A revised inoceramid biozonation for the Upper Cretaceous based on high-resolution carbon isotope stratigraphy in northwestern Hokkaido, Japan

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ABSTRACT:


Biostratigraphic correlations of inoceramid bivalves between the North Pacific and Euramerican provinces have been difficult because the inoceramid biostratigraphy of the Japanese strata has been based on endemic species of the northwest Pacific. In this study, carbon stable isotope fluctuations of terrestrial organic matter are assembled for the Upper Cretaceous Yezo Group in the Haboro and Obira areas, Hokkaido, Japan, in order to revise the chronology of the inoceramid biozonation in Japan. The carbon isotope curves are correlated with those of marine carbonates in English and German sections with the aid of age-diagnostic taxa. According to the correlations of the carbon isotope curves, 11 isotope events are recognised in the sections studied. As a result of these correlations, the chronology of the inoceramid biozones of the Northwest Pacific has been considerably revised. The revised inoceramid biozones suggest that the timing of the origination and extinction of the inoceramids in the North Pacific biotic province is different from the stage/substage boundaries defined by inoceramids, as used in Europe and North America.

Key words: Carbon isotope stratigraphy; Inoceramid biozones; Yezo Group; Upper Cretaceous; Hokkaido; Japan.

INTRODUCTION

Inoceramid bivalves show a high taxonomic diversity in the Upper Cretaceous, and are important age-diagnostic forms in global correlations (e.g., Ogg et al. 2004). Inoceramids are also abundant in the Cretaceous strata exposed in Hokkaido, Japan (e.g., Takahashi 2005), and inoceramid-based biostratigraphic studies have been carried out for a long time (e.g., Matsumoto 1959; Tanabe et al. 1977). Toshimitsu et al. (1995) integrated the ammonoid, inoceramid, foraminiferal, radiolarian and palaeomagnetic stratigraphies, and their scheme is widely followed in biostratigraphic studies in Japan (e.g., Wani and Hirano 2000; Moriya and Hirano 2001; Oizumi et al. 2005). Unfortunately, the North Pacific biotic province was well established since the Middle Albian (Iba and Sano 2007) and only a few interprovincial age-diagnostic taxa are known from the Japanese Upper Cretaceous, such as Mytiloides incertus (Jimbo), also reported from the Upper Turonian of the
The Japanese ammonoid zonation and interprovincial correlations using ammonoids were established by Matsumoto (e.g., Matsumoto 1959; Matsumoto 1977), and have subsequently been applied by later workers to the Japanese inoceramid successions. Age-diagnostic ammonoids, however, are rare; whereas inoceramids are more common. Consequently, establishing the reliable chronostratigraphic ranges of critical inoceramid taxa is of the utmost importance in correlation of the Japanese succession with the international standard zonal scheme.

Following the pioneering work of Scholle and Arthur (1980), carbon stable isotope studies are used to provide an effective chronostratigraphic framework. Temporal fluctuations in the carbon isotope ratios (δ13C) of marine carbonates are a reliable tool for regional and international correlations (e.g., Jenkyns et al. 1994; Erbacher et al. 1996; Voigt and Hilbrecht 1997; Stoll and Schrag 2000; Voigt 2000; Jarvis et al. 2002, 2006; Voigt et al. 2010). In Japan, δ13C stratigraphic studies on terrestrial organic matter have been undertaken for the Yezo Group (Hasegawa 1992; Hasegawa and Saito 1993; Hasegawa 1997; Hirano and Fukui 1997; Hasegawa and Hatsugai 2000; Ando et al. 2002, 2003; Hasegawa et al. 2003; Ando and Kakegawa 2007; Uramoto et al. 2007, 2009; Takashima et al. 2010). Hasegawa (1997) discussed the resemblance between the δ13C curves for marine carbonates and those for terrestrial organic matter, and concluded that the δ13C stratigraphy of terrestrial organic matter provides a reliable tool for correlation with the marine carbonates. Recently, Uramoto et al. (2009) supported the usefulness of this tool for correlation and indicated that δ13C fluctuations of terrestrial organic matter reflected the global isotopic patterns in the carbon reservoir of the ocean-atmosphere-terrestrial biosphere system. The δ13C-based correlations first require, however, determination of the approximate geological ages, based usually on biostratigraphy and complete stratigraphic successions.

The purpose of this study is to revise the chronostratigraphic position of the inoceramid biozones in Japan based on δ13C correlations between Japan and Europe. Although Uramoto et al. (2009) demonstrated the δ13C stratigraphy in the Obira area, the sampling intervals for the Coniacian were rather coarse, and their δ13C record was limited to the Santonian. In the present study, higher-resolution δ13C data are reported, and the analysis spans the Coniacian through to the lower Campanian. The need for a chronostratigraphic revision of the Japanese inoceramid zonation was indicated by Takashima et al. (2010) in their high-resolution δ13C stratigraphy for the Upper Cenomanian through to Lower Campanian of the Kotanbetsu area of Hokkaido. However, Takashima et al. (2010) reported the δ13C data from a single area and the only fossil records used were those of the inoceramids reported by Wani and Hirano (2000) from the same section. In the present study, on the other hand, the δ13C analyses were performed on material from sections with rich macrofossil and microfossil records in two different areas of Hokkaido. The high-resolution δ13C stratigraphy from the upper Turonian to the lower Campanian of the studied succession was then compared with the δ13C fluctuations reported by Voigt and Hilbrecht (1997), Hasegawa et al. (2003), Jarvis et al. (2006), Takashima et al. (2010), and Voigt et al. (2010).

GEOLOGICAL SETTING

The Yezo Group is interpreted as forearc basin sediments (Okada 1982), which consist of hemipelagic and shallow marine mudstone and sandstone (e.g., Ando 2003; Takashima et al. 2004) with abundant molluscan fossils. The studies were carried out in the Haboro and Obira areas (Text-fig. 1). The middle to upper parts of the Yezo Group crop out in both areas and yield abundant macrofossils. The Yezo Group is overlain unconformably by the Eocene Sankebetsu Formation (lower part) in the Haboro area and by the Miocene Jugosenzawa Formation in the Obira area. The lithostratigraphy in both areas was discussed by Igi et al. (1958), Tsushima et al. (1958), Tanaka (1963), Yamaguchi and Matsuno (1963), Toshimitsu (1985, 1988), Okamoto et al. (2003), Funaki and Hirano (2004), Takashima et al. (2004), and Oizumi et al. (2005). The Yezo Group has been subdivided into many lithostratigraphic units in northern Hokkaido (Igi et al. 1958; Tanaka 1963; Tanabe et al. 1977). Subsequently, some authors followed these lithostratigraphic units in the Haboro area (Okamoto et al. 2003) and the Obira area (Funaki and Hirano 2004; Oizumi et al. 2005). The lithostratigraphic classification of Funaki and Hirano (2004) and Oizumi et al. (2005) is followed herein.

In the sections studied, the Yezo Group is subdivided into the Saku Formation and the conformably overlying Haborgawa Formation. The Saku Formation is built of alternating sandstone and siltstone. The Haborgawa Formation is represented mainly by bioturbated dark grey mudstone with some coarsening-upward sequences that characterise the middle and upper parts of the formation. In the Obira area, a fine- to coarse-grained sandstone with slump deposits is developed in the lowest part of the Haborgawa Formation, and is a good regional key marker-bed (Kamikinenbetsu Sandstone Member; Funaki and Hirano 2004).
The Saku and Haborogawa formations have yielded well-preserved and abundant macro- and microfossils (Tanaka 1963; Tanabe et al. 1977; Sekine et al. 1985; Toshimitsu 1985, 1988, Toshimitsu et al. 1998; Okamoto et al. 2003; Funaki and Hirano 2004; Oizumi et al. 2005). The upper Turonian through to lower Campanian is documented.

MATERIALS AND METHODS

In this study, 123 mudstone and sandy mudstone samples were collected along the Chimeizawa River in the Haboro area (48 samples) and along the Obirashibe and Okufutamatazawa Rivers in the Obira area (75 samples) (Text-fig. 2).

To evaluate the kerogen type and the maturity of the organic matter, the total organic carbon (TOC) contents and Rock-Eval pyrolysis were analysed.

Powdered mudstone samples were treated with 6N HCl for 24 hours to remove carbonates. The elemental composition of 20–30 mg of each sample was analysed using a J-SCIENCE LAB Co., Ltd. Micro Corder JM10, calibrated with antipyrine (C11H12N2O) as the standard. The elemental composition of each sample was corrected based on the weight-percent of removed carbonates, and the TOC content of the whole rock was obtained.

The Rock-Eval pyrolysis was conducted using a VINCI Technologies model 6 device. The 100 mg powdered samples were pyrolysed from 300 to 650°C with a rate of heating of 25°C/min in a nitrogen atmosphere. The S1 is the amount of hydrocarbon that can be thermally distilled and was analysed with a flame ionisation detector (FID). The S2 is the hydrocarbons released by pyrolytic degradation of the kerogen and was analysed with the FID. The S3 is the carbon dioxide generated during pyrolysis at 390°C and was analysed with thermal conductivity detection (TCD). The temperature at which the maximum amount of S2 hydrocarbons was generated is Tmax. The Hydrogen Index (HI) is the ra-
The ratio of mg HC in S2/g TOC. The Oxygen Index (OI) is the ratio of mg CO2 in S3/g TOC.

For the δ13C analysis, the acid-processed samples were treated with a mixture of dimethyl ether and methanol (93:7) to remove the free hydrocarbons. Analyses of δ13C ratios were performed using a GV Instruments Isoprime EA mass spectrometer (precision of the δ13C measurements: ±0.10‰). The δ13C ratios were expressed as permil deviation from the Pee Dee Belemnite (PDB) standard.

RESULTS

Kerogen type and thermal maturity of organic matter

The results of the TOC content analysis and the Rock-Eval pyrolysis are shown in Table 1, and plots of the Hydrogen Index versus the T_{max} are shown in Text-fig. 3. These ranges are applicable to the type III kerogen, and the T_{max} values indicate immaturity.

<table>
<thead>
<tr>
<th>Sample</th>
<th>TOC (%)</th>
<th>S1 (mg/g)</th>
<th>S2 (mg/g)</th>
<th>S3 (mg/g)</th>
<th>HI (mg HC/g TOC)</th>
<th>OI (mg HC/g TOC)</th>
<th>T_{max} (°C)</th>
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<tbody>
<tr>
<td>OFM 4</td>
<td>0.63</td>
<td>0.02</td>
<td>0.21</td>
<td>0.14</td>
<td>33</td>
<td>22</td>
<td>424</td>
</tr>
<tr>
<td>OFM 33</td>
<td>0.81</td>
<td>0.09</td>
<td>0.31</td>
<td>0.29</td>
<td>38</td>
<td>36</td>
<td>424</td>
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<tr>
<td>CMI 50</td>
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<td>0.18</td>
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<td>24</td>
<td>48</td>
<td>417</td>
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<tr>
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<td>55</td>
<td>421</td>
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<td>0.37</td>
<td>28</td>
<td>42</td>
<td>423</td>
</tr>
<tr>
<td>CMI 22</td>
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<td>0.19</td>
<td>0.37</td>
<td>29</td>
<td>56</td>
<td>418</td>
</tr>
</tbody>
</table>

Table 1. Total organic carbon contents and Rock-Eval pyrolysis of the selected samples. The three letter initials are the same as those in Text-fig. 2.
Carbon isotope values

The δ¹³C values of organic matter (δ¹³C_<sub>org</sub>) range from -24.9‰ to -23.3‰ in the Haboro area and from -24.9‰ to -23.9‰ in the Obira area (Table 2, Text-figs. 4, 5).

In the Haboro area, the δ¹³C_<sub>org</sub> profile shows a positive shift, including fluctuations of ~0.5‰, up to an horizon between the sandstone key beds of MHs5 and UHs1. The δ¹³C_<sub>org</sub> values vary from -24.9‰ to -22.9‰. Thereafter, the δ¹³C_<sub>org</sub> profile shows a negative shift, including some fluctuations of ~0.5‰, in the uppermost part of the Haborogawa Formation.

In the Obira area, a positive anomaly of 0.6‰ characterises the lowermost part of the Haborogawa Formation. The δ¹³C_<sub>org</sub> profile shows a negative shift of 0.9 ‰ in the uppermost part of the Kamikinenbetsu Sandstone Member. The δ¹³C_<sub>org</sub> profile then shows a positive shift of 0.9 ‰, including two positive peaks, in the lower part of the Haborogawa Formation.

Inoceramid biostratigraphy

The Haboro area along the Haboro River and its tributaries; The Saku Formation

The inoceramid reported in the Saku Formation is *Inoceramus teshioensis* Nagao and Matsumoto, the lowest occurrence of which is in the upper part of this formation (Okamoto et al., 2003; Text-fig. 4).

The Haboro area along the Haboro River and its tributaries; The Haboro Formation

The highest occurrence of *I. teshioensis* is ~150 m above the basal part of the Haborogawa Formation (Okamoto et al., 2003). The lowest occurrence of *I. uwajimensis* Yehara was reported by Okamoto et al. (2003) to be ~150 m above the basal part of this formation along the Takemizawa River branch of the Sakasa River. *I. pedalionoides* Nagao and Matsumoto and *I. uwajimensis* were collected from the lower part of the formation along the Chimeizawa River and *Platyceramus szaszii* (Noda and Uchida) from the lower part of the formation along the Haboro River. The lowest occurrence of *Cremnoceramus mihoensis* (Matsumoto) was reported by Okamoto et al. (2003) along the Nakanofutamata River. The lowest occurrence of *Cordiceramus kawashitai* (Noda) is ~450 m above the basal part of this formation along the Chimeizawa River. The lowest occurrence of *Sphenoceramus naumanni* (Yokoyama) was reported by Toshimitsu (1988) near the horizon of the highest occurrence of *Cr. mihoensis* ~600 m above the basal part of this formation, and the species ranges up to the highest part of the formation. Although *Inoceramus amakusensis* Nagao and Matsumoto was not obtained in this study, the lowest occurrence of this species was reported by Okamoto et al. (2003) to be ~650 m above the basal part of this formation and the highest occurrence mentioned by Toshimitsu (1988) was just below the sandstone key bed UHs1. The lowest occurrence of *Platyceramus mantielli* (De Mercey) was confirmed by Toshimitsu (1988) at 340 m below the sandstone key bed MHs4 and the highest occurrence was confirmed near the UHs1 key bed in this study. The lowest occurrence of *Platyceramus ezoeensis* (Yokoyama) is at ~50 m above UHs1 (Toshimitsu 1988), and the highest occurrence is in the highest part of this formation. The lowest occurrence of *Platyceramus japonicus* (Nagao and Matsumoto) was reported by Moriya and Hirano (2001) just above the UHs1. Toshimitsu (1988) reported the occurrence of *Sphenoceramus schmidtii* (Michael) in the topmost part of the Haborogawa Formation (Text-fig. 4).
ported the occurrence of the Upper Turonian species Inoceramus peda-
lonoides (Nagao and Matsumoto, and Sekine et al. 2005). The lowest occurrence of I. amakusensis is near the lowest occurrence of S. naumannii, which ranges up to the highest part of this formation. The lowest occurrence of I. amakusensis is ~500 m above the basal part of this formation (Oizumi 1985). The occurrence of I. uwajimensis is just below the Kamikinenbetsu Sandstone Member (Funaki and Hirano, 2004). The lowest occurrence of both Cr. mihoensis (Sekine et al. 1985) and Cordiceramus cordiformis (J. de C. Sowerby) (Tanabe et al. 1977) are in the uppermost part of the Kamikinenbetsu Sandstone Member. These two species occur successively up to just above the Kamikinenbetsu Sandstone Member. The highest occurrence of Cr. mihoensis is near the lowest occurrence of S. naumannii, which ranges up to the highest part of this formation. The lowest occurrence of I. amakusensis is ~500 m above the basal part of this formation (Oizumi et al. 2005), and the highest occurrence is just below the UHs1 key bed. The lowest occurrence of P. cf. mantelli is 100 m below the MHS2 key bed, and the highest occurrence is near the MHS5 key bed (Toshimitsu 1988).

Table 2. Carbon isotope values in the study sections. The three letter initials are the same as those in Text-fig. 2

The Obira area along the Obirashibe River and its tributaries; The Saku Formation

Tanabe et al. (1977) reported the lowest occurrence of Inoceramus teshioensis and Inoceramus peda-
lonoides Nagao and Matsumoto, and Sekine et al. (1985) reported the lowest occurrence of Inoceramus tenuistriatus Nagao and Matsumoto (Text-fig. 5, 6) in the upper part of the Saku Formation.

The Obira area along the Obirashibe River and its tributaries; The Haborogawa Formation

I. pedalionoides, I. tenuistriatus and I. teshioensis occur successively in the lowermost part of the Haboro-
gawa Formation (Tanabe et al. 1977; Sekine et al. 1985; Asai and Hirano 1990). Asai and Hirano (1990) re-
ported the occurrence of the Upper Turonian species Mytiloides incertus (Jimbo) in the lowermost part of the formation. The lowest occurrence of I. uwajimensis is just below the Kamikinenbetsu Sandstone Member (Funaki and Hirano, 2004). The lowest occurrence of both Cr. mihoensis (Sekine et al. 1985) and Cordiceramus cordiformis (J. de C. Sowerby) (Tanabe et al. 1977) are in the uppermost part of the Kamikinenbetsu Sandstone Member. These two species occur successively up to just above the Kamikinenbetsu Sandstone Member. The highest occurrence of Cr. mihoensis is near the lowest occurrence of S. naumannii, which ranges up to the highest part of this formation. The lowest occurrence of I. amakusensis is ~500 m above the basal part of this formation (Oizumi et al. 2005), and the highest occurrence is just below the UHs1 key bed. The lowest occurrence of P. cf. mantelli is 100 m below the MHS2 key bed, and the highest occurrence is near the MHS5 key bed (Toshimitsu 1988).

<table>
<thead>
<tr>
<th>Sample</th>
<th>δ13C (‰)</th>
<th>Sample</th>
<th>δ13C (‰)</th>
<th>Sample</th>
<th>δ13C (‰)</th>
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<th>δ13C (‰)</th>
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<td>OFM 20</td>
<td>-24.06</td>
<td>OFM 30</td>
<td>-24.04</td>
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<td>OFM 19</td>
<td>-24.18</td>
<td>OFM 29</td>
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<td>OFM 28</td>
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<td>OFM 11</td>
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<td>OBR 17</td>
<td>-24.52</td>
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<td>OBR 14</td>
<td>-24.21</td>
<td>OBR 24</td>
<td>-24.25</td>
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<td>-24.78</td>
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REVISED INOCERAMID BIOZONATION FOR THE UPPER CRETACEOUS OF JAPAN

Text-fig. 4. Columnar section of the δ¹³Corg profile and the distribution of selected fossils in the Haboro area. Names of the rivers are mentioned in their occurrence out of this section. MHs4-5 and UHs1 are the key-marker-beds of Toshimitsu (1988).
This study -24-25

**Haborogawa Formation**
- UHs1
- MHs5
- MHs3 or 4
- MHs2

**Saku Formation (Part)**
- Kamiasaebasho sandstone Member

<table>
<thead>
<tr>
<th>Stratigraphic units</th>
<th>Columnar section</th>
<th>δ¹³Corg (‰) vs PDB</th>
<th>Selected fossils</th>
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<tr>
<td></td>
<td></td>
<td>-25</td>
<td>Inoceramids</td>
</tr>
<tr>
<td></td>
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<td>others</td>
</tr>
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<td>Yeze Group</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>0</td>
<td>500 m</td>
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</tr>
</tbody>
</table>

**Legend**
- Sandy mudstone
- Alternating beds of sandstone and mudstone
- Muddy sandstone
- Fine-grained sandstone
- This study
- Tanabe et al. (1977)
- Sekine et al. (1985)
- Toshimitsu (1988)
- Asai and Hirano (1990)
- Funaki and Hirano (2004); Oizumi et al. (2005)

- Mudstone
- Tuff beds
- Slump deposits

Text-fig. 5. Columnar section of the δ¹³Corg profile and the distribution of selected fossils in the Obira area. The columnar section is modified after Funaki and Hirano (2004) and Oizumi et al. (2005). Names of the rivers are mentioned in their occurrence out of this section. MHs4-5 and UHs1 are the key-marker beds of Toshimitsu (1988).
Stratigraphic distributions and geological ages in previous studies

The Saku and Haborogawa Formations yield well-preserved, abundant macro- and microfossils documented in many biostratigraphic studies (Tanaka 1963; Tanabe et al. 1977; Sekine et al. 1985; Toshimitsu 1985, 1988, Toshimitsu et al. 1995; Okamoto et al. 2003; Funaki and Hirano 2004; Oizumi et al. 2005). According to these studies, the sections have been correlated with macrofossils and range from the upper Turonian to the lower Campanian. The Turonian/Coniacian boundary is located in the lowest part of the Haborogawa Formation and has been defined by the lowest occurrence of the inoceramid Didymotis costatus and the occurrence of the ammonoid Barroisiceras onilahyense (Funaki and Hirano 2004) (Text-fig. 7). The Coniacian/Santonian boundary is located in the lower part of the Haborogawa Formation and has been defined by the lowest occurrence of I. amakusensis (Toshimitsu 1988; Toshimitsu et al. 1995; Oizumi et al. 2005) (Text-fig. 7). The Santonian/Campanian boundary is located in the upper part of the Haborogawa Formation and has been defined by the lowest occurrence of Platyceramus japonicus (Toshimitsu et al. 1995; Oizumi et al. 2005) (Text-fig. 7).

Inoceramid biozones

Funaki and Hirano (2004) recognised 7 inoceramid biozones in the Obira area by using inoceramid species that Toshimitsu et al. (1995) defined as inoceramid zonal indices. These biozones are as follows, in ascending order: 1) the Inoceramus virgatus Interval Zone; 2) the Actinoceramus sp. ex. gr. nipponicus Interval Zone; 3) the Inoceramus kamuy Interval Zone; 4) the Inoceramus hobetsensis Interval Zone; 5) the Inoceramus hobetsensis- Inoceramus teshoensis Concurrent-range Zone; 6) the Inoceramus teshoensis Partial-range Zone; and 7) the Inoceramus uwajimensis Interval Zone.

In this study, we recognise 4 inoceramid biozones above the I. teshioensis Partial-range Zone in both areas by using inoceramid species that Toshimitsu et al. (1995) defined as inoceramid zonal indices. These biozones are as follows, in ascending order: 1) the Inoceramus uwajimensis Interval Zone (redefined), which is defined in this study as the stratigraphic interval from the lowest occurrence of I. uwajimensis to the lowest occurrence of Crempnoceramus mihoensis; 2) the Crempnoceramus mihoensis Interval Zone, which is defined as the stratigraphic interval from the lowest occurrence of Cr. mihoensis to the lowest occurrence of Inocera-
Text-fig. 7. Correlation of the columnar sections of the distribution of selected fossils in the Haboro and Obira areas. The columnar section of the Obira area is modified after Funaki and Hirano (2004) and Oizumi et al. (2005). MHs4-5 and UHs1 are the key-marker-beds of Toshimitsu (1988). Abbreviations: Co., Coniacian; Ca., Campanian
**Correlation of $\delta^{13}C_{\text{TOM}}$ profiles in the Yezo Group**

Uramoto et al. (2009) showed the intrabasinal correlation of the $\delta^{13}C_{\text{TOM}}$ profile obtained in the Obira area with those of the previous studies (Kotanbetsu section: Hasegawa and Hatsuaki 2000; Oyubari section: Hasegawa 1997, Tsuchiya et al. 2003; Naiba section (Sakhalin): Hasegawa et al. 2003) based on the occurrence of the global age-diagnostic macro- and microfossils and biohorizons of the regional marker inoceramids. Uramoto et al. (2009) demonstrated that the $\delta^{13}C_{\text{TOM}}$ profiles show notable fluctuations at specific stratigraphic markers. The $\delta^{13}C_{\text{TOM}}$ values for the Obira area in this study and that of Uramoto et al. (2009) were integrated because the $\delta^{13}C_{\text{TOM}}$ profile in this study overlaps with part of the profile of Uramoto et al. (2009) and the fluctuation patterns of these profiles are the same in the overlapped section along the Obirashibe and Okufutamatazawa rivers. The lowest occurrences of the ammonoid *Yokoyamaoceras ishikawai* (Jimbo) and the inoceramid bivalve *Didymotis costatus* (Fric) were used as regional stratigraphic markers to correlate the $\delta^{13}C_{\text{TOM}}$ profiles of these three areas. The lowest occurrence of *D. costatus* can be used for correlation as a stratigraphic marker near the Turonian/Coniacian boundary in the Obira area (Funaki and Hirano 2004). We collected *D. costatus* in the Chimeizawa River in the Haboro area (Text-fig. 4), and we were able to recognise the same horizon in both the the Haboro and Obira areas. The lowest occurrence of *Y. ishikawai* can be used for correlation as a biostratigraphic marker because the species occurs continuously from the Santonian to the Campanian in the Yezo Group (e.g., Oizumi et al. 2005).

The $\delta^{13}C_{\text{TOM}}$ profiles show a negative excursion of 0.5‰ (HC1) in the Haboro area and of 0.9‰ (OC1) in the Obira area near the lowest occurrence of *D. costatus*, and a positive excursion of 1.0‰ (HC2) in the Haboro area and of 0.9‰ (OC2) in the Obira area above the horizon of the previously-mentioned negative excursion (Text-fig. 8). These $\delta^{13}C_{\text{TOM}}$ fluctuations were also recognised in the Naiba area of Sakhalin by Hasegawa et al. (2003), albeit *D. costatus* was not found (Text-fig. 8). The correlation of these positive-negative $\delta^{13}C_{\text{TOM}}$ fluctuations was carried out by Uramoto et al. (2009), and it was confirmed that these fluctuations can be correlated between the Haboro, Obira and Naiba areas. The small positive peaks (HC3, OC3) were correlated between the Haboro and Obira areas because the amplitudes of these peaks are the same in both areas. The positive shift (HC4, OC4) is near the lowest occurrence of *Yokoyamaoceras ishikawai* in all three areas (Text-fig. 8). The amplitude of this shift is 0.7‰ (HC4) in the Haboro area, 1.2‰ (OC4) in the Obira area and 0.8‰ in the Naiba area (Hasegawa et al. 2003), respectively. It is considered that this positive shift and the negative shifts accompanied by a positive shift are correlatable fluctuations between the three areas. Our correlation of these fluctuations agrees with that of Uramoto et al. (2009). A long-term trend of the $\delta^{13}C_{\text{TOM}}$ curve of the Haboro area shows a positive shift including small fluctuation above the lowest occurrence of *Y. ishikawai*. A maximum value of -22.9‰ (HC5) is recognised in the upper part of the *L. amakusensis* Interval Zone of the Haboro area, and the trend becomes negative above this horizon. These trends are comparable with the $\delta^{13}C_{\text{TOM}}$ profile of the Naiba area in Sakhalin from Hasegawa et al. (2003) (Text-fig. 8). However, this suggested isotopic correlation cannot be confirmed because there is inadequate biostratigraphic correlation be-
Text-fig. 8. Correlation of the Upper Cretaceous δ13C curves of terrestrial organic matter (TOM) of the Yezo Group in Hokkaido, Japan and Sakhalin, Far East Russia. Obira area: composite curve of Uramoto et al. (2009) (grey line) and this study (black line); Haboro area: this study. Naiba area: Hasegawa et al. (2003). Correlations of the carbon isotope fluctuations are marked by the dashed lines. Solid lines represent the lowest occurrence of Didymotis costatus and Yokoyamaoceras ishikawai, respectively. Macrofossil data after Matsumoto et al. (1981), Hasegawa et al. (2003), Okamoto et al. (2003), Funaki and Hirano (2004) and Ohzumi et al. (2005). Abbreviations: I. h., Inoceramus hobetsensis; I. t., Inoceramus teishoensis; I. u., Inoceramus uwajimensis; Cr. m., Cremnoceramus mihoensis; I. amakusensis, Inoceramus amakusensis; P. japonicus, Platyceramus japonicus; S. schmidti, Sphenoceramus schmidti. OC1-4, HC1-5: See text.
between the two areas, the relevant stratigraphic marker fossils having not so far been found in the Naibi section. The two δ13C_TOM profiles in this study are identical in the patterns of fluctuation and amplitude to each other and are similar to the profile of the Naibi area in Sakhalin from Hasegawa et al. (2003). Thus, the δ13C_TOM fluctuations in this study were interpreted to represent the averaged δ13C_TOM fluctuations of the Yezo Group.

Relationship between the carbon isotope fluctuations and the occurrence of inoceramids

It is demonstrated that the δ13C_TOM profiles can be correlated between Yezo Group sections and that positive and negative spikes and shifts in isotopic values can be used as chemostratigraphic datum levels in the Haboro and Obira areas. The relationship between the δ13C_TOM profiles and the occurrence of inoceramids is shown in Text-fig. 9.

The lowest occurrence of the inoceramid Didymotis costatus is in the basal part of the Cr. mihoensis Interval Zone in the Haboro area and in the middle part of the I. uwajimensis Interval Zone in the Obira area. The negative peaks of the δ13C_TOM profiles (HC1 and OC1) are in the lowest part of the Cr. mihoensis Interval Zone in both areas (Text-fig 9). The lowest occurrence of the ammonoid Yokoyamaoceras ishikawai is in the lower part of the I. amakusensis Interval Zone in both areas. The HC3 positive peak is in the basal part of the I. amakusensis Interval Zone in the Haboro area and the corresponding OC3 peak is in the lowest part of I. amakusensis Interval Zone in the Obira area. The timing of the occurrence of inoceramids in the range from the I. uwajimensis Interval Zone to the I. amakusensis Interval Zone in the Haboro and Obira areas corresponds well, and the occurrence of Inoceramus pedalionoides and Platyceramus mantelli, which occur less commonly in these areas, is only different between these two areas based on the correlation of the δ13C_TOM fluctuations. I. pedalionoides ranges from the I. teshioensis Partial-range Zone to the I. uwajimensis Interval Zone, and P. mantelli from the Cr. mihoensis Interval Zone to the I. amakusensis Interval Zone (Noda and Matsumoto 1998; Toshimitsu et al. 2007). However, the difference in occurrence of these two rare species would not be inconsistent with the correlation of the δ13C_TOM profiles. Therefore, it is demonstrated that the δ13C_TOM profiles of the Haboro and Obira areas, which are correlated by Didymotis costatus and Yokoyamaoceras ishikawai, are consistently correlated by inoceramids except for the rare occurrence of I. pedalionoides and P. mantelli.

δ13C correlation between terrestrial organic matter of the Yezo Group and marine carbonate of the European sections

The δ13C_TOM profiles and the inoceramid biozones in the Haboro and the Obira areas were integrated to correlate the terrestrial organic δ13C fluctuation with the marine carbonate δ13C record in Europe. The recognizable positive and negative isotope peaks are designated H1 to H13, in ascending stratigraphic order (Text-fig, 10, 11).

The δ13C_TOM profile in the I. teshioensis Partial-range Zone is characterised by a negative peak (H1) from Uramoto et al. (2009) in the lowest part and a positive peak (H2) in the upper part (Text-fig. 10, 11). These two peaks lie between the occurrences of Subprionocyclus cf. neptuni and D. costatus that are correlated with the Upper Turonian. Therefore, the H1 and H2 peaks are correlated with the Bridgewick Isotope Event (Jarvis et al. 2006) and the Hitch Wood Isotope Event (Gale 1996) respectively (Text-fig. 10, 11).

The δ13C_TOM profile shows a negative shift above the H2 positive peak from the upper part of the I. teshioensis Partial-range Zone to the I. uwajimensis Interval Zone. The occurrence of D. costatus is in this interval.

The Upper Turonian strata are characterised by two Didymotis Events (Wood et al. 1984, 2004; Kauffman et al. 1996) in Europe. The Didymotis Events in Europe lie between the Hitch Wood and Navigation isotope events (Jarvis et al. 2006). In the Cr. mihoensis Interval Zone, the δ13C_TOM curve consists of a negative peak (H3) in the basal part and a positive peak (H4) in the upper part (Text-fig. 10, 11). In the Obira area, the lowest occurrence of D. costatus lies between the Hitch Wood Event and the H3 negative peak. Therefore, the H3 negative peak, which lies above the correlative of the Hitch Wood Event in the basal part of the Cr. mihoensis Interval Zone, is correlated with the Navigation Isotope Event in the English Chalk (Jarvis et al. 2006) (Text-figs 10, 11). The Navigation Event characterises the Turonian/Coniacian boundary (Jarvis et al. 2006), and the I. uwajimensis Interval Zone is correlated with the upper Upper Turonian. The H4 positive peak in the upper part of the Cr. mihoensis Interval Zone probably correlates with the White Fall Isotope Event (Jarvis et al. 2006) in the lower Middle Coniacian, albeit this correlation is not supported by the biostratigraphic calibration. We correlate the Cr. mihoensis Interval Zone with the Lower Coniacian to the Middle Coniacian, albeit the stratigraphic interval with the occurrence of Cr. mihoensis was hitherto correlated with the upper Coniacian (Toshimitsu et al. 1995).
Text-fig. 9. Correlation of the stratigraphic distribution of inoceramid zones and the $\delta^{13}$CTOM curves of the Yezo Group (Haboro area: this study; Obira area: composite curve of Hasegawa and Saito, 1993; Uramoto et al. 2007, 2009 (grey line) and this study (black line)). Correlations of the carbon isotope fluctuations are indicated by the dashed lines. Solid lines represent the lowest occurrence of bivalve or ammonoid. Macrofossil data after Tanabe et al. (1977), Matsumoto et al. (1981), Sekine et al. (1985), Toshimitsu (1985, 1988), Asai and Hirano (1990), Moriya and Hirano (2001), Moriya et al. (2001), Okamoto et al. (2003), Funaki and Hirano (2004) and Oizumi et al. (2005). Abbreviations: A. nipponicus, Actinoceramus sp. ex gr. nipponicus; I. k, Inoceramus kamayi; I. b, Inoceramus hobetensis; I. t, Inoceramus tehoensis; I. u, Inoceramus uwajimensis; Cr. m., Cremnoceramus mihoensis; I. a, Inoceramus amakusensis; P. japonicus, Platyceramus japonicus.
The carbon isotope stratigraphy between the Haboro and Obira areas (this study; Hasegawa and Saito 1993; Uramoto et al. 2007, 2009), Kotanbetsu area (Takashima et al. 2010), Salzgitter Salder and Söhlde section (Voigt and Hilbrecht 1997), Lägerdorf-Kronsmoor-Hemmoor succession (Voigt et al. 2010) and the English Chalk (Jarvis et al. 2002, 2006). Correlations of the carbon isotope fluctuations are indicated by the grey bands and dashed lines. Macrofossil data after Tanabe et al. (1977), Matsumoto et al. (1981), Toshimitsu (1985, 1988) and Moriya et al. (2001). The lower limit of the *I. amakusensis* zone of Takashima et al. (2010) is revised after Hirano et al. (2011).

Abbreviations: *I. v.*, *Inoceramus* virgatus; *I. k.*, *Inoceramus kamuy*; *I. h.*, *Inoceramus hobotensisis*; *I. t.*, *Inoceramus teshiensis*; *I. w.*, *Inoceramus wajimensis*; *C. m.*, *Cremnoceramus mihonensis*; *I. amakusensis*, *Inoceramus amakusensis*; *P. japonicus*, *Platyceramus japonicus*; *R. cushmani*, *Rotali-pora cushmani*; *W. a.*, *Whiteinella archaeocretacea*; *H. helvetica*, *Helvetoglobotruncana helvetica*; *M. sinuosa*, *Margnobotruncaina sinuosa*; *C. fornicata*, *Contusotruncanus fornicata*; *G. arca*, *Globotruncanus arca*; Alb, Albian; Cen., Cenomanian; Co., Coniacian
The δ13C_{TOM} curve in the lower part of the I. amakusensis Interval Zone is characterised by two positive peaks (H5 and H7) and a negative peak (H6). The δ13C_{carb} curve rises above the Navigation Event, with short-term fluctuations, and reaches a maximum at the Middle/Upper Coniacian boundary. This δ13C maximum is the Kingsdown Isotope Event (Jarvis et al. 2006). The δ13C_{carb} values then fall throughout the Upper Coniacian to Lower Santonian both in England (Jarvis et al. 2006) and in Germany (Voigt et al. 2010). The δ13C_{TOM} values, conversely, rise in the Cr. mihoensis Interval Zone, reaching a maximum (H5) in the basin part of the I. amakusensis Interval Zone and display a negative shift above the H5 positive peak. This trend of the δ13C_{TOM} curves is similar to the δ13C_{carb} curve, thus the H5 positive peak, in the lowest part of the I. amakusensis Interval Zone, correlates with the Kingsdown Isotope Event (Text-fig. 10, 11). A small positive peak between H5 and H6 probably correlates with the Michel Dean Isotope Event, which is very close to the base of the Santonian (Jarvis et al. 2006) (Text-fig. 10, 11). The H6 negative peak above the inferred Michel Dean Event of the δ13C_{TOM} curves, is correlated with the Haven Brow Isotope Event (Jarvis et al. 2006), based on the long-term trend of the δ13C fluctuations. The H7 positive peak, below the occurrence of the Santonian ammonoid Texanites (Plesiotexanites) kaswasakii (Kawada), is the largest excursion in the lower part of the I. amakusensis Interval Zone, thus the δ13C_{TOM} values decrease above this horizon. Because of this long-term trend, the H7 positive peak is correlated with the Horseshoe Bay Isotope Event (Jarvis et al. 2006).

The δ13C_{TOM} curve in the upper part of the I. amakusensis Interval Zone is characterised by a negative peak (H8) and two positive peaks (H9 and H10). The δ13C_{carb} profile displays a positive shift with short-term fluctuations through the Middle Santonian to the Santonian/Campanian boundary (Jarvis et al. 2006, Voigt et al. 2010). This long-term trend is similar to that of the δ13C_{TOM} curve. Based on the long-term trend, the H8 negative peak is correlated with the Buckle Isotope Event (Jarvis et al. 2006), and the H9 positive peak with the Hawks Brow Isotope Event (Jarvis et al. 2006) (Text-fig. 10, 11). Jarvis et al. (2002) defined the Santonian/Campanian Boundary Event as a positive excursion at the Santonian/Campanian boundary. The δ13C_{carb} values then decline through the Lower Campanian, with small fluctuations (Jarvis et al. 2002, Voigt et al. 2010). This trend is recognised in the δ13C_{TOM} curve of the Yezo Group, and the H10, the second significant positive peak, is correlated with the Santonian/Campanian Boundary Event (SCBE) (Text-fig. 10, 11). Voigt et al. (2010) demonstrated that the SCBE in the Lägerdorf-Kronsmoor-Hemmoor succession in northern Germany comprises a negative trough between two positive peaks (Text-fig. 10) and suggested that the stratigraphic interval at the Santonian/Campanian boundary was therefore condensed in the English Chalk. The δ13C_{TOM} fluctuation pattern of the SCBE of the Yezo Group is similar to the SCBE δ13C_{carb} fluctuations of the Lägerdorf-Kronsmoor-Hemmoor succession in northern Germany (Text-fig. 10). Moriya et al. (2001) reported the occurrence of the Lower Campanian planktonic foraminifer Contusotruncana patelliformis (Gandolfi) just above the UHS1 key bed, which is ~160 m above the Santonian/Campanian Boundary Event in the Haboro area and supports the chemostratigraphic correlation. Although the I. amakusensis Zone was hitherto correlated with the Santonian by Toshimitsu et al. (1995), the I. amakusensis Interval Zone actually correlates with the Middle/Upper Coniacian to the lower Lower Campanian (Text-fig. 10, 11).

The δ13C_{TOM} profile in the P. japonicus Interval Zone is characterised by a negative peak (H11) and two positive peaks (H12 and H13). These peaks might be interpreted to correlate with the small fluctuations of the Lower Campanian δ13C_{carb} profile (Jarvis et al. 2002, Voigt et al. 2010). However, the biostratigraphic correlations are not established above the Santonian/Campanian Boundary Event and the shape of the carbon isotope curves is different between Hokkaido and Europe. Although the P. japonicus zone was correlated with the basalt Campanian to the lower Campanian by Toshimitsu (1988) and Toshimitsu et al. (1995), the P. japonicus Interval Zone is correlated with the upper Lower Campanian in this study (Text-fig. 10, 11).

Takashima et al. (2010) reported the correlation of the carbon isotope events in the Cenomanian–Campanian succession of the Kotanbetsu areas of Hokkaido; the correlations between their δ13C profiles do not differ from those in this study (Text-fig. 10). However, their reported position of the lowest occurrence of I. amakusensis does differ significantly from ours.
Takashima et al. (2010) examined only a single section for the inoceramid biostratigraphy, based on records by Wani and Hirano (2000). The interpretation of the lowest occurrence of *I. amakusensis* differs because of the different correlations of the columnar sections between Wani and Hirano (2000) and Takashima et al. (2010) in the Kotanbetsu area and, moreover, because the identification of *I. amakusensis* is not correct (Hirano et al. 2011). The inoceramid biostratigraphy used in this study is a comprehensive compilation of our results since 1977 (Text-fig. 5) in both the Haboro and Obira areas and thus provides more reliable data.

**Age of the occurrence of the inoceramids**

The stratigraphic ranges of the inoceramids were studied by Nagao and Matsumoto (1939, 1940) for the first time, and summarised by Toshimitsu et al. (1995), Noda and Matsumoto (1998) and Takahashi (2005). However, the *I. uwajimensis Interval Zone, Cr. mihoensis Interval Zone, I. amakusensis Interval Zone* and *P. japonicus Interval Zone* are correlated herein with the uppermost Turonian, the Lower to Middle Coniacian, Middle/Upper Coniacian to lower Lower Campanian, and upper Lower Campanian, respectively, based on the chronostratigraphic correlations discussed above. Accordingly, the chronostratigraphic ages of the inoceramid zonal indices defined by Toshimitsu et al. (1995) are revised significantly. In this section, we describe the stratigraphic ranges of the inoceramids in detail.

The Middle/Upper Turonian boundary was proposed as the horizon of the lowest occurrence of the ammonoid *Romaneoceras deverianum* (d’Orbigny) in the Tethyan biotic realm and as the horizon of the lowest occurrence of the ammonoid *Subprionocyclus neptuni* in the Boreal regions (Bengtson 1996). Subsequently, Wiese and Kaplan (2001) proposed as candidate GSSP for the Middle/Upper Turonian boundary the Lengerich quarry section in the Münster Basin of northern Germany and indicated that the horizon of the lowest occurrence of *Subprionocyclus neptuni* and *Inoceramus perplexus* Whitfield was useful for correlation. The occurrence of *Subprionocyclus et neptuni* was reported by Tanabe et al. (1977) in the *I. hobetsensis-I. teshioensis Concurrent-range Zone* in the Obira area of Hokkaido. Funaki and Hirano (2004) correlated this zone with the Middle/Upper Turonian boundary transition, and the *I. teshioensis Partial-range Zone* with the Upper Turonian. In the Obira area, the occurrence of *I. pedalionoides* is in the *I. teshioensis Partial-range Zone*, and the highest occurrence of this species is in the uppermost part of the *I. uwajimensis Interval Zone*. Consequently, *I. pedalionoides* is the Late Turonian species. Takahashi and Mitsugi (2002) suggested that the range of *I. pedalionoides* overlapped with that of *I. hobetsensis* in the Teshionakagawa area, northern Hokkaido, and indicated the possibility that the lowest occurrence of *I. pedalionoides* was correlated with the Middle Turonian. On the basis of this correlation, *I. pedalionoides* can possibly range from the Middle Turonian to the Upper Turonian. Mytiloides incertus occurs together with *I. tenus-triatus* and *I. teshioensis* (Matsumoto and Noda 1983; Noda and Matsumoto 1998), and this species occurs in Upper Turonian strata worldwide (e.g., Matsumoto and Noda, 1983; Noda 1984; Noda and Matsumoto 1998; Dhondt 1992; Walaszczyk and Cobbân 2000). Though the occurrence of *Mytiloides incertus* is rare in the study areas (Text-fig. 5, 6), it is mostly concurrent with *I. teshioensis* but not with *I. uwajimensis* in the Ikushunbetsu area, central Hokkaido (e.g., Noda and Matsumoto 1998). Thus, the range of *M. incertus* is included within the *I. teshioensis Partial-range Zone*. As previously mentioned, the *I. teshioensis Partial-range Zone* is correlated with the Upper Turonian (Funaki and Hirano 2004) and includes the Upper Turonian Bridgewick and Hitch Wood Isotope events. Therefore, the chronostratigraphic age of *M. incertus*, based on the δ13C correlation, corresponds to the previous biostratigraphic interpretations (Matsumoto and Noda 1983; Noda 1984; Noda and Matsumoto 1998). The highest occurrence of *I. teshioensis* and the lowest occurrence of *I. uwajimensis* are between the Hitch Wood and Navigation Isotope events (Text-fig. 11). Thus, the lowest occurrence of *I. uwajimensis* is in the uppermost Turonian. This interpretation corresponds to the biostratigraphic correlation of Funaki and Hirano (2004). The occurrence of *Platyceramus szaszi* (Noda and Uchida) ranges from the *I. uwajimensis Interval Zone* to the *Cr. mihoensis Interval Zone*. This species was reported in the middle Coniacian by Noda and Uchida (1995). However, this study has shown that *P. szaszi* ranges from the uppermost Turonian to the Middle Coniacian because the highest occurrence of this species is below the inferred equivalent of the White Fall Isotope Event.

The base of the Coniacian is taken at the lowest occurrence of *Crennoceramus deformis erectus* (Meek) (Kaufman et al. 1996; Walaszczyk and Wood 1998), and this horizon corresponds to the Navigation Isotope event Event (Jarvis et al. 2006). The Navigation Event is recognised in the lower part of the Haborogawa Formation by the correlation of the δ13C_TOM fluctuations with the δ13C_carb curve. The lowest occurrence of *Cr. mihoensis* is at this horizon. Although the occurrence of *Cr. mihoensis* was believed to indicate the upper Coniacian (e.g., Toshimitsu et al. 1995), the lowest occurrence of *Cr. mihoensis* marks the base of the Coniacian Stage.
The lowest occurrence of *Cordiceramus kawashitai* (Noda) is in the middle part of the *Cr. mihoeensis* Interval Zone (Text-fig. 11). The lowest occurrence of *I. amakusensis* is below the horizon of the Kingsdown Isotope Event. The occurrence of *I. amakusensis* was correlated with the Santonian (Toshimitsu 1988; Toshimitsu et al. 1995). In this study, however, the lowest occurrence of *I. amakusensis* is in the Middle Coniacian. The occurrence of *P. mantelli* was correlated with the upper Coniacian through the Santonian in the conventional biostratigraphic scheme in the North Pacific province (Noda and Toshimitsu 1990). However, the lowest occurrence of *P. mantelli* and *S. naumannii* occurs in the Santonian succession, and the highest occurrence of these species is above the Santonian/Campanian Boundary Event.

The base of the Santonian is marked by the lowest occurrence of *Cladoceramus undulatoplicatus* (Roemer) (Lamolda and Hancock 1996), which is associated with the Michel Dean Isotope Event (Jarvis et al. 2002, 2006). The highest occurrence of *I. amakusensis* and *P. mantelli* is just above the horizon of the Santonian/Campanian Boundary Event, and the highest occurrence of these species is correlated with the lowermost Campanian. *P. ezoensis* ranges from the uppermost part of the *I. amakusensis* Interval Zone to the *P. japonicus* Interval Zone, which is correlative with the lower Campanian, but not with the basal part of the stage (Text-fig. 11). The occurrence of *P. japonicus* is correlated with the upper Lower Campanian.

Takashima et al. (2010) correlated their bulk wood δ¹³C curve with the δ¹³Ccarb record of the English Chalk reported by Jarvis et al. (2006). They correlated the *I. uwajimensis*, *I. amakusensis* and *P. japonicus* zones with the uppermost Turonian, basal Coniacian to basal Campanian and upper Lower Campanian, respectively. They investigated the high-resolution chemostratigraphy of the sections along the Kotanbetsu River, which is located between the Haboro and Obira areas. Takashima et al. (2010) used the inoceramid records reported by Wani and Hirano (2000); however records from a single section in one area would be inadequate to enable revision of the Japanese inoceramid biozonal scheme. The inoceramid biostratigraphy of the Yezo Group is herein revised significantly, at least in northwestern Hokkaido. Further studies are needed to improve the inoceramid biozonal scheme in the North Pacific biogeographic province.

**Implications of the revised inoceramid biostratigraphy**

The uppermost Turonian of the Euramerican region is characterised by the disappearance of the *Mytiloides* group and the lowest occurrence of *Cremnoceramus* (Walaszczyk and Wood 1998; Walaszczyk and Cobban 2000). The period from the Middle Coniacian to the Santonian of the United States Western Interior and Europe represents the highest taxonomic and morphological diversity in inoceramids (Walaszczyk and Cobban 2006). Meanwhile, Takahashi (2005) showed the diversity changes in the Japanese inoceramids in the context of the previous biozonal scheme, but did not refer to the differences in these changes between Japan and Euramerica. Thus, it is important to discuss the differences in the diversity changes in inoceramids between Japan and Euramerica using the revised inoceramid biozones and chronostratigraphic ages for the Coniacian through Santonian interval, with the aim of evaluating the timing of the originations and the extinctions between the inoceramid evolutionary patterns and the environmental factors in each biogeographic region for further study.

In Europe and the Western Interior of the United States, the Turonian/Coniacian, Lower/Middle Coniacian, Middle/Upper Coniacian and Coniacian/Santonian boundaries are generally determined by the lowest occurrence of the age-diagnostic inoceramid species, and these boundaries correspond to changes in the generic composition of the inoceramid assemblages (e.g., Walaszczyk and Wood 1998; Walaszczyk and Cobban 2000; Walaszczyk and Cobban 2006). The base of the Coniacian is taken at the lowest occurrence of *Cremnoceramus deformis erectus* (Kauffman et al. 1996; Walaszczyk and Wood 1998; Walaszczyk and Cobban 2000). The Lower/Middle Coniacian boundary is taken at the lowest occurrence of *Volviceramus koeneni* (G. Müller) (Kauffman et al. 1996) and the Middle/Upper Coniacian boundary at the lowest occurrence of *Magadiceramus subquadратus* (Schlüter) (Kauffman et al. 1996). The base of the Santonian is taken at the lowest occurrence of *Cladoceramus undulatoplicatus* (Roemer) (Lamolda and Hancock 1996). These genera, including the age-diagnostic species, characterise each stage or substage: *Cremnoceramus* indicates the Lower Coniacian, *Volviceramus* the Middle Coniacian, *Magadiceramus* the Upper Coniacian, and *Cladoceramus* the Santonian in the Euramerican region (Walaszczyk and Wood 1998; Walaszczyk and Cobban 2000; Walaszczyk and Cobban 2006). Moreover, the highest occurrence of *Cladoceramus undulatoplicatus* has been suggested as a
marker for the Lower/Middle Santonian boundary, and the lowest occurrence of *Cordiceramus muelleri* (PetrascHECK) has been approximately correlated with the Middle/Upper Santonian boundary, albeit these are not formal proposals (e.g., Walaszczzyk and Cobban 2006). Conversely, Gale et al. (2008) indicated that the Santonian/Campanian boundary is not associated with a corresponding inoceramid event in the candidate Santonian GSSP in the Waxahachie Dam Spillway section, north Texas, USA; the Santonian/Campanian boundary lies within the *P. ezoensis* Acme Zone. Therefore, the timing of the extinction and origination of inoceramids in the Euramerican region correspond to the stage or substage boundaries at least in the interval from the Early Coniacian to the Upper Santonian.

Text-fig. 12 shows that several inoceramids range across the stage boundaries in the Yezo Group. For example, *I. uwajimensis* ranges from the uppermost Turonian to the Middle Coniacian, and *I. amakusensis, P. mantelli* and *S. naumanni* all range from the Middle or Upper Coniacian to the Lower Campanian. *P. japonicus* appears to occur in the upper Lower Campanian. Above the Lower Coniacian, the timing of origin and extinction of inoceramids does not correspond to the stage or substage boundaries.
boundaries in Hokkaido, based on the chemostratigraphic correlations (Text-fig. 12). Takahashi (2005) reported high extinction rates at the Turonian/Coniacian boundary (75.0%) and at the Lower/Middle Coniacian boundary (70.0%). Takahashi (2005) also indicated that the generic composition of the inoceramid assemblage changed drastically at the Turonian/Coniacian boundary. Nevertheless, the previous Turonian/Coniacian and the Lower/Middle Coniacian boundaries are correlated with the uppermost Turonian by the chemostratigraphic correlations in this study. Therefore, the low extinction rates, constant origination rates and similar generic compositions were shown from the Turonian/Coniacian boundary (Middle/Upper Coniacian boundary of Takahashi 2005) to the Santonian/Campanian boundary (Takahashi 2005). The results of this study reflect the trend of inoceramid diversity changes in Japan (Takahashi 2005), and the timing of originations and extinctions of inoceramids does not correspond to the stage or substage boundaries.

It is reasonable to suggest that the timing of originations and extinctions of inoceramids in Japan is different from those of Europe and North America. Because the Santonian Stage in Japan could not be subdivided by using the inoceramid biozones (Text-fig. 12) and has not been subdivided into substages, we do not discuss the difference of the changes in the generic composition above the Middle Santonian between the North Pacific biotic province and the Euramerican biogeographic region. Therefore, inoceramids belonging to the North Pacific biotic province would have been controlled by different bioevents from those in the Euramerican region, at least in the interval from the Early Coniacian to Early Santonian.

CONCLUSIONS

We presented high-resolution carbon isotope records of terrestrial organic matter for the Yezo Group in the Haboro and Obira areas of northwestern Hokkaido, Japan. The integrated δ13C_TOM curve correlates with the δ13C_carb record in England and Germany for the Upper Turonian–Lower Campanian interval. Based on the chemostratigraphic correlations, we recognised 11 of the isotope events identified in the English Chalk by Jarvis et al. (2006): the Bridgewick Event, the Hitch Wood Event, the Navigation Event, the White Fall Event, the Kingsdown Event, the Michel Dean Event, the Haven Brow Event, the Horseshoe Bay Event, the Buckle Event, the Hawks Brow Event and the Santonian/Campanian Boundary Event. Based on the recognition of these isotopic events, we revised the chronostratigraphic ages of the inoceramid biozones of the Yezo Group.

1) The Inoceramus uvajimensis Interval Zone is defined as the stratigraphic interval from the lowest occurrence of I. uvajimensis to that of Cremnoceramus mihoensis. The age of this zone is latest Late Turonian.
2) The Cremnoceramus mihoensis Interval Zone is defined as the stratigraphic interval from the lowest occurrence of C. mihoensis to that of Inoceramus amakusensis. The age of this zone is Early to Middle Coniacian.
3) The Inoceramus amakusensis Interval Zone is defined as the stratigraphic interval from the lowest occurrence of I. amakusensis to that of Platyceramus japonicus. The age of this zone is the Middle/Late Coniacian to early Early Campanian.
4) The Platyceramus japonicus Interval Zone is defined as the stratigraphic interval from the lowest occurrence of P. japonicus to that of Sphenoceramus schmidti. The age of this zone is late Early Campanian. This correlation suggests that the timing of the inoceramid originations and/or extinctions differs that of the stage and substage boundaries in the interval from the Lower Coniacian to the Santonian. The timing of the diversity changes in the North Pacific inoceramids is inconsistent with those in the Euramerican region for this period.

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