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FIELD EXCURSION GUIDEBOOK

FE-A1

Shallow to offshore marine bio- and lithofacies changes along basin transect and Cenomanian-Turonian oceanic anoxic event in Cretaceous Yezo forearc basin, central Hokkaido

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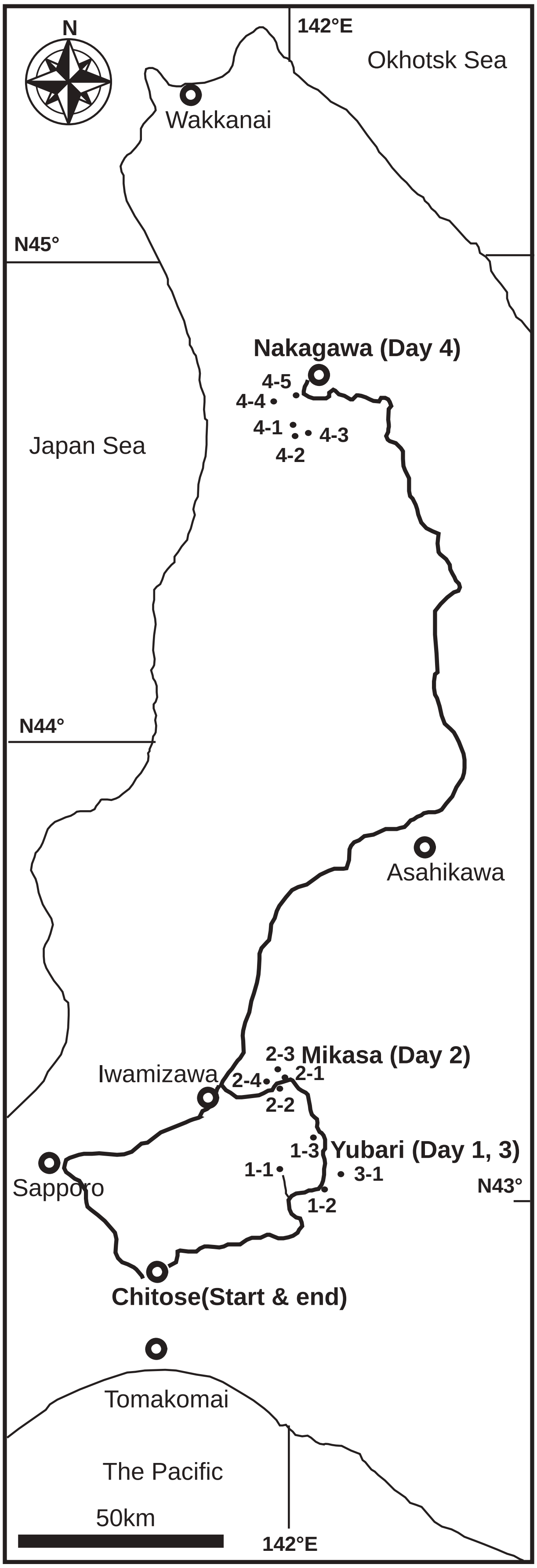
ROUTE MAP


N
142°E
Okhotsk Sea
Wakkanai
N45°
Nakagawa (Day 4)
4-5
4-4
4-1
4-3
4-2
Japan Sea
N44°
Asahikawa
2-3
Mikasa (Day 2)
Iwamizawa
2-4
2-1
2-2
1-3
Yubari (Day 1, 3)
1-1
3-1
Sapporo
N43°
1-2
Chitose(Start & end)
Tomakomai
The Pacific
50km
142°E

Itinerary

DAY 1: Wednesday, August 23rd, 2006

12:30 Participants arrive at Chitose Airport
Move to Yubari
Stop 1-1 --- Yubari Coal Mine Museum
Stop 2-2 --- Oyubari Dam, Hakobuchi gorge, Shuparo River (High-frequency shallow-marine parasequences of the Campanian-Paleocene Hakobuchi Formation)
Stop 1-3 --- Forestry road of Panke-horokayuparo River (HCS sandstone facies of the Hakobuchi Formation) if available
18:00 Arrival at Katsurazawa Kanko Hotel
19:00 Dinner
20:00-21:30 Preliminary meeting and overview lecture

DAY 2: Thursday, August 24th, 2006

07:30 Breakfast
08:30 Leave hotel for field
Stop 2-1 --- Path along covered prefectural road in Katsurazawa (Cenomanian-Turonian shallow-marine facies of the Mikasa Formation in the eastern limb of the Ikushumbetsu Anticline)
Stop 2-2 --- Katsurazawa sandstone quarry & lunch (Turonian storm-formed sandstone succession, the upper part of the Mikasa Formation
Stop 2-3 --- Ponbetsu River section (Cenomanian-Turonian shallow-marine facies of the Mikasa Formation in the western limb of the Ikushumbetsu Anticline)
Stop 2-4 --- Mikasa City Museum (Excellent ammonite collection)
17:00 Leave the museum to Katsurazawa Kanko Hotel
18:30 Dinner and welcome party

DAY 3: Friday, August 25th, 2006

07:00 Breakfast
08:00 Leave hotel for field
Stop 3-1 --- Shirakin (Hakkin-zawa) River, Oyubari area (C/T boundary section in the offshore mudstone facies of the Saku Formation)
Stop 3-1'-- Takinosawa River, Oyubari area (C/T boundary section along forestry road)
Lunch in bus
13:30 Leave Yubari to Nakagawa through Mikasa (Katsurazawa Kanko Hotel)
18:30 Arrival at Ponpira Hotel (Nakagawa Ponpira Aqua Lizning Hotel)
19:00 Dinner
20:00 Explanatory lecture

DAY 4: Saturday, August 26th, 2006

07:30 Breakfast
08:30 Leave hotel for field
Stop 4-1 --- Osoushinai River (Offshore mudstone facies bearing ammonite fauna of the Osoushinai Formation)
Stop 4-2 --- Abeshinai River (Cretaceous seep carbonate with well-preserved fossil chemosynthetic community of the Omagari Formation)
Picnic lunch
Stop 4-3 --- Forestry road along the Shibunnai River, Kyowa (Channel facies of the Saku Formation)
Stop 4-4 --- Forestry road along the Uttsu River, Enbetsu (Coarsening-upward facies successions and large-scale forset cross-bedding of the Hakobuchi Formation)
Stop 4-5 --- Nakagawa Museum of Natural History
17:30 Leave field to Ponpira Hotel
18:30 Dinner and farewell party

DAY 5: Sunday, August 27th, 2006

07:00 Breakfast
08:00 Check out of room and leave Nakagawa to Chitose Airport
Lunch in bus
13:30 Arrival at Chitose Airport

Shallow to offshore marine bio- and lithofacies changes along basin transect and Cenomanian-Turonian oceanic anoxic event in Cretaceous Yezo forearc basin, central Hokkaido

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Keywords: shallow marine to offshore siliciclastic sedimentation, sequence stratigraphy, taphonomy, Cenomanian/Turonian, oceanic anoxic event, cool seep carbonate, Cretaceous forearc basin, Hokkaido

Introduction

Cretaceous to Paleocene sediments filling the Yezo forearc basin (Okada, 1983), are widely distributed over a distance of 1,400 km from south Sakhalin to offshore of north Honshu through the meridian zone of central Hokkaido and have a North–South trend (e.g., Matsumoto, 1942, 1943; Hirano et al., 1992; Ando, 2003; Takashima et al., 2004) (Fig. 1). The sediments well exposed in central Hokkaido, northern Japan, are called the Yezo Group (Matsumoto, 1951). This group consists of a very thick sedimentary sequence of mudstones and sandstones with subordinate conglomerates conformably overlying the Sorachi Group, an ocean floor sequence that was formed during the Late Jurassic-Barremian. The Yezo Group is 10,000 m thick in the type section in the Oyubari area (Matsumoto, 1942; Motoyama et al., 1991; Takashima et al., 2004). It is separated by a disconformity or a gentle angular unconformity from the overlying Middle–Upper Eocene coal-bearing Ishikari Group, the Upper Eocene–Lower Oligocene Poronai Group, or Miocene marine strata.

As the Yezo Group contains various, abundant, well-preserved macro- and microfossils, many biostratigraphic schemes have been established (e.g. Matsumoto, 1942, 1943; Toshimitsu et al., 1995, 1998; Ando et al., 2001; Nishi et al., 2003). In the last decade, carbon isotope excursions of organic materials have also been detected across the Cenomanian/Turonian boundary (OAE2), middle Albian (OAE1c) and upper Lower Aptian (Hasegawa and Saito, 1993; Hirano, 1995; Hasegawa, 1995, 1997, 2003; Hirano and Fukuju, 1997; Ando et al., 2002, 2003). Furthermore, on the basis of oxygen isotopic analyses, the thermal structure of the Yezo forearc sea has recently been investigated by Moriya et al.(2003).

Sedimentological studies were also thoroughly carried out by Tanaka (1963, 1970, 1971) and Tanaka and Sumi (1981) from the viewpoint of palaeocurrent system and turbidite sequence, by Fujii (1958), Okada (1965, 1974) and Matsumoto and Okada (1971, 1973) from sandstone petrography and sedimentary cycle, and recently by Ando (1987, 1990a, b, 1993, 1997, 2003, 2005, etc.) from sedimentary facies and sequence stratigraphy.

In this field excursion, we will observe the lithofacies and biofacies changes of the Yezo Group accumulated on the western part of the Cretaceous to Paleocene Yezo forearc basin, from such various viewpoints as biostratigraphy, chemostratigraphy and paleoceanography as well as sedimentology and sequence stratigraphy. The east-westward facies changes are most dominant for the Cenomanian and Turonian in the Yubari and Mikasa areas (Days 1-3). The western shallow-marine facies called the Mikasa Formation is characterized by hummocky cross-stratified sandstone and molluscan assemblages including thick-shelled trigonid and veneroid bivalves (Day 2), and the eastern offshore mudstone-dominated facies called the Saku Formation by various kinds of heteromorph and smoothed ammonites (Day 3). We can trace the Cenomanian-Turonian oceanic anoxic event horizon by carbon isotope excursion in the Saku Formation of the Oyubari area.

The Coniacian transgression domestically called the Urakawan transgression in Japan, resulted in the prevalent Coniacian to lowest Campanian mudstone facies all around the basin. We will observe such facies bearing well-preserved ammonites and some other fossils in the Nakagawa area, north Hokkaido (Day 4). We will also see a cool-seep limestone block recently discovered in the mudstone facies Omagari Formation (= the middle part of the Haborogawa

Formation: Day 4) (Hikida et al., 2003). During the Campanian and Maastrichtian time the Yezo basin was uplifted and filled up with the shallow-marine to non-marine sediments well exposed in the Nakagawa (Day 4) and Yubari areas (Day 1). Later, the Yezo Group was eroded to some extent, and some coal measures were formed depending on oscillations of sea level from Eocene onward (Day 1).

Additionally, participants can briefly get information on the historical background of the Ishikari Coal Field region from streets and museums of the Yubari and Mikasa Cities (Days 1-3), and also the nature and culture of Hokkaido.

Geologic Setting

Hokkaido, the north island of Japan, having a rhombic or cubic shape with a N-S trending diagonal line, comprises six major tectonostratigraphic units from west to east, i) Oshima, ii) Rebun-Kabato, iii) Sorachi-Yezo, iv) Hidaka, v) Tokoro and vi) Nemuro Belts, on the basis of the lithofacies and tectonic features of the Mesozoic and the lower Cenozoic (Fig. 1; Kiminami et al., 1986; Ueda et al., 2000; Ando, 2003; Takashima et al., 2004).

The N-S trending zonal geologic framework is a product of subduction and collision processes in the northeastern margin of the Eurasia plate. The western four belts are regarded as elements of the Paleo-Japan arc-trench system (Oshima, Rebun-Kabato, Sorachi-Yezo and Hidaka Belts). The Rebun-Kabato and Oshima belts represent an Early Cretaceous volcanic arc and the underlying Jurassic accretionary complexes, respectively. The Sorachi-Yezo Belt was formed in the Cretaceous-Paleocene forearc basin and the eastern trench slope. The Hidaka Belt may be an accretionary complex formed by westward subduction of the Izanagi-Kula plates beneath the Eurasia continental margin during early Paleogene (Fig. 2). On the other hand, the eastern two belts may represent the Paleo-Kuril arc-trench system composed of forearc basin sediments (Nemuro Belt) and associated accretionary complex (Tokoro Belt). After the Izanagi-Kula plate had subducted northward

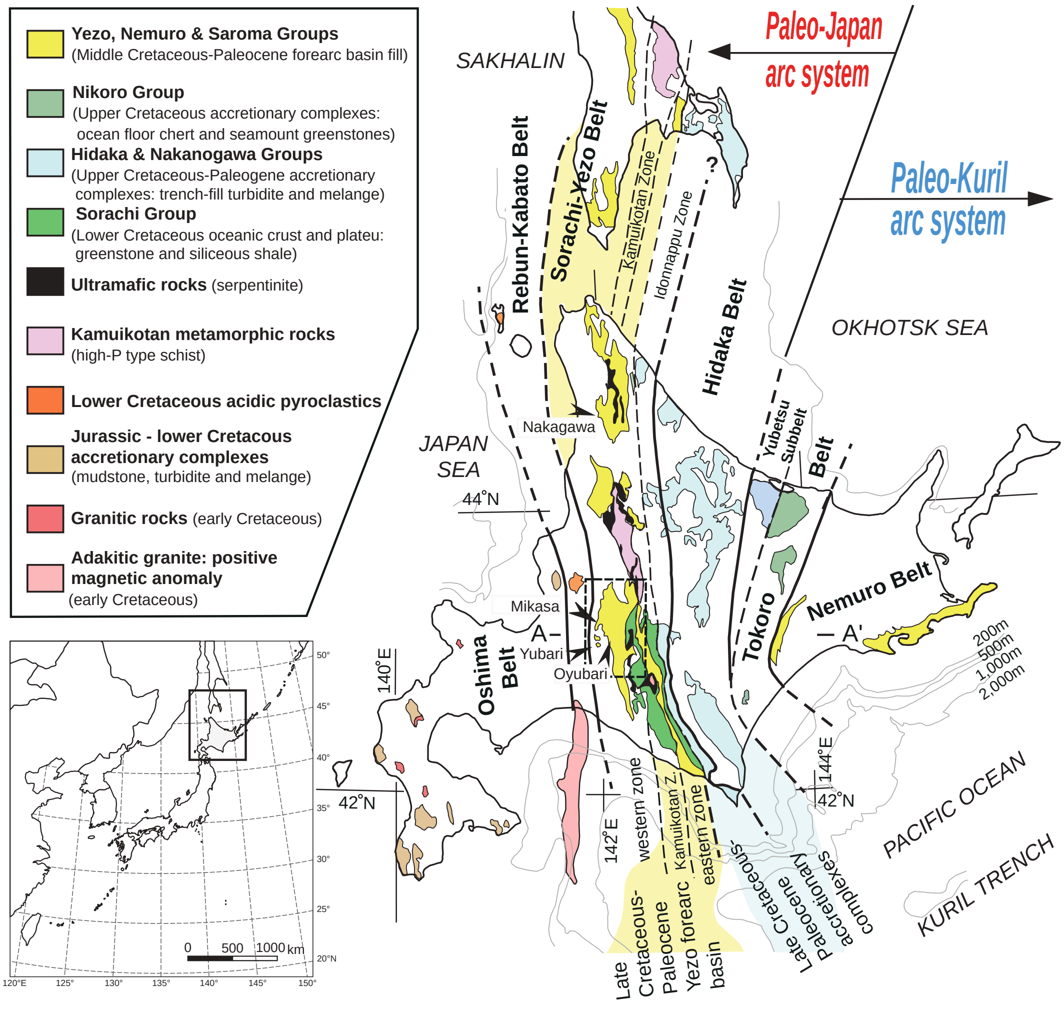

Fig. 1. Major geologic units and distribution of the Mesozoic to lower Paleogene systems in Hokkaido. Modified from Ando (2003, 2005) and Takashima et al. (2004). Rectangle: location of Fig. 4. A-A': location of cross section in Fig. 2.

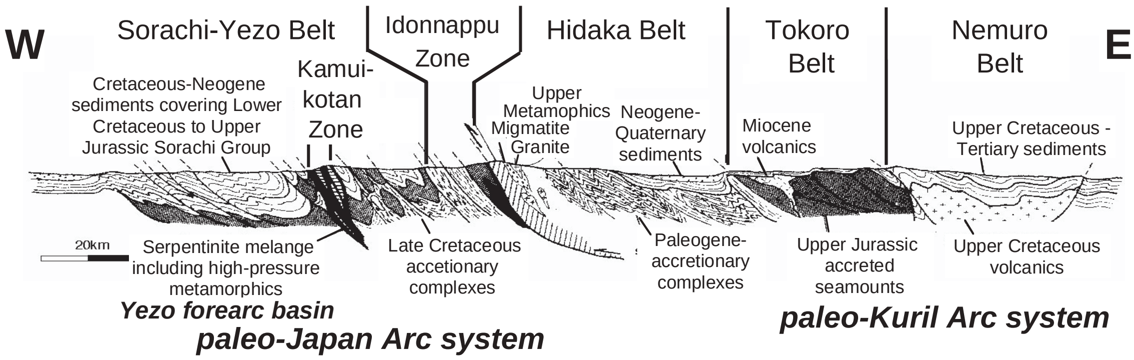

Fig. 2. East-westward geologic profile of Hokkaido. Location of cross section A-A' shown in Fig. 1. Modified from Kimura (1986) and Ando (2005).

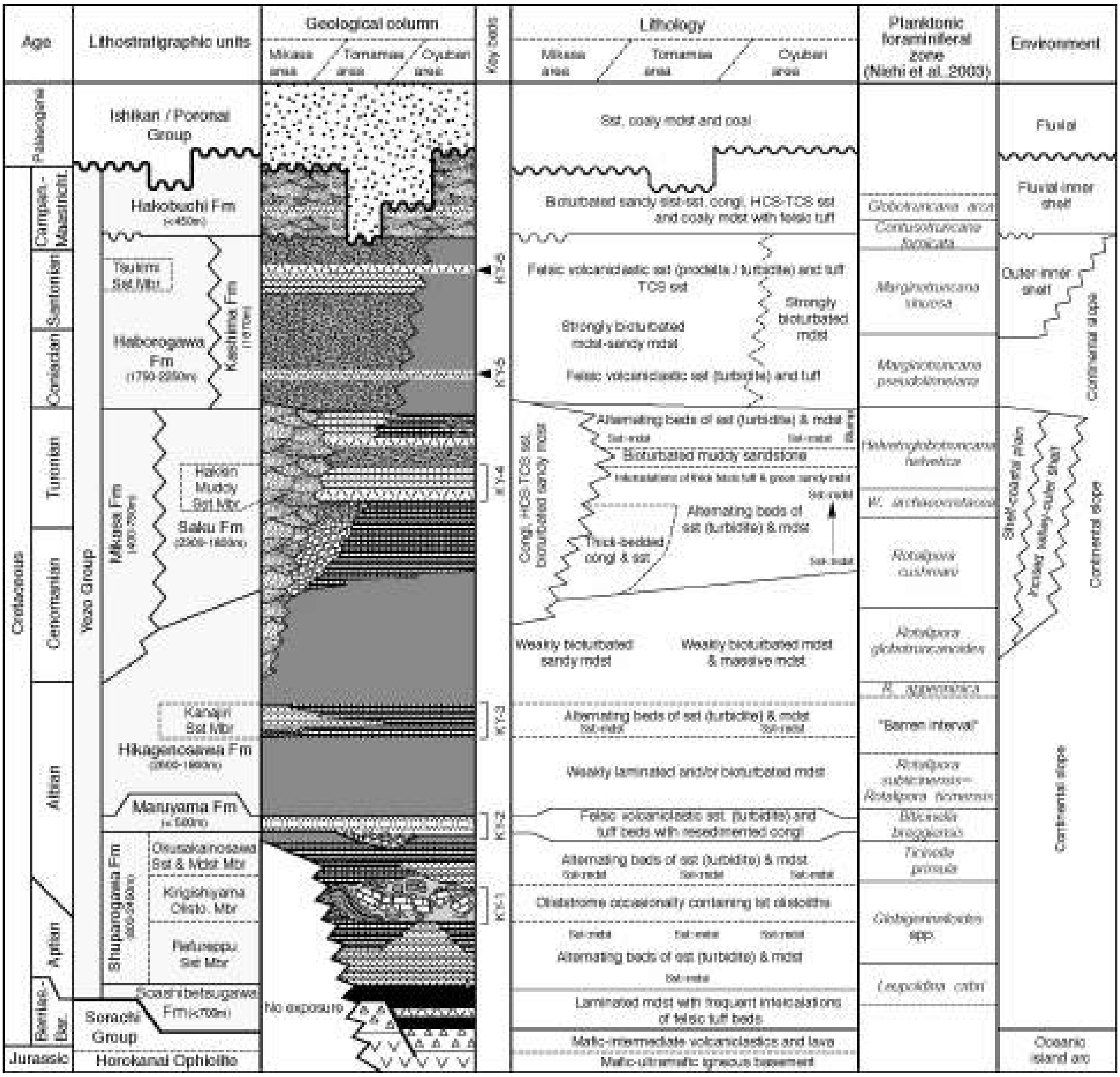

Fig. 3. Schematic stratigraphical profile of the Yezo Group in the central Yezo-Sorachi Belt, central Hokkaido. The geological column shows eastward-deepening facies trend (after Takashima et al., 2004).

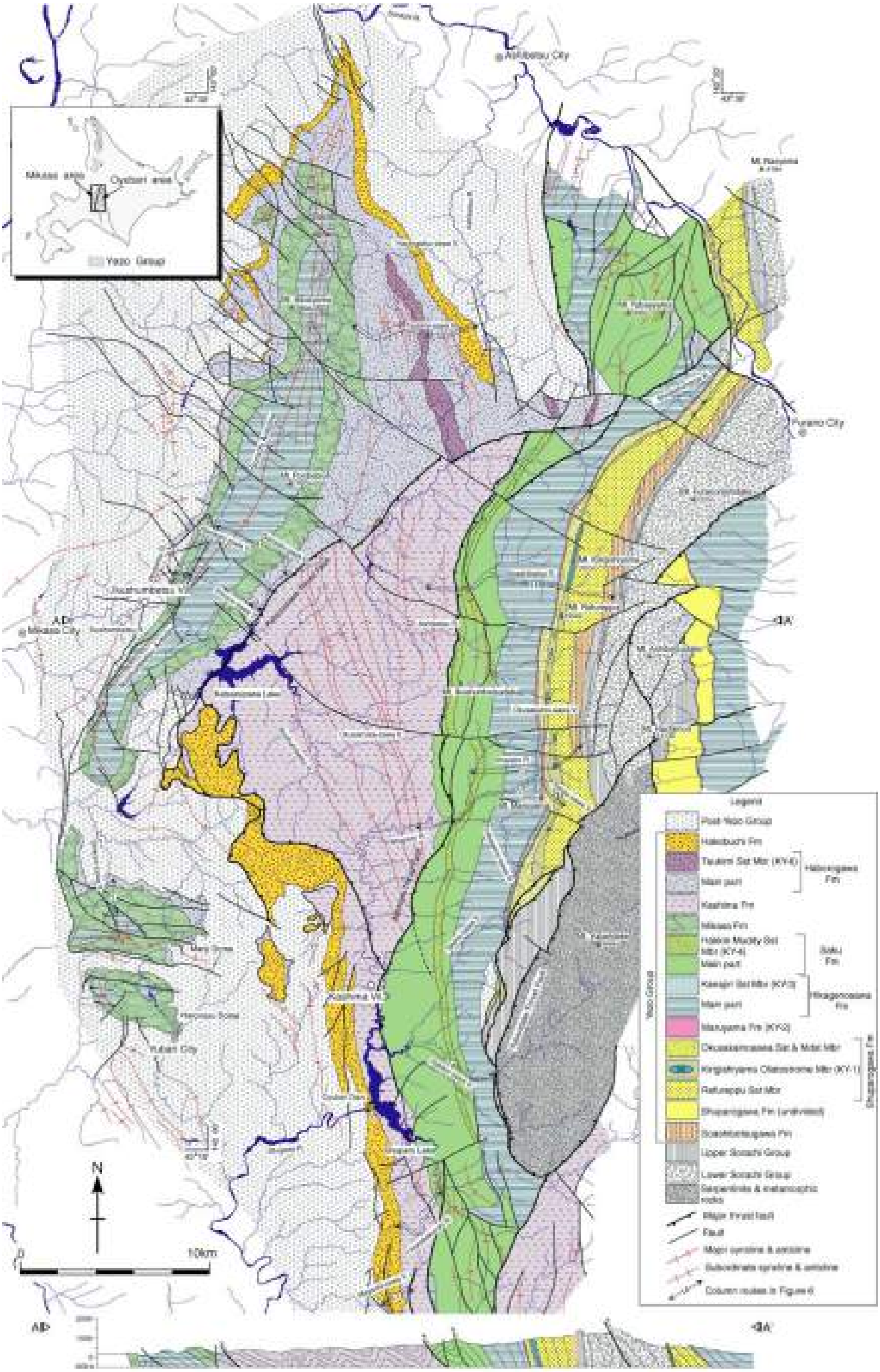

Fig. 4. Geological map and structural profile section of the Yezo Group in the central Yezo-Sorachi Belt, central Hokkaido (after Takashima et al., 2004). The south-eastern Oyubari and north-western Mikasa areas are bounded by the Katsurazawa Thrust Fault.

beneath the Okhotsk paleoland/microplate during late Cretaceous and Paleogene, two belts collided to create the four belts of the Paleo-Japan arc-trench system with a nearly 90-degree clockwise rotation in Miocene.

The Sorachi-Yezo Belt consists of a coherent succession, from the Horokanai Ophiolite through the Sorachi Group to the Yezo Group (Fig. 3), and the accretionary complexes of the Idonnapu and Kamuikotan zones (Ueda et al., 2000). The Horokanai Ophiolite and the lower part of the Sorachi Group represent a piece of basaltic oceanic crust (Takashima et al., 2002), while the upper part of the Sorachi Group is represented by subaqueous calcalkaline and alkaline volcano-sedimentary sequences, suggesting an oceanic island arc setting (Girard et al., 1991; Takashima et al., 2002). The Yezo Group conformably overlies the Sorachi Group and comprises very thick sandstone and mudstone sequences. The sandy clastics of this sequence were derived from Cretaceous granitic rocks and Jurassic accretionary complexes of the Oshima Belt, which represents a

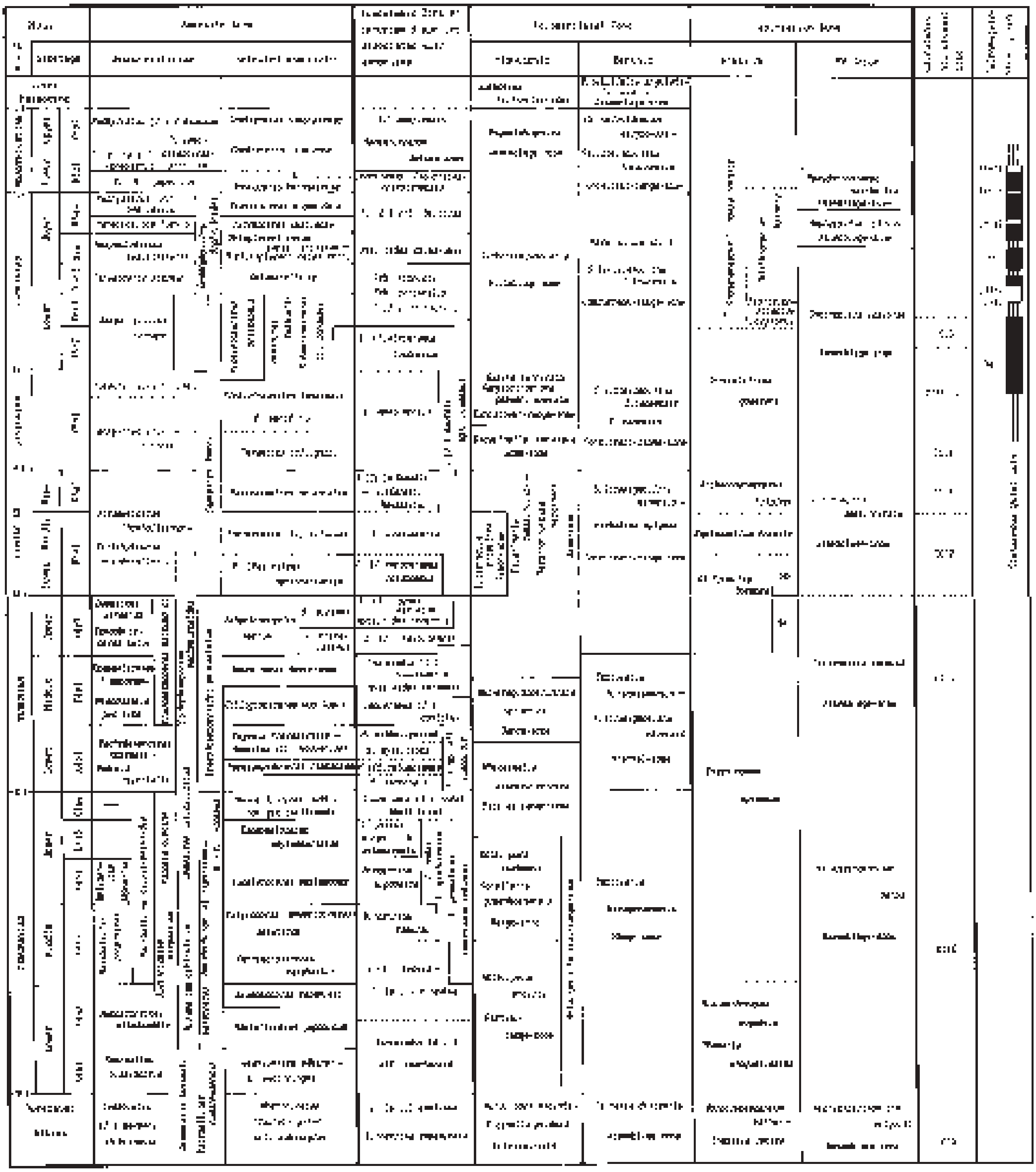

Fig. 5. Biostratigraphic zonation of Cenomanian to Maatsrichtian in Japan by Toshimitsu et al. (1995).

contemporaneous continental arc setting (Kito et al., 1986). Besides these, serpentinite melanges with high-P and low-T type Kamuikotan metamorphic blocks and other mélange complexes constitute an axial part and a large-scale anticlinorium of the belt called the Kamuikotan Zone (Niida and Kito, 1986; Nakagawa and Toda, 1987). Therefore, the Yezo Group is distributed in both the eastern and western sides of the axis forming two rows.

In the central part of the Sorachi-Yezo Belt, the Yezo Group widely crops out in the eastern and western slopes of the Yubari mountain range whose core is composed of the Sorachi Group and the Yubari-dake serpentinite melanges (Nakagawa and Toda, 1987; Takashima et al., 2004; Fig. 4). The group of the west has been well studied in the Mikasa and Oyubari areas as the basement rocks for the Eocene coal measures called the Ishikari Group. The Ishikari Coal Field region including the Ashibetsu, Mikasa, Manji, Oyubari and Yubari areas from north to south, is the standard and reference area also for the Cretaceous biostratigraphy in Japan since Matsumoto (1942, 1943) because of the more abundance of zonal megafossils as ammonites and inoceramids than other areas (Fig. 5). It is structurally characterized by the N-S trending and north plunging Sorachi Anticline in the north, the NNE-SSW trending and south plunging Ikushunbetsu Anticline in the mid-west, and the Manji and Hatonosu Domes in the south. In the east bordering the Yubari mountain range, it strikes NNE to N, and steeply overturns west. Westward-overturned folds and thrusts including nappe structures are conspicuous in the western part of the Oyubari area (Figs. 2 and 4).

The Nakagawa area, northern Hokkaido, is also a classical and important region for Cretaceous biostratigraphy due to abundance of well-preserved megafossils. The area is situated in the western limb of the anticlinorium formed by the Yezo and Sorachi Groups and the Shirikomanai serpentinite mélanges. The Yezo Group is characterized by the N-S structural trend and is distributed westward in ascending order (Fig. 1).

Although the upper part of the Hakobuchi Formation, the uppermost of the Yezo Group includes the upper Paleocene in the Oyubari and Nakatonbetsu areas (Ando et al., 2001; Ando and Tomosugi, 2005), the geological age of this group ranges mostly from early Aptian to early Maastrichtian. Many hiatuses exist between the Campanian and Maastrichtian. The sedimentary environment of this group shows an eastward-deepening facies trend, from fluvial to continental slope (Fig. 3).

Stratigraphy

As reviewed in Hirano et al. (1992), Ando (2003) and Takashima et al. (2004), the nomenclature of lithostratigraphic divisions of the Yezo Group are complicated and differ between the researchers and the areas investigated within Hokkaido. This is because this group generally consists of a monotonous sequence of sandstone and mudstone and their alternating beds, which occasionally exhibit lateral facies changes. Several names have been used synonymously for the same lithostratigraphic unit: e.g., the Yezo Supergroup (Okada, 1983) was proposed to unify the conventionally-used Lower, Middle and Upper Yezo groups and Hakobuchi Group in ascending order. Takashima et al. (2004) proposed a new, synthesized stratigraphic framework based on extensive mapping, macro- and microfossil biostratigraphy of the entire area in the central region of Hokkaido. They revealed that the Yezo Group throughout Hokkaido is basically characterized by six alternations of mudstone-dominant units and sandstone-common units, with intercalations of six distinct stratigraphic key units (Figs. 3 and 6): the Soashibetsugawa Formation (siliceous mudstone unit: lower Aptian); the Shuparogawa Formation (sandstone-dominant turbidite unit: Aptian-lower Albian); the Maruyama Formation (felsic tuff and tuffaceous sandstone unit: middle Albian); the Hikagenosawa Formation (mudstone-dominant unit: upper Albian-lower Cenomanian); the Saku Formation (sandstone-common turbidite unit: lower Cenomanian-upper Turonian); the Kashima Formation (mudstone unit: Coniacian-lowest Campanian) and the Hakobuchi Formation (shallow-marine sandstone unit: Lower Campanian–Paleocene) in ascending order. They also recognized the sandstone-dominant, outer-shelf to shoreface Mikasa Formation (uppermost Albian-upper Turonian) and the overlying, sandy mudstone-dominant outer-shelf Haborogawa Formation (Coniacian-lowest Campanian), both of which represent the western marginal facies of the Yezo forearc basin. The former is exposed in the Mikasa area, and the latter in the Tomamae and Mikasa areas (Figs. 4 and 7). The geological ages of these formations correspond to the Saku and Kashima formations, respectively. Additionally, they named six stratigraphic key units as KY-1 to KY-6 consisting of olistostrome (KY-1), tuffaceous sandstone (KY-2, KY-4 to 6), and sandstone-conglomerate units (KY-3) (Figs. 3, 6 and 7).

This guidebook follows their standard stratigraphy instead of the conventionally-used quadripartite division (Lower, Middle and Upper Yezo groups

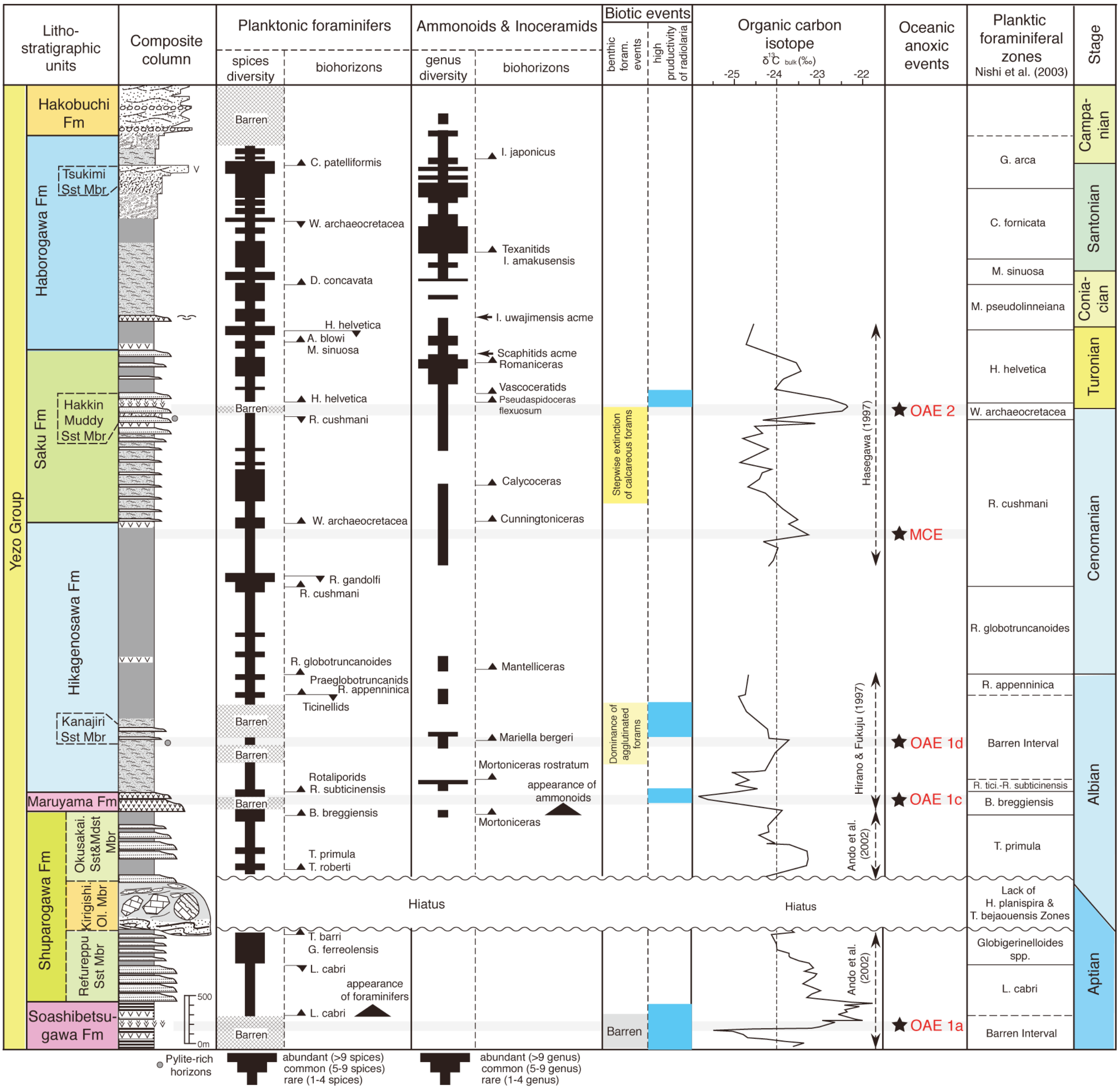

Fig. 6. Composite column of the Yezo Group, summarizing lithology, biostratigraphy, microfossil biotic events and carbon isotope stratigraphy (after Takashima et al., 2004).

and Hakobuchi Group) and examines the outline of formations observed in our excursion. Synthesized biostratigraphical zonation mainly based on the Yezo Group (upper Albian to Maastrichtian) is provided by Matsumoto et al.(1991) and Toshimitsu et al. (1995)(Fig. 5).

Soashibetsugawa Formation

The Soashibetsugawa Formation, the basal unit of the Yezo Group conformably overlying the Sorachi Group (Kito, 1987), is characterized by dark grey siliceous mudstone with abundant but no age-diagnostic radiolarian fossils. Microfossil assemblages and deep-sea trace fossils suggest an abyssal environment (Figs. 3 and 7, columns 11, 12).

2. Shuparogawa Formation

This formation is mainly composed of muddy to sandy turbidites and offshore mudstone intercalated with a thick olistostrome bed in the middle part (Kirigishiyama Olistostrome Member). The lower part called the Refureppu Sandstone (formerly Tomitoi Sandstone) Member constitutes alternating beds of turbiditic sandstone and dark grey mudstone and contains slump beds locally. The Kirigishiyama Olistostrome Member contains huge allochthonous blocks of massive sandstone (<40 m thick), alternating beds of sandstone and mudstone (<20 m thick) and limestone (<60 m thick) in a muddy matrix. Limestone olistoliths consist of corals, large foraminifers (*Orbitolina*), rudists, nerinean gastropods, calcareous

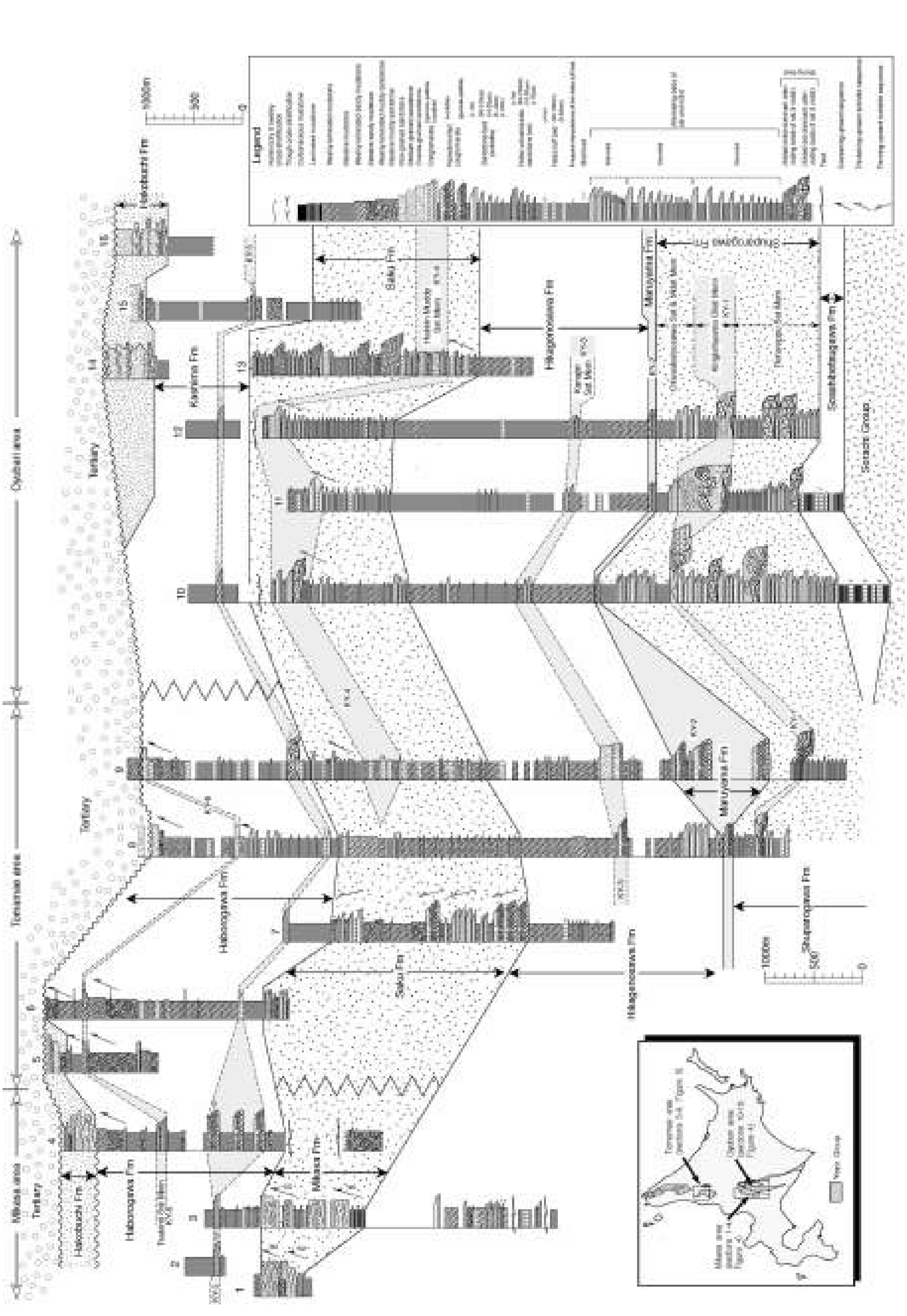

Fig. 7. Correlation of selected sections from central Hoakkaido (after Takashima et al., 2004). 1-5, Mikasa area. 1, Shikoro-zawa Valley; 2, Ponbetsu River; 3, Yonno-sawa Valley; 4, Ganseki-zawa ValleyeNanashi-zawa Valley; 5, Tsukimi-sawa Valley. 6-10, Tomamae area. 6, Sankebetsu River; 7, Nakafutamata River; 8, Shumarinai River; 9, Sounnai RivereKotanbetsu River; 10, Gosen RivereKanajiri-zawa ValleyeAkanosawa Valley. 11-17, Oyubari area. 11, Soashibetsu River; 12, Shuparo River; 13, Tengu-sawa Valley; 14, Hakkin-zawa Valley; 15, Oyubari dam; 16, Horokakuruki River; 17, Mayachizawa Valley. Each section is cited in Fig 4.

algae and ooids, contaminated with pebbles of chert, granite and sandstone. This member is widely traceable throughout central Hokkaido as a key unit (KY-1) (Figs. 3 and 7, columns 9-13). The Urgonian-type limestone is correlated with the shallow-marine Miyako Group exposed along the Sanriku Coast in northeast Honshu as an extension, in terms of such fossil composition. After the limestone had been formed on a carbonate platform such as a rimmed shelf along the Asian continental margin (Sano, 1995), the shallow carbonate platform collapsed by submarine sliding or something resembling that and mixed with the bathyal mudstone around the Aptian/Albian boundary (Okada, 1974; Niida and Kito, 1986).

The upper Okusakainosawa Sandstone and Mudstone Member basically comprises mudstone-dominant alternating beds, and varying thicknesses of sandstone, from 5 to 50 cm depending on the area.

3. Maruyama Formation

This formation is composed of an assemblage of hard felsic volcaniclastic sandstones, tuffs and associated conglomerates (Motoyama et al., 1991) (Figs. 3 and 7, columns 9-13). It also yields an excellent stratigraphic marker (KY-2), which extends throughout Hokkaido. In the central part of the Tomamae area, the total thickness of the conglomeratic beds exceptionally reaches as much as 900 m (Fig. 7, column 10). The conglomerates are thick-bedded, poorly-sorted, clast-supported and structureless. Abundant volcaniclastic materials in this formation suggest that huge, felsic volcanic eruptions episodically occurred along the western circum-Pacific/Asian continental margin. Main transporting channels for the volcanic sediments are inferred to have been located in the Tomamae area.

4. Hikagenosawa Formation

This formation is defined by the predominance of dark grey mudstone (Motoyama et al., 1991; Figs. 3 and 7, columns 4-14), although there are intercalations of a thin sandstone-dominant unit (Kanajiri Sandstone Member) in the lower middle part, which can be used as a stratigraphic marker, KY-3. The total thickness reaches 2,600m at its maximum in the Oyubari area. The occurrence of macrofossils (ammonoids and inoceramids) becomes common above the lower part of this formation. While the late Albian-middle Cenomanian ammonoids occur from calcareous concretions of various sizes, planktonic foraminifers indicative of the Late Albian-Late Cenomanian age (Nishi et al., 2003; Fig. 6) also occur from mudstone matrix. Benthic foraminiferal assemblages suggest that this formation was deposited in the lower part of the upper bathyal zone under relatively oxygenated conditions (Motoyama et al., 1991; Kaiho et al., 1993).

5. Saku Formation

This formation comprises alternating beds of turbiditic sandstone and mudstone, and incorporates a unit characterized by a predominance of greenish grey muddy sandstones with abundant trace fossils of *Planolites* and frequent felsic tuff beds of less than 2 m thick (Hakkin Muddy Sandstone Member; KY-4) in the middle part (Figs. 3 and 7, columns 7-16). The blackish-grey mudstone intercalated in the basal part of the member is correlated with the Cenomanian/Turonian boundary, based on the results of carbon isotope, mega- and microfossil stratigraphy (e.g., Hasegawa and Saito, 1993; Hirano, 1995; Hasegawa, 1997). Although macrofossils are few in the Hakkin Muddy Sandstone Member, Lower Turonian indicators, such as *Pseudaspidoceras flexuosus* (Powell) and vascoceratids, rarely occur.

The upper part of the formation begins with dark grey mudstone and changes to alternating beds of sandstone and mudstone. Slump beds and sandstone dykes are common in the southern Oyubari area. Sandstones are occasionally intensively bioturbated and bedding planes of some beds are destroyed. Mudstones and sandy mudstones are dark grey to grey and intensively bioturbated.

The abundant ammonites and inoceramids enable biostratigraphic zonation from the upper Cenomanian to middle Turonian. The upper part of this formation is marked by an abundant occurrence of heteromorph ammonoids, including *Nipponites*, *Eubostrichoceras* and scaphitids, and *Inoceramus hobetsensis* (bivalve) with minor Middle Turonian indicators such as *Romaniceras* spp. (ammonoid). Microfossils commonly occur throughout the sequence; radiolarians are especially abundant in the Hakkin Muddy Sandstone Member. This formation ranges from the *Rotalipora cushmani* to *Helvetoglobotruncana helvetica* pf zones, assigned to the Upper Cenomanian-Middle Turonian (Nishi et al., 2003; Fig. 6).

The benthic foraminiferal assemblages indicate the lower part of upper bathyal depth-zone with relatively low-oxygen conditions (Kaiho et al., 1993). The Saku Formation represents the contemporaneous heterotopic eastern facies for the Mikasa Formation, the western marginal sandstone-dominant facies. Thickness of this formation in the Oyubari area reaches 2,300 m a few times that of the Mikasa Formation. Paleocurrent analyses of the Saku Formation by Tanaka (1963,

1970) and Tanaka and Sumi (1981) showed that turbidity currents are characterized by dominant axial currents from SSW and lateral currents mainly from the west.

6. Mikasa Formation

The Mikasa Formation (300-750 m thick) distributed only in the western central part of the Sorachi-Yezo Belt represents the western marginal facies of the Yezo basin. It is mainly composed of shallow-marine to coastal sandstone, conglomerate and siltstone, which yield such bivalves as trigonids, glycymerids, ostreids, etc., more commonly than ammonites. This formation is the contemporaneous, shallower facies of the Saku Formation, and is characterized by the predominance of sandstones with hummocky and trough cross-stratification (HCS and TCS) and gravel/shell lags, and intensively bioturbated sandy mudstone (Figs. 3 and 7, columns 1, 2, 4) (Matsumoto, 1951; Ando, 1987, 1990a).

It is divided into three coarsening- and shallowing-upward successions, assigned as third-order depositional sequences (DS1, DS2 and DS3), each of which further includes three fourth-order sequences (4th DS) or parasequences (Ando, 1997; Fig. 8). As three DSs show conspicuous lateral and vertical facies changes, conglomerate and coarse sandstone tend to thicken in the west, and interbedded sandy mudstone becomes dominant and thick in the east. The detailed descriptions about depositional facies and their lateral changes are explained in the following chapter.

Shallow-marine bivalves (including *Cucullaea*, *Glycymeris*, *Pseudoptera*, *Pinna*, *Pterotorigonia*, *Apiotrigonia*, *Yaadia, Meekia*, *Thetis*, etc), gastropods (e.g., *Margarites*, *Semisolarium*) occur as storm-lag deposits within HCS sandstones (Figs. 11 and 17). Bioturbated, muddy sandstones to sandy mudstones contain rare to common ammonoids and inoceramids, but no microfossils. The Cenomanian ammonoids, *Mantelliceras* sp., *Calycoceras* sp. and *Desmoceras* spp. have been reported from the DS1 deposits (Matsumoto et al., 1991). The Turonian species, *Inoceramus hobetsensis* and *I. teshioensis* Nagao and Matsumoto, are abundant in bioturbated sandy mudstones of DS2 and DS3, respectively (Ando, 1990a, b; Fig. 17).

7. Kashima Formation

This formation is characterized by offshore, dark grey, bioturbated, massive mudstone reaching 400 to 1,700 m thick conformably overlying the sandy strata of the Saku Formation (Figs. 3 and 7, columns 11-17). It grades into muddy sandstone in the uppermost part. It is rarely intercalated with thin sandstone layers and very thin layers of acidic tuff. It is also intercalated with a felsic volcaniclastic unit of 10-20 m thick in the lower part. The unit consists of thick-bedded, coarse to fine volcaniclastic sandstones with interbedded dark grey mudstones. A diagnostic feature is abundant occurrences of *Inoceramus uwajimensis* Yehara from the interbedded mudstone. This unit is an excellent stratigraphic marker (KY-5) throughout Hokkaido.

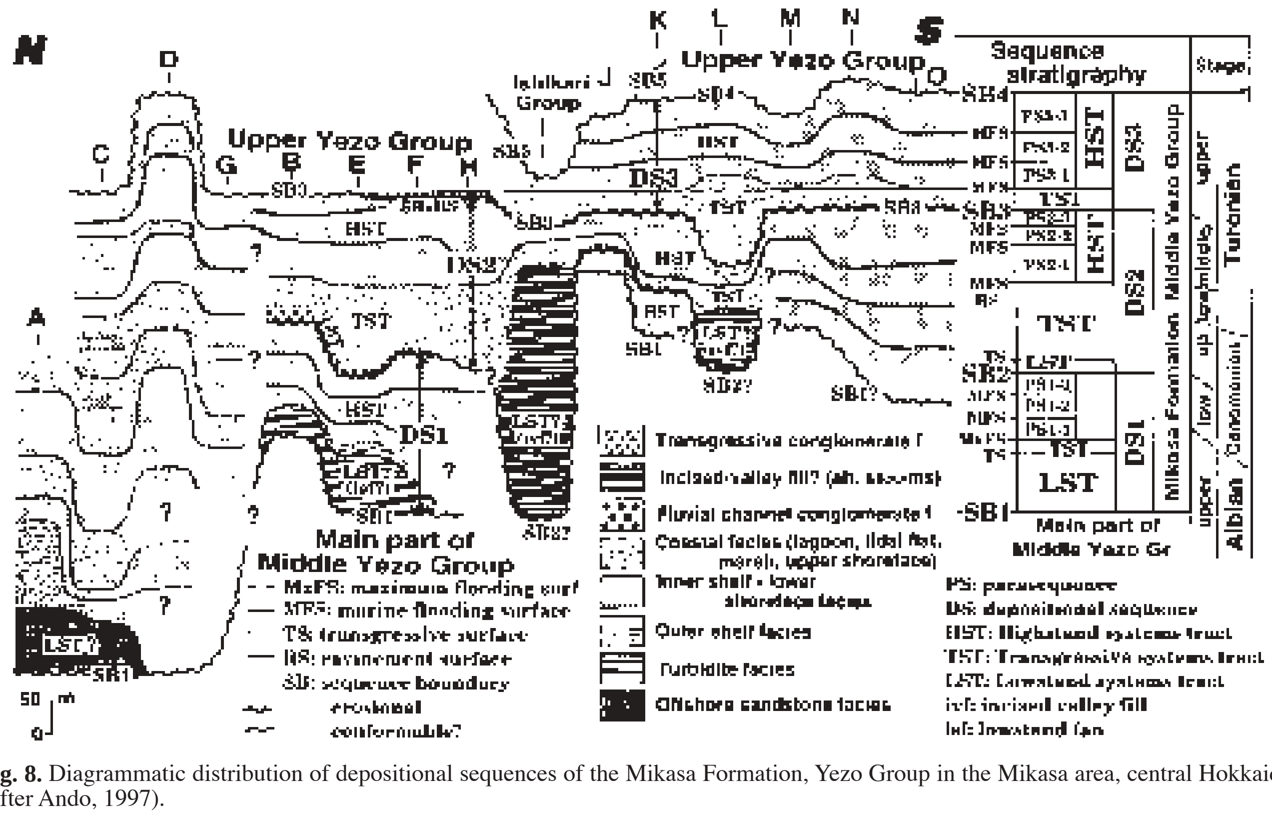

Fig. 8. Diagrammatic distribution of depositional sequences of the Mikasa Formation, Yezo Group in the Mikasa area, central Hokkaido (after Ando, 1997).

The Kashima Formation contains abundant calcareous concretions, including macrofossils such as ammonoids and inoceramids. *I. uwajimensis* is particularly abundant in the KY-5 unit. Microfossils (foraminifers and radiolarians) are abundant, although Tethyan marker-species are very rare. The four mid-latitude zones of planktonic foraminifers have, therefore, been proposed from the Late Turonian to Campanian in central Hokkaido, and can be correlated directly with the Tethyan planktonic foraminiferal zones (Nishi et al., 2003). The benthic foraminiferal assemblages indicate the upper part of the upper bathyal environment with medium-to relatively high-oxygen levels (Kaiho et al., 1993).

8. Haborogawa Formation

The Haborogawa Formation was proposed by Takashima et al. (2004) for the synchronous shallower-water facies of the Kashima Formation (Figs. 3 and 7, columns 3-10). While the lower part of this formation is mainly composed of bioturbated mudstone without sandstone intercalations, overlying the Saku or Mikasa formations, the upper part is characterized by coarsening-upward successions, from mudstone to muddy sandstone and/or sandstone. The lithology and sedimentary cycles of this formation differ between the Tomamae and Mikasa areas. The thickness is about less than 2,000m and 2,250 m at the maximum.

In the Mikasa area the formation forms a single, coarsening-upward sequence, from bioturbated sandy mudstone to very fine sandstone. Two felsic volcaniclastic turbidite units of the KY-5 and KY-6 (Tsukimi Sandstone Member) are intercalated in the lower and middle parts, respectively. In the Tsukimi-sawa Valley section, the KY-5 becomes channel-fill conglomerates, including well-rounded pebbles of chert, sandstone and mudstones and rhyolitic rocks, with abundant fragments of *I. uwajimensis*. The KY-6 of 20 m thick exposed in the eastern Mikasa area consists mostly of volcaniclastic sandstones with very thin interbedding of dark grey mudstones.

In the Tomamae area, this formation consists of two coarsening-upwards sequences. Both begin with strongly bioturbated mudstone, grade into bioturbated muddy sandstone, and end in medium-to coarse, cross-laminated sandstone. The lower sequence incorporates the volcaniclastic marker unit of the KY-5 in the lower part and the KY-6 at the top, respectively.

This formation yields abundant, well-preserved macrofossils from calcareous concretions (e.g., Futakami, 1986a,b; Wani, 2001; Moriya et al., 2003). Several regional biozones have been proposed in the Tomamae area by Toshimitsu and Maiya (1986). Although Tethyan planktonic foraminifers are sporadic, the four mid-latitude zones can be identified (Moriya et al., 2001; Nishi et al., 2003; Fig. 6). Its geological age is considered to be Coniacian to earliest Campanian. The palaeodepth of this assemblage is considered to be outer shelf. The cross-stratified sandstone situated towards the top of each succession (i.e., KY-6) in the northern Tomamae area is inferred to have been deposited in inner shelf to lower shoreface environments (Wani, 2003).

9. Hakobuchi Formation

This formation prevails in shallow-marine, sandy and conglomeratic strata around the basin except the eastern Nakatonbetsu area. It corresponds to the Hakobuchi Group of Matsumoto (1942). It conformably overlies the Kashima Formation in the Oyubari area and the Haborogawa Formation in the northeastern Mikasa and Tomamae areas (Figs. 3 and 7, columns 5, 6, 15-17). However, the unconformable relationship between the Haborogawa and Hakobuchi formations is recognized in the northwestern limb of the Sorachi Anticline. The Hakobuchi Formation is overlain by a disconformity, or a gentle angular unconformity, and is covered by deposits younger than the Paleocene, such as the middle-upper Eocene Ishikari Group, containing coal measures, the upper Eocene-lower Oligocene offshore-marine Poronai Group or the Miocene formations. The thickness varies from several tens of meters in the northern Mikasa area and 450 m along the Hakobuchi gorge in the Oyubari area to 2,600m in the eastern Nakatonbetsu area.

It has been recognized through stratigraphic and sedimentological studies that the Hakobuchi Formation shows the shallow-marine complicated stacking patterns of third- and fourth-order depositional sequences (DSs) (e.g., Ando, 1993, 1997, 2003; Ando and Ando, 2002). The number of the sequences differs in sections depending on the predominant facies, but the maximum reaches over 15, including third- and fourth-order DSs. Several sequence boundaries and related key features such as ravinement and marine flooding surfaces are regionally traceable in places. Owing to limited paleontological evidence in shallow-marine to non-marine facies, they have not been well documented biostratigraphically. Each DS consists mainly of coarsening-upward facies succession (CUS), of a few tens to 100 m thick, of offshore bioturbated sandy siltstone to shoreface HCS/TCS sandstone (Figs. 13 and 37). Often, there is an associated thin, fining-upward marine succession (FUS), less than ten meters thick, below the CUS. CUS and FUS are interpreted to be highstand systems tract (HST) and transgressive systems tract (TST), respectively. Fluvial conglomerate, sandstone, mudstone and often coaly beds are sometimes intercalated in the basal part of the DSs as lowstand deposits (lowstand systems tract: LST) in several sections. Very thick marine conglomerates and fluvial-channel conglomerates are occasionally developed at a few horizons of some sections. If LST and TST are lacking, only HSTs repeat with sharp facies boundaries (marine flooding surfaces or ravinement surfaces). Felsic tuffs are interbedded at a few horizons, and thicken in the Oyubari and northern Tomamae areas, where the beds reach 30 and 80 m in thickness, respectively.

Depending upon the stratigraphic position within the third- or fourth-order DSs, the depositional environments represented change regularly and repetitively. They include shallow-marine environments, such as outer to inner shelf and shoreface, and subordinately estuarine, incised valley, and riverine gravelly/sandy river-channel, back-marh and flood plain. Compared with the Mikasa Formation, the Hakobuchi Formation is characterized by a smaller amount of offshore mudstone and a larger amount of conglomerate and tuff. However, the eastward offshore facies represented by the Nakatonbetsu area, show the monotonous thick sequences of sandy mudstone with only a few cyclic sedimentary units (Ando et al., 2001; Ando and Tomosugi, 2005).

As a few macrofossils, such as *Sphenoceramus schmidti*, *S. hetonaianus* and *Inoceramus shikotanensis*, occur from the Nakatonbetsu area, north Hokkaido and the Hobetsu area, south Hokkaido (Ando, 1997; Ando et al., 2001), the Hakobuchi Formation can be assigned approximately to lower Campanian and lower Maastrichtian. The planktonic foraminifers *Globotruncana rugosa* and *Subbotina triloculinoides* occur in the lower and upper parts of this formation, respectively (Yasuda, 1986). The former is assigned to the Campanian, and the latter is of Paleocene age. Recently, Late Paleocene dinoflagellates and nannofossils were discovered from the upper part of the Hokobuchi Formation in the Oyubari area (Suzuki et al., 1997) and the Nakatonbetsu area (Okada et al., 1998), respectively. More recently, Ando and Tomosugi (2005) found an important major unconformity in the Nakatonbetsu area, which seems to have eroded the K/Pg boundary, uppermost Maastrichtian and Lower Paleocene. This interpretation is located on biostratigraphy and an erosional surface within the continuously exposed section. This means that a different sedimentary cycle of the Paleocene beneath the overlying post-early Eocene beds, exists in the uppermost part of the Hakobuchi Formation in the Nakatonbetsu and Oyubari areas, and the Yezo forearc basin had continued until late Paleocene.

Kurita and Obuse (1997) reported the late Paleocene to early Eocene dinoflagellates and pollen flora from the Haboro Formation in the surface section of the Haboro area and in a drill hole. The Haboro Formation is composed of sandstone and mudstone associated with several coaly beds. It seems to have been deposited under nearshore and paralic environments at the last stage of the Yezo basin, judging from the lithological similarity with the uppermost part of the Hakobuchi Formation.

Lateral Change of Sedimentary Facies of Yezo Group: Two Second-order Megasequences

The Yezo Group is lithologically characterized by an alternating sequence of turbidite-dominant and hemipelagic mudstone-dominant units (Fig. 3). The Aptian-Albian successions are laterally similar and continuous throughout central Hokkaido, comprising the laminated mudstone Soashibetsugawa Formation, the turbiditic Shuparogawa and Maruyama formations, and the mudstone Hikagenosawa Formation, in ascending order. Sedimentary structures, facies and their successions show slope fan with channel-fill as depositional environments. Scarce occurrences of macrofossils, and common occurrences of deep-sea trace fossils, suggest abyssal environments in the Aptian. Benthic foraminifers indicate the upper bathyal zone of about 300-600 m in depth, in the Albian.

The Cenomanian-lower Campanian successions display east-west lateral variations in sedimentary facies, tending to westward coarsening and shallowing (Fig. 3). The uppermost Albian-Turonian Mikasa Formation is typically composed of shallow-marine, including fluvial, estuarine and outer-shelf sediments, suggesting rapid uplift in the western margin of the Yezo forearc basin. The overlying Haborogawa Formation represents deeper facies than the Mikasa Formation in terms of sedimentary environment, as indicated by the occurrence of shoreface to outer shelf, and partly upper bathyal basin-plain deposits. On the other hand, the Cenomanian to Turonian Saku Formation and Coniacian-lower Campanian Kashima Formation exhibit slope fan on continental slope and basin-plain successions, respectively. Based on benthic foraminiferal assemblages, these formations were deposited in upper bathyal depths. The neritic to non-marine Hakobuchi Formation, deposited during the Late Campanian-Early Maastrichtian and Late Paleocene interval, completely covers the underlying deep-sea sediments across the whole area from north to south. This formation indicates the final stage of deposition and uplift of the Yezo forearc basin.

As already reported by Ando (1997, 2003), major surface stratigraphic sections of the shallow-marine and non-marine strata in the Cretaceous Yezo forearc basin were correlated through stacking patterns of facies, depositional sequences and the timing of sequence boundaries and key surfaces bounding systems tracts. They appear considerably concordant in frequency and phase with the oscillation patterns of the Haq curves (Haq et al., 1988). There are two second-order upward-shallowing cycles in the Yezo Group, represented by the Soashibetsugawa to Saku/Mikasa formations (Aptian to Turonian) and the Kashima and Hakobuchi formations (Coniacian to Maastrichtian) (Matsumoto and Okada, 1971; Ando, 1997). According to the stratigraphic duration of two cycles, they seem to represent megasequences (Ando, 2003, 2004, 2005).

In the case of the Mikasa Formation, the long-term relative sea level rise after a major fall in early Cenomanian had remained until late Turonian. The oscillations of small-scale, rapid rise and stand-still during late Cenomanian to middle Turonian are somewhat similar to the representative part of Haq et al.(1988)'s curve. The sedimentation during the age may have somewhat reflected the global eustacy.

Mikasa Formation as Western Marginal Sandstone-dominated Facies in Yezo Forearc Basin

The Mikasa Formation as the shallow-marine and coastal facies provides more evidence for marginal sedimentation, paleogeography and local relative sea-level change of the central-western Yezo forearc basin (Ando, 1990a, b). As it is distributed along the Sorachi-Ikushunbetsu Anticline and the Manji and Hatonosu Domes, a total of 40 km in north-south and 10 km in east-west direction, we can trace lateral changes of sedimentary facies and thickness (Ando, 1987, 1990a, b, 1997, 2003; Figs. 3 and 8).

The Mikasa formation comprises three third-order depositional sequences (DS1, DS2 and DS3), each of which further includes three fourth-order sequences (4th DS; DS1-1, 1-2, 1-3, 2-1, etc.) or parasequences. They show coarsening- and shallowing-upward facies successions in general (Fig. 8). A single and thick body of shallow-marine to coastal sandy strata (<250 m thick) in the western area grades eastward into a few tongues (each < 100m), and thins out more eastwardly with thickening of offshore muddy strata (>500 m in total thickness). The lateral and vertical facies changes show onshore-offshore gradients of the westward coarsening (shallowing) depositional environments. In the northwestern Mikasa area, the DS1 begins with alternating beds of turbiditic sandstone and mudstone, and grades into HCS sandstone with bioturbated, very fine sandstone/sandy mudstone. A basal, cross-stratified thick conglomerate

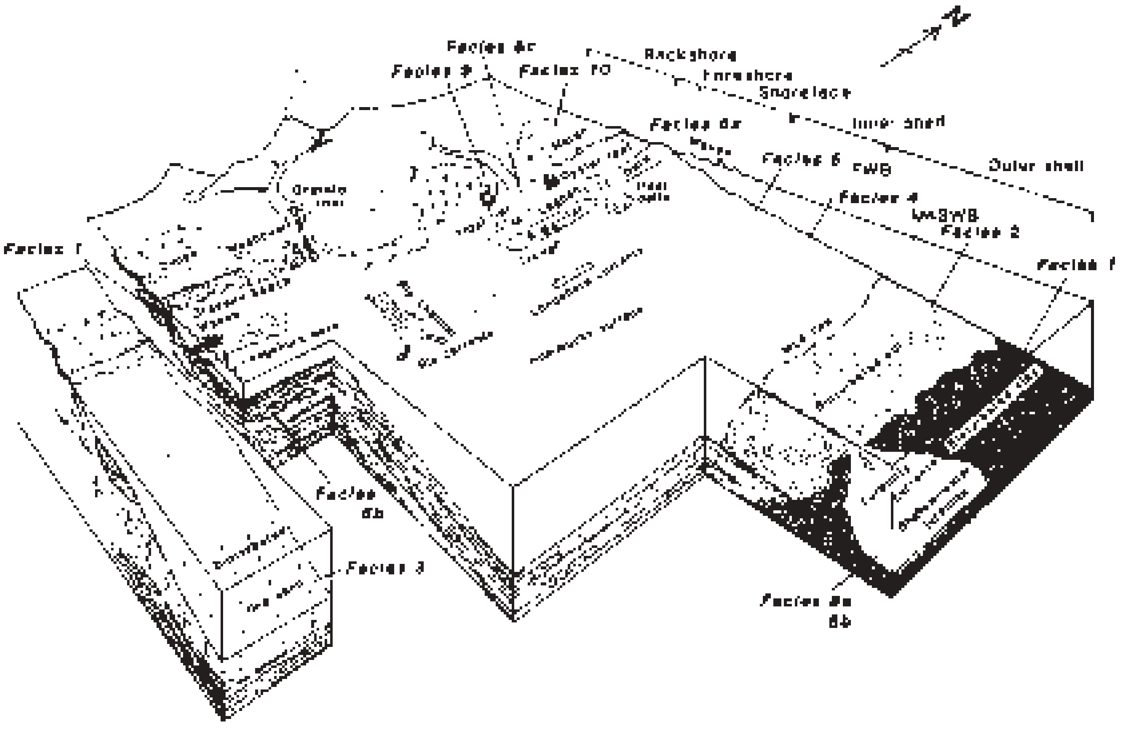

Fig. 9. Schematic reconstruction illustrating depositional environments and bedding sequences for the Mikasa Formation. MnSWB: mean storm wave base; FWB: fair weather wave base (after Ando, 1990a).

of the DS2 covers HCS sandstones of DS1 with a sharp erosional base (unconformity) (Fig. 8, column E; Fig. 17). The DS2 comprises a wide variety of lithofacies, such as cross-stratified conglomerate, carbonaceous mudstone, sandy mudstone with oyster-shell beds, medium-to coarse sandstone with TCS, HCS fine sandstone and bioturbated sandy mudstone. The DS3 deposits are distributed in the southern Mikasa area, mainly comprising bioturbated, sandy mudstone and HCS sandstones. The intercalations of HCS sandstone become frequent in the upper part of each 4th DS.

The depositional environment of the DS1 deposits is interpreted as basin-plain on continental slope to lower shoreface through shelf (Fig. 10). The DS2 represents non-marine to shallow-marine environments, such as fluvial channel, back marsh, flood plain and tidal flat in the lower part, followed by deeper marine (shoreface to inner shelf, though partly outer shelf) in the upper. The DS3 is thought to have been deposited in lower shoreface to outer shelf environments.

There had been a north-south running coastline and westerly volcanic hinterland (Fig. 9). The abundance of storm deposits represented by hummocky cross-stratified (HCS) sandstone suggests that storm-dominated lower shoreface and sandy upper shelf were widely developed as a delta front. Disarticulated, thick-shelled bivalves (*Pterotrigonia*, *Apiotrigonia*, *Yaadia*, *Glycymeris*, *Aphrodina* and others) are often concentrated in gravel or shell lags and HCS lamina (Fig. 11). The species composition varies depending on the age and depositional environments of the fossil horizons. Forset inclinations of cross-stratified, coarse- to medium sandstone, suggest longshore currents of NNE-SSW direction on the wave-dominated upper shoreface with longshore bars and troughs. Tidal flat and lagoon associated with oyster reefs and tidal channels in places seem to have been developed as closed environments behind barrier bars along the coastline, on the basis of thick and variable tidal deposits. Thick conglomerate suggests the presence of gravelly rivers supplying a large volume of coarse sediments from a westerly volcanic arc (Rebun-Kabato Belt). Gravel was transported onto the beach by storm waves, which had filled troughs and rip channels on the upper shoreface. A few thick layers of black mudstone bearing abundant plant remains show that back marsh and swamp were somewhat developed on a delta plain.

On the other hand, storm-induced turbidite or distal storm sheet sand layers were deposited on wide muddy outer shelf to basin plain below the maximum storm wave base, because the gradational relation from distal turbidite to HCS sandstone is observed in the Ponbetsu River section (Figs. 10 and 17). This muddy turbidite is the main facies of the heterotypic Saku Formation distributed extensively in the eastern part of the basin (Matsumoto and Okada, 1973).

Judging from the stacking patterns of facies, DSs and 4th DSs of the Mikasa Formation, the Mikasa delta system has repetitively prograded and generally shifted southward within the distribution area (Ando, 1997, 2003; Fig. 10).

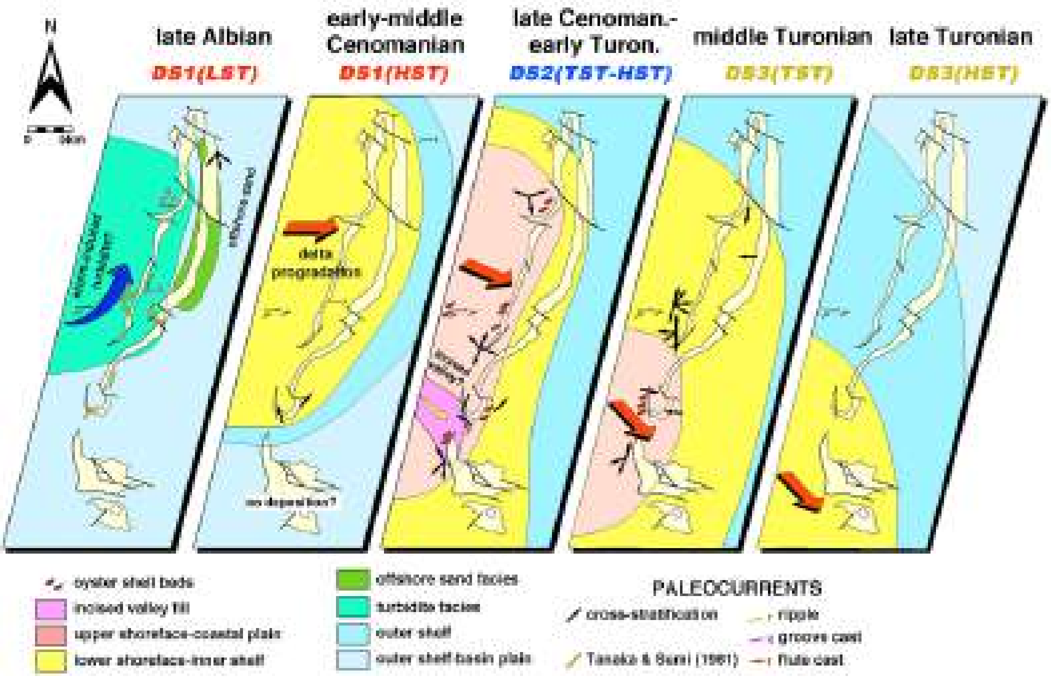

Fig. 10. Schematic reconstruction illustrating depositional history for the Mikasa shelf in the western-central margin of the Yezo forearc basin during late Albian to late Turonian.

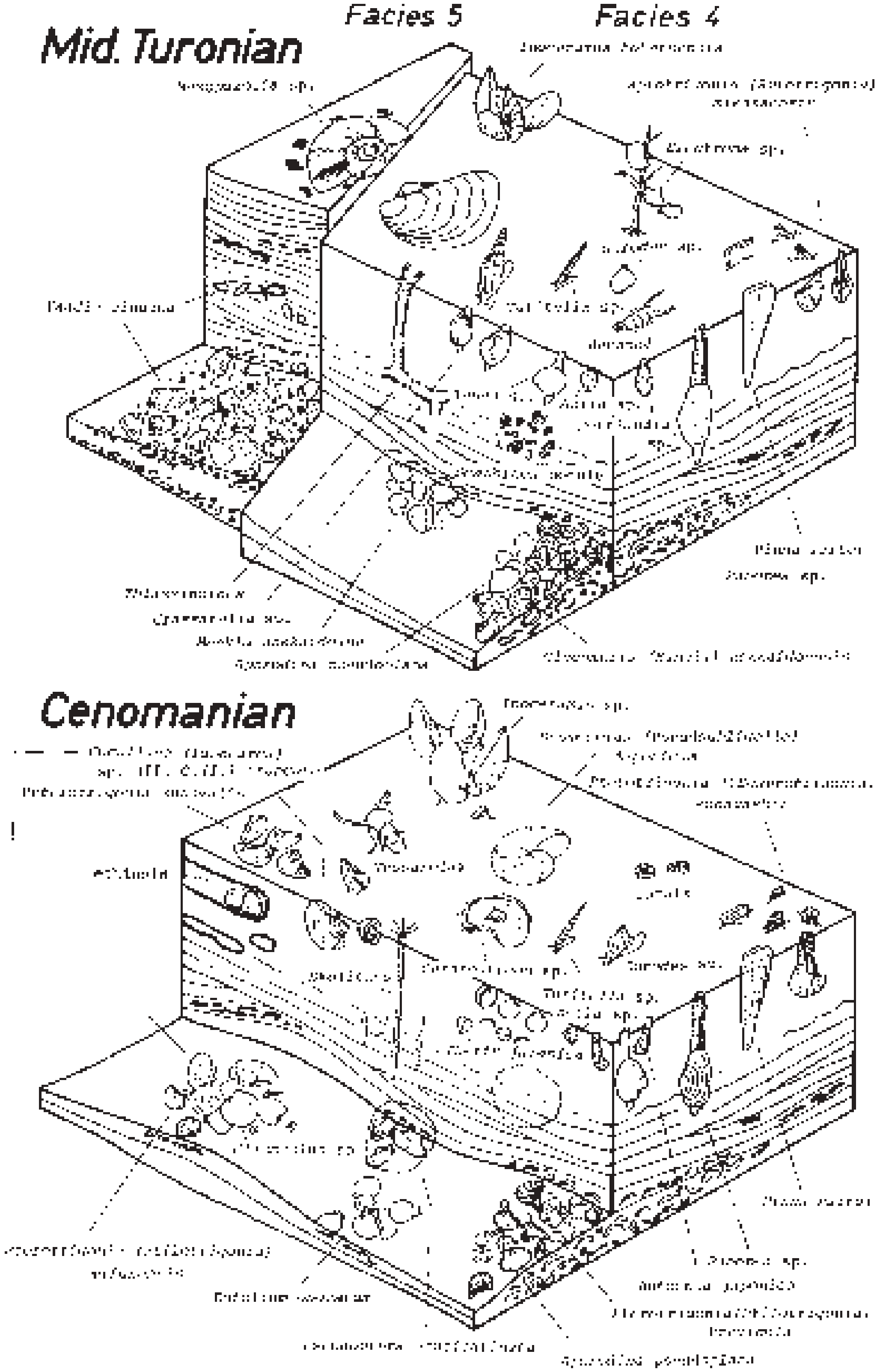

Fig. 11. Schematic mode of fossil occurrence in hummocky cross-stratified sequences of the Mikasa Formation (Cenomanian and middle Turonian). After Hirano et al.(1992).

Researches on OAEs in Japan

1. Initial phase of OAE-related researches in Japan

Oceanic Anoxic Events (OAEs) is a term for repeated oceanic events during Jurassic and Cretaceous and is not strictly defined. “Oceanic events of restricted time range during which highly concentrated organic matter had buried under various oceanic settings in regions of the world” may explain the term. OAEs and related events are interpreted to have produced the majority of oil-source rocks around the Persian Gulf. About 40% of petroleum in the world including major oil fields in North and South America and Africa are believed to be originated from sediments of restricted Cretaceous Period (Albian through Coniacian) (Irving et al., 1974).

Japanese researchers had been aware of their significance to interpret Japanese Cretaceous strata when Hirano et al. (1991) firstly translated the term into Japanese and expressed OAEs as “海洋無酸素事変 (kaiyo-musanso-jihen)”. During the early stage of OAEs study in Japan, mega- and micropaleontologists initiated discussion insisting that OAEs had been affected around Japan. Well-laminated sediments yielding poor macrofossil assemblages recognized in sequences of Aptian through Albian (correlative to OAE1) was employed as evidence for infection of OAE in Japan by Maeda et al. (1987). On the other hand, macrofossil biostratigraphy (Hirano et al., 1990) identified OAE2-correlative range including Cenomanian/Turonian (C/T) boundary and recognized conspicuous mudstone darker than horizons above and below it. Hirano et al. (1991) further recognized higher concentration of total sulfur in the mudstone and interpreted it as a signal of affection of OAE in the NW Pacific. Benthic foraminiferal study (Kaiho et al., 1993) had also submitted an independent signature of dysaerobia across the C/T boundary and suggested the possible OAE2 onset in Japan. Then Hasegawa and Saito (1993) showed a technique to identify an OAE2 horizon on the basis of terrestrial-organic-carbon isotope stratigraphy that enables us to discuss the regional phenomenon as a part of global events within a framework of international correlation. It brought considerable progress for OAE-related researches in Japan. All of the above mentioned studies about OAEs paid special attention to observation in the Oyubari area.

2. Japanese researches on carbon isotope stratigraphy for OAE horizons

When Hirano et al. (1991) presented their discussion, positive carbon isotope excursion across the C/T boundary had been well known from carbonate sequences as a chemo-stratigraphic marker (Scholle and Arthur, 1980). Mass withdrawal of organic carbon from an ocean-atmosphere system and its subsequent burial under the bottom of the sea during the restricted time span had been discussed by Arthur et al. (1988). Calcareous planktons such as planktonic foraminifers use carbonate ion in the surface of the sea as a source of their shells. Globally parallel fluctuation of carbon isotope ratio ($\delta^{13}C$) is expected for such carbonate ion in the surface of the sea, and therefore, for time-series of calcareous shells of the planktons. Therefore, positive carbon isotope excursion in carbonate sequences offers synchronous time slice globally.

Hasegawa (1992) and Hasegawa and Saito (1993) studied carbon isotope values across the horizon discussed by Hirano et al. (1991) to verify its chronological identity as the OAE2-equivalent. The C/T boundary sequence of the Yezo Group in Japan is composed of grey mudstone and sandstone. Considerably recrystallized calcareous fossils do not allow us to evaluate their carbon and oxygen isotope values as paleoenvironmental proxies. They then studied carbon isotope values of organic carbon on the basis of following idea: As far as the origin is apparent, carbon isotope excursion should be recorded in any carbon media produced within the ocean-atmosphere circulation system. The origin of their organic carbon was terrestrial plants. Terrestrial plants assimilate organic matter from atmospheric carbon dioxide that can be interpreted to be carbon-isotopically equilibrated with surface water of the sea under geologic time scale. Hasegawa and Saito (1993) first established biostratigraphy of calcareous nannoplankton and planktonic foraminifers in the Oyubari and Tappu areas. Next, they extrapolated time-control horizons in their stratigraphic profiles of carbon isotope value from the biochronology, and recognized a conspicuous ~2‰ positive excursion of the value within a restricted range near the internationally designated C/T boundary. This fundamental study made a tide of international researches on OAEs using Japanese materials within the framework of international correlation.

Carbon isotope stratigraphy of the Yezo Group employing the bulk rock combustion method was carried out by many authors in this decade. Identification and/or evaluation of the origin of organic matter are a prerequisite for such study. Hasegawa (1997), Shimizu et al. (2001) and Takahashi and Hirano (2003) among others evaluated its origin (terrestrial plants) on the basis of multiple methods including microscopic visual observation. As the Yezo

Group is marine strata, organic matter derived from marine plankton could be a considerable component of total organic matter in a sample mudstone. Organic matter from different origins (marine plankton against terrestrial plants) generally has a different carbon isotope ratio even from samples representing identical age. Change in the mixing rate of these organic matters from different origins could cause artificial excursion of carbon isotope value in its stratigraphic profile.

3. Research history about Cenomanian/Turonian boundary event from Japanese materials

Hasegawa (1995) discussed correlation between the Oyubari section in Hokkaido and Rock Canyon in Colorado, US (Global Boundary Stratotype Section and Point for the C/T boundary selected in 2003; see Ogg et al., 2005) on the basis of carbon isotope profiles across the OAE2-equivalent horizon. Hirano (1995) summarized megafossil biostratigraphy and Hirano et al. (1997) studied radiometric age (K-Ar age) across the horizon. They provided reasonable age values including 95.5±2.1 Ma from 80m below the boundary in the Oyubari area and 93.0±2.0Ma from 100m above the boundary in the Tappu area (IUGS-ISC time scale published as Ogg et al., 2005 showed 93.5±0.8Ma as the numerical age value for the C/T boundary).

Hasegawa (1997) comprehensively summarized litho-, bio (planktonic foraminifera)- and chemo (carbon isotope)- stratigraphy through the Cenomanian and Turonian. The word OAE meaning "an event that caused deposition of organic-rich black mudstone throughout wide regions of the world" do not necessarily have a sense of "global anoxia of the entire ocean" nor "deposition of organic-rich sediments under the entire oceans of the world" . Actually, Hasegawa (1997) and Hasegawa and Hatsugai (2000), Hasegawa et al. (2003) did not recognize concentration of organic matter across the C/T boundary. However, this fact does not mean that OAE2 did not affect their study area (Hokkaido) but may reflect inherent depositional setting, rate of sedimentation and/or other intrinsic factors for the sedimentary basin of the Yezo Group. Hasegawa (1997) discussed lower rate of sedimentation across the C/T boundary than strata above and below the boundary in the Oyubari area with evidence from biostratigraphy and comparative study on carbon isotope profile with the European standard profile (Jenkyns et al., 1994) employing flexion points as tie points. The upper half of the carbon isotope excursion that characterizes the C/T boundary has been lost because of post depositional reworking. In spite of its rich data inventory about mega- and microfossils as well as carbon isotope value across the C/T boundary sequence of the Shirakin section of the Oyubari area, the boundary itself is absent in the outcrop. Very sharp shift-back of the carbon isotope curve at a clear lithologic boundary instead of gradual recovery indicates the absence of the boundary only (see fig. 7 of Hasegawa, 1997). Fortunately, the main phase of the OAE2 is known to be included in the lower half of the excursion (chronostratigraphic equivalent of the Plenus Marl of the Eastbourne section in England) and is preserved in the Shirakin section.

Among the international community that is interested in OAE2, paleontological studies have expanded our knowledge about the C/T boundary transition in Japan. Matsumoto et al. (1991), Nishida et al. (1992, 1993, 1998), Toshimitsu et al. (1995), Hirano (1995), Kawabe et al. (1996), Kawabe (2000), Kuihara and Kawabe (2003) among others revealed detailed biostratigraphy of inoceramids and ammonoids across the C/T boundary in the Oyubari, Kotanbetsu and Shumarinai areas. Hirano (1993) studied certain taxon of ammonoids and sulfur content in mudstones as an index of redox condition, and discussed the relationship between phylogenic evolution and development of oxygen-depleted water mass. Kurihara and Kawabe (2003) compared the pattern of appearance and disappearance of megafossils across the C/T boundary between Rock Canyon and the Shirakin sections on the basis of the detailed correlation by the carbon isotope stratigraphy. They then argued that the faunal change had been introduced by OAE2 extending to the NW Pacific. They exaggerated widespread feature of OAE2 around the world. They also mentioned the expansion pattern of oxygen-depleted water that had been different from that of Europe or North America on the basis of the faunal reaction pattern. Toshimitsu et al. (2003) established a database of Cretaceous ammonoids in Japan and showed a conspicuous drop of their diversity at the OAE2 horizon as well as at the OAE1 subevent horizons, and concluded that OAEs greatly controlled diversity development for the mid-Cretaceous ammonoids in Japan.

Kaiho and Hasegawa (1994) investigated compositional turnover of benthic foraminiferal fauna and demonstrated the minimum oxygen content in the bottom water through the latest Cenomanian and early Turonian relative to the before and after. Hasegawa (1999) described planktonic foraminiferal species through the time series of Cenomanian and Turonian from the Shirakin section and recognized limited occurrence of cosmopolitan subtropical species for the period of middle Cenomanian and early Turonian.

He then discussed the northward migration of Paleo-Kuroshio current during the period.

Geochemical research on paleoenvironmental change across OAE2 have been well performed in Europe and the US; however, fewer in Japan. Hirano et al. (1991) is one of the pioneering studies focused on a geochemical technique for OAE2 that showed increased concentration of sulfur near the C/T boundary from three sections in the Oyubari area. Arai and Hirano (1996) examined the concentration of Ti, Al, Fe, Mn, Mg, Ca, Na, K, Sr and Ba through 40m in thickness encompassing the boundary in the Shirakin section and concluded that the entire range was reduced assuming upper shelf or upper slope depositional setting. Hasegawa (2003) summarized published stratigraphic profiles of carbon isotope value through the Cenomanian and Turonian, and found a decoupling between the profiles from marine carbonate (Jenkyns et al., 1994) and East Asian terrestrial higher plants (Hasegawa, 1997). He discussed a warmer and more humid climate in the East Asian continent through the period from mid-Cenomanian to early Turonian on the basis of negatively depressed features of the profile from terrestrial plants relative to that from marine carbonate.

The “Shirakin” section in the Oyubari area is often called the “Shirokinkagawa”, “Hakkin River” or “Hakkinzawa” section depending on different translations from Japanese Kanji character into sounds (Each Japanese Kanji character generally has three or four different pronunciations). All of them mean “platinum river” and derived from a single Kanji word (白金川). “白金” generally pronounced as “Hakkin” but “Shirakin” by local people complicated earlier researchers. “川”, which originally means river, is generally pronounced as “kawa” or “gawa” but some former researchers preferred using “sawa” or “zawa” that means a smaller size of river than “kawa (gawa)”.

Chemosynthetic Communities in Cretaceous Yezo Forarc Basin

Chemosynthetic autotrophic communities (hereafter “chemosynthetic communities”) depend on chemosynthetic methanotrophic and/or sulphide oxidizing bacteria at sea-floor hydrothermal vents or hydrocarbon seeps (Sibuet and Olu, 1998; Tunnicliffe et al., 1998). Modern vent and seep communities are composed mainly of chemosynthetic bivalves and vestimentiferan tubeworms and occur at a wide variety of marine settings, ranging from shallow to deep water, with cool to hot, and CH_4-dominated to H_2S-dominated fluids (Sibuet and Olu, 1998; Van Dover, 2000; Kojima, 2002). Chemosynthetic communities are associated with various geologic phenomena, such as carbonate mounds, brine pools, pockmarks, mineralized chimneys, subduction zones, spreading centers, seamounts, salt diapirs, and corroded platform escarpments (Beauchamp and Savard, 1992; Gaillard et al., 1992; Little et al., 1997, 1999; Campbell, 2006).

In the Yezo Group, four chemosynthetic communities are reported (Table 1); (1) The Upper Albian Ponbetsu community (Kanie et al., 1993; Kanie and Sakai, 1997), (2) The Lower Cenomanian Kanajiri community (Kanie and Kuramochi, 1996), (3) The Lower Cenomanian Soeushinai community (Kanie et al., 2000; Kanie and Nishida, 2000), (4) The Lower Campanian Omagari community (Hikida et al., 2003).

Albian and Cenomanian communities consist mainly of chemosynthetic bivalves, while the

Table 1. List of fossil chemosynthetic community in the Cretaceous Yezo Group (Modified after Majima et al., 2005)

	1. Pombetsu community	2. Kanajiri community	3. Soeushinai community	4. Omagari community
Lithology and age	Siltstone of Upper Albian (106 Ma) Hikagenosawa Formation	Calcareous concretions in mudstone of Lower Cenomanian (97 Ma) Saku Formation	Calcareous concreation in mudstone of Lower Cenomanian (95 Ma) Saku Formation	Carbonate lens in sandy mudstone of Lower Campanian Omagari Formation (=middle part of the Haborogawa Formation)
Paleobathymetry, Tectonic setting	Subneritic; forearc	Slope; forearc	?; forearc	Slope; forearc
Chemoautotrophic species	*Nipponothracia ponbetsuensis*, *Calyptogena* (*Ectenagena*) sp., *Solemya* cf. *angusticaudata*, *Conchocele* sp	*Thracia yezoensis*, *Miltha* sp., *Nipponothracia* (?) sp.	*Vesicomya inflata*, *Acharax cretacea*, *Miltha* sp.	*Miltha* sp., *Thyasira* sp., *Calyptogena* sp., *Nipponothracia* cf. *ponbetsensis*, Vestimentiferan tubeworm
Associated species	*Yoldia* (*Megayoldia*) cf.*thraciaeformis*, ammonoids (*Anagaudryceras sacya*, *Diploceras cristatum*, *Desmoceras* sp.)	Ammonoid (*Anagaudryceras* sp.)	-	*Margarites* sp., *Bathyacmaea* cf. *nipponica*, *Serradonta* cf. *vestimentifericola*, Terebratulid brachiopods.
Mode of fossil occurrence	Autochthonous: sporadic occurrence of chemoautotrophic bivalves associated with calcareous concretions	Autochthonous: sporadic occurrence of chemoautotrophic bivalves associated with calcareous concretions	Autochthonous: aggregated occurrence of articulated chemoautotrophic bivalves in a large calcareous concreation (1.5 m in diameter)	Autochthonous: aggregated occurrence of chemoautotrophic species within bedding-normal-developed carbonate body depleted greatly in ^{13}C ($\delta^{13}C$: -41 to -45‰ (PDB)) (see next page in detail)
References	Kanie et al., 1993 Kanie and Sakai, 1997	Kanie et al., 1996 Kanie and Kuramochi, 1996	Kanie et al., 2000; Kanie and Nishida, 2000	Hikida et al., 2003

Campanian community that we will observe on this excursion is different by having well-preserved worm tube assemblages. Chemosynthetic communities of the Yezo Group were found in carbonate rocks or calcareous concretions enclosed in muddy to sandy turbidite. Judging from the biota and/or $\delta^{13}C$ values of the host carbonate, these communities appear to live in a cold seep (methane seep) site of slope to subneritic environments.

DESCRIPTION OF FIELDSTOPS

DAY 1

Stop 1-1 (Yubari Coal-Mine Museum)

The Yubari Coal-Mine Museum was opened in July, 1980 at the site of an abandoned coal pit in order to explain the history of the Yubari Coal-Field in Yubari City. The exhibition of the museum consists of four sections: natural history of coal-bearing formations, coal mining customs in coal pits, coal mining machinery and the history of the Yubari coal mines. The remarkable highlight is a model coal pit faithfully preserved for the exhibition. Three coal beds of the Eocene Ishikari Group can be observed at a large outcrop near the exit of the pit. This outcrop was designated as a natural monument by the Hokkaido local government in 1974.

This museum has a paleontological laboratory exhibiting several fossil specimens collected from the city and adjacent areas, i. e. ammonoids, bivalves, reptiles, plants from the Cretaceous Yezo Group; turtles, leaf impressions and silicified wood from the Paleogene Ishikari Group; bivalves and gastropods from the Paleogene Poronai Formation.

Stop 1-2: (Oyubari Dam section, Hakobuchi gorge, Shuparo River: High-frequency shallow-marine parasequences of the Campanian-Paleocene Hakobuchi Formation)

This stop is the type section of the Hakobuchi Formation (Nagao et al., 1954). From the dam office building north of the dam site facing Shuparo Lake to the downstream area of the dam, a sandstone sequence of 300 m in thickness clearly crops out, trending nearly N-S and overturning steeply westward (Fig. 12). The formation conformably overlies the Kashima Formation and unconformably underlies the Eocene Ishikari Group. The basal transitional part shows a coarsening-upward facies succession from dark gray mudstone of the Kashima Formation to HCS sandstone of DS1, though only the boundary is not exposed due to valley erosion of the Shuparo River.

The Hakobuchi Formation is characterized by 12 third-/fourth-order depositional sequences (DSs) mostly showing a coarsening-upward facies succession, though a few such as DS6 or 9 are associated with a thin fining-upward unit in the basal part. Sequence boundaries coincide with marine flooding surfaces or RSs except in DS3. Following DS2 composed of siliceous black mudstone (5 m) and massive acid tuff (25 m) and the overlying HCS fine sandstone (<30m) in ascending order, DS3 comprises six or more upward-fining units several meters thick of meandering river plain in origin as lowstand incised valley-fill. Those units are composed of poorly-sorted, trough cross-stratified, thick, coarse sandstone and sandy often coaly mudstone with plant remains.

The middle part includes a thick (ca. 10m), mostly clast-supported, pebble to cobble conglomerate layer as a transgressive lag formed by heavy shoreface erosion. The conglomerate rests upon the trough cross-stratified medium sandstone of DS4 with sharp and flat erosional surface which is equivalent to a ravinement surface (RS). The upper part of the formation consists mainly of massive fine sandstone, and subordinately sandy siltstone in the middle part of DS6, coarse sandstone and conglomerate in DS8, 9 and 12. The sandstone is almost massive and bioturbated, but occasionally hummocky or ripple cross-stratified whose lithofacies suggests inner shelf to lower shoreface in sedimentary environment.

Recently, Suzuki et al. (1997) found late Paleocene dinoflagellates and pollen fossils from DS10. Because of no critical lithofacies change within the formation, the disconformity is presumed to be present between DS8 and 9. This seems to be comparative with the K/Pg unconformity discovered in the Nakatonbetsu area, north Hokkaido by Ando and Tomosugi (2005). The conspicuous unconformity (disconformity) with the Eocene coal-bearing Noborikawa Formation,

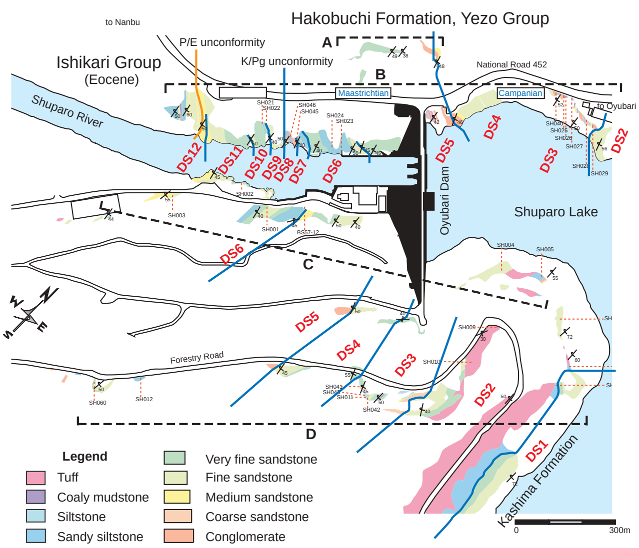

Fig. 12. Geological route map of the Hakobuchi Formation, Yezo Group around the Oyubari Dam along the Hakobuchi gorge, Shuparo River (Stop 1-2). Alphabets refer to the locations of correlated columnar sections shown in Fig. 13

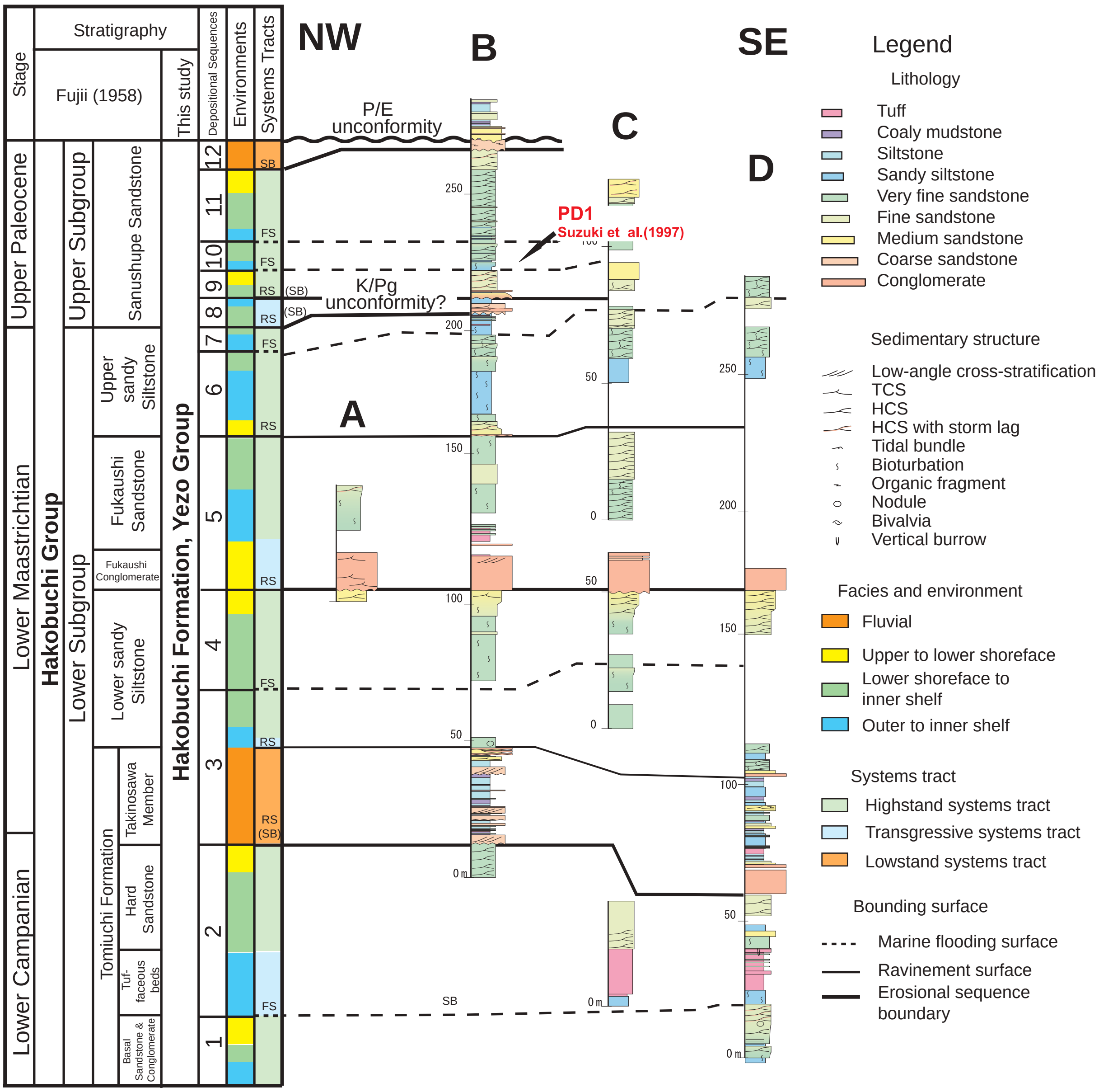

Fig. 13. Correlated geological columnar sections of the Hakobuchi Formation around the Oyubari Dam. Twelve depositional sequences (DSs) are well detected in the overturned strata of about 450 m thick. Most of DSs show upward-coarsening facies successions that are mainly assigned as high stand systems tracts (HST).

Ishikari Group can be seen along a river cliff on the right downstream side. The basal part of the Noborikawa Formation consists of alternating beds of thick/bedded sandstone, mudstone and coaly mudstone without a basal conglomerate layer. Its sedimentary environments are of fluvial origin, such as river channel to flood plain. Though the sandstone lithology is very similar between the two formations, there is at least 15 m.y. hiatus.

Due to the sandy and more consolidated lithology of the Hakobuchi Formation compared with the underlying and overlying strata, a V-shaped valley and ridge was formed as an erosional topography. The newer and larger dam called the Yubari Shuparo Dam is now under construction in the lower stream side of the present dam, taking advantage of such a topographic feature.

DAY 2

Stop 2-1 (Path along covered prefectural road in Katsurazawa: Cenomanian-Turonian shallow-marine facies of the Mikasa Fomation in the eastern limb of the Ikushunbetsu Anticline)

Stop 2-1 is the type locality of the Mikasa Formation, Yezo Group (Matsumoto, 1951). Here the formation and the overlying Haborogawa Formation are well exposed about 800 m long along the large outcrops above a shelter covering the prefectural road from Ikushunbetsu to the Katsurazawa Dam, and dip 30° to 40° NE. Matsuno et al. (1964) divided this formation into four members, Ta, Tb, Tc and Td (Fig. 14).

Ta: The lowest transitional part from the Hikagenosawa Formation is not well exposed here

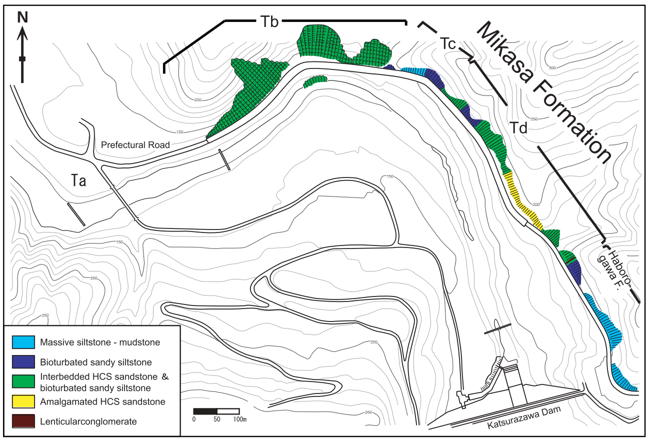

Fig. 14. Route map of the Ikushunbetsu River section in the eastern limb of the Ikushumbetsu Anticline (Stop 2-1)

now. According to Matsumoto et al.(1991), this sandy siltstone member is assigned to the lower Cenomanian *Desmoceras kossmati-Graysonites adkinsi* Zone.

Tb: The Tb Member is composed of inner shelf, interbedded HCS fine sandstone and sandy siltstone in the lower part, and outer shelf, bioturbated sandy siltstone in the upper. The interbedded lithofacies dominate throughout the Mikasa Formation.

We can easily collect the lower Cenomanian fauna of bivalves and ammonites from the lower part. The mode of bivalve occurrence is schematically shown in Fig. 11. Disarticulated bivalves occur on the bases of HCS sequences as shell lags or shell lamina within H units. They had rapidly settled within H units when storm waves or currents waned after storm-reworking and accumulation of them during storm peaks. Articulated bivalves sporadically preserved in Mb (bioturbated sandy siltstone) units are thought to be recolonizing species during inter-storm fair weather, but individuals in life-position are occasionally found. As well as the mode of fossil occurrence, the species composition is somewhat different between H and Mb units, reflecting the sedimentary processes of HCS sequences. Hummocky surface and wave ripples in H units are observable on well-exposed bedding planes.

The upper part of Tb (middle Cenomanian) sporadically contains offshore articulated bivalves different from those in the lower Tb and compressed ammonites as *Calycoceras* (*Newboldiceras*) *orientale* and *Desmoceras* (*Pseudouhligella*) *japonicum*.

Matsumoto et al. (1991) recognized three ammonite-inoceramid zones of upper lower to middle Cenomanian, namely *Mantelliceras japonicum-Inoceramus tenuis*, *Cunningtoniceras takahashii-Inoceramus reduncus* and *C.* (*N.*) *orientale-Birostrina tamurai* Zones (Fig. 7).

Tc: The upper Cenomanian Tc Member consists of dark gray sandy siltstone to siltstone. The lower part showing the most offshore facies in the Mikasa Formation rarely contains calcareous concretions with *Eucalycoceras pentagonum*, *Calycoceras* (C.) aff. *naviculare* and *Inoceramus ginterensis*. From the upper siltstone, *Euomphaloceras septemseriatum*, *Pseudocalycoceras dentonense* and *Sciponoceras kossmati* were obtained with *Inoceramus pictus* (Matsumoto et al., 1991).

Td: This member is mainly composed of inner shelf, interbedded HCS sandstone and sandy siltstone to shoreface amalgamated HCS sandstone in the middle to upper parts, and inner shelf bioturbated sandy siltstone often intercalated with thin sandstone layers in the lower part. The amalgamated HCS sandstone occasionally containing lenticular pebble layers, is predominant in the upper part. This is the sandiest facies within the Mikasa Formation of the eastern Ikushunbetsu River section. Though the lower part is hardly fossiliferous, Matsuno et al.(1964) reported the occurrence of a lower Turonian index, *Inoceramus* cf. *labiatus*. Because this member is too sandy, ammonites scarcely occur. But the middle to upper parts commonly contain *Inoceramus hobetsensis* characteristic of the middle Turonian. As shown in Fig. 11, the middle Turonian bivalve fauna is different from the Cenomanian fauna in composition.

Haborogara Formation

The sudden facies change into monotonous sandy siltstone of the Haborogawa Formation suggests a rapid transgression locally called the Urakawan transgression at late Turonian. The lowest member, Ua by Matsuno et al. (1964) or U1 (Futakami, 1986), commonly contains calcareous concretions with upper Turonian *Inoceramus teshioensis* and prolific ammonites represented by *Subprionocyclus minimus* or *Subprionocyclus neptuni* (Futakami, 1986a,b; Matsumoto et al., 1991).

Stop 2-2 (Katsurazawa sandstone quarry: Turonian storm-formed sandstone succession, the upper part of the Mikasa Formation)

Stop 2-2 highlights shoreface fine to medium sandstone successions including storm-formed sedimentary structures such as HCS and shell lags in the upper part of the Mikasa Formation. This stop is a large sandstone quarry at the southern downstream side of the Katsurazawa Dam and the other side of Stop 2-1. Concrete aggregate materials of the Katsurazawa Dam had been mined from the middle to upper parts of Td (lower-middle Turonian) exposed in this quarry. A huge bench-cut exposure on the upper ridge observed here is prepared for the future mining of concrete materials of the New Katsurazawa Dam now under planning just above the present dam.

In this quarry, there are three fourth-order

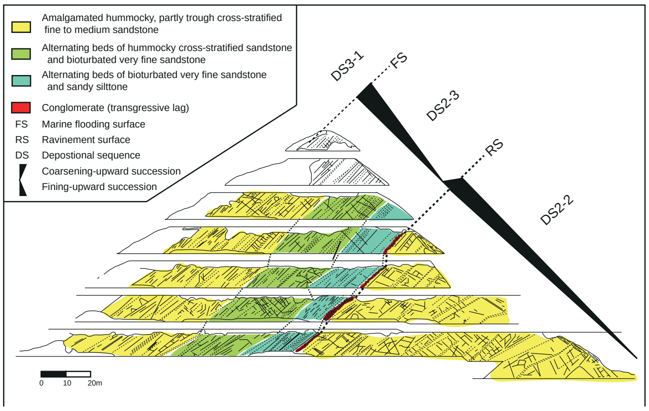

Fig. 15. Outcrop sketch showing two coarsening-upward facies successions in the upper part of the Mikasa Formation at the Katsurazawa sandstone quarry (Stop 2-2).

depositional sequences showing coarsening-upward facies successions, of the lower to middle (DS2-2), middle (DS2-3) and lower upper Turonian (DS3-1), respectively (Fig. 15). DS2-2 shows a thick and conspicuous coarsening-upward facies succession following thin fining-upward succession above the transgressive conglomerate with a basal erosional surface, namely a ravinement surface. The sandstone of DS2-2 and 2-3 is, though apparently massive, fine, amalgamated HCS sandstone, sometimes associated with sharp-based, lenticular gravel layers of less than 1 m thick as lags. Thick-shelled bivalves dominated by two trigonians (*Yaadia ainuana* and *Apiotrigonia mikasaensis*), *Glycymeris hokkaidoensis*, *Meekia hokkaidoana* and *Aphrodina pseudoplana*, are often concentrated within the gravel lags and H units (Fig. 11). Giant ammonites assigned as *Pachydesmoceras* or *Mesopuzosia* and giant *Inoceramus hobetsensis* of over 40 cm long in open-valve/reclining position also occasionally occur solitarily. The sandstone may have been deposited on lower shoreface above fair weather wave base where suspension mud was transported away offshore.

Stop 2-3 (Ponbetsu River section: Cenomanian-Turonian shallow-marine facies of the Mikasa Formation in the western limb of the Ikushunbetsu Anticline)

This stop is one of the highlights in this excursion, because we can throughly observe the Mikasa Formation along a nearly continuous section of about 450 m thick with unexposed parts of only 40 m in total (Figs. 16 and 17). The section also shows the typical western limb facies of the Ikushunbetsu Anticline and two coarsening-upward successions which may be equivalent to third-order depositional sequences (Me-Twa-Twb and Twc-Twd Members: Matsuno et al., 1964 , Ando, 1987, 1990a, b, 1997, Ando and Kodama, 1998). Matsuno et al.(1964) assigned the Me Member as the lower formation, but we include it with the Mikasa Formation because of the gradational relation between Me and Twa and their sandstone lithology (Ando, 1987). A new dam about 70 m high is now planned to be constructed near the Kamui Bridge within the next several years.

Me: The Mikasa Formation starts with about 100 m thick, regularly or rhythmically medium-bedded

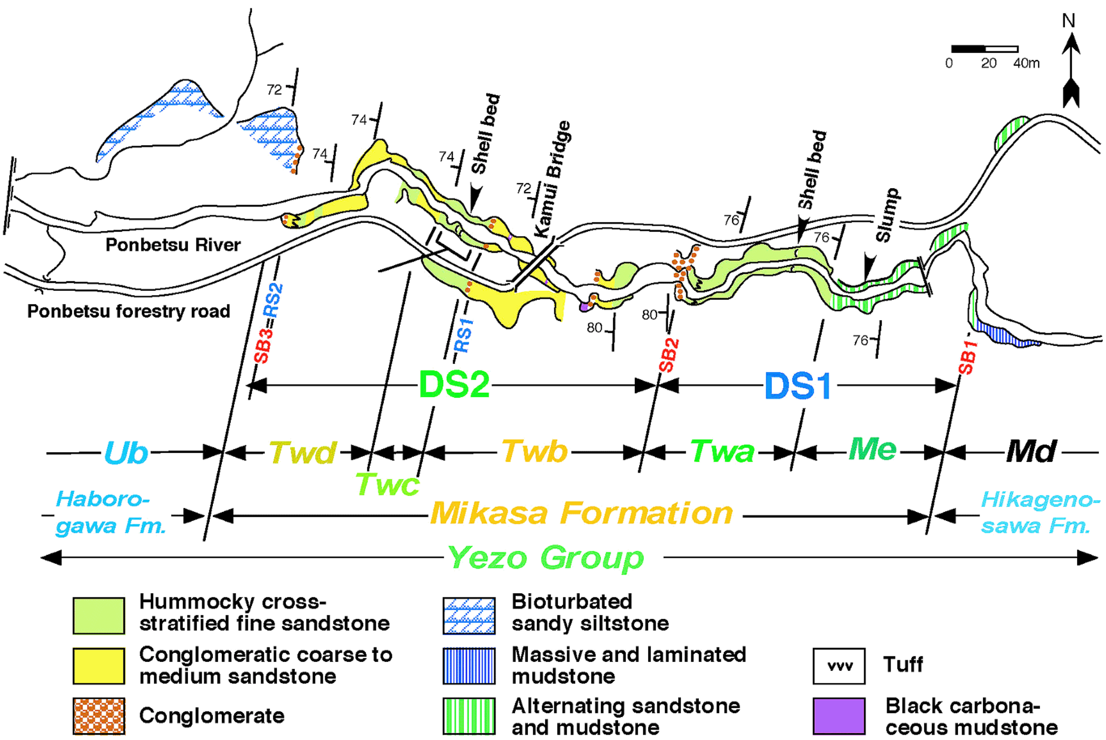

Fig. 16. Geological route map of the Mikasa Formation, Yezo Group in the Ponbetsu River section (Stops 2-3). Modified from Ando and Kodama (1998). DS: depositional sequence; SB: sequence boundary; RS: ravinement surface.

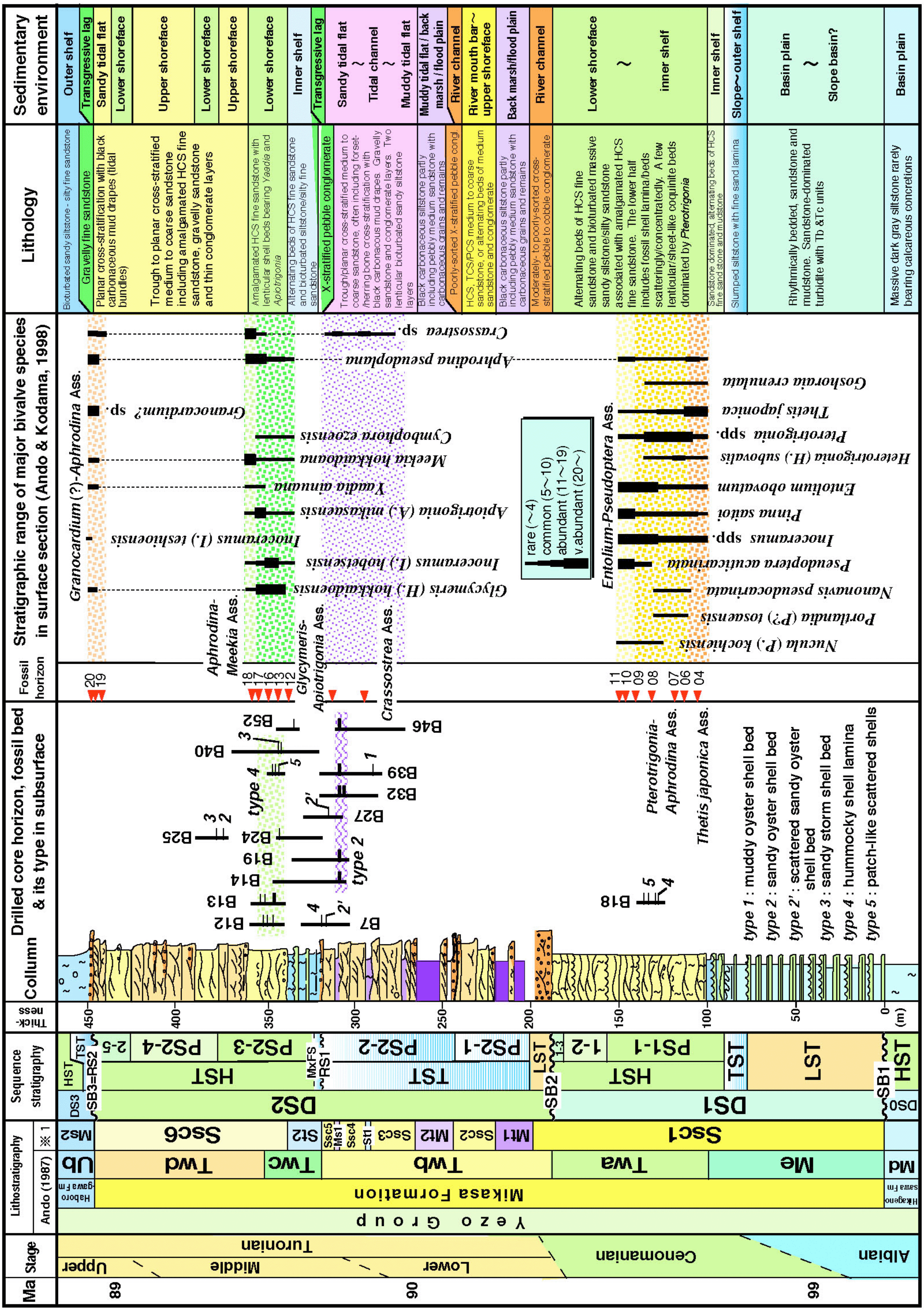

Fig. 17. Columnar section of the Mikasa Formation in the Ponbetsu River section (Stop 2-3), showing lithology, sedimentary environments, sequence stratigraphy and stratigraphic ranges of major bivalve species and associations.

turbidite (Me) with trace fossils as *Helminthopsis*, *Palaeodictyon* and *Nereites* typical of deep-sea facies (Tanaka, 1971). The uppermost alternation (7 m thick) overlying a slumped bed (several meters thick) is a transitional part into interbedded HCS sandstone and sandy siltstone of Twa, though lacking an exposure of a few meters thick between the two. The considerably sudden changes of facies and inferred sedimentary environments from basin plain or outer shelf to inner shelf, suggest a rapid relative sea-level fall and/or tectonic uplift of the basin during latest Albian and early Cenomanian.

Twa: This member consists of apparently massive, very fine- to fine sandstone of 90 m thick. But rock surfaces soaked with river water distinctly show various sedimentary structures as hummocky lamination, amalgamation surfaces, wave ripples and dehydration structures, trace fossils (*Ophiomorpha*, *Skolithos*, *Planolites*, *Schaubcylindrichnus*, etc.) and others. Some sharp-based coquinite lenses intervening in the lower part contain stacking shells of *Pterotrigonia brevicula*, *Aphrodina pseudoplana*, *Glycymeris hokkaidoensis*, *Thetis japonica* and others (Fig. 11). Laminar shell layers are common, but their composition is variable bed by bed. Besides those shell concentrations, somewhat different bivalves, gastropods and solitary corals sporadically occur from bioturbated sandy siltstone (Mb) units of HCS sequences.

Twb: The upper shoreface to delta plain deposits, Twb is mainly composed of massive to trough or planar cross-stratified, medium to coarse sandstone. Occasionally intervening beds are back-marsh or flood plain black mudstone bearing plant remains, lagoonal sandy siltstone with oyster shells and fluvial-channel conglomerate. The basal cross-stratified conglomerate of 8 m thick erosively overlying Twa may be incised valley fill deposits formed during a lowstand of earliest Turonian above the lower sequence boundary. In the uppermost part of Twb, medium-scale trough cross-stratified sandstone with tidal bundles and tidal channels is overlain by a sharp-based conglomerate layer of 40 to 60 cm thick (Figs. 17 and 18). The sharp basal plane may represent a ravinement surface formed by shoreface erosion during the early phase of the transgression at early middle Turonian.

Twc: The fourth member, Twc consists of inner shelf interbedded HCS sandstone and mudstone in the lower part and lower shoreface amalgamated HCS sandstone in the upper part. The lithofacies are very similar to those of Twa. *Inoceramus hobetsensis*, a Middle Turonian standard fossil occurs commonly. The lowest, mudstone-dominated interbedded lithofacies seem equivalent to a maximum flooding surface. A few coquinite lenses are intervening in the upper part (Fig. 11).

Twd: The last member Twd is lithologically similar to Twb, though without lagoonal and back-marsh mudstone. The uppermost conglomerate of several tens of cm thick, overlying tidal coarse sandstone with a sharp-based ravinement surface, suddenly changes to outer shelf, massive and bioturbated sandy siltstone

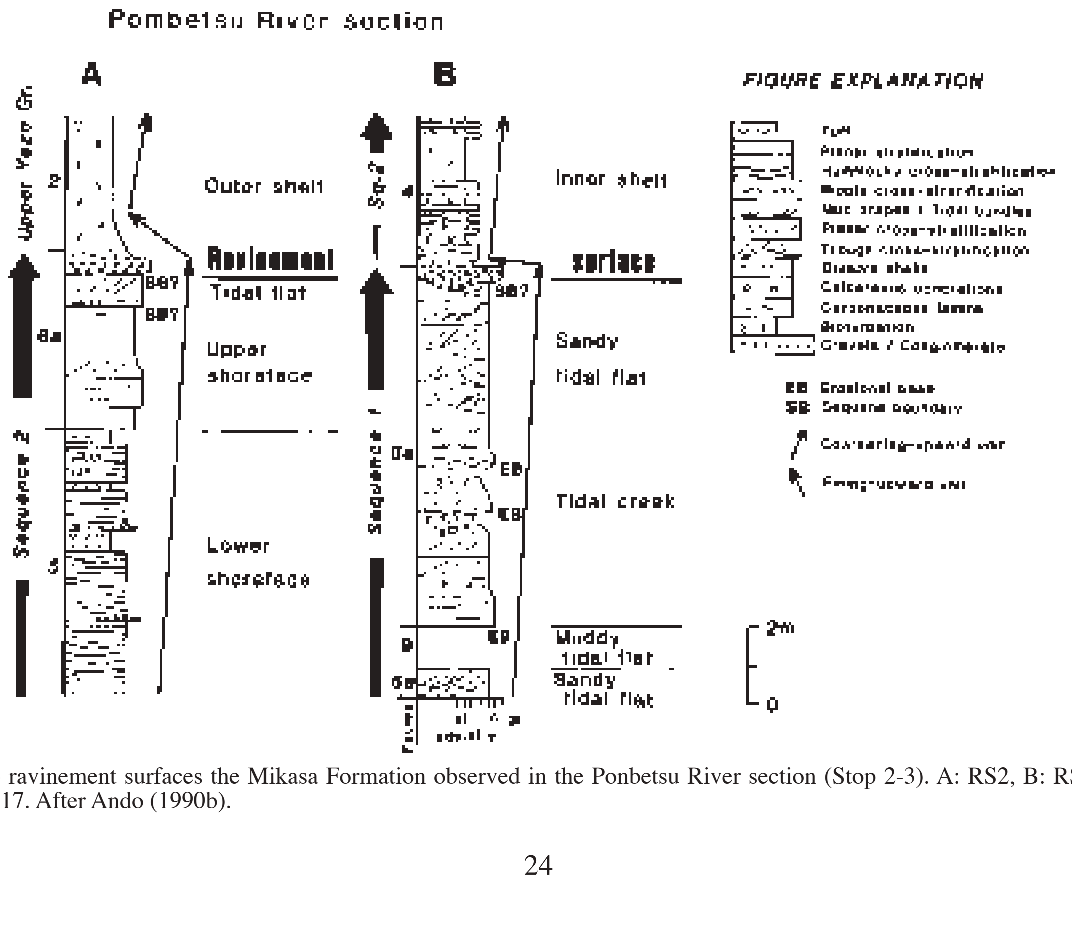

Fig. 18. Two ravinement surfaces the Mikasa Formation observed in the Ponbetsu River section (Stop 2-3). A: RS2, B: RS1 shown in Figs. 16 and 17. After Ando (1990b).

of the Haborogawa Formation (Fig. 18). *Inoceramus teshioensis* obtained from the tidal sandstone indicates that the uppermost part of Twd reaches the upper Turonian.

Haborogawa Formation (Upper Turonian)

The Haborogawa Formation, which is fossiliferous fine-sandy siltstone or silty sandstone with some thin acid tuff and glauconitic sandstone beds, can be observed in the lower stream side of the Mikasa Formation (Figs. 16 and 17). It is unconformably overlain by the Paleogene (Eocene) Ishikari Group in this section. The total thickness is almost 120 m. It is biostratigraphically nearly upper Turonian, but the uppermost part is confirmed to be the Coniacian due to the occurrence of *Inoceramus uwajimensis* and *Baculites* cf. *yokoyamai* (Futakami et al., 1980; Matsumoto et al., 1981).

Stop 2-4 (Mikasa City Museum: Excellent ammonite collection)

The Mikasa City Museum was established in July 1979 to exhibit the nature and cultural history of the city. This is one of the best known museums in Japan for the richness of its excellent ammonite collections. The exhibition highlights gigantic, conspicuously ornate, and heteromorph ammonites as well as prolific smoothly-surfaced ammomnites. Most of their specimens were obtained from various horizons of the Yezo Group around Hokkaido, and were voluntarily contributed to the museum by several ammonite collectors living around the city. Other associated fossils as some marine reptiles as mosasaurid and elasmosaurid, bivalves, gastropods and echinoids, crinoids, teleostei fish bones and shark teeth are also displayed.

DAY 3

Stop 3-1 (Shirakin [Hakkin-zawa] river, Oyubari area: Cenomanian-Turonian [C/T] boundary section in the offshore mudstone facies of the Saku Formation)

Stop 3-1 highlights how the oceanographic deterioration related to OAE2 affected the upper bathyal fore-arc basin along the northwestern margin of the paleo-Pacific from the standpoint of lithology, carbon-isotope stratigraphy, micropaleontology and macrofossil paleontology (Fig. 19). To reach the outcrop, the best-studied Cenomanian/Turonian (C/T) boundary sequence in Japan, we must take a 40-50 minute hike.

Lithology: Along the course of the Shirakin River, the Saku Formation (redefined by Takashima et al., 2004) is largely continuously exposed of more than 200 m in stratigraphic thickness with nearly a vertical dip, and is composed predominantly of dark-gray mudstone with either occasional intercalations of turbiditic sandstone layers of less than 10cm in thickness or rhythmically alternating layers of turbiditic sandstone and siltstone. Some characteristic lithofacies (OY-a-d) are observable near the C/T boundary as shown in Fig. 20. One is a conspicuous greenish gray silty, very fine sandstone (33 m in thickness), named “Radiolarian sandstone” by Hasegawa and Saito (1993). Common intercalations of bentonite layers of 20-50 cm in thickness are observed in and above the Radiolarian sandstone. The other is a dark gray to blackish gray, pyrite-rich clayey siltstone overlain by the Radiolarian sandstone. These lithologic units are traceable throughout the Oyubari area.

Biostratigraphic signature: The stratigraphic distribution of planktonic foraminiferal species of the

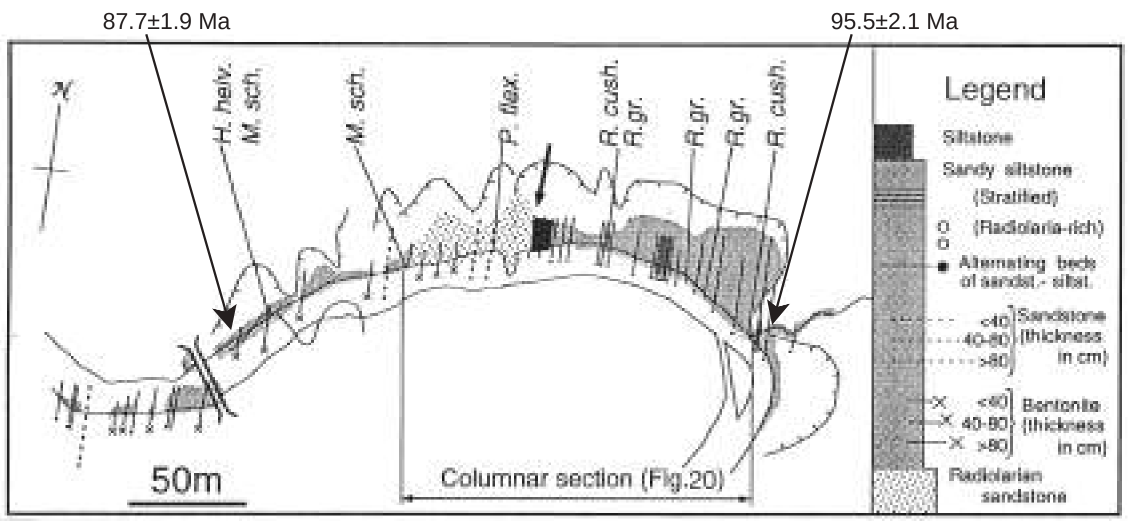

Fig. 19. Route map showing the Cenomanian/Turonian boundary section (Stop 3-1) along the Shirakin River (Hakkin-zawa), Oyubari area (After Ando et al., 1994).

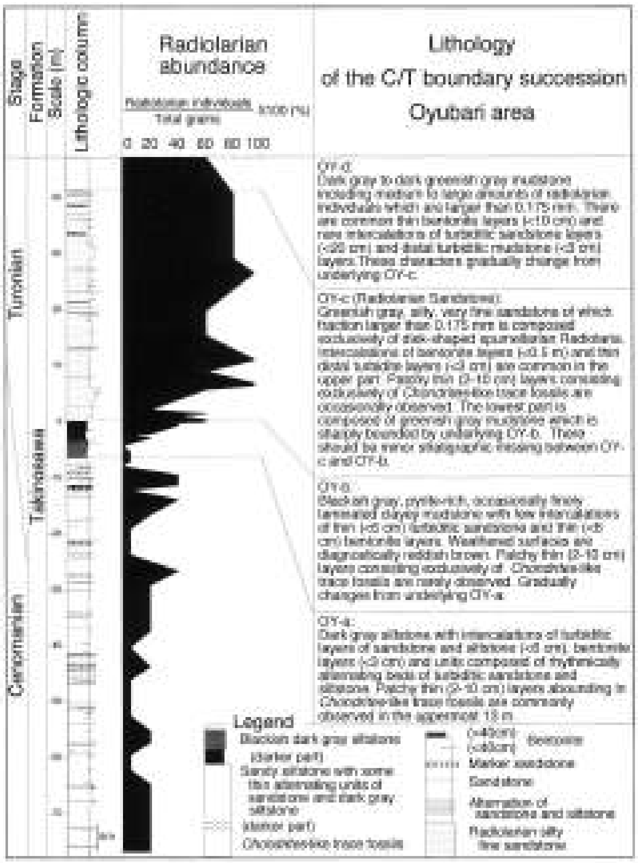

Fig. 20. Lithology and radiolarian abundance across the Cenomanian/Turonian boundary along the Shirakin River. The boundary sequence is subdivided into 4 subunits. Radiolarian abundance refers to percentage of radiolarian individuals relative to the total number of grains larger than 175μm including radiolarians, foraminifers and the others (Hasegawa, 1997).

outcrop at stop 3-1 (Fig. 21) shows a "zone of rare occurrence" across the C/T boundary in the uppermost OY-a, OY-b and lower part of OY-c suggesting environmental pressure for planktonic foraminifers, especially deep dwellers. This phenomenon may reflect paleo-oceanographic change around the northwestern Pacific across OAE2.

The Upper Cenomanian is commonly indicated by *Inoceramus pennatulus* but the uppermost Cenomanian of the Hakkinzawa section is represented by *Inoceramus nodai*. The first occurrence of *Pseudaspidoceras flexuosum* marks one of the important datum-planes for the interregional correlation of the C/T boundary. A stratigraphic marker of the end of the Cenomanian, the 12 m interval is recognized between the carbon-isotopic maximum and the first occurrence of *P. flexuosum*. This interval is a time-equivalent of the *W. devonense* Zone of Pueblo, Western Interior of North America (Kurihara and Kawabe, 2003). The local lower Turonian index, *Inoceramus* aff. *saxonicus* (=*Inoceramus kamuy*) and the local basal Turonian index, *Mytiloides* aff. *sackensis* commonly occur below the first occurrence of *P. flexuosum*. Both *I. kamuy* and *M.* aff. *sackensis* occur above the δ^{13}C excursion. The *M.* aff. *sackensis* Subzone is correlated with the *W. devonense* Zone.

Carbon isotope signals: Stratigraphic fluctuations in the isotopic ratio of terrestrial organic carbon from the Cenomanian to Turonian of the Shirakin River section show numerous details (Figs. 22 and 23). Six conspicuous isotope events are observed in the Oyubari area. Numbers from Hl to H6 are given to them in ascending order (Fig. 22), for the sake of convenience in the following discussion:

H1: Positive excursion in KS19a (middle-late Cenomanian) is a 1 ‰ positive excursion (-23. 27 ‰) occurring in the uppermost Hikagenosawa Formation.

H2: Negative excursion at the top of KS19b (latest Cenomanian) is represented by relatively negative δ^{13}C values from -24. 69 ‰ to -24. 21 ‰ in the lower Saku Formation. Event H2 is regarded as the final phase of the gradual decreasing trend between Hl and H3 events.

H3: Strong positive excursion (isotopic spike) with a double peak in KS20 (latest Cenomanian-earliest Turonian is the most conspicuous character of the carbon isotopic curve. Event H3 occurs in the lower part of the Saku Formation (uppermost part of OY-a and OY-b; Fig. 23).

H4: Isotopic shoulder in the upper KS20 and lower KS21 (lower Turonian) is represented by the δ^{13}C value dropping to -23.59 ‰, then reaching a stable plateau and finally decreasing gradually to a rapid drop near the FAD of *M. pseudolinneiana*.

H5: Level segment above the FAD of *M. pseudolinneiana* is represented by consistent relatively low δ^{13}C values (-24. 32 to -25. 07 ‰) through KS22 in the middle-upper Turonian.

H6: Rising segment through the upper Turonian.

Events H2, 3, 4, and 5 are also observable in the Tappu and Kotanbetsu sections, Hokkaido (Hasegawa and Saito, 1993; Hasegawa, and Hatsugai, 2000; Fig. 22). Stratigraphic comparison among the three sections suggests that the blackish mudstone facies (OY-b) had an exceptionally low sedimentation rate in the Oyubari area (Fig. 23). The stratigraphic range of H3 isotope event (7 m) and KS20 (*W. archaeocretacea* Zone) (38 m) are thin and compared to the same intervals (300-400 m and 330 m respectively) in the Tappu section. The OY-b layer is condensed sediments and is not redeposited sediments except for a few turbidite layers because it is horizontally traceable for more than 20 km. The outcrop at stop 3-1 shows no stratigraphic intervals to be missing due to faulting. However, there must be a hiatus at the top of OY-b because there is an obvious lithological change between OY-b and OY-c and a discontinuity in the

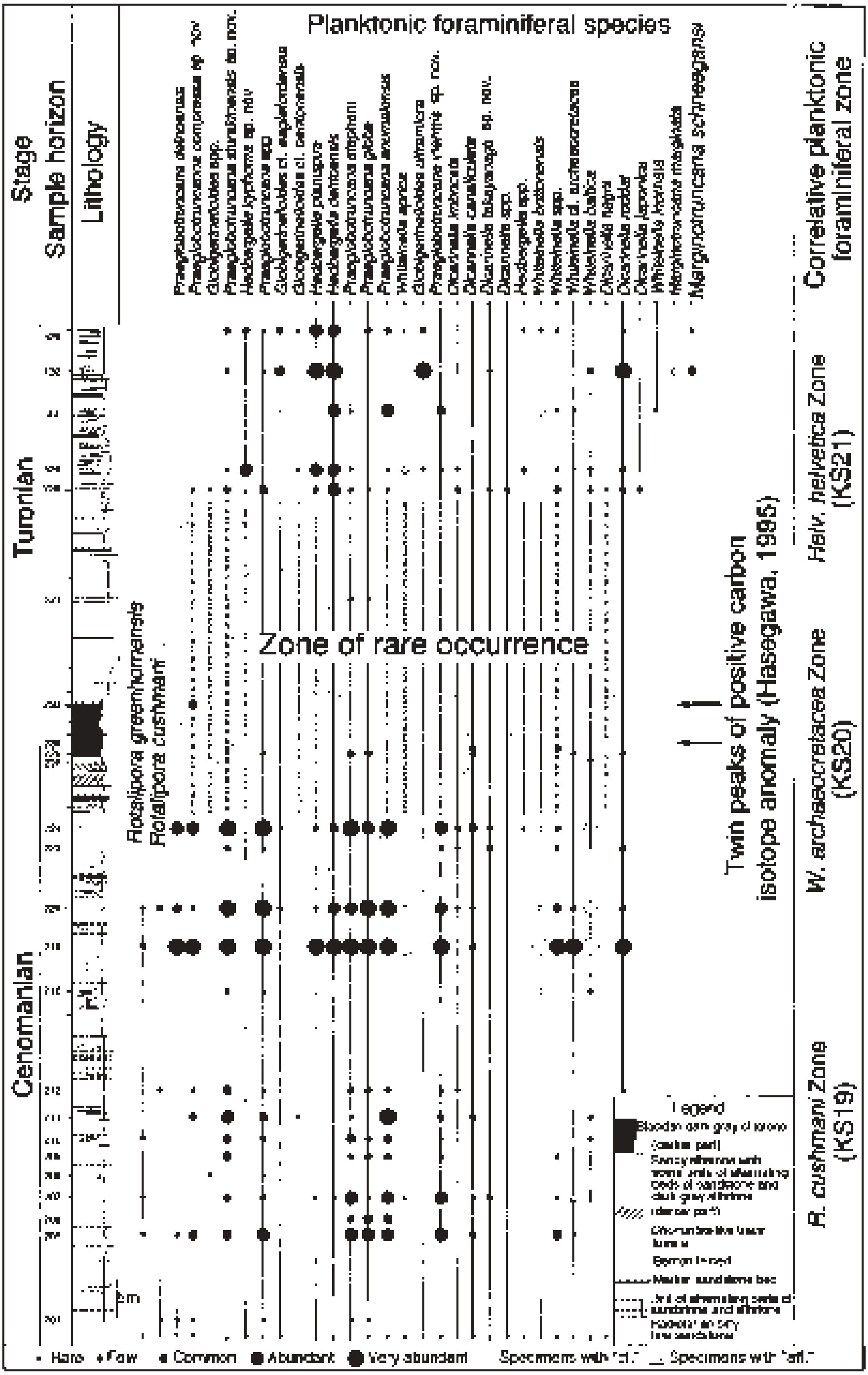

Fig. 21. Stratigraphic distribution of planktonic foraminiferal species across the Cenomanian/Turonian boundary along the Shirakin River (Hasegawa, 1995, 1999). Twin peaks for a positive $\delta^{13}C$ anomaly and stratigraphic rangea of rare planktonic foraminiferal occurrences are also indicated. Symbols denote the number of specimens included in each 240 g rock sample. Very abundant: >21 specimens, Abundant: 10-20, Common: 6-9, Few: 3-5, Rare: 1 or 2.

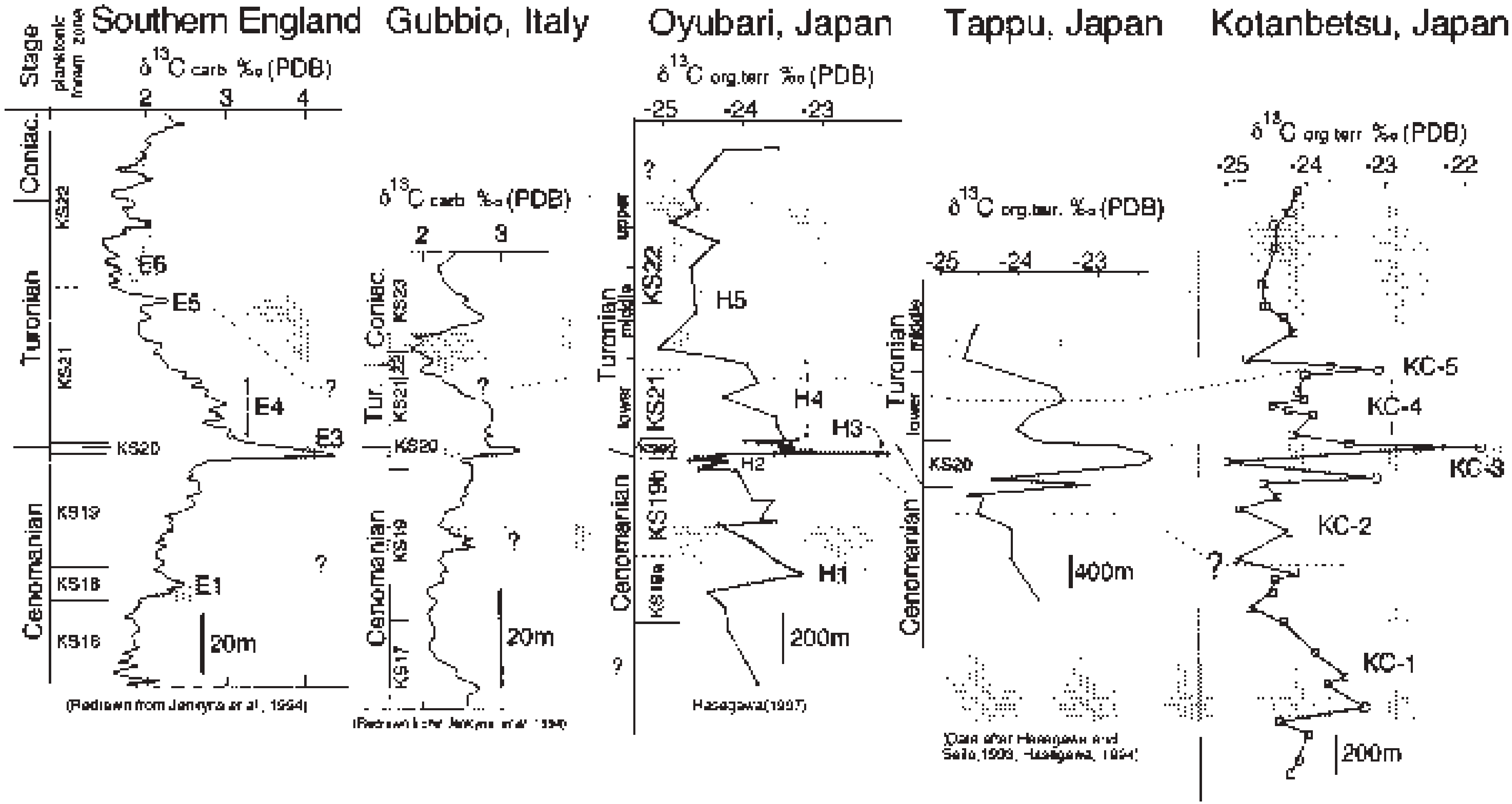

Fig. 22. Comparison of carbon isotope profiles for carbonate (southern England and Gubbio, Italy) and terrestrial organic matter (Oyubari, Tappu and Kotanbetsu sections, Japan). Event-notations for southern England and Oyubari are given by Hasegawa (1997). Note the good correlation between the three carbon-isotope events (spike at the C/T boundary, shoulder at the lower Turonian and a minimum at middle or upper Turonian). $\delta^{13}C_{carb}$: carbon-isotope ratio for carbonate; $\delta^{13}C_{org.terr.}$: carbon-isotope ratio for terrestrial organic matter (Hasegawa and Hatsugai, 2000).

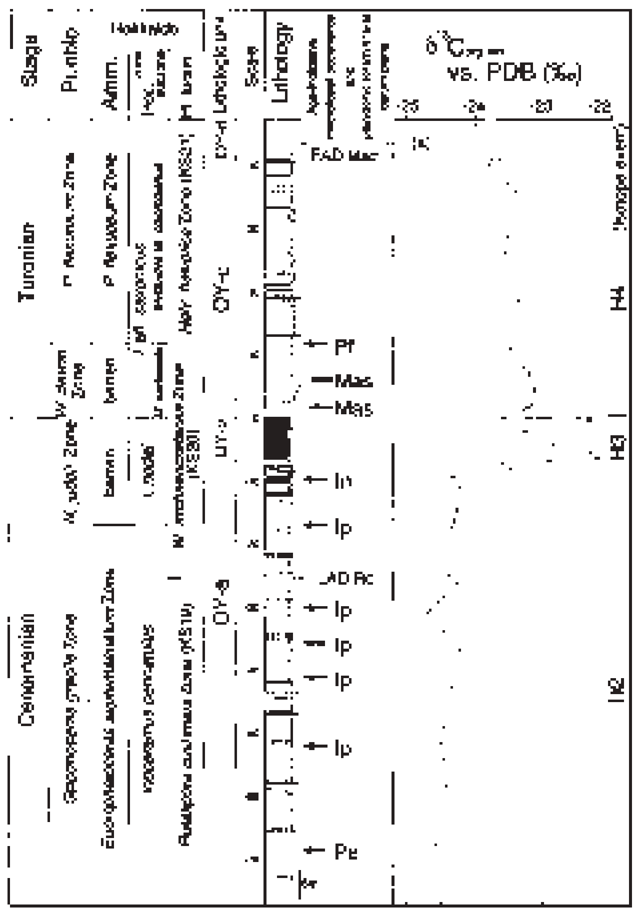

Fig. 23. Integrated ammonite, inoceramid, planktonic foraminifer zonation of the Shirakin River (= Hakkin-zawa) section, with the carbon-isotope profile for organic carbon. The position of the Cenomanian/Turonian boundary is based on Hasegawa (1995). Pe= *Puzosia elegans*; Ip: *Inoceramus* cf. *pennatulus*; In= *Inoceramus nodai*; Mas= *Mytiloides* aff *sackensis*; Pf= *Pseudaspidoceras flexuosum*; FAD Msc= FAD of *Marginotruncana schneegansi*; LAD Rc= LAD of *Rotalipora cushmani*. Correlative ammonite zones established for Pueblo section, Colorado are also indicated. The data source for the macro-fossils is Matsumoto et al. (1991), Hirano et al. (1989a-c, 1990) and Toshimitsu et al. (1995). The data source of planktonic foraminifers and carbon isotope stratigraphy is Hasegawa (1995, 1997). This figure is based on Hasegawa (1995) and Hirano

carbon-isotope curve. The missing interval is small, and is not problematic for the discussion in carbon isotope stratigraphy due to the following reasons: 1) Cenomanian-type inoceramids (*Inoceramus nodai* and *I. pennatulus*) continuously occur above the LAD of *R. cushmani* within OY-a suggesting that uppermost Cenomanian exists in this section. 2) *P. flexuosum*, a very short-ranged ammonoid index species, which first appears about 80 cm above the C/T boundary in the Pueblo section (Kennedy and Cobban, 1991), has been reported in the Oyubari section (Hirano, l995). 3) *Mytiloides* aff. *sackensis* (Keller), also short-ranged species spanning C/T boundary in the Pueblo section, was also reported at 2 m and 7 m above the OY-b/OY-c boundary (Hirano, 1995; Toshimitsu et al., 1995) in the Oyubari section. Since there is no stratigraphic discontinuity between the occurrence of *P. flexuosum* and the OY-b/OY-c boundary, the observed *M.* aff. *sackensis* Zone includes, at least, the equivalent of the upper part of this zone (lowest Turonian) of the Pueblo section.

Radiometric ages: Two radiometric ages have been reported near the outcrop (Hirano et al., 1997; Fig. 19). A K-Ar age 95.5±2.1 Ma was obtained from a white acidic tuff bed of 15 to 30cm thick and about 100 m upstream of the C/T boundary. The tuff bed stratigraphically lies in the Middle and Upper Cenomanian *Inoceramus pennatulus* zone in inoceramid biostratigraphy, middle Upper Cenomanian *Euomphaloceras septemseriatum* zone in ammonoid biostratigraphy and middle Upper Cenomanian *Rotalipora cushmani* zone in foraminiferal biostratigraphy (Hasegawa, 1995; Hirano, 1995). Another K-Ar age, 87.7±1.9 Ma was reported from a white acidic tuff bed of 25 cm thick, which is about 100 m above the last peak of $\delta^{13}C$ excursion at the C/T boundary. It is also about a 20m distance upstream from the locality of abundant *Mytiloides labiatus* on the right bank of the Shirakin River. There are some thick white tuff beds on the bank between the exposures of this sample and the blackish mudstone bed across the C/T boundary, however, no fresh biotites have been separated from them.

International correlation: Detailed international correlation at stop 3-1 has been achieved on the basis of globally age-indicative biohorizons of megafossil species, i. e. (1) First occurrences of *Pseudaspidoceras flexuosum* and (2) *Mytiloides* aff. *sackensis*; those of planktonic foraminiferal species, i. e. (3) the last occurrences of *Rotalipora greenhornensis* and (4) *Rotalipora cushmani* and (5) First occurrrence of *Marginotruncana pseudolinneiana*; (6) stratigraphic profile for carbon isotope with its double peaked shape and (7) K-Ar radiometric age. These signatures are well recognized in the Pueblo section, Western Interior of North America, a candidate type locality of the Cenomanian/Turonian boundary (Kennedy and Cobban, 1991). We shall visit the best chronostratigraphically resolved and correlated outcrop in the Cretaceous system in East Asia. Hasegawa (1995), Hirano (1995) and recently Kurihara and Kawabe (2003; Fig. 24) discussed in detail about the international correlation arising from the study of this outcrop.

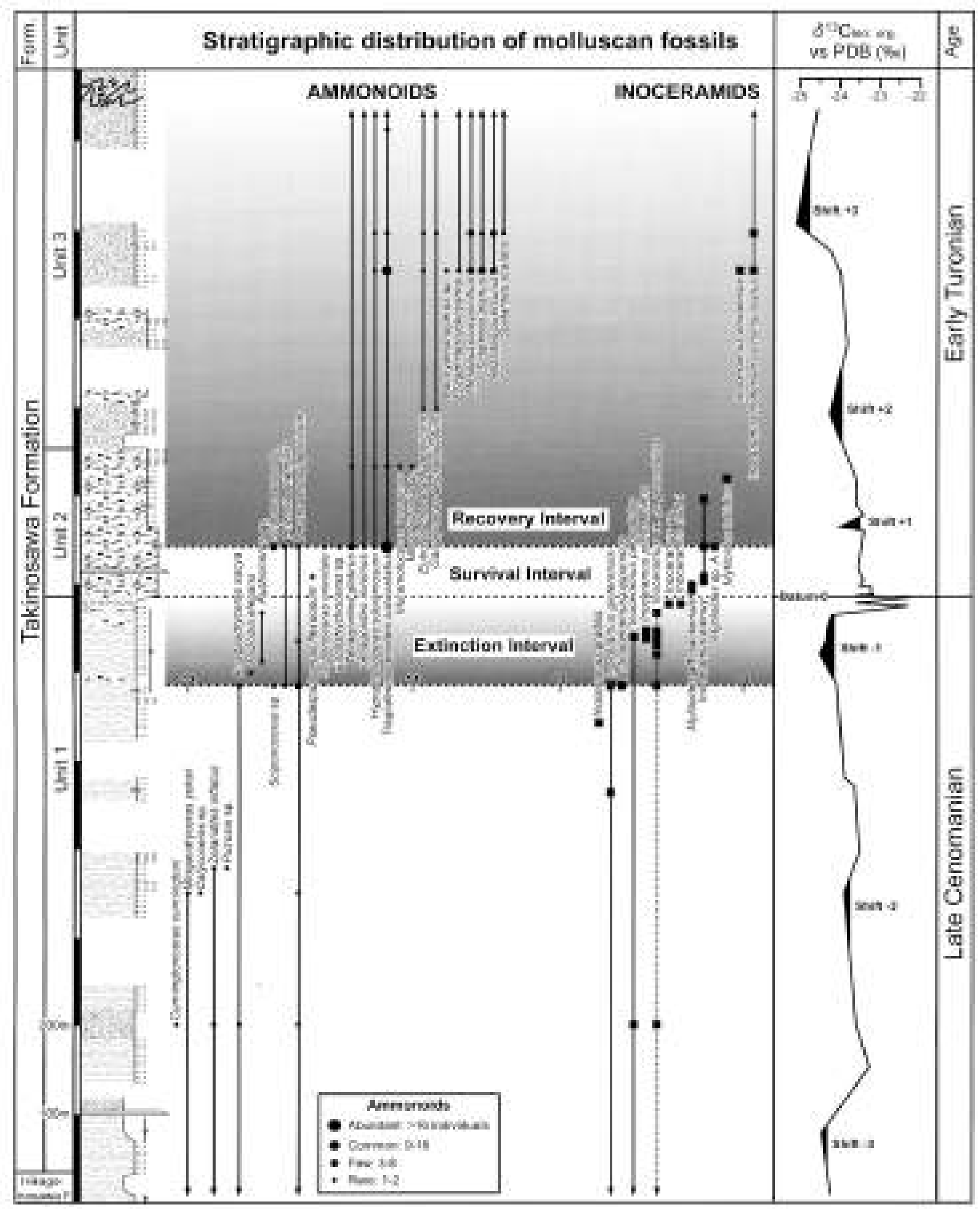

Fig. 24. Stratigraphic distribution of molluscan fossils and molluscan events in the Shirakin (Hakkin) River section (Kurihara and Kawabe, 2003).

DAY 4

Stop 4-1 (Osoushinai River: Offshore mudstone facies bearing ammonite fauna of the Osoushinai Formation)

We will observe offshore mudstone facies of the Osoushinai Formation that is the most fossiliferous sequence in the Nakagawa area. We can collect well-preserved ammonoids and inoceramids from calcareous concretions in the type locality along the Osoushinai River (Figs. 25 and 26-1). The Osoushinai Formation conformably overlies the Omagari Formation (see Stop 4-2), and conformably underlies the Hakobuchi Formation (see Stop 4-4). Both of the two formations are equal to the upper and middle parts of the Haborogawa Formation respectively in central Hokkaido (Takashima et al., 2004).

It is composed mainly of bioturbated sandy mudstone and muddy sandstone intercalated with conglomerate horizons in the uppermost part, and shows a coarsening-upward trend. Though the lower part is often parallel laminated, the formation is generally massive due to heavy bioturbation. Trace fossils are often found in bioturbated sandy mudstone (Fig. 26-2). Dark green mineral grains (maybe glauconite) were sometimes contained in the upper muddy sandstone and conglomerate matrix. The formation is correlated to the Lower Campanian by stage-diagnostic ammonoids and inoceramids (Takahashi et al., 2003). They reported seventeen ammonoid species and ten inoceramid species. The lower part of the formation yields various ammonoids such as *Yokayamaoceras ishikawai*, *Gaudryceras tenuiliratum*, *Phyllopachyceras ezoense* and *Polyptychoceras*, but the upper part yields mainly *Canadoceras* (Fig. 26-3). An inoceramid genus *Sphenoceramus* occurs abundantly and is often concentrated in several horizons. *S. naumanni* is dominant in the lower to middle parts of the

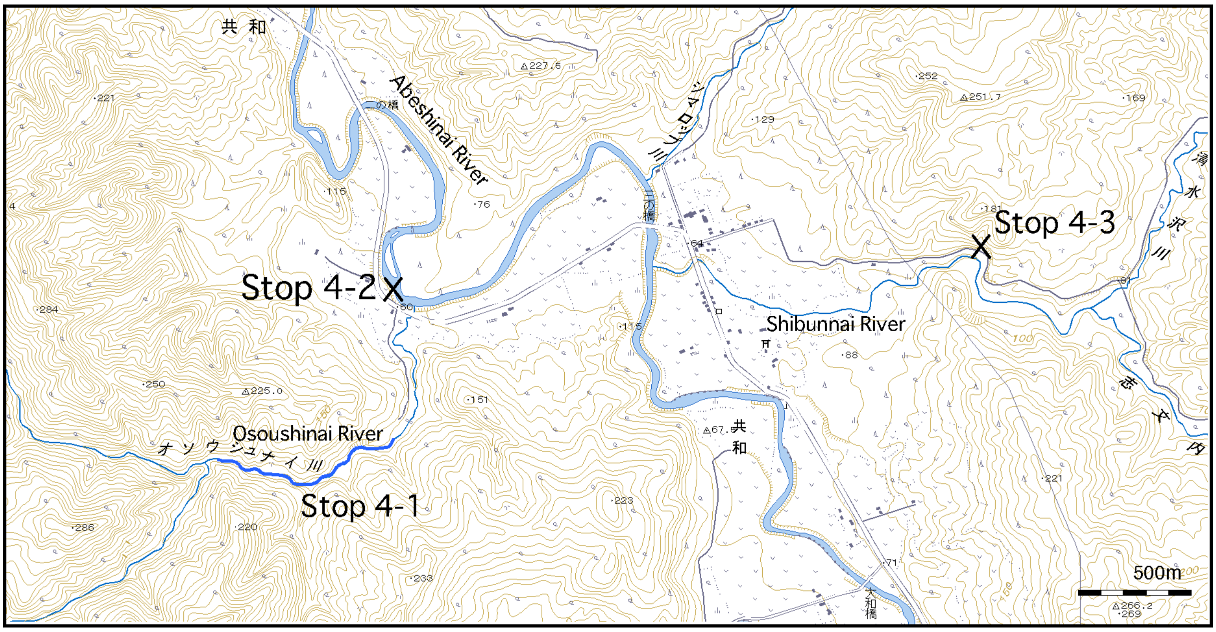

Fig. 25. Map showing the stops in Day 4. Topographic map is a part of 1:25,000 map sheet 'Kyowa' published by Geographical Survey Institute of Japan.

Fig. 26. Outcrop photos of the Osoushinai Formation. **1.** Large calcareous concretion in bioturabated sandy mudstone. **2.** Trace fossils in sandy mudstone. **3.** Mode of occurrence of large ammonite (*Canadoceras* sp.). **4.** Autochthonous occurrence of inoceramid bivalve (*Sphenoceramus schmidti*).

formation, while *S. schmidti* and *S. sachalinensis* in the upper part. Their many individuals show articulated, *in situ* to parautochthonous modes of occurrence (Fig. 26-4).

The Osoushinai Formation also contains numerous invertebrate fossils such as bivalves, gastropods, gigantic limpets, nautiloids, etc. Recently, Tanabe et al. (2006) described a large jaw of coleoid and proposed a new genus and species (*Yezoteuthis giganteus*) for it. This formation also yields marine vertebrates, *i.e.*, dermochelyid turtle (Hirayama and Hikida, 1998) and long-necked elasmosaurid (Sato, 1998). Recently, terrestrial vertebrates such as therizinosaurid dinosaurs and turtles were found.

Stop 4-2 (Abeshinai River: Cretaceous seep carbonate with well-preserved fossil chemosynthetic community of the Omagari Formation)

The Stop 4-2 highlights the exceptionally well-preserved fossil seep site in the view of carbonate facies and mode of occurrence of biota. We must go across the Abeshinai River to reach the Omagari carbonate islet (Fig. 27). The following descriptions are modified and summarized after Hikida et al. (2003).

The carbonate lens (named the Omagari carbonate lens) with a chemosynthetic community is enclosed in muddy turbidite of the Omagari Formation of the Yezo Group (Fig. 28). The similar carbonate lenses of less than 1 m thick having fewer fossils also occur along the Abeshinai River and its branches (Fig. 28-b). These lenses seem to be distributed sporadically and narrowly along a north-south structural trend extending for 10 km.

The Omagari Formation is composed of muddy to sandy turbidites intercalated with conglomerate horizons and thick sandstone beds, and contains many slump deposits. Thick sandstone beds are predominant in the upper part of the formation. It conformably overlies the Nishichirashinai Formation composed of siltstone to sandy mudstone, and conformably underlies the Osoushinai Formation as described in Stop 4-1. The Omagari Formation is correlated to the Campanian by stage-diagnostic ammonoids and inoceramids (Takahashi et al., 2003).

The chemosynthetic community occurs from a resistant carbonate lens that weathered out from the host siltstone, and forms an islet in a pool of the Abeshinai River (Fig. 28-a). The Omagari carbonate lens is roughly ellipsoidal in plan view, with a diameter of between 6 and 10 m, and a thickness of about 5 m. The surrounding bedded siltstone and sandstone layers strike north-south and dip 60° to 90° eastward. The long axis of the carbonate lens is parallel to the strike of the host beds. Concordant geopetal structures within both articulated bivalve shells and worm tubes indicate normal deposition of the lens *in situ*. Some macrofossils were scattered in the surrounding siltstone.

1. Lithofacies of Omagari carbonate lens

Judging from the mode of occurrence and fossils, the lens is divided into two facies (Figs. 28 and 29). One is the upper worm tube boundstone facies prolific in worm tubes, and the other is the lower carbonate brecciated facies composed mainly of carbonate

Fig. 27. Photos of the Omagari carbonate 'islet'. **1.** Omagari carbonate (arrow) from the view of the upstream in the Abeshinai River. **2:** Different view of the carbonate.

breccia with abundant molluscan fossils. The carbonate of the lens is composed of various textures of calcite, such as micrite, splayed and sparitic, containing several to 10 mol% magnesium (ratio of Ca-Mg-Fe-Mn system) with little iron and manganese.

Carbonate brecciated facies.-- This facies occurs in the western half of the lens, and is stratigraphically beneath and marginal to the worm tube boundstone facies. The brecciated facies consists of dark-grey muddy carbonate and dark-grey calcareous mudstone breccias (Figs. 29 and 30-3&4). Long axes of these angular pebbles are of several to 30 cm in length. It also contains irregular layers of tuffaceous sandstone and siltstone, the latter being similar to the siltstone enclosing the lens. The tuffaceous sandstone layers underwent deformation and fluidization. The irregular tuffaceous sandstone and siltstone layers, and the

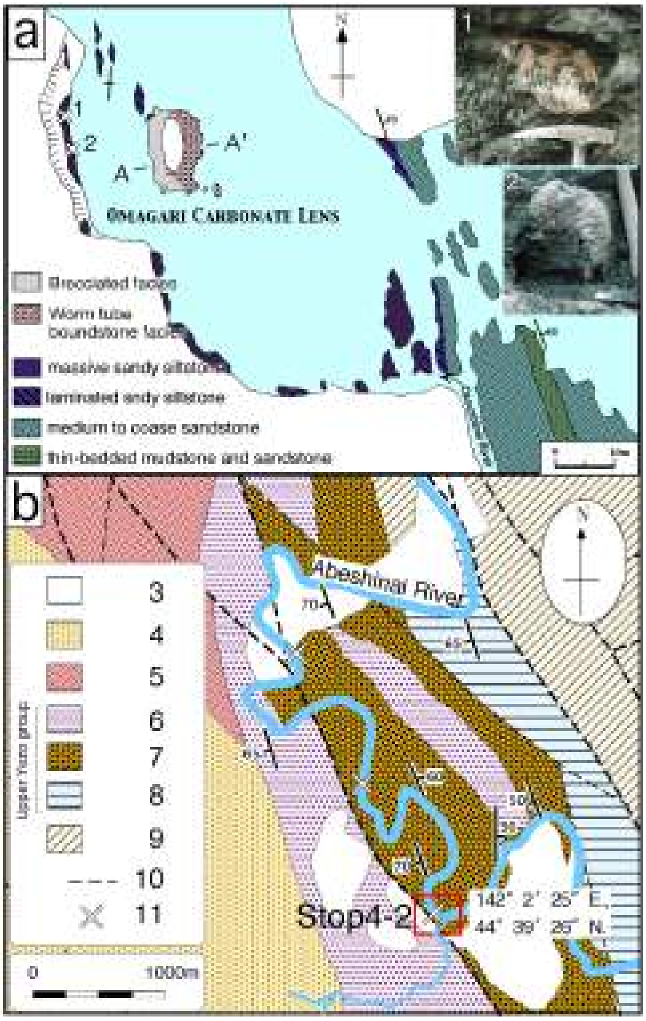

Fig. 28. a, b. Route map near the Omagari carbonate lens (**a**) in the Abeshinai River (flow to NW) and simplified geological map around the Stop 4-2 (**b**). The geological map was modified after Hashimoto et al. (1967). **1-2:** Photos showing the mode of occurrence of fossils in the outcrop of left river bank (**1**: ammonoid *Gaudryceras intermedium*, **2**: inoceramid *Inoceramus ezoensis*), **3:** Alluvial and terrace deposits, **4:** Tertiary deposit, **5:** Hakobuchi Formation, **6:** Osoushinai Formation, **7:** Omagari Formation, **8:** Nishichirashinai Formation, **9:** middle part of Yezo Group, **10:** Fault, **11:** Seep carbonate.

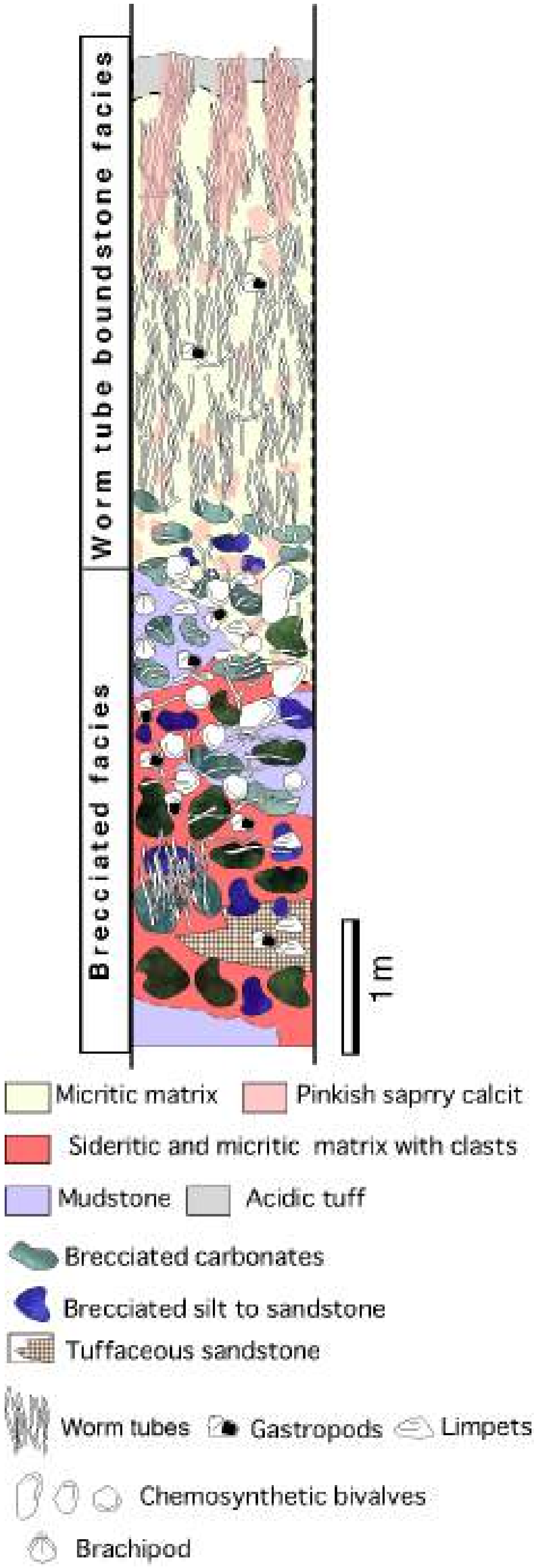

Fig. 29. Schematic columnar section of the Omagari carbonate lens (modified after Hikida et al., 2003).

Fig. 30. Outcrop photos of the Omagari carbonate lens. **1:** Outcrop photo of the worm tube boundstone facies. **2:** Natural occurrence of vestimentiferan worm tubes in the boundstone facies. **3:** The mode of occurrence of chemosynthetic bivalve (white arrow) and ammonoid (black arrow) in the brecciated facies, **4:** Close-up view of the brecciated facies with sideritic matrix. Small molluscs are included in the matrix.

Fig. 31. Photos showing hand samples of carbonate chimney. **1:** Carbonate chimney from surface of the outcrop. **2:** Polished slab (cross section) of the carbonate chimney. Pinkish calcite grew around worm tubes.

sideritic matrices contain small trochid gastropods, limpets, fragments of ammonites, and small calcareous concretions of 3 to 5 mm in diameter (Fig. 30-4). Small fossils are also common in the siltstone around selectively cemented carbonates. Brachiopods are predominant, and limpets, mesogastropods, nuculacean bivalves and foraminiferans are also included. This facies also includes chemosynthetic bivalves (Fig. 30-3).

Worm tube boundstone facies -- This facies occurs in the eastern part of the lens, and contains numerous worm tubes (Figs. 29 and 30-1&2). However, macrofossils are very rare except small gastropods. The facies is changed gradually from the brecciated one, and is composed of light-grey massive carbonates with vein-like to sheet pinkish calcite of several to 20 cm thick. Dense stands of worm tubes are observable on the surface of the carbonate because of corrosion of the host rock. Pinkish 'carbonate chimneys' (Fig. 31) are found in the worm tube-dominated part, and vein-like precipitates of high-Mg pinkish calcite are also found in this facies. Veins of breccia are found within the worm tube-dominated boundstone, indicating periodic fluid escapes.

The tube walls were often dissolved and filled by sparite, however, brownish walls of many tubes are preserved. The pinkish sparry calcite grew around the tubes, and resultant carbonate chimneys occurred. In cross-sections of the chimney, zoned pinkish sparry calcite was formed around vestimentiferan circular tubes and within the tubes. Such occurrence of pinkish calcites indicates that tubes acted as seep fluid conduits once the organisms died (cf. Campbell et al., 2002). The matrices of the facies with little clastic contents consist mainly of micritic high-Mg calcite.

2. Chemosynthetic community of Omagari carbonate lens

Worm tubes -- Abundant worm tube fossils with a chimney-like appearance (Figs. 30-2 and 31) characterize the seep communities in the Omagari carbonate lens. Brownish to black tubes (1 to 4 mm in diameter and more than 100 mm in length) may represent vestimentiferans, and their wall may have originally been organic, for example, made of chitinous material (Brusca and Brusca, 1990; Naganuma et al., 1996).

Chemosynthetic bivalves -- It has been reported that the lucinid and vesicomyid *Calyptogena* characterize chemosynthetic bivalves in hydrothermal vent and/or cold seep (Hashimoto et al., 1995; Van Dover, 2000; etc.). Kanie and Sakai (1997) indicated that the fossil thracid *Nipponothracia* from Cretaceous and Miocene deposits was a member of the chemosynthetic community. These chemosynthetic bivalves were also abundantly found in the Cretaceous Omagari carbonate lens. These include *Miltha* sp., *Nipponothracia* cf. *ponbetsensis*, *Thyasira* sp. and *Calyptogena* sp. (Fig. 32). All of the bivalves are articulated and randomly oriented, indicating *in situ* to parautochthonous modes of occurrence.

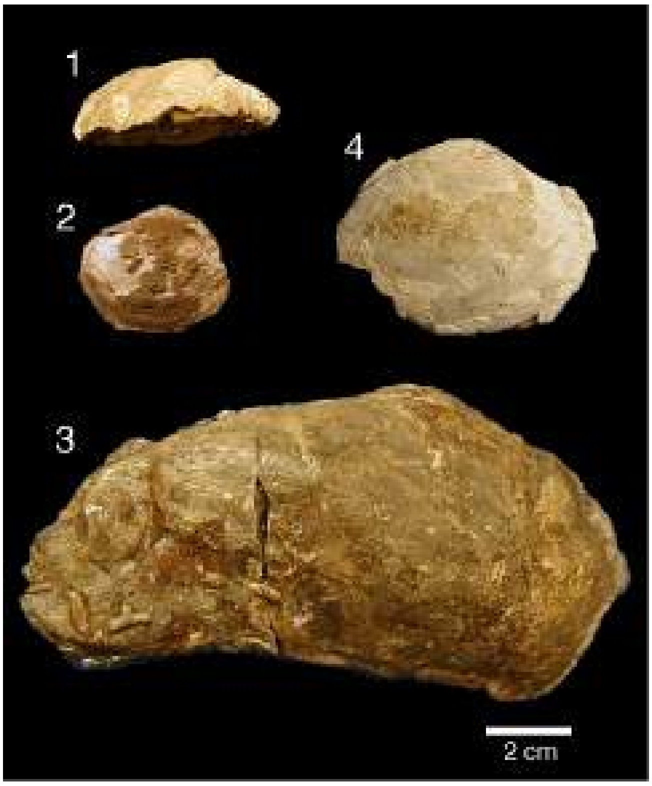

Fig. 32. Chemosynthetic bivalves in the Omagari carbonate lens. **1.** *Thyasira* sp., **2.** *Miltha* sp., **3.** *Calyptogena* sp., **4.** *Nipponothracia* cf. *ponbetsuensis*. All specimens are housed in the Nakagawa Museum of Natural history.

3. Isotope geochemistry

$\delta^{13}C$ values for all specimens range from -41 to -45 ‰ (vs. PDB), and clearly show that the carbonate lens was derived from bacterial oxidation of methane. $\delta^{18}O$ values for carbonates of the boundstone facies are the lowest, ranging from -10 to -7.5‰, while the values are higher for the brecciated facies, ranging from -3.5 to -0.7‰ (Fig. 33).

The biota described above is contained in an isotopically light carbonate lens. The authigenic carbonates were formed by bacterial sulfate reduction and methane oxidation like modern seep sites (Hattori et al., 1996; Boetius et al., 2000; Michaelis et al., 2002). These kinds of carbonates are also recognized in fossil seep communities (Goedert and Squires, 1990; Kauffman et al., 1996; Peckmann et al., 2001; Campbell et al., 2002; Majima et al., 2003; Nobuhara, 2003). The Omagari carbonate lens appears to have formed under the same conditions.

Campbell et al. (2002) discussed about stable carbon and oxygen isotopic data for 33 globally distributed seep-carbonates, ranging in age from Devonian to Recent. Paleozoic-Mesozoic seep-carbonates clearly preserved a signal of $\delta^{13}C$, however, $\delta^{18}O$ values of Paleozoic-Mesozoic seep-carbonates indicated a strong diagenetic overprint. $\delta^{18}O$ values for the Omagari carbonates are ranging from -10 to

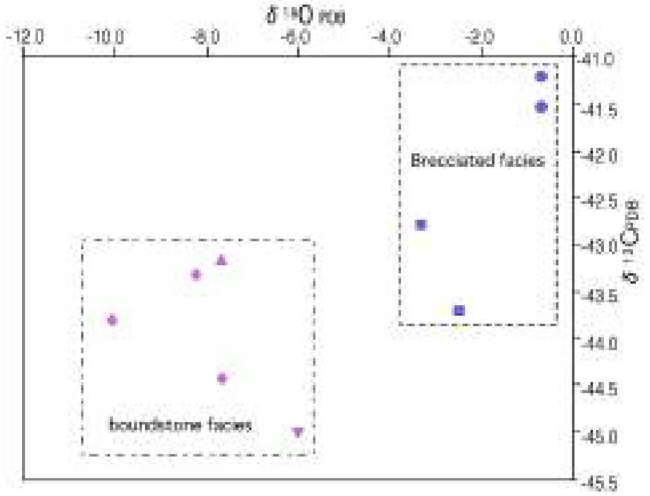

Fig. 33. Oxygen vs. carbon isotope cross-plot of the Omagari carbonate lens (modified after Hikida et al., 2003). Each symbol indicates a data set for a single measurement.

-0.7 ‰. These data may indicate influences of burial/meteoric/warmer fluids.

4. Reconstruction of Omagari seep site

The community described here is the first record from the Campanian of the Yezo Group, and is different from the other ones by having well-preserved worm tube assemblages. The presence of unabraded and articulated shells of bivalves and brachiopods, together with fragile worm tubes, small limpets and gastropods suggests their *in situ* fossilization. The Cretaceous community of the Nakagawa area (named here the Omagari community) is characterized by the dominant occurrence of vestimentiferans and infaunal bivalves. The most dominant chemosynthetic bivalve is a lucinid *Miltha* sp.; the others are another lucinid *Thyasira* sp., a thraciid *Nipponothracia* cf. *ponbetsensis*, and a vesicomyid *Calyptogena* sp. The Omagari community is defined as a vestimentiferans-lucinids assemblage. This assemblage somewhat resembles the recent cold seep community in Kanesu-no-Se Bank, Enshu-Nada (138°15'E, 34°17'5''N; Hashimoto et al., 1995) which is also dominanted by vestimentiferans and lucinid bivalves.

Detailed study of the Omagari carbonate lens, together with comparisons of modern seep sites allows the following reconstruction of the Cretaceous seep community (Fig. 34). Vestimentiferan worms lived on authigenic carbonates, and semi-infaunal *Calyptogena* lived in the sediment. The infaunal species *Nipponothracia*, *Miltha* and *Thyasira* lived in muddy to sandy sediments which contained ample amounts of hydrogen sulfide around brecciated carbonates. Abundant small brachiopods, trochid gastropods and limpets lived within or near the colony. These small limpets and gastropods probably grazed on bacteria that lived on the surfaces of bivalves and worm tubes. There is no proof that the ammonites lived within or near the seep site.

Stop 4-3 (Forestry road along the Shibunnai River, Kyowa: Channel facies of the Saku Formation)

This large outcrop of about 100 m wide or more shows the channel-fill facies erosionally overlying the ordinary mudstone facies within the upper part of the Saku Formation. As shown in Fig. 35, Matsumoto and Okada (1973) described the outline of lithofacies and sedimentary structures. In the left side of the outcrop, the channel-fill deposits are characterized by a few meters thick basal conglomerate with an irregularly-undulated erosional base and the overlying massive and thick sandstone, though lateral changes are observable. The conglomerate is mainly clast-supported and is mostly composed of round pebble and cobble of sandstone, mudstone and calcareous concretions, many of which seem to have derived from the lower horizons of the Yezo Group. Recently Takahashi and Mitsugi (2002) reported that some concretion gravels within the conglomerate contains

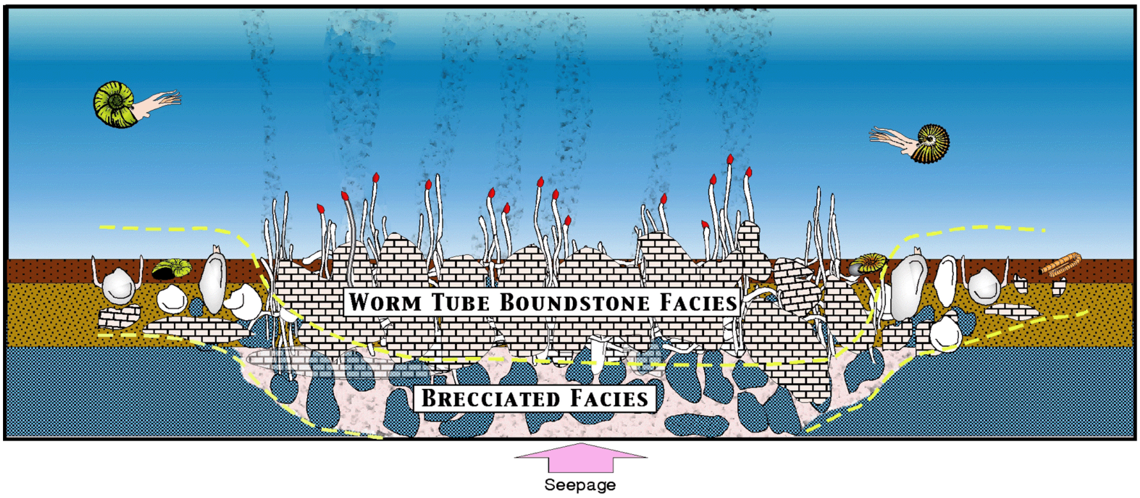

Fig. 34. Schematic reconstruction of the Cretaceous Omagari seep site in the Nakagawa area.

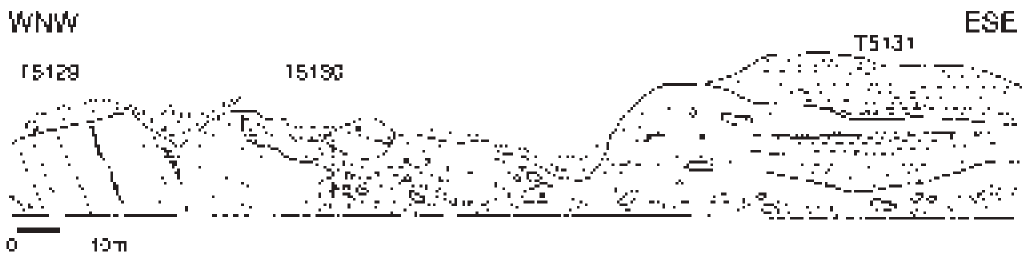

Fig. 35. Sketch showing the outline of channel-fill deposits within the upper part of the Saku Formation along Shibunnai forestry road. Modified from Matsumoto and Okada (1973).

the upper Cenomanian inoceramid such as *Inoceramus pictus minimus*, as well as the commonly bearing, middle to upper Turonian ammonite and inoceramids (*Eubostrychoceras japonicum*, *Inoceramus hobetsensis*, *Inoceramus teshioensis*, etc.). They thought that the channel was formed and filled during late Turonian.

The overlying thick sandstone is partly conglomeratic and slumped, and contains large blocks of sandstone and interbedded sandstone and mudstone. Though the right side of the outcrop is heavily covered by vegetation, two channelized units of less than 10 m thick are filled with interbedded sandstone and mudstone (turbidite).

Stop 4-4 (Forestry road along Uttsu River, Enbetsu: Coarsening-upward successions and large-scale forset cross-bedding of the Hakobuchi Formation)

The Hakobuchi Formation in the Nakagawa area is mainly composed of shallow-marine fine to medium sandstone with sandy siltstone, representing the western marginal facies of Campanian age within the Yezo forearc basin. It constitutes five parasequences (PS: possibly equivalent to fourth-order depositional sequences) each of which consists mostly of thick coarsening-upward facies successions (CUS) and subordinately of thin fining-upward successions (FUS) below CUS (Figs. 36 and 37). Their thickness ranges from 30 to 120 m. In general, CUS includes outer shelf bioturbated sandy siltstone, inner shelf interbedded HCS sandstone and siltstone, lower shoreface amalgamated HCS fine sandstone and upper shoreface/tidal flat cross-stratified medium to coarse sandstone in ascending order, while FUS is represented by several meters of shoreface sandstone and siltstone, if present, following transgressive lag/conglomerete of less than 1m thick. Taking distribution of facies within a PS into account, CUS, FUS and their boundary are interpreted to be HST (highstand systems tract), TST (transgressive systems tract) and MFS (maximum flooding surface), respectively. Each PS is sharply bounded by two marine flooding surfaces or ravinement surfaces with abrupt facies changes from coarse- to fine-grained facies at the boundary. These PSs are traceable throughout the Nakagawa area, though a part of PS4 to 5 is eroded away by unconformity and covered by the Neogene sediments. Judging from stacking patterns of PSs and their thickness trends, the lower three and upper two PSs can be grouped into two parasequence sets (PSS1, PSS2), respectively. Especially, PSS1 shows a thinning-upward trend and appears to represent a progradation of terrigeneous depositional systems.

Although fossils are not so abundant due to sandstone-dominated lithology, commonly occurred molluscan fossils indicate the cyclic patterns depending on facies successions (Fig. 37). The lower part of PS1 is characterized by occurrence of the lower to middle Campanian *Sphenocramus schmidti*. The upper Campanian index ammonite, *Metaplacenticeras subtilistriatum* occurs only from inner shelf sandy siltstone to silty sandstone facies in the lower part of PS2 to 5, namely representing the early stage of HST within a PS. Therefore, the stratigraphic range of the Hakobuchi Formation in the Nakagawa area covers the upper Lower Campanian to lower Upper Campanian.

4-4-1 (Marine flooding surface within PS4)

In the lower part of PS4, we can observe a somewhat smaller-scale marine flooding surface

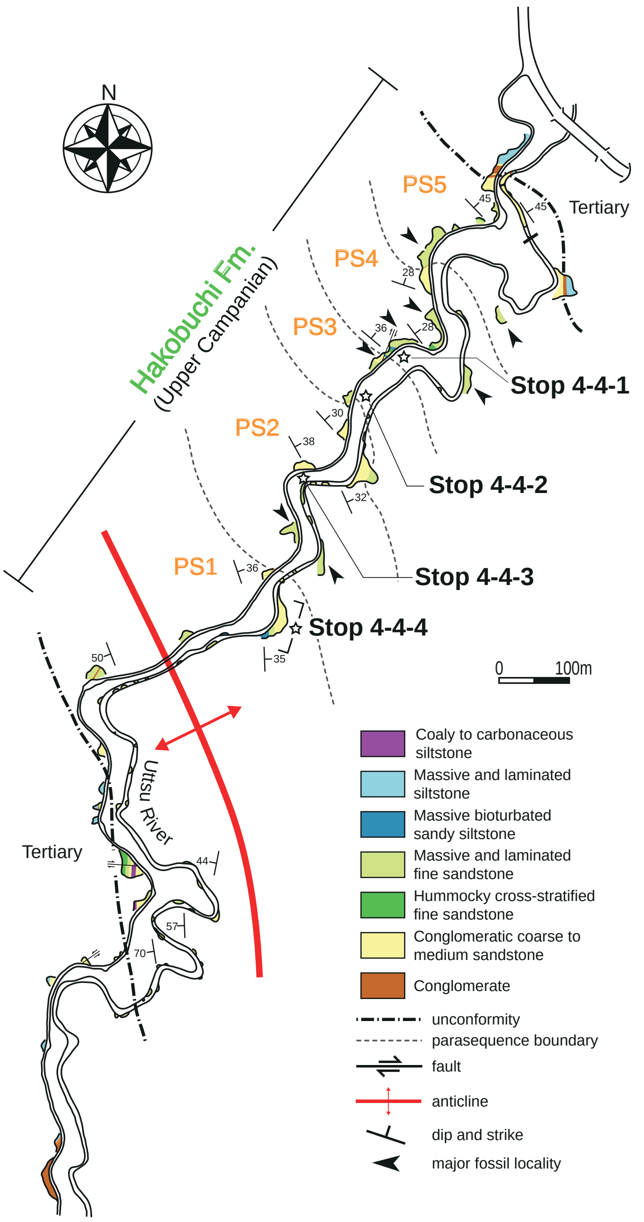

Fig. 36. Geological route map of the Uttsu River section showing the five coarsening-upward facies successions of the Hakobuchi Formation (Upper Campanian).

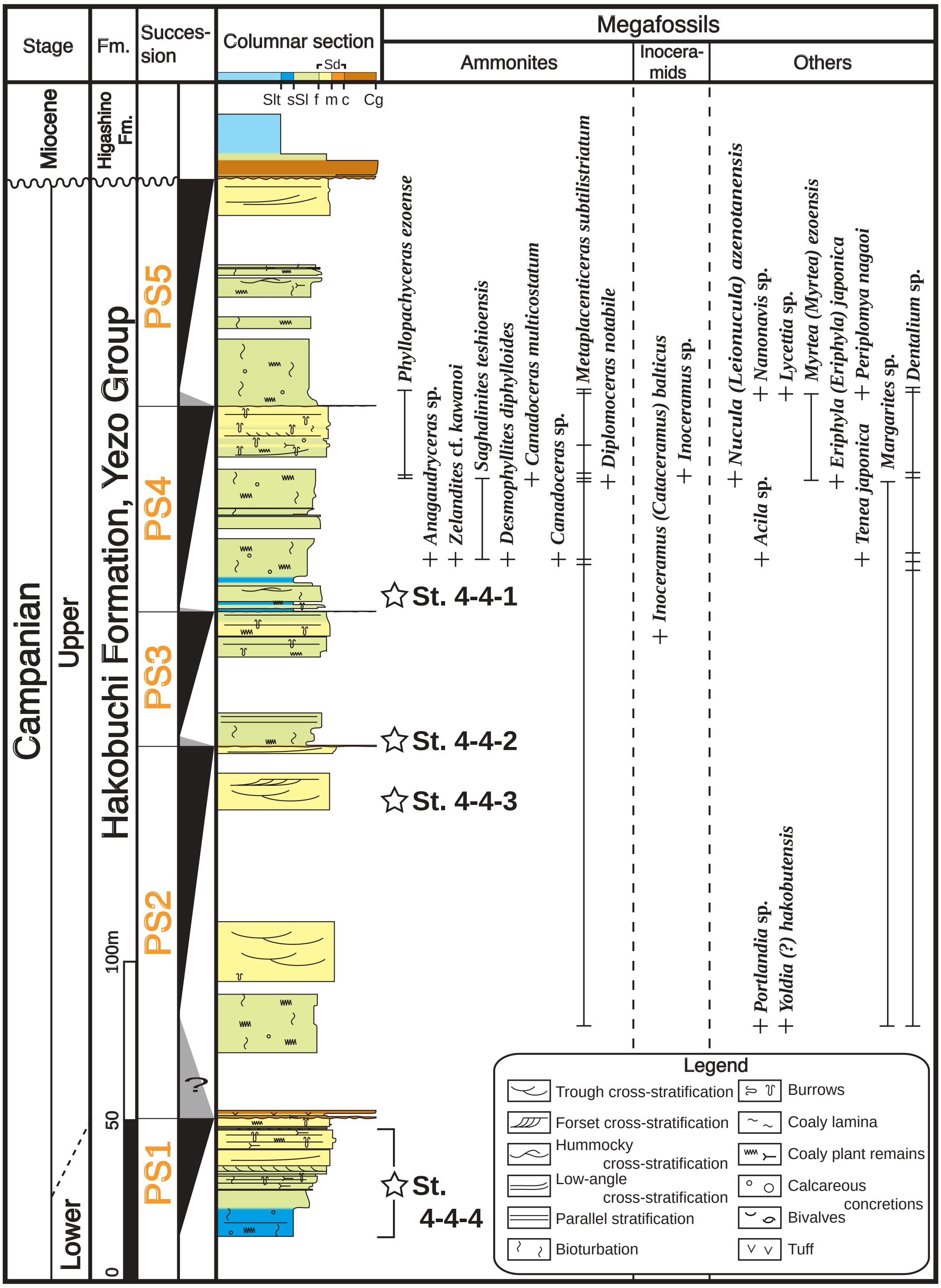

Fig. 37. Geological columnar section of the Hakobuchi Formation along the Uttsu River section

(FS) compared with that between PS3 and 4 (Fig. 38-1). Facies suddenly change from amalgamated HCS sandstone to bioturbated sandy siltstone at this boundary. On the horizon at about 10 m lower than the FS between PS3 and 4, a lenticular sandy siltstone of about 15 cm thick including concentrated, articulated, *Inoceramus* (*Cataceramus*) *balticus* in closed-/open-valve position is intercalated with upper shoreface medium sandstone (Fig. 38-2). This peculiar mode of occurrence seems to be derived from a colony of the species.

4-4-2 (Ravinement surface between PS2 and 3)

This distinctive facies boundary is assigned as a ravinement surface by shoreface erosion during a fourth-order transgression. Following the surface above PS2, a transgressive lag as matrix-supported granule conglomerate of about 20 cm thick grades into bioturbated silty fine sandstone of inner shelf environment (Fig. 38-3).

4-4-3 (Trough and large-scale forset cross-stratified medium sandstone in the upper part of PS2)

Distinctive sedimentary structures represented by trough and large-scale forset cross-stratification are observed in medium sandstone of 20 m thick of the upper PS2 (Fig. 39). The cross stratification shows several cross sets with gravel, coarse sand and silt lamina and burrow traces suggesting the intermittent and repetitive sedimentation by higher energy currents and subsequent stagnation. This sandstone is thought to have deposited under upper shoreface strongly influenced by tidal currents or sandy tidal flat.

4-4-4 (Coarsening-upward facies succession of PS1)

The coarsening-upward facies succession of PS1 can be well observed even within a large outcrop (Fig. 38-4).

Stop 4-5 (Nakagawa Museum of Natural History)

The Nakagawa Museum of Natural history opened in 2002 to exhibit the natural and cultural history of Nakagawa Town. The museum buildings were used as the Saku Junior High School until its closure in 1999. Nakagawa Town is one of the most famous ammonite localities in Japan. Many exhibited fossil specimens ranging from Cretaceous to Quaternary in age were collected from Nakagawa Town and the adjacent areas. The exhibition highlights magnificent giant, ornate and heteromorph ammonites, and numerous smooth ammonites, and furthermore, some reptiles such as dermochelyid sea turtles, long-necked elasmosaurids (Fig. 40) and a claw of a therizinosaurid dinosaur. Other fossils are bivalves,

Fig. 38. Photos of outcrops and fossils of the Hakobuchi Formation ≈ **1:** Small-scale marine flooding surface observed in the lower part of PS2 (Stop 4-4-1). **2:** The mode of occurrence of *Inoceramus* (*Cataceramus*) *balticus* on a bedding surface of PS3 (Stop 4-4-1). **3:** Ravinement surface observed as a parasequence boundary between PS2 and PS3 (Stop 4-4-2). **4:** Coarsening-upward facies succession of PS1 observable in a large outcrop (Stop 4-4-4).

Fig. 39. Large-scale foreset and low-angle cross-stratification developed in medium sandstone of tidal sand ridge deposits of the Hakobuchi Formation along the Uttsu River section (Stop 4-4-3).

Fig. 40. Main hall displaying a long-necked elasmosaur, the Nakagawa Museum of Natural history.

gastropods, echinoids, crinoids, fish bones, shark teeth, Neogene pinniped and dolphins.

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