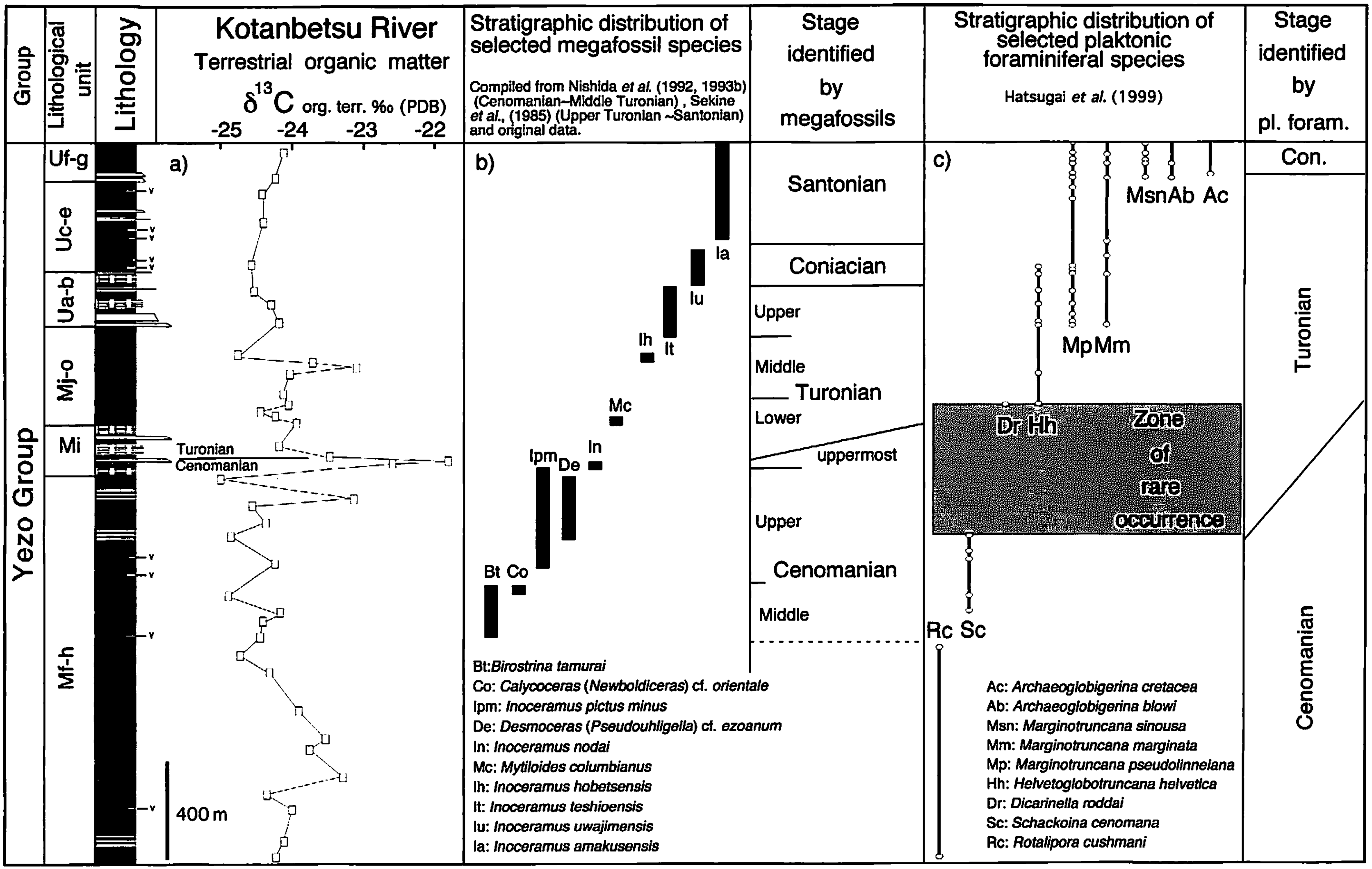

Figure 6. Comparison of carbon isotope-stratigraphy and biostratigraphy along the Kotanbetsu River section. a) Carbon isotope stratigraphy. The Cenomanian/Turonian boundary expected from the isotope stratigraphy is drawn just above the isotopic "spike". b) Stratigraphic distribution of age indicative of macrofossil species. Data source: Nishida *et al.* (1992, 1993b) and original data of this study for the Cenomanian through Middle Turonian, Sekine *et al.* (1985) for strata above the Middle Turonian. c) Stratigraphic distribution of age indicative of planktonic foraminiferal species. Zone of rare occurrence is observed in the middle of this section encompassing the prominent isotopic event (KC-3). Cenomanian/Turonian boundary is limited between the last occurrence of *Schackoina cenomana* and the first occurrence of *Helvetoglobotruncana helvetica*. Coniacian is identified at the top of the section. See Figire 3 for legend.

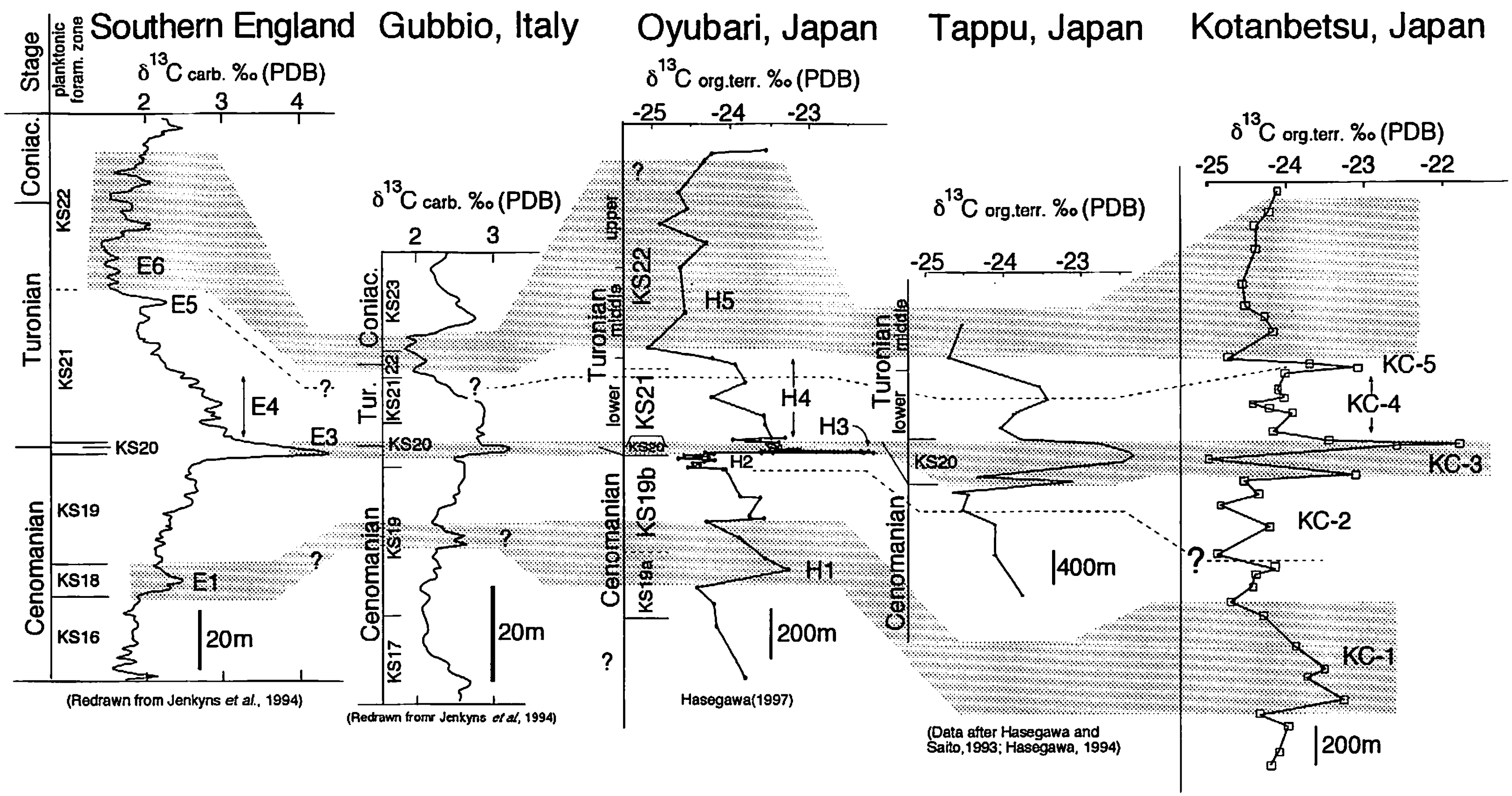

Figure 7. Comparison of carbon-isotope profiles for carbonate (southern England and Gubbio, Italy) and terrestrial organic matter (Oyubari, Tappu and Kotanbetsu sections, Japan). Event notations for southern England and Oyubari are given by Hasegawa (1997). Note the good correlation between the three carbon-isotope events (spike at the C/T boundary, shoulder at the lower Turonian and a minimum at middle or upper Turonian). Biochronology for planktonic foraminifera is based on Caron (1985), Robaszynski and Caron (1979) and Sliter (1989) and for megafossils is based on Toshimitsu *et al.* (1995). $\delta^{13}C_{carb}$: carbon-isotope ratio of carbonate; $\delta^{13}C_{org.terr.}$: carbon-isotope ratio of terrestrial organic matter.

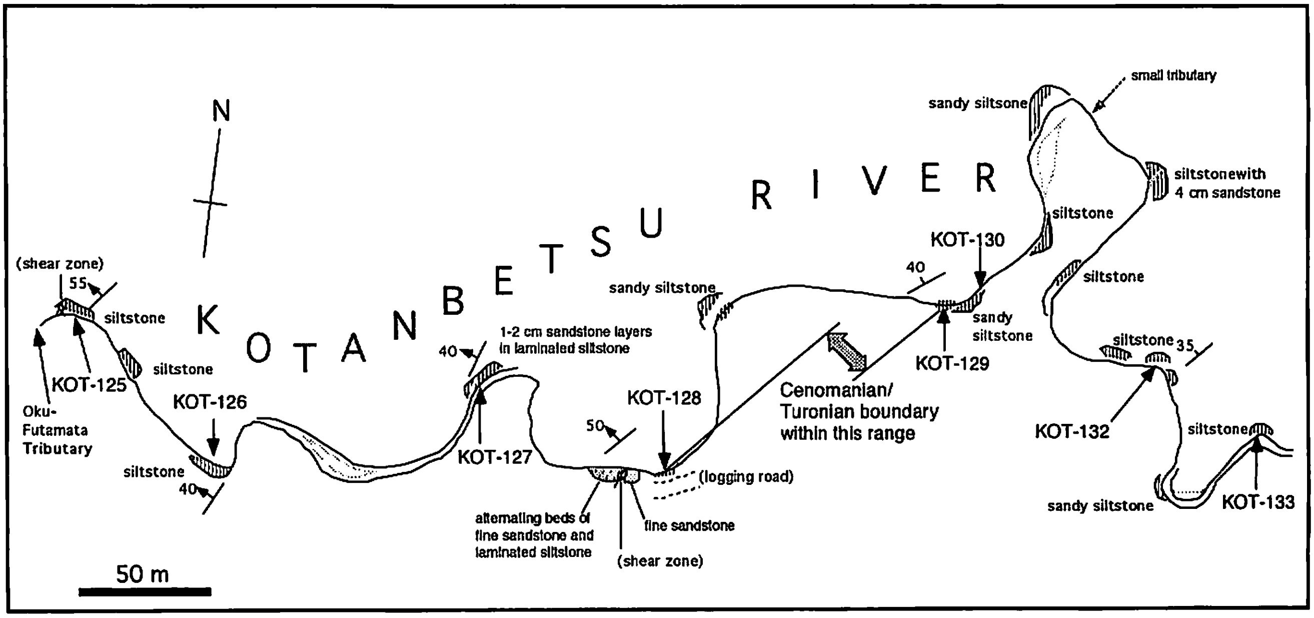

Figure 8. Plan map along the Kotanbetsu River showing detailed position of the Cenomanian/Turonian boundary expected from carbon isotope stratigraphy. The possible boundary is limited stratigraphically within ~14 m between KOT-129 and KOT-128.

though inconclusively, due to sparse sampling encompassing KC-3 and difference of amplitude of the subevent KC-3b. Hence it is still open to question whether the entire KC-3 or only KC-3c corresponds to the globally oberved carbon isotope excursion at the C/T boundary (see Schlanger *et al.*, 1987). As discussed in detail by Hasegawa (1995), the C/T boundary can be drawn just above the positive $\delta^{13}C$ excursion; the C/T boundary in the Kotanbetsu River section is drawn just above the horizon of KOT-129 (Figures 6, 8). The horizon of the C/T boundary is stratigraphically limited to ~14 m between KOT-129 and KOT-128.

Nishida *et al.* (1993b) reported occurrences of *Inoceramus nodai* just below KOT-129. In the Oyubari area, *I. nodai* was reported from 10 m below the carbon-isotopic excursion identifying the C/T boundary (Hasegawa, 1995; Nishida *et al.*, 1993a; Hirano, 1995) suggesting *I. nodai* is an important boundary marker in Hokkaido. According to Hatsugai *et al.* (1999), KC-3 is stratigraphically included in a "zone of rare occurrence" of planktonic foraminifera. A similar planktonic foraminiferal event encompassing the carbon isotopic excursion at the C/T boundary is also reported from the Oyubari area (Hasegawa, 1999) and the Tappu area (Hasegawa, 1994) suggesting an environmental deterioration across the boundary. Controlling factors other than $\delta^{13}C$ fluctuation in the global CO_2 reservoir may have disturbed the stratigraphic position of KC-3 and might have spoilt the discussion above the C/T boundary. In such a case, additional "noise" should be superimposed on the global signal derived from isotopic change of the CO_2 reservoir. Even though such a possibility cannot completely be rejected, KC-3 event showing similar magnitude of $\delta^{13}C$ excursion to that of carbonate (e. g. Jenkyns *et al.*, 1994; Pratt *et al.*, 1985) and terrestrial organic matter (Hasegawa and Saito, 1993; Hasegawa, 1997) should contain the least "noise" for correlation of the C/T boundary. Uličný *et al.* (1997) interpreted isotopic fluctuation of organic carbon encompassing parasequence boundary near the C/T boundary based on a steady isotopic ratio of terrestrial organic carbon through the sequence in Bohemia. The present study and Hasegawa (1997) clearly shows that this interpretation cannot be accepted because the major positive "spike" of terrestrial organic carbon exists across the C/T boundary. Based on 200 m/m.y. for sedimentation rate; duration of KC-3 (from KOT-133 to KOT-129) is estimated as 0.73 m.y.

Another international event is KC-4 just above the C/T boundary and is represented by a stable "plateau" of the isotopic curve (Figure 7). Both megafossil and planktonic foraminiferal chronology indicate KC-4 falls in the lower-middle Turonian (Figure 6). Both in the Oyubari and Tappu areas, a similar isotopic event is also recognized. On the isotopic curve of the Kotanbetsu River section, there is a minor positive event (KC-5) above KC-4. A similar feature also exists on the curve from the Tappu section but is diminished in magnitude on the curves from Oyubari (Figure 7). KC-5 could be correlated to E5 of southern England (Figure 7); however, this is not definite because of the insufficient age control and different magnitude of the positive excursion between these areas. Therefore, KC-5 can be either a global signal or a local/regional isotopic perturbation superimposed on the global KC-4 event caused by influx of less mixed (isotopically not averaged) plant debris derived from a narrower provenance.

Contrary to the chronostratigraphic concordance of megafossil and planktonic foraminifera below the middle Turonian, there are considerable discrepancies above it (Hatsugai *et al.*, 1999). Motoyama *et al.* (1991) also discussed a chronostratigraphic discrepancy on the

Turonian/Coniacian boundaries at the Oyubari area between megafossils and microfossils. Even though internationally it is recognized that the total range of *Helvetoglobotruncana helvetica* is limited to the middle Turonian (Robaszynski and Caron, 1979; Caron, 1985; Sliter, 1989), the stratigraphic distribution of *Inoceramus teshioensis* spans the Upper Turonian and *Inoceramus uwajimensis* the Coniacian (Toshimitsu *et al.*, 1995) which all overlap the range of *H. helvetica*. The first occurrence of *Inoceramus amakusensis* is positioned far below the first occurrence of *Marginotruncana sinuosa* (indicating the top of the Turonian; Caron, 1985) and genus *Archaeoglobigerina* (indicating the basal Coniacian; Caron, 1985). They show clear discrepancies with the stratigraphic relationship compiled by Toshimitsu *et al.* (1995) (Figure 6; see also Table 1 of Toshimitsu *et al.*, 1995). As a result, the stages identified by megafossils tend to give a younger age than that identified by planktonic foraminifers. These chronological inconsistencies occur above the top of the stratigraphic range of *I. hobetsensis*. This fact means that stratigraphic distributions of either/both inoceramids (*I. teshioensis, I. uwajimensis* and *I. amakusensis*) and/or planktonic foraminifers (*H. helvetica, M. sinuosa* and genus *Archaeoglobigerina*) show diachroneity.

Above isotopic profile KC-5, the carbon-isotope ratio reaches a minimum at KOT-117. This horizon can be correlated to the oldest part of the negative isotope event (H5 of the Oyubari section and E6 of the South England section: see Fig. 6 and 8 of Hasegawa, 1997). The steady isotopic ratios between -24.6 and -24.1‰ above horizon KOT-115 suggest that this section does not extend to the upper part of the Santonian. Hasegawa *et al.* (1997) reported a positive carbon-isotope event in the middle Santonian from an equivalent of the Yezo Group in Sakhalin. This Santonian event can be correlated to southern England (Jenkyns *et al.*, 1994) and Italy (Corfield, 1995; Jenkyns *et al.*, 1994). If the Kotanbetsu River section in this study reached the Santonian, the positive excursion should be observed near the top of the stratigraphic column in Figure 6. Comparing general carbon isotopic patterns from southern England and Italy (Corfield, 1995; Jenkyns *et al.*, 1994; Figure 7), the uppermost part of the Kotanbetsu River section studied herein can be interpreted to be the lower part of the Coniacian. This chronological assumption is close to the age assignment by planktonic foraminifera rather than that based on inoceramids.

Conclusion

In order to demonstrate the applicability of carbon-isotope stratigraphy of the Yezo Group for correlation, a stratigraphic time-series isotopic analysis of terrestrial organic carbon was studied from the Cenomanian to Coniacian along the Kotanbetsu River in Hokkaido, Japan. The carbon-isotope curve generated was compared with similar profiles of terrestrial organic carbon from Oyubari and Tappu in Hokkaido (Hasegawa, 1995, 1997) and marine carbonate from southern England and Italy (Jenkyns *et al.*, 1994). The salient conclusions are as follows:

1. The origin of organic carbon is interpreted to be exclusively terrestrial woody plants. Petrographic study on organic matter in mudstone samples reveals practically no marine organic matter in the seven examined samples. The carbon-isotope ratios of organic matter from the Kotanbetsu River section can be interpreted as that of an average lignitic material from woody plants. Global carbon-isotope events can be recognized in the isotopic curve from Kotanbetsu.

2. Event KC-3 records the isotopic event of the Cenomanian/Turonian boundary. It is still unclear which carbon-isotope event, namely all of KC-3 or only KC-3c, represents the C/T boundary. Notwithstanding this, the Cenomanian/Turonian boundary is drawn just above sample KOT-129, which has the most positive δ^{13}C ratio.

3. Event KC-4 is correlated to the event H4/E4 of both the Oyubari and southern England sections.

4. A negative event above KC-5 is correlated to the earliest part of event H5/E6 of Oyubari and southern England.

5. The most plausible chronologic interpretation for the younger part of KC-6 is middle Turonian to Coniacian and supports planktonic foraminiferal evidence rather than that derived from inoceramids. In spite of occurrences of *Inoceramus amakusensis*, the studied succession does not reach the Santonian because the general isotopic pattern differs from that of the Santonian from southern England (Jenkyns *et al.*, 1994) and Sakhalin (Hasegawa *et al.*, 1997).

Acknowledgments

The authors express their deep appreciation to K. Konishi of Kanazawa Univ. for his critical readings of the manuscript and helpful discussions, and to L. M. Pratt of Indiana Univ. for providing T. Hasegawa an opportunity to use instruments at Indiana Univ. The authors wish to extend their appreciation to S. Studley and J. Fong of Indiana Univ. for their helpful support during analyses. Acknowledgments are also due to T. Matsumoto of Kyushu Univ. for his identification of megafossils and M. Mastalerz of the Indiana Geological Survey for her advice and helpful discussions during work on organic petrology. Financial support for this study was provided by a Grant-in-Aid for Encouragement of Young Scientists from the Ministry of Education, Science and Culture of the Government of Japan, no. 09740387 and by a Grant for Encouragement of Young Scientists from the Nissan Science Foundation (both given to T. Hasegawa).

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*, vol. 335, p. 714-717.

Beerling, D. J. and Jolley, D. W., 1998: Fossil plants record an atmospheric $^{12}CO_2$ and temperature spike across the Palaeocene-Eocene transition in NW Europe. *Journal of Geological Society, London*, vol. 155, p. 591-594.

Bustin, R. M., Cameron, A. R., Grieve, D. A. and Kalkreuth, W. D., 1983: Coal petrology, its principles, methods, and applications. *Geological Association of Canada Short Course Note*, vol. 3, p. 230, Geological Association of Canada, Victoria.

Corfield, R. M., 1995: An introduction to the techniques, limitations and landmarks of the carbonate oxygen isotope palaeothermometry. *In*, Bosence, D. B. J. and Allison P. A. *eds., Marine Palaeoenvironmental Analysis from Fossils, Geological Society Special Publication* no. 83, p. 27-42, The Geological Society, London.

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

Gale, A. S., Jenkyns, H. C., Kennedy, W. J., and Corfield, R. M., 1993: Chemostratigraphy versus biostratigraphy: data from around the Cenomanian-Turonian boundary. *Journal of the Geological Society, London*, vol. 150, p. 29-32.

Gradstein, F. M., Agterberg, F. P., Ogg, J. G., Hardenbol, J., Veen, P. V., Thierry, J. and Huang, Z., 1995: A Triassic, Jurassic and Cretaceous time scale. *In*, Berggren, W. A., Kent, D. V., Aubry, M.-P. and Hardenbol, J. *eds., Geochronology, Time Scales and Global Stratigraphic Correlation, SEPM (Society for Sedimentary Geology) Special Publication* no. 54, p. 95-126, SEPM (Society for Sedimentary Geology), Tulsa.

Gröcke, D. R., Hesselbo, S. P. and Jenkyns, H. C., 1999: Carbon isotope composition of Lower Cretaceous fossil wood: Ocean-atmosphere chemistry and relation to sea level change. *Geology*, vol. 27, p. 155-158.

Hasegawa, T., 1994: Cretaceous paleoenvironment across the Cenomanian/Turonian boundary based on analytical data from the Yezo Group, Hokkaido, Japan, 197 p. *D. Sc. Dissertation of Institute of Geology and Paleontology, Tohoku University*, Sendai.

Hasegawa, T., 1995: Correlation of the Cenomanian/Turonian boundary between Japan and Western Interior of the United States. *The Journal of the Geological Society of Japan*, vol. 101, p. 2-12.

Hasegawa, T., 1997: Cenomanian-Turonian carbon isotope events recorded in terrestrial organic matter from northern Japan. *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 130, p. 251-273.

Hasegawa, T., 1999: Planktonic foraminifera and biochronology of the Cenomanian-Turonian (Cretaceous) sequence in the Oyubari area, Hokkaido, Japan. *Paleontological Research*, vol. 3, p. 173-192.

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*, vol. 2, p. 181-191.

Hasegawa, T., Maeda, H., Shigeta, Y. and Kase, T., 1997: Carbon isotope stratigraphy as a tool for international correlation-applicability for the Cretaceous Cenomanian-Maastrichtian strata. *Abstracts with Programs, the 1997 Annual Meeting of the Paleontological Society of Japan*, p. 88. (*in Japanese*)

Hatsugai, T., Saito, T. and Nishi H., 1999: Geology and planktonic foraminiferal biostratigraphy of the Upper Cretaceous in Northwestern Hokkaido. *Abstracts with Programs, the 1999 Annual Meeting of the Paleontological Society of Japan*, p. 92. (*in Japanese*)

Hirano, H., 1995: Correlation of the Cenomanian/Turonian boundary between Japan and Western Interior of the United States in relation with oceanic anoxic events. *The Journal of the Geological Society of Japan*, vol. 101, p. 13-18.

Hirano, H., Koizumi, M., Matsuki, H. and Itaya, T., 1997: K-Ar age study on the Cenomanian/Turonian boundary of the Yezo Supergroup, Hokkaido, Japan, with special reference to OAE-2 and biostratigraphic correlation. *The Memoirs of the Geological Society of Japan*, no. 48, p. 132-141.

Igi, S., Tanaka, K., Hata, M. and Sato, H., 1958: *Explanatory Text of the Geological Map of Japan, "Horokanai"*, 55 p., Geological Survey of Japan, Kawasaki.

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. *Geological Magazine*, vol. 131, p. 1-34.

Kuypers M. M., Pancost, R. D. and Sinninghe Damste, J. S., 1999: A large and abrupt fall in atmospheric CO_2 concentration during Cretaceous times. *Nature*, vol. 399, p. 342-345.

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. *The Journal of the Geological Society of Japan*, vol. 97, p. 507-527. (*in Japanese with English abstract*)

Nguyen Tu, T. T., Bocherens, H., Mariotti, A., Baudin, F., Pons, D., Broutin, J., Derenne, S. and Largeau, C., 1999: Ecological distribution of Cenomanian terrestrial plants based on $^{13}C/^{12}C$ ratios. *Palaeogeography Palaeoclimatology Palaeoecology*, vol. 145, p. 79-93.

Nishida, T., Matsumoto, T., Kyuma, Y. and Maiya, S., 1992: Integrated inoceramid-foraminiferal biostratigraphy of the Cenomanian and Turonian (Cretaceous) in the Kotanbetsu Valley, Hokkaido. *Journal of the Faculty of Education, Saga University*, vol. 39, p. 21-59. (*in Japanese with English abstract*)

Nishida, T., Matsumoto, T., Maiya, S., Hanagata, S., Yao, A. and Kyuma, Y., 1993a: Integrated mega- and micro-biostratigraphy of the Cenomanian stage in the Oyubari area, Hokkaido —with special reference to its upper and lower limits—. *Journal of the Faculty of Education, Saga University*, vol. 41, p. 11-57. (*in Japanese with English abstract*)

Nishida, T., Matsumoto, T., Yao, A. and Maiya, S., 1993b: Towards an integrated mega-micro biostratigraphy on the Cenomanian (Cretaceous) Sequence in the Kotanbetsu Valley, Hokkaido, including the C-T boundary problem. *Journal of the Faculty of Education, Saga University*, vol. 40, p. 95-127. (*in Japanese with English abstract*)

Okada, H., 1979: Geology of Hokkaido and plate tectonics. *Earth (Chikyu)*, vol. 1, p. 869-877. (*in Japanese*)

Okada, H., 1983: Collision Orogenesis and Sedimentation in Hokkaido, Japan, *In*, Hashimoto, M. and Uyeda, S. *eds., Accretion Tectonics in the Circum-Pacific Regions*, p. 91-105, Terra Scientific Publishing Company, Tokyo.

O'Leary, M. H., 1993; Biochemical basis of carbon isotope fractionation. *In*, Ehleringer, J. R., Hall, A. E. and Farquhar, G. D. *eds., Stable Isotopes and Plant Carbon-Water Relations*, p. 19-28, Academic Press, London.

Popp, B. N., Takigiku, R., Hayes, J. M., Louda, J. W. and Baker, E. W., 1989: The post-Paleozoic chronology and mechanism of ^{13}C depletion in primary marine organic matter. *American Journal of Science*, vol. 289, p. 436-

454.

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*. p.38-48. Society of Economic Paleontologists and Mineralogists, Tulsa.

Robaszynski F. and Caron, M. (coordinators), 1979: Atlas de Foraminifères planctoniques du Crétacé moyen. Parts 1-2. *Cahiers de Micropaléontologie*, vol. 26, no. 1, p. 1-185; no. 2, p. 1-181p. pls. 1-80.

Schlanger, S.O. and Jenkyns, H.C., 1976: Cretaceous oceanic anoxic events: Causes and consequences. *Geologie en Mijnbouw*, vol. 55, p. 179-184.

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 $\delta^{13}C$ excursion. *In*, Brooks, J. and Fleet, A. J. *eds., Marine Petroleum Source Rocks, Geological Society Special Publication*, no. 26, p. 371-399, Blackwell Scientific Publications, Oxford.

Scholle, P. A. and Arthur, M. A., 1980: Carbon isotope fluctuations in Cretaceous pelagic limestones: potential stratigraphic and petroleum exploration tool. *The American Association of Petroleum Geologists Bulletin*, vol. 64, p. 67-82.

Sekine, H., Takagi, A. and Hirano, H., 1985: Biostratigraphical study of the Upper Cretaceous of the north-east part of the Obira area, Hokkaido. *Fossils* (*Palaeontological Society of Japan*), vol. 38, p. 1-15. (*in Japanese with English abstract*)

Shibata, K. and Miyata, Y., 1978: Isotopic ages of the Cretaceous tuff from the Obira area, Hokkaido. *Bulletin of Geological Survey of Japan*, vol. 29, 31-36. (*in Japanese with English abstract*)

Shibata, K., Maeda, H. and Uchiumi, S., 1997: Age of the Cenomanian-Turonian boundary in Hokkaido. *The Journal of the Geological Society of Japan*, vol. 103, p. 669-675.

Sliter, W. V., 1989: Biostratigraphic zonation for Cretaceous planktonic foraminifers examined in thin section. *Journal of Foraminiferal Research*, vol. 19, p. 1-19, pls. 1-3.

Takashima, R., Nishi, H., Saito, T. and Hasegawa, T., 1997: Geology and planktonic foraminiferal biostratigraphy of Cretaceous strata distributed along the Shuparo River, Hokkaido, Japan. *The Journal of the Geological Society of Japan*, vol. 103, p. 543-564. (*in Japanese with English abstract*).

Toshimitsu, S., Matsumoto, T., Noda, H., Nishida, T. and Maiya, S., 1995: Towards an integrated mega-, micro-, and magneto-stratigraphy of the Upper Cretaceous in Japan. *The Journal of the Geological Society of Japan*, vol. 101, p. 19-29.

Uličný, D., Hladíková, J., Attrep, M. J. Jr., Cech, S., Hradecká L. and Svobodová, M., 1997: Sea-level changes and geochemical anomalies across the Cenomanian-Turonian boundary: Pecínov quarry, Bohemia. *Palaeogeography Palaeoclimatology Palaeoecology*, vol. 132, p. 265-285.