Bull. Natn. Sci. Mus., Tokyo, Ser. C, **25**(1, 2), pp. 1–27, June 22, 1999

Stratigraphy of the Upper Cretaceous System in the Kril'on Peninsula, South Sakhalin, Russia

Yasunari Shigeta[1], Haruyoshi Maeda[2], Kazuhiko Uemura[1] and Alexander V. Solov'yov[3]

[1] Department of Geology, National Science Museum, 3–23–1 Hyakunincho, Shinjuku-ku, Tokyo, 169–0073 Japan
[2] Department of Geology and Mineralogy, Faculty of Science, Kyoto University, Kitashirakawa-Oiwake-cho, Sakyou-ku, Kyoto, 606–8502 Japan
[3] Institute of Volcanology and Geodynamics, Academy on Natural Sciences of the Russian Federation, Box 18, Yuzhno-Sakhalinsk, 693008 Russia

Abstract The Upper Cretaceous System in the Kura and Gorbusha areas of the Kril'on Peninsula, South Sakhalin was investigated stratigraphically and paleontologically by the first Japanese-Russian expedition after the Second World War. The Upper Cretaceous System of the Kril'on Peninsula is divided into two formations, the Bykov and Krasnoyarka formations in upward sequence. The former is composed of dark gray massive mudstone, and is correlated to the "Upper Yezo Group" in Hokkaido. The later consists mainly of sandstone and sandy mudstone, being correlated to the "Hakobuchi Group". Inoceramid bivalves, pachydiscid and gaudryceratid ammonites are abundant throughout the sequence, in which six inoceramid zones were recognized successively, i.e., *Inoceramus amakusensis*, *Platyceramus japonicus*, *Sphenoceramus schmidti*, *Inoceramus balticus*, *Mytiloides shimanukii*, and *Inoceramus shikotanensis* zones in ascending order. These zones suggest the Santonian to uppermost Campanian or lowest Maastrichtian stages.
Key words: ammonites, inoceramids, Kril'on Peninsula, South Sakhalin, stratigraphy, Upper Cretaceous

Introduction

The Cretaceous Yezo Group consists of fore-arc basin clastic deposits (Okada, 1979, 1983). It is widely distributed in the central zone of Hokkaido and western zone of Sakhalin. Numerous ammonite and inoceramid species have been described from the Yezo Group by previous authors (e.g. Yokoyama, 1890; Jimbo, 1892; Yabe, 1903, 1904; Nagao & Matsumoto, 1939, 1940; see Matsumoto, 1975) and, based on these ammonoids and inoceramids, a biostratigraphic scheme for the Cretaceous System in Hokkaido has been well established (Matsumoto, 1942, 1943, 1954, 1959, 1977; Toshimitsu *et al*., 1995a, 1995b).

A complete succession of marine fossil assemblages spanning the Campanian-Maastrichtian is not recorded in Hokkaido, because regressive deltaic facies become predominant in the uppermost part of the Cretaceous System there (Matsumoto, 1954; Maeda, 1986). In contrast, fossiliferous mudstone facies is still dominated in the uppermost part of the Cretaceous System of South Sakhalin, and stratigraphic and faunal successions are readily observable toward the top of the sequence (Vereshchagin *et al.*, 1965; Vereshchagin, 1970, 1977; Fursenko, 1974).

The stratotype of the Cretaceous System in South Sakhalin is located in the Naiba River area, and the megafossil zonation has been attempted by many authors (Kawada, 1929; Shimizu, 1929; Matsumoto, 1942, 1943, 1954; Vereshchagin, 1961, 1963; Vereshchagin & Salinikov, 1968; Pergament, 1974; Zonova, 1974; Zakharov *et al.*, 1981, 1984, 1996; Zonova, 1987; Mirolyubov, 1987; Zonova *et al.*, 1993; Yazykova, 1994; Alabushev & Wiedmann, 1997).

In addition to the stratotype locality, the Kura and Gorbusha areas in the Kril'on Peninsula (Fig. 1) provide one of the best reference sections of the Upper Cretaceous of South Sakhalin (Vereshchagin, 1961; Vereshchagin, 1970, 1977). No detailed geological maps, columnar sections, or route maps of the peninsula have been published for this area.

To establish the up-to-date biostratigraphic zonation for the Upper Cretaceous System of Sakhalin, a field expedition was carried out by the authors in 1996 along

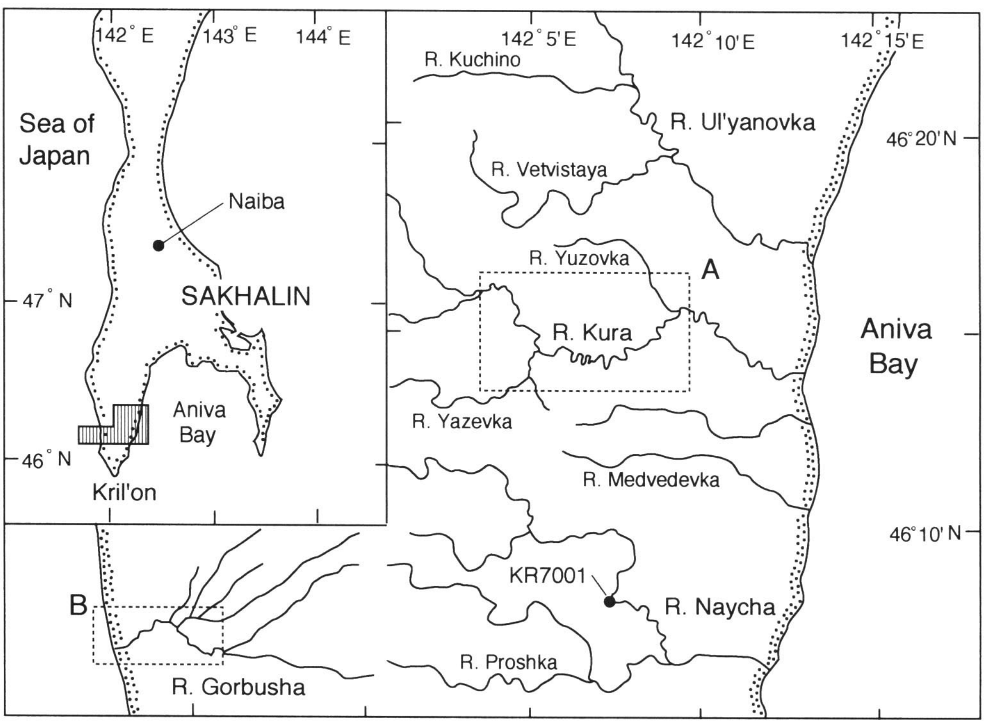

Fig. 1. Map showing the study area in the eastern part of the Kril'on peninsula, South Sakhalin. A: Kura area, B: Gorbusha area.

the Kura and Gorbusha rivers (Fig. 1). This was the first geological expedition by a joint Japanese-Russian research team to the Kril'on Peninsula since the Second World War.

Previous Studies of the Kril'on Area

During the mid 19th to early 20th centuries, a few Russian and Japanese geologists undertook a geological expedition in the Kril'on Peninsula, and discovered Cretaceous deposits and fossils there (Hirano & Tsurumaru, 1908; see Vereshchagin, 1977). In the 1930's, Murayama (1933) made a geological survey in the Dorokawa (=Ul'yanovka) area, and described the Dorokawa Formation, consisting of black shale and green sandstone containing many Cretaceous ammonites and inoceramids. In the western part of the Kril'on Peninsula, Ishizaki and Sakakura (1937) described the Cretaceous rocks as the Togushi Black Shale and the Togushi Green Sandstone formations.

After the Second World War, many Russian geologists conducted a geological survey in the Kril'on Peninsula, and the megafossil assemblage and stratigraphy of the Cretaceous System were summarized by Vereshchagin (1970, 1977) and Furesenko (1974). They divided the Cretaceous deposits into the Bykov and Krasnoyarka formations in upward sequence, as in those of the type section in the Naiba area. Subsequently, ammonites and inoceramids from these formations have been partly described by Zonova (1993) and Yazykova (1992, 1994).

Stratigraphy in the Kura Area

The Yezo Group is widely exposed along the upper course of the Kura River. The strata strike N10–85°E, and dip 15–30° westward and are unconformably overlain by the Neogene deposits. The Cretaceous sequence are partly exposed repeatedly in the middle course of the river by faults (Figs. 2, 3).

The Yezo Group along the Kura River can be divided into two units, the Bykov and Krasnoyarka formations in upward sequence, as defined by Vereshchagin (1961) along the Naiba River (Figs. 4, 5). These are respectively equivalent to the Upper Yezo and the Hakobuchi groups of Hokkaido.

Bykov Formation (Vereshchagin, 1961)

Stratotype: Naiba River, South Sakhalin.

Localities: Middle course of the Kura River (Locs. KR6049–6052); the Yazevka River (Locs. KR6213–6223).

Thickness: Greater than 60 m.

Lithology: Only the uppermost part is exposed. It is composed mainly of dark gray, intensely bioturbated mudstone. Lenticular calcareous nodules, 30–60 cm in di-

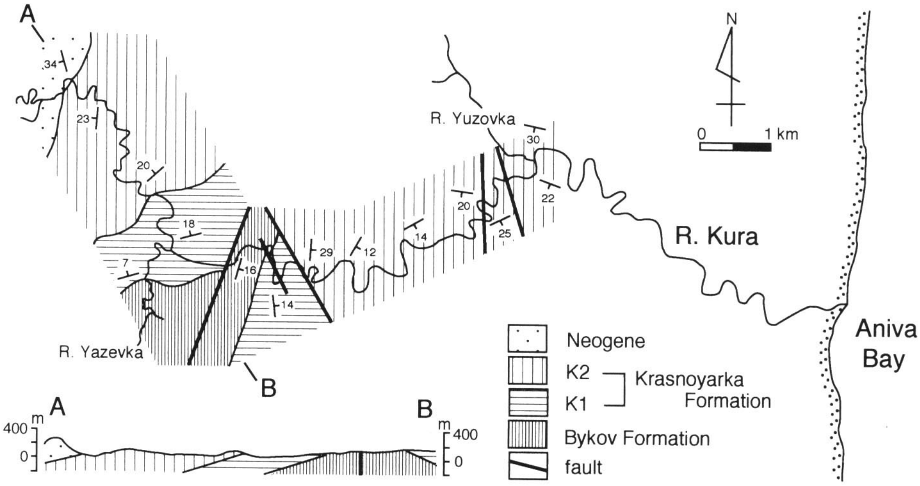

Fig. 2. Geological map and profile along the Kura River.

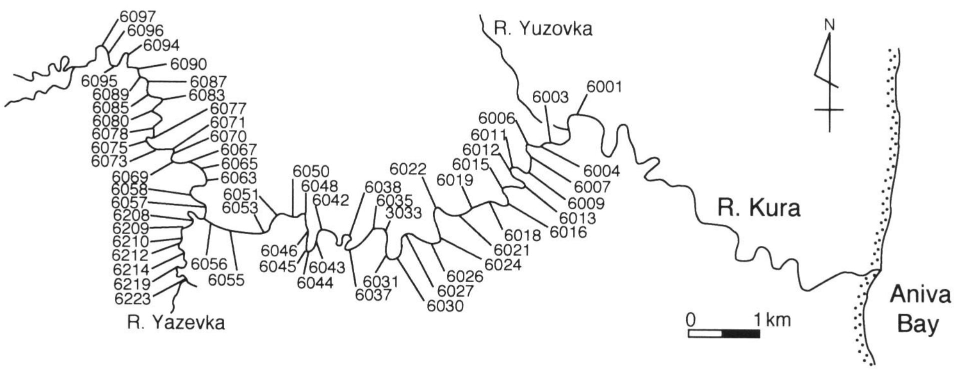

Fig. 3. Locality map along the Kura River. Prefix KR is omitted for each locality number.

ameter, are commonly embedded in the mudstone.

Fossil: *Eupachydiscus haradai* (Jimbo) is abundant, and occurs both from calcareous nodules and from the host rock. Specimens are usually adult forms, and attain more than 30 cm in diameter.

Krasnoyarka Formation (Vereshchagin, 1961)

This formation consists mainly of sandstone and sandy mudstone, and the total thickness attains to about 1,060 m. It conformably covers the Bykov Formation, and is subdivided into two members, K1 and K2 in ascending order.

Stratotype: Krasnoyarka River, a branch of the Naiba River, South Sakhalin.

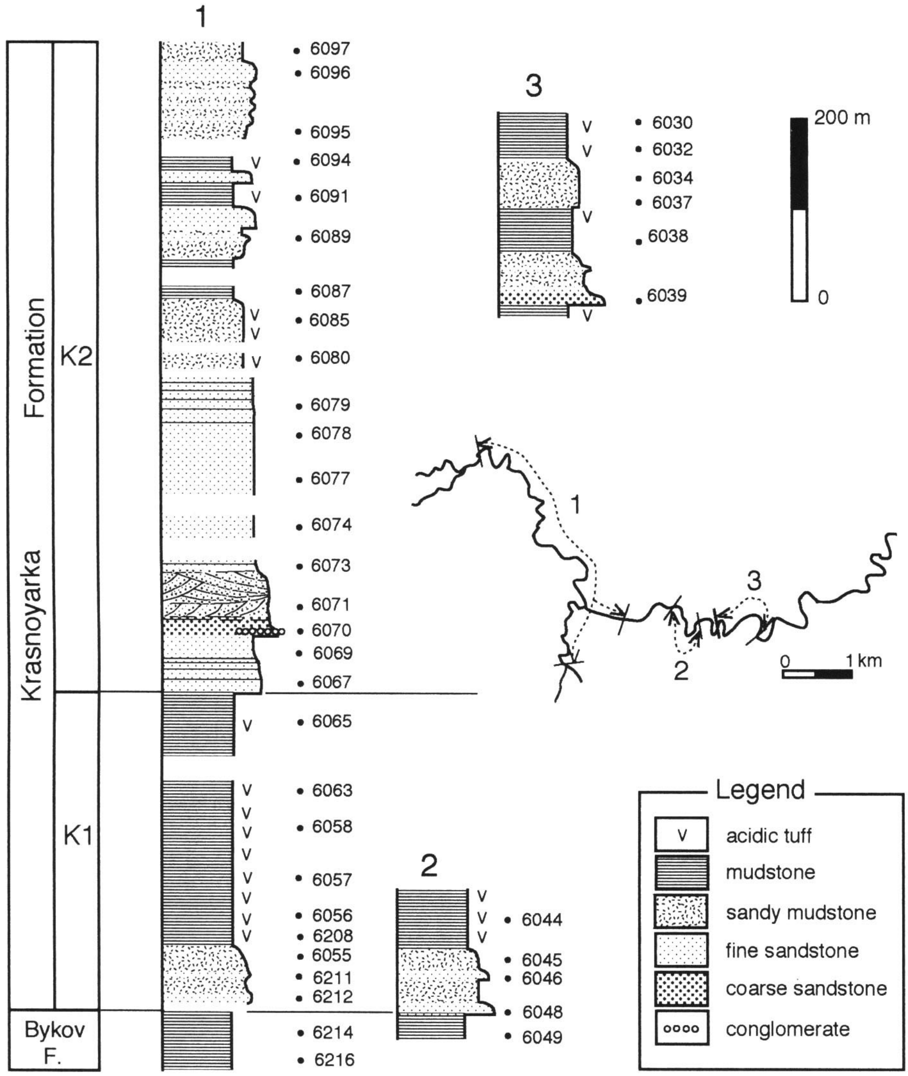

Fig. 4. Columnar section of the Upper Cretaceous along the Kura River. Localities can be found on the locality map (Fig. 3).

K1 Member

Localities: Upper course of the Kura River (Locs. KR6053-6066, typical section); middle course of the Kura River (Locs. KR6042-6048); the Yazevka River (Locs. KR6201-6212)

Thickness: 350 m.

Lithology: This member rests on the Bykov Formation, and conformably under-

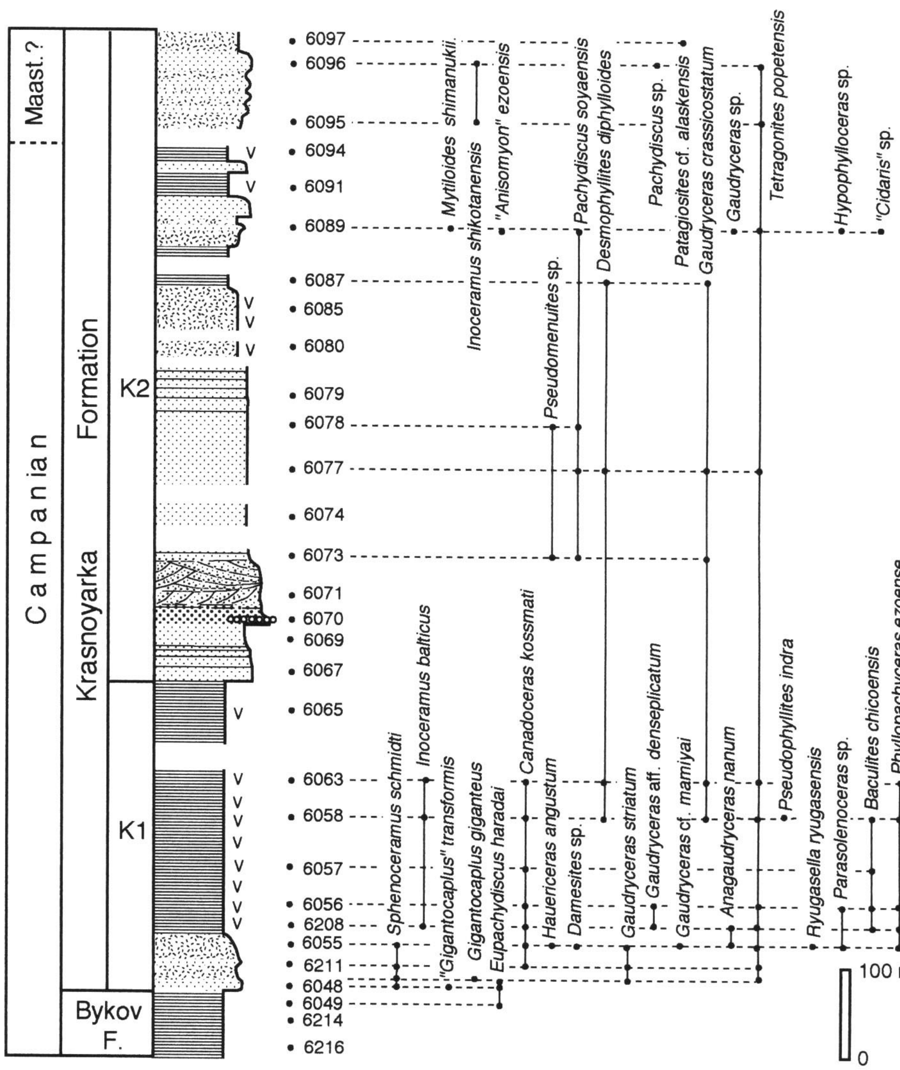

Fig. 5. Stratigraphic occurrences of ammonites, inoceramids and other invertebrates along the Kura River. Legend is shown in Figure 4.

lies the K2 Member. The basal part of the K1 consists of greenish gray and poorly sorted bedded sandstone, and rich in andesitic volcanic rock fragments. It changes upward to intensely bioturbated massive sandy mudstone and mudstone interbedded with thin tuff beds in the middle and upper parts. Spherical or lenticular calcareous nodules, which contain abundant fossils, are common particularly in the lower and middle parts.

Fossils: The entire member is fossiliferous. In the basal part, *Sphenoceramus* *schmidti* Michael, *Eupachydiscus haradai* (Pl. 2, fig. 1), and large pattelliform gastropods, "*Gigantocaplus*" *transformis* (Dundo) (Pl. 1, fig. 4) and *Gigantocaplus giganteus* (Schmidt) (Pl. 1, fig. 5) are found in abundance, both from calcareous nodules and host rock.

The muddy sandstone at approximately 50 m above the base of the K1 Member is particularly fossiliferous, and the following ammonites and inoceramid bivalve were found at Loc. KR6055: *Canadoceras kossmati* Matsumoto, *Damesites* sp., *Hauericeras angustum* Yabe, *Ryugasella ryugasensis* Wright & Matsumoto, *Parasolenoceras* sp., *Tetragonites popetensis* Yabe, *Gaudryceras striatum* (Jimbo), *Gaudryceras* cf. *mamiyai* Matsumoto & Miyauch, *Anagaudryceras nanum* Matsumoto, *Phyllopachyceras ezoense* (Yokoyama), and *Sphenoceramus schmidti* (Pl. 1, fig. 2). Small brachiopods are also found in cluster, together with ammonites in calcareous nodules.

The faunal composition changes toward the upward sequence within the middle part of the K1 Member. In the lower middle part of the member, *Baculites chicoensis* Trask (Pl. 1, fig. 1), *Parasolenoceras* sp., and *Gaudryceras* aff. *denseplicatum* Jimbo are common, while *Desmophyllites diphylloides* (Forbes), *Gaudryceras crassicostatum* Jimbo, and *Pseudophyllites indra* (Forbes) are abundant in the upper middle part. These ammonites occur mostly from calcareous nodules. In addition, *Inoceramus balticus* Böhm, *C. kossmati* (Pl. 3, fig. 1), *T. popetensis*, and *P. ezoense* are common in calcareous nodules, in association with plant remains. *C. kossmati* in the upper middle part tends to possess dense ribs in adult stage, resembling *Canadoceras multicostatum* Matsumoto.

No fossils were found in the upper part of the member.

K2 Member

Localities: Upper course of the Kura River (Locs. KR6067–6097, typical section); middle course of the Kura River (Locs. KR6001–6041).

Thickness: 710 m.

Lithology: The member conformably overlies the K1 Member, and conformably underlies the Neogene deposits. The lowest part of the member consists of greenish gray, fine- to medium-grained, bedded sandstone and changes upward to greenish gray, medium- to course-grained sandstone interbedded with a thin conglomerate bed. This conglomerate bed consists mainly of angular to subrounded pebbles of andestic volcanic rock. Higher still, the lithology changes upward to greenish gray, trough-cross-stratified, coarse- to medium-grained sandstone, and further changes to dark, intensely bioturbated muddy sandstone. The middle to upper parts of the member consist of dark greenish gray, intensely bioturbated sandy mudstone and muddy sandstone interbedded with thin tuff beds.

Fossils: The cross-stratified sandstone and conglomerate in the lowest part of the K2 Member lack megafossils, but the overlying fine-grained sandstone is fossilif-

Table 1. List of ammonites, inoceramids and other invertebrates from the Krasnoyarka Formation along the Kura River.

Species	Krasnoyarka Formation	
	K1 member	K2 member
Inoceramids		
Sphenoceramus schmidti Michael	6043, 6045, 6046, 6048, 6053, 6054, 6055, 6210, 6211, 6212	
Mytiloides shimanukii Matsumoto & Noda		6015, 6022, 6089
Inoceramus balticus Böhm	6208, 6058, 6063	
Inoceramus shikotanensis Nagao & Matsumoto		6095, 6096
Gastropods		
"*Gigantocaplus*" *transformis* (Dundo)	6048	
Gigantocaplus giganteus (Schmidt)	6048	
"*Anisomyon*" *ezoensis* Nagao & Otatume		6089
Ammonites		
Eupachydiscus haradai (Jimbo)	6048, 6049	
Canadoceras kossmati Matsumoto	6042, 6043, 6044, 6045, 6054, 6055, 6056, 6057, 6058, 6063, 6201, 6207, 6208, 6209, 6210, 6211	
Pachydiscus soyaensis Matsumoto & Miyauchi		6073, 6077, 6078, 6089
Pseudomenuites sp.		6073, 6078
Patagiosites cf. *alaskensis* Jones		6097
Pachydiscus sp.		6096
Hauericeras angustum Yabe	6055	
Damesites sp.	6055	
Desmophyllites diphylloides (Forbes)	6058, 6063	6015, 6077, 6087
Tetragonites popetensis Yabe	6043, 6044, 6045, 6048, 6055, 6056, 6058, 6060, 6063, 6207, 6208, 6209, 6211	6077, 6089, 6095, 6096
Pseudophyllites indra (Forbes)	6058	6009
Gaudryceras striatum (Jimbo)	6043, 6048, 6055, 6211	
Gaudryceras cf. *mamiyai* Matsumoto & Miyauchi	6055	
Gaudryceras aff. *denseplicatum* Jimbo	6056, 6208, 6209	
Gaudryceras crassicostatum Jimbo	6058, 6063	6073, 6077, 6087
Gaudryceras sp.		6089
Anagaudryceras nanum Matsumoto	6042, 6055, 6208	
Ryugasella ryugasensis Wright & Matsumoto	6055	
Parasolenoceras sp.	6055, 6056	6015
Diplomoceras sp.		6015
Baculites chicoensis Trask	6044, 6056, 6057, 6058, 6207, 6208	
Phyllopachyceras ezoense (Yokoyama)	6043, 6044, 6055, 6056 6058, 6063, 6208	
Hypophylloceras sp.		6089
Echinoid		
"*Cidaris*" sp.		6089

erous; *Pachydiscus soyaensis* Matsumoto & Miyauch (Pl. 4, figs.1–3), *Gaudryceras crassicostatum*, *Desmophyllites diphylloides*, and *Pseudomenuites* sp. (Pl. 5, figs.1, 2) are particularly abundant in the lower part. Fossils of *P. soyaensis* are represented by adult shells only, attaining 30–50 cm in diameter.

In the middle part of the member, *Mytiloides shimanukii* Matsumoto & Noda (Pl. 1, fig. 3), *Gaudryceras* sp., *P. soyaensis*, *T. popetensis*, *Hypophylloceras* sp., *Pseudophyllites indra*, *Diplompceras* sp., *Cidaris* sp., and "*Anisomyon*" *ezoensis* Nagao & Otatsume (Pl. 1, fig. 6) were found from calcareous nodules.

Inoceramus shikotanensis Nagao & Matsumoto is found in abundance both from calcareous nodules and host rock in the upper part of the K2 Member. It co-occurs with *Patagiosites* cf. *alaskensis* Jones (Pl. 5, figs.3, 4) and *T. popetensis*. This is the stratigraphically highest fauna in the Kura River area.

Stratigraphy in the Gorbusha Area

The Yezo Group along the lower course of the Gorbusha River is exposed in the north-northwest trending syncline area. The strata on the western limb strike N10–20°W and dip 20° eastward; those on the eastern limb strike N–S and dip 50–60° westward. They are unconformably covered by supposed Neogene deposits which consist chiefly of poorly-indurated sandstone, with basal conglomerate, and contain marine mollusks and rare plant megafossils, such as *Zelkova ungeri* (Ettingshausen) Kovats and silicified woods of *Taxodioxylon*, *Picea* and *Ulmus* (Figs. 6, 7).

The Cretaceous Yezo Group exposed along the Gorbusha River can be divided into the Bykov and Krasnoyarka formations in ascending order, as is the case of the Kura area in the eastern part of Kril'on Peninsula (Figs. 8, 9).

Bykov Formation (Vereshchagin, 1961)

Stratotype: Naiba River, South Sakhalin.

Localities: Middle course of the Gorbusha River (Locs. KR1016–1054).

Thickness: Greater than 770 m.

Lithology: Only the upper part is exposed, composing mainly of dark gray, intensely bioturbated mudstone interbedded with white vitric tuff layers ranging 5 to 20 cm thick. Lenticular or Spherical calcareous nodules, 30–60 cm in diameter, are commonly embedded in the mudstone.

Fossils: The formation is fossiliferous. In the lower to middle parts, *Inoceramus amakusensis* Nagao & Matsumoto, *Damesites damesi* (Jimbo), *Menuites sutneri* (Yokoyama), *Yokoyamaoceras ishikawai* (Jimbo), *Gaudryceras tenuiliratum* Yabe, *Tetragonites popetensis*, *Tetragonites glabrus* (Jimbo), *Hypophylloceras subramosum* (Shimizu), *Polyptychoceras obstrictum* (Jimbo), and *Subptychoceras yubarense* (Yabe) were found from calcareous nodules.

Platyceramus japonicus (Nagao & Matsumoto) is found in abundance in the

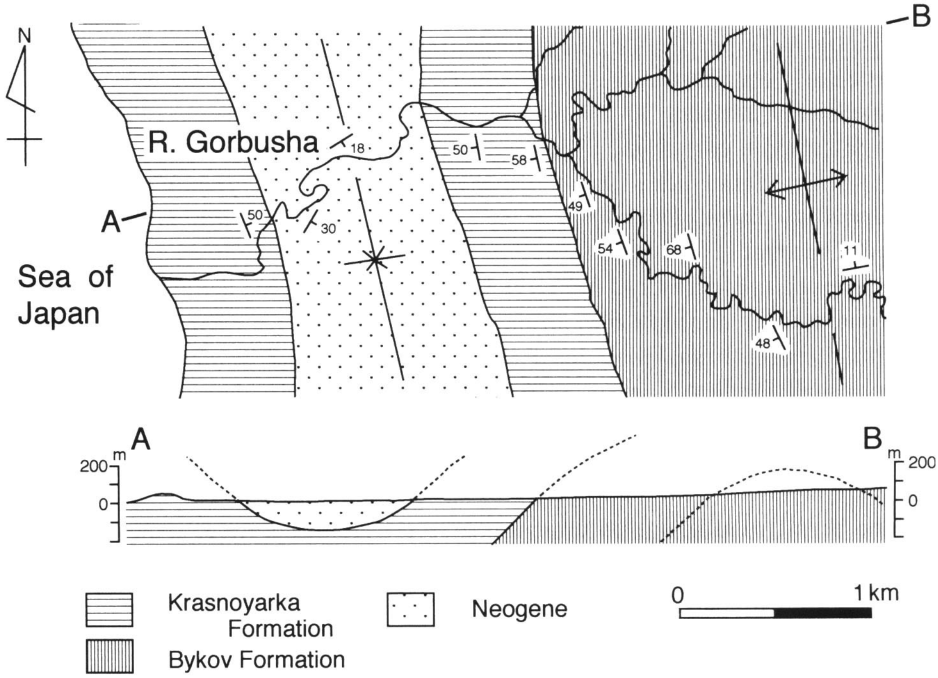

Fig. 6. Geological map and profile along the Gorbusha River.

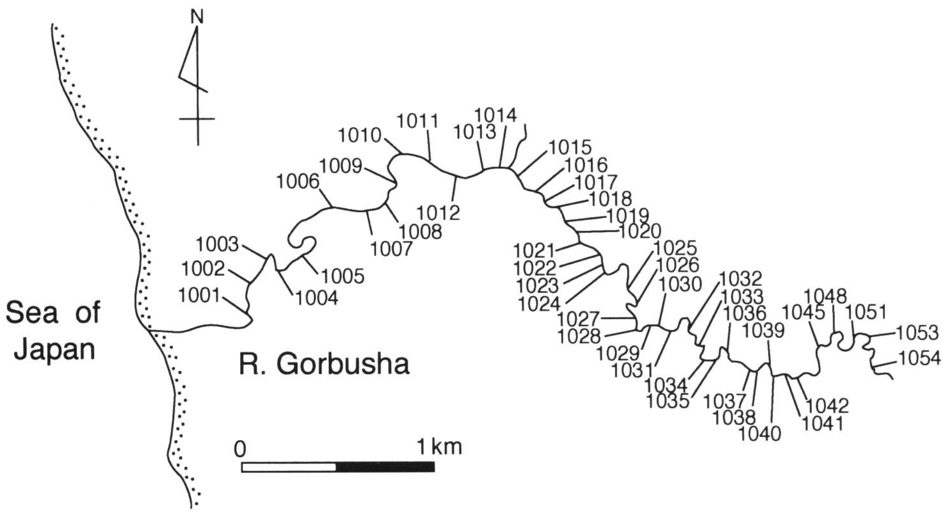

Fig. 7. Locality map along the Gorbusha River. Prefix KR is omitted for each locality number.

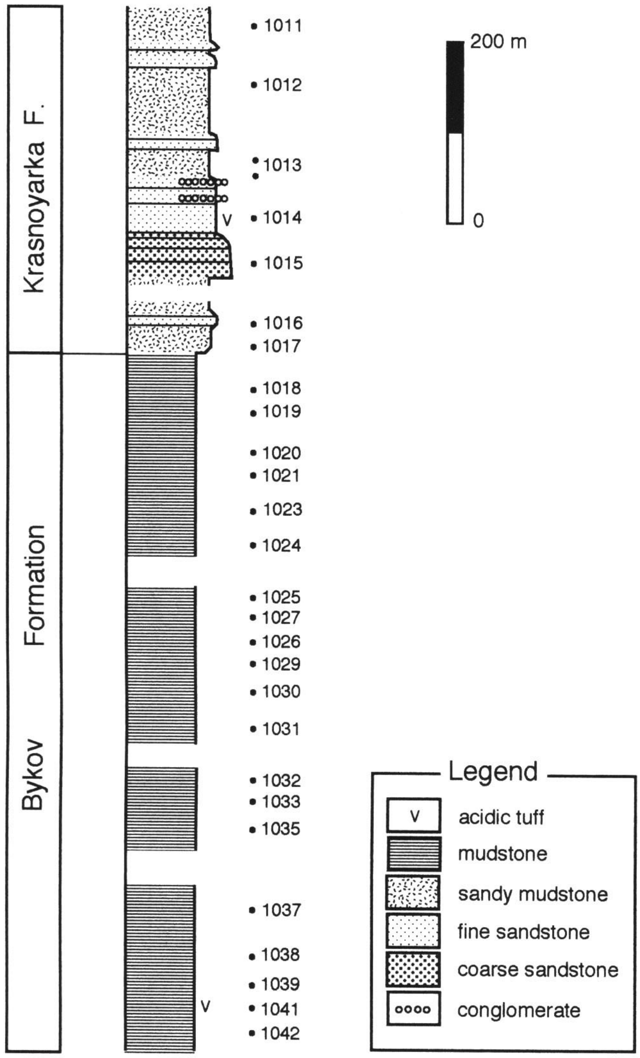

Fig. 8. Columnar section of the Upper Cretaceous along the Gorbusha River. Localities can be found on the locality map (Fig. 7).

upper part of the formation. It commonly co-occurs with *Eubostrychoceras densicostsus* Matsumoto, *Gaudryceras densiplicatum* Jimbo, *G. tenuiliratum*, *T. poptetensis*, *T. glabrus*, *Y. ishikawai*, *Hauericeras angustum*, *P. obstrictum*, and *S. yubarense*.

Krasnoyarka Formation (Vereshchagin, 1961)

The Krasnoyarka Formation consists mainly of sandstone and sandy mudstone, rich in andesitic volcanic rock fragments. It conformably overlies the Bykov Forma-

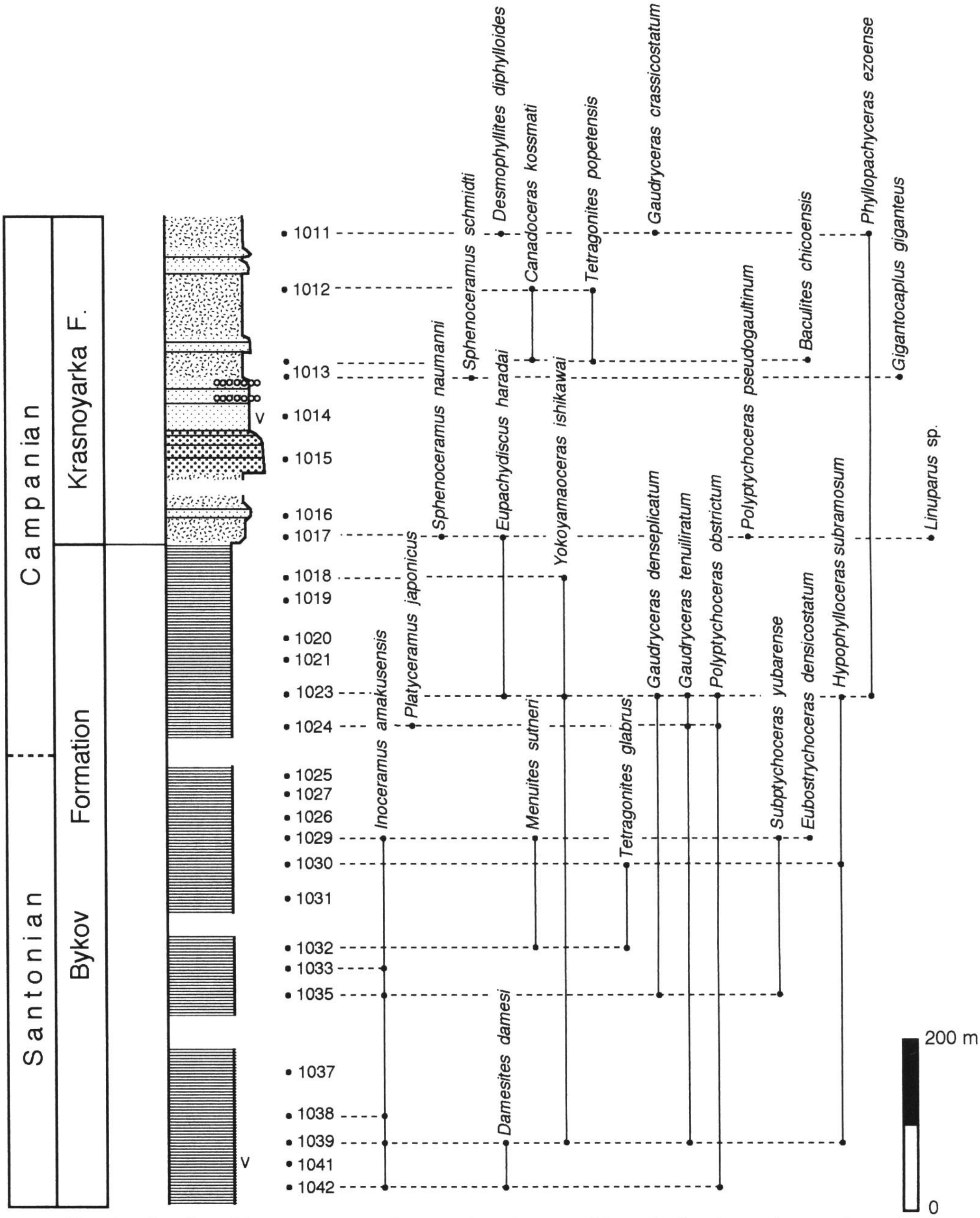

Fig. 9. Stratigraphic occurrences of ammonites, inoceramids and other invertebrates along the Gorbusha River. Legend is shown in Figure 8.

Table 2. List of ammonites, inoceramids and other invertebrates from the Bykov and Krasnoyarka formations along the Gorbusha River.

Species	Bykov Formation	Krasnoyarka Formation
Inoceramids		
Inoceramus amakusensis Nagao & Matsumoto	1042, 1039, 1038, 1035, 1033, 1029	
Platyceramus japonicus (Nagao & Matsumoto)	1024	
Sphenoceramus naumanni (Yokoyama)		1017
Sphenoceramus schmidti Michael		1013
Gastropod		
Gigantocaplus giganteus (Schmidt)		1013
Ammonites		
Damesites damesi (Jimbo)	1042, 1039	
Desmophyllites diphylloides (Forbes)		1011
Menuites sutneri (Yokoyama)	1032, 1029	
Eupachydiscus haradai (Jimbo)	1023	1017
Canadoceras kossmati Matsumoto		1013, 1012
Yokoyamaoceras ishikawai (Jimbo)	1039, 1023, 1018	
Tetragonites glabrus (Jimbo)	1032, 1030	
Tetragonites popetensis Yabe		1013, 1012
Gaudryceras denseplicatum (Jimbo)	1035, 1023	
Gaudryceras tenuiliratum Yabe	1039, 1024, 1023	
Gaudryceras crassicostatum Jimbo		1011
Polyptychoceras obstrictum (Jimbo)	1042, 1024, 1023	
Polyptychoceras pseudogaultinum (Yokoyama)		1017
Subptychoceras yubarense (Yabe)	1035, 1029	
Eubostrychoceras densicostatum Matsumoto	1029	
Baculites chicoensis Trask		1013
Hypophylloceras subramosum (Shimizu)	1039, 1030, 1023	
Phyllopachyceras ezoense (Yokoyama)	1023	1011
Crustacea		
Linuparus sp.		1017

tion.

Stratotype: Krasnoyarka River, a branch of the Naiba River, South Sakhalin.

Localities: Middle course of the Gorbusha River (Locs. KR1011–1017); mouth of the Gorbusha River (Locs. KR1001, 1002).

Thickness: 380 m.

Lithology: The lower part of the formation consists of greenish gray, poorly-sorted, bedded, fine- to coarse-grained sandstone and muddy sandstone. The formation changes upward to intensely bioturbated massive muddy sandstone interbedded with conglomerate in the middle part and to fine-grained sandstone in the upper part. Sandy mudstone often contains spherical calcareous concretion, about 30–50 cm in diameter, and some of them are fossiliferous.

Fossils: *Sphenoceramus naumanni* (Yokoyama), *Eupachydiscus haradai*, *Polyptychoceras pseudogaultinum* (Yokoyama), and *Linuparus* sp. were found in muddy sandstone of the basal part of the formation. *Sphenoceramus schmidti* and *Gigantcaplus giganteus* are found in the middle part, and *Canadoceras kossmati*, *Tetragonites poptensis*, and *Desmophyllites diphylloides* occur in the upper part. We also discovered *Pachydiscus soyaensis* from a floated calcareous nodule possible derived from the uppermost part of the Krasnoyarka Formation on the western limb of the syncline.

Correlation

Kura area

The ammonite and inoceramid zonation applied in the Kura area is based on the studies of Matsumoto (1942, 1954, 1959, 1984), Zonova *et al.* (1993), Yazykova & Zonova (1994), Yazykova (1994), and Toshimitsu *et al.* (1995). The presence of *Sphenoceramus schmidti* and *Eupachydiscus haradai* in the basal part of the K1 Member of the Krasnoyarka Formation suggests the middle Lower Campanian. The middle part of the K1 Member is characterized by the presence of *Inoceramus balticus* and *Canadoceras kossmati*, and is correlated to the upper Lower Campanian.

Various Upper Campanian faunal elements, typically represented by *Pachydiscus soyaensis* occur from the K2 Member. *Mytiloides shimanukii* is also found in the lower to middle parts of the K2 Member. This species, together with *Metaplacenticeras subtilistriatum* (Jimbo) and *Hoplitoplacenticeras monju* Matsumoto, dominantly occur in the Upper Campanian of the Hakobuchi Group in Hokkaido (Matsumoto, 1984; Matsumoto & Noda, 1985); the latter two species, however, have not yet been found in Sakhalin.

The uppermost part of the K2 Member contains *Inoceramus shikotanensis* and *Patagiosites* cf. *alaskensis*. The former is an index of the lower Lower Maastrichtian, but comparable specimens occur from the Upper Campanian of the Izumi Group of Japan (Morozumi, 1985). *Patagiosites alaskensis* is one of the characteristic species of the *Pachydiscus kamishakensis* Zone in southern Alaska, and the age is probably latest Campanian or early Maastrichtian (Jones, 1963). Therefore, the uppermost part of the K2 Member is probably correlated to the uppermost Campanian or lower Lower Maastrichtian.

Gorbusha area

Inoceramus amakusensis, from the lower to middle parts of the Bykov Formation, shows the presence of the Lower Santonian stage in the Gorbusha area. The upper part of the Bykov Formation is characterized by *Platyceramus japonicus*, which indicates the lower part of the Lower Campanian. *Sphenoceramus schmidti* is found commonly in the middle part of the Krasnoyarka Formation; therefore the hori-

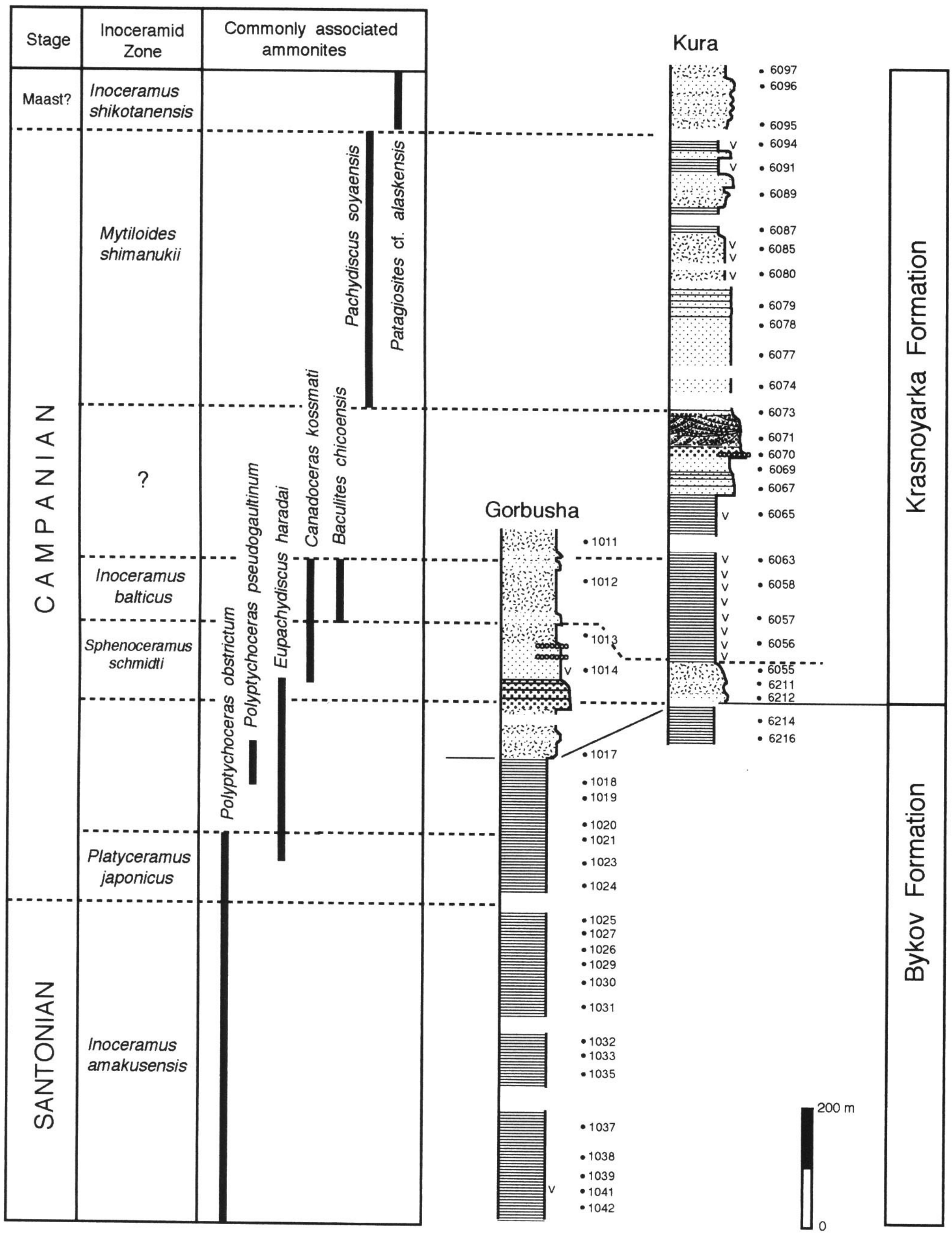

Fig. 10. Summary of biostratigraphy of the Cretaceous System in the Kril'on area.

zon is correlated to the upper part of the Lower Campanian.

No inoceramids were found in the upper part of the Krasnoyarka Formation, but the ammonite fauna, consisting of *Canadoceras kossmati*, *Desmophyllites diphylloides*, and *Pachydiscus soyaensis*, suggests the lower part of the Upper Campanian.

Discussion

Sedimentary facies of the Cretaceous strata are similar between the Kura and Gorbusha areas (Fig. 10). Deep-water, offshore mudstone facies predominates throughout the Bykov Formation (="Upper Yezo Group" of Hokkaido) from Santonian to lowest Campanian age. In contrast, the overlying Krasnoyarka Formation (="Hakobuchi Group" of Hokkaido) is sandy and clearly shows shallowing upward sequence both in the Kura and Gorbusha areas. However, there are some differences in detail.

The base of the Krasnoyarka Formation in the western Gorbusha area is approximately within the *Sphenoceramus schmidti* Zone, or the lower Lower Campanian (Fig. 9). Above this level, coarse-grained sandstone and conglomerate are dominant throughout the formation. The stratigraphical occurrence of fossils is discontinuous and rather sporadic. In contrast, fossiliferous mudstones are still abundant in the Lower Campanian K1 Member of the eastern Kura area (Fig. 5).

Based on the lateral change of litho- and biofacies of Hokkaido, an eastward-deeping setting for the Cretaceous "Yezo Fore-arc Basin" has been inferred (Matsumoto & Okada, 1971; Tanaka, 1977). Lithological and faunal differences between the contemporaneous strata in the eastern and western parts of the Kril'on Peninsula, Sakhalin, can be similarly attributable to an eastward-deepening setting of the fore-arc basin at that time. A comprehensive facies reconstruction throughout the "Yezo Fore-arc Basin" is needed to elucidate details of basin sedimentation and geometry.

The typical Maastrichtian fauna (Zonova *et al.*, 1993, Yazykova, 1994) and Sinegorsk fauna, which may suggest Danian age (Kalishevitch & Posylny, 1958; Kalishevitch *et al.*, 1981), are widely distributed in the Sinegorsk, Naiba, Manuy, and Makarov areas of Sakhalin. Although such faunas were not found in the Kura and Gorbusha areas, we found *Sphenoceramus hetonaianus* (Matsumoto) and *Gaudryceras tombetsuense* Matsumoto (Pl. 6, fig. 1) from the middle course of the Naycha River (loc. KR7001), about 10 km south of the Kura River (Fig. 1). They are diagnostic of the upper Lower Maastrichtian (Toshimitsu *et al.*, 1995a, 1995b). This may suggest that the stratigraphic and faunal successions of the Maastrichtian are well preserved in the Kril'on Peninsula, along the uppermost course of the Naycha River.

Concluding Remarks

Similar to the Naiba section, the Cretaceous Yezo Group in the eastern Kura and western Gorbusha areas in the Kril'on Peninsula, South Sakhalin, is lithologically divided into the Bykov and Krasnoyarka formations in ascending order. Although the lower part of the succession is not exposed in these areas, the age ranges from at least Santonian to uppermost Campanian or lowest Maastrichtian (Fig. 10).

Because of discontinuous and sporadic occurrence of megafossils, the biostratigraphic framework of the uppermost Cretaceous remains ambiguous in both Hokkaido and Sakhalin. Continuous sequences spanning into the Campanian-Maastrichtian are not observable even in the well-known reference sections of the Ikushumbetsu (Hokkaido) and Naiba (Sakhalin) areas. In contrast, stratigraphical and faunal successions of the Campanian are well preserved in the Kril'on Peninsula. Almost all megafossil assemblages known from the middle to Upper Campanian of Hokkaido and the Naiba area are found in a few sections in the Kura area. This area may therefore provide an important key to establish precise biostratigraphical framework of the Cretaceous in the Western Pacific region including Japan and Far Eastern Russia.

Acknowledgments

We are very much grateful to Director G. S. Steinberg of the Institute of Volcanology and Geodynamics (Yuzhno-Sakhalinsk) for his kind help and cooperation throughout the field survey. We also thank Director P. V. Sadovnik and Dr. V. M. Radiush of Sakhalin GEOLKOM (Yuzhno-Sakhalinsk) for the permission and constructive help of the field program in Sakhalin. Thanks are extended to Drs. O. A. Melnikov (Institute of Marine Geology and Geophysics, Yuzhno-Sakhalinsk), Y. D. Zakharov (Far East Geological Institute, Vladivostok), J. W. Haggart (Geological Survey of Canada, Vancouver), T. Kase (National Science Museum, Tokyo) ,K. Kodama (Kochi University) and K. Terada (Fukui Prefectural Museum) for helpful suggestions on the geology, paleontology and magnetostratigraphy of Sakhalin. This study was supported by Grant-in-Aid for International Scientific Research (Field Research) (nos. 08041113 and 09041114) from the Ministry of Education, Science, Sports and Culture, Japan.

References

Alabushev, A. & J. Wiedmann, 1997. Upper Cretaceous ammonites from Southern Sakhalin and Northwestern Kamchatka (North-East Russia). *Palaeontographica*, Abt. A, **244**: 1–36, pls. 1–11.

Fursenko, A. V. (ed.), 1974. Biofatsialnye osobennosti mezokainozoiskikh basseinov Sakhalina i Kurilskikh ostrovov. 252 pp. Nauka, Novosibirsk. [Biofacial peculiarities of Meso-Cenozoic basins of Sakhalin and Kuril Islands.] (In Russian.)

Hirano, R. & Y. Tsurumaru, 1908. Reports of the preliminary survey at the Notoro coal field. *In*: Report of the ore deposits of Karafuto as of 40th year of Meiji, pp. 54-95. Karafuto-cho. (In Japanese.)

Ishizaki, M. & K. Sakakura, 1937. Geology of the western part of the Notoro peninsula. *Jour. Geol. Soc. Japan*, **44**: 1128–1141. (In Japanese.)

Jimbo, K., 1892. Beiträge zur Kenntniss der Fauna der Kreideformation von Hokkaido. *Palaeont. Abhandl. N. F.*, **2**(3): 147–194, pls. 17–25.

Jones, D. L., 1963. Upper Cretaceous (Campanian and Maestrichtian) ammonites from Southern Alaska. *Prof. Pap. U.S. Geol. Surv.*, **432**: 1–53, pls. 6–41.

Kawada, M., 1929. On the Cretaceous deposits of the Naibuchi district, Sakhalin. *Jour. Geol. Soc. Japan*, **36**: 1–11. (In Japanese.)

Kalishevitch, T. G. & V. Y. Posylny, 1958. Ob otsutstvii pereryva v osadkonakoplenii mezhdu kainozoem i mezozoem v rajone Sinegorska-Zagorska na Sakhaline. *Dokl. AN SSSR ser. geol.*, **119**(4): 766–768. [About absence of break of sedimentation between Cenozoic and Mesozoic in the Sinegorsk-Zagorsk region on Sakhalin.] (In Russian.)

Kalishevitch, T. G., E. D. Zaklinskaya & M. Y. Serova, 1981. Razvitiye organicheskogo mira Tikhookeanskogo poyasa na rubezhe mezozoya i kainozoya. 164 pp. Nauka, Moscow. [Organic evolution of the Circum-Pacific during the Mesozoic-Cenozoic transition.] (In Russian.)

Maeda, H., 1986. Stratigraphy and fossil molluscan fauna of the Upper Cretaceous System in the Bibai area, Hokkaido, north Japan. *Jour. Geol. Soc. Japan*, **92**(2):135–153, pl. 1. (In Japanese with English abstract.)

Matsumoto, T., 1942. Fundamentals in the Cretaceous stratigraphy of Japan, Part 1. *Mem. Fac. Sci., Kyushu Imp. Univ.*, Ser. D, **1**: 129–280, pls, 1–20.

Matsumoto, T., 1943. Fundamentals in the Cretaceous stratigraphy of Japan, Part 2 & 3. *Mem. Fac. Sci., Kyushu Imp. Univ.*, Ser. D, **2**: 97–237.

Matsumoto, T. (ed.), 1954. The Cretaceous System in the Japanese Islands. 324 pp. Japan Society for the Promotion of Science, Tokyo.

Matsumoto, T., 1959. Zonation of the Upper Cretaceous in Japan. *Mem. Fac. Sci., Kyushu Univ.*, Ser. D, **9**: 55–93, pls. 6–11.

Matsumoto, T., 1975. Ammonitology in Japan—a Historical review. *Trans. Proc. Palaeont. Soc. Japan*, N. S., **97**: 1–6.

Matsumoto, T., 1977. Zonal correlation of the Upper Cretaceous in Japan. *Palaeont. Soc. Japan, Spec. Pap.*, **21**: 63–74.

Matsumoto, T., 1984. Ammonites from the Upper Campanian of the Teshio Mountains. *In* T. Matsumoto (ed.), Some ammonites from the Campnaian (Upper Cretaceous) of Northern Hokkaido. Part 1, pp. 5–32, pls. 1–9. *Palaeont. Soc. Japan, Spec. Pap.*, **27**.

Matsumoto, T & H. Okada, 1971. Clastic sediments of the Cretaceous Yezo Geosyncline. *Mem. Geol. Soc. Japan*, **6**: 61–74.

Matsumoto, T. & M. Noda, 1985. A new Inoceramid (Bivalvia) species from the Upper Campanian (Cretaceous) of Hokkaido. *Proc. Japan. Acad.*, **61**(B): 9–11.

Mirolyubov, Y. G., 1987. Ammonity. *In* Z. N. Poyarkova (ed.), Oporny razrez melovykh otlozhenij Sakhalina (Naibinskij razrez), pp. 83–87. Nauka, Leningrad. [Ammonoids. *In* Z. N. Poyarkova (ed.), Reference section of Cretaceous deposits in Sakhalin (Naiba section).] (In Russian.)

Morozumi, Y., 1985. Late Cretaceous (Campanian and Maastrichtian) ammonites from Awaji Island, Southwest Japan. *Bull. Osaka Mus. Nat. Hist.*, **39**: 1–58, pls. 1–18.

Murayama, K., 1933. Geology of the area between upper course of the Dorokawa and Minami-nayoshi in the Notoro peninsula. *Karafuto Oil Field Geol. Rep.*, **2**: 67–74. (In Japanese.)

Nagao, T. & T. Matsumoto, 1939. A monograph of the Cretaceous *Inoceramus* of Japan, Part 1. *Jour. Fac. Sci., Hokkaido Imp. Univ.*, Ser. 4, **4**: 241–299, pls. 23–34.

Nagao, T. & T. Matsumoto, 1940. A monograph of the Cretaceous *Inoceramus* of Japan, Part 2. *Jour. Fac. Sci., Hokkaido Imp. Univ.*, Ser. 4, **6**: 1–64, pls. 1–22.

Okada, H, 1979. The geology of Hokkaido and its plate tectonics. *Earth Monthly*, **1**: 869–877. (In Japanese.)

Okada, H., 1983. Collision orogenesis and sedimentation in Hokkaido, Japan. *In* M. Hashimoto & S. Ueda (eds.), Accretion Tectonics in the Circum-Pacific Regions, pp. 91–105. Terra Scientific Publishing Co., Tokyo.

Pergament, M. A., 1974. Biostratigrafiya i inotseramy senona (santon - maastrikht) tikhookeanskikh rajonov SSSR. *Trudy GIN*, **260**: 1–266, pls. 1–46. [Biostratigraphy and Inoceramus of Senonian (Santonian–Maastrichtian) of the USSR Pacific Region.] (In Russian.)

Shimizu, S., 1929. Cretaceous deposits of North and South Saghalin, A comparison. *Proc. 4th Pacific Sci. Cong.*: 905–917.

Tanaka, K., 1977. Cretaceous System. *In* K. Tanaka & T. Nozawa (eds.), Geology and Mineral Resources of Japan, vol. 1, pp.182-206, Geol. Surv. Japan, Kawasaki.

Toshimitsu, S., T. Matsumoto, M. Noda & S. Maiya, 1995a. Towards an integrated mega-, micro- and magneto-stratigraphy of the Upper Cretaceous in Japan. *Jour. Geol. Soc. Japan*, **101**(1): 19–29. (In Japanese with English abstract.)

Toshimitsu, S., T. Matsumoto, M. Noda & S. Maiya, 1995b. Integration of mega-, micro-, and magneto-stratigraphy of the Upper Cretaceous in Japan. *In* K. H. Chang & S. O. Park (eds.), Environmental and tectonic history of East and South Asia with emphasis on Cretaceous correlation (IGCP 350), pp. 357–370. Proceedings of 15th International Symposium of Kyungpook National University, Taegu.

Vereshchagin, V. N., 1961. Skhema stratigrafii melovykh otlozhenij Sakhalina. *In* N. B. Vassoyevich (ed.), Resheniya mezhvedomstvennogo soveshchaniya po razrabotke unifitsirovannykh stratigraficheskikh skhem dlya Sakhalina, Kamchatki, Kurilskikh i Komandorskikh ostrovov, pp. 11. Gostoptekhizdat, Leningrad. [Scheme on stratigraphy of Cretaceous deposits of Sakhalin. *In* N. B. Vassoyevich (ed.), Decisions of Interdepartmental meeting on development of unified stratigraphical schemes for Sakhalin, Kamchatka, Kuril and Commandor Islands.] (In Russian.)

Vereshchagin, V. N., 1963. Zonalnoe delenye verkhnemelovykh otlozhenij severa Tikhookeanskoy biogeografitcheskoj provincii. *In* B. K. Egazarova (ed.), Geologiya Koryakskogo nagorja, pp. 50-63. Gosgeoltekhizdat, Moscow. [Zonal dividing of Upper Cretaceous deposits on North Pacific biogeographical province. *In* B. K. Egazarova (ed.), Geology of Koryak Highland.] (In Russian.)

Vereshchagin, V. N., 1970. Zapadno-Sakhalinckie gory. *In* V. N. Vereshchagin & Y. M. Kovtunovitch (eds), Geologiya SSSR, t. 33, Ostrov Sakhalin, Geologicheskoe opisanie, pp. 67–87. Nedra, Moscow. [Western Sakhalin Mountain . *In* V. N. Vereshchagin & Y. M. Kovtunovitch (eds.), Geology of USSR, v. 33, Sakhalin Island.] (In Russian.)

Vereshchagin, V. N., 1977. Melovaya sistema Dalnego Vostoka. *Trudy VSEGEI*, N.S., **242**: 1–207. [The Cretaceous of Far East.] (In Russian.)

Vereshchagin, V. N. & B. A. Salinikov, 1968. O printsipakh i metodakh izucheniya opornykh stratigraficheskikh razrezov na primere stratotipicheskogo razreza verkhnogo mela Tikhookeanskoj biogeograficheskoj oblasti (o-v Sakhalin). *Trudy VSEGEI*, N.S., **143**: 45–58. [On principles and methods of studying of reference stratigraphical sections for example of stratotypical section of Upper Cretaceous of the Pacific biogeographical area (Sakhalin Island).] (In Russian.)

Vereshchagin, V. N., V. P. Kinasov, K. V. Paraketsov & G. P. Terekhova, 1965. Polevoj atlas melovoj fauny Severo-Vostoka SSSR. 216 pp. Magadan. [Field atlas of the Cretaceous fauna from northeast USSR.] (In Russian.)

Yabe, H., 1903. Cretaceous Cephalopoda from Hokkaido. Part 1. *Jour. Coll. Sci., Imp. Univ. Tokyo*, **18**(2): 1–55, pls. 1–7.

Yabe, H., 1904. Cretaceous Cephalopoda from Hokkaido. Part 2. *Jour. Coll. Sci., Imp. Univ. Tokyo*, **20**(2): 1–45, pls. 1–6.

Yazykova, E. A., 1992. Ammonoidea verkhnego mela vostoka SSSR. *In* T. D. Zonova & K. O. Rostovtsev (eds.), Atlus rukovodyashchikh grup fauny mezozoya yuga i vostoka SSSR, pp. 192–200. *Trudy*

VSEGEI, N.S., **350**, S.-Peterburg. [Upper Cretaceous ammonites from East USSR. *In* T. D. Zonova & K. O. Rostovtsev (eds.), Atlas of index fossils in the Mesozoic fauna of South and East USSR.] (In Russian.)

Yazykova, E. A., 1994. Maastrichtian ammonites and biostratigraphy of the Sakhalin and the Shikotan Islands, Far Eastern Russia. *Acta Geological Polonica*, **44**(3–4): 277–303, pls. 1–20.

Yazykova, E. A. & T. D. Zonova, 1994. Zonalnoe raschlenenie maastrikhta Tikhookeanskogo poyasa v predelakh Rossii. *In* A. N. Oleinikov (ed.), Zonalnye podrazdeleniya i mezhregionalnaya korrelyatsiya paleozoiskikh i mezozoiskikh otlozhenij Rossii i sopredelnykh territorij, 2. Mezozoi, pp. 158–185. VSEGEI, S.-Petersburg. [Zonal division of Pacific Maastrichtian within Russia. *In* A. N. Oleinikov (ed.), Zonal subdivision and interregional correlation of the Paleozoic and Mesozoic deposits of the Russia and adjacent territories, 2, Mesozoic.] (In Russian.)

Yokoyama, M., 1890. Versteinerungen aus der japanischen Kreide. *Palaeontographica*, **36**: 159–202, pls. 18–25.

Zakharov, Y. D., V. S. Grabovskaya & T. G. Kalishevich, 1981. Suktsessionnyj ryad morskikh organizmov naibinskoj i bykovskoj svit v opornom razreze verkhnyego mela Sakhalina. *In* V. A. Krassilov (ed.), Evolyutsiya organizmov i biostratigraphiya melovogo perioda, pp.47–85. DVNC Akademii nauk SSSR, Vladivostok. [Successional row of the marine organisms from the Naiba and Bykov formations of the basic Upper Cretaceous section in Sakhalin. *In* V. A. Krassilov (ed.), Evolution of the Cretaceous biota and biostratigraphy.] (In Russian.)

Zakharov, Y. D., V. S. Grabovskaya & T. G. Kalishevich, 1984. Pozdnemelovaya suktsessiya morskikh soobshchestv na yuge Sakhalina i klimaticheskiye osobennosti Severo-Zapadnoj Patsifiki. *In* M. N. Gramm & Y. D. Zakharov (eds.), Sistematika i evolyutsiya bezpozonochnykh Dal'nego Vostoka, pp. 41–90. DVNC Akademii nauk SSSR, Vladivostok. [Late Cretaceous succession row of the marine communities of the North-West Circum Pacific. *In* M. N. Gramm & Y. D. Zakharov (eds.), Systematics and evolution of Far Eastern invertebrates.] (In Russian.)

Zakharov, Y. D., A. V. Ignatyev, N. G. Ukhaneva & T. B. Afanaseva, 1996. Cretaceous ammonoid succession in the Far East (South Sakhalin) and the basic factors of syngenesis. *Bull. del'institute Royal des Sci. Naturelles de Belgique*, **66**: 109–127.

Zonova, T. D., 1974. Zonalnoe delenie melovykh otlozhenij ostrova Sakhalin po inotseramam. *In* B. Kh. Egizarov & V. N. Vereshchagin (eds.), Stratigrafiya i litologiya melovykh, paleogenovykh i neogenovykh otlozhenij Koryaksko-Anadyrskoj oblasti, pp.82-91. NIIGA, Leningrad. [Zonal dividing of Cretaceous deposits of Sakhalin Island by Inoceramus. *In* B. Kh. Egizarov & V. N. Vereshchagin (eds.), Stratigraphy and lithology of Cretaceous, Paleogene and Neogene deposits of Koryak-Anadyr region.] (In Russian.)

Zonova, T. D., 1987. Inotseramidy. *In* Z. N. Poyarkova (ed.), Oporny razrez melovykh otlozhenij Sakhalina (Naibinskij razrez), pp. 63–75. Nauka, Leningrad. [Inoceramids. *In* Z. N. Poyarkova (ed.), Reference section of Cretaceous deposits in Sakhalin (Naiba section).] (In Russian.)

Zonova, T. D., L. I. Kazintsova & E. A. Yazykova, 1993. Atlas rukovodyashchikd grupp melovoj fauny Sakhalina. 327 pp. Nedra, S.-Petersburg. [Atlas of index fossils in the Cretaceous fauna of Sakhalin.] (In Russian.)

Explanation of Plates

Plate 1.

Fig. 1. Cluster occurrence of *Baculites chicoensis* Trask in a calcareous nodule. NSM PM16116, from Loc. KR6056, along the Kura River. ×1.0.

Fig. 2. *Sphenoceramus schmidti* (Michael). NSM PM16111, left lateral view, from Loc. KR6055, along the Kura River. ×1.0.

Fig. 3. *Mytiloides shimanukii* Matsumoto & Noda, NSM PM16112, right lateral view, from the upper course of the Kura River. ×1.0.

Fig. 4. "*Gigantocaplus*" *transformis* (Dundo). NSM PM16113, apical view, from Loc. KR6048, along the Kura River. ×0.8.

Fig. 5. *Gigantocaplus giganteus* (Schmidt). NSM PM16114, apical view, from Loc. KR6048, along the Kura River. ×0.5.

Fig. 6. "*Anisomyon*" *ezoensis* Nagao & Otatsume. NSM PM16115, apical view, from Loc. KR6089, along the Kura River. ×2.0.

Plate 2.

Fig. 1. *Eupachydiscus haradai* (Jimbo). NSM PM16117, right lateral view, from Loc. KR6048, along the Kura River. ×1.0.

Plate 3.

Fig. 1. *Canadoceras kossmati* Matsumoto. NSM PM16118, right lateral view, from Loc. KR6057, along the Kura River. ×0.5.

Plate 4.

Figs. 1–3. *Pachydiscus soyaensis* Matsumoto and Miyauchi. NSM PM16119, ventral, left lateral and apertural views, from the upper course of the Kura River. ×0.3.

Plate 5.

Figs. 1, 2. *Pseudomenuites* sp. NSM PM16120, ventral and left lateral views, from the upper course of the Kura River. ×0.7.

Figs. 3, 4. *Patagiosites* cf. *alaskensis* Jones. NSM PM16121, apertural and right lateral views, from Loc. KR6073, along the Kura River. ×0.55.

Plate 6.

Fig. 1. *Gaudryceras tombetsuense* Matsumoto. NSM PM16122, left lateral view, from Loc. KR7001, along the Naycha River. ×0.8.

Plate 1

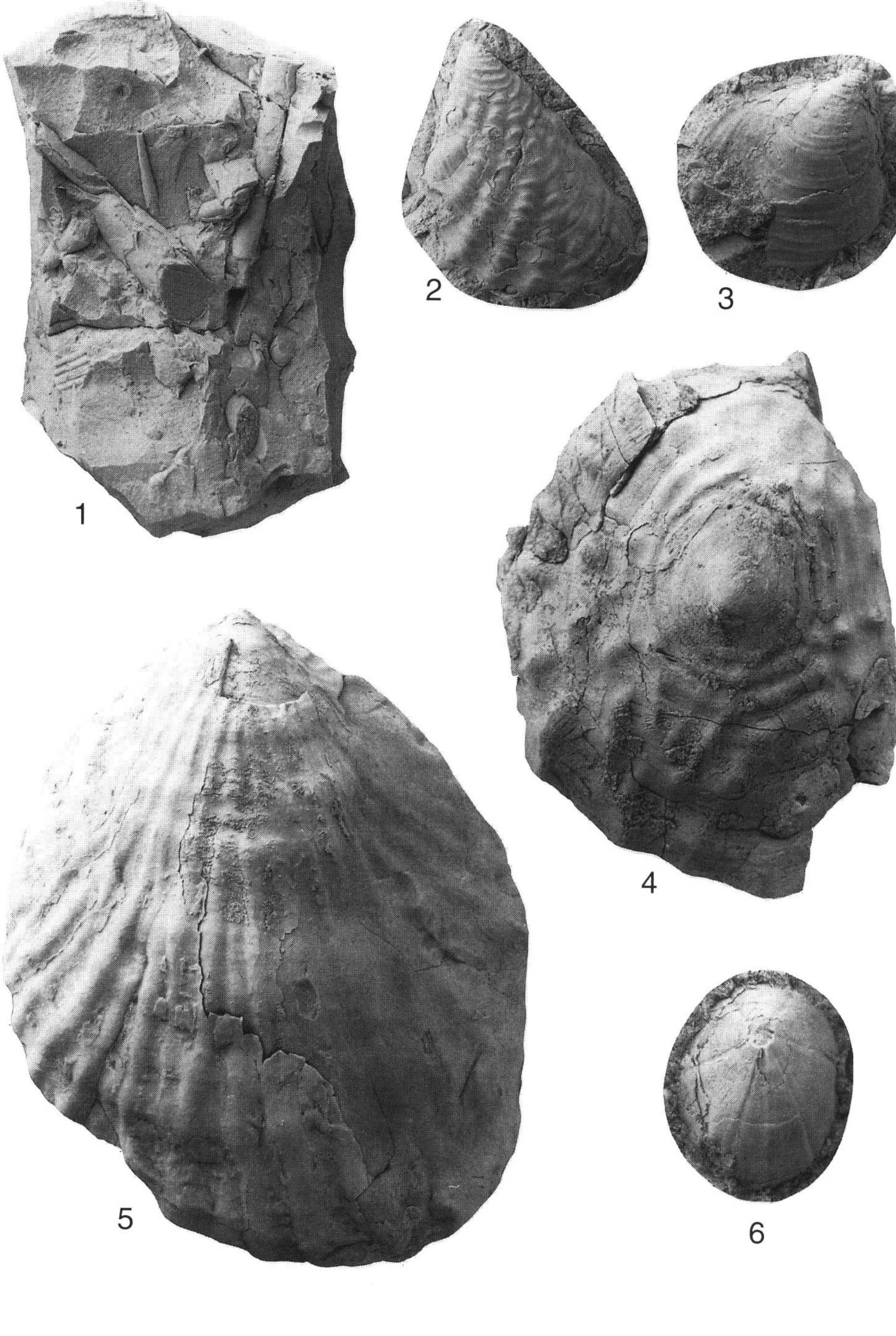

Plate 2

1

Plate 3

1

Plate 4

3

2

1

Plate 5

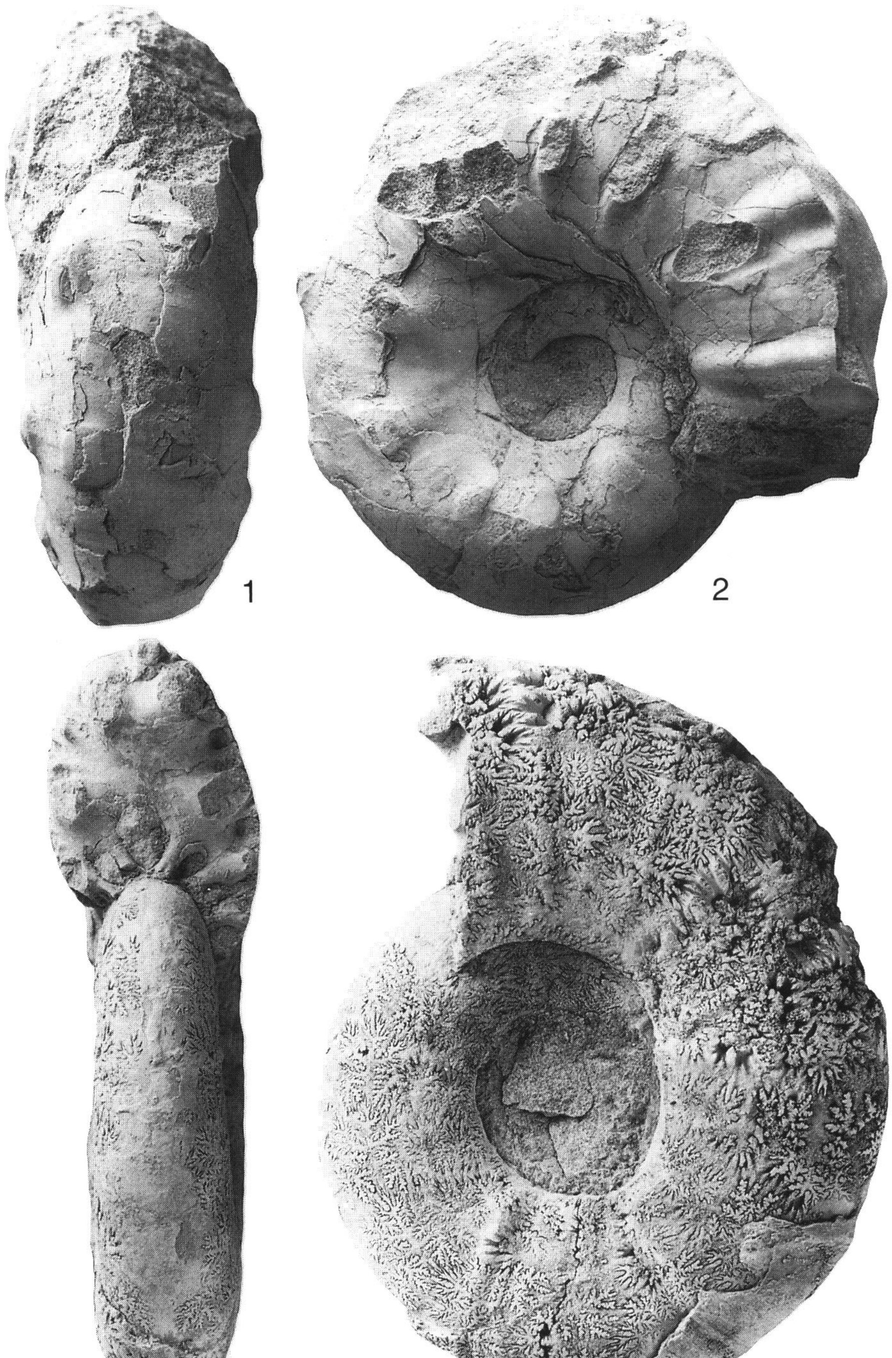

Plate 6

1