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Field Excursion Guidebook

for the 7th International Symposium, Cephalopods - Present & Past - Sapporo, Japan, 2007

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三笠市立博物館
Mikasa City Museum

三笠市立博物館紀要　自然科学　第11号　2007年3月

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Itinerary of Field Excursion

Field Trip #1: September 17, 2007

8:30–9:00 AM. Load onto vehicles at the Conference Hall in the Sapporo Campus, Hokkaido University

9:00 AM. Depart from Sapporo to Mikasa City.

Stop 1 — Outcrop along the prefectural road in the Ikushumbetsu area, Mikasa; the Cenomanian-Turonian shallow water facies of the Mikasa Formation

Stop 2 — Mikasa City Museum

Stop 3 — Outcrop along the Shuparogawa River, Yubari; the Coniacian-Santonian offshore facies of the Kashima Formation

5:30 PM. Arrive at Sapporo.

Field Trip #2: September 18–21, 2007

Day 1 (September 18)

8:30–9:00 AM. Load onto vehicles at the Conference Hall in the Sapporo Campus, Hokkaido University

9:00 AM. Depart from Sapporo to Nakagawa Town.

Stop 1-1 — Nakagawa Museum of Natural History

Day 2 (September 19)

8:30 AM. Leave the Ponpira Hotel

Stop 2-1 — Nio River; Santonian to Lower Campanian ammonoids from offshore mudstone

Stop 2-2 — Gakkousawa Creek: Turonian ammonoids from the Saku Formation

4:00 PM. Arrive at the hotel

Day 3 (September 20)

8:30 AM. Leave the hotel

Stop 3-1 — Tannosawa Creek to Abeshinai River: Lower Campanian ammonoids from the middle to upper parts of the Osoushinai Formation

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4:00 PM. Arrive at the hotel

Day 4 (September 21)

9:00 AM. Leave the hotel

Stop 4-1 — Kiyokawa forestry road: Upper Campanian ammonoids from the Hakobuchi Formation

5:30 PM. Arrive at Sapporo

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EXCURSION GUIDEBOOK (Field Trip #1; September 17, 2007) of The 7th International Symposium, Cephalopods - Present and Past

Ammonoid faunas and stratigraphy of the Cretaceous Yezo forearc basin, Hokkaido, Japan

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Introduction

Cretaceous to Paleogene sediments filling the Yezo forearc basin (Okada, 1983), are widely distributed over a distance of 1,400 km from offshore of north Honshu, through the central zone of Hokkaido, to Sakhalin Island, Russia (e.g., Matsumoto, 1942; Tanaka, 1963; Hirano et al., 1992; Ando, 2003; Takashima et al., 2004; Yazykova, 2004, Fig. 1). The sediments well exposed in central Hokkaido, are called the Yezo Group (Matsumoto, 1951).

The Yezo Group was probably deposited at about 35–45°N (Kodama et al., 2002) along the westward subduction margin in the northeastern Asian continent during the Cretaceous. This group consists of a 10,000-m-thick forearc sedimentary sequence of sandstones and mudstones with subordinate conglomerates (Takashima et al., 2004). As the rocks contain abundant and well-preserved fossils, many biostratigraphic schemes for the Cretaceous System in Hokkaido were established (e.g., Matsumoto, 1942, 1977; Toshimitsu et al., 1995). Moreover, there are many paleontological studies using materials from Hokkaido, and Japanese scientists have contributed much to ammonoid paleobiology (see Landman et al., 1996).

The aim of field trips in Hokkaido is to understand the litho- and bio-facies changes of the Yezo Group, and collect Cretaceous ammonoids. We prepare two field trips (Fig. 1): Field Trip #1 (September 17), a one-day field trip will visit the Ishikari-Sorachi province, central Hokkaido in order to observe the Cenomanian-Turonian inshore facies in the Ikushumbetsu area, the Coniacian-Santonian offshore facies in the Oyubari area, and ammonoid collections at the Mikasa City Museum; Field Trip #2 (September 18–21), a four-days field trip will be continued to visit to the Teshionakagawa area, northern Hokkaido after the one-day trip, to observe the Campanian successions containing aragonite-preserved ammonoids and chemosynthetic fossil community, and ammonoid collections at the Nakagawa Museum of Natural History.

In the present paper, we first introduce the geology, stratigraphy and ammonoid assemblages of the Cretaceous Yezo Group, and secondly describe the field guide of the Field Trip #1. The filed guide for Trip #2 is described in another article of this bulletin (Takahashi et al., 2007).

Geological setting

Hokkaido, the northernmost island of Japan, having a rhombic shape with a N-S trending diagonal line, comprises six major tectonostratigraphic units from west to east, (1) Oshima, (2) Rebun-Kabato, (3) Sorachi-Yezo, (4) Hidaka, (5) Tokoro, and (6) Nemuro Belts, on the basis of the lithofacies and tectonic features of the Mesozoic and the lower Cenozoic (e.g., Niida and Kito, 1986; Kiminami et al., 1986) (Fig. 1).

The N-S trending zonal geological framework is a product of subduction and collision processes in the northeastern margin of the Eurasia Plate. The western four belts seem to be related with the Paleo-Japan arc-trench system (Oshima, Rebun-Kabato,

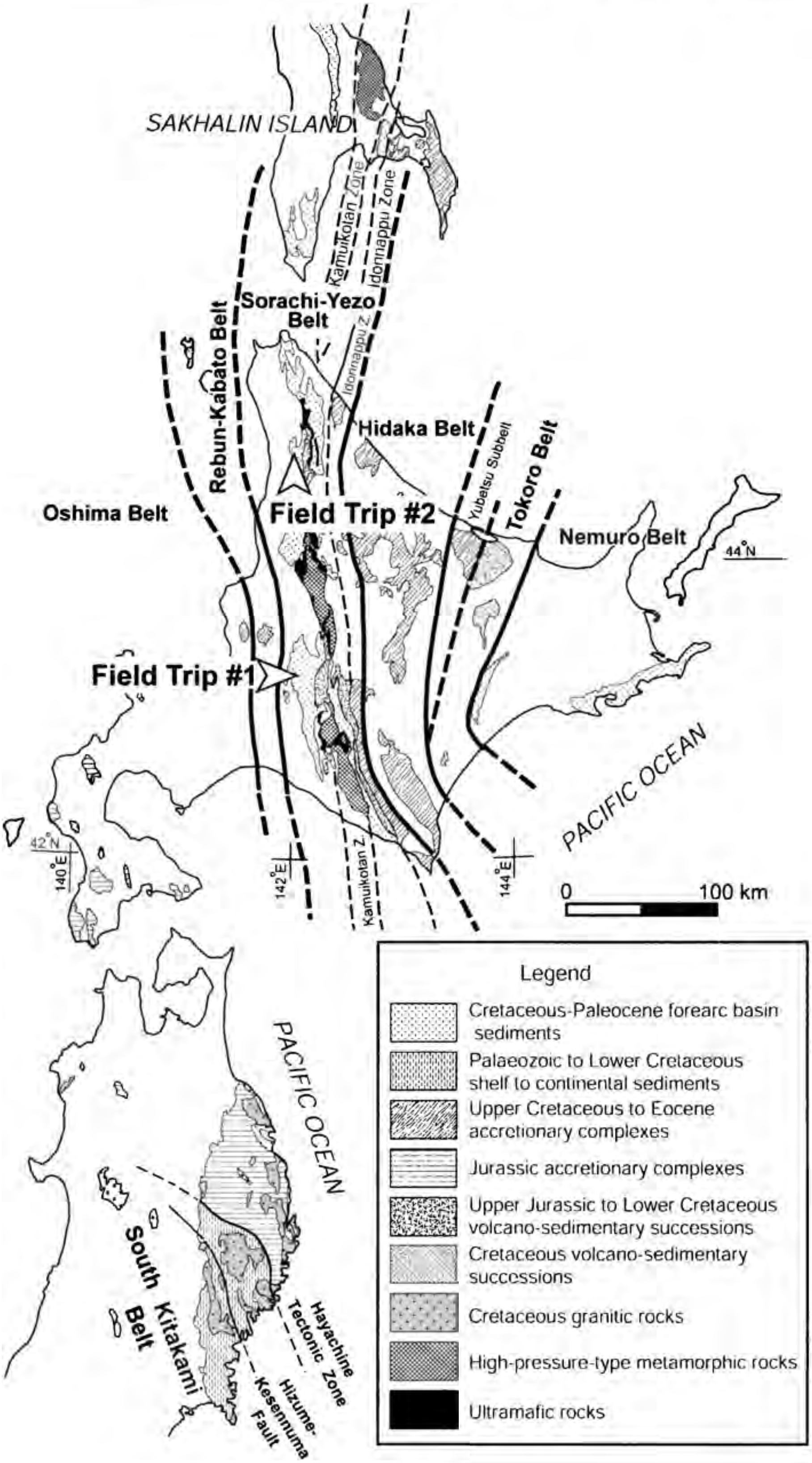

Fig. 1. Major geological units and distribution of the Mesozoic to lower Paleogene systems in Hokkaido. Modified after Ando (2003) and Takashima et al. (2004; reproduction permitted by Elsevier Science).

Sorachi-Yezo and Hidaka Belts), and the eastern two belts, the Paleo-Kuril arc-trench system (Tokoro, Nemuro Belts). The former system was formed along a westward-dipping subduction of the Izanagi-Kura plates under the eastern margin of the Asian continent (e.g., Okada, 1974).

The Sorachi-Yezo Belt consists of a coherent succession, from the Horokanai Ophiolite through the Sorachi Group to the Yezo Group (Fig. 2), and the accretionary complexes of the Idonnappu and Kamuikotan zones (Ueda et al., 2000) (Fig. 1). The Horokanai Ophiolite and the lower part of the Sorachi Group represent a piece of basaltic oceanic crust (Ishizuka, 1981; Takashima et al., 2002a), 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; Niida, 1992; Takashima et al., 2002b). The Yezo Group conformably overlies the Sorachi Group and comprises very thick sandstone and mudstone sequences. The sand clastics of this sequence were derived from Cretaceous granitic rocks and Jurassic accretionary complexes of the Oshima Belt, which represents a contemporaneous continental arc setting (Kito et al., 1986). Although a part of the Hakobuchi Formation includes the upper Paleocene in the Oyubari and Nakatonbetsu areas (Ando et al., 2001; Ando, 2003), the geological age of the Yezo Group ranges mostly from early Aptian to early Maastrichtian. Many hiatuses exist between the Campanian and the Maastrichtian. The sedimentary environment of this group shows an eastward-deepening facies trend, fluvial to continental slope (Fig. 2). The Yezo Group is unconformably capped by late Eocene, non-marine and shallow-marine sediments of the Ishikari and Poronai groups, or by younger Neogene deposits.

Lithostratigraphy

Lithostratigraphic nomenclature for the Yezo Group is confused, because this group basically consists of a monotonous sequence of sandstone and mudstone and their alternating beds, which occasionally exhibit lateral facies changes. Consequently, various stratigraphic definitions have been proposed, depending on the areas and the researchers (e.g., Kawaguchi and Kanie, 1985; Toshimitsu, 1985; Maeda, 1986; Toshimitsu et al., 1988; Motoyama et al., 1991; Kawabe et al., 1996; Mitsugi and Hirano, 1997; Takashima et al., 1997; Wani and Hirano, 2000; Ando et al., 2001; Moriya and Hirano, 2001; Okamoto et al., 2003; Takahashi et al., 2003; Kurihara and Hirano, 2003; Funaki et al., 2004; Oizumi et al., 2005). To resolve such problems, Takashima et al. (2004) proposed a new, synthesized stratigraphic framework, including macro- and microfossil biostratigraphy, based on extensive mapping of the entire area in the central region of Hokkaido. They revealed that the Yezo Group throughout Hokkaido is basically characterized by six units of mudstone-dominated turbidites and sandstone-common ones, with intercalations of six distinct stratigraphic key units (Fig. 2). The revised lithostratigraphic definitions are as follows: the Soashibetsugawa Formation, the Shuparogawa Formation, the Maruyama Formation, the Hikagenosawa Formation, the Saku Formation, the Kashima Formation and the Hakobuchi Formation, in ascending order (Fig. 2). Moreover, the sandstone-dominant, outer shelf to shoreface Mikasa Formation and the overlying sandy mudstone-dominant outer-shelf Haborogawa Formation are also recognized. The geological ages of these formations correspond to the Saku and Kashima formations, respectively (Fig. 2). This guidebook follows their synthesized lithostratigraphic divisions, and briefly describes these lithological features, geological ages, and depositional environments. The following descriptions are modified after Takashima et al. (2004).

1. Soashibetsugawa Formation (Thickness: 450–700 m)

This formation, which conformably overlies the Sorachi Group, consists of dark gray, parallel-laminated mudstone with many intercalations of felsic tuff beds. The laminae are composed of felsic tuff and very fine-grained sandstone layers.

The early Aptian planktonic foraminiferal species, *Leupoldina cabri*, occurs from the uppermost part of this formation. Microfossil assemblages and deep-sea trace fossils suggest an abyssal environment.

2. Shuparogawa Formation (Thickness: 800–2,450 m)

This formation, which conformably overlies the Soashibetsugawa Formation, is composed mainly of alternating beds of turbiditic sandstone and dark gray mudstone. This formation incorporates a thick olistostrome bed (Kirigishiyama Olistostrome Member) in the middle portion, and is subdivided into three members as follows: the Refureppu Sandstone, Kirigishiyama Olistostrome, and Okusakainosawa Sandstone and Mudstone members, in ascending order.

The Late Aptian planktonic foraminiferal species, *Globigerinelloides barri* and *G. duboisi* occur from mudstones of the Refureppu Sandstone Member. The Late Albian ammonoid, *Mortoniceras* cf. *geometricum*, occurs in the upper part of the Okusakainosawa Sandstone and Mudstone Member (Kawabe, 2000). Lithology and benthic foraminiferal data suggest that this formation was deposited on the continental slope (e.g., Motoyama et al., 1991).

3. Maruyama Formation (Thickness: a few to 900 m)

This formation, which conformably overlies the Shuparogawa Formation, is composed of tuffaceous sandstone beds, locally accompanied by conglomerates at the base. The formation is used as a stratigraphic marker.

No planktonic foraminifers and macrofossils have been obtained from this formation, whereas radiolarians (spumellarians) occur abundantly. Abundant volcaniclastic materials in this formation suggest that huge, felsic volcanic eruptions episodically occurred along the western circum-Pacific/Asian continental margin.

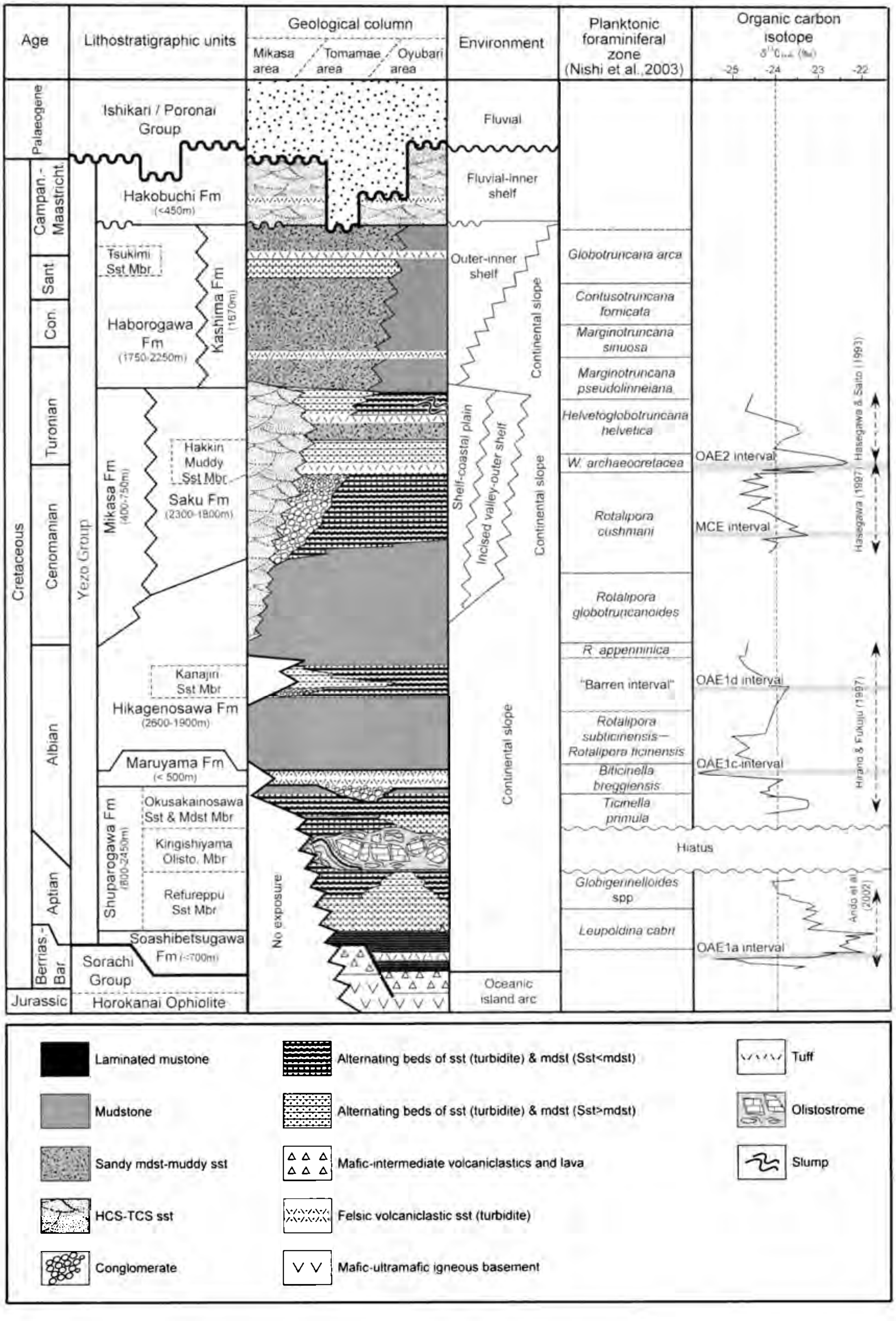

Fig. 2. Schematic diagram of the Yezo Group in Hokkaido. Note that the geological column shows eastward-deepening facies. Modified after Takashima et al. (2004; reproduction permitted by Elsevier Science).

4. Hikagenosawa Formation (Thickness: 1,900–2,000 m)

This formation, which conformably overlies the Maruyama Formation, is composed mainly of dark gray mudstone. A thin unit of alternating beds of sandstone/conglomerate and mudstone (Kanajiri Sandstone Member) is intercalated in the middle part of this formation. This unit is used as a stratigraphic marker.

The occurrence of macrofossils (ammonoids and inoceramids) becomes common above the lower part of this formation. The Late Albian–Middle Cenomanian ammonoids (*Mortoniceras rostratum*, *Mariella bergeri*, *Mantelliceras saxbii* and *Cunningtoniceras cunningtoni*) occur in the formation. Microfossils are also abundant throughout the sequence. 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 (Thickness: 1,800–2,300 m)

This formation, which conformably overlies the Hikagenosawa Formation, comprises alternating beds of turbiditic sandstone and mudstone, and intercalates with a unit characterized by a predominance of greenish gray muddy sandstones, including abundant trace fossils of *Planolites* in the middle part (Hakkin Muddy Sandstone Member).

The Cenomanian ammonoids, *Calycoceras* spp. occur in the lower part of the formation. The basal part of the Hakkin Muddy Sandstone Member is correlated to the Cenomanian/Turonian boundary with the conspicuous carbon isotope excursion (e.g., Hasegawa and Saito, 1993; Hasegawa, 1997). An Early Turonian ammonoid, *Pseudaspidoceras flexuosum*, occurs just above this carbon isotope excursion (e.g., Hirano, 1995; Kurihara and Kawabe, 2003). The upper sequence is marked by an abundant occurrence of heteromorphic ammonoids, including *Nipponites*, *Eubostrychoceras*, and scaphitids, with minor Middle Turonian indicators, *Romaniceras* spp. (ammonoids), and *Inoceramus hobetsensis* (bivalve). Microfossils commonly occur throughout the sequence. The benthic foraminiferal assemblages indicate that this formation was deposited in the lower part of upper bathyal zone with relatively oxygenated conditions (Kaiho et al., 1993).

6. Mikasa Formation (Thickness: 400–750 m)

This formation is the contemporaneous, shallower facies of the Saku Formation, and distributed in the western side of the Yezo Group (Mikasa area). It is characterized by a predominance of sandstone with hummocky and trough cross-stratification (HCS and TCS) and gravel/shell lags, and intensively bioturbated sandy mudstone. This formation was deposited on shelf environments (Ando, 1997).

Shallow-marine bivalves (including *Apiotrigonia*, *Glycymeris*, *Meekia*, *Pinna*, *Pseudoptera*, *Pterotrigonia*, *Thetis*, *Yaadia*), gastropods (e.g., *Margarites*, *Semisolarium*) occur at the base of HCS sandstones. The Cenomanian ammonoids, *Mantelliceras* sp., *Calycoceras* sp., and *Desmoceras* spp. have been reported from the lower part of the formation. The Turonian species, *Inoceramus hobetsensis* is abundant in the upper part of the formation. The formation was deposited on a storm-dominated lower shoreface and upper shelf in front of coastal plain and rivers supplying a large amount of coarse sediments, based on sequence stratigraphy and facies analyses (Ando, 1990a, b).

7. Kashima Formation (Thickness: about 1,670 m)

This formation, which conformably overlies the Saku Formation, is composed mainly of dark gray, bioturbated, massive mudstone, grading into muddy sandstones in the upper part. The mudstones are intercalated with two felsic volcaniclastic units, in the lower and middle parts, respectively. The lower unit includes abundant *Inoceramus uwajimensis*, and is used as a stratigraphic marker.

This formation contains abundant calcareous concretions, including macrofossils such as ammonoids and inoceramids. Microfossils are also abundant throughout the sequence. Macro- and microfossil data indicate that this formation is correlated to the Upper Turonian to the Campanian. 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 (Thickness: 1,750–2,250 m)

This formation is the contemporaneous, shallower facies of the Kashima Formation, and distributed in the western side of the Yezo Group (Mikasa and Tomamae areas). It consists of coarsening-upwards sequences, ranging form bioturbated sandy mudstone to sandstone with intercalations of two felsic volcaniclastic units, which are observable in the Saku Formation.

This formation contains abundant fossils as well as the Kashima Formation. The sedimentological features indicate that this formation was deposited on outer shelf through inner shelf to lower shoreface environments (Toshimitsu, 1985; Wani, 2003).

9. Hakobuchi Formation (Thickness: several tens to 450 m)

The general stratigraphic relationship between the Hakobuchi and the underlying Kashima or Haborogawa formations is conformable. However, in the northwestern limb of the Sorachi Anticline, northwestern Mikasa area, unconformable relationship is recognized. The formation is unconformably capped by late Eocene, non-marine and shallow-marine sediments of the Ishikari and Poronai groups, or by younger Neogene deposits.

As the deposits of the Hakobuchi Formation form complicated stacking patterns of the third- and fourth-order depositional sequences (DSs), the lithology varies depending on areas and horizons (Ando, 2003). They mainly consists of coarsening-upwards facies successions, a few tens to 100 m thick, of bioturbated sandy mudstone to HCS/TCS sandstone.

Although a few macrofossils, such as *Sphenoceramus schmidti*, *S. hetonaianus*, and *Inoceramus shikotanensis*, occur in this formation (Ando, 1997; Ando et al., 2001), there are no age-diagnostic species. The planktonic foraminifers *Globotruncana rugosa* and *Subbotina triloculinoides* occur in the lower and upper parts of this formation, respectively. The former is assigned to the Campanian (Robaszynski et al., 1984), and the latter is of Paleocene age (Yasuda, 1986). The Cretaceous/Paleogene boundary sequence has not been detected in the Hakobuchi Formation.

Ammonoid biostratigraphy (main text modified after Hirano et al., 2001)

As the Yezo Group yields abundant well-preserved macrofossils, numerous ammonoid and inoceramid species have been described from this group by previous authors (e.g., Yokoyama, 1890; Jimbo, 1892; Yabe, 1903, 1904; Nagao and Matsumoto, 1939, 1940; see Matsumoto, 1975) and, based on these ammonoids and inoceramids, a number of biostratigraphic schemes for the Cretaceous System in Hokkaido has been proposed (e.g., Matsumoto, 1942, 1943, 1954, 1959, 1977; Toshimitsu et al., 1995) (Fig. 3).

Faunas of this group differ widely from those of the stratotypes of the Cretaceous stages. In Hokkaido and Sakhalin, it is generally considered that the ammonoid fauna is characteristic of the North Pacific bio-province, and differs from those of the Tethyan and Boreal provinces, during the post-Albian. The Japanese faunas are composed mainly of endemic species of the planispiral Gaudryceratidae, Tetragonitidae and Desmoceratidae and, the heteromorphic Nostoceratidae, Diplomoceratidae, Scaphitidae and Baculitidae. On the other hand, the cosmopolitan Acanthoceratidae, Collignoniceratidae and Vascoceratidae entered episodically into the Yezo forearc basin during the Cenomanian to Coniacian time. The latter families encompass short-range species defining the stage and substage boundaries of the Tethyan stratotypes. The post-Coniacian faunas have few cosmopolitan species in Japan.

1. The Albian stage

The Albian of Hokkaido is not so prolific in ammonoids for establishing zonation. Some cosmopolitan species, however, are obtained in several sections and helpful for inter-regional correlation as below: lower Albian; *Douvilleiceras mammillatum*, *Ammonocerataites* sp., middle Albian; *Lyelliceras lyelli*, upper Albian; *Dipoloceras pseudaon*, *Hysteroceras orbigni*, *Mortoniceras (Mortoniceras) rostratum*, *M. (Durnovarites) subquadratum*, *Desmoceras latidorsatum*.

2. The Cenomanian stage

The continuous occurrence of *Desmoceras japonicum*, a North Pacific-type ammonoid, characterizes the Cenomanian strata in Hokkaido. The endemic inoceramids such as *Inoceramus ginterensis*, *I. pennatulus*, *Actinoceramus nipponicus* occur commonly in the middle to late Cenomanian. Toshimitsu et al. (1995) divided the Cenomanian of the Yezo Group into seven ammonoid zones and six inoceramid zones.

The base of the Middle Cenomanian in the world is defined by the first occurrence (FO) of *Cunningtoniceras* above the *Mantelliceras* beds (Rawson et al., 1996). In Japan, the *Cunningtoniceras takahashii* Zone is established in the lower Middle Cenomanian.

The basal criterion of the Upper Cenomanian substage is controversial. The subcommission on Cretaceous Stratigraphy did not propose a boundary criterion (Rawson et al., 1996). Juignet and Kennedy (1976) proposed the *Eucalycoceras pentagonum* Zone for the Upper Cenomanian in France. In Japan, *Eucalycoceras pentagonum* is used as a zonal index above the *Calycoceras asiaticum* Zone of the upper Middle Cenomanian. The *Euomphaloceras septemseriatum* Zone is located in the uppermost part of the Cenomanian, and *Inoceramus nodai*, an endemic inoceramid, marks the highest Cenomanian in the Japanese stratigraphic scale.

3. The Turonian stage

Ammonoids and inoceramids of the Turonian sequence are highly diversified (Fig. 3); the Turonian succession of the Yezo Group is divided into six ammonoid zones and five inoceramid zones.

The lower Turonian of the Yezo Group is directly correlative with the stratotype by the following pandemic species: *Vascoceras durandi*, *Fagesia thevestensis*, *Neoptychites cephalotus*, *Mammites* aff. *nodosoides*, *Mytiloides columbianus* and *M. mytiloides*. The endemic *Inoceramus kamuy* characterizes the lower Turonian in Hokkaido.

The Lower-Middle Turonian boundary of Hokkaido is placed at the base of the *Collignoniceras woollgari* Zone in accord with worldwide usage. The criterion of the Middle-Upper Turonian boundary presents the FO of *Subprionocyclus neptuni* in the Boreal realm, of *Romaniceras deverianum* in the Tethys realm, or of *Inoceramus perplexus* (Wiese, 1999; Wiese and Kaplan, 2001). In Japan, this substage boundary is placed at the FO of *S. neptuni*, above the *R. deverianum* Zone.

4. The Coniacian Stage

The mondial substage division of the Coniacian has been conventionally defined by collignonicertid ammonoids, although the internationally used ammonoids are rare and, moreover include an endemic species. Three ammonoid zones are proposed for Japan at present: the *Forresteria petrocoriensis* Zone of the Lower Coniacian, the *Forresteria alluaudi* Zone of the Middle Coniacian and the *Paratexanites orientalis* Zone of the Upper Coniacian.

5. The Santonian Stage

Cosmopolitan ammonoid and inoceramid marker species are

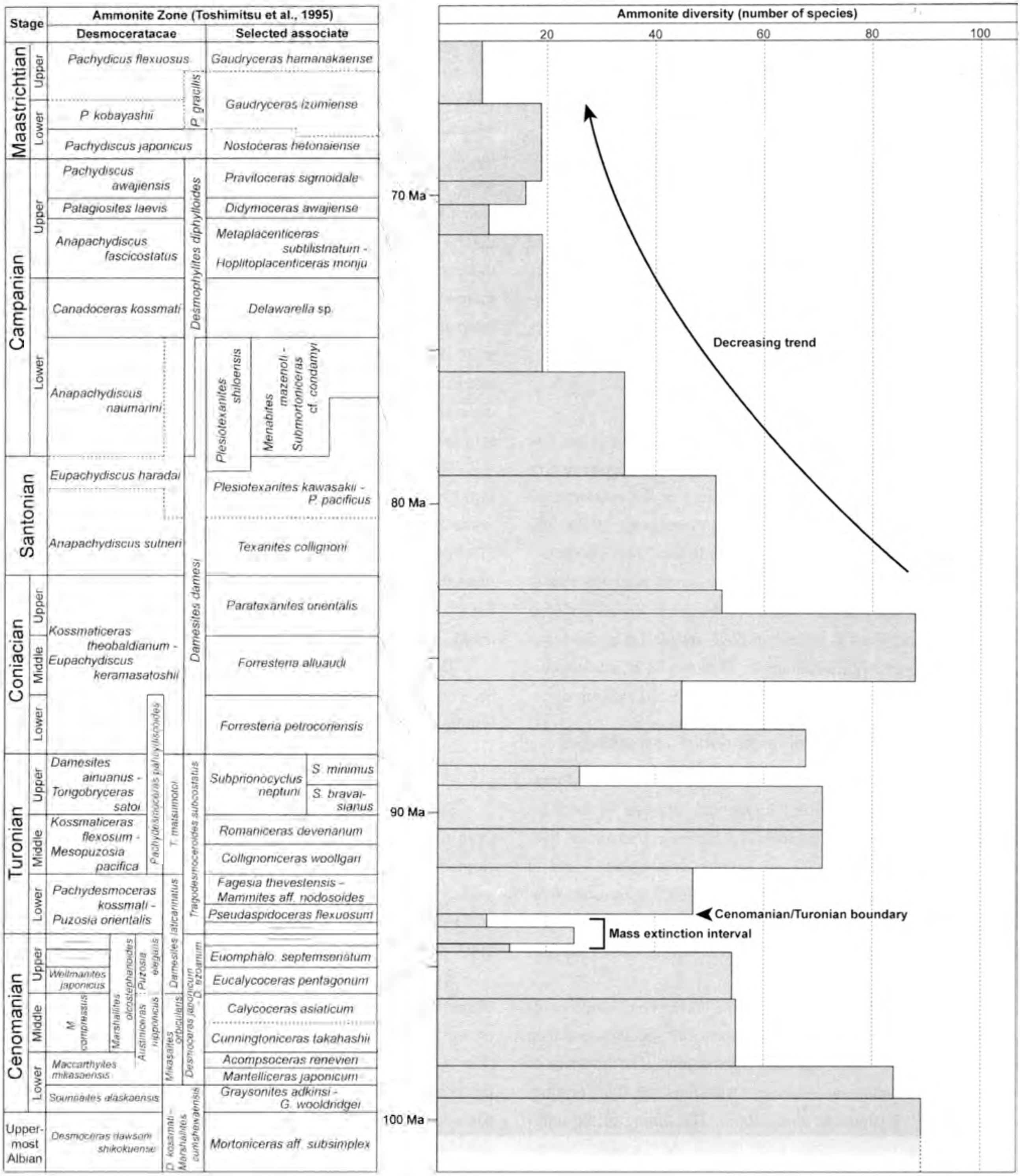

Fig. 3. Japanese ammonoid zonation proposed by Toshimitsu et al. (1995), and species diversity changes of Cretaceous ammonoids shown by Toshimitsu et al. (2003).

few in the Yezo Group for the Santonian. A threefold division is accepted for the Santonian in the world (see Rawson et al., 1996); however, it is impossible to divide the Yezo Group into these substages by using mega-fossils. The Santonian stage of this group is divided into the *Texanites (Texanites) collignoni* Zone below and the *Plesiotexanites kawasakii-Plesiotexanites pacificus* Zone above.

6. The Campanian Stage

Cosmopolitan marker species of ammonoids and inoceramids are few in the northwest Pacific region during the Campanian age. The subcommission on Cretaceous Stratigraphy has not made any formal proposal concerning definitions of the base of the substages of the Campanian stage (see Rawson et al., 1996). Regarding ammonoids, the *Anapachydiscus naumanni*, *Canadoceras kossmati* and *Metaplacenticeras subtilistriatum* zones are established in ascending order in Japan.

7. The Maastrichtian Stage

Cosmopolitan age-diagnostic species of megafossil are few in the Maastrichtian of the North Pacific region. The extinction of the majority of the inoceramids is a ground of the two-substage subdivision of the Maastrichtian stage (Rawson et al., 1996). The genus *Pachydiscus* is useful for biozones in the North Pacific region according to studies on the Yezo Group of Sakhalin Island, Russia (Maeda and Shigeta, 1998). The lowest *P. japonicum* Zone and the second lowest *P. flexuosus* Zone are placed in the lower part in association with inoceramids. The highest *P. subcompressus* Zone lies in the upper part after the inoceramid extinction.

Temporal changes of ammonoid assemblages

Toshimitsu and Hirano (2000) surveyed records of all Cretaceous ammonoid species from Japan, and reported 49 families, 281 genera, and 790 species from the Japanese Cretaceous System with details of their stratigraphic distribution, and a bibliography. Moreover, Toshimitsu et al. (2003) discussed relationship between species diversity changes of the Japanese ammonoids and marine environmental changes during the Cretaceous (Fig. 3).

The species diversity of Japanese Cretaceous ammonoids reached maximum during the Late Albian (89 species), and then decreased gradually until the Late Cenomanian. The diversity of the Late Cenomanian was 9 species (extinction rate; 0.58, origination rate; 0.17; Toshimitsu et al., 2003). The timing of the minimum diversity is concordant with that of the Oceanic Anoxic Event 2 (OAE2).

The Cenomanian-Turonian transition in Hokkaido is best exposed along the Hakkin-zawa River of the Oyubari area, central Hokkaido (Fig. 4). An ammonoid diversity decreased 0.5 to 0.9 m.y. prior to the Cenomanian/Turonian boundary (CTB) (extinction interval), reached a minimum just after the CTB (survival interval), and recovered 0.2 to 0.5 m.y. after the CTB (recovery interval), based on micro- and macrofossil biostratigraphy and carbon isotope chemostratigraphy (Kurihara and Kawabe, 2003) (Fig. 4). The timing of the extinction-recovery phases in Hokkaido is almost coincident with that in the U.S. Western Interior Province. Moreover, weakly laminated mudstone facies, suggesting dysoxic condition, is predominant in the extinction interval in Hokkaido. This fact suggests that ammonoid faunas in Hokkaido were affected by the OAE2, which expanded oxygen-depleted water, as well as those in the Western Interior. There, however, are some discrepancies in the extinction patterns of ammonoids between Hokkaido and the Western Interior (Kurihara and Kawabe, 2003). In the Western Interior, nekto-benthic ammonoids of acanthoceratids disappeared earlier than planktonic heteromorph ammonoids such as *Sciponoceras* and *Allocrioceras* in the extinction interval (Batt, 1993). By contrast, the nekto-benthic desmoceratids also appeared in the later part of the extinction interval in Hokkaido. This inconsistency presumably resulted from different expansion processes for oxygen-depleted water in an open ocean setting (Hokkaido) and a restricted seaway (Western Interior).

The ammonoid species diversity increased from the Turonian through the Santonian, except for the Early and Late Coniacian. Some long-ranging species never occur in the Coniacian interval (Toshimitsu et al., 2003), and dysoxic environments regionally expanded in the Yezo forearc basin (Hayakawa, 1992; Kurihara and Hirano, 2003). It seems that theses species avoided the dysoxic to anoxic water mass in the basin during Coniacian.

The diversity gradually decreased after the Santonian (Fig. 3). This trend is inconsistent with the global trend of ammonoid families shown by House (1989).

Lateral changes of ammonoid assemblages

Since the Yezo Group shows conspicuous facies changes from the coast and inner shelf, through the outer shelf and the slope, to the abyssal plain, it enables to carry out synecological studies of Cretaceous ammonoids (e.g., Tanabe et al., 1978; Tanabe, 1979; Matsumoto et al., 1981; Futakami, 1982; Kawabe, 2003; Wani, 2003).

Kawabe (2003) attempted to compare ammonoid assemblages with lithofacies in the Albian-Cenomanian successions. He records occurrences of the ammonoid assemblages as follows (Fig. 5A): (1) *Desmoceras* (Desmoceratidae) is widespread and predominates in faunas regardless of lithofacies; (2) Gaudryceratidae is the second-most abundant group in all lithofacies; (3) the abundance of *Zelandites* (Gaudryceratidae) specimens decreases offshore; and (4) other groups (e.g. Kossmaticeratidae, Acanthoceratidae) are uncommon in all lithofacies.

Desmoceras, the most abundant taxon, is characterized by an involute shell with subquadrate or oval whorl sections, and lacks ornamentation other than sigmoid constrictions and very fine striae on its outer surface. Both the depressed and compressed

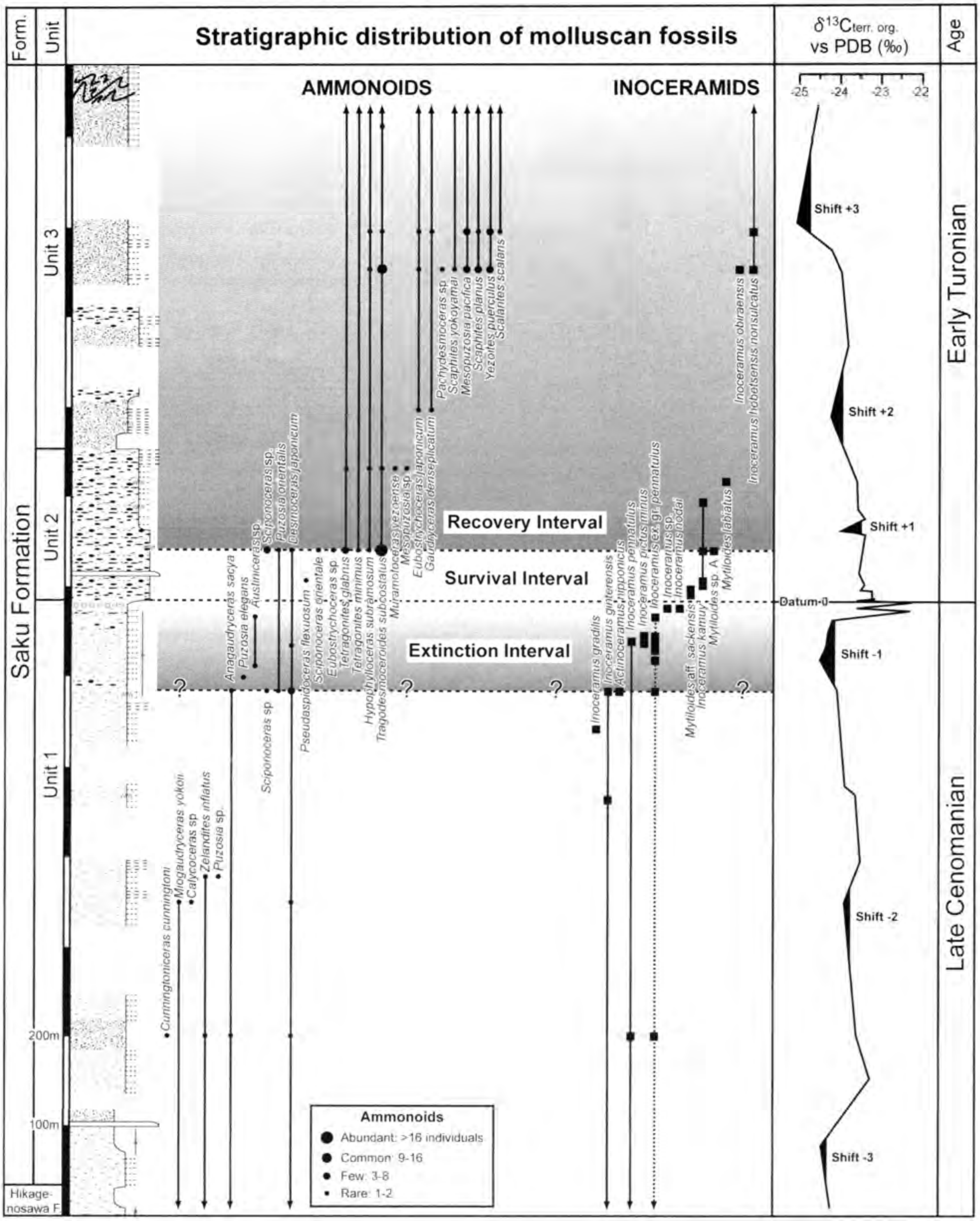

Fig. 4. Stratigraphic distribution of molluscan fossils, and molluscan events in the Hakkin-zawa River section of the Oyubari area. After Kurihara and Kawabe (2003; reproduction permitted by Palaeontological Society of Japan).

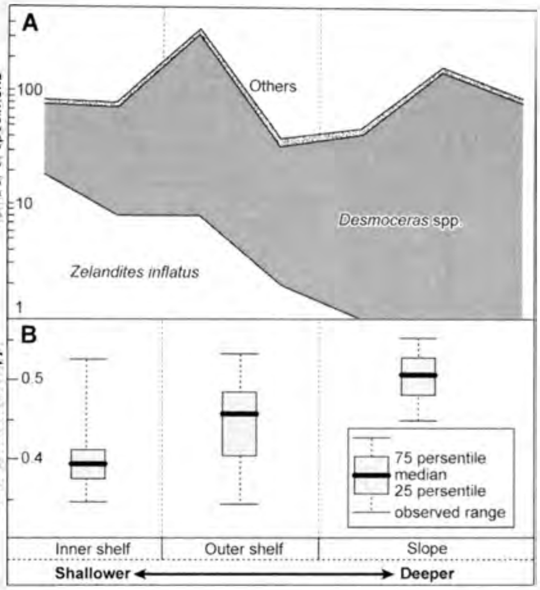

Fig. 5. A: Generalized profile of Cenomanian ammonoid assemblages from inshore to offshore, based on data from selected localities. B: shell compression of *Desmoceras* specimens compared with depositional environments. Shell compression is calculated as whorl breadth/shell diameter (B/D) in more than 10 mm specimens in diameter. Modified after Kawabe (2003).

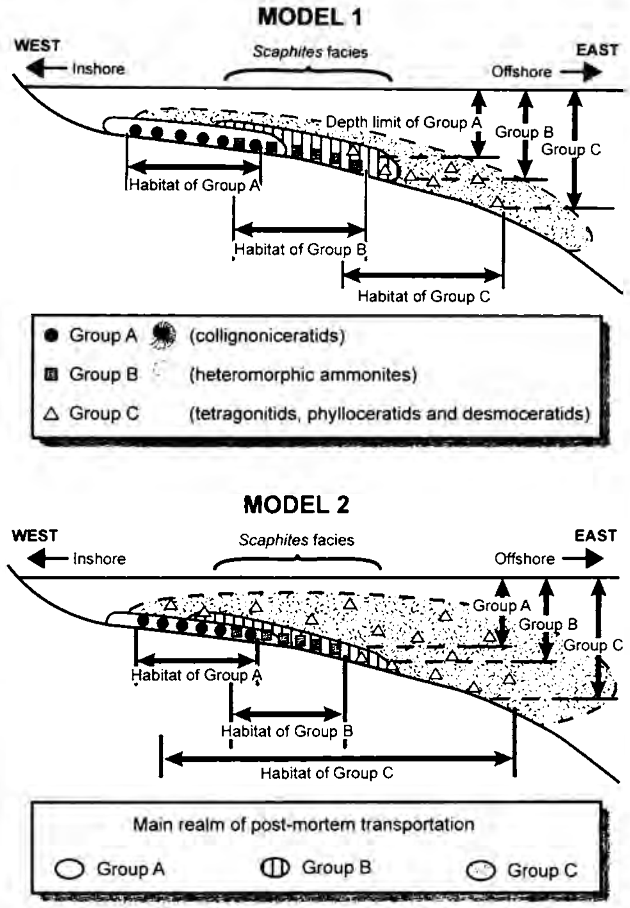

Fig. 6. Two different models to explain the relationship between presumed habitats and extent of post-mortem transportation for several ammonoid groups in Hokkaido in Turonian time. Modified after Tanabe (1979).

morphotypes and their intermediate morphs are common in the Albian-Cenomanian of Hokkaido. However, the frequency distributions of these morphotypes vary with facies (Fig. 5B); (1) inner-shelf specimens have lower values in thickness ratio (B/D: whorl breadth/shell diameter) as compressed morphs and slope specimens have higher B/D values as depressed morphs; and (2) samples from the intermediate outer shelf show a wide range of variation in B/D ratio. Moreover, the abundance of *Zelandites*, characterized by a smooth, slender, and narrowly umbilicate shell, also decreases toward offshore. The morph of *Zelandites* is best for swimming at higher velocities, according to the ammonoid hydrodynamic work of Jacobs (1992). In addition, Wani (2006) reported that compressed disc-shaped *Metaplacenticeras* is predominant in the Campanian shallow-water sandy facies in the Nakagawa and Embetsu areas, northern Hokkaido. If ectocochleate cephalopods did not need to swim rapidly, then the shell shape of this compressed morph might have been essential for life in inshore sandy environments, where higher ambient current velocities prevail. In contrast, depressed morphs may have swum effectively at low velocities, as an adaptation to the calm environments represented by muddy facies.

Turonian ammonoid assemblages of Hokkaido (e.g. Tanabe, 1979; Matsumoto et al., 1981) show that acanthoceratids and collignoniceratids (strongly ribbed, noded, or tuberculate mophs; trachyostraca) were dominant in inshore facies, while gaudryceratids, tetragonitids, phylloceratids, and desmoceratids (smooth, finely ribbed morphs; leiostraca) were dominant in offshore facies (Fig. 6). These results are consistent with the generally accepted relationship between ammonoid facies and lithofacies for Cretaceous ammonoids; the less ornate super families of Phylloceratacea, Lytocerataceae, and Desmocerataceae characterize offshore and/or deep-water lithofacies, while the more ornate superfamilies of Acanthocerataceae and Hoplitaceae characterize inshore and/or shallow-water facies (e.g., Scott, 1940; Batt, 1989; Westermann, 1996).

Mid-Cretaceous ammonoid fauna in the Ishikari-Sorachi province: The guide for the Field Trip #1

In the Field Trip #1, we observe the litho- and biofacies changes in the Ishikari-Sorachi province. The Cretaceous of the Ikushumbetsu area in the west is characterized by shallow-water facies, and that of the Oyubari area in the east is characterized by the deep-water facies (Fig. 7). Furthermore, the N-S trending anticline (Ikushumbetsu Anticline) in the western part makes the fa-

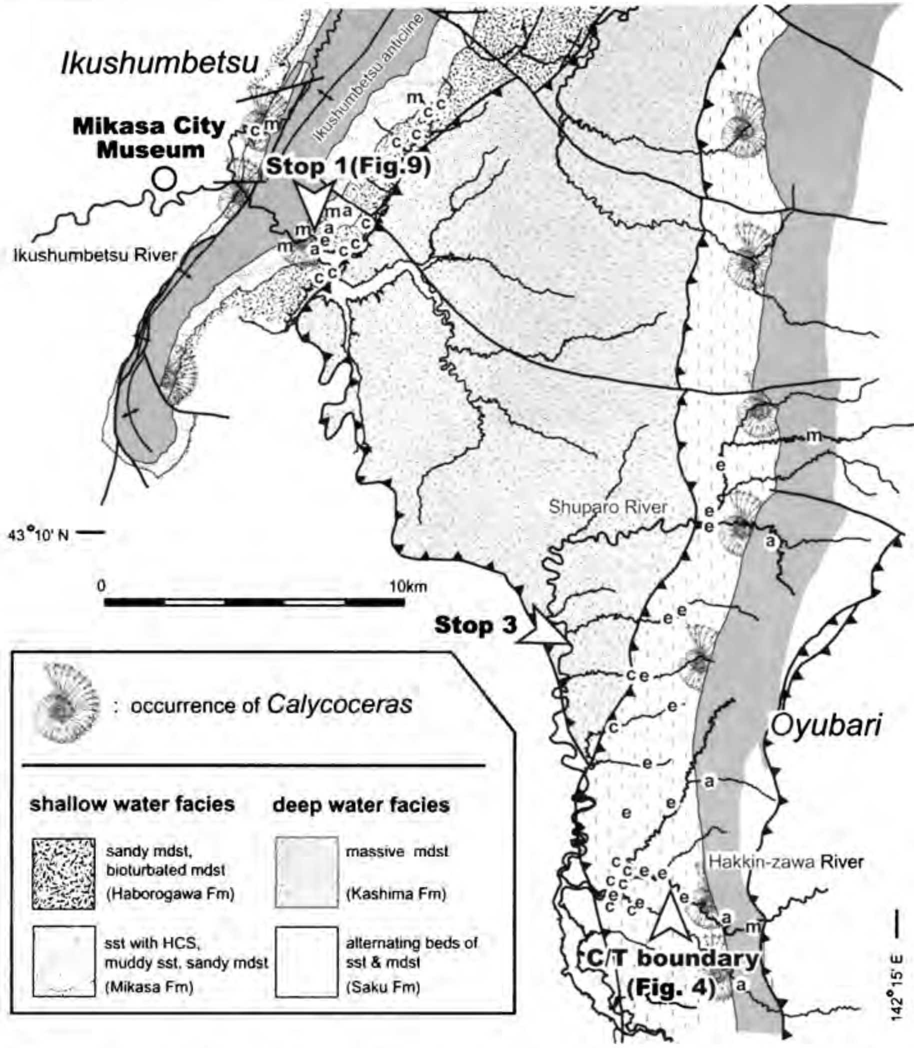

Fig. 7. Lithology and geographic distribution of selected acanthoceratids in the Ishikari-Sorachi province. Modified after Kawabe (2003). Abbreviations: a, Acanthoceratinae (*Acompsoceras, Acanthoceras, Cunningtoniceras, Sumitomoceras, Eucalycoceras, Pseudocalycoceras*); m, Mantelliceratinae (*Mantelliceras, Utaturiceras, Sharpeiceras*); e, Euomphaloceratinae (*Euomphaloceras, Pseudaspidoceras, Romaniceras, Neomphaloceras, Yubariceras, Shuparoceras*); c, Collignoniceratidae (*Collignoniceras, Subprionocyclus, Lymaniceras, Prionocyclus, Prionocycloceras, Barroisiceras*). These occurrences come from studies by Matsumoto et al. (1957, 1969, 1985, 1989), Matsumoto (1965, 1975, 1991), Matsumoto & Kawano (1975), Matsumoto & Obata (1982), Futakami (1986a, 1986b), Maeda (1986), Matsumoto & Suekane (1987), Matsumoto & Takahashi (1992), Matsumoto & Kawashita (1998), Asai et al. (2000), Kawabe (2000) and Kawabe & Shigeta (2001), and from the collections at the Waseda University, Tokyo.

cies changes on the shallow shelf so obvious that the Ishikari-Sorachi province is regarded as one of the most important regions to reconstruct sedimentary environments and marine biota of the Yezo forearc basin (e.g., Tanaka and Sumi, 1981; Ando, 1990, Hirano et al., 1992). Calcareous concretions with intact ammonite fossils are frequently embedded in the strata. We will meet shallow-water facies and faunas (Mikasa Formation; Stop 1), deep-water facies and faunas (Kashima Formation; Stop3), and beautiful ammonite and inoceramid specimens at the Mikasa City Museum (Stop2).

1. Daily schedule (September 17)

8:30–9:00 AM. Load onto vehicles at the Conference Hall in the Sapporo Campus, Hokkaido University.

9:00 AM. Depart from Sapporo. Mikasa City is about 50 km east of Sapporo City. Travel time to Mikasa City is about 1.5 hours.

10:30 AM. Arrive at Stop 1. We will observe the Cenomanian-Turonian shallow-water facies of the Yezo Group (Mikasa Formation), and collect ammonoids, bivalves and gastropods.

12:00 PM. Arrive at the Mikasa City Museum (Stop 2). You can eat lunch with excellent ammonite collections in the museum.

Fig. 8. A photograph of the outcrop (Stop 1), exposed above the shelter covering the prefectural road, Ikushumbetsu.

We will leave there at 1:00 PM.

1:30 PM. Arrive at Stop 3. We will observe the Coniacian-Santonian offshore facies of the Yezo Group (Kashima Formation), and collect ammonites and inoceramids. We will have two hours to collect fossils, and leave by 4:00 PM.

5:30 PM. Arrive at Sapporo.

2. Description of field stops

Stop 1 (Outcrop along the prefectural road in the Ikushumbetsu area; the Cenomanian-Turonian shallow water facies of the Mikasa Formation)

The Mikasa Formation is well exposed about 800 m long along the large outcrops above a shelter covering the prefectural road from Ikushumbetsu to the Katsurazawa Dam (Fig. 8). This stop is located in the eastern part of the Ikushumbetsu Anticline (Fig. 7) and the type locality of the Mikasa Formation (Matsumoto, 1951). Age-diagnostic acanthoceratids occur, and then this locality is a Japanese reference section of lower Cenomanian to middle Turonian biostratigraphy (Fig. 9; Matsumoto 1965; Matsumoto et al., 1991).

The Mikasa Formation in this area ranges from the lower Cenomanian to the middle Turonian, and represents two coarsening-upward successions assigned as third-order depositional sequences (Ando, 1997). In this field trip, we try to collect ammonoids from three major fossil horizons (Figs. 10).

Horizon 1 is correlated to the Lower Cenomanian by occurrence of *Mantelliceras*, and consists of alternating beds of fine-grained sandstone (beds 10-30 cm thick) and massive muddy sandstone to sandy mudstone (beds 20-100 cm thick) (Fig. 2). The sandstone beds contain hummocky cross-stratification (HCS) and current ripples. The massive muddy sandstone and/or sandy mudstone beds were influenced by intense bioturbation, and the trace fossils *Ophiomorpha* isp., *Zoophycos* isp., and *Thalassinoides* isp. are present. The frequent HCS sandstone beds suggest a storm-dominated sea floor in an inner shelf setting, while the mudstone beds were deposited from suspension during fair-weather periods. Ammonoids occur in the massive muddy sandstone intervals, with large quantities of shallow-marine bivalves such as *Pterotrigonia* sp., *Pseudoptera acuticarinata* (Nagao), *Pinna saitoi* Nagao and *Thetis japonica* (Yabe & Nagao), and gastropods such as *Semisolarium* sp. and *Margarites* sp. In the ammonoid assemblage, *Desmoceras* (60–75 % of the faunal spectrum within ammonoids) and *Zelandites* predominate.

Horizon 2 is correlated to the Middle Cenomanian by occurrence of *Calycoceras*, and consists of the muddy sandstone intercalated by a few discrete sandstone beds with cross- and parallel laminae. Bioturbation and mottling are common. This intensely bioturbated, muddy sandstone implies active behavior of benthic organisms during a physically stable interval. Burrowing destroyed storm-generated sedimentary structures, and the relict laminae seem to form a discrete hummocky sequence. The bivalve *Thetis japonica* and ammonoids *Calycoceras* and *Desmoceras* occur in the muddy sandstone. The depositional environment of this horizon is interpreted as having been the distal part of an inner shelf.

Horizon 3 is correlated to the Upper Cenomanian by occurrences of *Eucalycoceras pentagonum*, *Calycoceras* aff. *naviculare*, *Euomphaloceras septemseriatum*, and *Pseudocalycoceras dentonense*, and is characterized by monotonous mudstone that lacks laminations and contains rare intercalations of sandstone. The bivalve *Entholium* sp. and inoceramids are abundant, but ammonoids are rare. The depositional environment is considered to have been the distal part of the outer shelf.

Stop 2 (Mikasa City Museum: Excellent ammonoid collection)

Mikasa City is rich in nature and materials (e.g., coals, fossils) in spite of a short distance from main cities of Hokkaido (Sapporo, Chitose cities). Now the city only has a population of about 12,000, whereas it had over 60,000, and flourished as a coalmine city in 1950s. The Mikasa City Museum was established in July 1979 to respect the nature, culture and industry of the city.

This museum is known as "Museum of Fossils", and the most famous museum in Japan for the richness of excellent ammonoid collections. Over 800 ammonoid specimens (over 100 species), including heteromorphs such as *Nipponites*, are displayed in the museum. The holotypes of 11 ammonoid species are housed. The highlight of exhibition in this museum is a display of numerous gigantic ammonoids (Fig. 11). Visitors can touch these ammonoids and imagine the ancient ocean of the Cretaceous world. Specimens were obtained from various horizons and areas in Hokkaido, and were donated to the museum by several ammonoid collectors living around the city. A mosasaurid skull, discovered from Mikasa, is assigned as a natural monument of Japan. Other associated fossils, such as mosasaurids, elasmosaurids, bivalves, gastropods, echinoids, crinoids, fish bones and shark teeth, are also displayed.

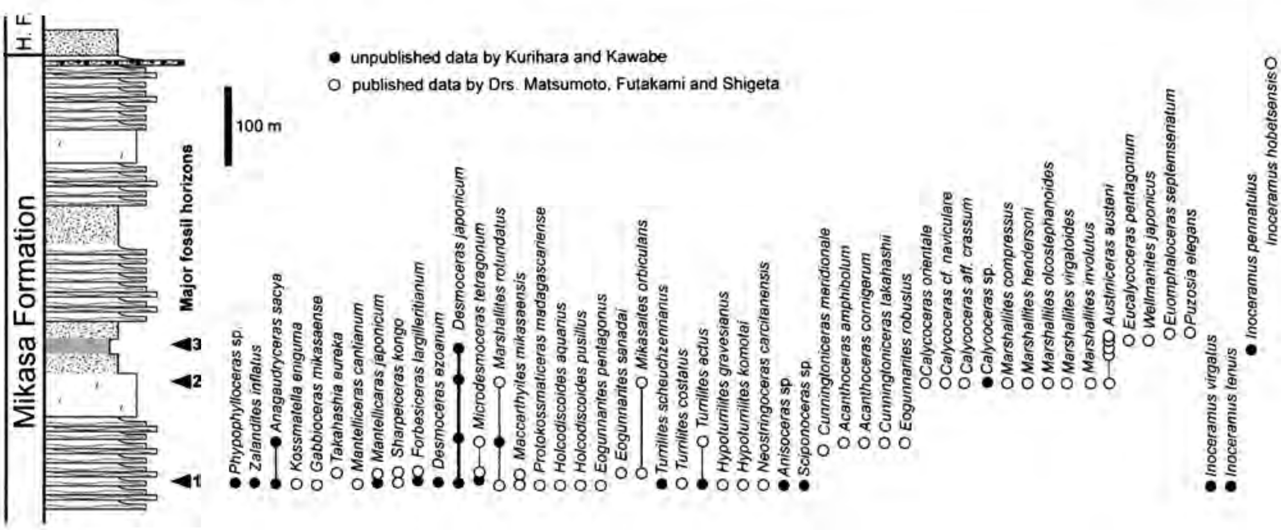

Fig. 9. Stratigraphic distribution of ammonoids and inoceramids at the outcrop (Stop 1), Ikushumbetsu.

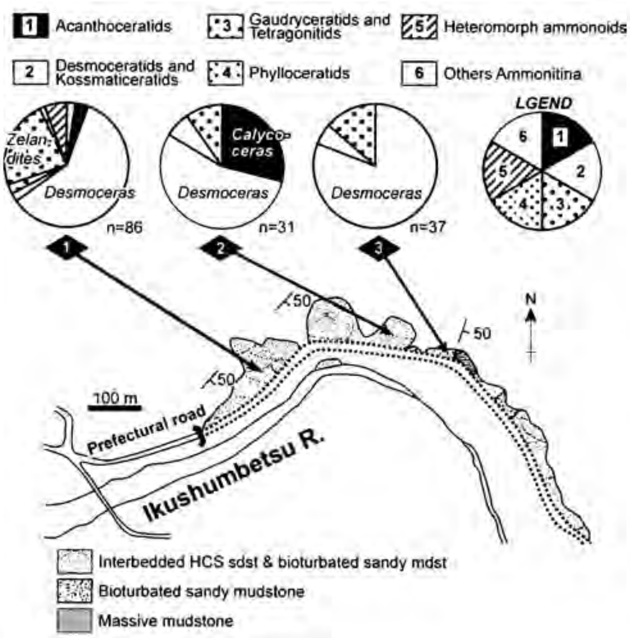

Fig. 10. Geological route map of Stop 1 and frequency of ammonoid group at the major fossil horizons shown in Fig. 9. Route map after Ando et al (2006) and ammonoid assemblages after the authors' collection.

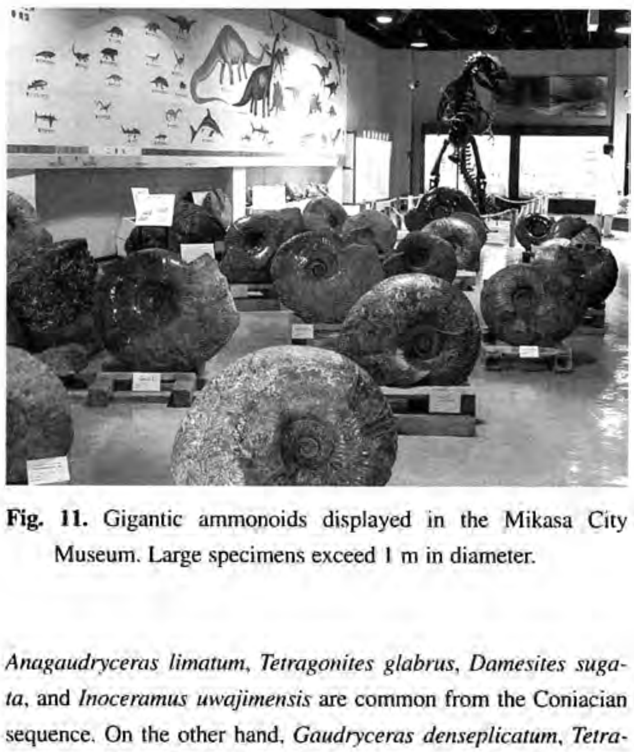

Fig. 11. Gigantic ammonoids displayed in the Mikasa City Museum. Large specimens exceed 1 m in diameter.

Stop 3 (Outcrop along the Shuparogawa River: the Coniacian-Santonian offshore facies of the Kashima Formation in the Oyubari area)

Stop 3 is about 20 km south of the Mikasa City Museum (travel time is about 30 minutes). The Kashima Formation, being composed of dark gray, massive mudstone, is well exposed along the Shuparogawa River in the Oyubari area. As molluscan fossils are abundant throughout the sequence, we can easily collect ammonoids and inoceramids from calcareous concretions in float. *Anagaudryceras limatum*, *Tetragonites glabrus*, *Damesites sugata*, and *Inoceramus uwajimensis* are common from the Coniacian sequence. On the other hand, *Gaudryceras denseplicatum*, *Tetragonites glabrus*, *Damesites damesi*, *Yokoyamaoceras* spp., *Polyptychoceras* spp. (heteromorphic ammonoid), and *Inoceramus amakusensis* occur abundantly from the Santonian sequence.

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Explanation of Plates

Plate 1. Selected ammonoids from the Cenomanian in the Yezo Group. All specimens are housed in the Mikasa City Museum. We will collect such ammonoids in the lower part of the Mikasa Formation (lower to middle Cenomanian) in the Mikasa area (Stop 1 of the Field Trip #1).

Fig. 1. *Desmoceras (Pseudouhligella) japonicum* Yabe, MCM.A.1086, x 1.0.
Fig. 2. Median cross section of *D. (P.) japonicum* Yabe, our own sample, x 0.75.
Fig. 3. *Mikasaites orbicularis* Matsumoto, MCM.A.567, x 1.0.
Fig. 4. *Hypoturrilites sp.*, MCM.T.232, x 1.0.
Fig. 5. *Turrilites costatus* Lamarck, MCM.A.494, x 1.0.
Fig. 6. *Zelandites inflatus* Matsumoto, MCM.A.1048, x 1.0.
Fig. 7. *Mantelliceras japonicum* Matsumoto, Muramoto & Takahashi, MCM.A.665, x 0.8.

Plate 2. Selected ammonoids from the Turonian in the Yezo Group. All specimens are housed in the Mikasa City Museum. We will collect such ammonoids in the Sakugawa and Saku formations in the Teshionakagawa area (Stop 2-2 of the Field Trip #2).

Fig. 1. *Scalarites scalaris* (Yabe), MCM.A.1043, x 0.75.
Fig. 2. *Gaudryceras denseplicatum* (Jimbo), MCM.A.1065, Obira town, x 0.75.
Fig. 3. *Nipponites mirabilis* Yabe, MCM.A.435, x 1.0.
Fig. 4. *Scaphites* sp., our own sample, x 1.0.
Fig. 5. *Eubostrychoceras muramotoi* Mastumoto, MCM.A.978, x 1.0.
Fig. 6. *Eubostrychoceras japonicum* (Yabe), MCM.A.1042, x 0.75.

Plate 3. Selected ammonoids from the Coniacian in the Yezo Group. All specimens are housed in the Mikasa City Museum. We will collect such ammonoids in the Kashima Formation in the Oyubari area (Stop 3 of the Field Trip #1).

Fig. 1. *Anagaudryceras limatum* (Yabe), MCM.K.50, x 0.75.
Fig. 2. *Forresteria (Forresteria) muramotoi* Matsumoto, MCM.K.55, x 1.0.
Fig. 3. *Damesites sugata* (Forbs), MCM.A.986, x 1.0.
Fig. 4. *Hypophylloceras (Neophylloceras) subramosum* (Spath), MCM.A.965, x 0.75.
Fig. 5. *Mesopuzosia yubarensis* (Jimbo), MCM.A. 1106, x 0.75.

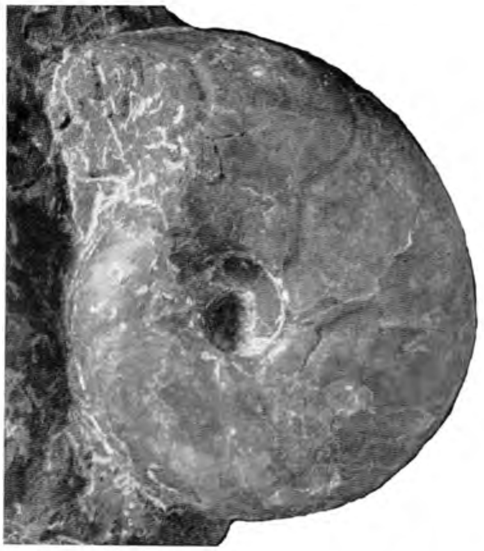
Plate 4. Selected ammonoids from the Coniacian through the Santonian in the Yezo Group. All specimens are housed in the Mikasa City Museum. We will collect such ammonoids in the Kashima Formation in the Oyubari area (Stop 3 of the Field Stop #1).

Fig. 1. *Plesiotexanites kawasakii* (Kawada), MCM.A.1103, x 1.0.
Fig. 2. *Polyptychoceras sp.*, MCM.A.876, x 1.0.
Fig. 3. *Eupachydiscus haradai* (Jimbo), MCM.A.1054, x 1.0.
Fig. 4. *Tetragonites glabrus* (Jimbo), MCM.A.1110, x 1.0.
Fig. 5. *Menuites japonicum* Matsumoto, MCM.K.10, x 1.0.

Plate 5. Selected inoceramids from the Upper Cretaceous (Turonian–Santonian) in the Yezo Group. All specimens are housed in the Mikasa City Museum. We will collect such inoceramids as many as ammonoids in the Field Trip.

Fig. 1. *Inoceramus (Inoceramus) hobetsensis* Nagao and Matsumoto, MCM.A.599, x 0.75.
Fig. 2. *Inoceramus (Inoceramus) teshioensis* Nagao and Matsumoto, MCM.A.250, x 1.0.
Fig. 3. *Inoceramus (Cremnoceramus) rotundatus* Fiege, MCM.T.148-3.
Fig. 4. *Inoceramus (Platyceramus) amakusensis* Mastumoto, x 0.5.
Fig. 5. *Inoceramus (Inoceramus) uwajimensis* Yehara, MCM.A.502, x 1.0.

Plate 1



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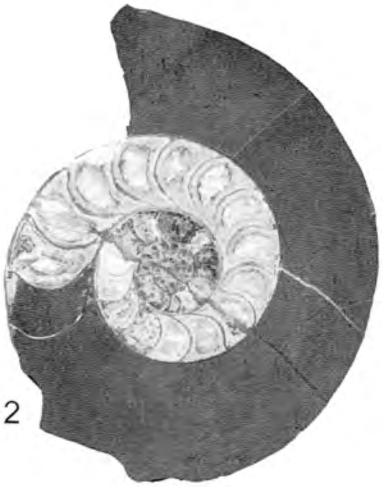

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Plate 2

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Plate 3


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Plate 4

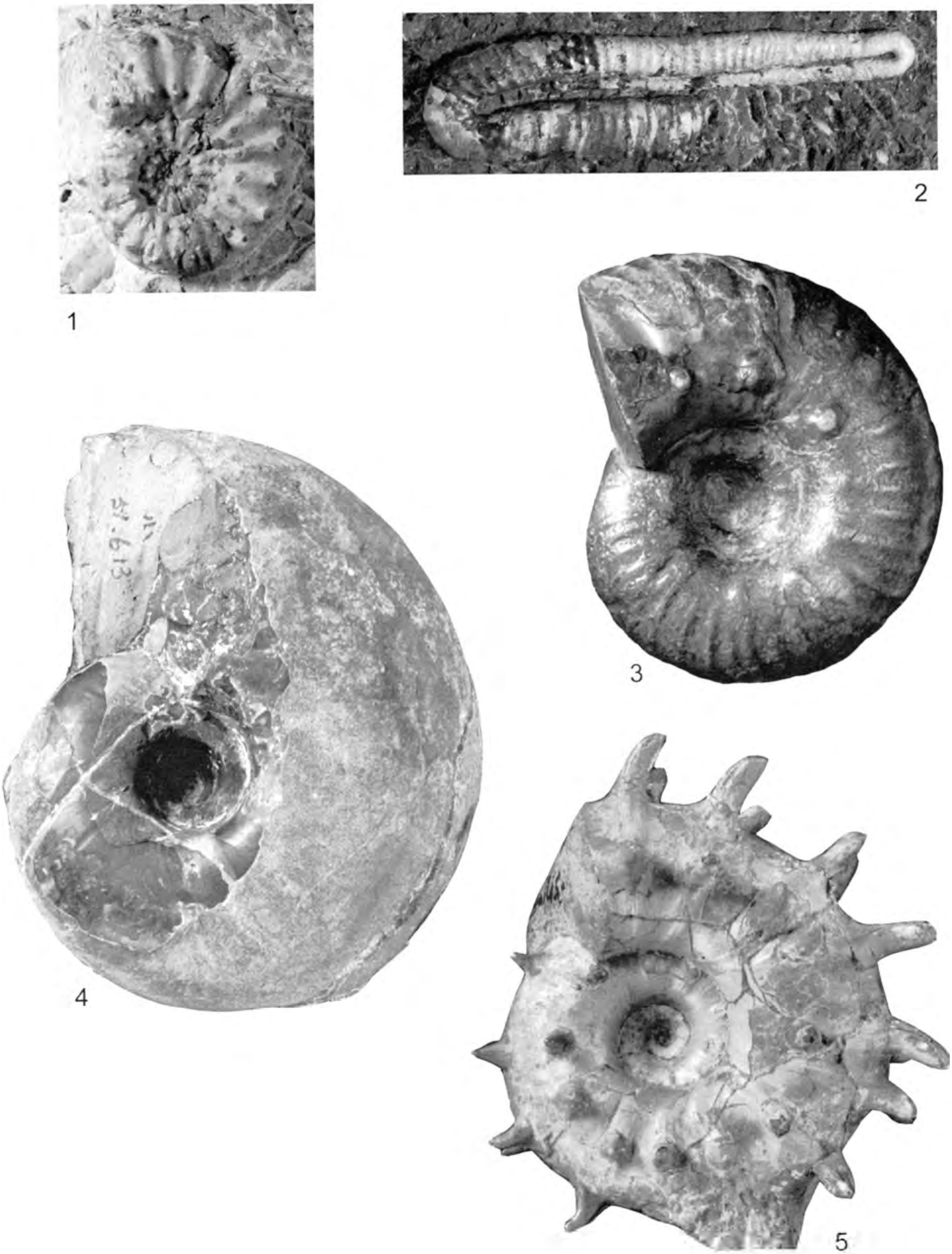
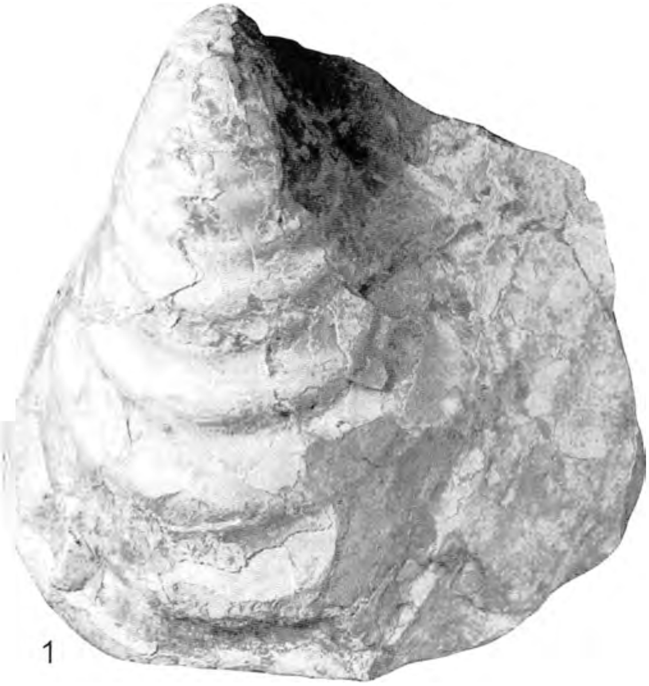


Plate 5



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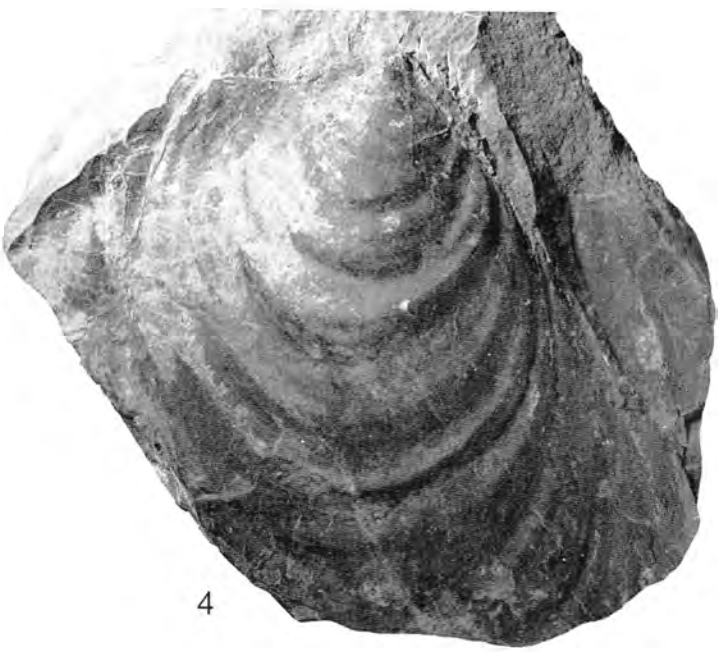

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EXCURSION GUIDEBOOK (Field Trip #2; September 18-21, 2007) of
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Stratigraphy and megafauna of the Upper Cretaceous Yezo Supergroup in the Teshionakagawa area, northern Hokkaido, Japan

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Introduction

This trip will emphasize collecting beautiful aragonitic ammonoids and inoceramid bivalves from the Yezo Supergroup in the Teshionakagawa area, northern Hokkaido, Japan. We will also visit the Campanian methane-seep locality associating with a chemosynthetic fossil community in the Teshionakagawa area, and the Nakagawa Museum of Natural History at which excellent specimens of Cretaceous ammonoids, inoceramids and marine reptile (plesiosaurs etc.) skeletons from the region are exhibited.

The Yezo Supergroup, deposited in the Cretaceous to Paleocene Yezo forearc basin in the Northwestern Pacific margin (Okada, 1983), is extensively distributed in a north-to-south belt in central Hokkaido, the northernmost Japanese island (see index map in Fig. 2), and in Sakhalin, Far East Russia. This supergroup is divided into the Lower Yezo, Middle Yezo, Upper Yezo and Hakobuchi groups, toward the top of the sequence, and is widely exposed in the Teshionakagawa area of northern Hokkaido, where it contains a variety of abundant, well-preserved megafossils, especially ammonoids, inoceramids and other molluskan fossils. A number of biostratigraphic and paleobiological studies (e.g., Ma tsumoto, 1942, 1943; Hirano, 1978; Tanabe, 1979; Takashima et al., 2004) have focused on this supergroup since the last century (see summary in Kimura et al., 1991).

Several workers (e.g., Ijima and Shinada, 1952; Osanai et al., 1960; Nagao 1962, Hashimoto et al., 1967; Okamura, 1977) have reported the litho- and biostratigraphy of the Teshionakagawa area, after the pioneering investigation by Matsumoto (1942). More recently, Takahashi et al. (2003) detailed the litho- and biostratigraphy of this supergroup (excluding the Lower Yezo Group) in the Teshionakagawa area. They also demonstrated that ammonoids and inoceramids are abundant in the Middle Yezo (part), Upper Yezo, and Hakobuchi groups, with showing biostratigraphic data and faunal lists. The present paper is based mainly on Takahashi et al. (2003). During the field excursion, we will observe Upper Cretaceous biofacies changes in the Teshionakagawa area and collect well-preserved ammonoids and inoceramids, which sometimes display aragonitic preservation.

The daily schedule

In this trip, we will observe the Campanian Osoushinai Formation exposed in the Nio River, the Abeshinai River and its tributaries, and collect well-preserved megafossils including ammonoids. Localities of observed points are indicated in Figs. 1 and 2. The Osoushinai Formation is composed mainly of bioturbated sandy mudstone, showing a coarsening-upward succession. This formation is the most fossiliferous sequence in the Yezo Supergroup in the Teshionakagawa area, and cephalopod fossils are especially abundant and diverse among the megafauna. They occur both in calcareous concretions and host rocks, and occasionally retain original aragonitic shell mineralogy and shell microstructure. Tanabe et al. (2006) recently described a teutid co-

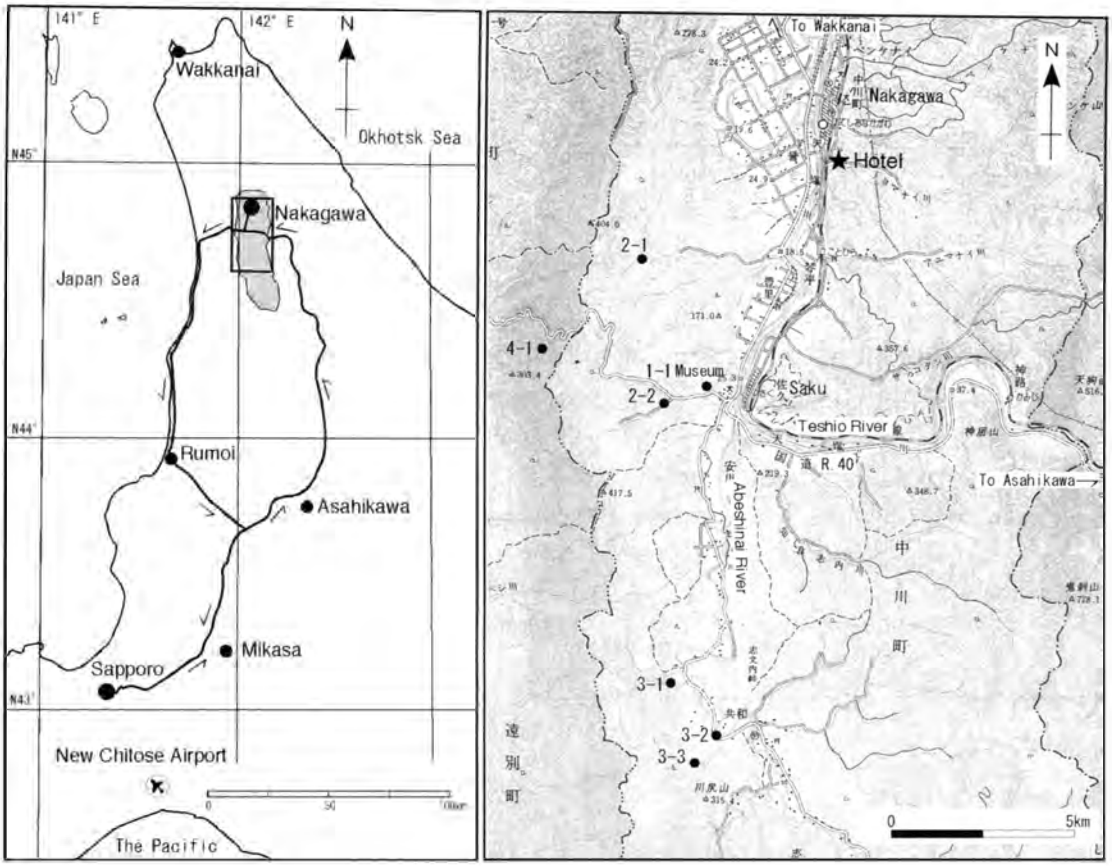


Fig. 1. Route map of Field Trip #2 (left) and location of each stop in the Teshionakagawa area (right). Topograohic map is based on a part of 1:50,000 map sheet 'Teshionakagawa', 'Kyowa' and 'Enbetsu' published by the Geographical Survey Institute of Japan.

leoid jaw from this formation and proposed a new genus and species (*Yezoteuthis giganteus*) for it. We can also collect bivalves, gastropods, nautiloid *Cymatoceras*, solitary corals and shark teeth. This formation also yields marine reptiles such as a dermochelyid turtle (Hirayma and Hikida, 1998) and long-necked elasmosaurids (e.g., Mochizuki et al., 2006). Recently, terrestrial vertebrates such as therizinosaurid dinosaurs and a trionychoid turtle were found.

September 18 (We will join at Conference Hall in Sapporo Campus, Hokkaido University)

8:30 a. m. Meet at Conference Hall in Sapporo Campus, Hokkaido University.

8:30 - 9:00 a. m. Load onto vehicles at Conference Hall in Sapporo Campus, Hokkaido University.

9:00 a. m. Depart from Sapporo. Nakagawa Town is about 300 km north of Sapporo City. 4.5 to 5 hours driving from Sapporo to Nakagawa Town (Fig. 1). We will take rests on the way several times. Picnic lunch.

Nakagawa Town is located in northern Hokkaido. The Teshio River, the fourth length (256 km) in Japan, flows across the Town, and we can see the Kitami Mountains to the east, Teshio Mountains to the west. The Teshio River rises in Mt. Teshio-Dake of the Kitami Mountains. The Town is 594.87 square kilometers, about 85% of the area is woodland. The climate is cold, with the average temperature in winter falling below 0℃ in all areas, and the Teshio River is frozen during the winter season. Population of the Town is about 2,000. Agriculture (mainly dairy farming) is a key industry, and there are about 3,500 milk cows.

Stop 1-1: Nakagawa Museum of Natural History (Fig. 3)

The Nakagawa Museum of Natural History opened in 2002 to exhibit the natural and cultural history of Nakagawa Town. The Saku Junior High School was closed in 1999 and the buildings were rebuilt to reuse for the museum. Nakagawa Town is one of the most famous ammonoid 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, smooth, ornate and heteromorph ammonoids, and furthermore, several reptiles such as dermochelyid sea turtles, long-necked elasmosaurids and claws of a therizinosaurid dinosaur (Fig. 3). Other fossils are bivalves, gastropods, echinoids, crinoids, fish bones, shark teeth, and Neogene pinniped and dolphin skeletal remains. When we visit the muse-

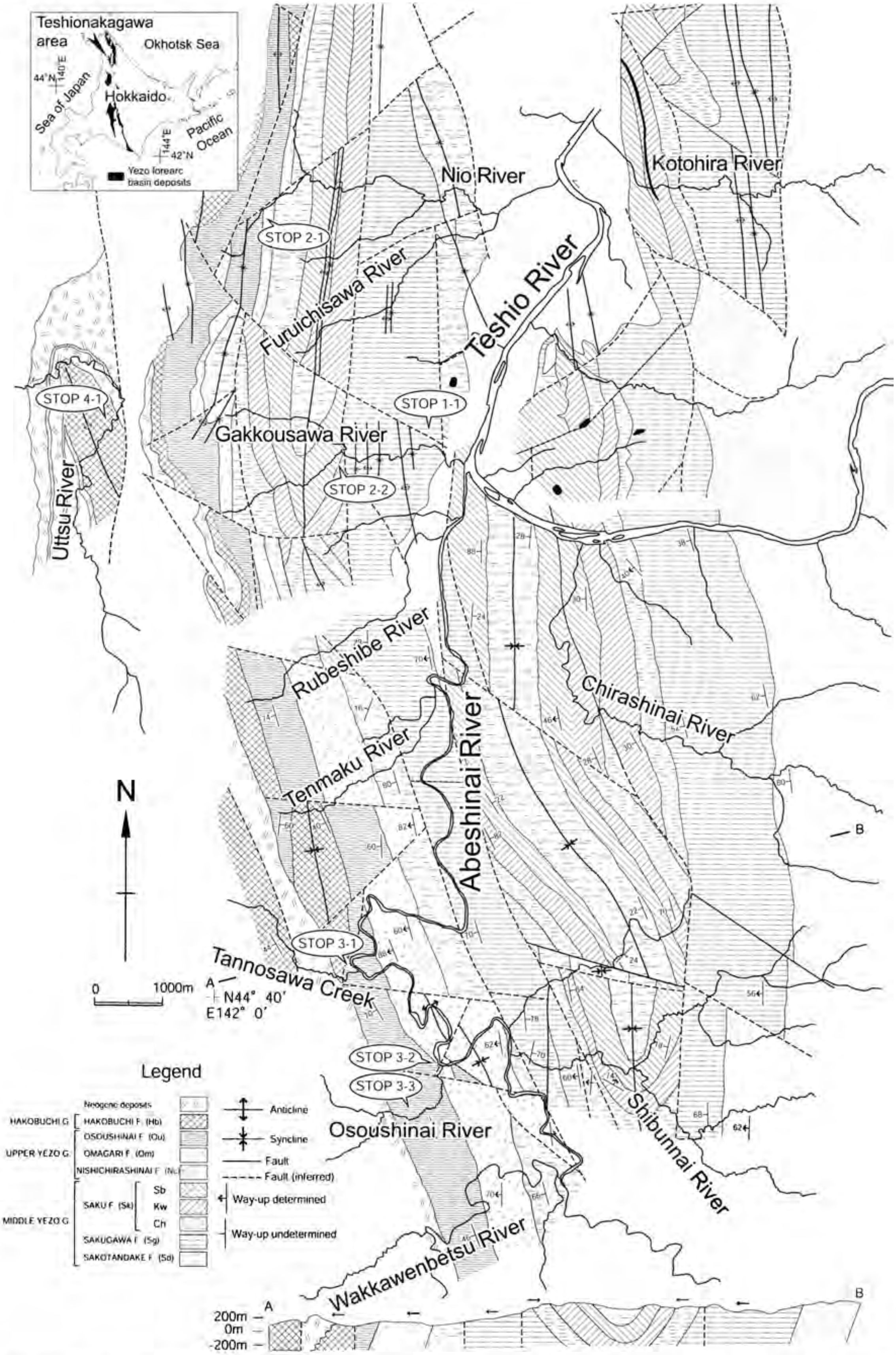


Fig. 2. Geological map and cross section of the Teshionakagawa area (compiled after Hashimoto, 1967; Hata and Tsushima, 1969 and Takahashi et al, 2003; reproduction permitted by the Geological Society of Japan). Arrows above the cross section point to a stratigraphically upward direction.

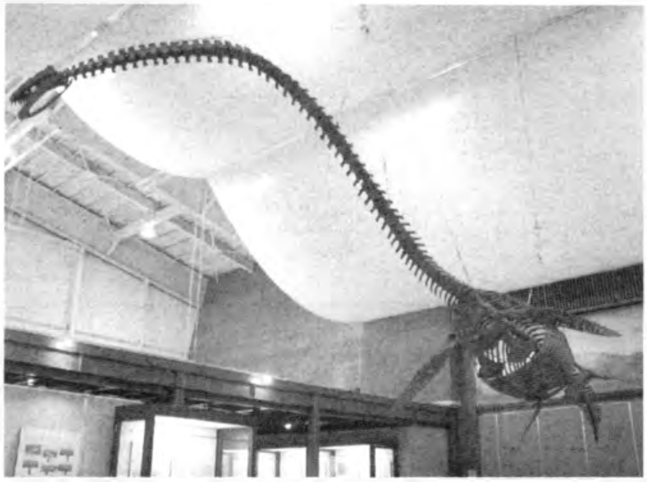


Fig. 3. Main hall of the Nakagawa Museum of Natural History displaying a long-necked elasmosaur (left) and gigantic ammonoids (right).

um, the temporary exhibition "Heteromorph ammonoids from the Nakagawa area" will be held. Excellent heteromorph ammonoids of Turonian to Campanian in age, including well-known *Nipponites* will be exhibited.

September 19 (Meet and Depart by 8:30 a. m.)

8:30 a. m. Leave the hotel. Backpacks with hammers, chisels and sturdy collecting back, rubber boots or water proof hiking shoes are necessary. Drink and lunch will be provided from the hotel. Stop 2-1 is located approximately 5 km southwest of the hotel. We will arrive at the outcrop at about 9:15 a. m., and take a lunch in the field.

Stop 2-1: Nio River; Santonian to Lower Campanian ammonoids from offshore mudstone.

We will collect beautiful aragonitic ammonoids and other molluskan fossils from the Osoushinai Formation exposed along the upper stream of the Nio River (Figs. 4, 6). The route is wet and muddy at several places, and there are many fallen trees in the stream. We will collect fossils there for about 3.5 hours.

The Osoushinai Formation exposed in this route is composed mainly of gray to dark gray bioturbated sandy siltstone and muddy sandstone, with intercalation of conglomerate and sandstone layers, and the bed strikes N-S and dips west. The upper stream of the river flows in parallel with the strike of the Osoushinai Formation. We can collect ammonoids from the middle and upper parts of the formation. They are mostly preserved in muddy to sandy calcareous concretions that are found either from outcrops or as floats in the riverbank. Beautiful aragonitic ammonoids are more abundant in muddy concretions than in sandy ones. The holotype of *Jouaniceras (Ainoceras) kamuy* (Matsumoto & Kanie) (Pl. 4-1, 2) was found from the river. Representative ammonoids are *Yokoyamaoceras ishikawai* (Jimbo) (Pl. 2-1, 2), *Gaudryceras tenuiliratum* Yabe (Pl. 1-5), *Phyllopachyceras ezoense* (Yokoyama) (Pl. 1-2), *Hauericeras angustum* Yabe (Pl. 3-2), *Tetragonites* and *Polyptychoceras* (Pl. 1-3, 4; Pl. 4-4, 5, 7) from the middle parts of the formation, whereas *Canadoceras* (Pl. 2-8) and *Eupachydiscus* (Pl. 3-3) from the upper part. This formation also yields marine reptiles. *Elasmosaur* (long-necked marine reptile) was discovered in the upper branch of this river (Mochizuki et al., 2006).

At about 13:30 p. m., we will leave this river and go to the next stop.

Stop 2-2: Gakkousawa River: Turonian ammonoids from the Saku Formation.

We will collect Turonian ammonoids from river pebbles in the lower course of the Gakkousawa River (Figs. 5, 6). The Sakugawa and Saku formations crop out repeatedly in the river. The Sakugawa Formation is composed mainly of mudstone, and the Saku Formation is composed of alternating beds of mudstone and sandstone. We can see huge concretions that contain a giant inoceramid *Inoceramus (Inoceramus) hobetsensis* Nagao & Matsumoto (Pl. 8-7) everywhere in the riverbank. At this stop, we are aimed at collecting Turonian ammonoids, but the Cenomanian ammonoids such as *Cunningtoniceras*, *Calycoceras (Newboldiceras)* and *Turrilites* are also found in floated concretions. Turonian ammonoids that can be collected at this stop are *Tetragonites (Tetragonites) glabrus* (Jimbo), *Subprionocyclus bakeri* (Anderson), *Puzosia (Mesopuzosia) pacifica* (Matsumoto), *Scaphites* (Pl. 7-1, 2), *Yezoites* (Pl. 7-3, 4) and *Scalarites* from sandy concreations. We may also collect *Nipponites mirabilis* Yabe (Pl. 7-5, 6) at this stop. *N. mirabilis* co-occurs with *P. (M.) pacifica*, *Scaphites*, *Yezoites*, and *Nostoceras (Eubostrychoceras)* and wood trunks in medium- to coarse-grained sandy concretions.

At about 15:45 p. m., we will leave this stop and go back to the hotel.

September 20 (Eat and Depart by 8:30 a. m.)

8:30 a. m. Leave the hotel. Stop 3-1 is at approximately 20

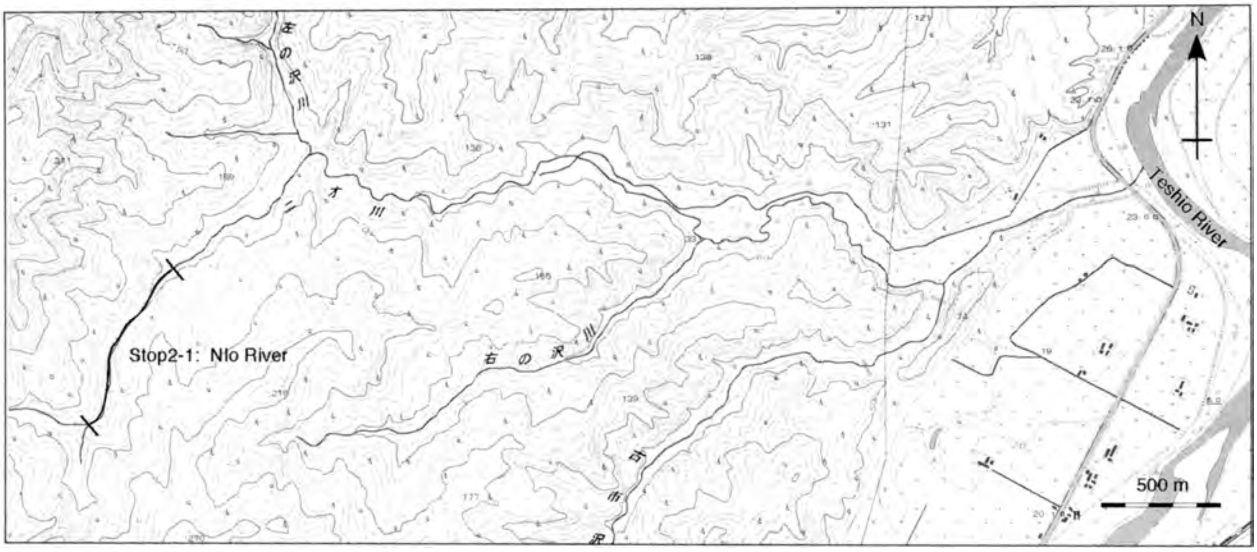


Fig. 4. Map showing Stop 2-1 on Day 2. Topograohic map is a part of 1:25,000 map sheet 'Teshionakagawa' published by the Geographical Survey Institute of Japan.

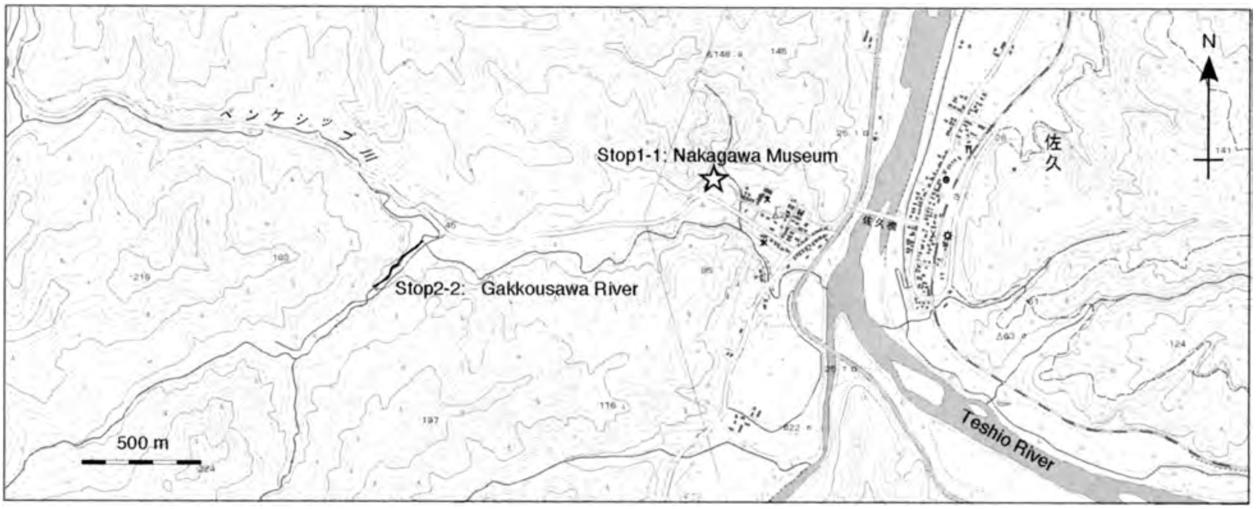


Fig. 5. Map showing Stop 1-1 on Day 1 and Stop 2-2 on Day 2. Topographic map is a part of 1:25,000 map sheet 'Saku' published by the Geographical Survey Institute of Japan.

km south of the hotel. We will arrive there at about 9:15 a. m.

Stop 3-1: Tannosawa Creek to Abeshinai River: Lower Campanian ammonoids from the middle to upper parts of the Osoushinai Formation.

The middle and upper parts of the Osoushinai Formation consisting mainly of bioturbated sandy mudstone are exposed at this stop (Figs. 7-9).

We will first observe several outcrops along the Tannosawa Creek (Fig. 7). The holotype of *Teshioites ryugasensis* Matsumoto (Pl. 2-6) was found from the creek. We can collect beautiful ammonoids having pearlescence, such as *Eupachydiscus* (Pl. 3-3), *Yokoyamaoceras* (Pl. 2-1, 2), *Gaudryceras* (Pl. 1-5, 6, 8), *Tetragonites* (Pl. 1-3, 4), and *Canadoceras* (Pl. 2-8). Several species of an inoceramid genus *Sphenoceramus* (Pl. 9) occur abundantly in both concretions and surrounding sandy mudstone. We can also collect well-preserved *Sphenoceramus schmidti* in sandy mudstone in the upper part of the formatin exposed along the creek.

Next, we will go down the creek, and collect ammonoids at the large outcrop exposed near the junction of the Tannosawa Creek and the Abeshinai River. We can see gigantic concretions in the riverbanks and cliffs along the river. The holotype of *Menuites japonica* Matsumoto (Pl. 6-4) was found from this outcrop. We can also collect beautiful ammonoids such as *Eupachydiscus* (Pl. 3-3), *Gaudryceras* (Pl. 2-1, 2), *Polyptychoceras* (Pl. 4-4, 5, 7), *Haueriseras* (Pl. 3-2), and *Baculites* (Pl. 4-6).

At about 11:30 a. m., we will leave this stop and go to the next stop.

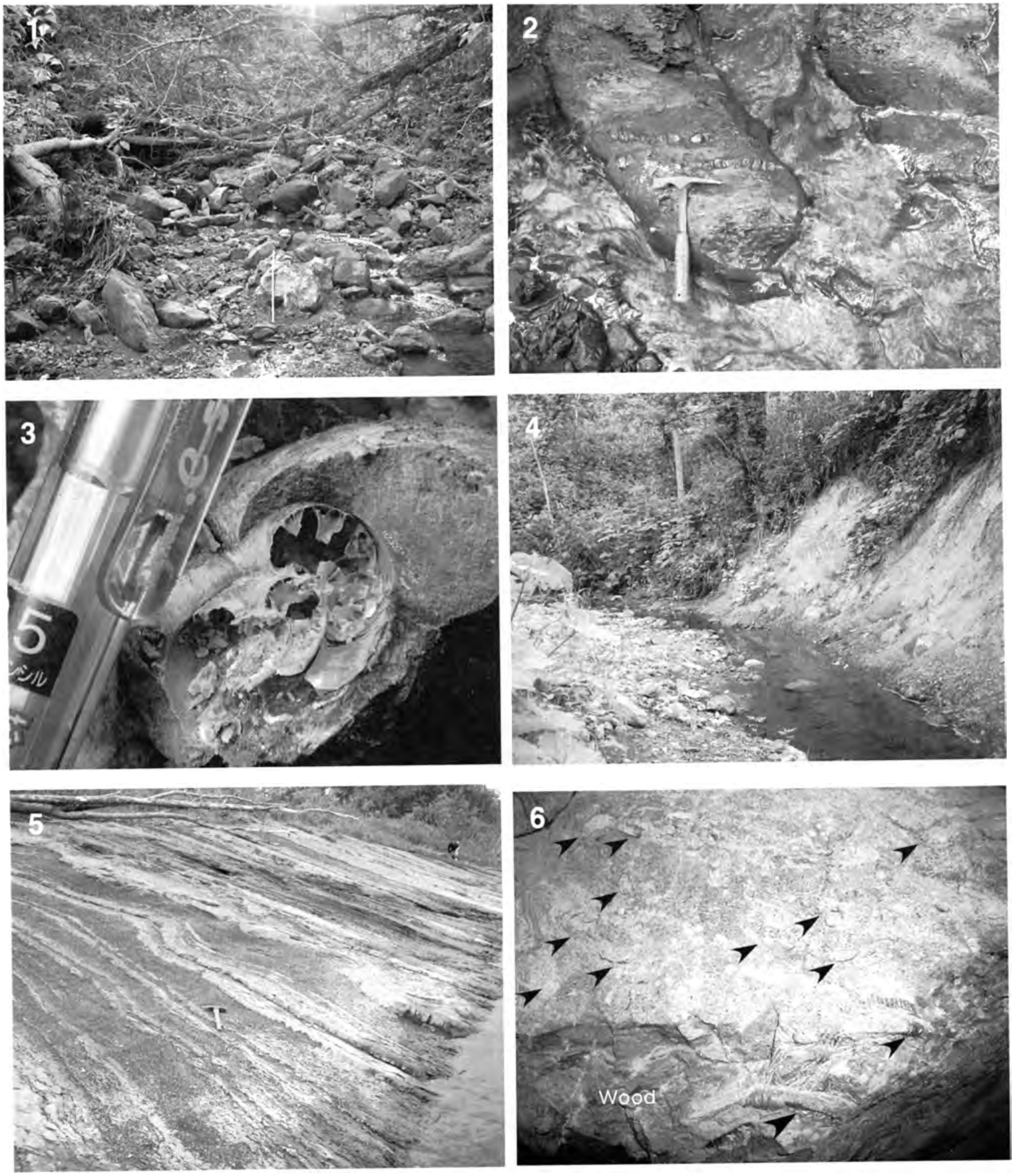


Fig. 6. Photos of outcrops and fossils in the Teshionakagawa area.

1. A Photo of the Nio River (Stop 2-1), 2. Offshore mudstone facies of the Osoushinai Formation. Fossiliferous concretions are often included in this facies, 3. An excellently preserved ammonoid (*Gaudryceras*) showing the hollow preservation of the phragmocone in which no secondary grown of calcite crystals developed. Such ammonoids are rare in occurrence. 4. Photos of the Gakkousawa River (Stop 2-2). 5. Turbidite facies of the Turonian Saku Formation at the type locality. 6. Modes of occurrence of heteromorph ammonoids and sunken wood in a sandy concretion embedded in the Saku Formation. Arrowheads point to ammonoids.

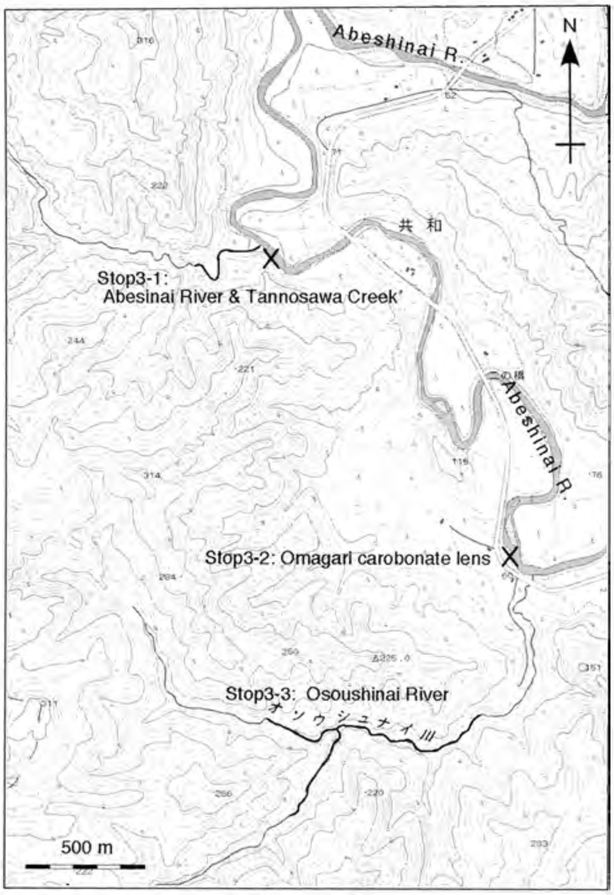


Fig. 7. Map showing the stops on Day 3. Topographic map is a part of 1:25,000 map sheet 'Kyowa' published by the Geographical Survey Institute of Japan.

Fig. 8. Modes of fossil occurrence in the mudstone of the Osoushinai Formation. Ammonoid *Canadoceras* (upper photo) and inoceramid *Sphenoceramus* (lower).

Stop 3-2: Abeshinai River: Omagari carbonate lens -Late Cretaceous methane seep carbonate- (see p. 43 in detail).

Stop 3-2 highlighted the largest Late Cretacoeus methane seep carbonate (Omagari carbonate lens; Hikida et al., 2003) yielding a large number of vestimentiferan worm tubes and tiny gastropods in this area. The lens measures approximately 10 m wide and 5 m high. It is solitarily exposed in the Abeshinai River. We will observe the modes of occurrence of chemosynthetic biota and may collect some ammonoids from the carbonate. If the water level is high, we cannot cross the river and observe the carbonate lens. We will take a lunch at this stop.

Stop 3-3: Osoushinai River: Lower Campanian ammonoids from the upper part of the Osoushinai Formation.

This stop is the last opportunity to collect Lower Campanian fossils in this field trip. The Osoushinai River is the type locality of the Osoushinai Formation, and the upper part of the formation crops out well. Species of *Sphenoceramus* (Pl. 9) occur abundantly and are often concentrated in both concretions and surrounding mudstone at several horizons. Occasionally inoceramid shells are articulated, suggesting a paraautochthonous mode of occurrence. Ammonoids are often discovered from concreations, together with many inoceramid shells. We can also find large limpet-shaped mollusks *Gigantocaplus giganteus* (Schmidt) (Pl. 8-5) and *Caprus transformis* Dundo (Pl. 8-4) from the upper part of the formation, though their exact higher taxonomic positions are still unsettled. A trionychoid land turtle was also reported.

At about 15:30 p. m., we will leave this stop and go back to the hotel.

September 21 (Eat and depart by 9:00 a. m.)

9:00 a. m. Leave the hotel. We must load all baggage onto a bus, but a backpack with a hammer, chisels and sturdy collecting backs are necessary to take with you, because we will collect Upper Campanian fossils from the final stop in the morning. We will collect beautiful ammonoids in a large outcrop, exposed along the forestry road, but it is better to search fossils from the outcrops in the Uttsu River, if you want to collect better ones. At about 11:00 a. m., we will leave this stop and arrive at Sapporo (Hokkaido University) at about 17:30 p. m.

Fig. 9. Photos showing the outcrrops and the modes of occurrence of ammonoids in the Osoushinai Formation.

1. Outcrop of muddy turbidite exposed at the junction of the Osoushinai River and the Abeshinai River (Stop 3-2), 2. Large outcrop of bioturbated mudstone at the junction of the Tannnosawa Creek and the Abeshinai River (Stop 3-1), 3 Mode of occurrence of *Eupachydiscus* in the mudstone, 4. *Yokoyamaoceras ishikawai* in a calcareous concretion, 5, 6. Gigantic ammonoid *Menuites fascicostatus* embedded in the mudstone (5) and the lateral view of the excavated ammonoid (6).

Stop 4-1: Kiyokawa forestry road: Upper Campanian ammonoids from the Hakobuchi Formation.

We will collect fossils at the large outcrop exposed along the forestry road (Fig. 10). The Hakobuchi Formation in the Teshionakagawa area is composed mainly of shallow-marine, fine- to medium-grained sandstone with sandy siltstone. We are aimed at collecting the Upper Campanian index ammonoid, *Metaplacenticeras subtilistriatum* (Jimbo) (Pl. 5-2, 3, 8). This species occurs only in the sandy siltstone to silty sandstone deposited in the inner shelf setting (Ando et al, 2006). Wani (2006) described the taphonomic attribute of this species in the Teshionakagawa area, and interpreted that this streamlined ammonoid was nektobenthic, lived in a shallow environment (shoreface-inner shelf) where its streamlined shell allowed it to align with prevailing currents, similar to a wind vane. We will observe the large outcrop of about 100 m wide and collect fossils for about 2 hours.

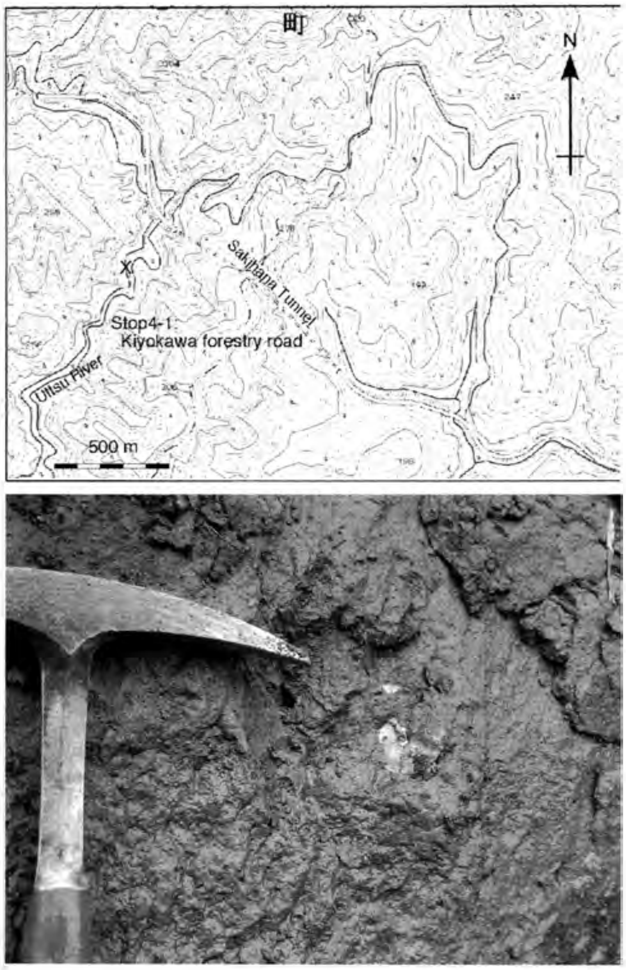


Fig. 10. Topographic map showing Stop 4-1 on Day 4 (a part of 1:25,000 map sheet 'Sengen' published by the Geographical Survey Institute of Japan; upper), and *Metaplacenticeras subtilistriatum* embedded in sandy siltstone exposed at the outcrop of Stop 4-1 (lower).

Geological Setting

The Yezo Supergroup (identical to the "Yezo Group" of Takashima et al., 2004) belongs tectonically to the Sorachi-Yezo Belt (Kiminami et al., 1986), in which the Yezo Supergroup, the latest Jurassic to Early Cretaceous ophiolitic Sorachi Group, and the Kamuikotan and Idonnap zones (accretionary complexes) are distributed. The Teshionakagawa area is located in the northern extent of the Yezo Supergroup in Hokkaido (Fig. 2).

The supergroup in northern Hokkaido forms a large-scale anticline, and the strata in the axial zone consist of serpentine and the Sorachi Group. The Teshionakagawa area is situated on the western limb of the anticline. The strata trend either N-S or NW-SE with a high to moderate dip and becomes younger to the west overall, although there is a moderate-scale syncline to the east of the Abeshinai River (Fig. 2). The Sakotandake (upper part), Sakugawa and Saku formations (Middle Yezo Group), the Nishichirashinai, Omagari and Osoushinai formations (Upper Yezo Group), and the Hakobuchi Formation (Hakobuchi Group), in ascending stratigraphic order, are distributed in the study area (geological map area of Takahashi et al., 2003). The Miocene Yamato Formation disconformably overlies the Osoushinai Formation or Hakobuchi Formation, with a basal conglomerate (Figs. 2, 11).

Lithostratigraphy

1. Middle Yezo Group

The group was divided into five formations by Nagao (1962), namely the Moehoro, Shirataki, Sakotandake, Sakugawa and Saku formations, in ascending order (Fig. 12). In this paper, we describe the upper three formations, the Sakotandake (upper part), Sakugawa and Saku formations.

(1) Sakotandake Formation (upper part; Sd)

Thickness: More than 140 m.

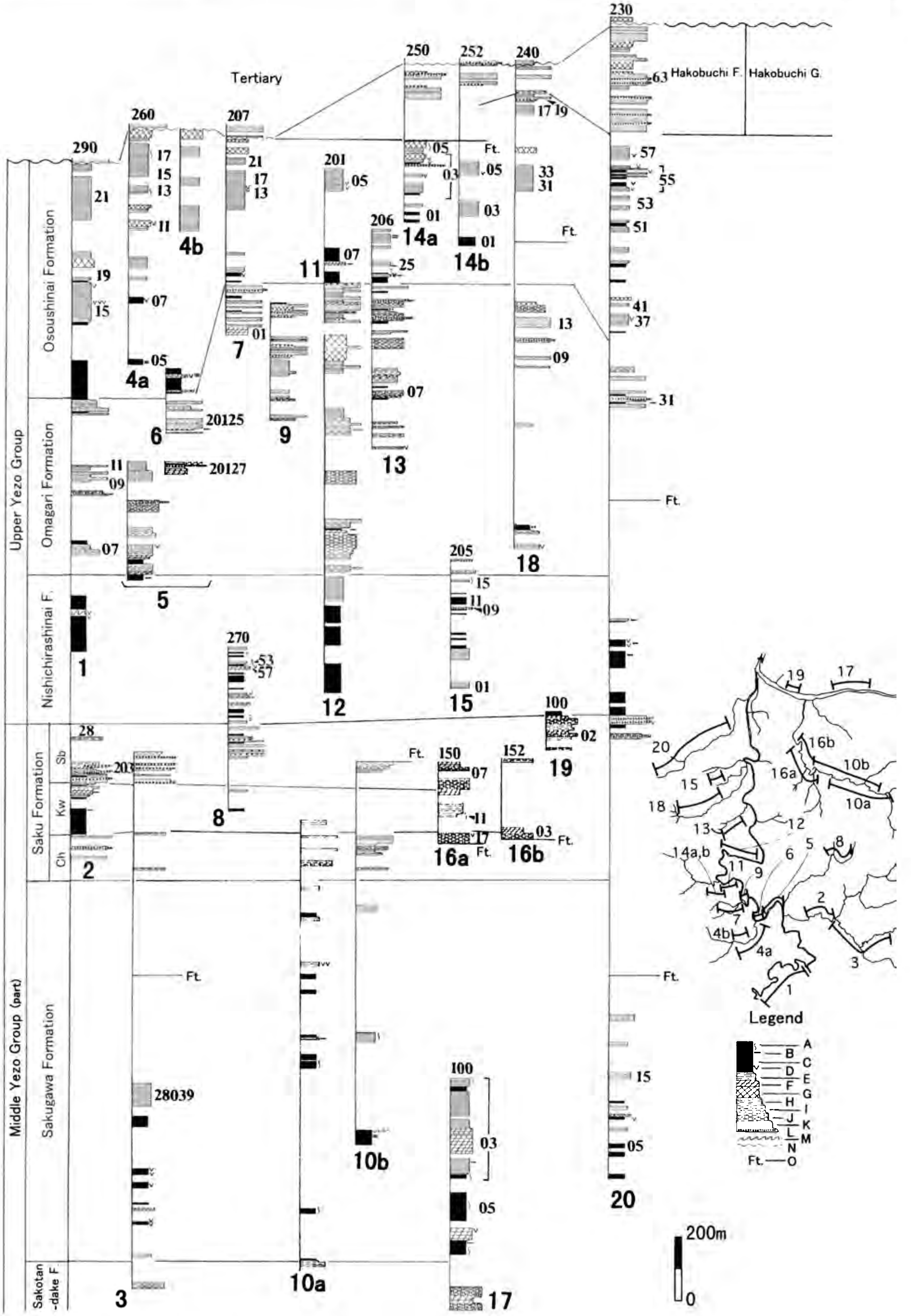
Descriptions: This formation is composed of alternating beds of sandstone and mudstone, whose thickness ranges from 1 to 150 cm and from 5 to 100 cm, respectively. The sandstones are mostly well-bedded, fine-grained and display well-preserved parallel laminations, hummocky cross-stratifications and swaley cross-stratifications. The bases of the sandstones are sharp and sometimes exhibit flute casts. Grading is common in the sandstones.

Fossils: Megafossils are absent.

(2) Sakugawa Formation (Sg)

Thickness: Approximately 1200 m.

Descriptions: This formation conformably overlies the Sakotandake Formation and consists mainly of bioturbated sandy siltstone. The boundary between the two formations is seen at loc. N15049 (Fig. 13) along the Chirashinai River. The lower part of this formation sometimes consists of laminated or intercalated thin (about 1 cm or less thick) silty sandstones, with predominant


Tertiary
Hakobuchi F.
Hakobuchi G.
Upper Yezo Group
Osoushinai Formation
Omagari Formation
Nishichirashinai F.
Saku Formation
Sb
Kw
Ch
Middle Yezo Group (part)
Sakugawa Formation
Sakotan -dake F.
Ft.
Legend
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
200m
0

intercalated acidic tuff beds. Calcite veins (<15 cm in thickness) and their concentrations are common, especially in the lower part of the formation.

Fossils: This formation contains 15 ammonoid species and 10 inoceramid species (Fig. 14). Its lower part rarely yields megafossils; although the abundance and diversity of the species is low in this lower part, *Gabbioceras mikasaense* Shigeta, *Cunningtoniceras takahashii* (Matsumoto) and other species are present. Species diversity and abundance gradually increase upsection. The middle to upper parts of this formation contain abundant megafossils, so, species diversity and fossil abundance in this formation are nearly as high as those in the higher Osoushinai Formation (Upper Yezo Group). Fossils occur both in concretions and host rocks (mudstone), though they are more abundant in concretions. *Inoceramus pennatulus* Pergament and *I. ginterensis* Pergament are the main species in host rocks, whereas *Desmoceras* (*Pseudouhligella*) *japonicum* Yabe, *D.* (*P.*) *ezoanum* Matsumoto and *Actinoceramus nipponicus* (Nagao and Matsumoto) occur abundantly in concretions.

(3) Saku Formation (Sk)

Thickness: 540–630 m.

Descriptions: The Saku Formation conformably overlies the Sakugawa Formation (Matsumoto, 1942; Okamura, 1977), and comprises conglomerates and alternating beds of turbidite sandstone and mudstone. This formation is divided into three members, namely the Chirashinai Sandstone Member (Ch), the Kyowa Mudstone Member (Kw) and the Sakubashi Alternating beds of sandstone and mudstone Member (Sb), in ascending order (Takahashi et al., 2003; Fig. 12).

Fossils: This formation yields 14 ammonoid species and six inoceramid species (Fig. 14). Concretions within the Kyowa Mudstone Member and the Sakubashi Member yield many heteromorph ammonoids, such as macro- and microconchs of *Yezoites puerculus* (Jimbo) (= *Scaphites planus* (Yabe) and *Otoscaphites puerculus* (Jimbo) in Fig. 14) (Pl. 7-3, 4) and *Nipponites bacchus* Matsumoto and Muramoto. Host rocks of other horizons often contain *Inoceramus hobetsensis* Nagao and Matsumoto (Pl. 8-7) and *I. teshioensis* Nagao and Matsumoto (Pl. 8-6), whose valves are sometimes articulated. The sandstones of the Sb member contain *Ostrea* (loc. N10002, N15001, Fig. 13). Hayakawa (1998) described a peculiar-shaped bivalve *Konbostrea konbo* Hayasaka and Hayasaka at loc. N10001 (Fig. 13). The weathered coarse-grained brown sandstones in the Sb Member along the Shimizusawa River (loc. N28303) contain abundant bivalves and echinoids, whose surfaces are worn away. Gravels in the channel-fill deposits include ammonoids and inoceramids, some of which are characteristic of the Upper Cenomanian stage (Takahashi and Mitsugi, 2002) and are therefore regarded as reworked concretions.

(3)-a. Chirashinai Sandstone Member (Ch)

Thickness: Approximately 190 m.

Descriptions: The boundary between this member and the underlying Sakugawa Formation is not exposed in the study area, but Matsumoto (1942) and Okamura (1977) documented that this member conformably overlies the Sakugawa Formation. This member consists mainly of alternating beds of turbidite sandstone and mudstone. The sandstone beds are turbiditic, with Tb-e, Ta, c-e divisions. Slump structures have developed in the strata exposed along the Shibunnai River. Thick sandstone and conglomerate beds occur at 100–120 m above the base of this member. These beds underlie coarsening-upward mudstone, which is covered by thick sandstones and conglomerates. The upper part of this member is an intercalation of intraformational clast-supported conglomerates with a thickness of 10–40 cm. Gravels are mainly composed of clastic rocks, such as mudstone, that have a maximum diameter in 7–8 cm. The uppermost part of this member consists of alternating beds of sandstone and mudstone. Sandstones sometimes include dense prismatic inoceramid shell fragments, and often contain glauconite and coaly fragments. The grain size fines southward, along the Shibunnai River.

(3)-b. Kyowa Mudstone Member (Kw)

Thickness: Approximately 190 m.

Descriptions: This member is continuously exposed along the Shibunnai River and consists of mudstones or mudstone-dominant turbidites. Along the Shibunnai River, the lower and middle parts mainly consist of weakly laminated siltstones, whereas the

← **Fig. 11.** Columnar sections of the Cretaceous deposits in the Teshionakagawa area (after Takahashi et al., 2003; reproduction permitted by the Geological Society of Japan). Identification numbers for localities, at which molluscan species were collected, are shown. Refer to Fig. 13 for locality numbers. The prefix N for each locality number is omitted. 1: Wakkawenbetsu River, 2,3: Shibunnai River, 4a: Osoushinai River, 4b: Osoushinai Forestry Road, 5,6,9,11,12: Abeshinai River, 7: Miginosawa River, 8: Shimaroppu River, 10a,16a: Chirashinai River, 10b,16b: Chirashinai Forestry Road, 13: Shimasankenai River, 14a: Tannosawa Creek, 14b: Tannosawa Forestry Road, 15: Neowennai River, 17,19: Teshio River, 18: Tenmaku River, 20: Rubeshibe River. Legend A: bioturbation, B: laminae, C: mudstone, D: tuff, E: sandy mudstone, F: mudstone with thin sandstone beds, G: muddy sandstone, H: alternating beds of sandstone and mudstone (mdst>sst), I: alternating beds of sandstone and mudstone (mdst=sst), J: alternating beds of sandstone and mudstone (mdst<sst), K: sandstone, L: conglomerate, M: slump, N: uncomformity, O: fault

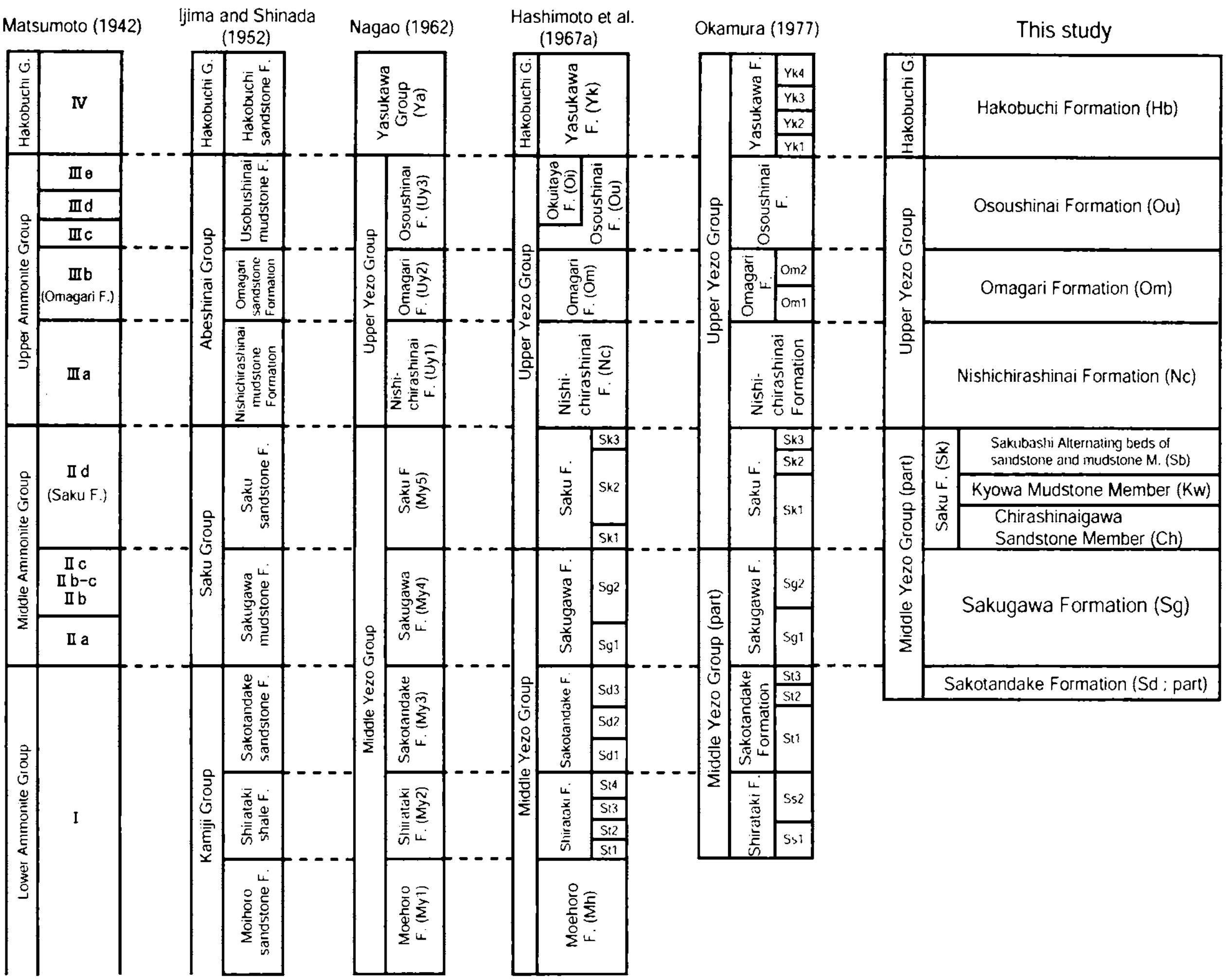


Fig. 12. Comparison of lithostratigraphic divisions proposed by previous researchers in the Teshionakagawa area (after Takahashi et al., 2003; reproduction permitted by the Geological Society of Japan).

upper part exhibits thickening-upward, alternating beds of turbidite sandstone and mudstone (mudstone-dominant). Sandstones predominantly display parallel lamination, cross-lamination, and convolution. The grain size of this member northward along the Chirashianai River is greater than that at the type section (the Shibunnai River section). Along the Chirashinai River, this member consists of mudstone with thin sandstone beds or mudstone-dominant alternating beds.

(3)-c. Sakubashi Alternating beds of sandstone and mudstone Member (Sb)

Thickness: 190–280 m.

Descriptions: The lower part is composed of medium- to coarse-grained sandstones with rip-up mudstone clasts, and partly contains intercalations of conglomerate (about 5 m in thickness) and alternating beds of sandy siltstone and fine-grained sandstone. Conglomerates are mainly matrix-supported and contain angular or subangular gravel. Channel-levee complexes and channels filled by conglomerates and sandstones are observed along the Shibunnai Forestry Road (loc. N28203; Fig. 13). The channel-levee complexes have a width ranging from a few meters up to about 20 m, and the depth varies from a few meters to about 10 m. They are covered by sandstone-dominant alternating beds of sandstone and mudstone. Cross-lamination and climbing-ripples are clearly developed in the sandstones.

The middle to upper part of this member comprises alternating beds of turbidite sandstone and mudstone that exhibit slump structures. Parallel-lamination is common in the mudstones, whereas parallel- and cross-laminations are common in the sandstones. *Thalassinoides* isp., which displays ramifications, is sometimes present on the base of the sandstones. At a locality (N28303; Fig. 13) along the lower reaches of the Shimizusawa River, this member contains medium- to coarse-grained sandstones, which are weathered brown and yield bivalves and echinoids.

2. Upper Yezo Group

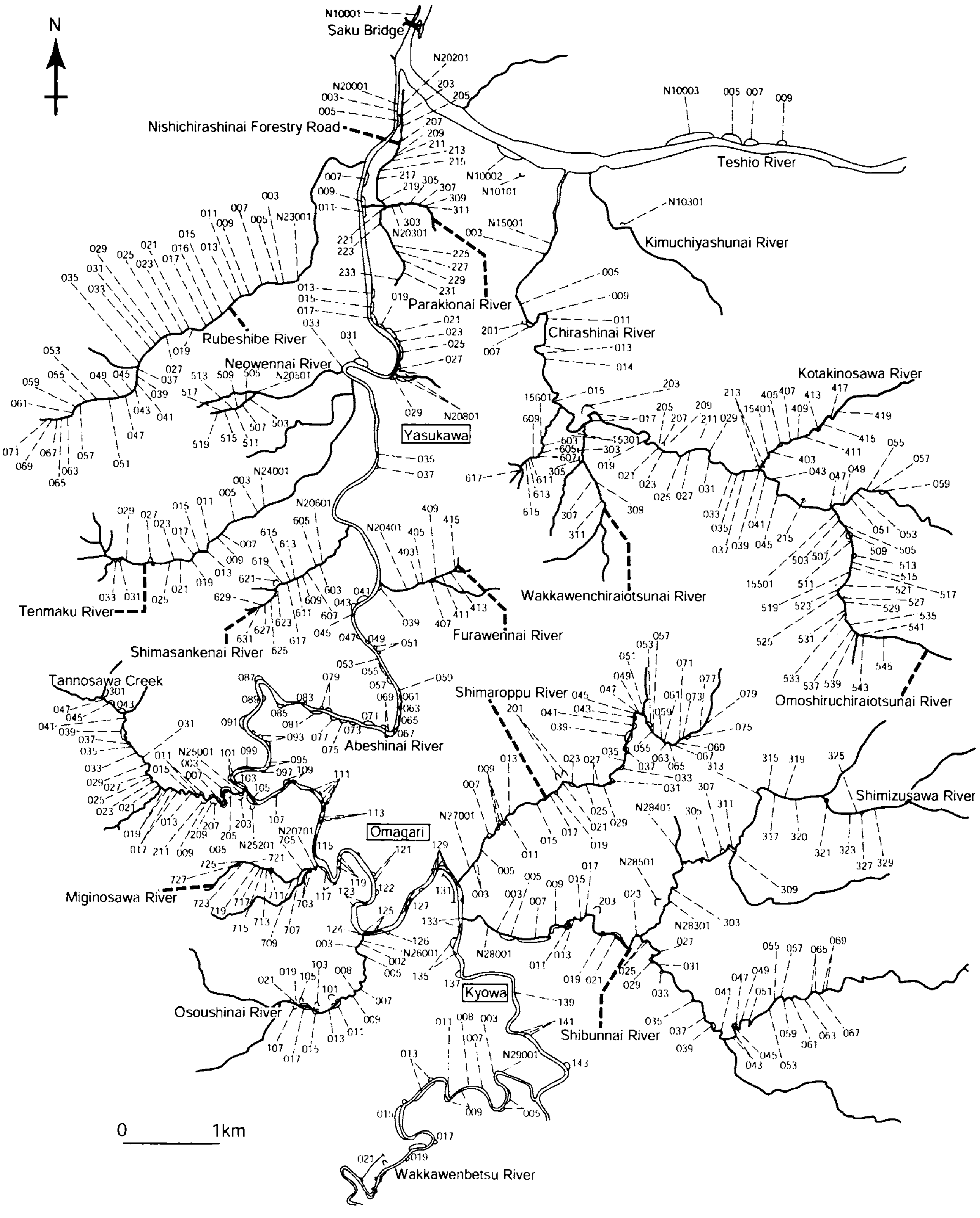


Fig. 13. Locality guide of the Teshionakagawa area (modified from Takahashi et al., 2003; reproduction permitted by the Geological Society of Japan).

Matsumoto (1942) divided the Upper Yezo Group into five formations, IIIa to IIIe, in ascending order (Fig. 12). Afterward, Ijima and Shinada (1952) assigned formations IIIc, IIId and IIIe to the Usobushinai Mudstone Formation, and divided the group (Abeshinai Group; Fig. 12) into the Nishichirashinai Mudstone Formation, Omagari Sandstone Formation, and Usobushinai Mudstone Formation, in ascending order. Takahashi (1959) changed the name of the Usobushinai Mudstone Formation to the "Osoushinai Formation." After Ijima and Shinada (1952), most workers accepted this three-formation division with only minor changes.

This group conformably overlies the Middle Yezo Group. The boundary between the Middle and the Upper Yezo groups is exposed along a branch of the Chirashinai River (loc. N15617; Fig. 13).

(1) Nishichirashinai Formation (Nc)

Thickness: More than 470 m.

Descriptions: This formation is composed mainly of gray siltstones or sandy siltstones, which are either well-bioturbated (mixed silt grains and very fine sand grains) or preserving laminations. These fine-grained beds are hardly intercalated with well-bedded, light gray to gray, fine- to coarse-grained sandstones that have an average thickness of 5 cm and a maximum thickness of 15 cm. Those sandstones are sometimes tuffaceous. White to gray-white acidic tuff beds, a few centimeters to 40 cm thick, are common in the lower to middle parts of this formation. A slump structure is present in the upper part of this formation along the Wakkawenbetsu River (loc. N29005; Fig. 13). Huge concretions, more than 1 m in maximum diameter, are abundant, which contain many fossils in the lowest horizons (locs. 20027, 20029, 20801; Fig. 13).

Fossils: The above-mentioned horizons (locs. 20027, 20029, 20801; Fig. 13) yield dense accumulations of *Inoceramus uwajimensis* Yehara, but otherwise this formation yields only a few low-diversity megafossils. Most shells of *I. uwajimensis* occur in concretions, whereas other fossils are found in both concretions and host rocks (mudstone), although fossils are more abundant in concretions than in the host rocks. Other fossils in this formation are *Gaudryceras denseplicatum* (Jimbo) and *Sphenoceramus naumanni* (Yokoyama) (Fig. 14; Pl. 9-1, 2).

(2) Omagari Formation (Om)

Thickness: 550–810 m.

Descriptions: This formation conformably overlies the Nishichirashinai Formation, as seen at the confluence of the Abeshinai and Shimaroppu rivers (loc. N20131; Fig. 13). This formation comprises channel-levee complexes, which consist of sandstones of turbidity- and debris-flow origin, and contain intercalations of thick conglomerates and thick, debris-flow-origin mudstones or thin, pelagic mudstones. Slump structures are abundant in the lower part of this formation. Sandstones derived from turbidity flows commonly exhibit the Ta, Tb, Tc, Ta-b, Tb-c, and Tb-d divisions of a Bouma sequence. Rip-up mudstone clasts are hardly present in the basal part of the sandstones, but are mainly seen in their middle part. The grain size of the levee or interchannel sandstones is relatively coarse (medium to coarse), although the beds are thin (about 5 cm in thickness). The sandstones often contain red grains of mafic volcanic origin. This formation includes intercalations of mudstones 5–10 m thick that contain rounded gravel up to 7 cm in maximum diameter. Amalgamated medium- to coarse-grained, thick (3-13 m), gray sandstones are common in the middle to upper parts of the formation. These sandstones include rounded intraformational conglomerates and lenses of mudstones, 5 to 15 cm thick. Gravels in intraformational conglomerates, a few 10 cm in maximum diameter, consist of mudstone, sandstone, andesite, and basalt. The basal parts of the sandstones sometimes include abundant plant remains, about 5 cm in maximum length, and a few *Thalassinoides* isp.

Fossils: This formation yields six ammonoid species and two inoceramid species (Fig. 14). Disarticulated bivalves (except inoceramids) are abundant, and ammonoids and inoceramids are relatively rare. Fossils are mainly found in host rocks, and are rare in calcareous concretions that are abundantly present in this formation. Thick sandstones often contain ostreids (e.g., *Konbostrea*) (locs. N10001, N20087, N20109, N29011; Fig. 13). Channel-fill conglomerate and sandstone with abundant extant shallow-marine mollusks, including *Acila*, *Glycymeris*, *Yaadia*, and *Tibia*, are in the upper part of this formation along the Rubeshibe River (loc. N23031; Fig. 13). In addition, disarticulated *Sphenoceramus naumanni* (Pl. 9-1, 2) are sometimes scattered on the basal facies of sandstones within alternating beds of sandstone and mudstone. On rare occasion, the turbidites include dense shell fragments with outlines like thin convex lenses. Other fossils in this formation are *Gaudryceras tenuiliratum* Yabe (Pl. 1-5) and *Inoceramus (Platyceramus) japonicus* (Nagao and Matsumoto).

(3) Osoushinai Formation (Ou)

Thickness: Approximately 600 m.

Descriptions: This formation conformably overlies the Omagari Formation. The contact can be observed near the Omagari area along the Abeshinai River (locs. N20093, N20109; Fig. 13) and the Wakkawenbetsu River (loc. N20131; Fig. 13). The formation is composed mainly of gray to dark gray siltstones, sandy siltstones and muddy sandstones, which display an overall coarsening-upward trend. The siltstone in the lower particular horizon of this formation is well-laminated and can be traced laterally as marker beds. Except for this horizon, bioturbation is relatively intense, and the middle and upper parts of the formation are massive. A matrix-supported conglomerate bed is intercalated in the sandy siltstones along the Tannosawa Creek (loc. N25003; Fig. 13), but it is not present in other stratigraphic sections. Some gray to bluish gray tuff beds, a few to 130 cm thick, are intercalated in this formation and are especially abundant in the upper part. The upper part of the formation contains abundant gigantic (more than 1m in shell height) inoceramids, *Sphenoceramus schmidti* (Michael) (Pl. 9-8) and *S. sachalinensis* (Sokolow) (Pl. 9-7), sometimes as concentrations. Within these horizons, gigantic limpet *Gigantocaplus giganteus* (Schmidt) (Pl. 8-5) sometimes co-occurs with or is closely associated with the gigantic inoceramids. Fossils in this formation are well-preserved and often retain aragonitic mineralogy.

Fossils: This formation yields the most diverse and abundant fossils in the Cretaceous of the Teshionakagawa area, and 17 ammonoid species and 10 inoceramid species have been found (Fig. 14). The ammonoids *Yokoyamaoceras ishikawai* (Jimbo) (Pl. 2-1, 2), *Gaudryceras tenuiliratum* Yabe (Pl. 1-5), *Phyllopachyceras ezoense* (Yokoyama) (Pl. 1-2) and *Polyptychoceras* (Pl. 4-4, 5, 7) are abundant in the lower to middle parts of the formation, whereas *Canadoceras* (Pl. 2-8) and *Eupachydiscus* (Pl. 3-3) are abundant in the upper part. The inoceramid *Sphenoceramus naumanni* (Pl. 9-1, 2) is exceedingly abundant in the lower to middle parts of the formation, whereas numerous *S. schmidti* (Pl. 9-8) and *S. sachalinensis* (Pl. 9-7) are present in the upper part, as noted above. This formation also yields abundant bivalves, gastropods, nautiloid cephalopods, solitary corals, and shark teeth. Fossils occur in both concretions and host rocks, being especially abundant in the latter. They are especially abundant and diverse within the stratigraphic occurrence range of the *S. schmidti – S. sachalinensis* interval (Fig. 14).

3. Hakobuchi Group

Takahashi (1959) thought that in the Teshionakagawa area, the Hakobuchi Group disconformably overlies the Upper Yezo Group and that it correlates with the upper part of the Hakobuchi Group in other areas. In consequence, he proposed the term "Yasukawa Group" for this group in the Teshionakagawa area. Osanai et al. (1960) and Nagao (1962) followed this usage. Hashimoto et al. (1967) did not adopt the Yasukawa Group, but concluded that the boundary between the two groups is disconformable. Takahashi et al. (2003) confirmed that the boundary between the Upper Yezo Group (Osoushinai Formation) and the Hakobuchi Group (Hakobuchi Formation) is conformable based on outcrop observations and fossil occurrences. Since this group lithologically corresponds to the "Hakobuchi Group" in other areas, we use the term Hakobuchi Group, following Matsumoto (1942) and Ijima and Shinada (1952). This group consists solely of the Hakobuchi Formation in the present study area.

(1) Hakobuchi Formation (Hb)

Thickness: This formation is 360 m in maximum thickness in the study area and is disconformably overlain by the Neogene strata.

Descriptions: The conformable boundary between this formation and the Upper Yezo Group (Osoushinai Formation) is exposed along the Tenmaku River (loc. N24027; Fig. 13). This formation is composed mainly of poorly sorted, fine- to coarse-grained sandstones and pebbly sandstones. There are intercalations of dark gray sandy siltstones and muddy sandstones, 40 m in thickness, in the interval 180–220 m above the base of this formation. Sandstones are often massive or rarely display indistinct hummocky cross-stratifications and swaley cross-stratifications. Bedded sandstones and alternating beds of sandstone and mudstone sometimes are present in the lower part of the formation. Some yellowish-gray layers of concentrated plant remains also occur. Conglomerates and pebbly sandstone layers, a few centimeters to 50 cm thick, are often intercalated in this formation, and the maximum diameter (long axis) of the clasts is about 10 cm. Most of the conglomerates are matrix-supported and consist of subangular to angular gravels made up largely of mudstone, sandstone, and chert. Longer axes of the gravels are sometimes arranged parallel to the bedding plane.

Fossils: This formation has yielded two ammonoid species (Fig. 14). Although inoceramids are not present in the area studied by Takahashi et al. (2003), this formation contains *Inoceramus* (*Endcostea*) *balticus* (Böhm) (Pl. 9-3) along the Uttsu Forestry Road and along the Uttsu River in the Embetsu area (Hayakawa et al., 1994). Calcareous concretions within muddy sandstones in the middle horizon often yield dense accumulations of *Metaplacenticeras subtilistriatum* Jimbo (Pl. 5-2, 3, 8). Bivalves occur in the same horizon.

Biostratigraphic Correlation

International correlations of the Japanese Upper Cretaceous based on ammonoids and inoceramids are difficult, because of the rarity of zone index fossils that characterize European (Tethys) biotic elements (e.g., Iba and Sano, 2007). Toshimitsu et al. (1995) compiled the occurrences of age-diagnostic species and documented the biotic zones in Japan, including those based on ammonoids, inoceramids, foraminifers, radiolarians, and calcareous nannofossils, in addition to magnetostratigraphy. Those biozones are based mainly on Matsumoto's work (e.g., Matsumoto, 1959, 1977).

Matsumoto (1942, 1943) and Hashimoto et al. (1967) comprehensively compiled megafossil occurrences in the Teshionakagawa area. However, these authors described only approximate stratigraphic distributions for those fossils, but did not document their detailed horizons. Takahashi et al. (2003) presented the detailed stratigraphic distribution of ammonoids and inoceramids and discussed biostratigraphic correlations based upon them (Fig. 14). The present study follows the international correlations used by Takahashi et al. (2003), which are based mainly on the definitions of Toshimitsu et al. (1995) by using ammonoids and inoceramids.

1. Cenomanian Stage

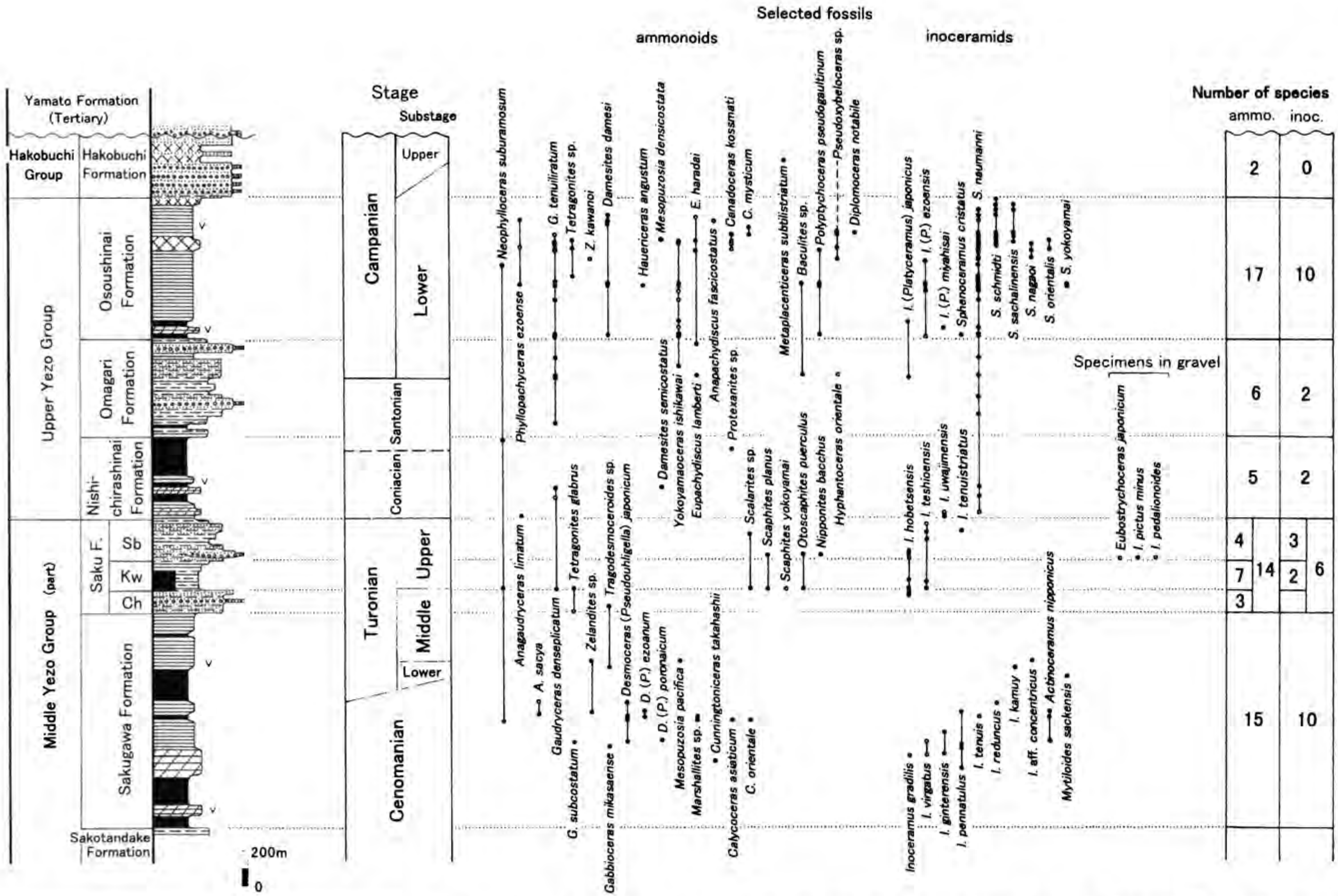


Fig. 14. Generalized geological columnar section and stratigraphic distribution of ammonoids and inoceramid bivalves in the Teshionakagawa area (after Takahashi et al., 2003; reproduction permitted by the Geological Society of Japan). For legends see Fig. 11. *Neophylloceras* = *Hypophylloceras* (*Neophylloceras*), *Calycoceras* = *Calycoceras* (*Newboldiceras*), *Mesopuzosia* = *Puzosia* (*Mesopuzosia*), *Scaphites planus* = macroconch of *Yezoites puerculus*, *Otoscaphites puerculus* = microconch of *Yezoites puerculus*, *Eubostrychoceras* = *Nostoceras* (*Eubostrychoceras*). Solid circles: identified specimens. Open circles: specimens compared to these species.

The Cenomanian in Hokkaido was divided into eight ammonoid biozones by Matsumoto et al. (1991a), and into nine biozones by Matsumoto et al. (1991b). Matsumoto and Noda (1986), Matsumoto et al. (1987, 1988), Matsumoto and Tanaka (1988), Matsumoto (1989), and Matsumoto and Asai (1989) described Cenomanian inoceramids and detailed their stratigraphic occurrences. Toshimitsu et al. (1995) divided the Cenomanian into six inoceramid biozones.

Among the useful species proposed by Matsumoto (1991a, b) and Toshimitsu et al. (1995) for international correlations, Takahashi et al. (2003) reported the occurrence of the ammonoids *Cunningtoniceras takahashii* (Matsumoto), *Calycoceras* (*Newboldiceras*) *asiaticum* (Jimbo), and *Calycoceras* (*Newboldiceras*) *orientale* Matsumoto, Fukuda and Saito (Fig. 14). *Cunningtoniceras takahashii* occurs in the lower part of the Sakugawa Formation (400 m above its base), and is characteristic of the lower Middle Cenomanian. A large outcrop (loc. N20067; Fig. 13) along the Abeshinai River with *Calycoceras* (*Newboldiceras*) *asiaticum* and *C.* (*N.*) *orientale* is assigned in age to the upper Middle Cenomanian.

Gaudryceras subcostatum Matsumoto, *Desmoceras* spp., *Inoceramus pennatulus* Pergament, *I.* cf. *tenuis* Mantell, *I. reduncus* Pergament, and *Actinoceramus nipponicus* (Nagao and Matsumoto), all occur in the strata above those horizons. *A. nipponicus* basically characterizes the Upper Cenomanian (Matsumoto and Asai, 1989; Toshimitsu et al., 1995).

2. Cenomanian/Turonian boundary

The Cenomanian/Turonian boundary (C/T boundary) is a major focus of attention for interdisciplinary researchers in earth sciences and allied fields, because Oceanic Anoxic Event 2 prevailed worldwide from the latest Cenomanian to the C/T boundary.

A detailed stratigraphic position for the C/T boundary in the Teshionakagawa area has not been identified by past researchers. Matsumoto (1942), Matsumoto and Okada (1973) and Okamura (1977) reported the occurrence of diagnostic Cenomanian fossils in the middle part of the Sakugawa Formation, and reported diagnostic Turonian species such as *Mytiloides labiatus* (Schlotheim) in the upper part of the same formation. These studies imply that the stratigraphic position of the C/T boundary in the Teshionakagawa area is in the middle to upper part of the Sakugawa Formation, but this has not been confirmed by detailed stratigraphic studies, as noted above.

Takahashi et al. (2003) collected *Anagaudryceras* cf. *sacya* (Forbes) from an outcrop (loc. N15039; Figs. 13, 15) along the Chirashinai River, and *Desmoceras* (*Pseudouhligella*) *japonicum* Yabe from loc. N15213 (Figs. 13, 15) along the Chirashinai Forestry Road. The stratigraphic horizons for both outcrops are nearly the same, within the middle part of the Sakugawa Formation (Figs. 14, 15). *A. sacya* is an index species for the Albian and Cenomanian, whereas *D.* (*P.*) *japonicum* is a Cenomanian index species (Matsumoto, 1995; Toshimitsu et al., 1995; Toshimitsu and Hirano, 2000).

Mytiloides sackensis Elder occurs at loc. N15037 (365 m below the base of the Saku Formation; Figs. 13, 15) along the Chirashinai River, whereas *Inoceramus kamuy* Matsumoto and Asai occurs at loc. N15035 (Figs. 13, 15). Although *M. sackensis* (identical to *M. hattini* of Kennedy et al., 2005) appeared in the uppermost Cenomanian at the GSSP (global boundary stratotype section and point) at the top of the bed 84 in Pueblo, Colorado, USA (Kennedy et al., 2005), most individuals of that species occur abundantly in the lowest Turonian (Elder, 1991). Therefore, we consider that *M. sackensis* approximately characterizes the lowest Turonian. In addition, *I. kamuy* is an important index species for the Lower Turonian (Toshimitsu et al., 1995; Matsumoto and Asai, 1996, Takahashi, 2005a, b). Therefore, it is possible that the outcrops in question (locs. N15035 and 15037; Figs. 13, 15) along the Chirashinai River correlate with the Lower Turonian.

In summarry, the C/T boundary is located between locs. N15037 and N15039 along the Chirashinai River (Figs. 13, 15). In other words, the C/T boundary lies approximately 365–500 m below the boundary between the Sakugawa and Saku formations (Fig. 15).

3. Turonian Stage

Matsumoto and Okada (1973) and Okamura (1977) reported the diagnostic Turonian species *Mytiloides labiatus* and *Fagesia* cf. *rudra* (Stoliczka) in the upper part of the Sakugawa Formation. Matsumoto (1942) also reported *Fagesia thevestensis* (Peron), a Turonian index species, in Ⅱc (= the upper part of the Sakugawa Formation). In addition, Hashimoto et al. (1967) and Okamura (1977) collected *Inoceramus hobetsensis* (Pl. 8-7), which characterizes the Middle Turonian (e.g., Toshimitsu et al., 1995), in the lower part of the Saku Formation. Based on these occurrences, the Lower/Middle Turonian boundary is located in the upper part of the Sakugawa Formation or near the Sakugawa/Saku Formation boundary.

Takahashi et al. (2003) investigated the position of the Lower/Middle Turonian boundary along the Chirashinai River. As mentioned above, the diagnostic Lower Turonian species *I. kamuy* occurs at loc. N15035, whereas *Mesopuzosia pacifica* Matsumoto (=*Puzosia* (*Mesopuzosia*) *pacifica* (Matsumoto)) occurs at loc. N15033, which is 35–40 m above loc. N15035 (Fig. 15). *M. pacifica* is indicative of the Middle Turonian according to Toshimitsu et al. (1995). However, biozones of Toshimitsu et al. (1995) are not "taxon-range zones," so the occurrence of *M. pacifica* does not always signify the Middle Turonian. In fact, *M. pacifica* is known to range from the uppermost Cenomanian to Upper Turonian in Japan (Toshimitsu and Hirano, 2000). Therefore, the *Kossmaticeras flexuosum* – *M. pacifica* zone of Toshimitsu et al. (1995) is better interpreted as an "acme zone." In other areas where the Yezo Supergroup occurs, *M. pacifica* is abundant in the

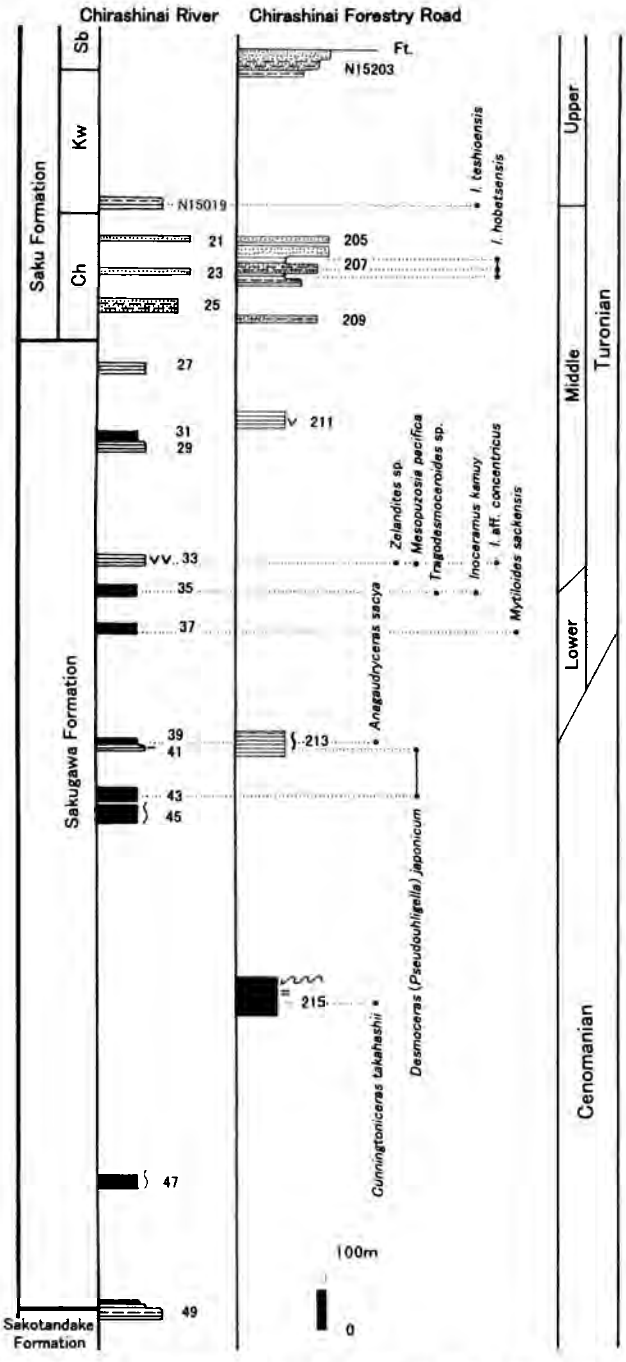


Fig. 15. Columnar sections showing the stratigraphic distributions of ammonoids and inoceramids along the Chirashinai River and Forestry Road (after Takahashi et al., 2003; reproduction permitted by the Geological Society of Japan). For legends see Fig. 11. Solid circles: identified specimens. Open circle: specimen compared to the species.

Middle to Upper Turonian (e.g., Asai and Hirano, 1990; Kawabe, 2000). Therefore, loc. N15035 lies within the Middle Turonian (Fig. 15). Based on these data, it seems quite likely that the Lower/Middle Turonian boundary lies between locs. N15033 and N15035, so that the boundary would be situated 283–320 m below the base of the Saku Formation (Fig. 15).

Noda and Matsumoto (1998) demonstrated that *Inoceramus teshioensis* Nagao and Matsumoto (Pl. 8-6) generally characterizes the entire Upper Turonian in Japan. Therefore, the *I. teshioensis* zone of Toshimitsu et al. (1995) may be interpreted as a taxon-range zone. Takahashi et al. (2003) assigned the Middle/Upper Turonian boundary to the first appearance of *I. teshioensis*, so this boundary lies within the lowest part of the Kyowa Mudstone Member of the Saku Formation (Figs. 14, 15). Matsumoto and Okada (1973) reported the occurrence of *Collignoniceras woollgari bakeri* (Anderson) (=*Subprionocyclus bakeri* (Anderson); Harada and Tanabe, 2005), which is a diagnostic Middle to Upper Turonian species, from the member IId3, the upper part of the Saku Formation.

4. Coniacian Stage

Takahashi et al. (2003) collected *Inoceramus uwajimensis* from the lower part of the Nishichirashinai Formation. Toshimitsu et al. (1995) claimed that this species is a general indicator of the Coniacian, whereas Noda and Matsumoto (1998) showed the stratigraphic range of this species in the Lower and Middle Coniacian. Because *I.* cf. *teshioensis*, an Upper Turonian indicator, occurs in the uppermost part of the Saku Formation (about 25–30 m below the base of the Nishichirashinai Formation = Upper Yezo Group; Fig. 14), the Turonian/Coniacian boundary is placed near the Saku/Nishichirashinai Formation boundary (= Middle Yezo/ Upper Yezo Group boundary). Therefore, there is no time gap between the Middle Yezo and Upper Yezo groups, which is in agreement with lithologic observations. Even though the Coniacian stage in Japan was divided into three biozones by Toshimitsu et al. (1995, 2007), based on both ammonoids and inoceramids, zonal-marker ammonoid and inoceramid species have not yet been found in the Teshionakagawa area.

5. Santonian Stage

Inoceramus (*Platyceramus*) *undulatoplicatus* (Roemer), the Santonian boundary marker species proposed by the Subcommission on Cretaceous Stratigraphy (Lamolda and Hancock, 1996), does not occur in Japan, so presently we are unable to determine the precise location of the Coniacian/Santonian boundary (Toshimitsu et al., 2007). The Santonian stage in Japan was divided into two biozones by Toshimitsu et al. (1995, 2007), based on texanitine ammonoids. From the perspective of inoceramid biostratigraphy, the Santonian consists of a single zone (Toshimitsu et al. 1995, 2007).

Previous studies on the Cretaceous in the Teshionakagawa area did not cite diagnostic Santonian species. Takahashi et al. (2003) reported the occurrence of *Protexanites* sp. in the upper part of the Nishichirashinai Formation (Fig. 14). Most *Protexanites* species occur within the Santonian in Japan, although some species have been reported from the lower Campanian (Toshimitsu and Hirano, 2000). Therefore, it is quite likely that the Coniacian/Santonian boundary is situated in the Nishichirashinai Formation (Fig. 14).

6. Campanian Stage

Toshimitsu et al. (1995, 2007) showed that *Inoceramus (Platyceramus) japonicus* (Nagao and Matsumoto) is an index species for the lowest Campanian, and stated that its first appearance corresponds to the base of the Campanian stage. Moriya et al. (2001) demonstrated that the first appearance of *I. (P.) japonicus* is in agreement with the base of the Campanian, on the basis of a comparison between inoceramid and planktonic foraminiferal biostratigraphy in the Haboro area, Hokkaido. Takahashi et al. (2003) followed those researchers' definition of the Santonian/Campanian (S/C) stage boundary, and assigned the S/C boundary to the upper part of the Omagari Formation (Fig. 14).

Toshimitsu et al. (1995) divided the Campanian of Japan into two substages, namely the Lower and Upper Campanian. They stated that the middle Lower Campanian to upper Lower Campanian is characterized by the *Sphenoceramus schmidti – S. orientalis – I. (P.) chikoensis* zone. The Cretaceous of the Teshionakagawa area contains abundant *S. schmidti* (Pl. 9-8) and *S. orientalis* (Pl. 9-5). The first appearance of *S. orientalis* is slightly below that of *S. schmidti*, and the stratigraphic range of *S. orientalis* is much shorter than that of *S. schmidti* (Fig. 14). The stratigraphic range of *S. sachalinensis* (Pl. 9-4, 7) nearly corresponds to that of *S. schmidti* (Fig. 14).

Canadoceras (Pl. 2-8; Pl. 5-9, 10) occurs abundantly in the Campanian of the Teshionakagawa area. Toshimitsu et al. (1995) showed that *Canadoceras kossmati* Matsumoto (Pl. 2-8) characterizes the upper Lower Campanian. In the Teshionakagawa area, the first appearance of *C.* cf. *kossmati* approximately corresponds to that of *S. orientalis* and is within the lower part of the stratigraphic range of *S. schmidti* (Fig. 14). Although Toshimitsu et al. (1995) showed that the upper stratigraphic limit of *Eupachydiscus haradai* Jimbo (Pl. 3-5, 6) is the middle Lower Campanian, *E.* cf. *haradai* occurs above the upper limit of *Canadoceras* (Fig. 14).

The middle part of the Hakobuchi Formation (loc. N23063; about 200 m above the base of the formation; Figs. 13, 14) yields a hoplitid ammonite *Metaplacenticeras subtilistriatum* (Pl. 5-2, 3, 8), which characterizes the lower Upper Campanian (Matsumoto, 1977, 1982; Toshimitsu et al. 1995). Since the last appearance of *S. schmidti* (Pl. 9-8) is at the upper limit of the Osoushinai Formation, the Lower/Upper Campanian boundary is there in the lower part of the Hakobuchi Formation.

Late Cretaceous methane-seeps in the Teshionakagawa area

We will also observe a methane-seep-related carbonate body yielding chemosynthesis-based organic remains, that were recently discovered in the mudstone facies of Omagari Formation (Hikida et al., 2003).

1. Chemosynthetic ecosystem

Densely accumulated novel animals, which sometimes have no or degenerated gut and mouth, have been in limelight since the surprising discovery of the animals around hydrothermal vents in the Galápagos Rift in 1977 (Lonsdale, 1977). The animals depend upon chemosynthetic bacteria for their major food sources, such as sulfur-oxidizing bacteria, which gain energy from the oxidation of reduced compounds, such as hydrogen sulfide (see reviews by Van Dover, 2000; Campbell, 2006). Explorations during the last 30 years have shown that such chemosynthesis-based communities occur not only around hydrothermal vents but also around methane- or hydrocarbon-seeps, sunken whale carcasses, sunken drift wood and the rotting cargo of a sunken ship (Sibuet and Olu, 1998).

The fossil record of chemosynthesis-based communities goes back to the Silurian (Barbieri et al., 2004). The faunal composition of these communities changed from a brachipods-dominant community to a mollusks-dominant community during the late Mesozoic to Paleogene (Little and Vrijenhoek, 2003). Molecular analyses have also suggested that most animals in the modern chemosynthesis-based communities diverged from the "normal" fauna during late Mesozoic to Paleogene. Thus, in order to reveal the origins of this kind of "modern-type chemosynthetic ecosystem", it is important to study late Mesozoic chemosynthetic ecosystems.

Among the Japanese ancient methane-seep sites (see Majima et al., 2005), one of the best preserved late Mesozoic to Paleogene methane-seep sites can be found in the Late Cretaceous deposits in the Teshionakagawa area (Hikida et al., 2003). Several ancient methane-seeps have been recognized (Hikida et al., 2003). Two of them, the Yasukawa and Omagari methane-seeps, have been studied by means of paleontological, petrographical and geochemical approaches (Hikida et al., 2003; Jenkins, 2006; Jenkins et al., 2007a, b, and Amano et al., 2007).

Stop 3-2 highlighted a largest methane-seep-related carbonate body developed in the Omagari Formation in this area. The carbonate body and surrounding mudstone have numerous numbers of vestimentiferan worm tube (Fig. 16) and tiny gastropods (Fig. 17). An approximately 10 m wide and 5 m high carbonate body is isolatedly exposed in the Abeshinai River. It has been interpreted that the carbonate body was formed under influence of methane-seep activity during Campanian time (Hikida et al., 2003). This interpretation is supported by the following lines of evidence; (1) carbonate minerals growth onto the worm tubes, (2) the body has brecciated structures, (3) the carbonate has very negative carbon isotopic compositions as low as -45‰ (4) highly accumulated archaeal biomarkers, crocetane and PMI, with extremely negative carbon isotopic compositions as low as -122‰ have been exrtracted (Hikida et al., 2003; Jenkins, 2006).

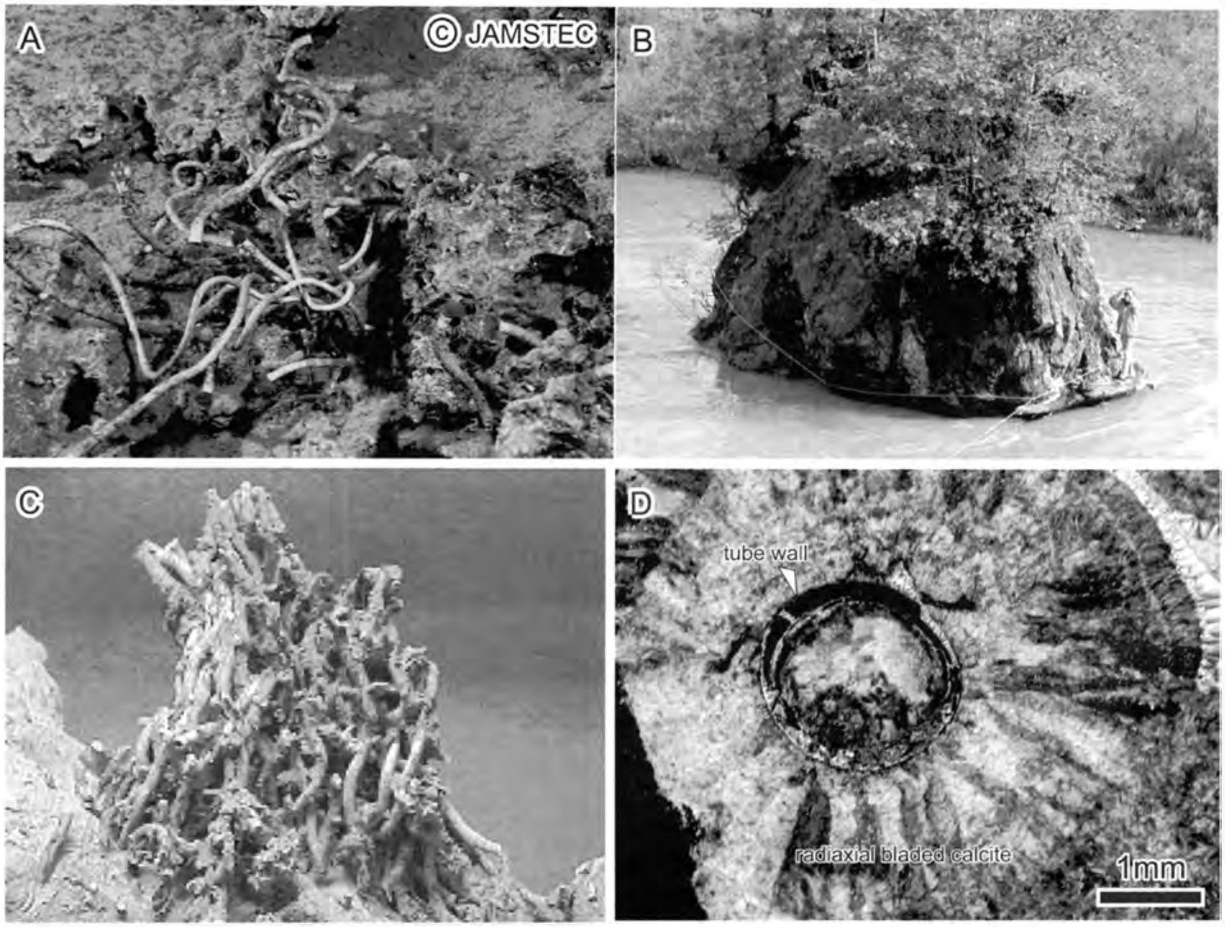


Fig. 16. Photos of Recent (A) and Late cretaceous tube worm-dominant methane-seeps (B-D). A. Photo of living vestimentiferan tube worm at a site, off Enshunada, Nankai Trough (1221 m deep) (by courtesy of the Japan Agency for Marine-Earth Science and Technology). B. Photo of the Omagari methane-seep-related carbonate body exposed in the Abeshinai River. C. Weathering surface of the carbonate. Vestimentiferan worm tube remains can be observed (after Hikida et al., 2003). D. Thin-section of the carbonate body. Radiaxial bladed calcite grew onto a worm tube.

These lines of evidence suggest that the anaerobic methane-oxidizing archaea oxidized methane under influence of methane. This process might result in an increase of alkalinity, and carbonate minerals were precipitated within the close proximity of the seafloor.

2. Fossils from the Omagari methane-seep deposit

Common macrofaunal remains recovered from the Omagari methane-seep deposit are shown in Fig. 17 (Hikida et al., 2003; our unpublished data). The most abundant fossil found at this locality is the probable vestimentiferan worm tube. Subordinate fossils are large (~10 cm in size) bivalves such as *Miltha* sp., *Nipponothrasia* cf. *pombetsensis* and *Thyasira* sp., and less than 1 cm-sized gastropods. Recent relatives of ?vestimentiferans, *Thyasira* sp., *Acharax cretacea*, *Serradonta* cf. *vestimentifelicola*, *Bathyacmaea* cf. *subnipponica*, and *Provanna* sp. are well known from the vents and seeps as members of chemosynthetic communities (see Tunnicliffe, 1991; Sibuet and Olu, 1998). *Miltha* (Lucinidae) is unknown in Recent methane-seeps, but lucinid bivalves usually housed chemosynbiotic bacteria (Taylor and Glover, 2006). *Miltha* has been commonly found in Japanese Mesozoic and Cenozoic methane-seep deposits (Majima et al., 2005). Recent counterparts of *Nuculana* and *Acila* are not chemosymbiotic, but have sometimes been found in reduced environments (Reid, 1990). These two genera have been found throughout the Omagari Formation (Takahashi et al., 2003), accordingly they are regarded to be a generalist in the Late Cretaceous deep-water settings.

3. Omagari chemosynthetic paleoecosystem

Reconstruction of the Omagari methane-seep based on aforementioned features is shown in Fig. 18 (Hikida et al., 2003; Ando et al., 2006). According to our interpretation, at the Omagari methane-seep site, pore fluid with methane content gushed out from the seafloor, and the anaerobic methane-oxidizing archaea oxidizized methane by means of sulfate-reducing bacteria, and

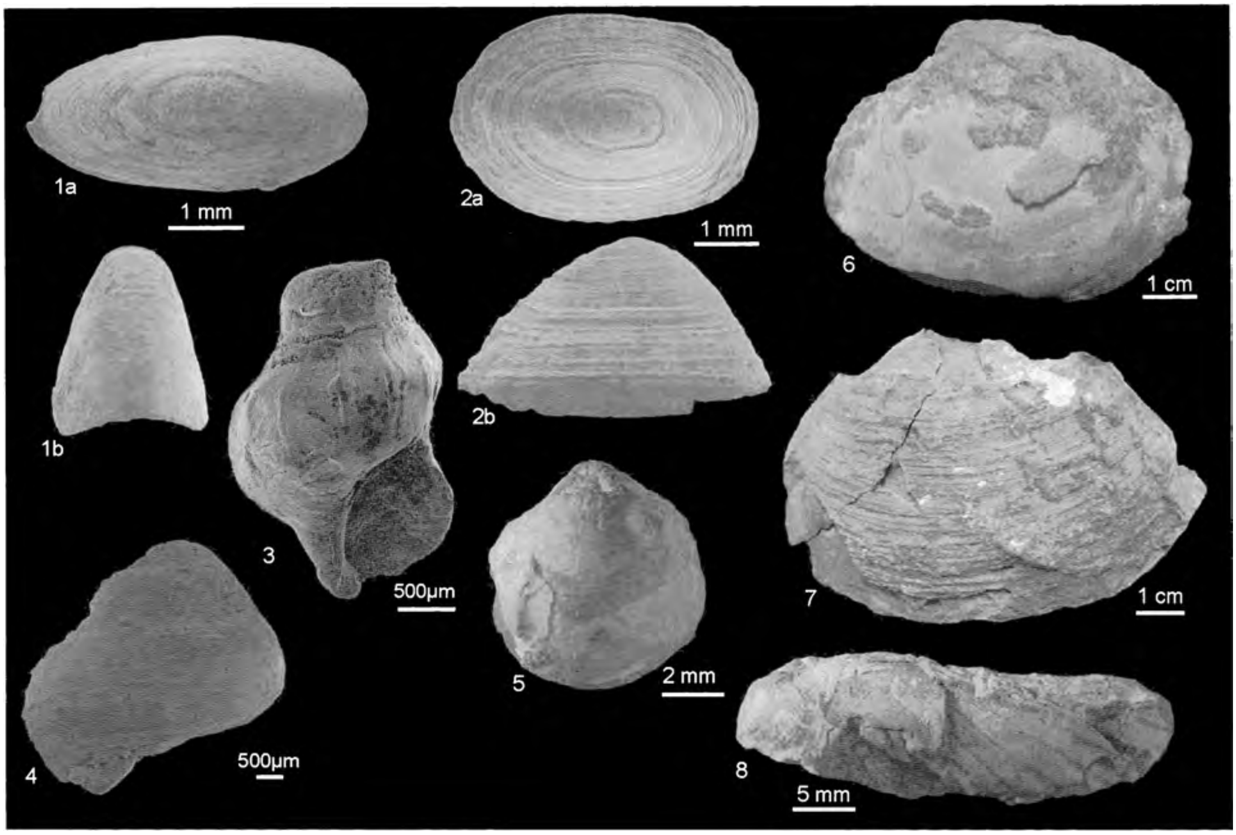


Fig. 17. Selected mollusk fossils form the Omagari and Yasukawa seeps (after Jenkins et al., 2007a, b). 1a, b. *Serradonta* cf. *vestimentifericola*. Apical (a) and anterior (b) views. 2. *Bathyacmaea* cf. *subnipponica*. Apical (a) and lateral (b) view. 3. *Provanna* sp. 4. *Homalopoma* sp. 5. *Thyasira* sp. 6-7. *Miltha* sp. 8. *Acharax cretacea*.

produced hydrogen sulfide and carbonate ions. The hydrogen sulfide was used as an energy source by free-living bacteria, and symbiotic sulfur-oxidizing bacteria were housed by vestimentiferan tube worm, lucinid, thyasirid and solemyid bivalves, and provannid gastropods. One of the acmaeid limpets, *Serradonta* cf. *vestimentifericola*, lived on vestimentiferan worm tubes and the other one, *Bathyacmaea* cf. *subnipponica*, lived on small-sized substrates and probably grazed bacterial mat flourished on the substrates (Jenkins et al., 2007a). A byproduct of the anaerobic oxidation of methane, *i.e.*, carbonate ions, aided to increase alkalinity, and the carbonate precipitated mostly in the sediment but sometimes on theworm tubes above the seafloor. Brecciations occurred syndepositionally when the methane-seep became strong.

Acknowledgements

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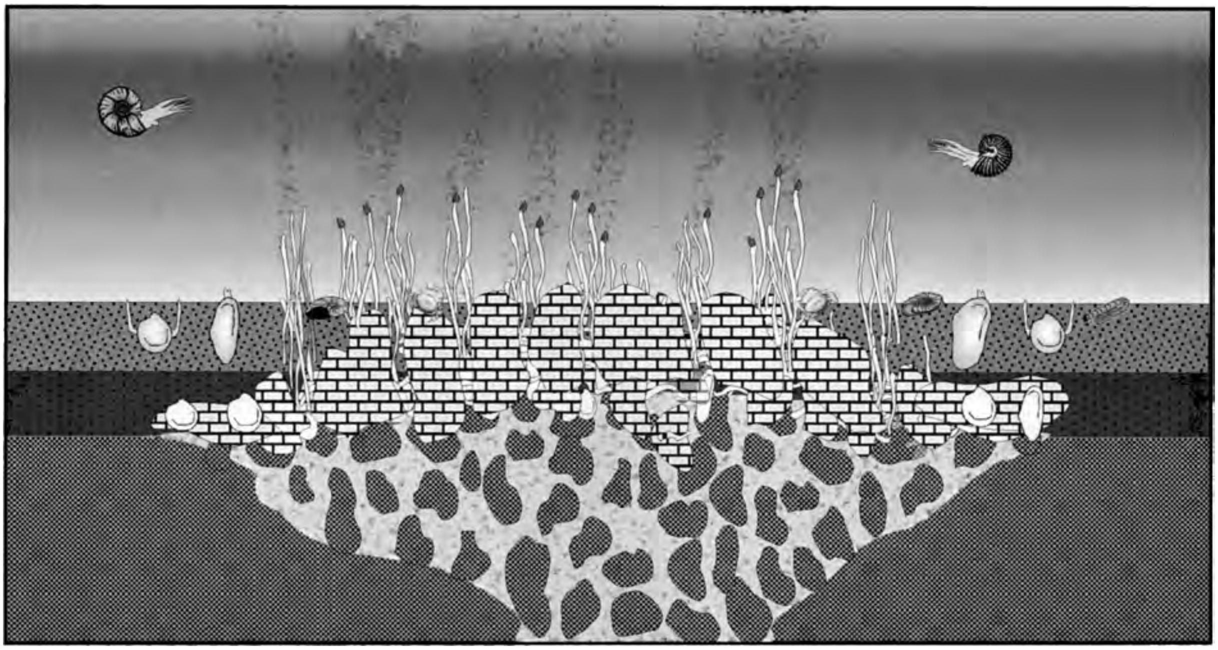

Fig. 18. Schematic illustration of the Cretaceous Omagari methane-seep (after Ando et al., 2006). Vestimentiferans lived on carbonate mound and mollusks lived upon and/or in muddy sediments around the carbonate mound.

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Explanation of Plates

Plate 1. Selected ammonoids from the Lower Campanian Osoushinai Formation in the Teshionakagawa area. All specimens are housed in the Nakagawa Museum of Natural History. Scale bars: 1 cm for 1-7; 5 cm for 8.

1: *Hypophylloceras* (*Neophylloceras*) *subramosum* Shimizu; specimen number; NMA33, 2: *Phyllopachyceras ezoense* (Yokoyama); NMA217, 3: *Tetragonites* (*Tetragonites*) *minimus* Shigeta; NMA274, 4: *Tetragonites* (*T.*) *popetensis* Yabe; NMA282, 5: *Gaudryceras* (*Gaudryceras*) *tenuiliratum* Yabe; NMA514, 6: *Gaudryceras* (*G.*) cf. *denseplicatum* (Jimbo); NMA515 (Miyazaki, A. coll.), 7: *Anagaudryceras yokoyamai* (Yabe); NMA395, 8: *G.* (*G.*) *intermedium* (Yabe); NMA37.

Plate 2. Selected ammonoids from the Lower Campanian Osoushinai Formation in the Teshionakagawa area. All specimens are housed in the Nakagawa Museum of Natural History. Scale bars: 1 cm.

1-2: *Yokoyamaoceras ishikawai* (Jimbo); specimen number; NMA37, NMA44, 3: *Damesites damesi* (Jimbo); NMA228, 4: *Damesites semicostatus* Matsumoto; NMA417, 5: *Menuites japonicus* Matsumoto; NMA517, 6: *Teshioites ryugasensis* Matsumoto; TNC56 (Nishino, T. coll.), 7: *Teshioites teshioensis* Matsumoto; NMA192 (Hayakawa, H. coll.), 8: *Canadoceras kossmati* Matsumoto; NMA414 (Iba, Y., Taki, S., & Takamatsu, D. coll.).

Plate 3. Selected nautilid and ammonoids from the Lower Campanian Osoushinai Formation in the Teshionakagawa area. All specimens are housed in the Nakagawa Museum of Natural History. Scale bars: 1 cm for 1, 2 cm for 2-3, 5 cm for 4-5, 10 cm for 6-7.

1: *Eutrephoceras kobayashii* Matsumoto; specimen number; NMA258 (Ishimura, T. coll.), 2: *Hauericeras angustum* Yabe; NMA438 (Takahashi, T. coll.), 3: *Eupachydiscus lamberti* Collignon; NMA394, 4: *Menuites fascicostatus* (Yabe); NMA502, 5: *Eupachydiscus haradai* (Jimbo); NMA256 (Takahashi, T. & Shishido, K. coll.), 6: *Eupachydiscus haradai* (Jimbo) ; NMA90 (Tsuchida, S. coll.), 7: *Eupachydiscus teshioensis* (Jimbo); NMA74.

Plate 4. Selected heteromorph ammonoids from the Lower Campanian Osoushinai Formation in the Teshionakagawa area. All specimens are housed in the Nakagawa Museum of Natural History. Scale bars: 1 cm.

1: *Jouaniceras* (*Ainoceras*) *kamuy* (Matsumoto & Kanie); specimen number; NMA222, 2: *Jouaniceras* (*Ainoceras*) *paucicostatum* (Matsumoto & Kanie); NMA71, 3: *Neocrioceras spinigerum* (Jimbo); NMA248, 4: *Polyptychoceras* (*Polyptychoceras*) *obatai* (Matsumoto); NMA269, 5: *Polyptychoceras* (*Subptychoceras*) *yubarense* (Yabe); NMA291, 6: *Baculites tanakae* Matsumoto & Obata ; NMA512, 7: *Polyptychoceras* (*Polyptychoceras*) *pseudogaultinum* (Yokoyama); NMA295 (Tsuchida, T. & Ohoni, T. coll.).

Plate 5. Selected ammonoids from the Upper Campanian Hakobuchi Formation in the Teshionakagawa area. All specimen are housed in Nakagawa Museum of Natural History. Scale bars; 1 cm.

1: *Hypophylloceras* (*Neophylloceras*) cf. *ramosum* (Meek); specimen number; TNC24 (Nishino, T. coll.), 2: *Metaplacenticeras subtilistriatum* (Jimbo); TNC15 (Nishino, T. coll.), 3: *M. subtilistriatum* (Jimbo); TNC18 (Nishino, T. coll.), 4: *Desmophyllites diphylloides* (Forbes); TNC23 (Nishino, T. coll.), 5: *Desmophyllites diphylloides* (Forbes); TNC25 (Nishino, T. coll.), 6: *Saghalinites teshioensis* Matsumoto; TNC21(Nishino, T. coll.), 7: *S. teshioensis* Matsumoto; TNC19 (Nishino, T. coll.), 8: Mode of occurrence of *M. subtilistriatum* ; NMA407, 9: *Canadoceras multicostatum* Matsumoto; TNC30 (Nishino, T. coll.), 10: *C. multicostatum* Matsumoto; NMA201 (Abe, K. coll.).

Plate 6. Selected ammonoids from the Upper Campanian Hakobuchi Formation in the Teshionakagawa area. All specimens are housed in Nakagawa Museum of Natural History. Scale bars: 1 cm for 1-2, 2 cm for 4-5, 5 cm for 3 & 6.

1: *Pseudoxybeloceras* (*Schlueterella*) *kawadai* (Matsumoto & Miyauchi); specimen number; NMA516, 2: *P.* (*S.*) *kawadai* (Matsumoto & Miyauchi); TNC49 (Nishino, T. coll.) 3: *P.* (*S.*) *kawadai* (Matsumoto & Miyauchi); NMA100, 4: *Menuites sanadai* Matsumoto; NMA51, 5: *Menuites fascicostatus* (Yabe); TNC48 (Nishino, T. coll.), 6: *Pachydiscus* (*Pachydiscus*) *soyaensis* Matsumoto; NMA50.

Plate 7. Selected ammonoids from the Turonian Saku Formation in the Teshionakagawa area. All specimens were collected by Nishino T., and these are housed in Nakagawa Museum of Natural History. Scale bars: 1 cm for 1-7; 5 cm for 8.

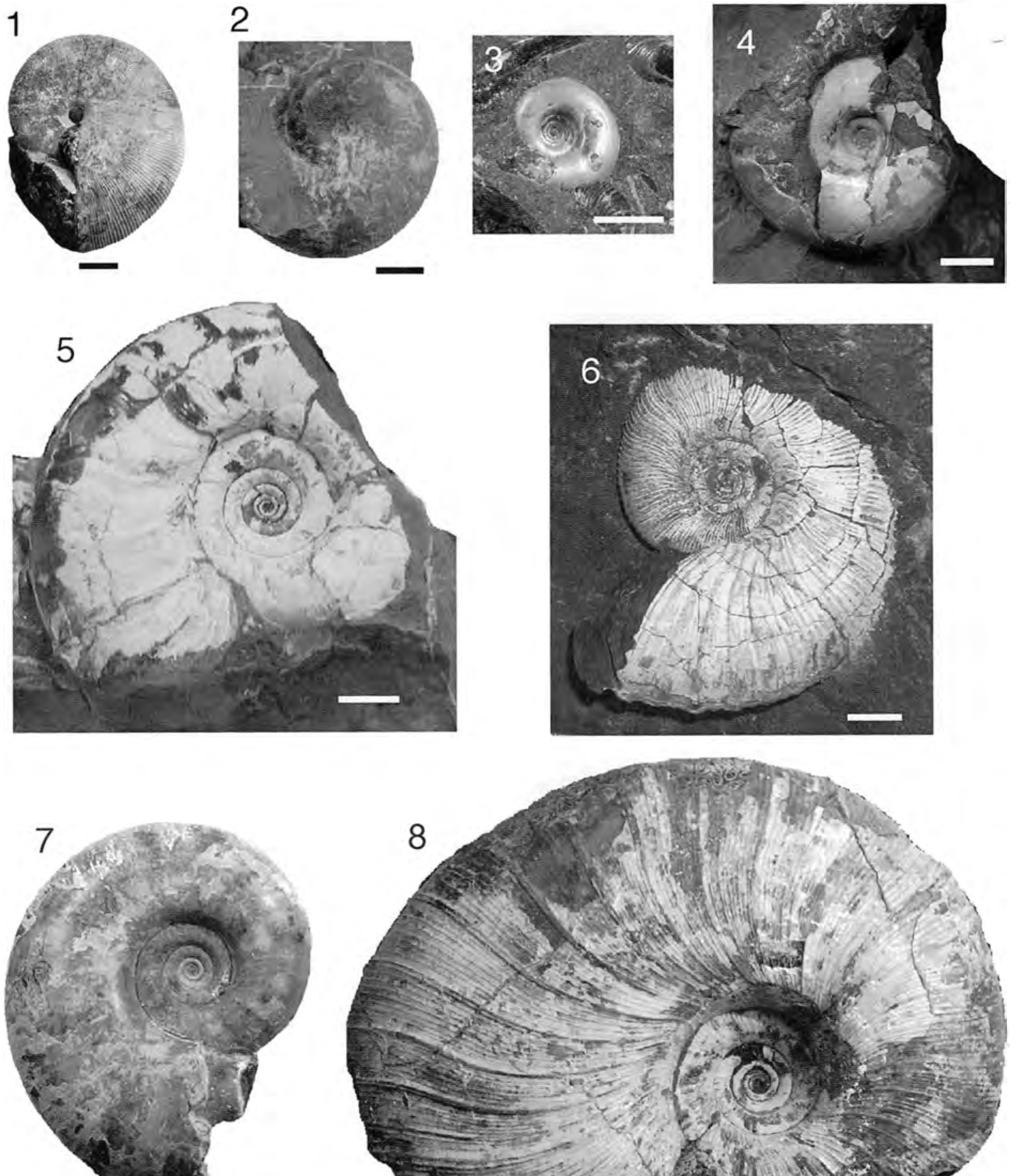
1: *Scaphites* aff. *subdelicatulus* Cobban and Gryc; specimen number; NMA244, 2: *S. yokoyamai* Jimbo; NMA245, 3: *Yezoites puerculus* (Jimbo), macroconch; NMA246, 4: *Yezoites puerculus* (Jimbo), microconch; NMA247, 5: *Nippoites mirabilis* Yabe (left) and *Puzosia* (*Mesopuzosia*) *pacifica* (Matsumoto) ; TNC12, 6: *N. mirabilis* Yabe; TNC5, 7: *N. mirabilis* Yabe; TNC6, 8: Typical

Turonian concreation with heteromorph ammpnoids; *Nostoceras* (*Eubostrychoceras*) *japonicum* (Yabe) (central) and *P.* (*M.*) *pacifica* (Matsumoto)(left), ; TNC2.

Plate 8. Selected fossils from the Lower Campanian Osoushinai Formation (1-5) and the Turonian Saku Formation (7-8) in the Teshionakagawa area. All specimens are housed in the Nakagawa Museum of Natural History. Scale bars: 1 cm for 1-4, 5 cm for 5-7.
1: *Yezoteuthis giganteus* Tanabe, Hikida & Iba; specimen number; NMA335 (Koike, T. coll.), 2: *Nanonavis sachalinensis* (Schmidt); NMM110, 3: *Pseudogaleodea tricarinata*; NMM111, 4: *Capulus transformis* Dundo; NMM75, 5: *Gigantocapulus giganteus* (Schmidt); NMM61, 6: *Inoceramus* (*Inoceramus*) *teshioensis* Nagao & Matsumoto; NMM78 (Nishino, T. coll.), 7: *I.* (*I.*) *hobetsuensis* Nagao & Matsumoto; NMM29.

Plate 9. Selected inoceramids from the Campanian deposits in the Teshionakagawa area. All specimens are housed in Nakagawa Museum of Natural history. Scale bars: 1 cm for 1-7; 3 cm for 8.
1: *Sphenoceramus naumanni* (Yokoyama); specimen number; NMM133 (same specimen as that shown in Nikkawa et al, 2000, fig. 1), 2: *Sphenoceramus naumanni* (Yokoyama) ; NMM203, 3: *Inoceramus* (*Endocostea*) *balticus balticus* Böhm; NMM114, 4: *Sphenoceramus sachalinensis* (Sokolow) ; NMM202, 5: *Sphenoceramus orientalis* (Sokolow) ; NMM103, 6: *Inoceramus* (*Platyceramus*) *ezoensis* (Yokoyama) ; NMM10, 7: *Sphenoceramus sachalinensis* (Sokolow); NMM205, 8: *Sphenoceramus schmidti* (Michael) ; NMM8.

Plate 1



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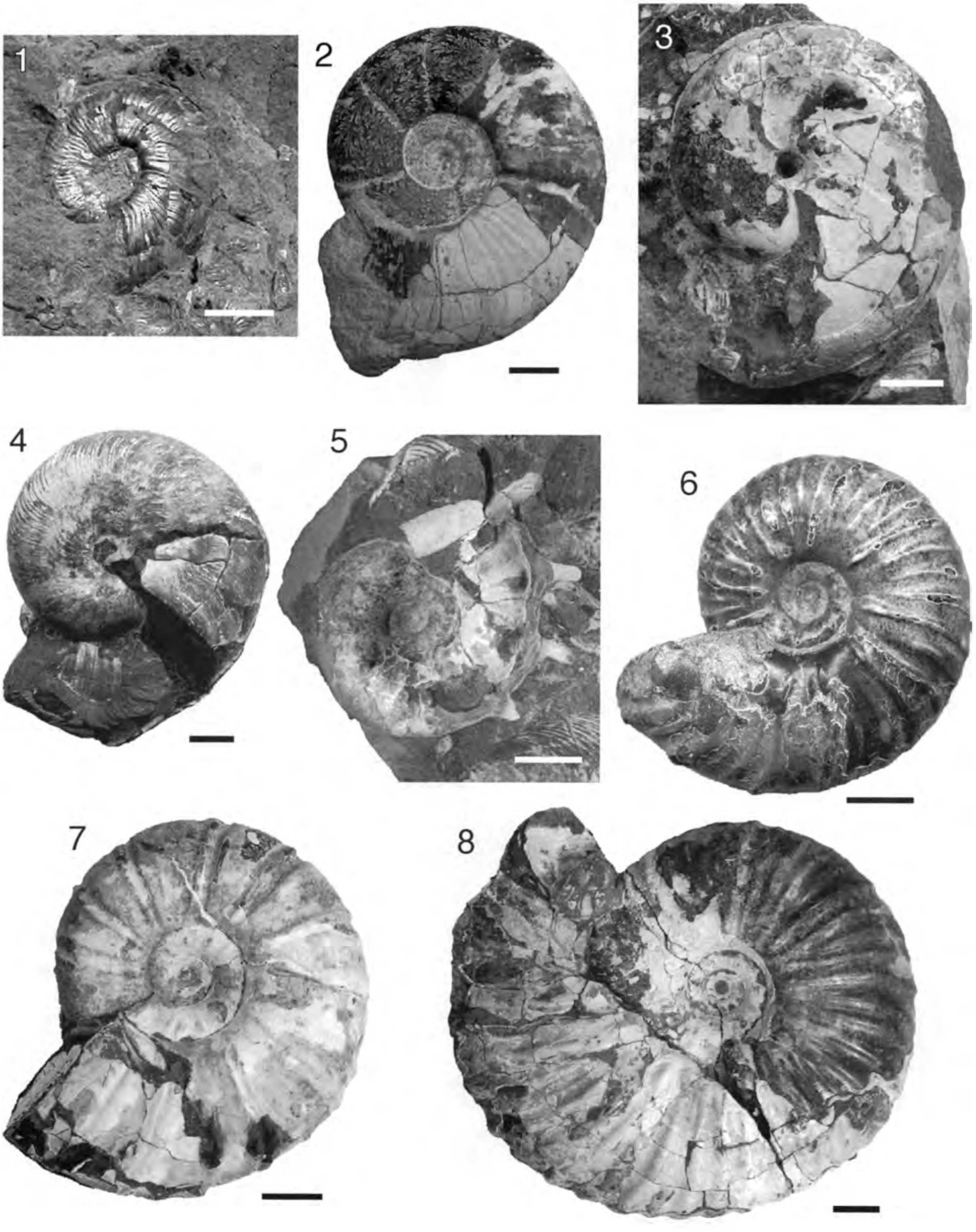

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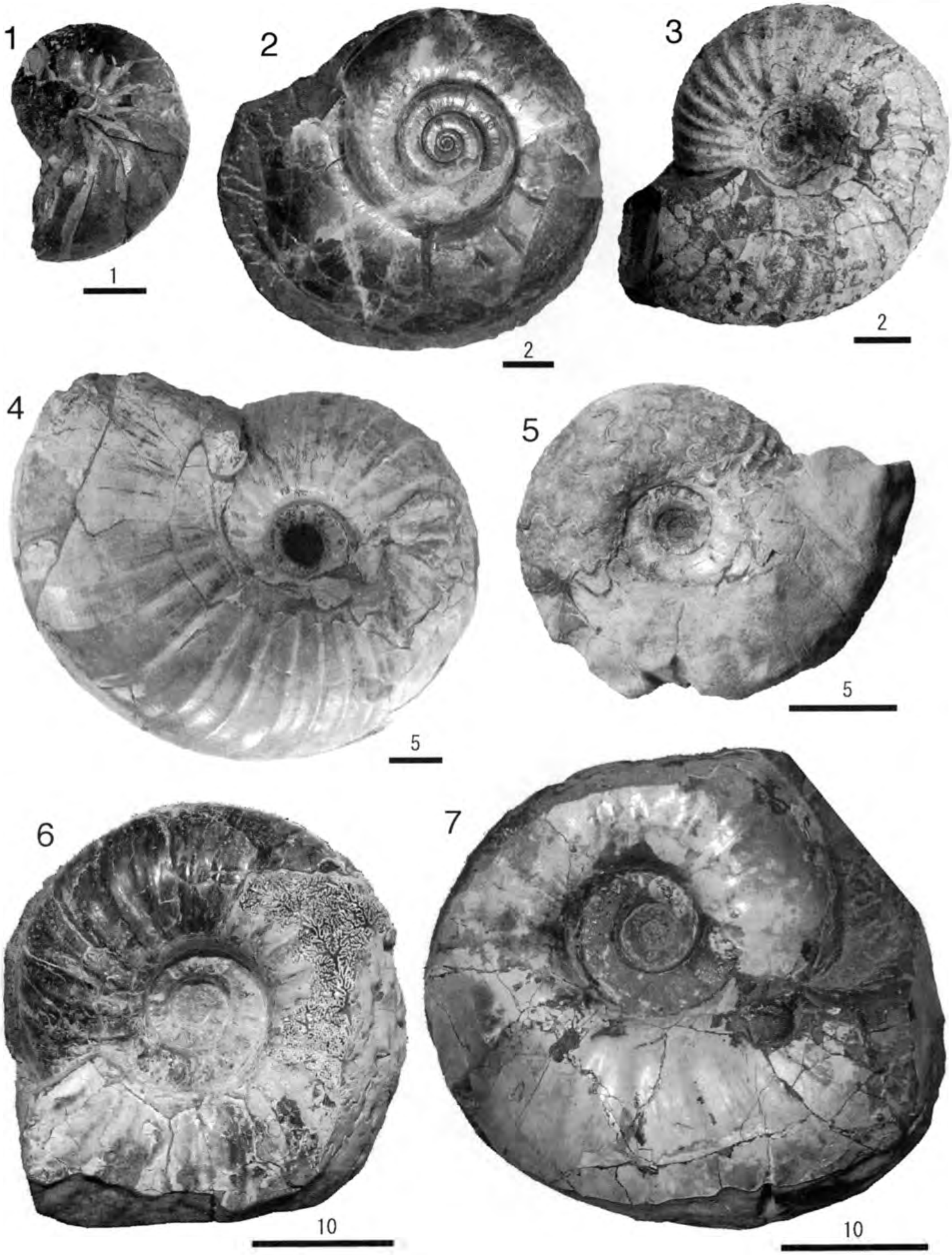

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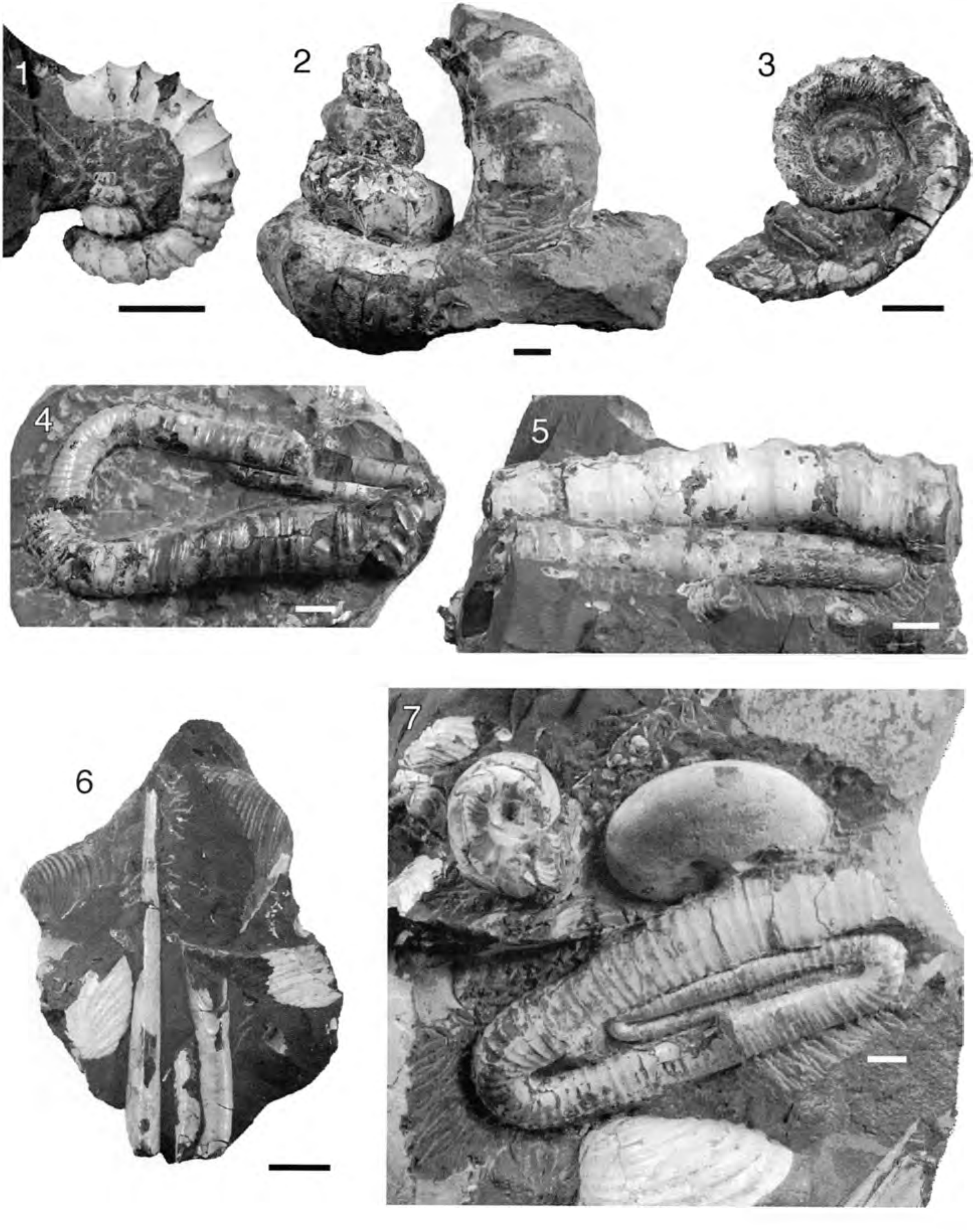

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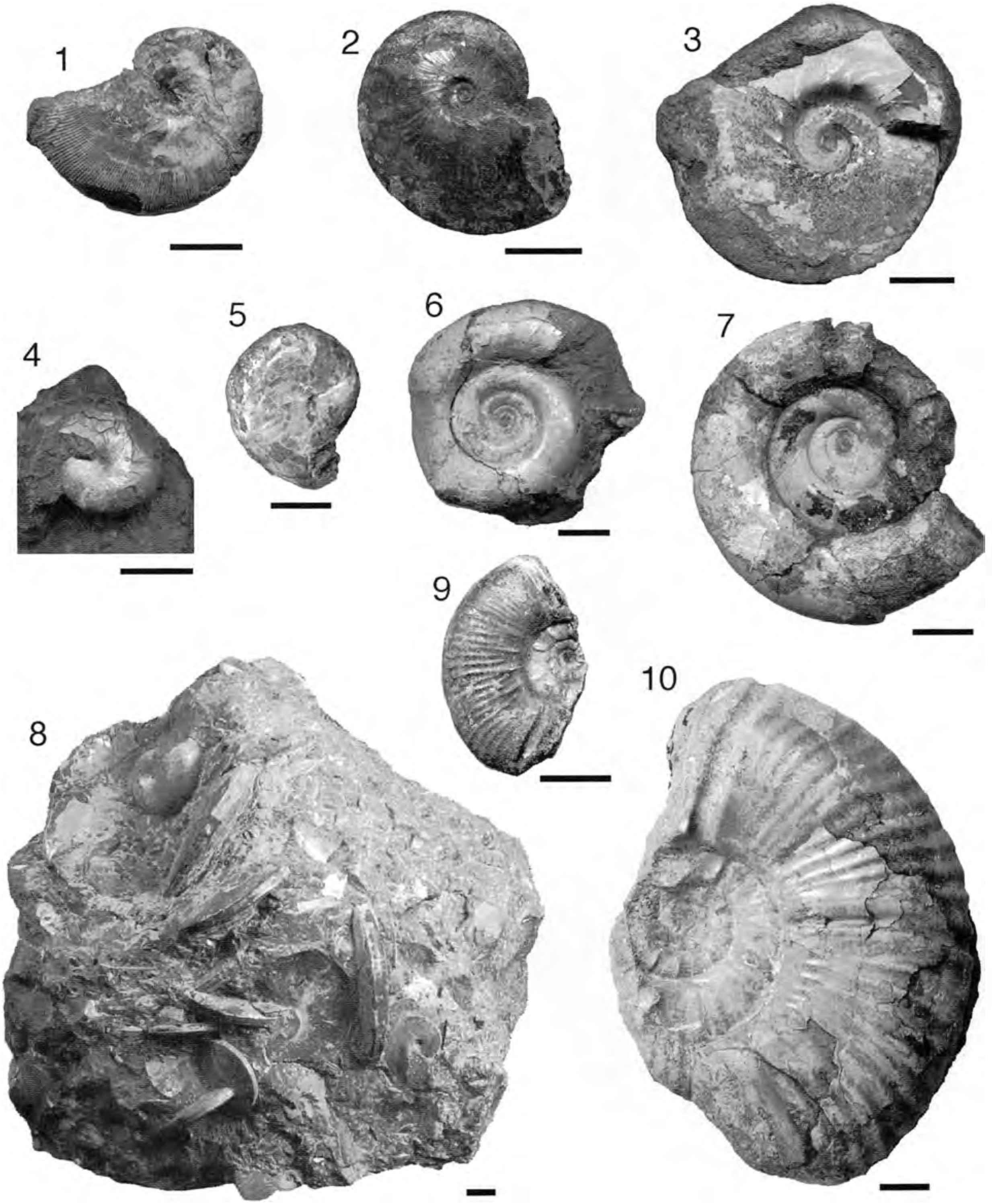

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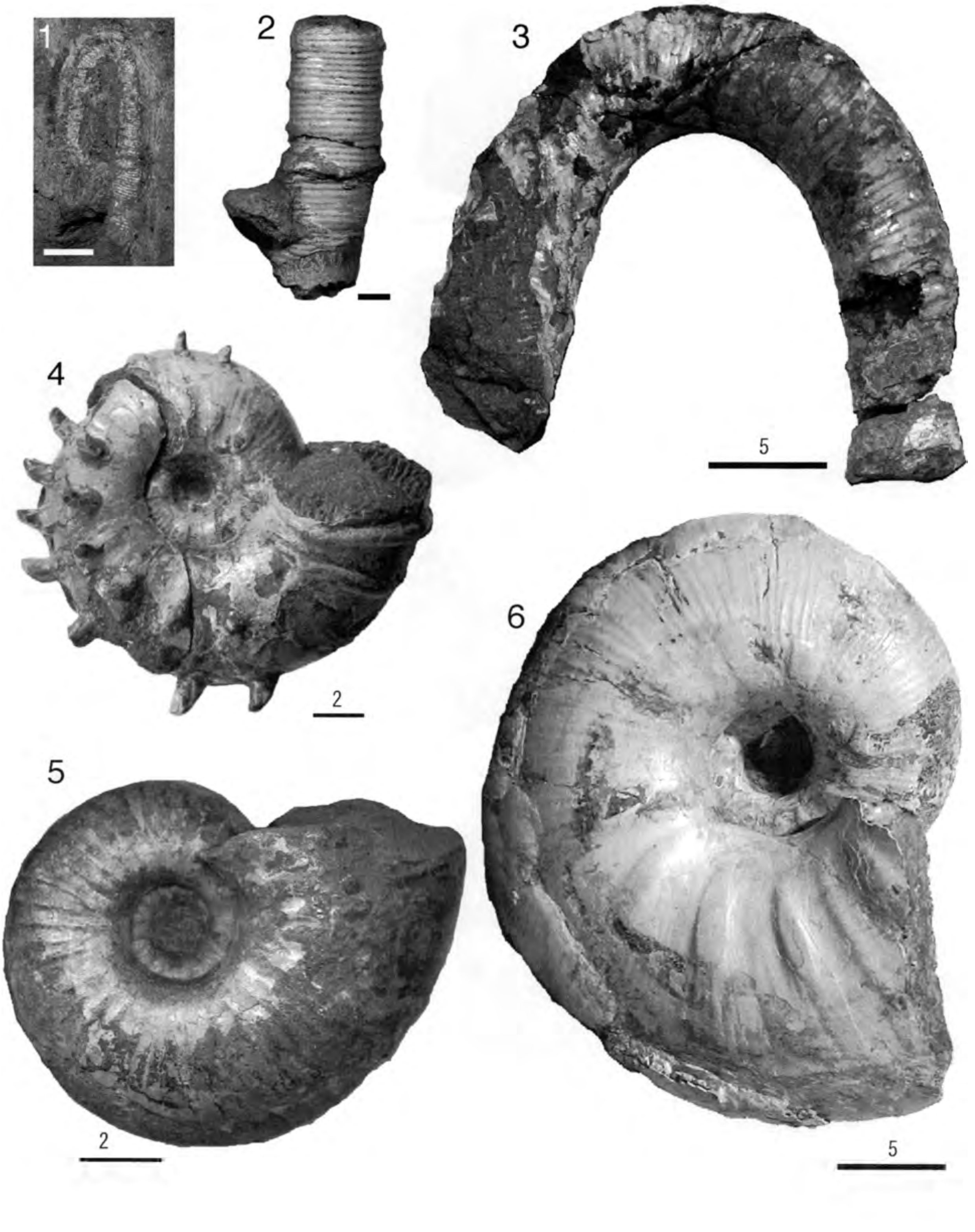

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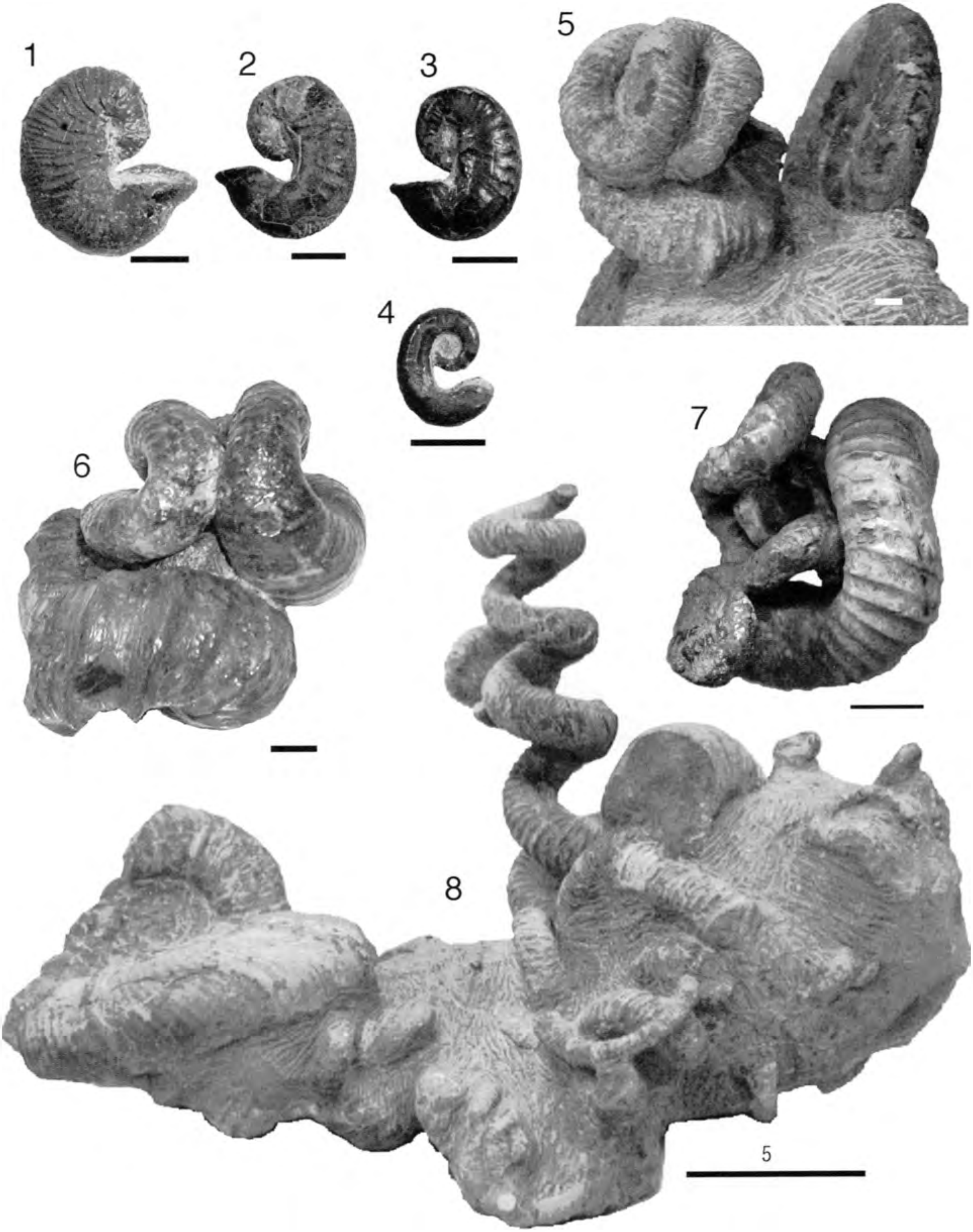

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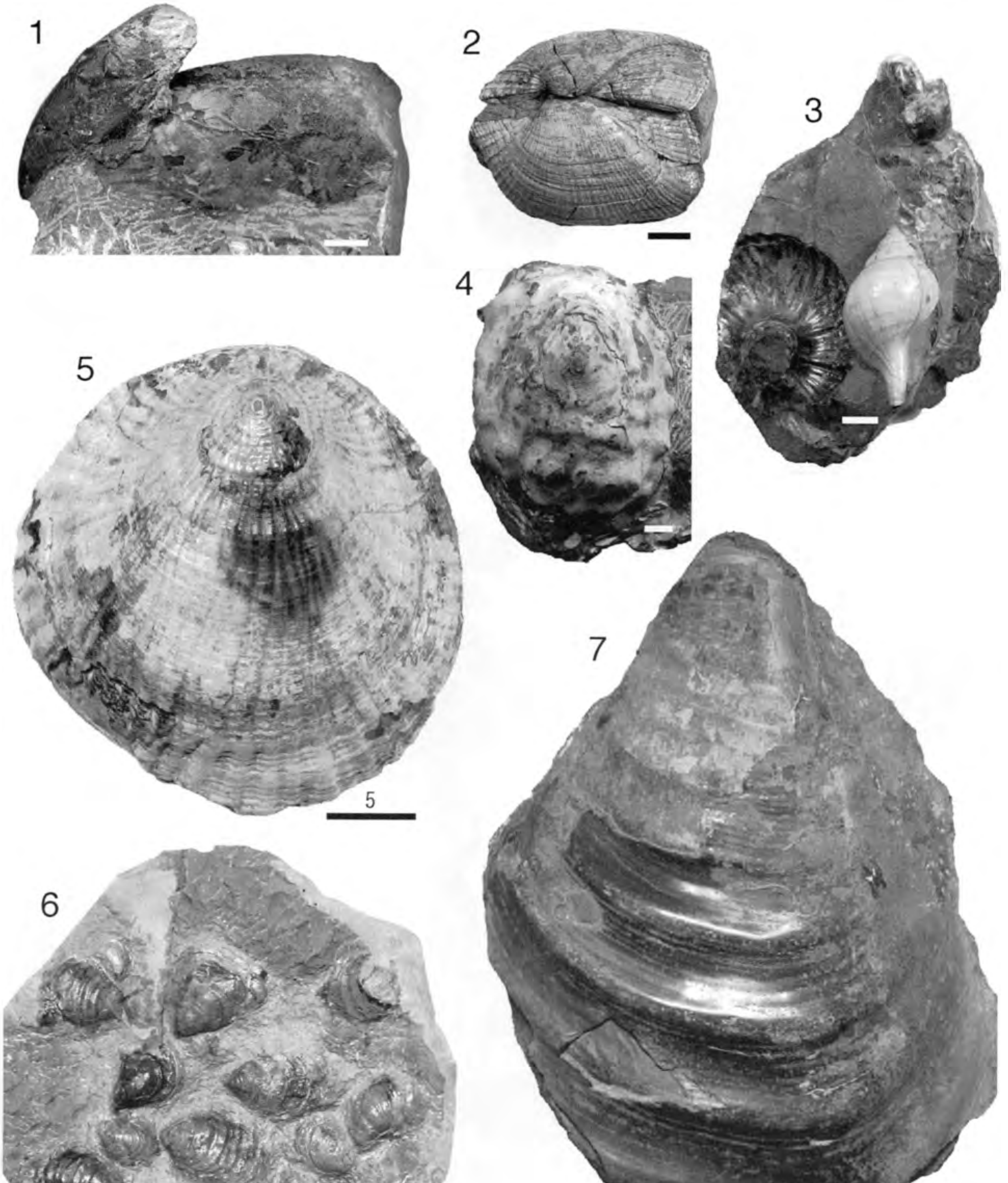
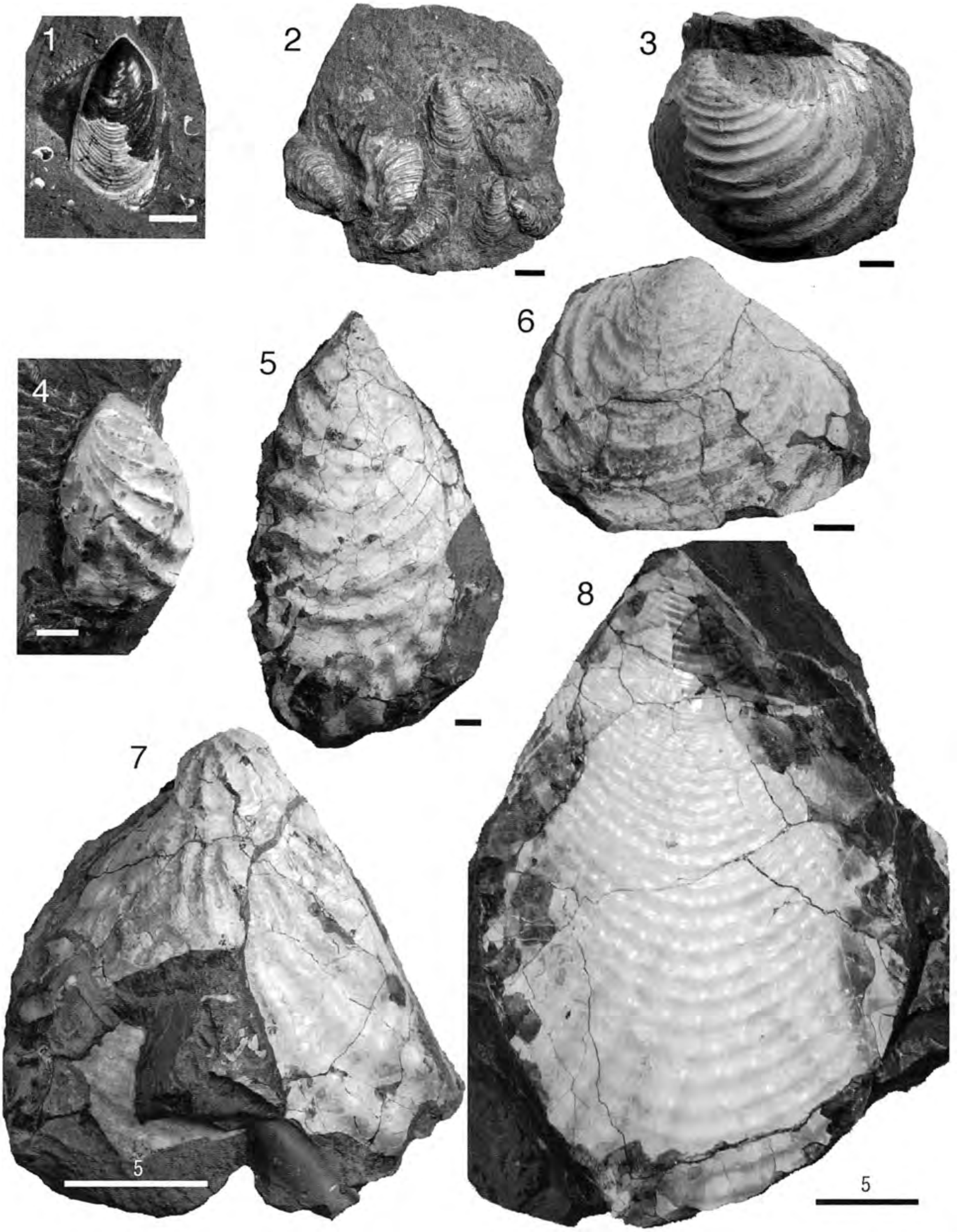


Plate 9



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幾春別背斜東翼部の蝦夷層群三笠層〜羽幌川層の堆積相とシーケンス層序 —セノマニアン—コニアシアンの第3〜4オーダー堆積シーケンス

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Depositional facies and sequence stratigraphy of the Mikasa to Haborogawa formations, Yezo Group, in the eastern limb area of Ikushunbetsu Anticline, Hokkaido, Japan: Cenomanian to Coniacian third- to fourth-order depositional sequences

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Abstract. The Mikasa and Haborogawa formations of the Yezo Group (Cretaceous forearc sediments) distributed in the eastern limb area of Ikushunbetsu Anticline, central Hokkaido, are examined through sedimentary facies analysis and sequence stratigraphy. Nine recognized depositional facies and their distribution suggest that the Mikasa and Haborogawa formations were deposited under inner to outer shelf and associated lower shoreface environments, and outer to subordinately inner shelf ones, respectively. A total of 12 fourth-order depositional sequences for the Mikasa Formation and 6 sequences for the Haborogawa Formation can be traced around the study area on the basis of the repetitively developed coarsening-upward facies successions (CUS). One CUS is typically composed of bioturbated sandy siltstone to fine/medium, massive/hummocky cross-stratified (HCS) sandstone through bioturbated silty sandstone in upward sequence. Some sequences include thin fining-upward successions (FUS) below CUS in some sections. Furthermore, three and two third-order depositional sequence sets for the Mikasa and Haborogawa formations, respectively, can be identified through stacking patterns of the sequences.

Megafossil (ammonites and inoceramids) biostratigraphy shows that the Mikasa and Haborogawa formations were deposited during Cenomanian to middle Turonian and late Turonian to late Coniacian in age. Shallow-marine bivalve assemblages commonly occur from the middle Cenomanian and the middle Turonian, but their composition is mostly different between the two horizons. The Cenomanian assemblages are more diverse in composition. Few megafossils occur from the upper Cenomanian to lower Turonian, although careful survey for the C/T boundary horizon and nearby.

Keywords: sequence stratigraphy, Mikasa Formation, depositional facies, Yezo Group, Cenomanian, Turonian, Coniacian, shallow marine deposits

はじめに

北海道中軸部の空知－蝦夷帯に南北に広く分布する白亜系－下部古第三系の蝦夷層群は，サハリン中部から常磐－鹿島沖にまで続く蝦夷堆積盆（Ando, 2003；安藤，2005, 2006）のうちの北海道亜堆積盆で形成された地層群である．古ユーラシアプレート東縁の前弧海盆に堆積した厚い珪質砕屑物を主体とし，蝦夷堆積盆の層序や化石の記録を最もよく残しており，特に北西太平洋地域の白亜系の模式地域となっている．Matsumoto (1942-43) による総括的研究以降，数多くの層序学的・古生物学的研究がなされてきており，その研究史は安藤が機会あるごとにまとめてきている（安藤，1990a, 1998, 2005；安藤ほか，1994；Ando, 2003; Ando et al., 2006；Hirano et al., 1992）．また最近では，Takashima et al. (2004) が，蝦夷層群分布域の主要部である大夕張－三笠－芦別地域と小平－羽幌地域において，大型化石－微化石，炭素同位体比層序を総括的に見直し，蝦夷層群全体の統一された岩相層序区分を提唱・定義している．今後はこの層序区分にしたがって，他地域の層序も見直していく必要がある．

白亜系下部のアプチアン階から下部古第三系暁新統におよぶ蝦夷層群は，一般に暗灰色の泥質岩や泥質タービダイトが卓越するが，北海道中央部西側の三笠地域における最上部アルビアン～チューロニアンの三笠層と，北海道全域における下部カンパニアン以上の函淵層では砂質岩が卓越しており，蝦夷堆積盆西縁の浅海～河川相を代表している．そのため三笠層は層準や地域による堆積相変化に富んでおり，高精度の堆積相解析やシーケンス層序解析に適している．さらに三笠層は，東側の泥質沖合相である佐久層と同時異相の関係にある（松本・岡田，1973）ため，両者を比較することで堆積盆の東西，つまり海陸方向の堆積相や堆積環境変化の特徴を把握することができる．

三笠層の層序と堆積相については，すでに安藤（1987, 1990a, b, 2000, 2001），安藤・小玉（1998）で詳述しており，大型化石層序を考慮した堆積相層序やその時空分布およびシーケンス層序も提示した．三笠層の分布は，北海道中央部の，いわゆる石狩炭田地域に限られるが，堆積相分布，堆積システムの発達様式は一様ではない．しかし，三笠層は大局的には，後期アルビアン～後期チューロニアンにかけての，陸域～浅海堆積システムの 3 回におよぶ前進・後退サイクル，あるいは 3 回の相対的海水準変動サイクルによって形成された，3 層の第 3 オーダーシーケンスからなる．それぞれはいずれも，3 層の第 4 オーダーシーケンス（あるいはパラシーケンス：van Wagoner et al., 1990）が認められ，一つのセクションですべてが見られるわけではないが，三笠層分布域全体で見ると少なくとも 9 回の反復的な堆積相サクセッション（facies succession）が確認できる．さらに河川～浅海成の砂層をもたらした堆積システムの中心は時代と共に北から南に移動したことも推定できる（安藤 1990a, b; Ando, 1997, 2003）．このことは岩相層序単元である三笠層の下限や上限が地域によって時代が異なる（diachronous）ことを意味しており，特に上限は羽幌川層（Takashima et al., 2004 の定義：従来の上部蝦夷層群下部）と指交関係にある．

三笠層からは浅海生の二枚貝・巻貝・アンモナイトを主とする軟体動物化石が豊富に産出しており，それらの産出様式は堆積相と密接に関係する．これまで化石相と堆積相との相互関係を論じた研究には，小畠・二上 (1975)，Obata and Futakami (1977)，Tanabe et al. (1978)，二上ほか (1980)，二上 (1982)，Futakami (1986a, b) などがあるが，いずれも大局的な傾向を捉えたものである．したがって，奔別川セクションを扱った安藤・小玉（1998）や安藤 (2000, 2001)，数セクションの汽水生二枚貝カキ密集層を調べた安藤ほか (2003) のような，堆積相層序やシーケンス層序に化石層序や群集解析あるいはタフォノミーを加えた研究を，全地域・全層準に広げていく必要がある．こうした研究は，蝦夷堆積盆西縁の堆積環境やその変遷史を精密に描き出すことにつながるであろう．

三笠層は，南北性の空知背斜と幾春別背斜，およびその南方延長の万字ドーム，鳩ノ巣ドームをなして分布するため，背斜の西翼と東翼側で堆積相が異なり，西翼ほど浅海相が，東翼ほど沖合相が多くて厚い．安藤（1990a, b）で示したように，東翼側のセクションでは下部外浜～内側陸棚環境の細粒砂岩相や内側陸棚以深の沖合泥岩相が厚く発達する．第 3 ～ 4 オーダーシーケンスにおける堆積相変化量が小さい割には側方変化が大きく，また凝灰岩や特徴的な岩相を示す鍵層に乏しいため，異なるセクション間でのシーケンスの追跡や対比が難しい．安藤（1990a, b）では，空知背斜から幾春別背斜北部までの東翼側の八月沢，岩石沢，幾春別川（三笠層の模式地）の 3 セクションの対比を試みているが，その精度は十分ではない．三笠層における高精細な堆積史復元には，背斜東翼側での精密シーケンス層序を確立することが必要である．

一方，三笠層の軟体動物化石は，セノマニアン中下部とチューロニアン中部に多産するが，セノマニアン上部からチューロニアン下部ではその産出頻度がきわめて低く，海洋無酸素事変（OAE）層準をはさんだ動物相変化解明のための試料に乏しい（安藤・小玉，1998）．したがって，精密シーケンス層序に基づいて連続的に採取したなるべく多くの化石試料が必要である．

本論文では，こうした 2 つの課題を解決することを目的として，三笠地域北東部～芦別地域南部の幾春別背斜東翼部において，三笠層および羽幌川層下部の堆積相とシーケンス層序を詳述する．また，セノマニアン階からチューロニアン階にかけてみられる二枚貝化石相の変化についてもわずかながら触れておく．

謝辞：まずは小論の執筆の機会を与えて下さった三笠市立博物館の栗原憲一博士，加納　学氏に感謝したい．また，野外調査に当たっては各種の便宜を戴いた長谷川浩二館長をはじめとする博物館の皆さんに御礼申し上げたい．三笠市長の小林和男氏には，野外調査期間中の宿泊地の面倒を

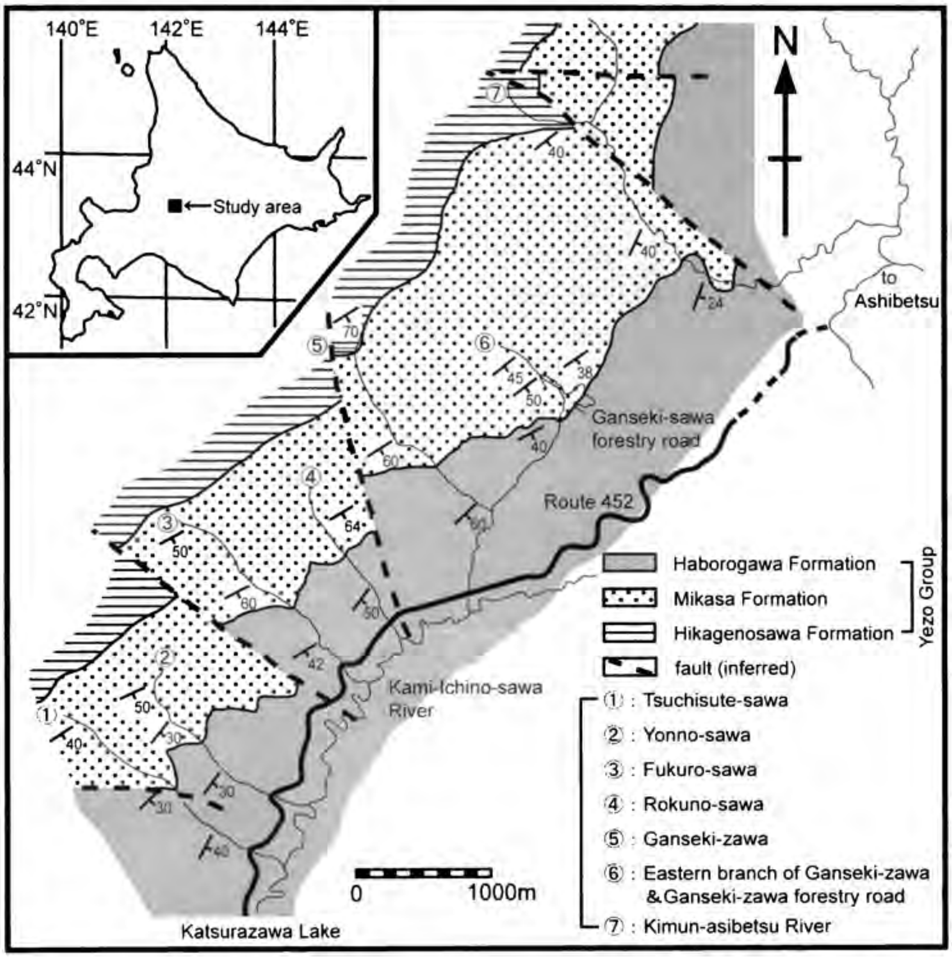

Fig. 1. Geological map of the Mikasa Formation in the northern part of the eastern limb area of Ikushunbetsu Anticline, Mikasa City.

見て戴いた上，様々な面で御厚意を賜った．京都大学大学院の松永　豪氏，早稲田大学大学院の栗原　慧氏をはじめとする峨眉山荘の学生の方々にも色々とお世話戴いた．茨城大学大学院の矢野　健氏，永田　潤氏，堤　匡史氏には，調査や研究にあたりご協力戴いた．調査にあたって，空知森林管理署に入林の許可を戴いた．本研究には日本学術振興会科学研究費基盤研究 (C)No. 17540441（代表者：安藤寿男），(B)No.15340178（代表者：早稲田大学平野弘道教授）の一部を支出した．以上の方々，機関に御礼申し上げる次第である．

地質概説

1．北海道中央部の蝦夷層群の大構造

空知－蝦夷帯中央部に位置する夕張山地では，蝦夷層群は大局的には南北に延びる複背斜褶曲帯をなして東西 2 列に分布する．下位の空知層群や夕張岳蛇紋岩メランジをなす神居古譚亜帯を中軸として，その西翼側には，北部では北にプランジした南北性の空知背斜と，中部ではその南方延長である北北東－南南西～北東－南西方向に軸を持つ幾春別背斜が発達している．神居古譚亜帯と空知－幾春別背斜の間には向斜性の中規模褶曲構造や大規模な衝上断層がある（Takashima et al., 2004）．幾春別背斜は軸面が東に傾斜する西側に転倒した褶曲で，東翼の傾斜が 30 ～ 60° であるのに対し，西翼は 70 ～ 90° である．

2．調査地域

今回の調査地域は，幾春別背斜東翼の北部に位置する，三笠市北東部の幾春別川支流の上一ノ沢川の右岸（北西）側支流から芦別市南部の芦別川支流キムン芦別川上流部にかけての，東西約 6 km，南北約 6 km の地域である (Fig. 1)．走向は褶曲軸に平行な北東方向で，軸を切る胴切り型の断層もいくつか存在する．この地域は走向に対して直交または急角度で下刻して南東に流下する谷が幾つか発達しているために，地層の露出距離が短く，その上露出状況も比較的よいため，連続的な地質柱状を抽出しやすい．さらに，複数の谷で抽出した地質柱状を対比して堆積相の層序的，地理的な変化を追跡するのに適している．

3．幾春別背斜東翼地域の白亜系研究史

幾春別背斜東翼地域の幾春別川沿いは，長尾ほか (1938)

以降，桂沢ダムの建設に伴う調査（深田ほか，1953）や5万分の1地質図幅調査（吉田・神戸，1955；松野ほか，1964），そして松本達郎による一連の大型化石層序学的研究（Matsumoto, 1954, 1959, 1965）などによって，北海道の蝦夷層群の中で最も多くの研究がなされた地域の一つになっている（Fig. 2）．その後もFutakami (1986a,b) が大型化石層序を，松本ほか（1991）が大型化石・微化石統合層序を，安藤（1990a, b）が堆積相層序を詳述している．最近，深田（2001, 2003）が桂沢ダム建設前の調査の経緯やその後の研究の進展についてまとめており参考になる．桂沢ダム下流は三笠層の模式地にも指定されており（松本，1951），安藤らが機会ある毎に巡検を行っている（Hirano et al., 1992; 安藤ほか，1994；安藤，1998；Ando et al., 2006）．

4．幾春別背斜東翼の白亜系層序

本地域に分布する蝦夷層群は，下位より日陰ノ沢層，三笠層，羽幌川層からなり，下流に向かって順次新しい地層が累重する (Fig. 1)．均質な暗灰色シルト岩相の日陰ノ沢層は，細粒砂岩からなる三笠層最下部に明瞭な堆積相変化をもって整合で覆われるのに対し，三笠層から羽幌川層への変化は漸移的で両者の岩相変化量は少ないため，その境界は漸移的である．場所によってはその境界の認定は難しい．

三笠層は，ハンモック状斜交層理（以下HCSと略す）砂岩や生物擾乱によって塊状になった細粒砂岩を主体とし，シルト岩からシルト質砂岩に至る細粒堆積物やごく一部に礫岩を伴う．大局的にみて，北方のセクションほど泥質相（砂質シルト岩～シルト質砂岩）に富み，層厚も厚い傾向がある．実際には，土捨沢で約630m，岩石沢で約780mと積算される．化石としてはシルト質砂岩から細粒砂岩中からトリゴニア類 (*Pterotrigonia*, *Yaadia*, *Apiotrigonia* など)，タマキガイ (*Glycymeris*) などの浅海生二枚貝が多く産出し，砂質シルト岩中に含まれる石灰質ノジュール中から，また時には母岩中から，主にアンモナイトおよびイノセラムス類が産出する．

模式地（幾春別川セクション）の三笠層については，深田ほか（1953），Matsumoto (1954)，Fujii (1958)，松野ほか (1964)，Matsumoto (1965) によって詳細な柱状図が示されており，Matsumoto (1954, 1965) によれば，三笠層は最下部 (IIa)，下部 (IIb)，中部 (IIc)，および上部 (IId) の4部層に区分されており，松野ほか(1964)ではそれぞれTa, Tb, Tc, Tdと呼称されている (Fig. 2)．

本研究では幾春別川セクションより北側の7調査セクションに共通して採用できる部層区分として，MSS1, MSS2, MSS3を使う．これは，堆積相サクセッションに基づいて認定できる12の堆積シーケンスとそれらの累重様式の特徴から区分できる，堆積シーケンスセットに相当する．例えば，MSS1は三笠層の第1シーケンスセットを意味する．そして，各部層中の堆積シーケンスに対しては，例えばMSS1の3つのシーケンスであれば，M1-1, M1-2, M1-3と呼ぶ．

三笠層の時代は地域によってその範囲が異なるが，北東部の八月沢ではアルビアン期末～セノマニアン期後期，北西部の美唄から中部の三笠地域ではアルビアン期末～チューロニアン期中期で，奔別川ではチューロニアン期後期に達する．つまり，上限，下限ともに北方ほど古く，南方ほど新しくなる傾向がある（安藤，1990a；Ando, 2003）．

一方，羽幌川層は，三笠層よりもはるかに細粒な砂質シルト岩ならびにシルト質砂岩からなり，生物擾乱を強く受けているために層理の発達が悪く塊状である．全体として，上方ほど細粒化しシルト岩が卓越する．一部に層厚数～数10 cmの生物擾乱を強く受けた塊状砂岩層が挟在する．化石は砂質シルト岩中に含まれる石灰質ノジュール中や母岩からアンモナイトおよびイノセラムスに代表される軟体動物化石を産する．層厚は下限より約300～550 mを調査したにすぎないので上限は不明である．本層は外側陸棚上部～内側陸棚下部程度の比較的沖合の堆積環境が推定される．時代は，Takashima et al.(2004) によれば，チューロニアン期末～カンパニアン期前期に及ぶ．今回調査を行った範囲では6つの堆積シーケンスが認められ，下位4層とその上位（2層以上）との2つのシーケンスセット（HSS1とHSS2）が識別できるので，2部層に区分することが可能である．

堆積相と堆積環境

1．堆積相区分

幾春別背斜東翼地域の蝦夷層群について，安藤（1990a）を参考に，堆積構造，岩相，化石相に基づき，9つの堆積相が認定できる（Fig. 3）．番号が大きいほど粗粒な堆積相を示し，堆積環境も順次陸側を示す．浅海～陸棚の堆積環境は，浅い方から前浜 (foreshore)，外浜 (shoreface)，内側陸棚 (inner shelf)，外側陸棚 (outer shelf) に区分する（斉藤，1989）．外浜－内側陸棚の境界は平均静穏時波浪限界，内側陸棚－外側陸棚の境界は平均ストーム時波浪限界とする．

堆積相1：塊状シルト岩

三笠層では少ないが，下位の日陰ノ沢層，上位の羽幌川層で卓越する堆積相で，灰～暗褐色の塊状シルト岩からなり，生物擾乱を受けて葉理は希である．一般に包含化石は少ないが，稀に含まれる石灰質ノジュールより，アンモナイトや二枚貝化石（イノセラムス）が産出する．

本相は，細粒な岩相であることから，低エネルギー条件において浮遊泥が沈積し，砂質砕屑物の流入が稀な，外側陸棚で形成されたと推定される，三笠層内で最も沖合成の堆積物である．

堆積相2：生物擾乱砂質シルト岩

羽幌川層，日陰ノ沢層で卓越し，三笠層でも比較的よく見られる堆積相で，暗灰～暗褐色を呈する塊状な砂質シルト岩からなる．全体的に生物擾乱が顕著で，葉理はほとんど見られない．この堆積相からイノセラムスや *Nanonavis pseudocarinata*, *Thetis japonica*, *Parvamussium*? sp. などの砂質泥底群集が破片化した状態(稀に離弁)で得られる．黒

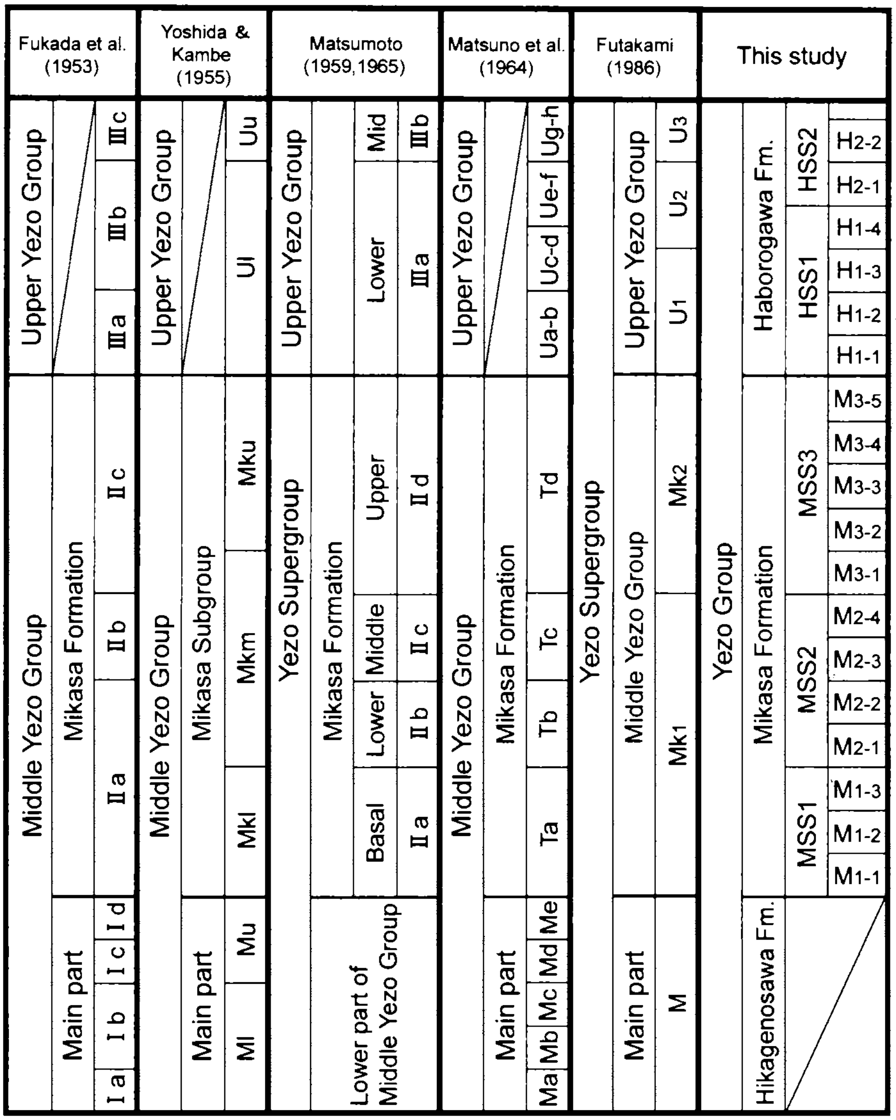

Fig. 2. Comparison of lithostratigraphic divisions of the Yezo Group in the eastern limb area of Ikushunbetsu Anticline.

色の三日月形フィルム状の生痕化石がしばしば含まれる．

本相は，生物擾乱が顕著なシルト質の岩相からなり，波浪の示相構造に乏しいこと，二枚貝化石群集の組成や頻度から，堆積相1よりも浅い陸側の外側陸棚上部で堆積したものと推定される．

堆積相3：生物擾乱シルト質砂岩

三笠層に卓越する堆積相の一つで，塊状～群雲（じらくも）状のシルト質砂岩からなり，生物擾乱が非常に顕著なため葉理はほとんど認められず，わずかに層理が発達する程度である．稀に層厚数10 cmの細粒砂岩層をシート状に挟む場合がある．

産出化石は *Pinna* (*Pinna*) *saitoi*, *Entolium obovatum*, *Pterotrigonia* (*Pterotrigonia*) *kobayashii* などが母岩から散在して産することが多いが，密集した化石層をなすものも少なくない．石灰質ノジュールを多く含み，その中からも軟体動物化石を産出する．群雲状不定形の生痕化石が多く，定型のものは少ないが，水平性の管状生痕が見られる．

本相は，堆積相2の上位，4の下位に含まれる，波浪の示相構造に乏しい砂質堆積物で，浅海生化石が少なくないことから，ストーム波浪によって砂質堆積物がもたらされても活発な底生生物活動で堆積構造が破壊されるような，内側陸棚下部の環境で形成されたのであろう．

堆積相4：生物擾乱細粒砂岩

三笠層にて最も卓越する堆積相で，やや不淘汰な極細～細粒砂岩からなる．生物擾乱が顕著で群雲状を呈するが，不明瞭な葉理を残していることもある．塊状部と層理または葉理を呈する部分は漸移的であり，両者は岩相もよく似ているため，それらは生物擾乱の程度の違いが堆積構造の保存の差異として表れたものと考えられる．掃き寄せ状に密集した産状で，*Cucullaea* (*Idonearca*) *ezoensis* や *Glycymeris* (*Hanaia*) *hokkaidoensis*, *Anthonya japonica*, *Goshoraia crenulata* などの二枚貝化石が含まれることが多い．*Ophiomorpha* とみられる長さ数cmほどの管状生痕化石がしばしば認められる．

No.	Column (silt / sandy silt / silty sand / v f sand / fine sand / medium sand / coarse sand / conglomerate)	Facies	Lithofacies and sedimentary structures	Sedimentary environment
1		Bioturbated siltstone	gray to dark brownish gray, bioturbated massive siltstone; rarely containing calcareous concretions occasionally with ammonite and inoceramid fossils	outer shelf
2		Bioturbated sandy siltstone	gray to dark brownish gray, bioturbated, massive sandy siltstone rarely containing calcareous concretions; often crescent-form burrows scattered	
3		Bioturbated silty sandstone	bioturbated, massive silty sandstone commonly mottled, rarely containing calcareous concretions; occasionally intercalated with sheet-like very fine sandstone layers	inner shelf
4		Bioturbated fine sandstone	more or less poorly-sorted, bioturbated fine sandstone with *Ophiomorpha* and other burrows; occasionally parallel-laminated	
5		Fine sandstone - bioturbated sandy siltstone	sandstone-dominated, interbedded fine sandstone (5-20 cm thick) and sandy siltstone (2-5cm thick); upper surfaces of sandstone layers commonly bioturbated	outer shelf
6		Interbedded hummocky cross-stratified fine sandstone -bioturbated sandy siltstone	interbedded hummocky cross-stratified sandstone and mudstone; occasionally associated with shell lag on the base of HCS and shell fragment lamina within HCS	inner shelf
7		Amalgamated hummocky cross-stratified fine sandstone	amalgamated hummocky cross-stratified fine sandstone rarely intercalated with coarse sandstone and granule conglomerate layers; gradationally changeable with facies 6	lower shoreface - inner shelf
8		Bioturbated medium sandstone	more or less poorly-sorted, thick, bioturbated medium sandstone: gradationally changeable with facies 4, 6 and 7	lower shoreface
9		Thick conglomerate	sharp-based, thick, granule to pebble conglomerate with moderately-sorted medium sand matrix; chert and greenstone gravel common	upper shoreface

Fig. 3. Sedimentary facies and their characteristics of the Yezo Group in the eastern limb area of Ikushunbetsu Anticline.

本相は，堆積相 3，6 の下位や上位に見られ，波浪堆積構造が少ない細粒砂岩相で，厚殻の浅海生二枚貝化石がしばしば多産することから内側陸棚の堆積環境が推定される．

堆積相 5：細粒砂岩－砂質シルト岩互層

三笠層上部や羽幌川層下部でわずかにみられる堆積相で，層厚 5 ～ 20 cm の極細～細粒砂岩に層厚 2 ～ 5 cm の砂質シルト岩が挟まれる砂岩優勢の互層となっている．砂岩・泥岩ユニットは，級化構造が発達するが砂岩層の上面やシルト岩部は生物擾乱を激しく受けている．

本相の堆積物は，堆積相 2 の上位に出現し，細粒砂岩相に漸移すること，HCS を伴わないが砂岩層が規則的に含まれることなどから，平均ストーム時波浪限界より深い外側陸棚に堆積したストーム起源のシート状砂岩層と推定される．

堆積相 6：ハンモック状斜交層理細粒砂岩－砂質シルト岩互層

三笠層に多い堆積相の一つである．淘汰の良い砂岩部は，厚さ 10 cm 以上で，1 m をこえるものも少なくない．典型的なハンモック状斜交層理（HCS: hummocky cross-stratification）シーケンス（Dott and Bourgeois, 1982）のハンモック状低角斜交葉理部 (H)，平行葉理部 (F)，リップル斜交葉理部 (X)，生物擾乱泥岩部 (Mb) のすべて揃うことはまれで，一般に X が生物擾乱によって保存されていないことが多く，ときには F も欠如して H の上に Mb がのることもある．実際に，今回の調査で典型的HCSシーケンスが認められたセクションと層準は，袋沢，岩石沢，キムン芦別川の三笠層最上部のみである．軟体動物化石は HCS シーケン

ス基底に 10 数 cm ～数 10 cm のラグとして密集して産出するものと HCS 葉理に沿って数 mm ～数 cm の以内の厚さでやや密集するものに区別でき，そのタイプによって含まれる化石種も異なってくる．

本相の堆積環境は，典型的な HCS シーケンスが卓越することから，平均ストーム時波浪限界以浅，平均静穏時波浪限界以深の内側陸棚と推定される．

堆積相 7：癒着ハンモック状斜交層理細粒砂岩

HCS シーケンスの F, X, Mb が欠如し，H が癒着 (amalgamation) して連続する極細～細粒砂岩からなり，堆積相 6 から漸移する，より砂質な堆積相である．層理に乏しく塊状砂岩に見えることもあるが，一般に癒着面は起伏に富み，直上の H 葉理中に黒色泥岩や軟体動物殻片が薄いラグをなしていることがある．

本相は，癒着 HCS 砂岩が発達することから，浮遊泥が波浪によって沖合に移動するような平均ストーム時波浪限界以浅，平均静穏時波浪限界以深での堆積環境が推定され，堆積相 6 より供給源側の下部外浜を指示すると考えられる．

堆積相 8：生物擾乱中粒砂岩

四の沢や袋沢など，調査地域の南部ほど卓越する堆積相で，やや不淘汰な中粒砂岩からなる．5 ～ 10 m 程度のまとまった層厚を持ち，下部ほど細粒で上部ほど粗粒になる上方粗粒化傾向を示す．一般に生物擾乱が顕著に発達し，初生堆積構造はほとんど保存されず，不明瞭な葉理が見られる程度である．今回の調査では，本相より化石を得ることができなかったが，安藤 (1990a) では，キムン芦別川の三笠層下部の同相より，*Desmoceras* (*Pseudouhligella*) *japonicum* を得ている．

本相は，堆積相 4 から漸移するより粗粒な堆積物であることから内側陸棚の上部～下部外浜で堆積した可能性が示唆される．

堆積相 9：厚層礫岩

本相はキムン芦別川の M1-1, 1-3, 3-4 と土捨沢の M3-4 でみられる堆積相である．細礫～中礫大の亜円～亜角礫と中粒砂の基質からなる厚層礫岩を特徴とし，淘汰度は中程度で，礫種はチャートと緑色塩基性火山岩類を中心とする．本相を基底とする上位の堆積相サクセッションの下部が，下位に接する上方浅海化を示す堆積相サクセッションの最上部に比べ，はるかに深い堆積環境を示しており，この平坦な基底面を挟んで海進が生じたことが予想される．したがって本相は，海進時の外浜波浪により侵食されて残留した海進ラグ堆積物 (transgressive lag deposits：Nummedal and Swift, 1987) とみなされる．

2．堆積環境

上述したように幾春別背斜東翼地域北部の三笠層の堆積相は，シルト質の細粒堆積相（堆積相 2, 3, 4）が卓越しており，背斜西翼地域によく発達する中粒～粗粒砂岩や礫岩といった粗粒堆積物が少ない．堆積環境は，主に内側陸棚で，次いで外側陸棚，一部で下部外浜であったと推定され，上部外浜や前浜以浅の堆積物はほとんど認められない．

羽幌川層でも，背斜西翼地域よりも細粒相が卓越し，西翼は外側陸棚上部～内側陸棚上部の堆積環境を，東翼はより沖合成の外側陸棚下部～内側陸棚下部を示している．

幾春別背斜東翼地域は，三笠層分布域の中で外側陸棚の泥質岩相（堆積相 1, 2）や内側陸棚から下部外浜の細粒砂岩相（堆積相 3, 4）が最も卓越する地域で，キムン芦別川の三笠層上部と下部に見られる堆積相 9 を除くと，最も粗粒な部分でも堆積相 8 である．キムン芦別川や岩石沢など，北東部のセクションほど泥質岩相（堆積相 2）が厚い．一方，土捨沢や袋沢などの南西部のセクションでは泥質岩相は次第に薄くなり，逆に細粒砂岩相（堆積相 3, 4）が発達し，一部では中粒砂岩相（堆積相 8）が見られる．蝦夷堆積盆で想定されている南北性の海岸線を考慮すると，南西部のセクションは堆積当時，より陸側にあってより浅海の砂質堆積環境にあったものと考えられる．したがって，北東側の方がより沖合の泥質堆積環境であったことが示唆される．

堆積相層序とシーケンス層序

本研究では南西側より，土捨沢，四の沢，袋沢，六の沢，岩石沢，岩石沢北東支流（岩石沢林道），キムン芦別川の 7 セクションについて，100 分の 1 の地質柱状図を作成して，堆積相の層序的・水平的分布を追跡しシーケンス層序を組み立てた (Fig. 4)．柱状の対比は，上方粗粒化する堆積相サクセッション (facies succession) の特徴やその累重様式を隣接するセクションと比較して，順々に繋げていくという手法で行った．また，*Inoceramus* (*I.*) *hobetsensis*（チューロニアン中期）や *Desmoceras* (*P.*) *japonicum*（セノマニアン）などに代表される示標化石の産出層準も考慮に入れた．六の沢などの露頭が少ない層準は隣接セクションを参照し，堆積相と層厚から総合的に判断した．

1．堆積相の累重様式：堆積相サクセッション

幾春別背斜東翼地域において三笠層および羽幌川層下部を構成する堆積相は明瞭な規則性をもって累重している (Fig. 4)．一般的に三笠層の場合，外側陸棚のシルト質岩相（堆積相 1 ～ 2）で始まり，順次，内側陸棚の細粒砂岩相（堆積相 3 ～ 4）や HCS 砂岩泥岩互層（堆積相 6），下部外浜の癒着 HCS 砂岩層（堆積相 7）や中粒砂岩相（堆積相 8）と続く，層厚 20 ～ 100 m 強の上方粗粒化サクセッション (CUS: coarsening-upward succession) をなすことが多い．上限は，比較的明瞭な平坦面を介して上位のサクセッションの細粒堆積相（堆積相 1 ～ 3）に急変する．羽幌川層では全体的に細粒沖合性のため，上方細粒化の範囲は小さく堆積相 1 ～ 2 → 3 ～ 4 という変化になる．しかし，一部では，CUS の下位に層厚数 m から 30 m 以内の，堆積相 3 ～ 4（内側陸棚細粒砂岩相）から堆積相 1 ～ 2（外側陸棚砂質シルト岩相）と上方細粒化するサクセッション (FUS: fining-upward succession) を伴う．そして，FUS から CUS への変化は漸移的である．こうした CUS は，陸側の堆積システムがより海側に前進することによってできた

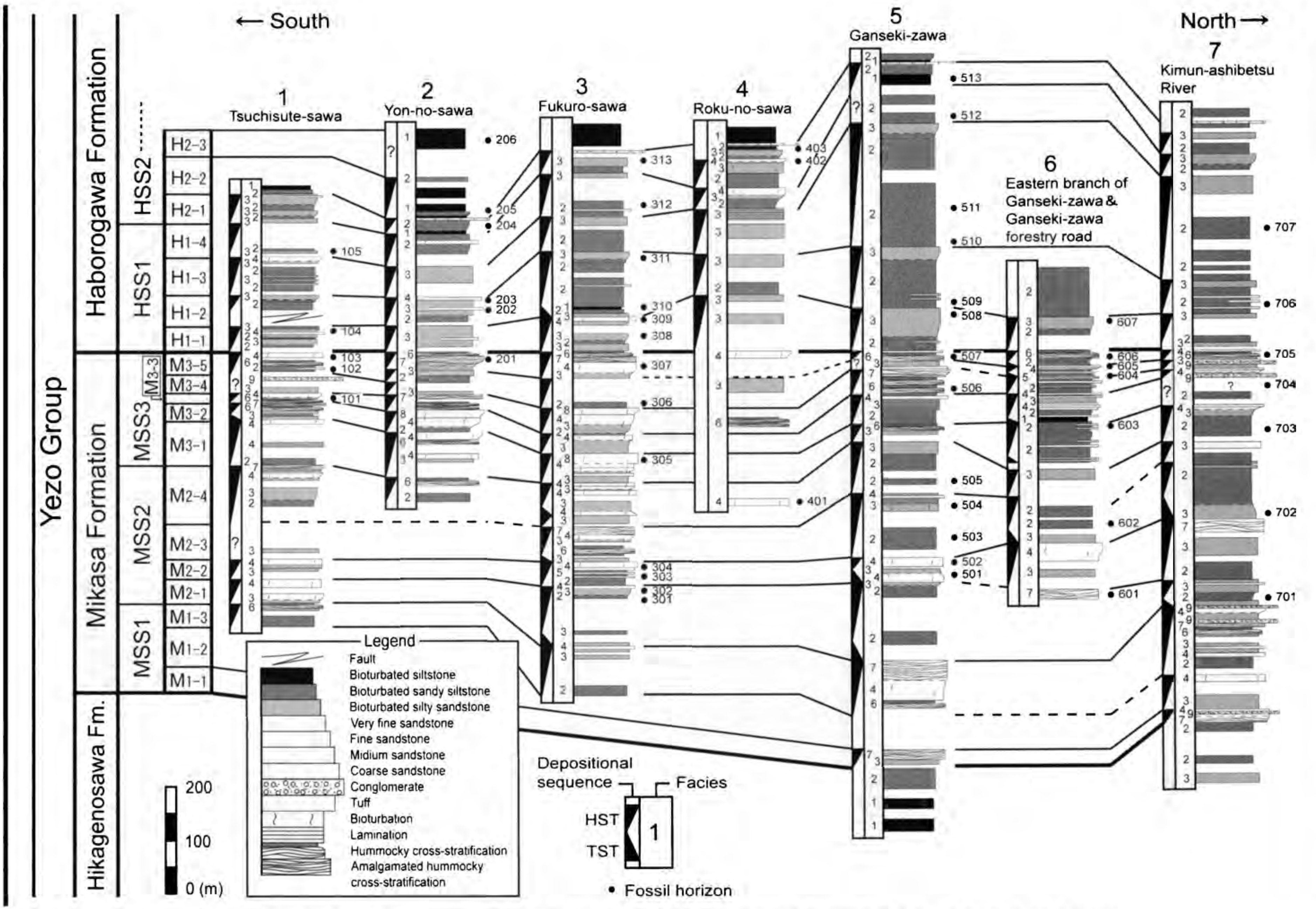

Fig. 4. Correlated geologic columnar sections of the Yezo Group in the northern part of the eastern limb area of Ikushunbetsu Anticline.

前進性サクセッション，あるいは海退性（浅海化）サクセッションとみなされる．一方，FUS は堆積システムが陸側に後退することによってできた後退性サクセッション，あるいは海進性（深海化）サクセッションとみなすことができる．

調査地域内の堆積相分布に地理的な側方変化があるため，北東部ほど CUS 上部の砂質堆積相（4 や 8）が減少し，泥質な堆積相 2 が優勢になる．逆に南西部ほど CUS 下部に堆積相 2 が減少し，堆積相 3 や 4 が多くなる傾向がある．これは，北東ほど沖合（外側陸棚）環境が卓越し，南西ほど浅海（内側陸棚から下部外浜）の環境が卓越していたことを反映したものである．

2．堆積シーケンスと堆積シーケンスセット

シーケンス層序学では，上述のような CUS はこれまでパラシーケンス（parasequence: van Wagoner et al., 1990）と呼ばれてきた．しかし，最近では，当初 CUS と海氾濫面で定義されたパラシーケンスの概念が様々な意味で用いられ混乱が生じているため，小スケールあるいは第 4 ～ 5 オーダーの堆積シーケンスとして扱われるようになってきている（Catuneanu, 2006）．本論では，一つの CUS，あるいは一組の FUS と CUS からなる層序ユニットを，いずれも堆積シーケンス（以下シーケンス；DS: depositional sequence）と呼ぶことにする．

7 調査セクションの三笠層および羽幌川層下部に連続して追跡できる CUS および FUS の分布や累重様式から，それぞれ 12 枚，6 枚のシーケンスを識別することができる（Figs. 4, 5, 6, 7）．CUS および FUS を伴うシーケンスの場合，CUS は高海水準期堆積体（HST: highstand systems tract），FUS は海進期堆積体（TST: transgressive systems tract）と解釈され，FUS と CUS の境界，すなわち TST/HST 境界付近の層準は，最も海進の進んだ時期を示す最大海氾濫面（MFS: maximum flooding surface: van Wagoner et al., 1990）に相当する．総計 18 枚のシーケンスの大半は HST を主体としており，TST はわずかに発達するのみである．これは，この地域が陸棚沖合側にあって，海進期の方が海退期より相対的海水準変動速度が大きかったために，海進期の堆積物が形成されなかった，もしくは保存されなかったのかもしれない．

さらにこれらのシーケンスは，連続する 2 ～ 5 枚でより大きなオーダーの上方粗粒化（海退）を表す，厚さ 200 ～ 400 m のシーケンスセット（DSS: depositional sequence set）を構成している．三笠層で 3 セット（下位より MSS1，MSS2，MSS3），羽幌層では 2 セット（HSS1，HSS2）が判別できる．各シーケンスセット中の堆積シーケンスに対しては，例えば MSS1 の 3 つのシーケンスであれば，M1-1，M1-2，M1-3 と呼ぶことにする．三笠層の 3 つのシーケンスセットは，吉田・神戸（1953）の 3 部層（下位より Mkl，Mkm，Mku）に相当し，Matsumoto (1959, 1965) の IIa，IIb+IIc，IId，松野ほか（1964）の Ta，Tb+Tc，Td に対応すると思われる．

Fig. 5 に本地域の代表的シーケンスやシーケンスセットの実例として，岩石沢林道における三笠層上部の詳細柱状図を示す．M3-1，M3-2，M3-4 は TST と HST から構成され，相対的海水準の上昇－下降に対応して形成されたシーケンスと思われる．M3-2 ～ M3-5 の上部には，オーダーの一つ小さい上方粗粒化サクセッションが認められるが，ほかのセクションでは発達していない．M3-3，M3-5 は，TST が発達しなかったシーケンスとみなされる．この場合，基底部は比較的急速な水深の上昇を示す海氾濫面（marine flooding surface: van Wagoner et al., 1990）に相当すると解釈される．

MSS3 はシーケンスセットのレベルで上方細粒化－粗粒化傾向を認めることができ，シーケンス層序解釈を行うと，M3-1 ～ M3-2 下部までが TST，M3-2 中部～ M3-5 が HST となり，M3-2 下部に大きいスケールでの最大海氾濫面が設定できる．

3．堆積シーケンス・堆積シーケンスセットの形成期間

Gradstein et al.(2004) の地質年代表（p.356）によると，セノマニアン，チューロニアン，コニアシアンの年代は，それぞれ 99.6 ± 0.9 - 93.5 ± 0.8，93.5 ± 0.8-89.3 ± 1.0，89.3 ± 1.0-85.8 ± 0.7 Ma であり，時代巾は 6.1，4.2，3.5 my（百万年間）である．三笠層下部のセノマニアンにはシーケンスが少なくとも 7 枚認められるので，一つのシーケンスの形成期間は平均約 0.87 my となる．三笠層上部のチューロニアン中下部には 5 枚あるので，チューロニアン前中期を 93.5-90.4 Ma とみなすと，こちらは平均約 0.58 my となる．一方，今回調査した羽幌川層の上限をコニアシアン下半部までとし，その堆積期間を約 1.75 my とみなすと，1 枚当たり 0.29 my と見積もられる．一方，シーケンスセットについては，三笠層の MSS1，MSS2，MSS3 のいずれも 2.5 ～ 3 my 程度と見積もられる．

これらの年代巾は，Vail et al., (1991) が示した，第 4 オーダー:0.08-0.5 my，第 3 オーダー:0.5-3 my，第 2 オーダー：3-50 my とする階層周期によると，シーケンスは第 3 オーダーでも第 4 オーダーどちらでも解釈可能である．しかし，de Graciansky et al.(1998) の汎世界的海水準変動曲線を参照して，シーケンスセットを第 3 オーダーの堆積シーケンス，シーケンスは第 4 オーダーに位置付けることが可能である．

4．各堆積シーケンスセットの特徴

1）MSS1

特徴：下部の露出が十分でないが，3 枚のシーケンス（M1-1 ～ M1-3）からなり，調査地域の三笠層の中で最も粗粒なシーケンスセットで，MSS2 や MSS3 より HCS 砂岩相（堆積相 6 ～ 7）がよく発達する．吉田・神戸（1953）の Mkl や Futakami（1986a）での Mk1 下部に対比される．幾春別川セクションの同層準と思われる IIa（Matsumoto, 1959, 1965）あるいは Ta（松野ほか，1964）よりはるかに砂質である．
層厚：約 200 m

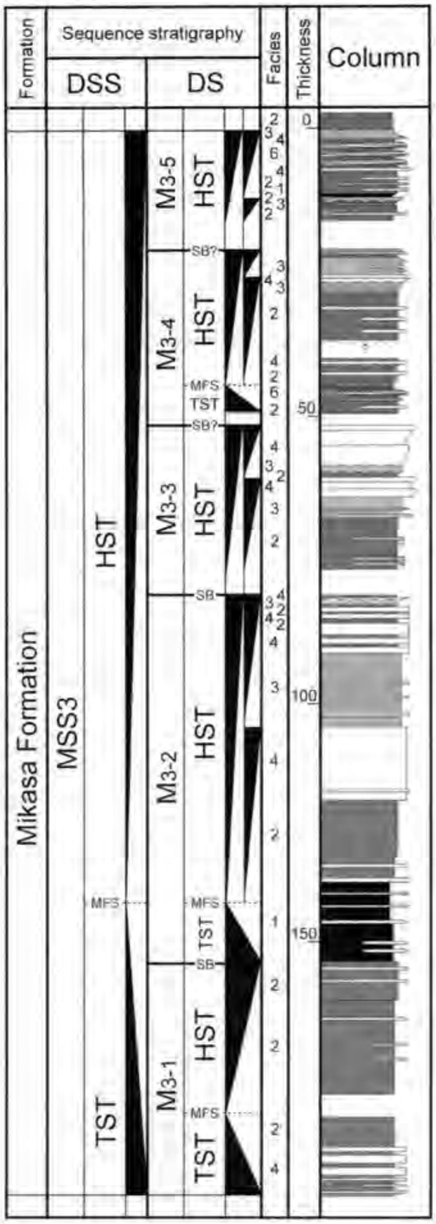

Fig. 5. Facies successions, depositional sequences and depositional sequence set of the upper part of the Mikasa Formation in the forestry road section of Gansekizawa-sawa River.

時代：セノマニアン階下部で一部アルビアン階最上部を含むと予想される.

2）**MSS2**

特徴：M2-1～M2-4 の 4 枚のシーケンスからなり，調査地域の三笠層の中で最も細粒なシーケンスセットで，砂質シルト岩（堆積相 2）とシルト質砂岩（堆積相 3）が卓越する．堆積相 4 や 6 の細粒砂岩相は南部のセクションに多い．吉田・神戸（1953）の Mkm，Futakami（1986a）の Mk1 上部に相当し，Matsumoto (1959, 1965) の IIb+IIc，松野ほか (1964) の Tb+Tc に比較される．6 箇所で認められる TST の基底のシーケンス境界のうち，キムン芦別川の M2-1 基底には厚さ 50cm の海進ラグ堆積物（堆積相 9）が含まれるため，その基底は外浜波浪による侵食を受けており，波浪ラビンメント面（wave ravinement surface: Nummedal and Swift, 1987）がシーケンス境界をなしているとみなすことができる．それ以外の整合的なシーケンス境界での堆積相変化は小規模であり，シーケンス境界の認定は堆積相変化の累重様式を慎重に把握した上で行う必要がある．シーケンスセット全体で見ると，M2-1 における TST を MSS2 の TST とみなすと，それより上位は MSS2 の HST に位置づけられる．

層厚：約 250～400 m

時代：セノマニアン階中部～上部．C/T 境界付近の層準は産出化石に乏しい．

3）**MSS3**

特徴：M3-1～M3-5 の 5 シーケンスからなり，Futakami（1986a）の Mk2 に対応し，Matsumoto (1959, 1965) の IId，松野ほか（1964）の Td に比較される．砂質シルト岩（堆積相 2）・シルト質砂岩（堆積相 3）との互層や HCS 細粒砂岩・砂質シルト岩互層（堆積相 6）を主体とし，下部ほど堆積相 2 が卓越する (Fig. 5)．MSS2 と堆積相が類似するがより砂質堆積相の割合が高い．土捨沢・キムン芦別川セクションの MSS3 上部に見られる堆積相 9 は上下の露出がないため断定はできないが，岩相と層序的位地から M3-5 の基底の海進ラグ堆積物の可能性がある．

層厚：約 170～240 m

時代：チューロニアン階下部～中部.

4）**HSS1**

特徴：H1-1～H1-4 の 4 枚のシーケンスからなり，Futakami (1986a) の U1～U2 下部に対応する．いずれのシーケンスも暗灰色砂質シルト岩（堆積相 2）からシルト質砂岩（堆積相 3）に変化する，生物擾乱の卓越する塊状細粒堆積相からなる．

層厚：220～470 m

時代：チューロニアン階中部～コニアシアン階上部

5）**HSS2**

特徴：H2-1～H2-2 の 2 枚のシーケンスを確認できており，その上位にも存在するが未調査のため詳細は不明である．Futakami（1986a）の U2 上部～U3 に対応する．

層厚：少なくとも 250m 以上

大型化石層序と年代論

北西太平洋の白亜紀後期のアンモナイト，イノセラムスフォーナは古生物地理学的に地域性が強いため，ヨーロッパの標準地域との直接的な対比が難しい．そのため本邦においては，アンモナイト・イノセラムスなどの大型化石および放散虫・有孔虫などの微化石の長年にわたる膨大な産出記録の蓄積により，独自の化石帯が組まれてきた．近年では，利光ほか（1995）によってアンモナイト類およびイノセラムス類に基づく化石層序に古地磁気層序を統合して整備された化石帯が広く用いられている．そこで，利光ほ

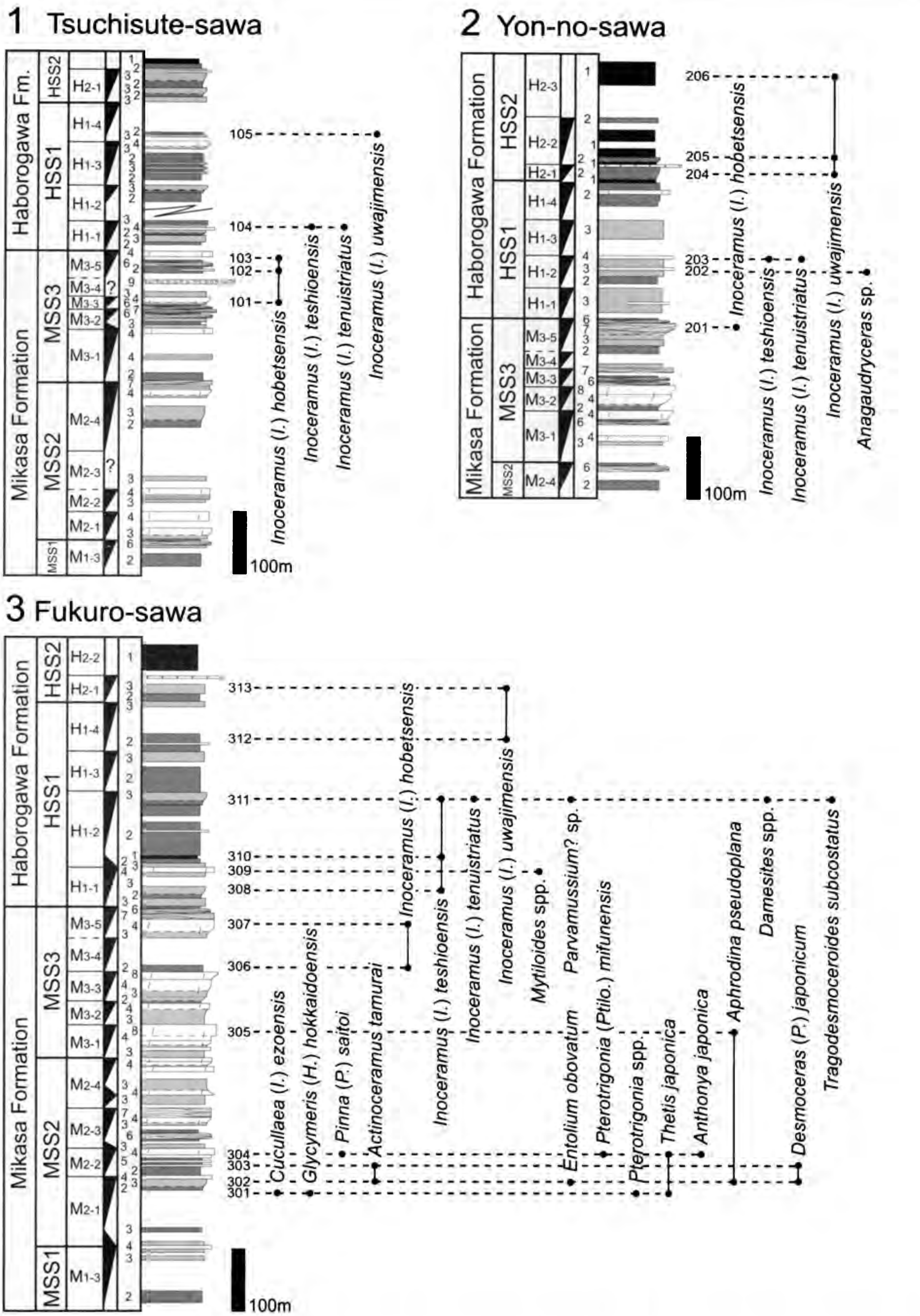

Fig. 6. Facies and biostratigraphic successions of the Mikasa and Haborogawa formations in the Tsuchisute-sawa, Yon-no-sawa and Fukuro-sawa sections. DS: depositional sequence, DSS: depositional sequence set.

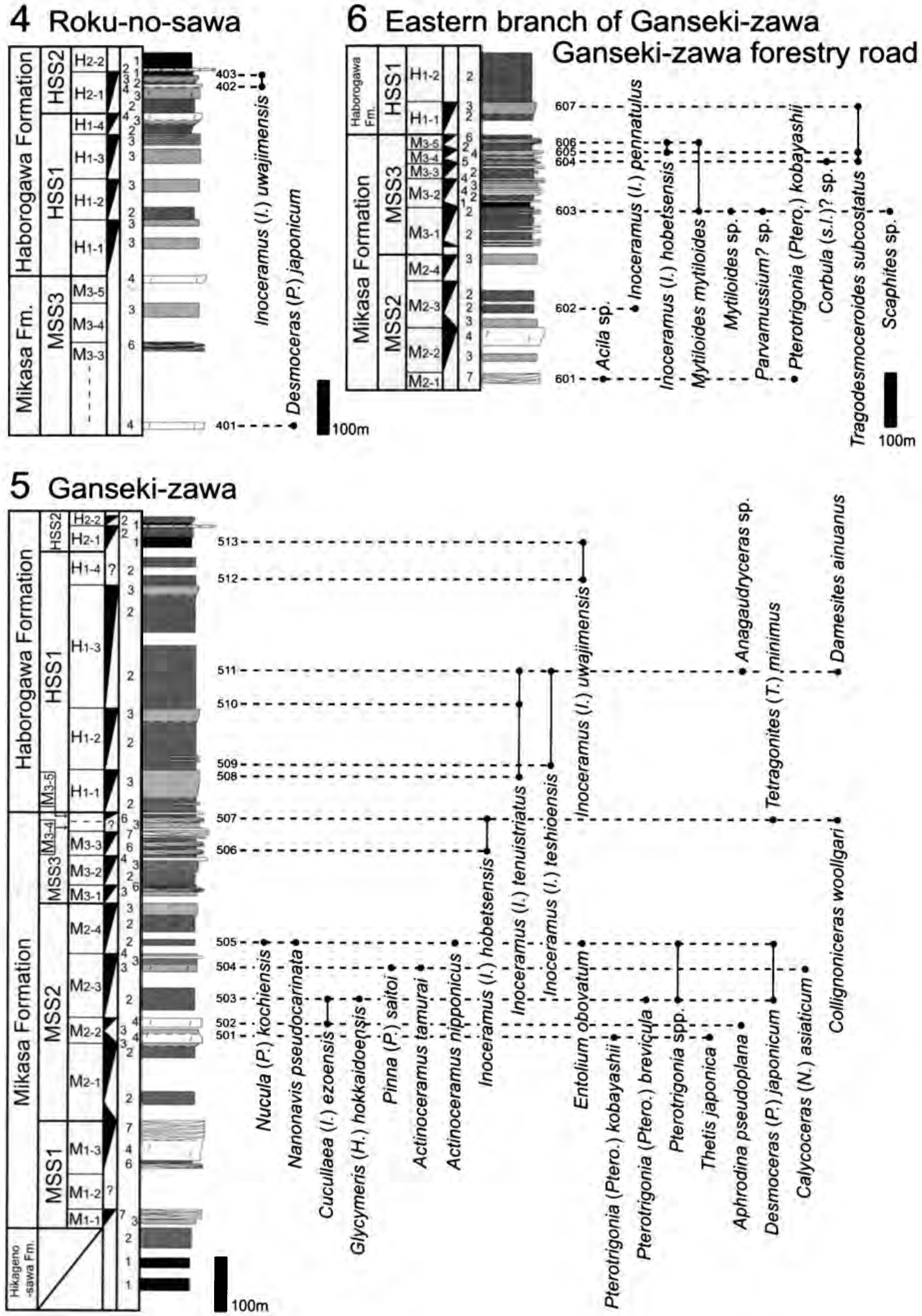

Fig. 7. Facies and biostratigraphic successions of the Mikasa and Haborogawa formations in the Roku-no-sawa, eastern branch of Gansekizawa and Ganseki-zawa sections.

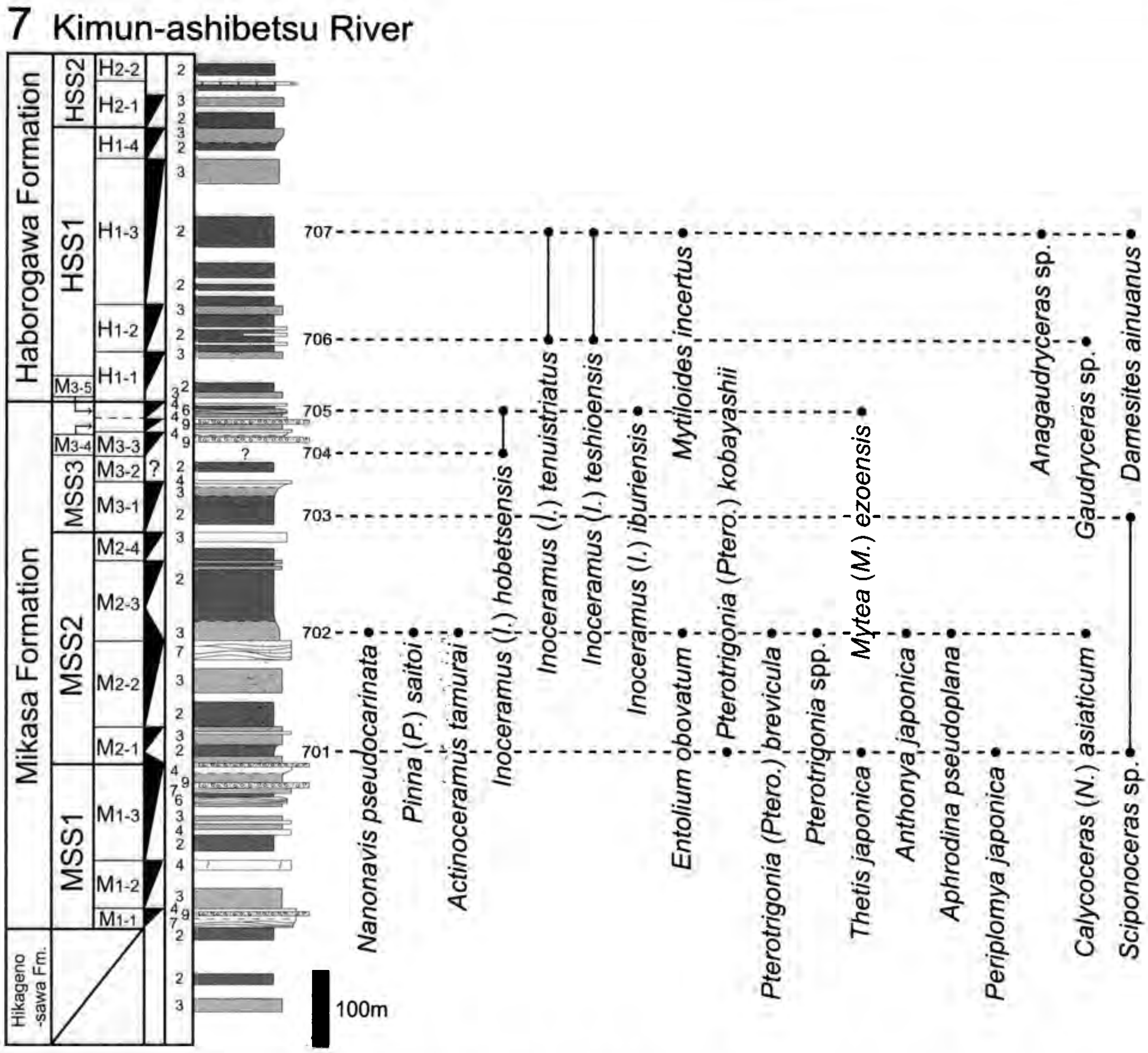

Fig. 8. Facies and biostratigraphic succession of the Mikasa and Haborogawa formations in the Kimun-ashibetsu section.

か（1995）に準拠し，対比柱状図（Fig. 4）と大型化石のレンジチャート（Figs. 5, 6, 7）を作成して年代対比を試みた．産出化石に乏しい層準は吉田・神戸（1955），Futakami（1986a），安藤（1990a）のデータを参照している．

1．セノマニアン階

今回の調査では，下部セノマニアン階を指示する化石は得られなかったが，後述するように M2-1 よりセノマニアン中期の指標種が産出したことから，M1-3 より下位が下部セノマニアン階に相当すると考えられる．

M2-1 最上部（袋沢）から M2-3 上部（岩石沢）にかけて *Actinoceramus tamurai* が連続的に得られる．さらに，岩石沢とキムン芦別川の M2-3 からは *Calycoceras* (*Newboldiceras*) *asiaticum* が産出した．したがって，M2-1 から M2-3 が中部セノマニアン階に対比することができる．また，*Cucullaea* (*I.*) *ezoensis*, *Glycymeris* (*H.*) *hokkaidoensis*, *Pinna* (*P.*) *saitoi*, *Entolium obovatum*, *Pterotrigonia* (*P.*) *kobayashii*, *Thetis japonica*, *Anthonya japonica* に代表されるセノマニアン型の二枚貝化石群は M2-1（特に M2-1 上部）から M2-4 下部にかけて産出する．

岩石沢の M2-4 下部より *Actinoceramus nipponicus* やセノマニアン階の指標種である *Desmoceras* (*P.*) *japonicum* が産出した．以上のことより，M2-4 を上部セノマニアン階とみなすことができる．しかし，セノマニアン階とチューロニアン階（C/T）境界層準付近からはいずれのセクションでも化石が得られなかったため，C/T 境界の詳細な層準は確定できなかった．

2．チューロニアン階

岩石沢東沢の M3-1 下部より *Mytiloides mitiloides* が産出し，M3-3 最下部より中部チューロニアン階を指示する *Inoceramus* (*Inoceramus*) *hobetsensis* が多産する．以上の

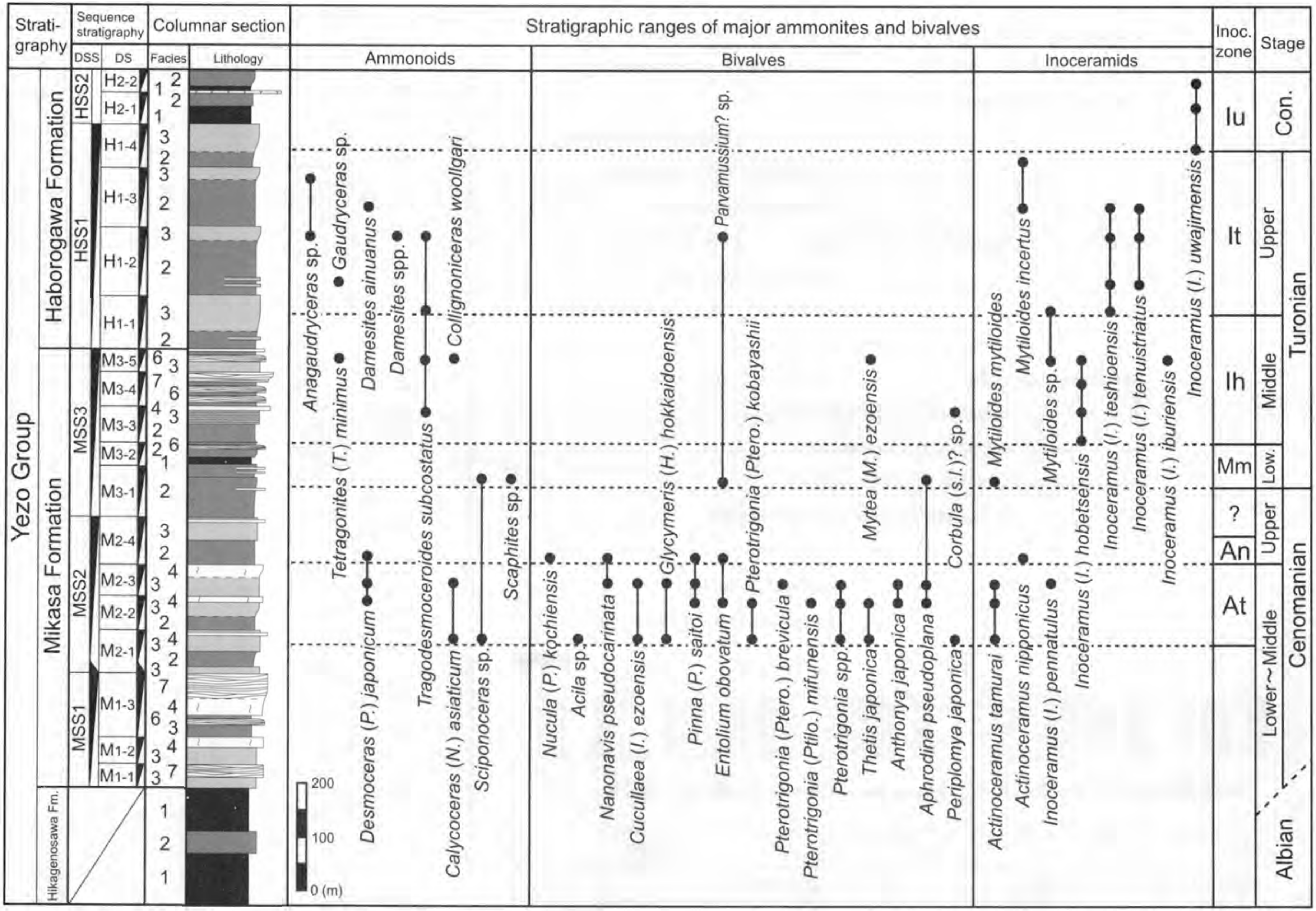

Fig. 9. Composite geologic columnar section and biostratigraphic succession in the eastern limb area of Ikushunbetsu Anticline.

ことより，M3-1 とM3-2 が下部チューロニアン階に相当すると考えられる．

M3-3 から M3-5 の最上部まで連続的に *Inoceramus* (*I.*) *hobetsensis* が産出する（例えば，岩石沢，岩石沢林道）．また，岩石沢の M3-5 上部にて *Collignoniceras woollgari* が得られた．よって，M3-3 から M3-5 が中部チューロニアン階に対比することができる．

羽幌川層の H1-1 上部から H1-3 まで連続的に *Inoceramus* (*Inoceramus*) *teshioensis* が産出する（例えば，袋沢）．さらに，岩石沢の H1-3 中部にて，上部チューロニアンの指示種である *Damesites ainuanus* が得られた．また，同層準からは，*I.* (*I.*) *teshioensis* と *Mytiloides incertus* が共産する．以上のことから，H1-1 から H1-3 は上部チューロニアン階に対比することができる．

3．コニアシアン階

H1-4 下部からほぼ連続的に *Inoceramus* (*Inoceramus*) *uwajimensis* が多産する．よって，H1-4 より上位がコニアシアン階とみなすことができる．

三笠層の軟体動物化石群集

三笠層の軟体動物化石は堆積相と層準によってその組成と産状が異なっている．幾春別東翼地域では，堆積相 1 や 2 の沖合シルト岩相にアンモナイトやイノセラムスが卓越し，東方の同時異相である佐久層と組成や産状が類似する．堆積相 2 ではイノセラムス以外の二枚貝がいくらか多い．それに対し堆積相 3，4，6，7 の浅海成細粒砂岩相では二枚貝，巻貝が卓越し，アンモナイトやイノセラムスを随伴する．砂岩の粒度が粗くなるほどアンモナイトの量は減る．生物擾乱が顕著で塊状な堆積相 3，4 では散在型やレンズ状～不定形密集型の産状を示すが，堆積相 6，7 では HCS の貝殻ラグ密集層や HCS 葉理密集層が時々含まれる．堆積相 6 の生物擾乱シルト質砂岩部では散在型やパッチ状の密集産状をなすことが普通である．密集層中の二枚貝殻に破片が少なくないが，保存のよい破片化していない離弁殻が多く，まれに合弁殻が密集する場合もある．したがって，化石の産出層準の岩相と生息当時の底質はほぼ対応するものと考えたい．

一方，化石産出層準については，安藤・小玉（1998）が詳述した幾春別背斜西翼側の奔別川セクションと同様，セノマニアン中部とチューロニアン中部に多産する．しかし，今回注意深く調査を行ったにもかかわらず，セノマニアン上部～チューロニアン下部（C/T 境界の上下付近）はほとんど化石が産出しなかった．

セノマニアンの群集は，*Cucullaea* (*I.*) *ezoensis*, *Glycymeris* (*H.*) *hokkaidoensis*, *Entolium obovatum*, *Pterotrigonia*, *Anthonya japonica* といった種で代表される．種構成は堆積相によって変化しており，堆積相 1 や堆積相 2 の砂質シルト岩相が卓越する北部のセクションでは砂質泥底群集が，堆積相 4，6 の細粒砂岩相が卓越する南方では砂底群集が多く産する．

中部チューロニアンでは，*Inoceramus* (*I.*) *hobetsensis*, *Aphrodina pseudoplana* の 2 種が優占している．セノマニアンと共通する種は *Aphrodina pseudoplana* を除いて見られない．幾春別川桂沢セクションでは，セノマニアンの *Pterotrigonia* で代表されるトリゴニア類は *Apiotrigonia* (*A.*) *mikasaensis* や *Yaadia ainuana* や *Meekia hokkaidoana* に置き換わっている（松野ほか，1964）が，本調査でこれらの種は得られなかった．

今回の研究では，セノマニアンとチューロニアンにおける化石群集組成の決定的な違いが確認できたが，奔別川セクション（安藤・小玉，1998）ほど産出頻度が高くないため，詳細な比較は今後の課題としたい．

まとめ

1．北海道中央部の幾春別背斜東翼地域北部にあたる，三笠市北東部～芦別市南部において，白亜系蝦夷層群の三笠層と羽幌川層の堆積相・シーケンス層序解析を行った．認定した 9 種の堆積相の特徴とその分布から，三笠層の堆積環境は主に内側陸棚で，次いで外側陸棚，一部で下部外浜，そして羽幌川層は主に外側陸棚で一部内側陸棚であったと推定される．

2．三笠層，羽幌川層は，ともに上方粗粒化堆積相サクセッションがよく発達しており，調査地域全域に追跡できる．一部のサクセッションは，セクションによって，その下部に薄い上方細粒化サクセッションを伴っている．いずれも堆積シーケンスとみなすことができ，三笠層で計 12 枚，羽幌層で 6 枚が確認できる．そして，各シーケンスにおける堆積相分布やシーケンスの累重様式から，三笠層では 3 つ，羽幌層で 2 つの堆積シーケンスセットが認定できる．想定される堆積期間や周期を考慮して，シーケンスは第 4 オーダー，シーケンスセットは第 3 オーダーに位置付けられる．

3．アンモナイト，イノセラムス化石層序から，本地域の三笠層は，セノマニアン～中期チューロニアン，羽幌川層下部は後期チューロニアン～下部コニアシアンに及ぶと考えられる．

4．三笠層の浅海生二枚貝化石は，セノマニアン中下部とチューロニアン中部に多産するが，両者の組成は大きく異なり共通する種はほとんどない．セノマニアン中部の群集はチューロニアン中部のものよりはるかに多様性が高い．セノマニアン上部～チューロニアン下部（C/T 境界の上下付近）からは注意深い調査にもかかわらずほとんど化石が産出しなかった．

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Table 1. List of molluscan fossils occurred from the Yezo Group in the eastern limb area of Ikushunbetsu Anticline. Locality numbers refer to Fig. 4.

Species	Mikasa Fm.	Haborogawa Fm.
Bivalvia		
Nuculoida		
Nucula (Pectinucula) kochiensis Tashiro and Matsuda	505	
Acila sp.	601	
Arcoida		
Nanonavis pseudocarinata Tashiro and Matsuda	505 702	
Cucullaea (Idonearca) ezoensis Yabe and Nagao	301 502 503	
Glycymeris (Hanaia) hokkaidoensis (Yabe and Nagao)	301 503	
Mytiloida		
Pinna (Pinna) saitoi Nagao	304 505 702	
Pterioida		
Mytiloides mytiloides (Mantell)	603 606	
Mytiloides incertus (Jimbo)		707
Mytiloides spp.		309 603
Actinoceramus tamurai Matsumoto and Noda	302 303 504 702	
Actinoceramus nipponicus (Nagao and Matsumoto)	505	
Inoceramus (Inoceramus) pennatulus Pergament	602	
Inoceramus (I.) hobetsensis Nagao and Matsumoto	101 102 103 201 306 307 506 507 605 606 704 705	
Inoceramus (I.) teshioensis Nagao and Matsumoto		104 203 308 310 311 508 510 511 706 707
Inoceramus (I.) tenuistriatus Nagao and Matsumoto		104 203 311 509 511 706 707
Inoceramus (I.) iburiensis Nagao and Matsumoto	705	
Inoceramus (I.) uwajimensis Yahara		105 106 204 205 206 312 313 402 403 512 513
Entolium obovatum (Stoliczka)	303 305 505 701	
Parvamussium? sp.	311 603	
Trigonioida		
Pterotrigonia (Pterotrigonia) kobayashii (Nakano)	501 601 701	
Pterotrigonia (Ptilotrigonia) brevicula (Yahara)	503 702	
Pterotrigonia (Ptilo.) mifunensis (Tamura and Tashiro)	304	
Pterotrigonia spp.	301 503 505 702	
Veneroida		
Mytea (Mytea) ezoensis (Nagao)	705	
Clisocolus (Clisocolus) odochiensis Tashiro and Kozai	704	
Thetis japonica (Yabe and Nagao)	301 304 501 701	
Anthonya japonica Matsumoto	304 702	
Aphrodina pseudoplana (Yabe and Nagao)	303 305 502 702	
Goshoraia crenulata (Matsumoto)	303	
Myoida		
Corbula (s.l.)? sp.	604	
Pholadomyoida		
Periplomya japonica Matsuda	701	
Ammonoidea		
Gaudryceratidae		
Anagaudryceras sp.		202 511 707
Gaudryceras sp.		706
Tetragonitidae		
Tetragonites (Tetragonites) minimus Shigeta		507
Desmoceratidae		
Desmoceras (Pseudouhligella) japonicum Yabe	303 401 503 505	
Damesites ainuanus Matsumoto		511 707
Damesites spp.		311
Tragodesmoceroides subcostatus Matsumoto	311 604	605 607
Acanthoceratidae		
Calycoceras (Newboldiceras) asiaticum (Jimbo)	504 702	
Collignoniceratidae		
Collignoniceras woollgari (Mantell)	507	
Baculitidae		
Sciponoceras sp.	701	703
Scaphitidae		
Scaphites sp.	603	

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Plate 1

A: bioturbated sandy siltstone of facies 2 in the middle part of H2-2, Yon-no-sawa section.

B: bioturbated silty sandstone of facies 3 in the upper part of M2-4, Ganseki-zawa section.

C: bioturbated fine sandstone of facies 4 in the upper part of M2-2, Ganseki-zawa section.

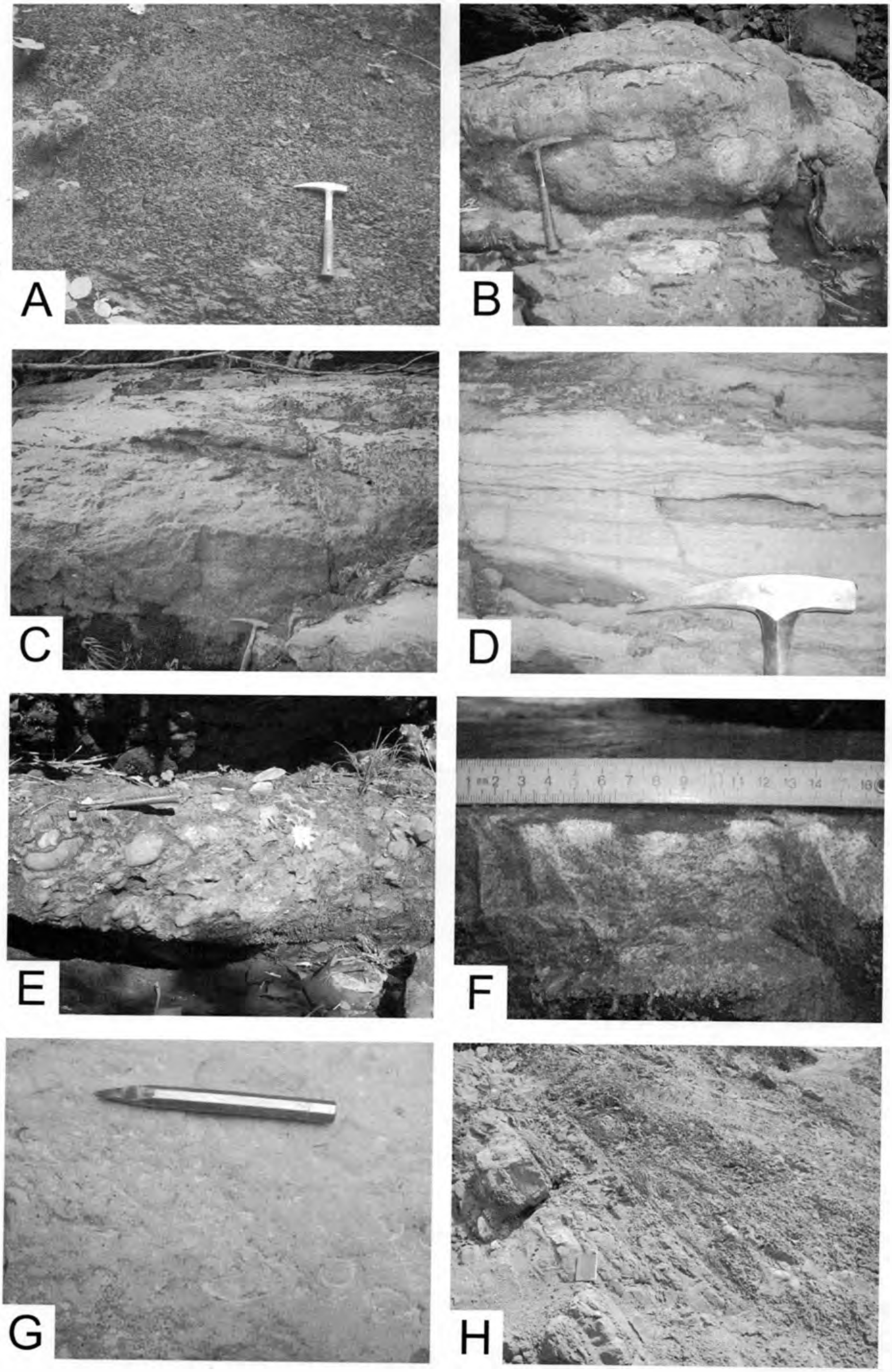
D: interbedded hummocky cross-stratified fine sandstone and bioturbated sandy siltstone of facies 6 in the upper part of M2-1, eastern branch of Ganzeki-zawa section.

E: thick conglomerate of facies 9 in the upper part of M3-4, Kimun-ashibetsu River section.

F: tuffaceous sandstone in the upper part of H2-1, Yon-no-sawa section.

G: shell concentration in the lower part of M2-2, Ganseki-zawa section.

H: boundary (left side) between Mikasa Formation (M3-5) and Haborogawa Formation (H1-1) as a marine flooding surface in Ganseki-zawa forestry road section.


A
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H

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