29th IGC FIELD TRIP C02

CRETACEOUS FOREARC BASIN OF CENTRAL HOKKAIDO: LITHOFACIES AND BIOFACIES CHARACTERISTICS

Hiromichi Hirano[1], Kazushige Tanabe[2],
Hisao Ando[3] and Masao Futakami[4]

1) *Institute of Earth Science, Faculty of Education, Waseda University, Tokyo, Japan*
2) *Geological Institute, University of Tokyo, Tokyo, Japan*
3) *Department of Earth Sciences, Ibaraki University, Mito, Japan*
4) *Kawamura Gakuen Woman's University, Abiko, Chiba, Japan*

INTRODUCTION

Hokkaido was the most suitable island in old Japanese text-books as teaching material to study a full orogenic cycle. There we have recognized ophiolite, offshore sediments, geosynclinal sediments including flysch-type, molasse sediments of post-orogenic stage and paired metamorphic rocks. Geotectonic history of Hokkaido was recently drastically remade like in many other regions of the world by the development of plate tectonics and detailed radiometric age data of metamorphic rocks. In current text-books, this island is one of the most favorable teaching material as an active margin. We can find various kinds of evidence on the collision and accretion processes of two micro-continents and allochthonous terrains.

In this field trip, we observe the lithofacies and biofacies changes of the Yezo Supergroup accumulated on the western part of the Middle to Late Cretaceous Yezo forearc basin as the main subject, from various view points like biostratigraphy, sequence stratigraphy, chemostratigraphy, etc. The east-westward facies changes are most dominant for the Cenomanian and Turonian in the area of this field trip. The western coastal facies called the Mikasa Formation is characterized by bivalvian assemblages including trigoniids, and the eastern offshore facies called the Saku Formation by various kinds of heteromorph and smoothed ammonites. We also can see fairly many acanthoceratacean ammonoids, which are useful for intercontinental correlation, in the intermediate area between the typical western and eastern areas. We can trace the Cenomanian-Turonian oceanic anoxic event horizon by sulfur contents excursion in the eastern offshore facies but not in the western coastal facies. The Coniacian transgression domestically called the Urakawan transgression, resulted in somewhat sudden fining-upward facies changes. After the transgression, the forearc basin was uplifted and filled up with the Campanian and Maastrichtian coastal sediments. Later, the Yezo Supergroup was eroded to some extent, and some coal measures were formed by some oscillations of sea level from Eocene onward.

Participants will be able to observe the fundamentally different characteristics of the active margin sediments in comparison with epicontinental or on-shield sediments through this field trip. Besides, they can briefly get information on the historical background of the Ishikari Coal Field from streets and museums of the Yubari and Mikasa Cities.

HISTORICAL REVIEWS

The Yezo Supergroup as the Cretaceous Yezo forearc basin deposits is narrowly distributed from north to south in the central part of Hokkaido. Our field trip area is situated in the central part of the distribution, around 142 °E and 43 °N. It administratively includes the Mikasa and Yubari Cities of Hokkaido Prefecture.

Hokkaido is one of the representative colliery areas in Japan, being composed of the Teshio, Ishikari and Kushiro Coal Fields. Our field trip area belongs to the Ishikari Coal Field. The Ishikari Coal Field was first surveyed by B. S. Lyman in 1877, who reported the Cretaceous System and the overlying Paleogene coal beds. Subsequently, railway was constructed for the first time in Hokkaido in 1880 for developing the coal field. Yokoyama (1890) researched the molluscan fauna of the Cretaceous of the Ishikari Coal Field and correlated it with ones from Utatur of India and the European Cenomanian to Gault. Later, Jimbo (1894), Yabe (1909) and Imai (1924) studied the stratigraphy and molluscan faunas of the Cretaceous and the coal-bearing Tertiary. In association with the development of the coal field many coal geologists and palaeontologists had been studied the stratigraphy and structure of the Cretaceous and Tertiary. The coal field was most actively developed in the period of 1950s and 1960s. But at the present most of mines are closed by some economical reasons in spite of the high-grade technology to work as deep as 1,200m. Thus, the stratigraphy and structure of this area have been studied not only at the surface level but also in the subsurface level. Recently, Tuchida (1991MS) clarified the structure of the Cretaceous Yezo Supergroup in the Oyubari area of Yubari City in detail by using satellite information.

The first detailed study of biostratigraphy and molluscan faunas of the Cretaceous in Sakhalin and Hokkaido was carried out by Matsumoto (1942, 1943), who named the Cretaceous siliciclastic deposits the Lower, Middle and Upper Yezo Groups (1951). The ammonoid- and inoceramid-biostratigraphy as the reference scale of the Northern Pacific Cretaceous was established by the continuous works of Matsumoto in the area of this field trip. Taxonomy of ammonoids and inoceramids, biostratigraphy and historical geology of the Japanese Cretaceous were published in about 200 scientific papers written in English and more than 120 in Japanese by Matsumoto. Micropaleontological studies have also been carried out since Takayanagi (1960). The newest biostratigraphical zonation is compiled by Matsumoto and his coworkers (Matsumoto et al., 1991, etc.; Tables 2, 3).

Megafossils of the Yezo Supergroup are obtained both from the matrix and calcareous nodules. As the preservation of fossils in calcareous nodules is very favorable, paleontological studies of marine Cretaceous mollusks are mostly based on fossils from the nodules. Studies concerned with ammonoids are for instance, relative growth analyses on *Desmoceras* and *Reesidites* by Obata (e.g., 1959, 1965), paleogenetical study of *Gaudryceras* in terms of relative growth analyses of population samples by Hirano (1978), functional morphology of *Scaphites* by Tanabe (1977), a series of morphological studies of jaw apparatuses by Tanabe (1983) and Tanabe & Fukuda (1987), paleoecological analysis of ammonoid faunas by Tanabe (1979), phyletic speciation of *Desmoceras* by Hirano et al. (1990), theoretical morphology of *Nipponites* and some heteromorphs by Okamoto (1988a-c, 1989), detailed morphological study of the Turonian collignoniceratids by Futakami (1990), and ontogenetic study of mode of life on *Tetragonites* and some other ammonoids by Shigeta (1992MS). Taphonomical studies have been carried out by Ando (1989) and Maeda (1991).

Sedimentological studies were carried out by Tanaka (1963, 1970, 1971) and Tanaka & Sumi (1981) from the viewpoint of palaeocurrent system and turbidite sequence, by Fujii (1958), Okada (1965) and Matsumoto & Okada (1969, 1971, 1973) from sandstone petrography and sedimentary cycle, and recently by Ando (1987, 1990a, b) from sedimentary facies and sequence stratigraphy. Geochemical environments of the muddy shelf bottom are analyzed with emphasis on siderite nodule formation by Hayakawa (1992MS). The Cenomanian-Turonian oceanic anoxic event, which is well recognized in Europe, Atlantic Ocean, North Africa and North America, was discussed by Hirano et al. (1991 and in press) and Hirano (in press) from chemostratigraphical study in the Oyubari area. Hasegawa (1992) recently preliminarily reported the existence of dC13-spike in and around the Cenomanian/Turonian boundary in this area. Historical geology of Hokkaido from the viewpoint of plate tectonics also has been studied and renewed year by year as mentioned in the section of tectonic setting.

TECTONIC SETTING

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

During this decade, many tectonic models have been proposed by many authors for the better understanding of tectonic development of Hokkaido. As a definite conclusion is not still settled, Table 1 shows the general agreement among their opinions. The N-S trending zonal geologic framework is a product of subduction and collision processes in the northeastern margin of the Eurasia Plate. The western four belts seem to be related with the Paleo-Japan arc-trench system (Oshima, Rebun-Kabato, Sorachi-Yezo and Hidaka Belts). The last Hidaka Belt may be an accretionary prism formed by westward subduction beneath the Eurasia continental margin during early Cretaceous to Eocene (Figs. 2, 3). The other two belts may represent the Paleo-Kuril arc-trench system (Nemuro Belt) and associated accretionary prism (Tokoro Belt). An oceanic plate (perhaps Izanagi-Kula Plate) had subducted northward beneath the Okhotsk paleoland/micro-

Table 1. Characteristics of six major geologic units in Hokkaido.

Tectonic division	Group	Lithology	Age	Tectonic setting
Oshima Belt	Matsumae Group Kamiiso Group	melange with Triassic - Jurassic limestone blocks	late Jurassic	ocean-continental plate boundary
Rebun-Kabato Belt	Rebun Group	andesitic pyroclastics & siliciclastics	early Cretaceous	magmatic arc
	Kumaneshiri Group	siliciclastics & basaltic - andesitic pyroclastics		
Sorachi-Yezo Belt	Sorachi Group	massive to pillow basalt, chert, volcanic sandstone, basic - intermediate tuff	late Jurassic - early Cretaceous	accretionary prism & trapped oceanic crust
	Yezo Supergroup	mudstone, muddy turbidite sandstone & conglomerate	late Barremian - Maastrichtian	mud-dominated forearc basin
Hidaka Belt	Hidaka Supergroup	melange & terrigenous siliciclastic	early - late Cretaceous - Eocene	accretionary prism
	Nakanogawa Group	turbidite, mudstone & melange	Campanian - Paleocene?	accretionary prism / collision complex
Tokoro Belt	Nikoro Group	greenstone, chert, limestone & pyroclastics	late Jurassic	accretionary prism, sea mount & ocean floor
	Saroma Group	turbidite & mudstone	Coniacian - Paleocene	forearc basin
	Yubetsu Group	turbidite, massive sandstone & red mudstone	Campanian - Paleocene	accretionary prism
Nemuro Belt	Nemuro Group	turbidite, mudstone, conglomerate & basalt	late Cretaceous - Paleocene	forearc basin

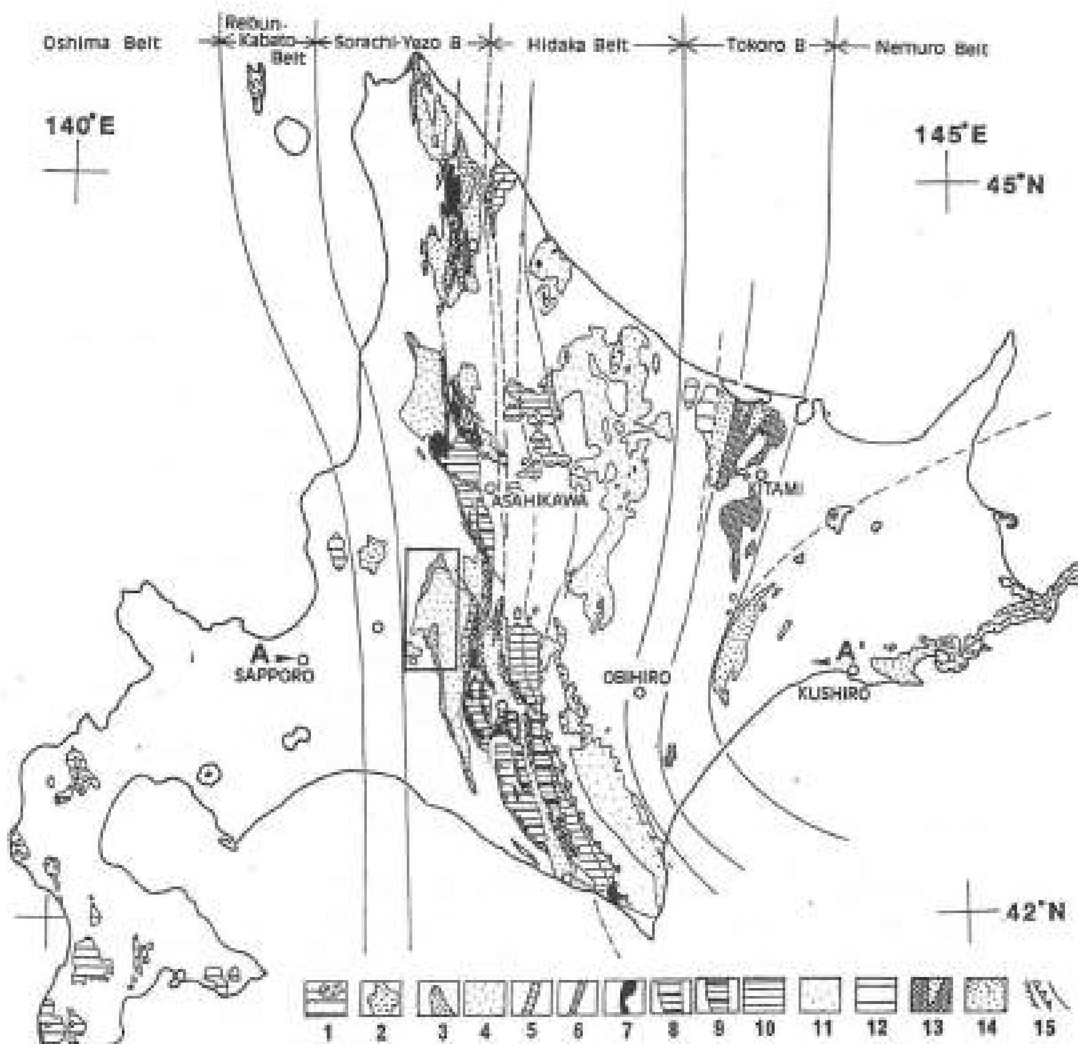

Fig. 1. Major geologic units and distribution of the Mesozoic systems in Hokkaido. Modified from Niida and Kito (1986). 1: Matsumae and Kamiiso Groups, 2: Kumaneshiri and Rebun Groups, 3: Hakobuchi Group, 4: Lower, Middle and Upper Yezo Groups, 5, 6: lower and upper parts of Sorachi Group, 7: serpentinite and peridotite, 8, 9: Lower Cretaceous melange complex I and II, 10: Middle Cretaceous melange complex, 11: flysch, 12: accretionary complex, 13: Nikoro and Saroma Groups, 15: faults. Rectangle: location of Fig. 5. A-A': location of Fig. 2.

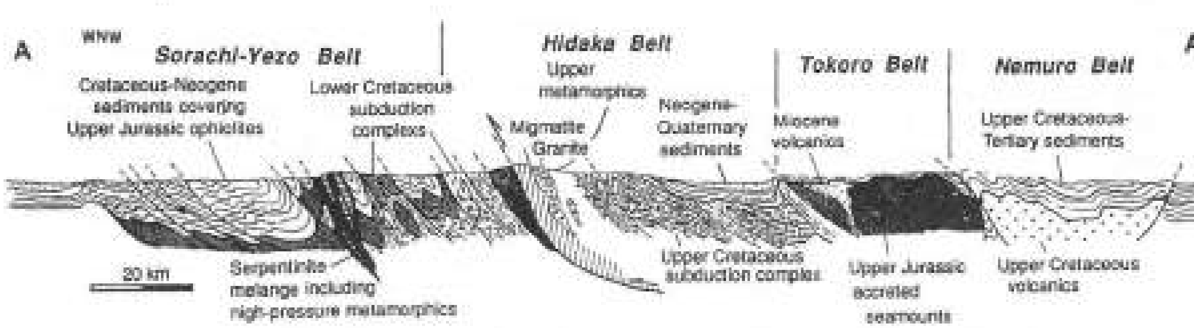

Fig. 2. East-westward geologic profile of Hokkaido. Location shown in Fig. 1. Modified from Kimura (1986).

plate during late Cretaceous to Paleogene.

The Yezo Supergroup on which we focus in this excursion, is situated on the Sorachi-Yezo Belt. This belt is stratigraphically composed of two major sedimentary units as the Sorachi Group and Yezo Supergroup. The two reflect paleogeographic setting of the late Jurassic to early Cretaceous ocean basin and the early to late Cretaceous forearc basin, respectively. Besides them, serpentinite melanges with high-P and low-T type Kamuikotan metamorphic blocks and other melange complexes

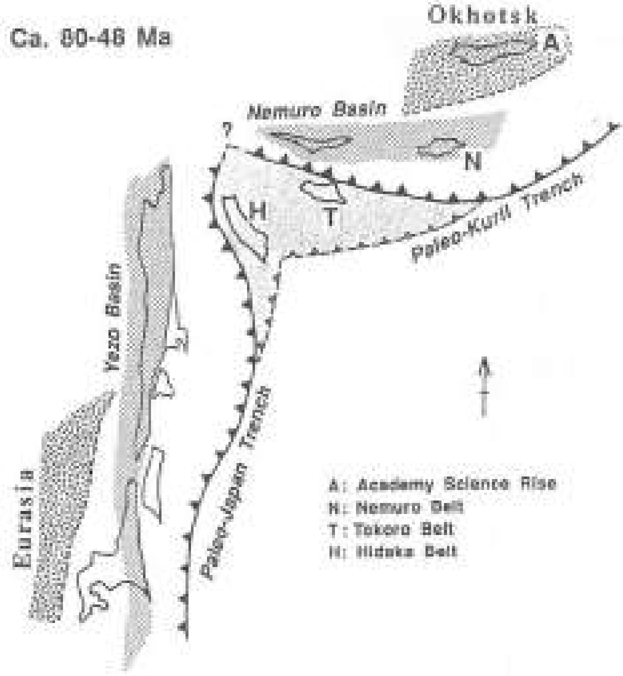

Fig. 3. Paleogeographic reconstruction of Hokkaido during Cretaceous to Paleogene time. Modified after Nanayama (1991).

constitute an axial part, the so-called 'Kamuikotan Tectonic Belt', of a large-scale anticlinorium (Maekawa, 1983; Ishizuka et al., 1983; Ishizuka, 1985; Niida & Kito, 1986; Nakagawa & Toda, 1987). Therefore, the Yezo Supergroup is distributed in both of the eastern and western sides of the axis forming two rows.

The Sorachi Group is lithostratigraphically characterized by such greenstones as massive or pillow basalt of MORB type lava and submarine pyroclastics including hyaloclastite in the lower part, and by green chert, siliceous shale, mudstone, volcanogenic sandstone turbidite and acidic tuff in the upper. Micritic limestone lenses are subordinately intercalated. This group is thought to represent the upper part of ophiolite sequence generally (Kito et al., 1986). The radiolarian biostratigraphy of the Furano area in the central part of the belt suggests that the Sorachi Group is Tithonian to Valanginian-Barremian in age (Kito, 1987). The stratigraphic relation with the Yezo Supergroup is now thought to be conformable (Kanie, et al., 1981; Kiminami et al., 1985; Kito, 1987).

In the central part of the Sorachi-Yezo Belt, the Yezo Supergroup widely crops out in the eastern and western slopes of the Yubari mountain range whose core is composed of the Sorachi Group and the Yubari-dake serpentinite melanges (Nakagawa & Toda, 1987). The Supergroup of the west has been well studied as the basement rocks for the Eocene coal measures called the Ishikari Group. The Ishikari Coal Field region including the Ashibetsu, Ikushumbetsu, Manji, Oyubari and Yubari areas from north to south, is a classical and important region also for the Cretaceous biostratigraphy in Japan since Matsumoto (1942-43) (Fig. 4). Particularly, the Ikushumbetsu and Oyubari areas are the standard and reference areas, because of the much more abundance in zonal megafossils as ammonites and inoceramids than other areas.

The Yezo Supergroup in the Ishikari Coal Field region is structurally characterized by the N-S trending and north plunging Sorachi Anticline in the north, the NNE-SSW trending and south plunging Ikushumbetsu Anticline in the mid-west, and the Manji and Hatonosu Domes in the south. In the east bordering the Yubari mountain range, it strikes NNE to N, and steeply overturns west. Westward thrusts and nappe structures are conspicuous in the western part of the Oyubari area (Figs. 4, 5).

STRATIGRAPHY

The very thick siliciclastic sequence of the Yezo Supergroup during Barremian to Maastrichtian extends 8,000 m in thickness along the type section of the Oyubari area (Matsumoto, 1942-43; Nagao et al., 1954; Hirano et al., 1980, 1981; Motoyama et al., 1991). It has been conventionally divided into the Lower, Middle and Upper Yezo Groups and Hakobuchi Group since Matsumoto (1951)'s stratigraphic revision following the quadripartite division by Yabe (1909, 1926) (Fig. 6). Recently, they are all included into the Yezo Supergroup by Okada (1983) as forearc basin sequence in contrast with the conformably underlying Sorachi Group of ocean floor sequence. As the five groups are recently known to be generally conformable except some local discordance (Kito et al., 1986; Kito, 1987, etc.), they may be categorized down to formations in the sense of nomenclature. Though Mo-

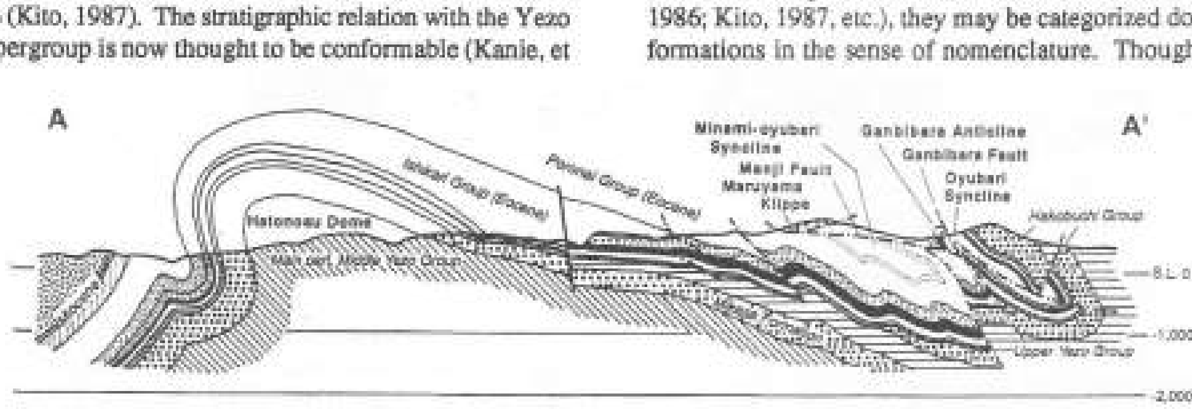

Fig. 4. Geological cross section from the Yubari to Oyubari areas. Modified after Shimokawa (1967). Location shown in Fig. 5.

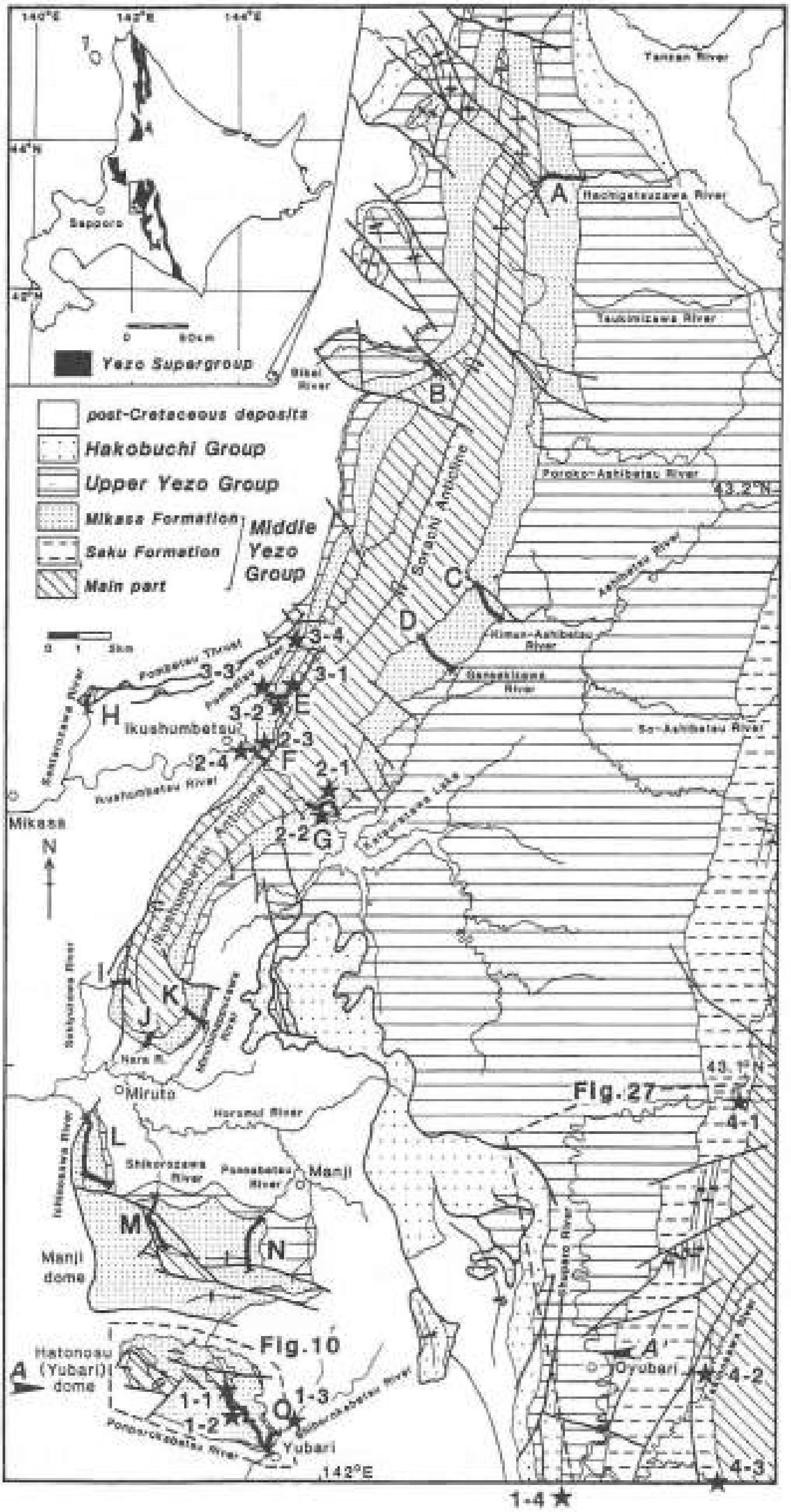

Fig. 5. Simplified geological map of the Yezo Supergroup in the Ishikari Coal Field region, central-western Yezo-Sorachi Belt. Broken lines for location of Figs. 10 and 27. A-A': location of Fig. 4. Modified after Ando (1990a).

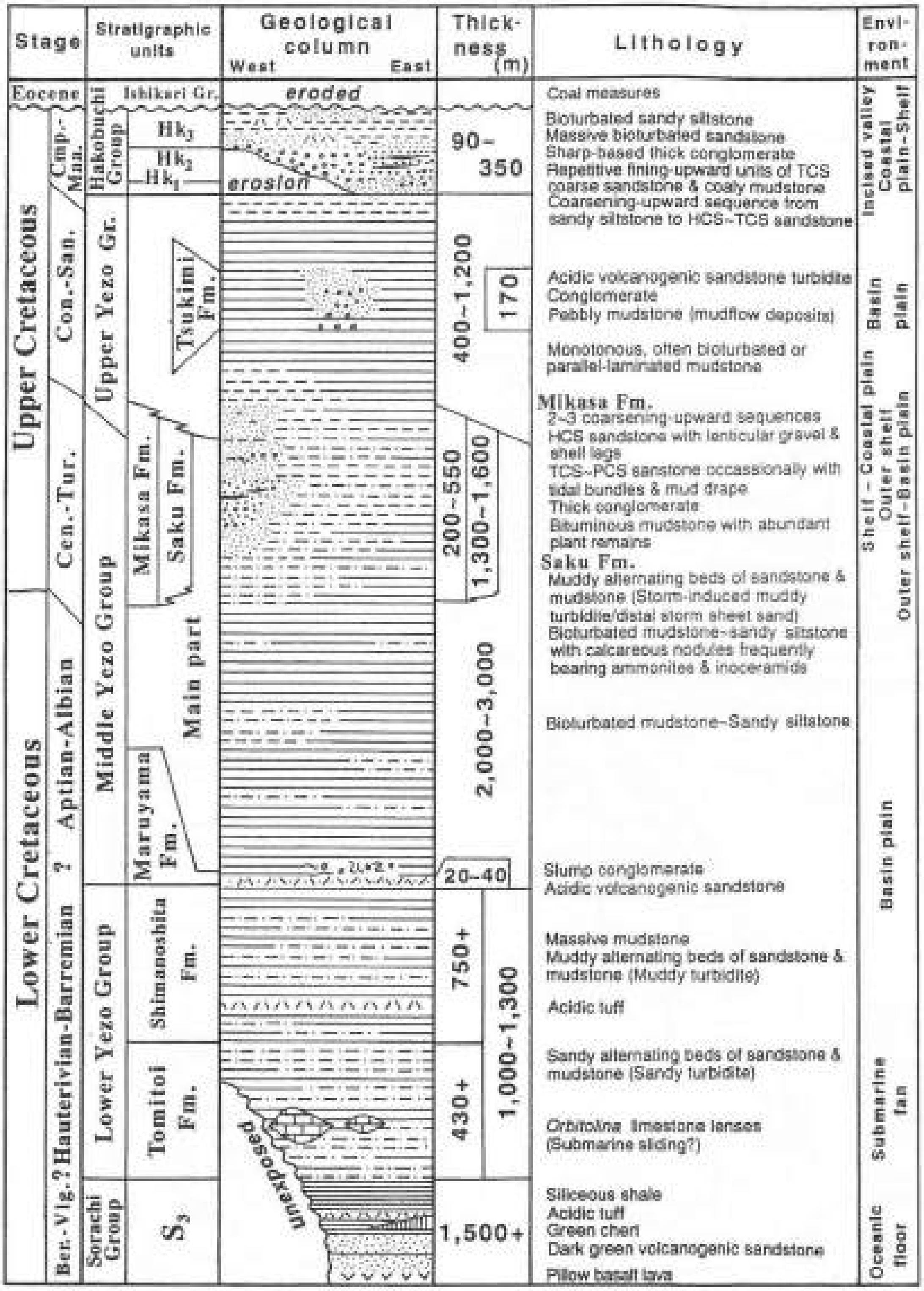

Fig. 6. Geological columnar section of the Yezo Supergroup in the Ishikari Coal Field region.

toyama et al. (1991) recently assigned the second to fourth together to the Yezo Group, we follow the Okada (1983)'s usage to avoid nominal confusion here.

Synthesized but still tentative biostratigraphical zonation mainly based on the Yezo Supergroup (Upper Albian to Maastrichtian) is very recently provided by Matsumoto and his coworkers (Matsumoto, 1991, Matsumoto et al., 1991; Tables 2, 3).

Lower Yezo Group

This group conformably overlying the Sorachi Group (Kito, 1987), is characterized by mainly muddy to sandy

Table 2. Zonation of the Cenomanian and Turonian in Japan (Adapted from Matsumoto et al., 1991).

STAGE	SUBSTAGE		Ammonite Zone: Desmoc.		Ammonite Zone: Acanthocerataceae	Inoceramid Zone	Planktonic foraminifera Zone		Benthic foraminifera Zone
Lower Coniacian				*Mesopuzosia yubarensis*	*Forresteria (Harleites) petrocoriensis*	*Inoceramus rotundatus*	*Dicarinella primitiva* Range-zone		*Silicosigmoilina ezoensis* — *Rzehakina epigona* Concurrent-range-z.
TURONIAN	Upper	K4b3	*Tragodesmoceroides subcostatus*; *T. matsumotoi*	*Mesopuzosia yubarensis*	*Subprionocyclus (Reesidites) minimus*	*I. tenuistriatus* — *Mytiloides incertus*	*Dicarinella canaliculata* — *Marginotruncana marginata* Acme-zone		*Silicosigmoilina ezoensis* — *Rzehakina epigona* Concurrent-range-z.
TURONIAN	Upper	K4b3	*Tragodesmoceroides subcostatus*; *T. matsumotoi*	*Mesopuzosia yubarensis*	*Subprionocyclus neptuni*	*Inoceramus teshioensis*	*Dicarinella canaliculata* — *Marginotruncana marginata* Acme-zone		*Silicosigmoilina ezoensis* — *Rzehakina epigona* Concurrent-range-z.
TURONIAN	Middle	K4b2	*Tragodesmoceroides subcostatus*	*Mesopuzosia pacifica*	*Collignoniceras woollgari*	*Inoceramus hobetsensis* — *Mytiloides teraokai*	*Helvetoglobotruncana helvetica* Range-zone		*Textularia hikagezawensis* *Silicosigmoilina ezoensis* Interval-zone
TURONIAN	Middle	K4b2	*Tragodesmoceroides subcostatus*	*Mesopuzosia pacifica*	*Neomphaloceras pseudomphalum*	*I. aff. hobetsensis* — *I. costatus*	*Helvetoglobotruncana helvetica* Range-zone		*Textularia hikagezawensis* *Silicosigmoilina ezoensis* Interval-zone
TURONIAN	Lower	K4b1	*Tragodesmoceroides subcostatus*	*Puzosia orientalis*	*Fagesia thevestensis* — *Mammites aff. nodosoides*	*M. subhercynicus*; *Inoceramus aff. saxonicus* — *Mytiloides mytiloides*	*Whiteinella archaeocretacea* Partial-range-zone		*Textularia hikagezawensis* *Silicosigmoilina ezoensis* Interval-zone
TURONIAN	Lower	K4b1	*Tragodesmoceroides subcostatus*	*Puzosia orientalis*	*Pseudaspidoceras flexuosum*	*Mytiloides columbianus* (?)	*Whiteinella archaeocretacea* Partial-range-zone		*Textularia hikagezawensis* *Silicosigmoilina ezoensis* Interval-zone
CENOMANIAN	Upper	K4a 6	*Desmoceras (Pseudouhligella) japonicum* —	*D. (Pr.) ezoanum*	*Neocardioceras juddii* (not yet confirmed)	*Inoceramus nodai* (small form)	↓ ?		*Textularia hikagezawensis* Range-zone
CENOMANIAN	Upper	K4a 5	*Desmoceras (Pseudouhligella) japonicum* —	*D. (Pr.) ezoanum*	*Eucomphaloceras septemseriatum*	*I. pictus minus* — *M. mikasaensis*; *I. nodai*	*Rotalipora cushmani* — *Rotalipora greenhornensis* Range-zone	*Rotalipora* Partial range zone	*Textularia hikagezawensis* Range-zone
CENOMANIAN	Upper	K4a 4	*Desmoceras (Pseudouhligella) japonicum* —	*D. (Pr.) ezoanum*	*Eucalycoceras pentagonum*	*Birostrina nipponica*; *I. reduncus*; *I. pennatulus*; *I. ginterensis*; *I. nodai*	*Rotalipora cushmani* — *Rotalipora greenhornensis* Range-zone	*Rotalipora* Partial range zone	*Textularia hikagezawensis* Range-zone
CENOMANIAN	Middle	K4a3	*Desmoceras (Pseudouhligella) japonicum* —	*D. (Pr.) ezoanum*	*Calycoceras (Newboldiceras) orientale*	*Birostrina tamurai*; *I. reduncus*; *I. pennatulus*; *I. ginterensis*	*Rotalipora cushmani* — *Rotalipora greenhornensis* Range-zone	*Rotalipora* Partial range zone	*Textularia hikagezawensis* Range-zone
CENOMANIAN	Middle	K4a3	*Desmoceras (Pseudouhligella) japonicum* —	*D. (Pr.) ezoanum*	*Cunningtoniceras takahashii*	*Inoceramus tenuis* — *Inoceramus virgatus*	*Rotalipora evoluta*	*Rotalipora* Partial range zone	*Textularia hikagezawensis* Range-zone
CENOMANIAN	Lower	K4a 2	*Desmoceras (Pseudouhligella) japonicum* —	*D. (Pr.) ezoanum*	*Acompsoceras renevieri*	*Inoceramus tenuis* — *Inoceramus virgatus*	*Rotalipora evoluta*	*Rotalipora* Partial range zone	*Textularia hikagezawensis* Range-zone
CENOMANIAN	Lower	K4a 2	*Desmoceras (Pseudouhligella) japonicum* —	*D. (Pr.) ezoanum*	*Mantelliceras japonicum*	*Inoceramus tenuis* — *Inoceramus virgatus*	*Rotalipora evoluta*	*Rotalipora* Partial range zone	*Textularia hikagezawensis* Range-zone
CENOMANIAN	Lower	K4a 1	*Desmoceras kossmati*		*Graysonites adkinsi* — *Graysonites wooldridgei*	*Inoceramus aff. virgatus* (small form)	Partial-range-zone	*Rotalipora* Partial range zone	*Textularia hikagezawensis* Range-zone
Uppermost Albian			*D. (Pr.) dawsoni shikokuense*		*Mortoniceras (Cantabrigites) aff. subsimplex*	*Inoceramus anglicus* — *Birostrina subsulcatus*	*Rotalipora evoluta* — *Ticinella primula* Interval-zone		*Tritaxia disjuncta* Assemblage-zone

Table 3. Tentative zonation of the Coniacian-Maastrichtian in Japan. Unpublished compilation by S. Toshimitsu, M. Noda & T. Matsumoto.

STAGE	Substage		Ammonite Zone: Desmoceratacese	Ammonite Zone: Selected associate	Inoceramid Zone or inoc species associated with ammonites	Foraminiferal Zone: Planktonic	Foraminiferal Zone: Benthic	Radiolarian Zone: Hokkaido	Radiolarian Zone: SW Japan	Calcareous nannofos. Zone	Paleo-magne
L. Paleocene						*Subbotina triloculinoides*	*Praebulimina angulata Cyclammina* Assembl.-z.				
MAASTRICHTIAN	Upper	K6b2	*Pachydiscus (P.) flexuosus*	*Gaudryceras hamanakense*		*Rugoglobigerina* Assemblage-zone	*Spiroplectammina grzybowskii*- *Silicosigmoilina futabaensis* Concurrent-range-zone				
			P. (Neodesmo.) gracilis	*G. venustum*	*Sph. hetonaiensis*						
	Lower	K6b1	*Pachyd. (P.) kobayashii*		*I. (?) kusiroensis*				*Pseudotheocampe abschnitta* Assemblage-zone		31r 32 1r
			P. (Neod.) japonicus	*Nostoceras hetonaiense*	*I. (E.) shikotanensis*						
CAMPANIAN	Upper	K6a3	*Pachyd. awajiensis*	*Pravitoceras sigmoidale*		*Globotruncana arca* Assemblage-zone	*Marginulina* sp. A - *Silicosigmoilina futabaensis* Concurrent-range-zone		*Amphipyndax tylotus* Assemblage-zone		32r 33
			Patagiosites laevis (*Desmophyllites diphylloides*)	*Didymoceras awajiense*							
			Anapachydiscus fascicostatus	*Metaplac. subtilistr.*- *Hoplitoplac. monju*	*Mytiloides shimanskii*						
	Lower	K6a2	*Canadoceras kossmati*	*Delawarella* sp.	*Sph. schmidti* - *Sph. orientalis* - *I. (Pl.) chicoensis*			*Spongostaurus (?) hokkaidoensis*	*Dictyomitra koslovae* Assemblage zone		33r
		K6a1	*Anapachydiscus naumanni*	*Menuites masenoi* *Submort. cf. condamyi*	↑ *I. (Platyceramus) japonicus*					CC18	
SANTONIAN	Upper	K5b2	*Eupachydiscus haradai*	*Plesiotexanites shiloensis*	*Sph. nagaoi*			*Orbiculiforma quadrata*		CC15-17	34
	Lower	K5b1	*Anapachydiscus sutneri* (*Damesites damesi*)	*Plesiotexanites kawasakii* *Texanites collignoni*	*I. amakusensis* (*Sph. naumanni*)	*Rosita fornicata*- *Marginotruncana pseudolinneiana* Concurrent-range-zone *Dicarinella concavata* Acme-zone	*S. futabaensis* - *S. ezoensis* Concurrent-range-zone		*D. koslovae* Assemblage-zone	CC14	
CONIACIAN	Up.	K5a2	*Kossmaticeras theobaldianum*	*Paratexanites orientalis*	*I. (Cremnoc.) mihoensis* (*I. (Pl.) mamatlii* -)	*Dicarinella canaliculata*-	*S. ezoensis*- *Rzehakina epigona* Concurrent-range-zone	*Archaeospongoprunum triplum*	*D. densicostata* Assemblage-zone	CC13	
	Mid.	K5a1		*Forresteria (F.) alluaudi*	*I. uwajimensis*	*Dicarinella primitiva*		*Squinabollum fossilis*		CC11-12	
	Low.			*F. (Harleites) petrocoriensis*	*I. (Cr.) rotundatus*			*Dictyomitra formosa*			
Up. TURONIAN			*Damesites ainuanus*	*Subprionocyclus (Reesidites) minimus*	*I. tenuistriatus*- *I. teshioensis* - *M. incertus*	*Marginotruncana marginata* Acme-zone			*D. formosa* Assemblage-zone		

turbidites and offshore mudstone with a limestone member. The lower part called the Tomitoi Sandstone prevails sandy turbidites. The age is confirmed to be within late Valanginian to middle Barremian on the base and middle Albian under the top, on the basis of very rarely discovered ammonites as *Pseudohaploceras*, *Parahoplites colossus* Matsumoto, *Douvilleiceras* and *Oxytropidoceras* (Matsumoto, 1977, 1984), and recently extracted radiolarians (Kito, 1987). The maximum total thickness is about 1,300 m in the type Oyubari section.

Lenticular reef limestones known as *'Orbitolina* limestones' are sporadically found in the muddy turbidite facies. The distinct difference of the lithofacies and inferred environment is recognized between the limestones and their surroundings. Therefore, they may have been originally deposited around tectonic highs or trench-slope break and were allochtonously displaced later by submarine sliding (Okada, 1974; Niida & Kito, 1986). These Urgonian-type limestones are correlated with the shallow-marine Miyako Group in the Sanriku Coast in northeast Honshu as extension, in terms of the fossil composition (e.g. rudists, nerinean gastropods, corals, hydrozoas, calcareous algae in addition to *Orbitolina* ; Yabe & Hanzawa, 1926, etc.).

Middle Yezo Group

The Middle Yezo Group is mainly composed of dark gray to bluish gray, thick offshore mudstone and occasionally intervening muddy turbidite beds except the shallower and coarser sediments of the upper part. The entire thickness reaches over 2,000 to 3,000 m. Prolific and well-preserved ammonites and inoceramids obtained from calcareous nodules of various sizes, indicate the group middle Albian to late Turonian in age, though its upper limit is more or less diachronous.

The lower half, the so-called 'Main part' starts with the basal acidic tuff a few tens to 40 m thick, which was named IIa by Matsumoto (1942-43), Okunosawa siliceous sandstone by Nagao et al.(1954) and Maruyama Formation by Motoyama et al.(1991). Some pebbly mudstones of slump origin, whose gravel may have been derived from the Sorachi and the Lower Yezo Groups, are intervened near the basal part (Hashimoto, 1955; Yoshida & Kambe, 1955). The late Albian age of the lower half is based on the rarely discovered standard ammonites as *Mortoniceras*, *Desmoceras* and others.

The upper half shows variable lithological changes due to the increase of sand influx from the westerly hinterland. The Mikasa Formation 300 to 700 m thick represents the western marginal facies of the Yezo basin. It is mainly composed of shallow-marine to coastal sandstone, conglomerate and siltstone which yield such bivalves as trigoniids, glycymerids, Ostrea, etc., more commonly than ammonites. The Saku Formation representing the contemporaneous heterotopic eastern facies consists of offshore mudstone frequently intercalated with thin sandstone layers, often forming thin-bedded turbidites or distal storm sheet sandstone beds. Slump structure is occasionally observed. The thickness is a few times of the Mikasa Formation. The abundant ammonites and inoceramids enable biostratigraphic zonation from the Upper Cenomanian to Middle Turonian. Paleocurrent analyses of the Saku Formation by Tanaka (1963, 1970) and Tanaka & Sumi (1981) showed that turbidity currents are characterized by dominant axial currents from SSW and lateral currents mainly from the west.

Upper Yezo Group

The offshore mudstone strata attaining 400 to 1,200 m thick, which gradually overlie the sandy strata of the upper Middle Yezo Group, are assigned to the Upper Yezo Group. They are rarely intercalated with thin sandstone layers and very thin layers of acidic to intermediate tuff. Due to the monotonous and homogeneous muddy lithology, the subdivision is difficult. But cyclic units are recognized in terms of grain size of mud, abundance of calcareous or siderite nodules and fossil contents (Tanaka, 1963). The base of the group is diachronous from early Turonian in the northern Ashibetsu area to Coniacian in the Yubari area. Prolific ammonites and inoceramids indicate the Group Coniacian to early Campanian in age.

Locally in the Ashibetsu area, the middle part interfingers with thick volcanic sandstone turbidite and some conglomerate 250 m in thickness, called the Tsukimi Formation (Shimizu et al., 1953).

Hakobuchi Group

This group is sandy and conglomeratic strata overlying the Upper Yezo Group gradationally in some places or abruptly in other places. It is distributed in the northern part of the Sorachi Anticline and separately in the Oyubari and the more southern areas. It comprises three formations (Hk_1, Hk_2, Hk_3), according to Shimizu et al. (1953). The lower one (Hk_1) shows a coarsening-upward sequence gradually from mudstone of the Upper Yezo Group, composed of the shallow-marine, HCS or massive sandstone. The middle (Hk_2) consists of thick fluvial channel to beach conglomerate, and coastal plain, plant remains-bearing sandstone and mudstone associated with coaly seams. The basal conglomerate of the middle formation overlies the Upper Yezo Group with an erosional sharp base and the sudden facies change where lacking the lower formation . The upper formation (Hk_3) is composed of thick and massive, lower shoreface sandstone and sandy mudstone.

No marine fossils occur in the Oyubari and the northern areas except for the lower formation. However, ammonites and inoceramids common in the southern area assign the group approximately to Upper Campanian and Lower Maastrichtian. Acidic to intermediate tuff layers are more intercalating at some horizons than in the lower groups. The thickness of the group varies from 450 m along the type Hakobuchi gorge in the Oyubari area to 900 m in the Hobetsu and Tomiuchi areas south of Oyubari where shallow marine deposits become to dominate instead of coastal plain ones.

MIKASA FORMATION AS THE WESTERN MARGINAL FACIES

As the Yezo Supergroup is generally dominated by mudstone and muddy turbidite facies, offshore sedimentation has been well studied by many geologists (Tanaka, 1963; Matsumoto & Okada, 1973; Tanaka & Sumi, 1981, etc.). On the other hand, the shallow-marine and coastal facies as the Mikasa Formation, Middle Yezo Group provide more evidence for marginal sedimentation, paleogeography and local relative sea-level change of the central-western Yezo forearc basin (Obata & Futakami, 1977; Futakami, 1986a,b; Ando, 1990a, b). Some of the previous researches emphasized the petrography and provenance of sandstone (Fujii, 1958; Okada, 1965; Matsumoto & Okada, 1971; Okada, 1974).

Facies changes and sedimentary environments

The Uppermost Albian to Upper Turonian Mikasa Formation (Matsumoto, 1951, 1954) is distributed along the Sorachi-Ikushumbetsu Anticline and the Manji and Hatonosu Domes (Fig. 4). Its single and thick body of shallow-marine to coastal sandy strata (<450 m thick) in the western area, grades eastward into a few tongues (each < 100m), and thins out more eastward with thickening of offshore muddy strata (700 m in total thickness). The lateral and vertical facies changes show onshore-offshore gradients of the westward-coarsening (shallowing) depositional environments (Ando, 1990a, b; Fig. 7).

The abundance of storm deposits represented by hummocky cross-stratified (HCS) sandstone (Harms et al., 1982; Dott & Bourgeois, 1982) suggests that storm-dominated lower shoreface and sandy upper shelf were well developed as a delta front. Disarticulated, thick-shelled bivalves (*Pterotrigonia, Apiotrigonia, Yaadia, Glycymeris, Aphrodina* and others) are often concentrated in gravel or shell lags and hummocky cross-laminated units (H: Dott & Bourgeois, 1982). The species composition varies depending on the age and environments of horizons. Forset inclinations of medium-scale cross-stratified, thick-bedded coarse- to medium-grained sandstone, suggest longshore currents of NNE-SSW direction on the wave-dominated upper shoreface with longshore bars and troughs. Tidal flat and lagoon behind barrier bars associated with oyster reefs and tidal channels in places, seem to have been developed along coastline, on the basis of thick and variable tidal deposits. Thick conglomerate suggests gravelly rivers supplying a large amount of coarse sediments from westerly volcanic arc (Rebun-Kabato Belt). Gravel had been transported into beach by storm waves, and had filled troughs and rip channels on upper shoreface. A few thick layers of black mudstone with abundant plant remains indicate that back-marsh and swamp were somewhat developed on a delta plain.

On the other hand, storm-induced turbidites or distal storm sheet sands have been deposited on wide muddy

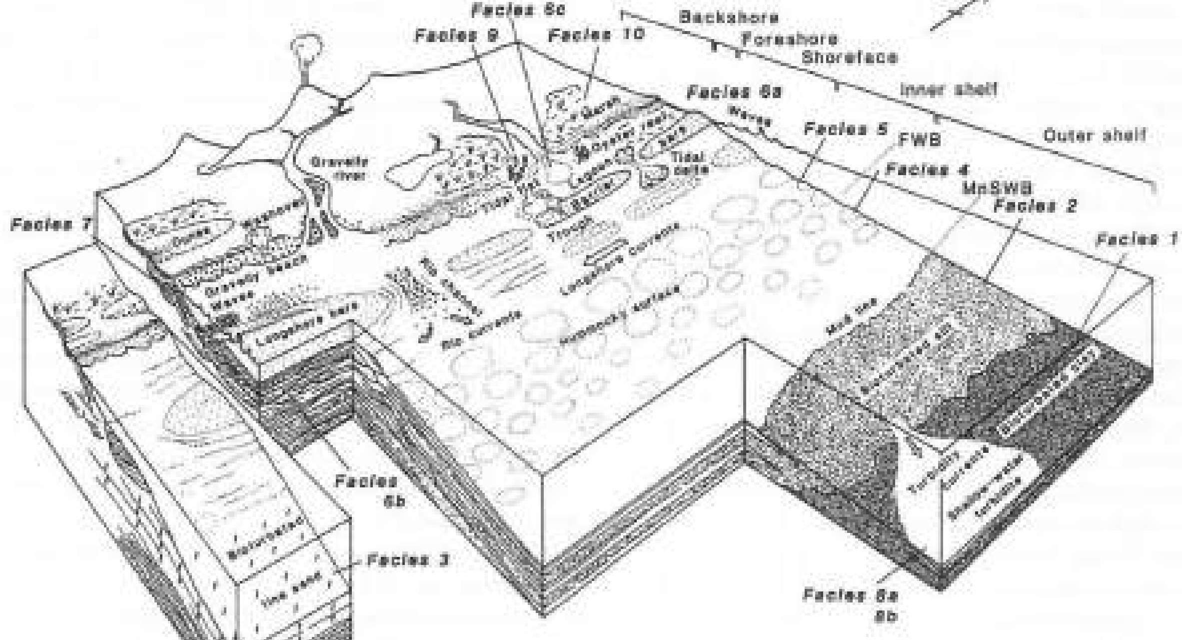

Fig. 7. Schematic reconstruction illustrating depositional environments and bedding sequences for the Mikasa Formation. MnSWB: mean storm wave base; FWB: fair weather wave base. After Ando (1990a).

outer shelf to basin plain below maximum storm wave base. This muddy turbidite is the main facies of the heterotopic Saku Formation distributed extensively in the eastern part of the Ishikari Coal Field region as the Ashibetsu, to Hobetsu through Oyubari areas (Matsumoto & Okada, 1973). Besides, offshore mudstone facies crop out in the eastern slope of the Yubari mountain range typically as the Hidaka area (Obata & Futakami, 1977).

Relative sea-level changes

The Mikasa Formation comprises three or two coarsening-/shallowing-upward sequences with a few small-scale sequences (parasequences: van Wagoner, 1988). Local and relative sea-level changes during latest Albian to late Turonian are preliminarily inferred from the facies distribution of the Mikasa formation, assuming that the subsidence rate and sedimentation rate are constant, and that the bed thickness is time-linear (Fig. 8). The generalized stratigraphic cross section along a west-east line about 10 km long is a composite of the first and second sequences in the Ikushumbetsu area and the third in the Manji area. Paleodepth curves are inferred from vertical facies changes in each side. The very thick inner shelf and coastal facies more than 220 m thick above turbidite facies in the first sequence, suggest high rate of local relative sea-level rise by basin subsidence. Relative sea-level might have risen 140 m at least, assuming maximum storm wave base is 80 m in depth. The long-term relative sea-level rise after a major fall in early Cenomanian had kept until late Turonian. The oscillations of small-scale, rapid rise and stand-still during late Cenomanian to middle Turonian are somewhat similar to the representative part of Haq et al.(1988)'s curve. The sedimentation during the age may have reflected the global eustacy.

RELATIONSHIP BETWEEN LITHO- AND BIOFACIES

The post-Aptian Yezo Supergroup in central Hokkaido yields abundant molluscan fossils at various horizons, allowing us to investigate the relationship between litho- and bio-facies. The molluscan assemblages show marked facies-linked lateral changes with respect to their species composition and mode of occurrence. This phenomenon is especially conspicuous in the Turonian during which a regression proceeded (Tanabe et al., 1978; Tanabe, 1979; Futakami et al., 1980; Matsumoto et al., 1981; Futakami, 1982; Futakami & Miyata, 1983; Ando, 1990b).

As summarized in Fig. 9, the Turonian strata of the Yezo Supergroup can be classified into three major sedimentary facies, i.e. inshore to nearshore, "intermediate", and offshore flysch facies. In the eastern offshore facies megafossils are rather rare, and ammonites mostly belong to smooth or weakly ornate morphotypes such as phylloceratids, desmoceratids and tetragonitids.

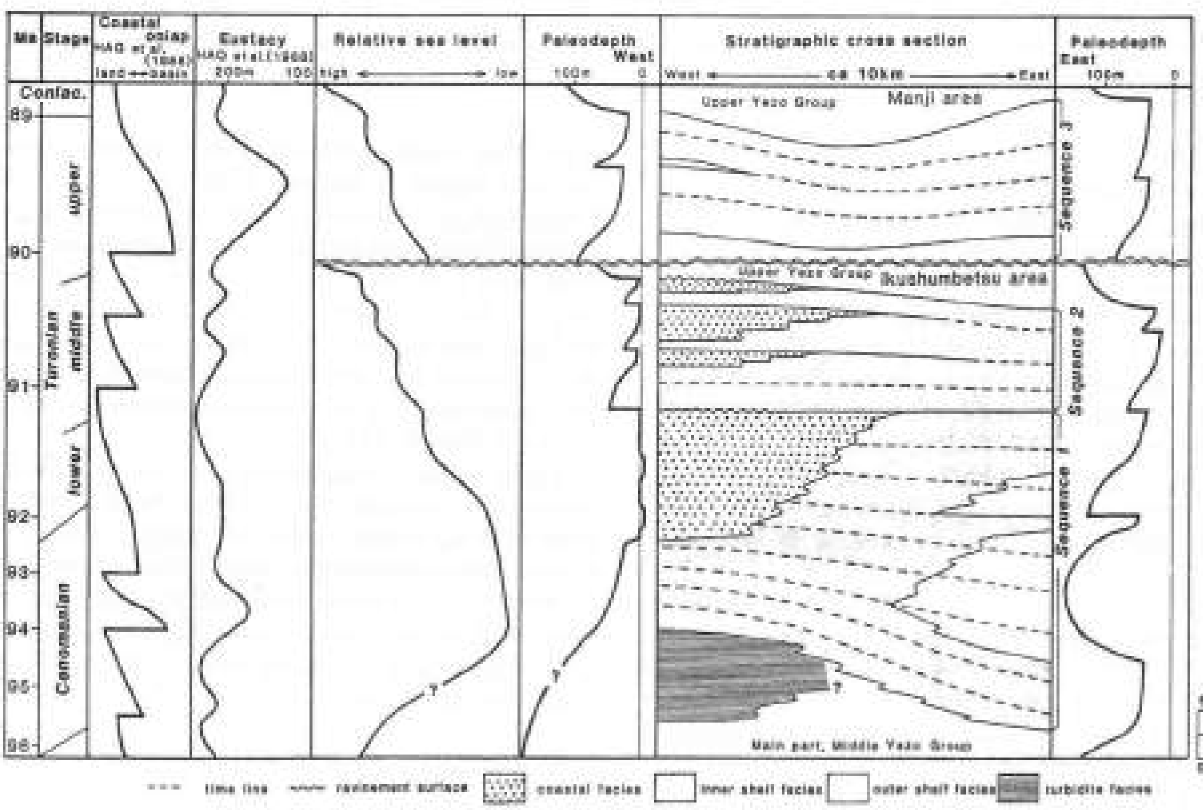

Fig. 8. Relative sea-level change in the western margin of the Yezo basin during late Albian to late Turonian, inferred from the facies distribution of the Mikasa Formation. Broken lines mean approximate time lines. After Ando (1990b).

WESTERN PART ←			CENTRAL PART			→ EASTERN PART	
Area	Hatonosu-Manji	Pombets	Saku	Oyubari	Ohira S.W. area	Ohira N.E. area	Hidaka-cho
Thickness	140-380 m	340 m ±	470 m ±	500 m ±	ca. 700 m	1200 m	600-700 m
Lithology	mainly fine to medium sandstone with some lenses of conglomerate	fine sandstone & sandy siltstone with thin beds of conglomerate	siltstone, alternating sandstone & mudstone, & thin beds of sandst.	alternating fine sandstone & mudstone, silty mudstone & some beds of tuffite	fine sandstone, sandy siltstone with some lenses of conglomerate	silty mudstone & tuffite	mainly mudstone
Plant fragments	very abundant	abundant	common	common	abundant	common	rare
Ostreids	abundant	abundant	abundant	absent	rare	absent	absent
Trigonians	abundant	abundant	rare	absent	absent		absent
Presumable paleoenvironment	inshore to nearshore "shelf-like" facies		"intermediate" facies of MATSUMOTO and OKADA (1973)			offshore flysch facies	

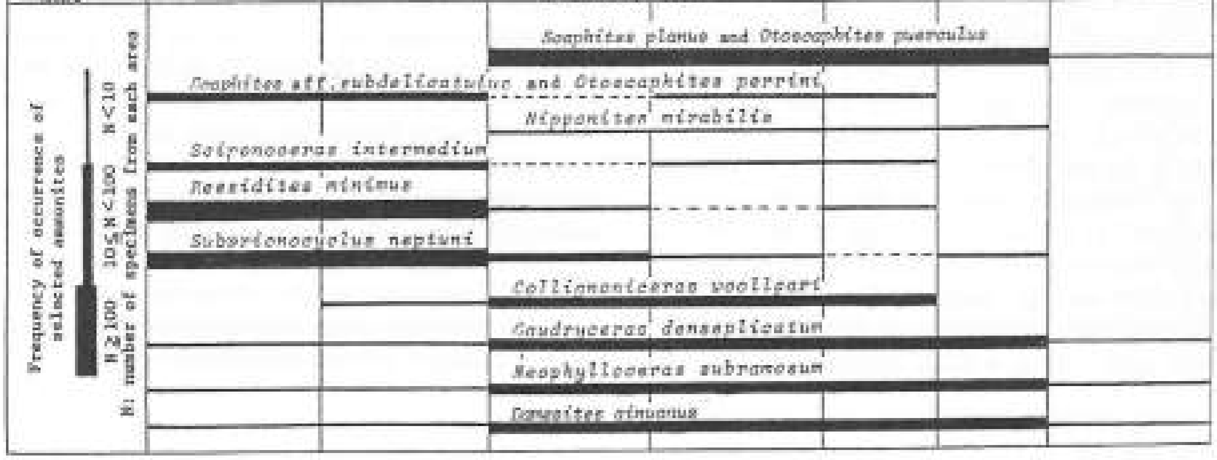

Fig. 9. Summary of litho- and bio-facies and frequency of occurrence of selected ammonite species in the Turonian sequences of Hokkaido (after Tanabe et al., 1978).

The "intermediate" facies are nearly equivalent to the Saku Formation of Matsumoto & Okada (1973) represented by a thick sequence of silty mudstone with frequent intercalations of fine-grained sandstone. The Saku Formation yields abundant molluscan fossils, especially ammonites and inoceramid bivalves (Matsumoto, 1942-43; Hirano, 1986). The ammonite assemblages from the formation generally have a high species diversity and consist of various morphotypes including heteromorphs (scaphitids, nostoceratids, diplomoceratis and baculitids), smooth or weakly ornate morphotypes (tetragonitids, gaudryceratids, phylloceratids, desmoceratids), and ornate morphotypes (*Romaniceras* spp., *Collignoniceras woollgari*, *Subprionocyclus neptuni*, etc.).

The inshore to nearshore facies represented by the Mikasa Formation are restricted to the western marginal areas of the Ishikari Coal Field region such as the Manji, Yubari, Pombetsu and Bibai areas. In HCS sandstones of the Mikasa Formation shallow-water bivalves (ostreids, trigonians, *Glycymeris*, *Aphrodina* etc.) and gastropods occur more abundantly than ammonoids, forming lenticular lag concentrations of apparently allochthonous storm origin. Ammonites occasionally occur at several horizons in fine-grained sandstone (H) and silty sandstone (Mb) units. They consist mostly of collignoniceratids (*Subprionocylcus neptuni*, *S. minimus*, *Lymaniceras planulatum*, *Subprionotropis muramotoi*, and *Prionocyclus* spp.). Species diversities of most ammonite assemblages from these facies are much smaller than those from the "intermediate" facies (Tanabe et al., 1978; Tanabe, 1979). In the Manji and Hatonosu areas specimens of *S. neptuni* and *S. minimus* frequently associate jaws within their body chambers, suggesting their autochthonous origin (Tanabe & Fukuda, 1987).

Original habitat distribution and post-mortem transportation or drift may both have controlled the facies-linked distribution and modes of occurrence and preservation of actual ammonite assemblages. As summarized above, the marked differences in shell morphology, mode of occurrence and distribution pattern among Turonian ammonites in Hokkaido may reflect the diversity of habitats and mode of life among them.

DESCRIPTION OF FIELDSTOPS

DAY 1

Stop 1-1: Forestry road along the Ponporokabetsu River. Upper Albian of the Main part, Middle Yezo Group in the Hatonosu Dome

The Cretaceous sequence of the Yubari (Hatonosu) area forms a dome-like structure called the Hatonosu Dome (Otatsume, 1950) as the southern extension of the Ikushumbetsu Anticline (Fig.10). It is stratigraphically divided into three units, the Main part and the Mikasa Formation of the Middle Yezo Group and the Upper Yezo Group in ascending order (Fig. 11). In accordance with the evidence of megafossils, they are assigned to the

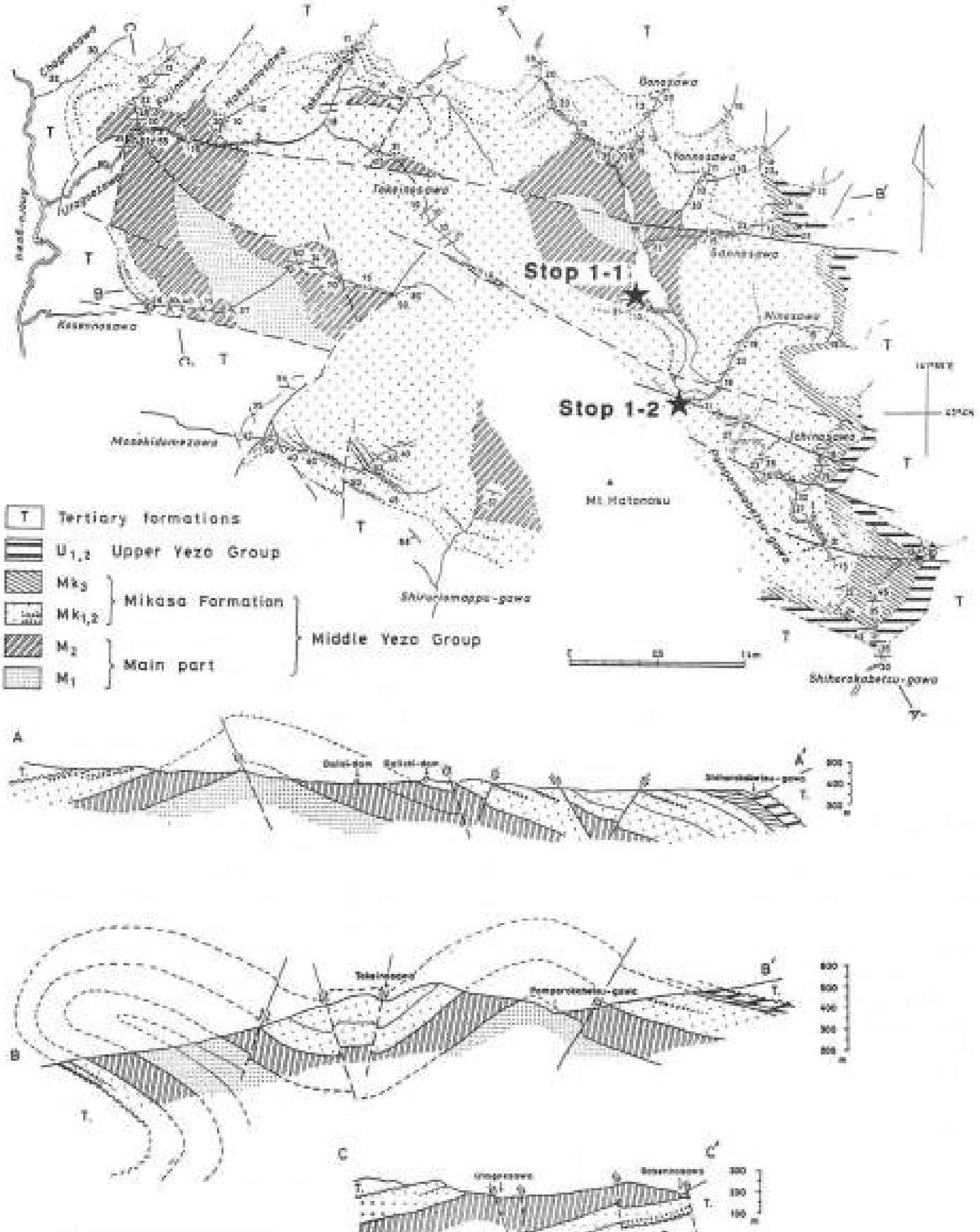

Fig. 10. Geological map and sections of the Yubari (Hatonosu) area. Location shown in Fig. 5. After Futakami (1982).

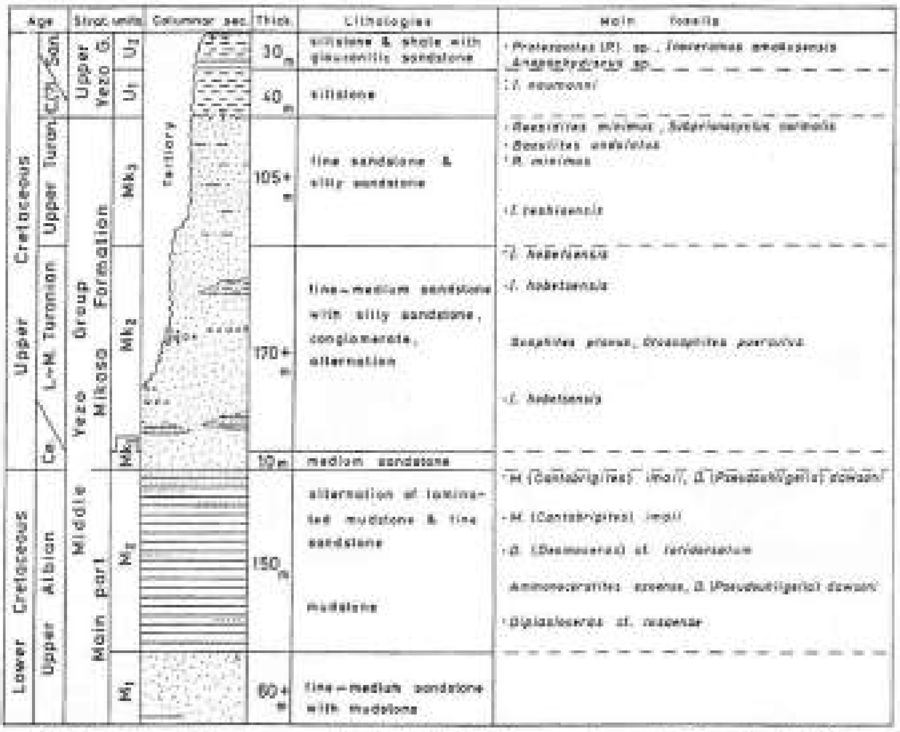

Fig. 11. Synthesized columnar section in the Yubari (Hatonosu) area. After Futakami (1982).

Upper Albian, Cenomanian-Turonian, and Coniacian-Santonian, respectively. The latter two are clino-unconformably overlain by coal-bearing sandstone and mudstone or pebble conglomerate of the Eocene Ishikari Group.

The following occurrences are particularly important in biostratigraphy: (1) some species of *Mortoniceras* and *Diplasioceras*, which are the most important indices of the Upper Albian, from the middle stream of the Ponporokabetsu River and its forestry road; (2) collignoniceratid ammonites such as *Subprionocyclus minimus* (Hayasaka & Fukada) and *S. neptuni* (Geinitz), both of which are the most important indices of the Upper Turonian, from the Shihorokabetsu River and eastern branches of the Ponporokabetsu River (Futakami, 1982, 1990; Futakami & Miyata, 1983).

At this stop the Upper Albian strata of the Main part, Middle Yezo Group and the ammonite fauna can be observed along the Ponporokabetsu Forestry Road (Fig. 12). The Main part consists of mudstone with thin layers of fine-grained sandstone in the upper part and fine- to medium-grained sandstone beds in the lower. Though megafossils are not yet found from the sandstone bed, the following ammonite species are obtained from the mudstone bed: *Desmoceras (Pseudouhligella) dawsoni* Whiteaves, *D. (Desmoceras) latidorsatum* (Michelin), *Puzosia subcorbarica* Matsumoto, *Mortoniceras (Cantabrigites) imaii* (Yabe & Shimizu), *Diplasioceras* cf. *tosaense* Matsumoto & Hirata, *M. (Deiradoceras)* sp., *Anagaudryceras* sp., *Idiohamites tuberculatus* (Sowerby).

Stop 1-2: Forestry road along the Ponporokabetsu River. Middle Turonian of the Mikasa Formation, Middle Yezo Group

The Cenomanian-Turonian Mikasa Formation of the Middle Yezo Group widely crops out along the Ponporokabetsu River, being controlled by a few opened folds and block faults (Fig. 12). At this stop it is characterized by the Middle Turonian bioturbated, massive or mottled, silty fine-grained sandstone. Megafossils dominated by such bivalves as *Inoceramus hobetsensis* Nagao & Matsumoto, *Apiotrigonia mikasaensis* Tashiro, *Glycymeris hokkaidoensis* (Yabe & Nagao), *Aphrodina pseudoplana* (Y. & N.), etc. are generally scattered, but are sometimes concentrated in lenticular fossil beds as storm lags. Articulated bivalves are common in mother rocks and calcareous nodules. Ammonite represented by collignoniceratids occasionally occur from the calcareous nodules.

The massive lithology and the scarcity of wave-formed structures in this sandstone suggest a more or less closed or quiet environment. The substrata may have been long reworked by bioturbation after intermittent storm sedimentation below fair-weather wave base above mean storm wave base.

Stop 1-3: Yubari Coal-Mine Museum

The Yubari Coal-Mine Museum was opened in July, 1980 at a site of an abandoned coal pit in order to explain the history of the Yubari Coal-Field in the Yubari City. Here was once the Yubari Coal-Mine of Hokkaido Colliery & Steam Company which had been the largest col-

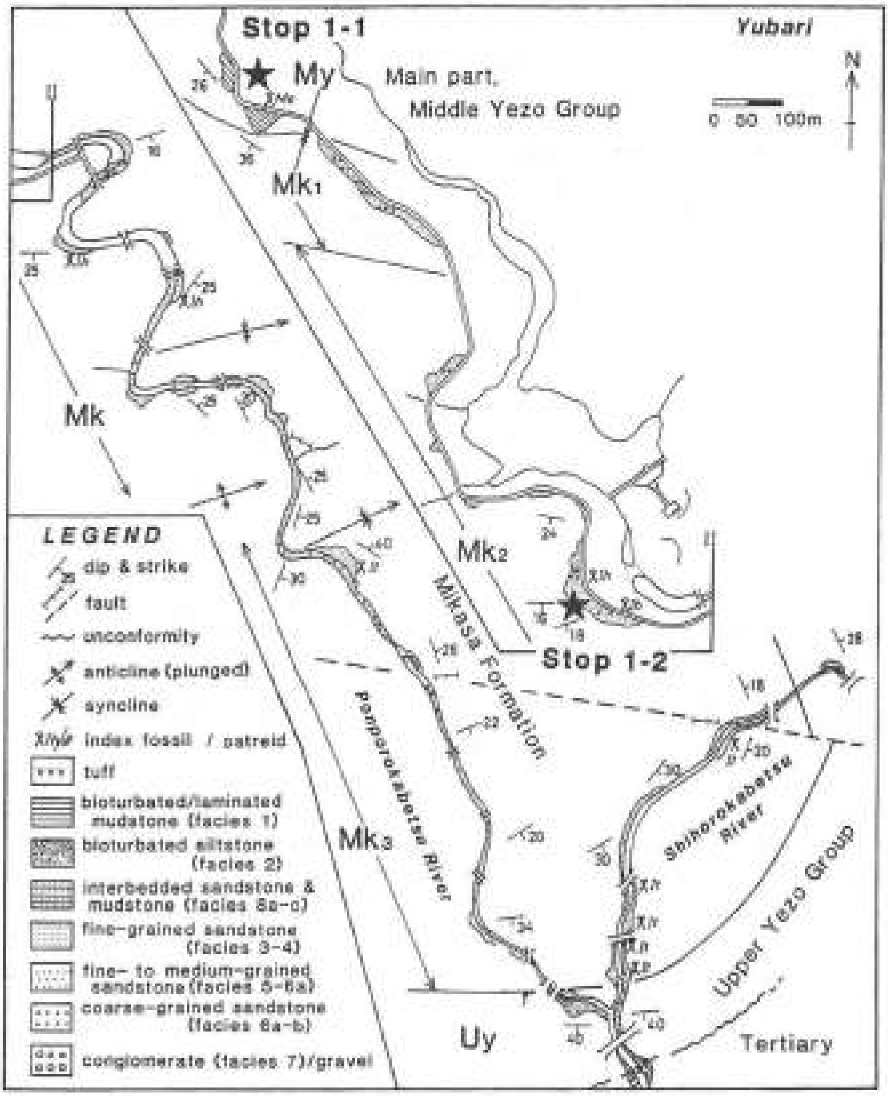

Fig. 12. Route map of the Ponporokabetsu River and its forestry road in the Yubari area (Stops 1-1, 1-2).

liery company possessing the richest coal mines in Hokkaido.

The exhibition of the museum consists of four sections: natural history of coal-bearing formations, coal mining customs in coalpits, coal mining machinery and history of the Yubari Coal-Mine. The remarkable highlight is a model coalpit faithfully preserved for the exhibition. Three coal beds of the Eocene Ishikari Group can be observed at a large outcrop near the exit of the pit. They are called "Roku-syaku"(=about 1.8 m thick), "Hassyaku"(2.4 m), and "Ju-ssyaku"(=3.0 m) Beds. This outcrop was designated as a natural monument by the Hokkaido local government in 1974.

Stop 1-4: Shuparo Dam Site, Hakobuchi gorge, Shuparo River Hakobuchi Group

This stop, Hakobuchi gorge along the Shuparo River is a type section of the Hakobuchi Group (Nagao et al., 1954). From the dam office building north of the dam site facing the Shuparo lake to the downstream of the dam, a sandstone sequence of 300 m in thickness well crops out, trending nearly N-S and overturning westward steeply (Fig. 13). The group conformably overlies the Upper Yezo Group and unconformably underlies the Eocene Ishikari Group.

The lower transitional part shows an upward-coarsening sequence from dark gray mudstone of the Upper Yezo Group to HCS sandstone and large-scale cross-stratified, coarse-grained sandstone. The basal part is not exposed due to river valley erosion at this stop.

Following siliceous black mudstone 5 m thick and massive acid tuff 30 m thick of the uppermost lower part, the middle part comprises six or more upward-fining units several meters thick of meandering river plain in origin. Those units are composed of poorly-sorted, thick trough cross-stratified, coarse-grained sandstone and sandy often coaly mudstone with plant remains.

The upper part 200 m thick begins with a basal conglomerate as a transgressive lag formed by shoreface erosion, which rests upon the middle fluvial plain deposits.

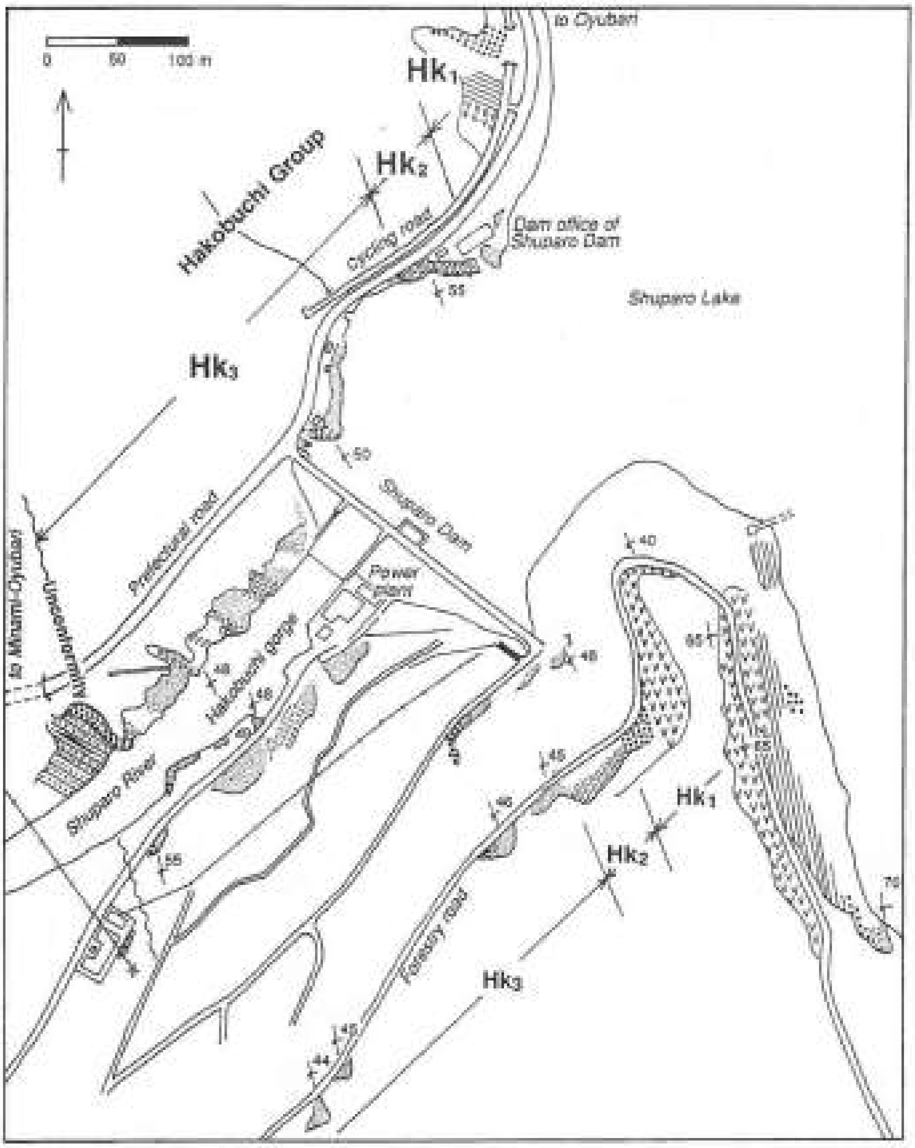

Fig. 13. Route map of Shuparo dam and its surroundings along the Hakobuchi gorge, Shuparo River (Stop 1-4).

The base of the conglomerate is equivalent to a ravinement surface. The upper part consists mainly of massive fine-grained sandstone, and subordinately sandy siltstone and conglomerate. The sandstone is almost massive and bioturbated, but occasionally hummocky or ripple cross-stratified. Though megafossils are scarce, the lithology suggests inner shelf to lower shoreface in sedimentary environment. The two thick conglomerate layers which is characterized by chert, sandstone and mudstone, are rather simple in composition than polymictic ones in the Mikasa Formation. This reflects the more stable conditions of the source area at that time than the time of the Mikasa Formation.

A disconformity with the overlying Eocene coal measures, Noborikawa Formation, Ishikari Group can be seen along a river cliff on the right downstream side of the dam. The sandstone lithology is very similar between the uppermost of the Hakobuchi Group and the lower part of the Noborikawa Formation.

DAY 2

East-westward facies changes of the Mikasa Formation, Middle Yezo Group, across the Ikushumbetsu Anticline along the Ikushumbetsu River

Stop 2-1: eastern limb of the Ikushumbetsu Anticline. Mikasa Formation, Middle Yezo Group and Upper Yezo Group

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

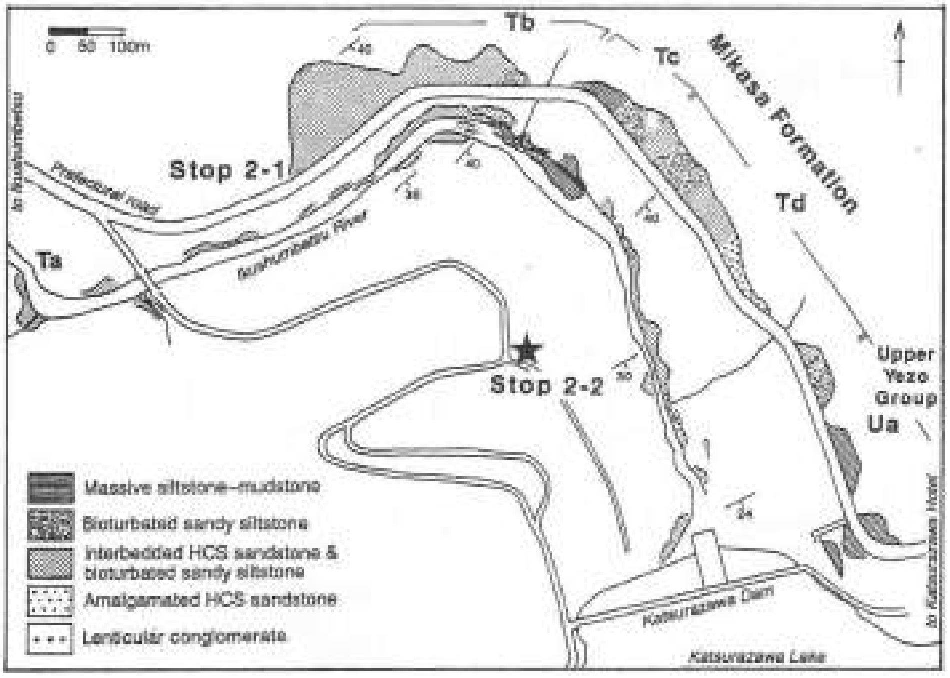

Fig. 14. Route map of the Ikushumbetsu River section in the eastern limb of the Ikushumbetsu Anticline (Stop 2-1).

a) Mikasa Formation, Middle Yezo Group

Ta. The lowest transitional part from the main part of the Middle Yezo Group (Ta) is not well exposed here now. According to Matsumoto (1965) and Matsumoto et al.(1991), this sandy siltstone member is assigned to the Lower Cenomanian *Desmoceras kossmati-Graysonites adkinsi* Zone.

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

We can easily collect the Lower Cenomanian fauna of bivalves and ammonites from the lower part. The mode of bivalve occurrence is schematically shown in Fig. 15. Disarticulated bivalves occur on bases of HCS sequences as shell lags or shell lamina within H units (Dott & Bourgeois, 1982). They had rapidly settled within H units when storm waves or currents waned after storm-reworking and accumulation of them during storm peaks. Articulated bivalves sporadically preserved in Mb (bioturbated sandy siltstone) units are thought to be recolonizing species during inter-storm fair weather, but individuals in life-position are very rare. As well as the mode of fossil occurrence, the species composition is somewhat different between H and Mb units, reflecting the sedimentary processes of HCS sequences. Wave ripples in an H unit are well observable on a well-exposed bedding plane.

The upper part (Middle Cenomanian) sporadically contains offshore articulated bivalves different from those in the lower Tb and compressed ammonites as *Calycoceras (Newboldiceras) orientale* Matsumoto, Fukada & Saito and *Desmoceras (Pseudouhligella) japonicum* (Yabe).

Matsumoto et al. (1991) recognized three ammonite-inoceramid zones of upper Lower to Middle Cenomanian, namely *Mantelliceras japonicum-Inoceramus tenuis*, *Cunningtoniceras takahashii-Inoceramus reduncus* and *C. (N.) orientale-Birostrina tamurai* Zones (Table 2).

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

Td. This member is mainly composed of inner shelf, interbedded HCS sandstone in the middle to upper parts, and outer shelf bioturbated sandy siltstone often intercalated with thin sandstone layers in the lower. But lower shoreface, amalgamated HCS sandstone occasionally containing with lenticular gravel layers, is predominant in the middle part. This is the most sandy facies in the eastern limb of the Ikushumbetsu Anticline along the Ikushumbetsu River. The middle part wide crops out in a big quarry on the opposite side of this stop. Though the lower part is hardly fossiliferous, Matsuno et al.(1964) reported the occurrence of Lower Turonian *Inoceramus* cf. *labiatus* (Schlotheim). Because this member is too sandy, ammonites scarcely occur. But the middle to upper parts commonly contains *Inoceramus hobetsensis* Nagao & Matsumoto characteristic of the Middle

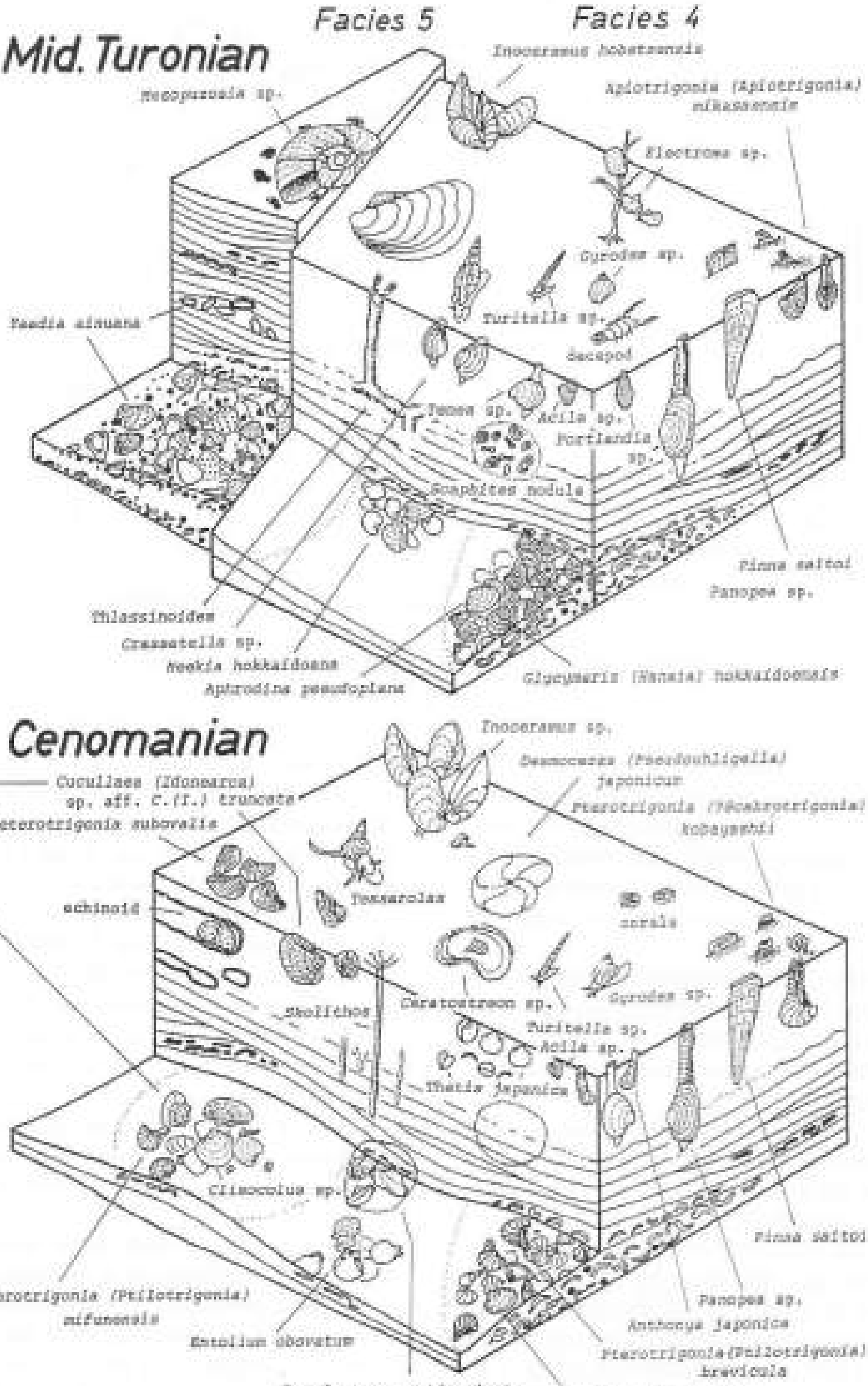

Fig. 15. Schematic mode of fossil occurrence in hummocky cross-stratified sequences of the Mikasa Formation (Cenomanian and middle Turonian).

Turonian. As shown in Fig. 15, Middle Turonian bivalve fauna is different from the Cenomanian fauna in composition.

b) Upper Yezo Group

The sudden facies change into monotonous sandy siltstone of the Upper Yezo Group suggests a rapid transgression at late Turonian. The lowest formation, Ua by Matsuno et al. (1964), IIIa by Matsumoto (1965) or U_1 (Futakami, 1986a), commonly contains calcareous nodules with Upper Turonian *Inoceramus teshioensis* Nagao & Matsumoto and prolific ammonites represented by *Subprionocyclus minimus* (Hayasaka & Fukada) or *Sub-*

prionocyclus neptuni (Geinitz) (Futakami, 1986a, 1990; Matsumoto, 1984; Matsumoto et al., 1991).

Stop 2-2: storm gravelly sandstone. Mikasa Formation (Lunch)

Stop 2-2 highlights storm-formed sedimentary structures and shell beds. This stop is a small park and garden at the southern downstream side of the Katsurazawa Dam and the other side of Stop 2-1. Near and before the owner's house, many sandstone blocks are arranged as garden stones. They are obtained from a big quarry at the back where foundation aggregate materials for the dam were mined from the middle part of Td (Middle Turonian). The blocks are, though apparently massive, fine-grained, amalgamated HCS sandstone, frequently associated with sharp-based, lenticular gravel layers less than 1 m thick as lags. Thick-shelled bivalves dominated by two trigonians (*Yaadia ainuana* (Yabe & Nagao) and *Aplotrigonia mikasaensis* Tashiro), *Glycymeris hokkaidoensis* (Y. & N.), *Meekia hokkaidoana* Tamura and *Aphrodina pseudoplana* (Y. & N.), are often concentrated within the gravel lags and H units (Fig. 16). Giant ammonites possibly assigned as *Pachydesmoceras* or *Mesopuzosia* (Fig. 17) and giant *Inoceramus hobetsensis* over 40 cm long in open-valve or reclining position also occasionally occur solitarily (Fig. 15). The sandstone may have been deposited on lower shoreface above fair weather wave base where suspension mud was transported away offshore.

Stop 2-3: western limb of the Ikushumbetsu Anticline. Mikasa Formation

This stop is a cycling road 1.5 km long from the Mikasa City Museum to the Keisen Bridge along the Ikushumbetsu River. This road was recently opened as an outdoor museum for a geological trip over 50 million years from Cenomanian to Eocene. Until the construction of the Katsurazawa dam in 1957, this road had used as a forestry railroad. The Mikasa Formation of the Middle Yezo Group, middle Eocene coal measures, Ikushumbetsu Formation of the Ishikari Group and Upper Eocene Poronai Group from east to west dip almost vertically (Fig. 17). Here, we can see the typical facies and their stratigraphic changes of the Mikasa Formation in the eastern limb of the Ikushumbetsu Anticline. Though the lower and upper boundaries are not exposed, the formation has fault and unconformable relations with the lower Middle Yezo Group and the Ikushumbetsu Formation, respectively.

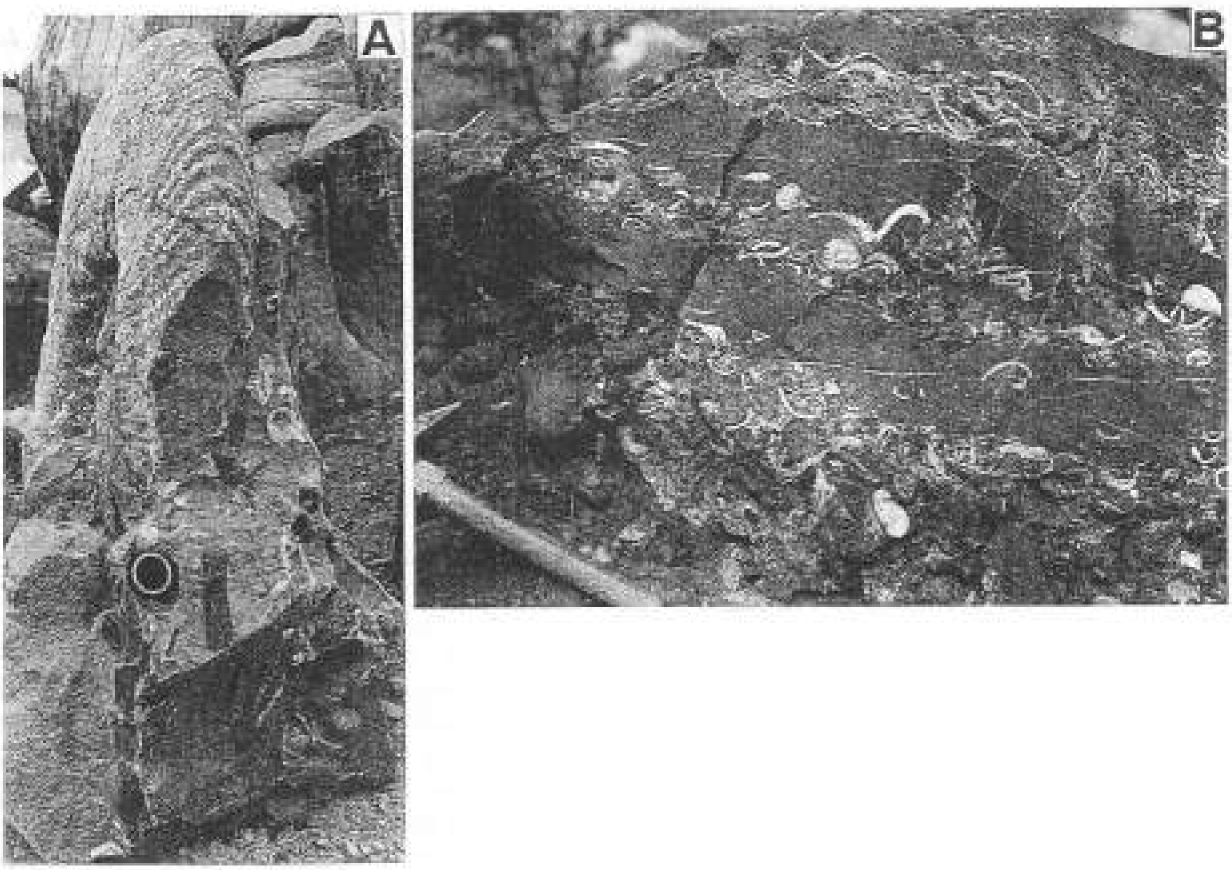

Fig. 16. A. A giant ammonite (*Pachydesmoceras* or *Mesopuzosia*) with trigonian (*Yaadia ainuana*) articulated shells and mudstone clasts in amalgamated hummocky cross-stratified, fine-grained sandstone from the Middle Turonian (Td) of the Mikasa Formation at a quarry southwest of the Katsurazawa Dam. Lens cap is 5 cm in diameter. B. Lenticular gravel and shell lags in amalgamated HCS sandstone. A, B. Stop 2-3.

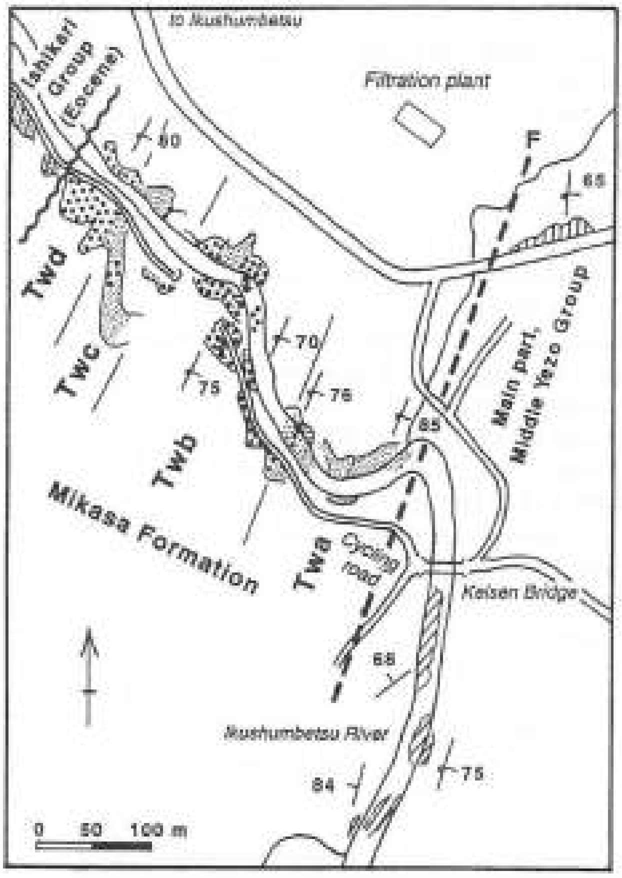

Fig. 17. Route map of the Ikushumbetsu River section in the western limb of the Ikushumbetsu Anticline (Stop 2-3).

We follow the quadripartite division from Twa to Twd by Matsuno et al.(1964), each two of which constitute an upward-coarsening / shallowing / regressive sequence (Twa-Twb and Twc-Twd).

Twa. This crops out on the riverbed and not along the road. It is composed of inner shelf, interbedded HCS sandstone and sandy siltstone in the lower part, and lower shoreface, amalgamated HCS sandstone in the upper. It constitutes the finer and lower part of the first upward-coarsening sequence. The lower part of Twa commonly contains Lower Cenomanian bivalves and ammonites in calcareous nodules or mother rocks. They are characterized by *Desmoceras (Pseudouhligella) japonicum*, *Calycoceras (Newboldiceras) asiaticum* (Jimbo), *Heterotrigonia subovalis* (Jimbo) and a few *Inoceramus* species.

Twb. This member is paralic deposits mainly composed of cross-stratified, coarse- to medium-grained sandstone intercalated with carbonaceous or sandy siltstone layers and thick conglomerate. The inferred sedimentary environments are variable, e. g. upper shoreface, foreshore, lagoon, marsh and fluvial channels. A minor fault with slickenside is observable on the southeastern tunnel exit. Near the northwestern end of the tunnel wall, some oyster patch reefs occur in the intervening lagoonal sandy siltstone.

Twc. This member is characterized by inner shelf, interbedded HCS sandstone and sandy siltstone commonly containing the middle Turonian bivalve fauna (Fig. 15). It widely crops out in an abandoned quarry on the upper slope of the northwestern tunnel exit. Lower shoreface, amalgamated HCS sandstone of the upper part shows the upward-coarsening trend. *Inoceramus hobetsensis* commonly occurs like in Td of the eastern limb of the Ikushumbetsu Anticline (Stop 2-3).

Twd. The upper part of the second upward-coarsening sequence is composed of the lower, amalgamated HCS sandstone with some lenticular gravel lags, and the upper alternating beds of coarse-grained, cross-stratified sandstone and conglomerate. The upward-coarsening facies change may reflect a shoaling of wave-dominated lower to upper shoreface. The sandstone and conglomerate couplets are thought to have been formed by migration processes of nearshore bars and troughs during storm and fairweather cycles. A large cliff exposing the upper part of Twd along the cycling road is mostly covered with concrete shelter. But we can see the upper typical facies through observation windows.

The unconformably overlying Eocene coaly measures, Ikushumbetsu Formation, Ishikari Group, comprises many cyclothem units of meandering river channel sandstone and flood plain mudstone or coal. The unconformity is nearly parallel in outcrop scale because of the same bed configuration (dip and strike) between the two groups, in spite of lacking an exposure. As the Upper Yezo Group lying between the two in the northern sections (e.g. Pombetsu River section, Stop 3-3) does not exist here, it may have been eroded away. You can step over the 50 million years time gap here. There are some small abandoned coalpits a few 10s years old along the road.

Stop 2-4: Mikasa City Museum (Upper to Middle Cretaceous ammonite collections)

Mikasa about 50 km east of Sapporo is a small city, but geologically remarkable in the Upper Cretaceous Yezo Supergroup rich in ammonite fauna and thick sequences of the Paleogene coal measures called the Ishikari Group. The city is one of the most famous ammonite localities in Japan.

The Mikasa City Museum was founded in July 1979 to exhibit the natural and cultural history of the city. It especially emphasizes on the excellent ammonite collections by the late Mr. Tatsuo Muramoto, his son Mr. Kikuo Muramoto, a curator of the museum, and many amateur ammonite collectors living in the city. They contributed a large amount of very good specimens obtained from many localities of the Yezo Supergroup throughout Hokkaido. As for the richness of the ammonite collection, this museum is one of the best in Japan and also in the world. The exhibition highlights magnificent giant, ornate, heteromorph ammonites, and additionally prolific smooth ammonites and some marine reptiles as mosasaurid and elasmosaurid. Other associated fossils as bivalves, gastropods, echinoids, crinoids, teleostei fish bone and shark teeth are also displayed. A mosasaurid skull from the Upper Yezo Group, known under the name of "Yezo-Mikasa-ryu" is one of the most interesting specimens in the museum.

DAY 3

Pombetsu River and its tributary Pombetsu-go-no-sawa River sections. Middle to Upper Yezo Groups

Stop 3-1: Pombetsu River section in the western limb of the Ikushumbetsu Anticline. Main part of the Middle Yezo Group

A section along the middle to lower stream of the Pombetsu River, a branch of the Ikushumbetsu River is extraordinarily well exposed perpendicularly across the strike direction, and is situated on the western limb of the Ikushumbetsu Anticline (Matsumoto, 1965; Ando, 1987; Figs. 18, 19). Here the upper Main part (Stop 3-1) and Mikasa Formation (Stop 3-2) of the Middle Yezo Group and the lower Upper Yezo Group (Stop 3-3) in upward sequence steeply dip west.

The Main part of the Middle Yezo Group is offshore or basin plain facies deposits such as massive mudstone and alternating beds of mudstone and fine-grained sandstone (muddy turbidites). Some slump folds are observable in the middle part of the Main part. The lower limit is not exposed in the axial part of the Ikushumbetsu Anticline. Few megafossils are obtained from the Main part, except for the common occurrence of *Ammonoceratites ezoensis* (Yabe) and *Hyperpuzosia tamon* Matsumoto. The approximate stage may be the upper Lower Albian or lower Middle to upper Upper Albian.

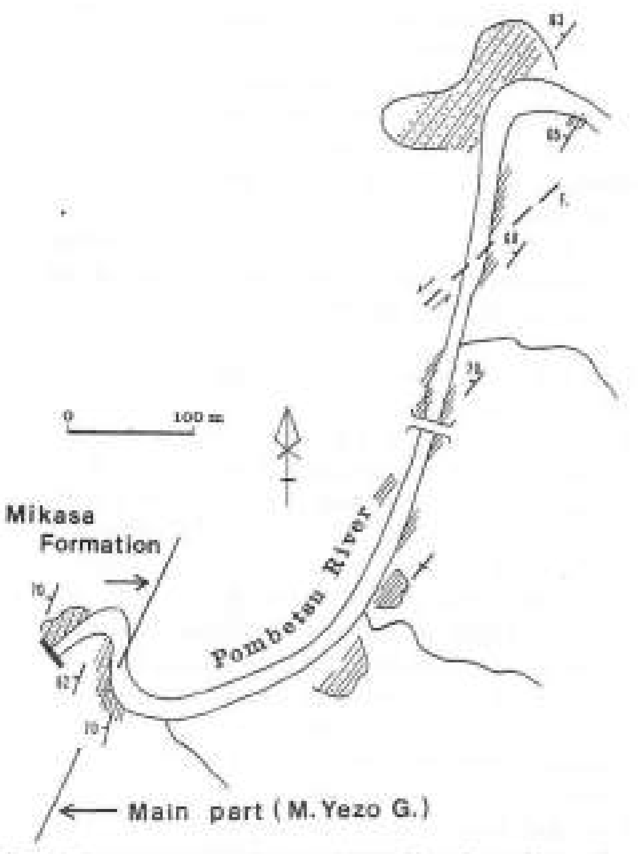

Fig. 18. Route map of the Main part, Middle Yezo Group (Upper Albian) in the upper stream side of the Pombetsu River section (Stop 3-1). Location shown in Fig. 19.

The uppermost Main part is characterized by mudstone bed with thin layers of fine-grained sandstone in the upper, and alternating beds of mudstone and sandstone in the lower. *A. ezoensis*, *Puzosia* sp., *Mortoniceras* ? sp. and others are obtained from the upper bed. On the other hand, *Anagaudryceras sacya* Forbes, *Desmoceras* sp. and *Dipoloceras cristatum* (Deluc) occur from the lower bed. Therefore, the lower bed is assigned to the lowest Upper Albian *D. cristatum* Subzone of the basal *Mortoniceras (M.) inflatum* Zone.

Stop 3-2: Pombetsu River section. Mikasa Formation, Middle Yezo Group

This stop is one of highlights in this excursion, because we can well observe the Mikasa Formation along a nearly continuous section about 450 m thick with unexposed parts only 40 m totally (Figs 20, 21). The section also shows the typical western limb facies of the Ikushumbetsu Anticline and the two upward-coarsening sequences (Me-Twa-Twb and Twc-Twd Members: Matsuno et al., 1964 and Ando, 1987). Except the lowest Me, the stratigraphy is generally the same as that of Stop 2-3. Matsuno et al.(1964) assigned the Me Member to the Main part, but we include it to the Mikasa Formation because of the gradational relation between Me and Twa (Ando, 1987).

A new dam about 70 m high is now planned to be constructed near the Kamui Bridge within several years.

Me. The Mikasa Formation starts with 100 m thick, regularly or rhythmically medium-bedded turbidite (Me) with trace fossils as *Helminthopsis*, *Palaeodictyon* and *Nereites* typical of deep-sea facies (Tanaka, 1971). The uppermost alternation (7 m thick) overlying a slumped bed (several meters thick) is a transitional part into interbedded HCS sandstone and sandy siltstone of Twa, though lacking an exposure a few meters thick between the two. The considerably sudden changes of facies and inferred sedimentary environments from basin plain or outer shelf to inner shelf, suggest a rapid sea-level fall and/or tectonic uplift of the basin during latest Albian and early Cenomanian.

Twa. This member consists of apparently massive, very fine- to fine-grained sandstone 90 m thick. But rock surfaces soaked with water distinctly show various sedimentary structures as hummocky lamination, amalgamation surfaces, wave ripples and dehydration structures, trace fossils(*Ophiomorpha*, *Skolithos*, *Planolites*, *Schaubcylindrichnus*, etc.) and others (Fig. 21A. Some sharp-based coquinite lenses intervening in the lower part contain stacking shells of *Pterotrigonia brevicula* (Yehara), *Aphrodina pseudoplana* (Yabe & Nagao), *Glycymeris*

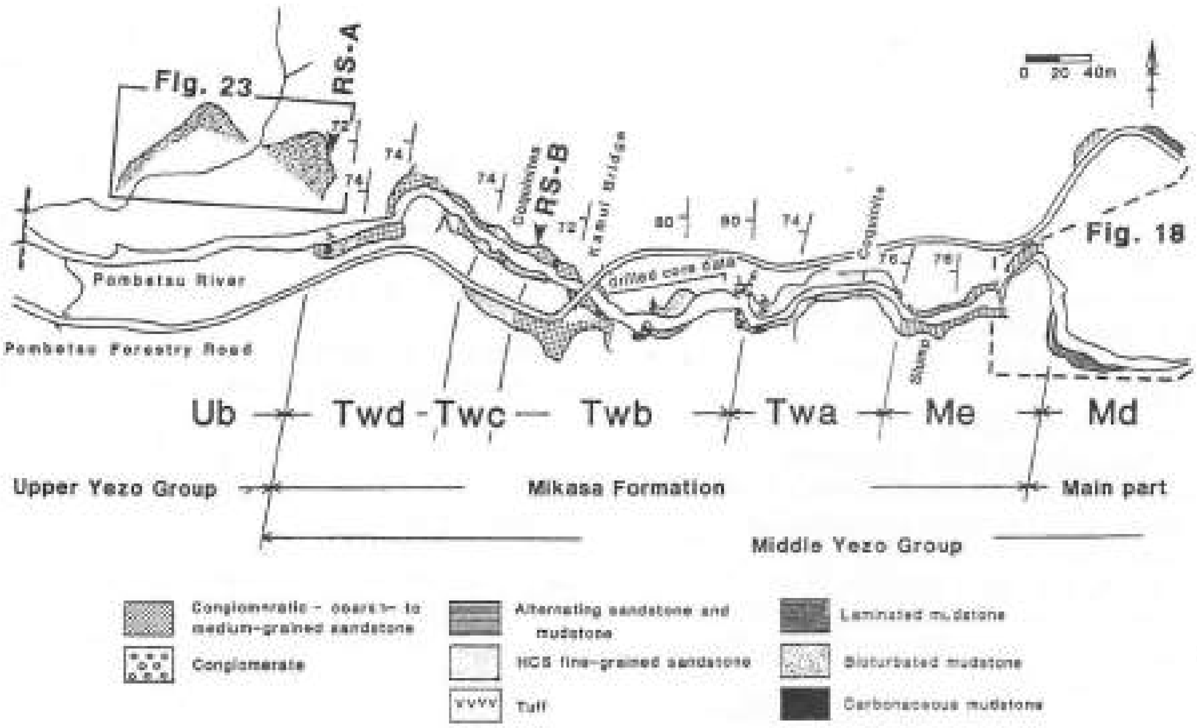

Fig. 19. Route map of the Pombetsu River section (Stops 3-2, 3-3). Left rectangle and right broken line show location of Figs. 18, 23, respectively. Modified after Ando (1987).

hokkaidoensis (Y. & N.), *Thetis japonica* (Y. & N.) and others (Fig. 21B). Laminar shell layers are common, but their composition is variable bed by bed. Besides the shell concentrations, somewhat different bivalves, gastropods and solitary corals sporadically occur from bioturbated sandy siltstone (Mb) units of HCS sequences (Fig. 15).

Twb. The upper shoreface to delta plain deposits, Twb is mainly composed of massive to trough or planar cross-stratified, medium- to coarse-grained sandstone. Occasionally intervening beds are back-marsh or flood plain black mudstone bearing plant remains, lagoonal sandy siltstone with oyster shells and fluvial-channel cross-stratified conglomerate. The cross-stratified conglomerate 8 m thick erosively overlying Twa may be incised valley fill deposits during the regression and subsequent lowstand of late Cenomanian and early Turonian. In the uppermost part, medium-scale trough cross-stratified sandstone with tidal bundles and tidal channels is overlain by a sharp-based conglomerate layer 40 to 60 cm thick (Fig. 22). The sharp basal plane may represent a ravinement surface formed by shoreface erosion (Demarest & Kraft, 1987) during the early phase of the transgression at middle Turonian.

Twc. The fourth member, Twc consists of inner shelf interbedded HCS sandstone and mudstone in the lower and lower shoreface amalgamated HCS sandstone in the upper. The lithofacies are very similar to those of Twa. *Inoceramus hobetsensis*, a Middle Turonian standard fossil occurs commonly. The lowest, mudstone-dominated interbedded lithofacies seem equivalent to a maximum flooding surface (Posamentier et al., 1988). A few coquinite lenses are intervening in the upper part (Fig. 15).

Twd. The last member Twd is lithologically similar to Twb, though without lagoonal and back-marsh mudstone. The uppermost conglomerate several tens cm thick, overlying tidal coarse-grained sandstone with a sharp-based ravinement surface, suddenly changes to outer shelf, massive and bioturbated sandy siltstone of the Upper Yezo Group (Fig. 22). *Inoceramus teshioensis* obtained from the tidal sandstone indicates that the uppermost part of Twd reaches to the Upper Turonian.

Stop 3-3: Pombetsu River section. Upper Yezo Group (Upper Turonian)

The Upper Yezo Group, which is the fossiliferous fine-sandy siltstone or silty sandstone with some thin acid tuff and glauconitic sandstone beds, can be observed in the lower stream side of Stop 3-2 (Figs. 19, 23). Here it is unconformably overlain by the Paleogene (Eocene) Ishikari Group. The total thickness is almost 120 m. It is biostratigraphically almost Upper Turonian, but the uppermost part is confirmed to be the Coniacian due to the occurrence of *Inoceramus uwajimensis* (Yehara) and *Baculites* cf. *yokoyamai* Tokunaga & Shimizu (Matsumoto, 1965; Futakami et al., 1980; Matsumoto e al., 1981).

The Upper Turonian ammonite fauna at this stop can be stratigraphically divided into three assemblages in accordance with the faunal composition (Fig. 24). The lower assemblage is characterized by the common occurrence

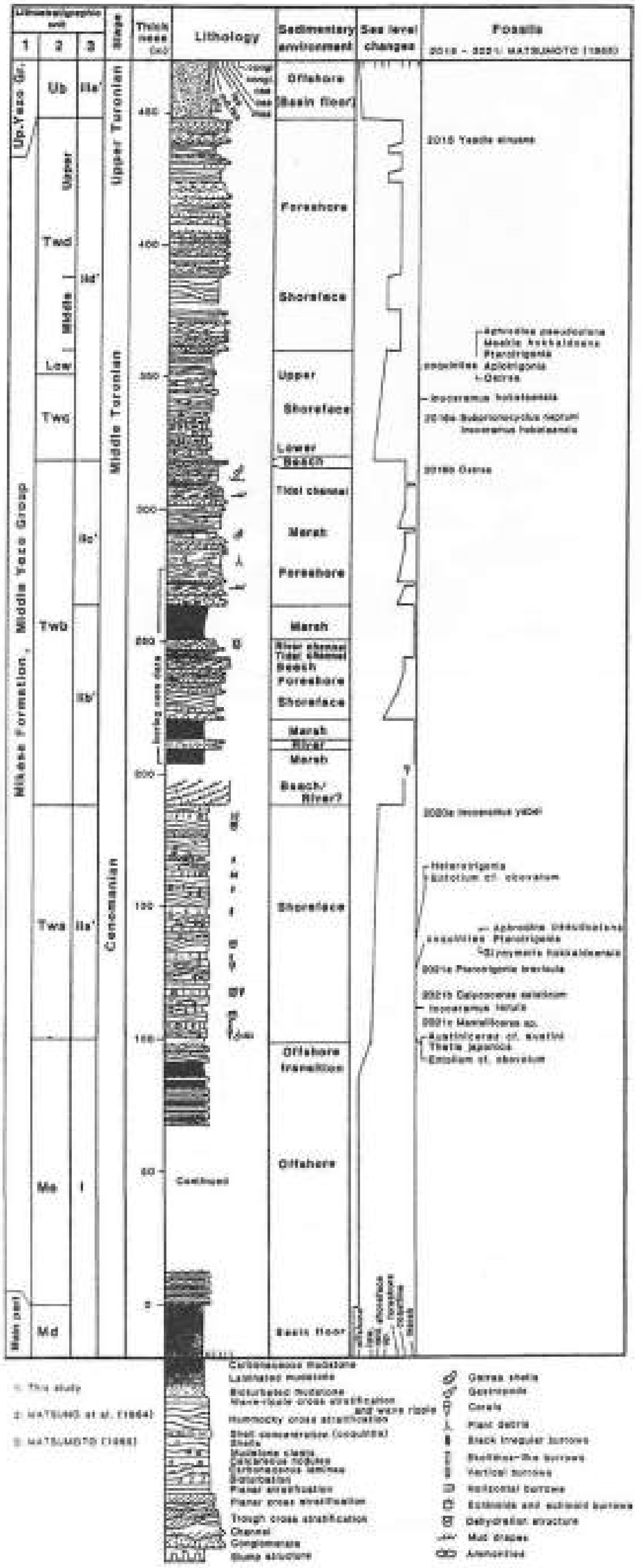

Fig. 20. Geological columnar section of the Mikasa Formation in the Pombetsu River section (Stop 3-2). After Ando (1987).

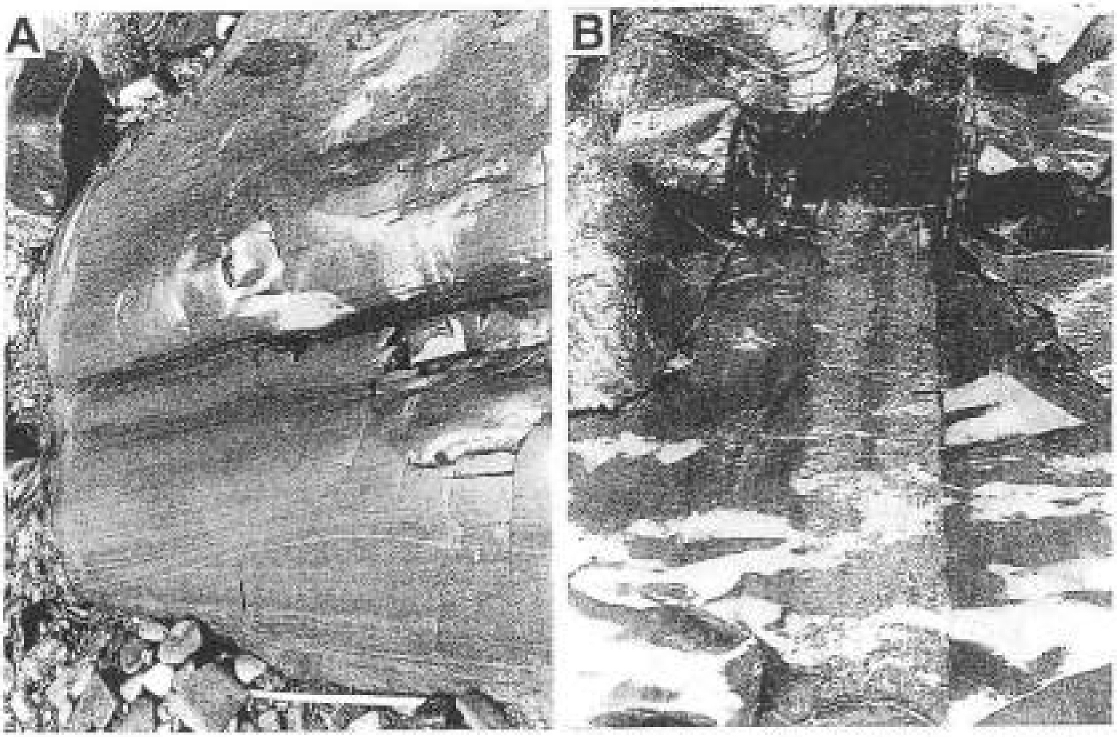

Fig. 21. A. Interbedded hummocky cross-stratified sandstone and bioturbated sandy siltstone of the Lower Cenomanian (Twa), Mikasa Formation in the Pombetsu River section (Stop 3-2). Scale is 30 cm. B. Amalgamated HCS sandstone with lenticular shell lags 10 to 30 cm thick on a sharp base (Stop 3-2). Left side is upward direction.

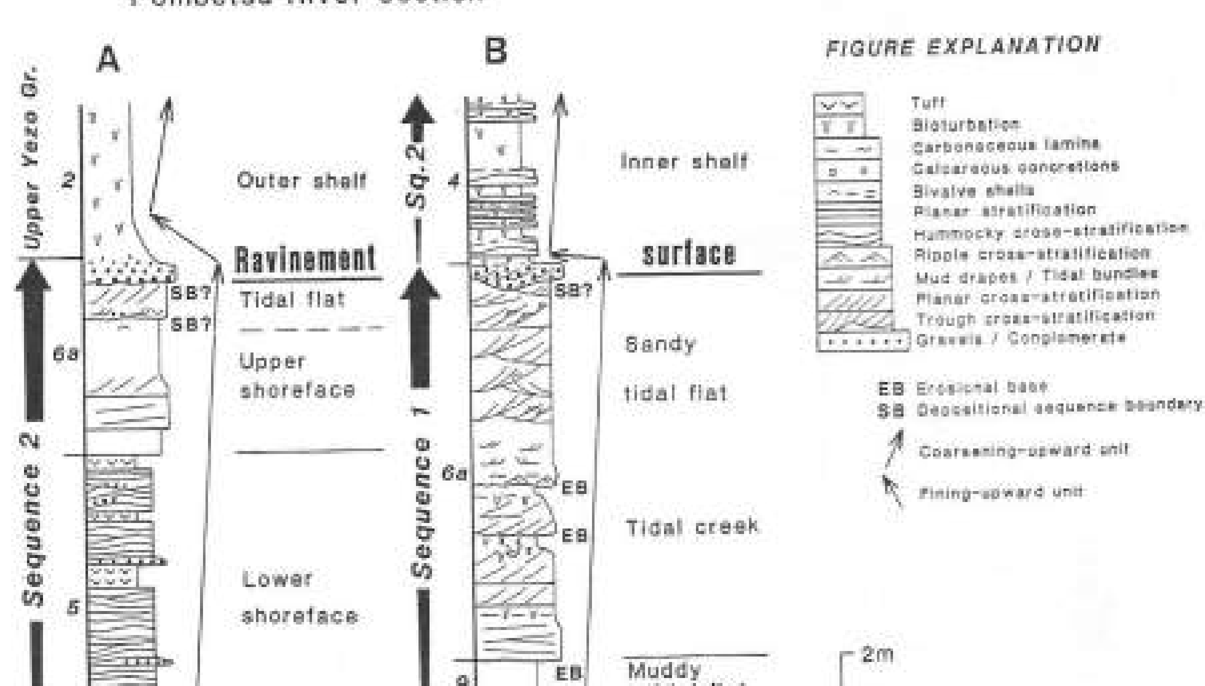

Fig. 22. Two ravinement surfaces (RS-A, B) of the Mikasa Formation observed in the Pombetsu River section (Stop 3-2). After Ando (1990b).

of a baculitid, *Sciponoceras intermedium* Matsumoto & Obata with associations of collignoniceratids, scaphitids, tetragonitids and others. Though the middle assemblage is similar to the lower one in the major species composition, but it differs in the absence of collignoniceratids. The upper one is rich in collignoniceratids such as *"Lymaniceras" planulatum* Matsumoto, *Prionocyclus aberrans* Matsumoto and *P. cobbani* Matsumoto with *Anagaudryceras limatum* (Yabe), *Damesites ainuanus* Matsumoto and others. The ascending biofacies changes may suggest to reflect the late Turonian transgression after the sand deposition of the Mikasa Formation and the following regression. The middle assemblage may indicate a transgressive peak.

The upper assemblage can be also observed in the Bibai area (north of Pombetsu) (Maeda, 1986; Futakami, 1986a), but not in the Ikushumbetsu, Manji and Yubari (Hatonosu) areas (south of Pombetsu) (Matsumoto, 1965; Obata & Futakami, 1975, 1977; Futakami, 1982; Futakami & Miyata, 1983). The another assemblage from the three areas is represented by the common occurrence of *Subprionocyclus minimus* (Hayasaka & Fukada) (=*Reesidites minimus* and *Subprionocyclus normalis*; see Futakami, 1990) that is very rare in Pombetsu. Therefore,

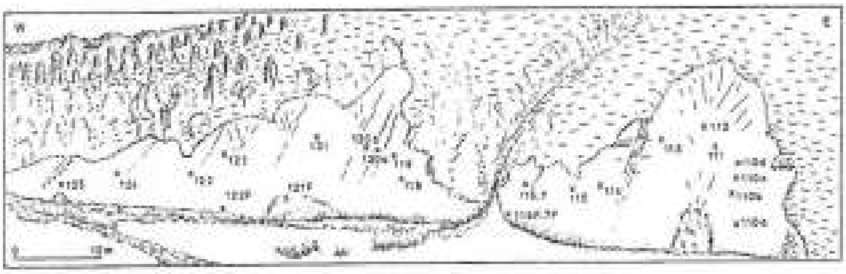

Fig. 23. Sketch of the Upper Yezo Group (Turonian) in the downstream side of the Pombetsu River section (Stop 3-3). Marks (x) and numbers show fossil horizons. Location shown in Fig. 19. After Futakami et al. (1980).

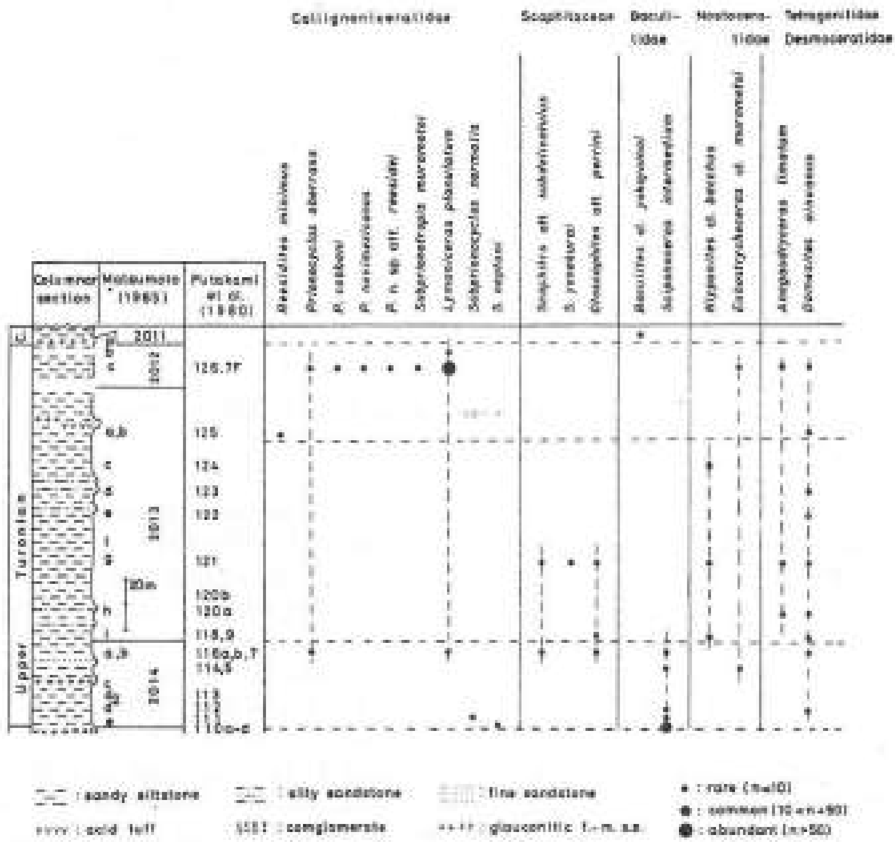

Fig. 24. Stratigraphic occurrence of ammonites of the Upper Yezo Group (Turonian) in the Pombetsu River section (Stop 3-3). After Futakami et al. (1980).

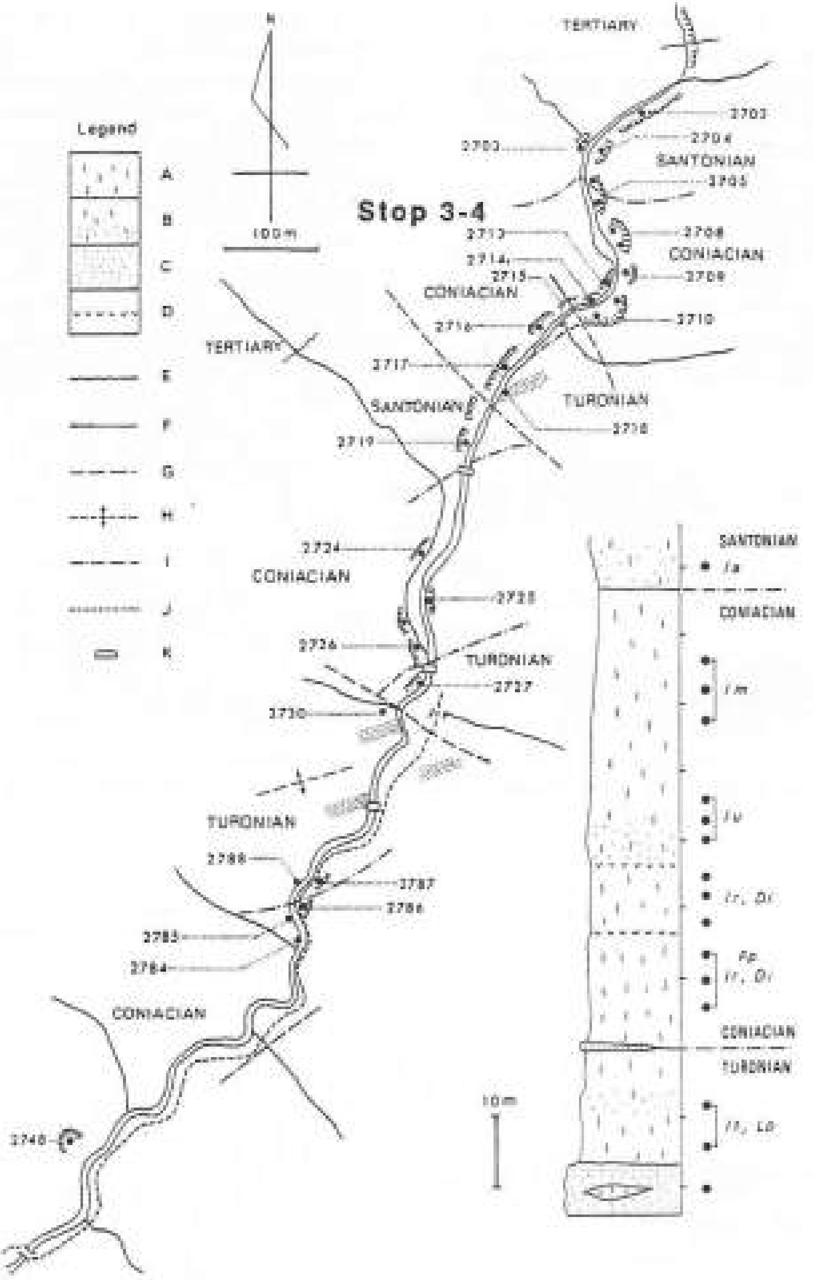

Fig. 25. Route map of the Pombetsu-go-no-sawa section (Stop 3-4). After Matsumoto & Noda (1985).

this fact may suggest a local segregation of habitats between *"Lymaniceras" planulatum* and *Subprionocyclus minimus* during late Turonian time.

Stop 3-4: Pombetsu-go-no-sawa section. Upper Yezo Group (Coniacian)

As pointed out by Matsumoto (1984) and Matsumoto & Noda (1985), this section is suitable for the reference section of the Coniacian megafossil biostratigraphy in Japan (Fig. 25). The Upper Yezo Group crops out along a narrow creek (Pombetsu-go-no-sawa River), being controlled by an anticline and a few block faults. The group consists of mainly sandy siltstone and silty fine-grained sandstone commonly with calcareous nodules frequently containing ammonites and inoceramids. The total thickness is about 95 m. The Upper Turonian in the lower most 20 m of the section and the Santonian in the uppermost 10 m are biostratigraphically characterized by the occurrences of *Inoceramus teshioensis* Nagao & Matsumoto and *Inoceramus amakusensis* N. & M., respectively. The Coniacian of 65 m in thickness is subdivided into three parts. They are defined by the occurrences of *Inoceramus rotundatus* Fiege, *Inoceramus uwajimensis* Yehara and *Inoceramus mihoensis* Matsumoto in upward sequence. The associated fossils as *Didymotis akamatsui* (Yehara) and *Forresterria (Reesideoceras) petrocoriensis* (Coquand) support the age determination of early Coniacian.

In this stop we can try fossil hunting easily. Find cal-

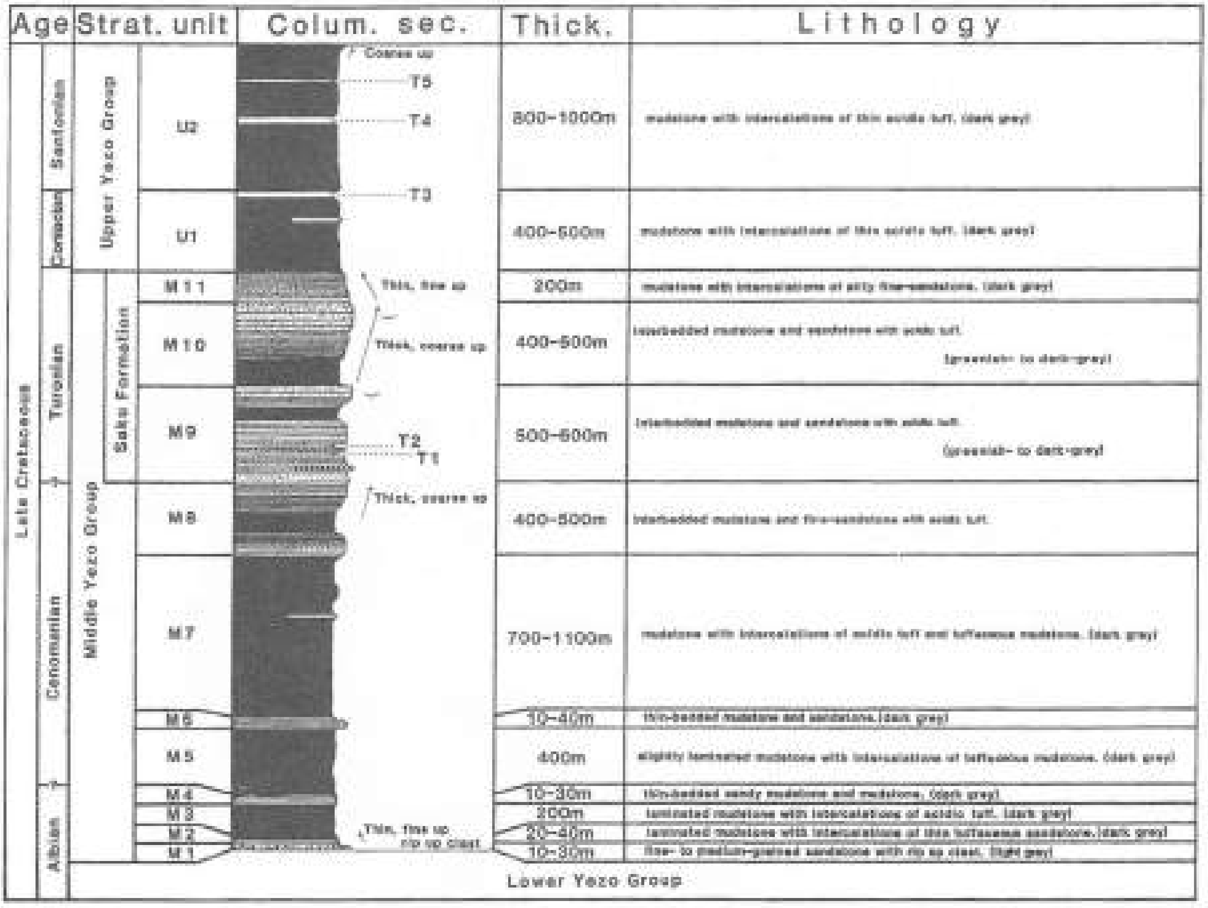

Fig. 26. Columnar section of the Middle and Upper Yezo Groups in the Oyubari area. After Tuchida (1991MS).

careous nodules carefully and extract fossils from mother rocks, and you will enjoy many remains of the Cretaceous life.

DAY 4

Oyubari area. Cenomanian-Turonian boundary in the offshore facies of the Middle Yezo Group

Stop 4-1: C-T boundary in the Hikagesawa Forestry Road

The Cenomanian/Turonian boundary is represented by one exposure along the forestry-road of the Hikagesawa River (Figs. 26-28). Both stages are characterized by massive mudstone occasionally with inoceramids and ammonoids and muddy turbidites. The upward-thickening of sandstone beds is visible just below the boundary. The uppermost Cenomanian is characterized by occurrence of *Inoceramus pennatulus* group and the basal Turonian is by *Inoceramus* aff. *saxonicus* (List of fossils will be distributed on the day). The C-T boundary exists within an interval about 40m thick (Fig. 29). The sulfur content excursion attains at the maximum (Fig. 31A; Hirano et al., 1991; Hirano et al., in press) in the interval below the basal Turonian and above the Upper Turonian index levels. The value indicates the reductive condition on sea floor (Koma et al., 1983).

Stop 4-2: C-T boundary in the Takinosawa Forestry Road

Transition between the Cenomanian and Turonian is continuously observable at an exposure along the forestry road of the Takinosawa River (Fig. 30). This exposure is about 10km southward of Stop 4-1, and the facies are characterized by muddy turbidites without any significant variation from that of Stop 4-1. As the Upper Cenomanian and Lower Turonian are frequently intercalated with acidic tuff, we also can see some acidic tuff layers here.

The uppermost Cenomanian is characterized by the occurrence of *I. pennatulus* group, and the basal Turonian is by *Pseudaspidoceras flexuosum*. The thickness between the occurrences of the two indices is 32 m. The peak value of sulfur contents detected at the interval suggests an anoxic-reductive condition (Fig. 31B). This stratigraphic relation that the anoxic horizon underlies the occurrence of *P. flexuosum* is the same as in the Tethyan realm (e.g., Bahloul Formation/Annaba Formation in Tunisia, Robaszynski et al., 1990).

Stop 4-3: C-T boundary and the Turonian in the Hakkinzawa River

The offshore facies of the Middle Yezo Group from the Upper Albian to Upper Turonian is continuously exposed along the Hakkinzawa River running westward from the Yubari mountain range (Fig. 32). We can observe and

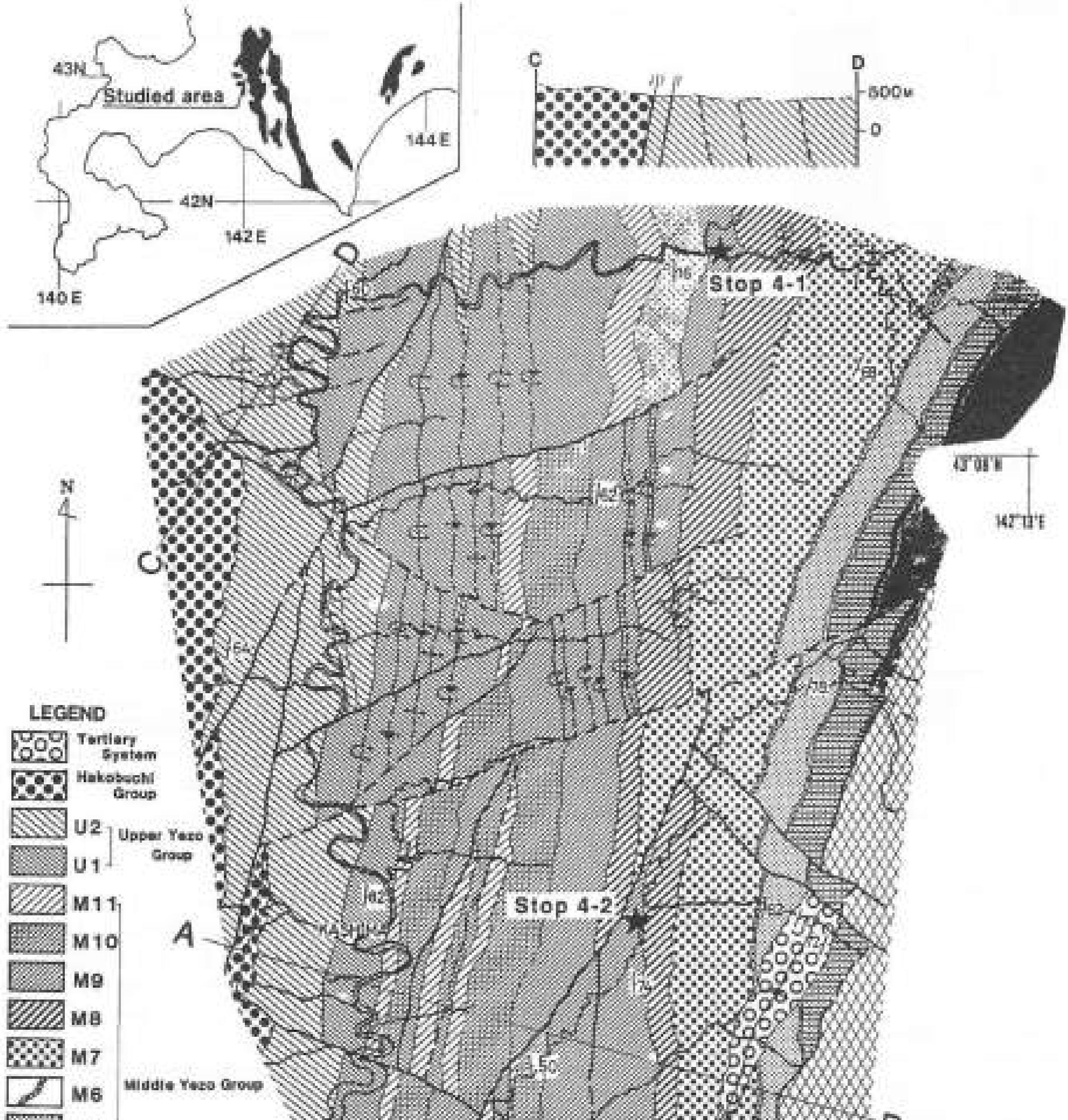

Fig. 27. Geological map of the Oyubari area. After Tuchida (1991MS).

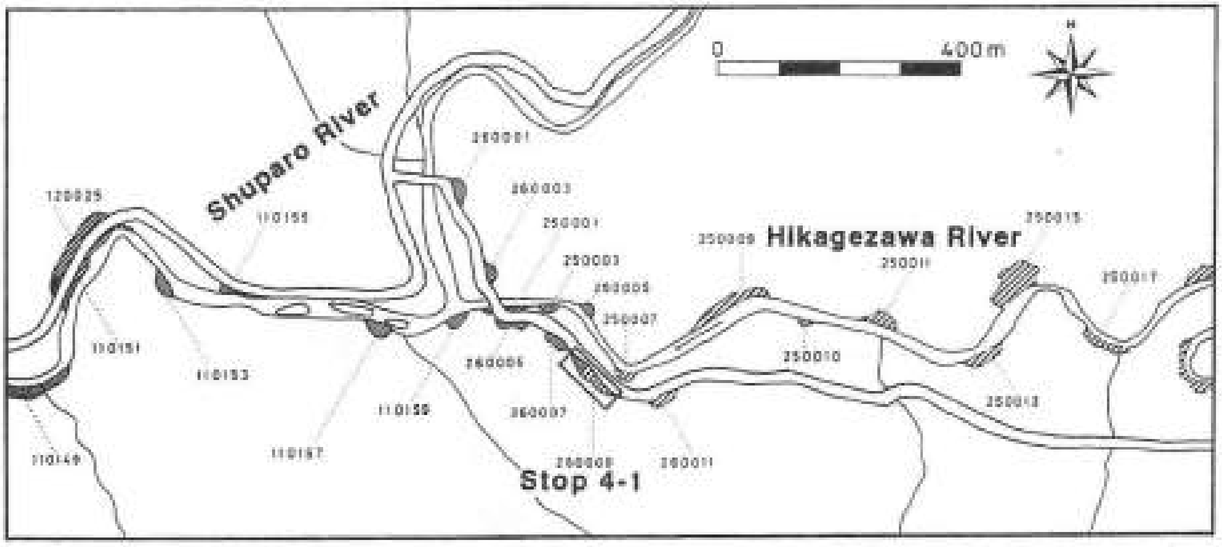

Fig. 28. Route map of the Hikagesawa Forestry Road section (Stop 4-1). Rectangle for location of Fig. 29. Modified after Hirano et al. (1989b).

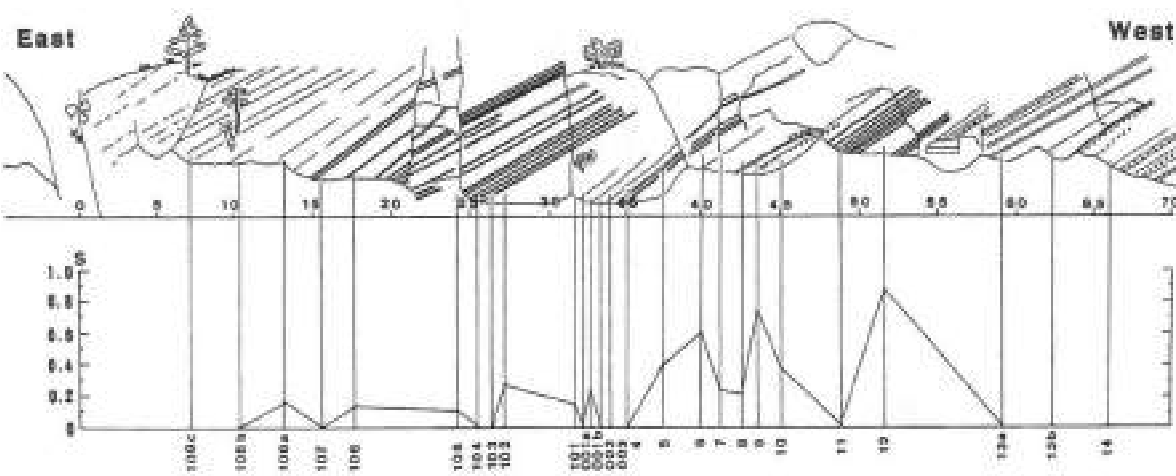

Fig. 29. Sketch of a C-T boundary exposure with excursion of sulfur contents (wt %) in Hikagesawa Forestry Road section (Stop 4-1). The Upper Cenomanian index, *Inoceramus* sp. ex. gr. *I. pennatulus* and the Turonian index, *Inoceramus*. aff. *saxonicus* occurred at 1.5 m below and 38.5 m above the level No. 105, respectively. The C-T boundary exists between them. The mudstone strata strike nearly N-S and steeply overturn west. Location shown in Fig. 28. After Hirano et al. (1991).

collect many ammonites and inoceramids ranging from the Upper Cenomanian to Middle Turonian for about 4 km along the river. In this section the basal Turonian is defined by the occurrence of *P. flexuosum*. The interval of no fossil occurrence is 33m in thickness where the peak value of sulfur contents (Fig. 33) is detected. Thus anoxic condition is suggested at the Cenomanian/Turonian boundary as observed in the previous two sections.

Acknowledgements

We wish to thank the Educational Board of Mikasa City, the Mikasa City Museum, the Educational Board of Yubari City and the Yubari Coal Museum for their help and support in many ways. Especially we must express our gratitude to the mayor of Mikasa City and the superintendents of education of Yubari and Mikasa Cities. The Iwamizawa and Yubari forestry offices permitted to access to the national forest areas in this field trip. Emer. Prof. Tatsuro Matsumoto of Kyushu Univ., Dr. Seiichi Toshimitsu of Geological Survey of Japan and Dr. Masayuki Noda provided us the tables of biostratigraphical zonation in Japan, part of which is still unpublished.

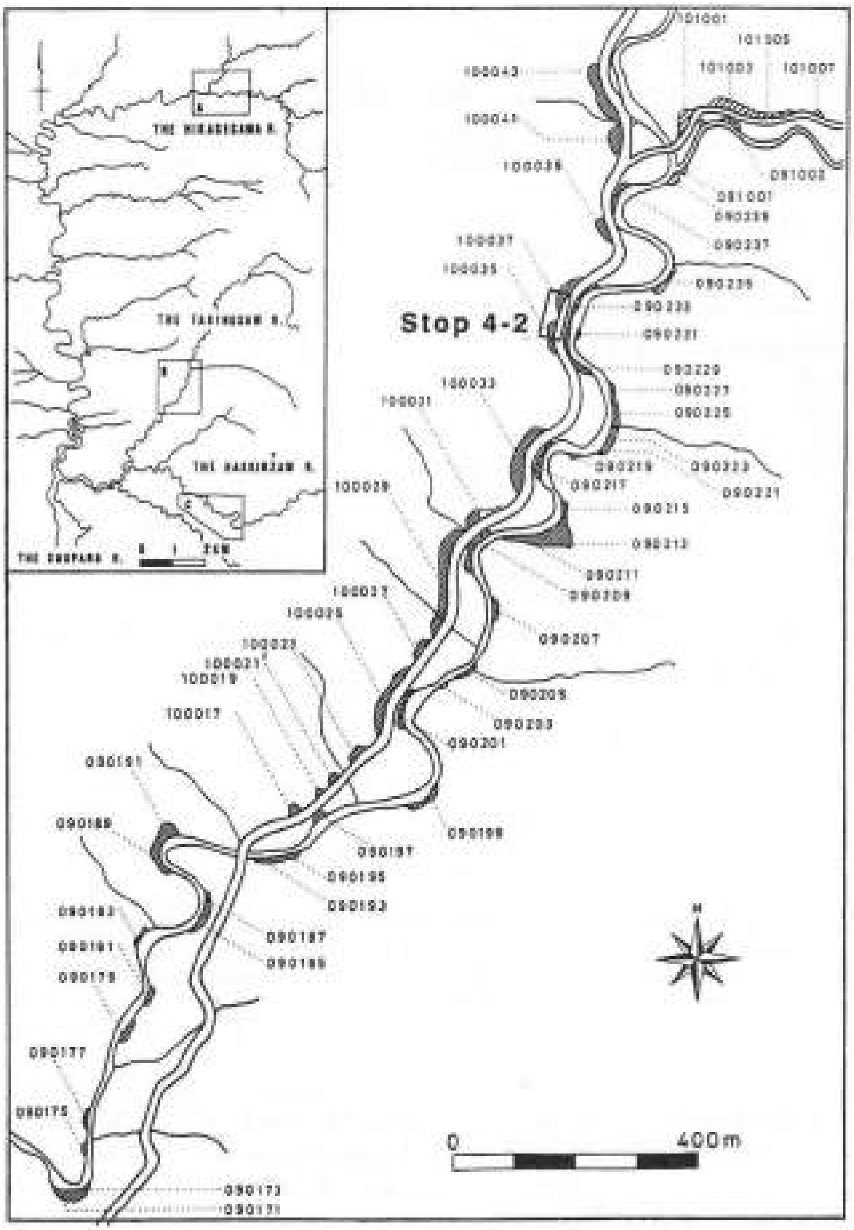

Fig. 30. Route map of the Takinosawa Forestry Road section (Stop 4-2). Modified after Hirano et al. (1989a-c). Inset indicates location of the three sections examined here.

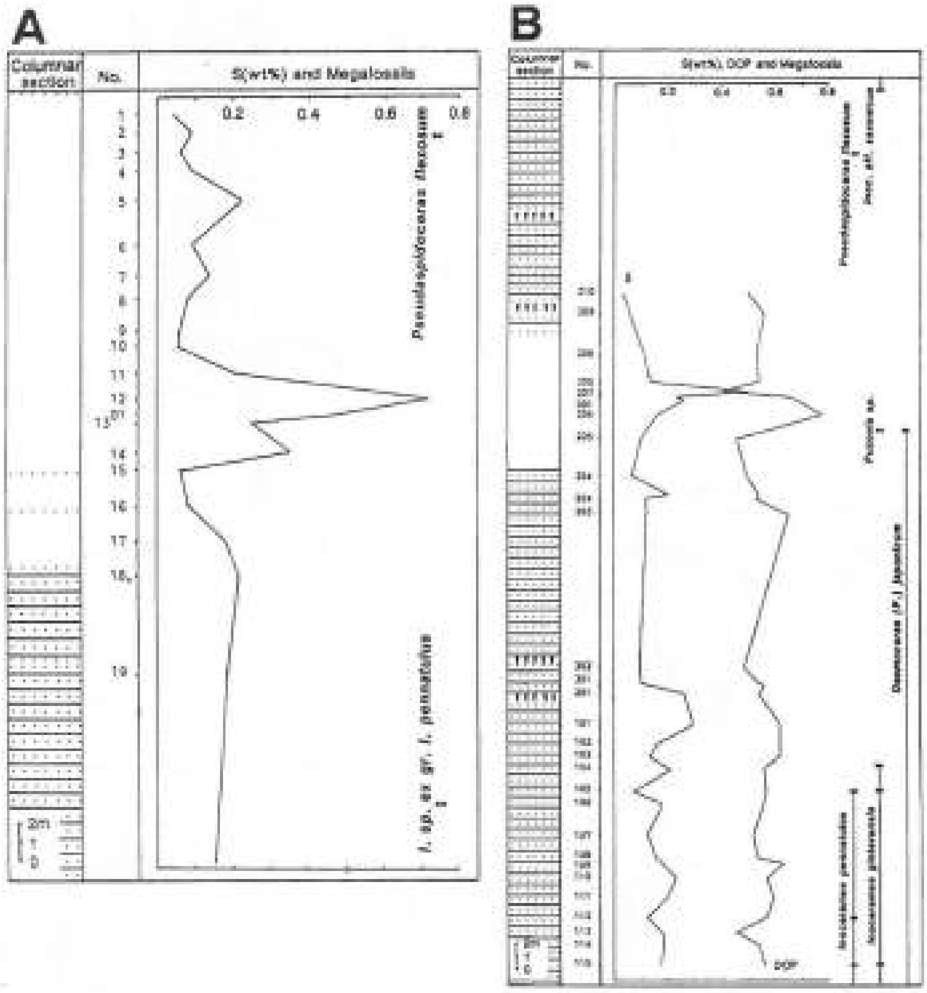

Fig. 31. Columnar sections and excursion of sulfur contents (S: wt %) along the Hikagesawa (A; Stop 4-1) and Takinosawa (B: Stop 4-2) Forestry Road sections. The C-T boundary exists between the levels of *Inoceramus* sp. ex. gr. *I. pennatulus* and *Pseudaspidoceras flexuosum* in (A) and between the levels of *Desmoceras (Pseudouhligella) japonicum* and *P. flexuosum* in (B). DOP: degree of pyritization. After Hirano et al. (in press).

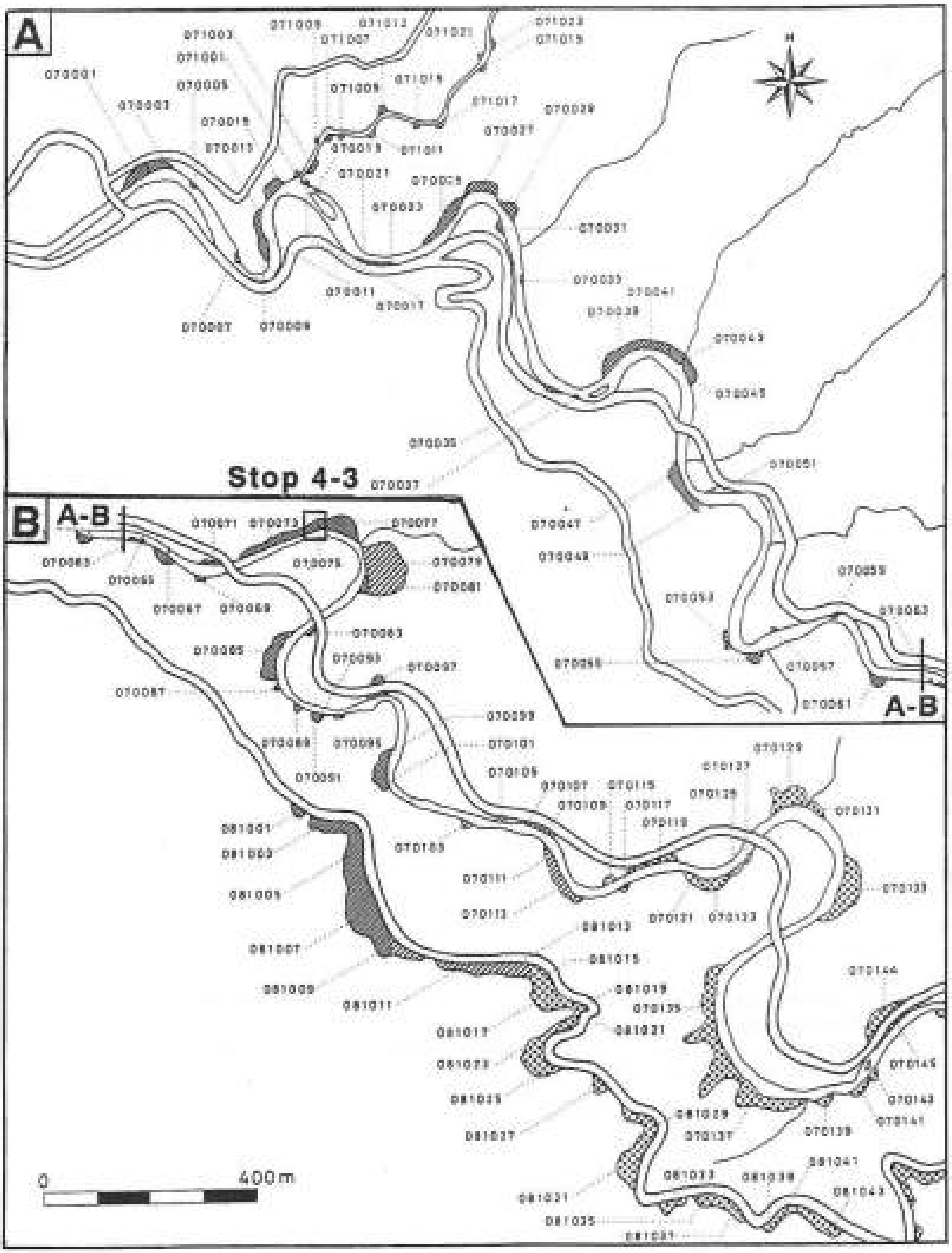

Fig. 32. Route map of the Hakkinzawa River section (Stop 4-3). After Hirano et al. (1989a).

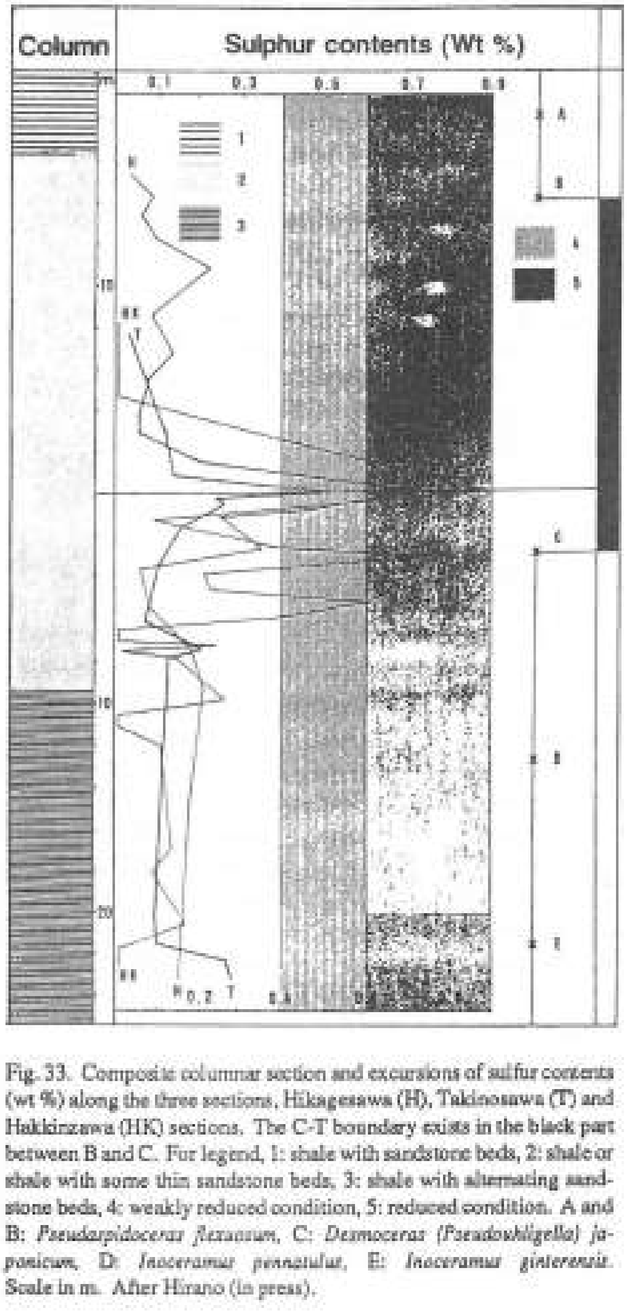

Fig. 33. Composite columnar section and excursions of sulfur contents (wt %) along the three sections, Hikagesawa (H), Takinosawa (T) and Hakkinzawa (HK) sections. The C-T boundary exists in the black part between B and C. For legend, 1: shale with sandstone beds, 2: shale or shale with some thin sandstone beds, 3: shale with alternating sandstone beds, 4: weakly reduced condition, 5: reduced condition. A and B: *Pseudaspidoceras flexuosum*, C: *Desmoceras (Pseudouhligella) japonicum*, D: *Inoceramus pennatulus*, E: *Inoceramus ginterensis*. Scale in m. After Hirano (in press).

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* in Japanese with English abstract

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