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Ammonite biozonation and litho-/chronostratigraphy of the Cretaceous in Sakhalin and adjacent territories of Far East Russia

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ABSTRACT:

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The stratigraphy and ammonite faunas of the Cretaceous succession in Sakhalin are discussed. A high-resolution biostratigraphic zonation (24 zones in total) is proposed; it is correlated with adjacent areas and corresponds well to inoceramid and radiolarian zones. The definition of all stage and some substage boundaries in Sakhalin is discussed, and possibilities for interregional and global correlations are assessed. In addition, the main mass extinction and faunal turnover events recognised in these sections are taken into consideration.

Key words: Cretaceous, Ammonites, Stratigraphy, Bioevents, Palaeoecology, Sakhalin, Far East Russia.

INTRODUCTION

The vast territory of Far East Russia constitutes a part of the northern province of the Pacific palaeobiogeographic realm, and includes Chukotka Peninsula, the Koryak Upland and Kamchatka Peninsula in the northeast, and Sikhote Alin, Sakhalin and the Kuril Islands in the south (Text-fig. 1). A major obstacle encountered in correlation with the type areas of the various Upper Cretaceous stages is the high degree of faunal endemism characterising the Pacific realm, which means that most of the recently proposed criteria for the recognition of stage boundaries cannot be applied. The huge thickness of the Upper Cretaceous sequence (e.g. in excess of 4,000 m in Sakhalin), with strong lateral facies changes, records a series of environmental changes and bioevents along the northwestern Pacific margin.

In the present paper, the author summarises and concludes her ongoing studies of the problems surrounding the placement of Cretaceous stage boundaries in this region, and in Sakhalin in particular. In comparison to other areas in Far East Russia, sections there are amongst the best exposed and easily accessible. Moreover, the Naiba River section is one of the most complete of the stratigraphic sections of Sakhalin Island and all of the Russian Far East. Additionally, these have yielded abundant, highly diverse ammonite assemblages. Most of the material described and/or illustrated is from the author's collection; additional specimens, presented to the author, derive from collections made by other scientists, amongst them VERESCHAGIN, ZONOVA, MIROLUBOV and POKHIALAJNEN.

The aims of the present work are fivefold. Firstly, a detailed biostratigraphic framework based on ammonites is established, and, secondly, correlation with adjacent

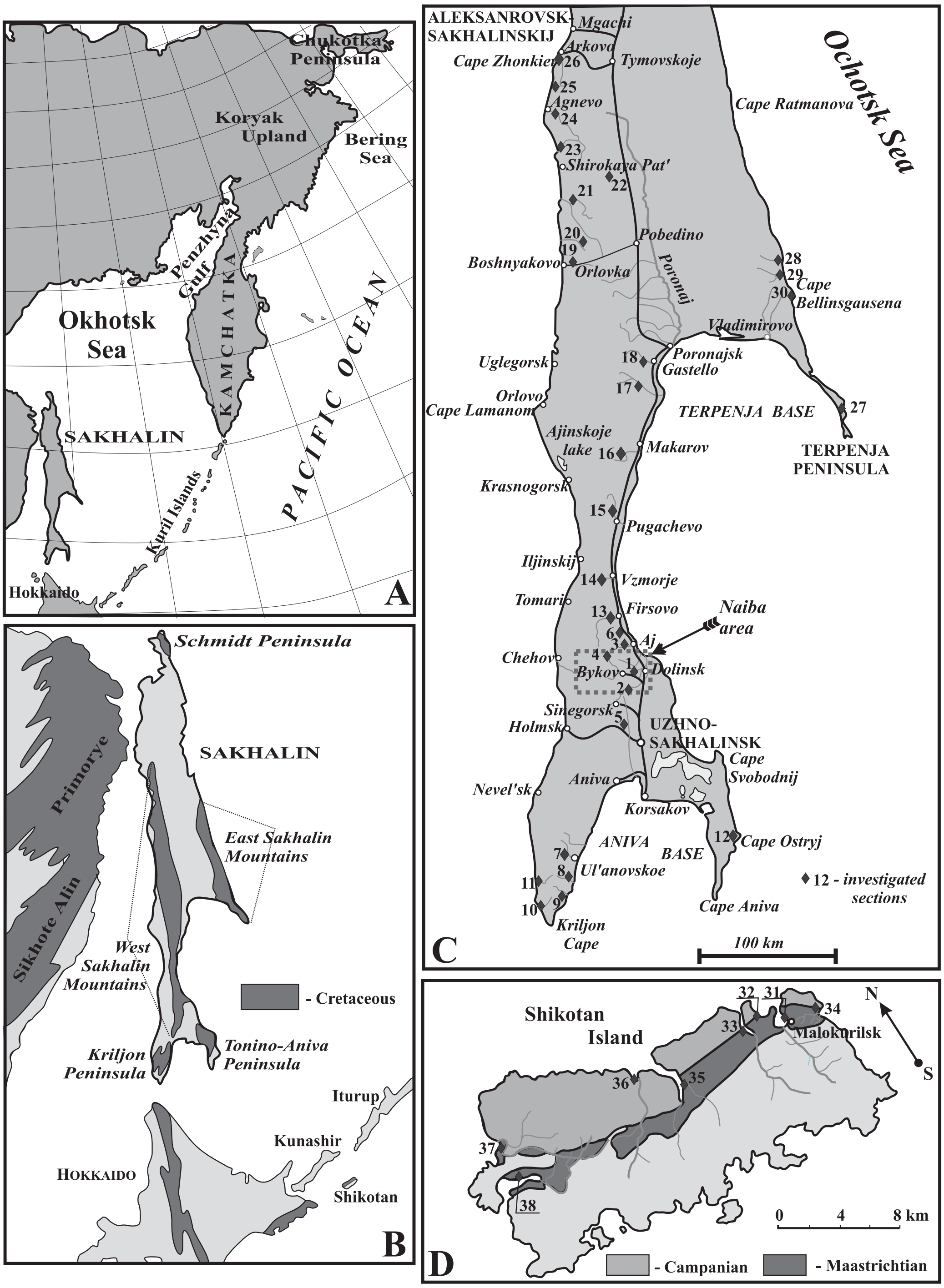

Fig. 1. **A** – The area of Far East Russia; **B** – Distribution of Cretaceous deposits in Sikhote Alin, Primorye and in the islands of Sakhalin and Shikotan; **C** – Map of Sakhalin showing the location of the sections studied: 1 – River Naiba area, 2 – River Malyj Takoj, 3 – River Aj, 4 – River Lebyazhja, 5 – River Susuya, 6 – River Malaya Podlesnaya, 7 – River Ul'anovka, 8 – River Kura, 9 – River Naicha, 10 – River Gorbusha, 11 – River Sakharovka, 12 – Tonino-Aniva Peninsula, 13 – River Firsovka, 14 – River Manuj, 15 – River Pugachevka, 16 – River Makarova, 17 – River Nituj, 18 – River Gastello area, 19 – River Bol'shaya Orlovka area, 20 – River Avgustovka, 21 – River Pilevka area, 22 – River Onor, 23 – River Naj-Naj, 24 – River Agnevo, 25 – River Popovskaya, 26 – Cape Zhonkier, 27 – Terpenja Peninsula, 28 – River Nerpichja, 29 – River Krivulya, 30 – River Borisovka; **D** – Map of Shikotan Island showing the location of sections studied: 31 – Malokurilskaya Bay, 32 – Chromova Bay, 33 – Otradnaya Bay, 34 – Shikotan Cape, 35 – Gorobec Bay, 36 – Krabovaya Bay, 37 – Zvezdnaya Bay, 38 – Dolphin Bay

areas is discussed. Thirdly, this regional biozonation enables boundaries between Cretaceous stages to be placed much more reliably, which in turn improves opportunities for global synchronisation. Lastly, on the basis of bioevents documented in the sections studied, palaeoecological and palaeoenvironmental reconstructions are interpreted.

PREVIOUS RESEARCH

The present paper summarises and revises all previous studies known to the author and documents new possibilities for defining local stage boundaries as well as for global correlations of these, and, more generally, discusses the ammonite biostratigraphy of Sakhalin. That is why the author has deemed it absolutely necessary to present here a brief historical overview of earlier works on ammonite stratigraphy in Sakhalin with analyses of the significance of the most important of these papers.

The earliest studies on the Cretaceous sequences in Sakhalin date from the second half of the nineteenth century. SCHMIDT (1868) was the first to publish a geological description and a list of fossils, including the first ammonites from Cape Zhonkier (Text-fig. 1); the palaeontological description of the fauna collected was completed five years later (SCHMIDT 1873).

The beginning of the twentieth century saw the publication of numerous papers by Japanese scientists, documenting ammonites, amongst other faunal elements: YABE (1909), KAWADA (1929), YABE & SHIMIZU (1924a, b), SHIMIZU (1929) and, mentioned by SHIMIZU (1935) and HAYASAKA (1921), although that paper cannot be traced now (SHIGETA, pers. comm., 2003). In the same period, SOKOLOV (1915) presented the first description of inoceramid faunas from Sakhalin and TIKHONOVICH & POLEVOJ (1915) conducted regional studies and noted a few ammonite finds. From 1917 onwards, detailed stratigraphic studies were carried out across Sakhalin Island by KRYSHTOFOVICH (1918, 1920, 1926, 1927a, b, 1937). A brief description of the geology and stratigraphy of southeast Sakhalin was published by KRASNOI (1937).

SHIMIZU (1935) presented a subdivision of the Cretaceous System for Japan, inclusive of sections in southern Sakhalin, as well as a correlation with eustatic events. Although that author did not complete a monograph, his paper was the first detailed documentation of a Cretaceous ammonite zonation in central and southern Sakhalin. It should be noted, however, that there are numerous problems in that paper with regard to age assignment of the succession and to exposed intervals. For instance, no Albian faunas were recorded and Campanian deposits were misdated as Maastrichtian, Turonian as Coniacian, Santonian as Campanian, Danian as Maastrichtian, etc. Later, MATSUMOTO (1959c) noted that, at first glance, the zones proposed by SHIMIZU appeared to compare well to those then known in Europe, but in fact they often conflicted with data obtained during subsequent field work.

Already in the 1930s appeared the first papers by MATSUMOTO, some of them concerning ammonite finds from Sakhalin (1936, 1938). Then, during the next few years, MATSUMOTO completed an ammonite zonation for the Cretaceous of Japan, inclusive of the Naiba area, the most complete Upper Cretaceous section in Sakhalin (MATSUMOTO 1942-1943, 1954a, b), and additionally revised some taxonomically uncertain ammonite genera from Sakhalin (WRIGHT & MATSUMOTO 1954). During the 1950s, several ammonite species from Sakhalin were published in Japanese papers (MATSUMOTO 1955a, b; MATSUMOTO & OBATA 1955; OBATA 1959). Subsequently, MATSUMOTO (1959c) revised the Cretaceous stratigraphy of Japan, as well as all pre-1959 data for the Naiba section, showing material from that section to be complementary to Hokkaido. MATSUMOTO attempted a global correlation, but only for Japanese strata and not specifically for those in Sakhalin. Unfortunately, that correlation scheme cannot be applied fully in Sakhalin since a number of taxa which he used as zonal indices in Hokkaido are absent from Sakhalin.

From 1957 onwards, comprehensive studies were conducted throughout Sakhalin by VERESCHAGIN and co-workers. The general succession was documented by these authors, inoceramid and ammonite zonations were established and descriptions of faunas were published (VERESCHAGIN 1957, 1961, 1963, 1977; LIVEROVSKAYA 1960; VERESCHAGIN & *al.* 1965, 1972). Of note is that comparatively few ammonites were recorded in this period; only VERESCHAGIN & *al.* (1965) provided short descriptions and illustrations of a handful of specimens. VERESCHAGIN and his group (see ZHURAVLEV 1969a; ZONOVA & *al.* 1986) documented the presence of the Albian deposits in Sakhalin, based on the occurrence of certain ammonite genera (including *Cleoniceras* and *Brewericeras*). SHUVAEV (1965) presented the geology and stratigraphy of the Upper Cretaceous of the East Sakhalin Mountains and mentioned, but did not illustrate, a few finds of Campanian ammonites.

The next zonal scheme, only the second one for Sakhalin, was proposed by VERESCHAGIN's group (Proceedings... 1982), showing correlations with adjacent areas and based on MATSUMOTO's revised zonation (1959c), plus new data. Although generally accepted at that time, this scheme had numerous 'barren' intervals from which no ammonites were recorded, e.g. the Maastrichtian part of the sequence.

Several years later, KANIE & *al.* (1978) and TANABE & *al.* (1978, 1980) mentioned some specimens from Naiba in their works on ammonite jaw elements. Yu.D. ZAKHAROV & *al.* (1978, 1981, 1984) described the general succession of marine faunal assemblages from the River Naiba section; only those of the Bykov Formation were described in any detail.

POKHIALAJNEN (1985) presented a detailed description of a representative of the genus *Forresteria*; this record was significant for the assignment of a Coniacian age to a part of the Sakhalin succession. It is now known that *Forresteria* appears already in the uppermost Turonian, and so cannot be utilized as an index for the Coniacian, but it can still be used for intra- and interregional correlations.

In recent years, ZONOVA and co-workers published a very detailed description of the Naiba reference section (see POYARKOVA 1987), inclusive of extensive palaeontological data on the main faunal groups, amongst which are ammonites. Included as well in this work is an integrated biostratigraphic scheme based on ammonites, inoceramids, foraminifera and radiolarians. However, the ammonite zonation in particular still revealed many problematic levels, especially in the Maastrichtian interval.

ALABUSHEV (1989) recorded and briefly described a few Late Cretaceous ammonites from the Naiba section. In a number of papers on Cretaceous ammonites and/or the biostratigraphy of the Cretaceous in Japan, some ammonites from Naiba have been published or referred to (MATSUMOTO & MIYAUCHI 1984; MOROZUMI 1985; OKAMOTO 1989; MATSUMOTO & *al.* 1986, 1991; MAEDA 1993; SHIGETA 1992, 1993; MATSUMOTO 1995; TANABE & *al.* 2000).

From 1990 onwards, the present author has been conducting an extensive study of Maastrichtian ammonites and biostratigraphy (ZONOVA 1990; YAZYKOVA 1991, 1992, 1993). Her PhD thesis, published in 1994 (YAZYKOVA 1994), presents a detailed ammonite zonation for the Maastrichtian in Sakhalin and Shikotan. Concurrently, the author was a member of the ZONOVA group, worked out an ammonite zonation for the Cretaceous sequences in Sakhalin (see ATABEKIAN & *al.* 1991), and provided descriptions of some ammonite species not previously recorded from Sakhalin (YAZYKOVA 1992).

In the same period, ZONOVA & *al.* (1993) described in detail the three main faunal groups occurring in the Cretaceous of Sakhalin, namely ammonites, inoceramids and radiolarians. ZONOVA & YAZYKOVA (1994b) presented a first note on the ammonite zonation and its correlation with the inoceramid scheme for Shikotan and ZONOVA & YAZYKOVA (1994a) outlined a zonal division for the Maastrichtian sequence in Sakhalin.

In 1995, ALABUSHEV introduced an ammonite zonation for the northwest Pacific region; unfortunately, this scheme exhibits several limitations, problematic levels and 'barren' or uncharacterised intervals (see e.g., ALABUSHEV 1995, fig. 2). A year later, the author presented an event stratigraphy for Far East Russia (YAZYKOVA 1996), a first attempt to find supportive data for global correlation, as based on faunal events. At the same time, Yu.D. ZAKHAROV & *al.* (1996) published a new ammonite zonal scheme for the Cretaceous in Sakhalin, but this unfortunately includes some mistakes in the interpretation of the Coniacian-Campanian strata. For instance, probably as a result of misidentification, the *Anapachydiscus* (*Neopachydiscus*) *naumanni-Peroniceras* Zone was regarded as of Santonian age. As the key index ammonites were not illustrated it is difficult to confirm or reject their identification. From various other papers it is well known that *Anapachydiscus* (*Neopachydiscus*) *naumanni* is characteristic of the lower Campanian, whereas *Peroniceras* is a typically Coniacian form. It appears that the former species was confused with *Eupachydiscus haradai*, well known from the Santonian of Sakhalin, Koryak Upland, Japan (YAZYKOVA 1992; ZONOVA & *al.* 1993) and Madagascar (COLLIGNON 1955, 1965); their *Peroniceras* is probably a misidentified *Texanites,* a latest Coniacian-Santonian genus.

Subsequently, ALABUSHEV (in ALABUSHEV & WIEDMANN 1997) described several ammonite taxa from the River Naiba section, but misinterpreted age assignments for some of these strata. ZONOVA & YAZYKOVA (1998) worked out a detailed description of the Turonian-Coniacian succession of Far East Russia, discussed the problems surrounding the placement of the Turonian/Coniacian boundary in Far East Russia, documented the marked faunal turnover at that level and indicated new possibilities for global correlation as based on bioevents.

SHIGETA & *al.* (1999) recorded some ammonite specimens from the Santonian-Campanian deposits of the Kriljon Peninsula (southern Sakhalin), while YAZYKOVA (in KOREN' & *al.* 2000) presented a detailed integrated biostratigraphy for the Santonian-Campanian succession and discussed the characteristics of the Santonian-Campanian event as recorded in the Naiba section.

YAZYKOVA (2002) recently summarised all data on the faunal succession across the Santonian-Campanian boundary, presenting additional information on local criteria for the recognition of the Santonian and Campanian stages and pointing out several tools for global correlation. YAZYKOVA & *al.* (2002, 2004) did the same for the lower/upper Campanian and Cenomanian/Turonian boundary sections in Sakhalin by presenting integrated biostratigraphies and by documenting palaeocommuni-

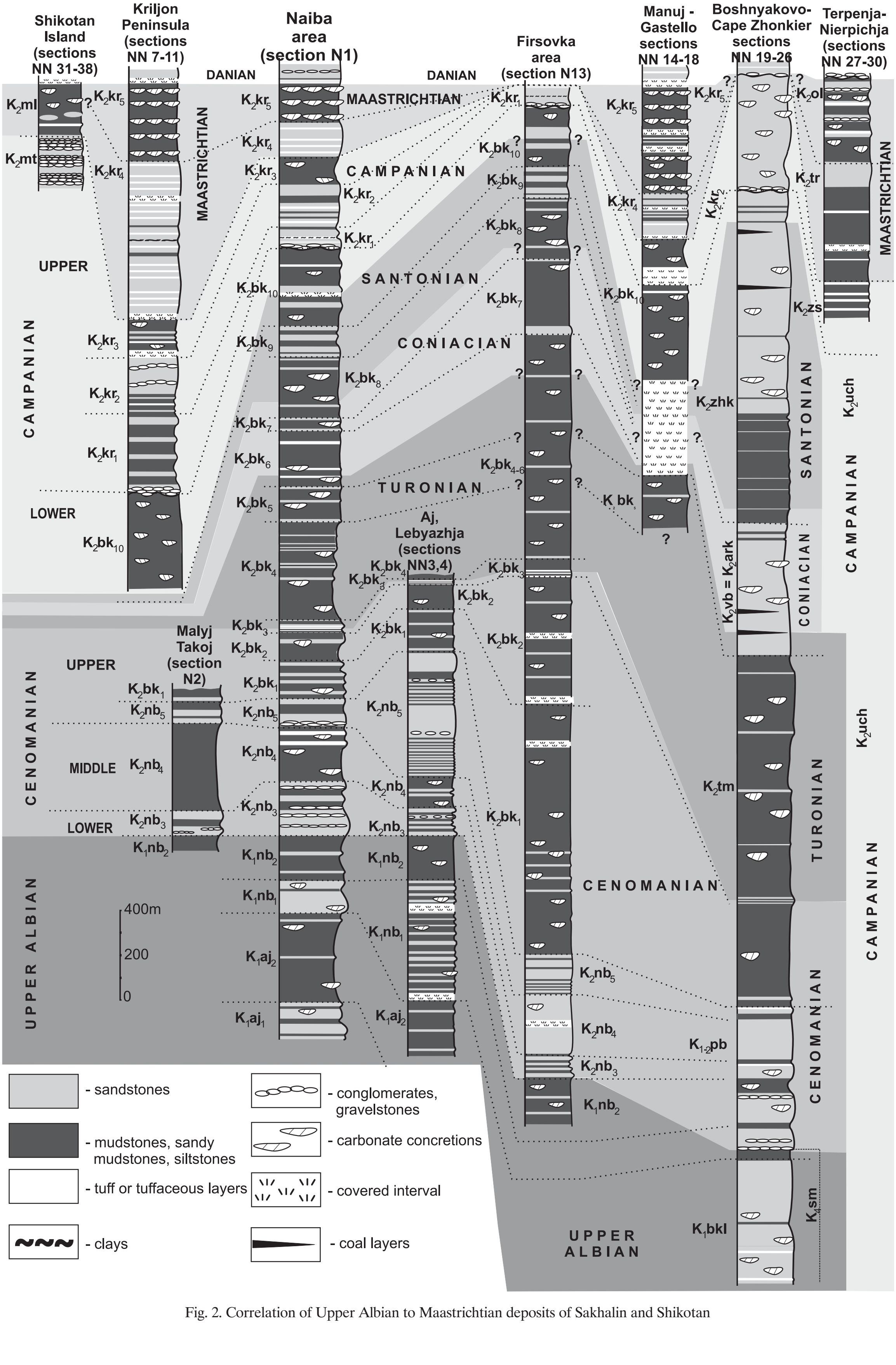

Fig. 2. Correlation of Upper Albian to Maastrichtian deposits of Sakhalin and Shikotan

ties and faunal trends as well as possibilities for global correlation.

GEOLOGICAL SETTING

Cretaceous deposits in Far East Russia occur in an extensive area ranging from Chukotka Peninsula to Primorye and Shikotan, the smallest island of the southern Kuril archipelago (Text-fig. 1A, B). According to KIRILLOVA (in press), the Early Cretaceous evolution of this region was controlled by oblique plate convergence, accretion of an island arc and oceanic fragments to the palaeo-Asian continent with related formation, eastward migration and disintegration of island arcs. In the late Albian, the angle of convergence increased, subduction resumed, and a giant East Asian volcanic belt formed along the continental margin. Morphologically, this belt was represented by a chain of mountain ridges (up to 3,000 m high), which created a sublongitudinal tectonic and climatic zonation. This active continental margin with a typical environmental arrangement consisting of marginal sea/island arc/open sea persisted until the end of the Cretaceous.

In Sakhalin, Cretaceous deposits are found in the following areas (from north to south):

Schmidt Peninsula: with ?Albian-Cenomanian to early Campanian deposits exposed.

West Sakhalin Mountains and **Kriljon Peninsula**: these are referred to as the Main Cretaceous Field, which extends for more than 600 km from Cape Kriljon in the south to Cape Hoj in central Sakhalin (Text-fig. 1B, C); the width of this field, with the Cretaceous exposed along river valleys and at the coast, varies between 10 and 70 km (VERESCHAGIN 1977) (Text-figs 1B, C and 2). The age of the Cretaceous deposits here ranges from the Albian to the Maastrichtian.

Tonino-Aniva Peninsula: The Cretaceous strata range in age from the Albian to the Campanian, and are represented in distinct sections at Cape Ostryj, along the Kommisarovka and Merej rivers, fringing Lake Busse and Lake Vavajskoje, as well as along the Chajka and Vorobjevka river valleys. The Late Cretaceous strata have also been documented in a borehole near Lake Chibisanskoje (VERESCHAGIN 1970).

Eastern Sakhalin area (sections NN 27-30, Text-figs 1, 2): The Upper Cretaceous deposits (of the Campanian-Maastrichtian age) extend along the Okhotsk Sea coast, from the Terpenja Peninsula northward, for a distance of 250 km to the Pursh-Pursh river. This area is about 20-25 km width.

Terpenja Peninsula: Here deposits of Berriasian-Valanginian (?) and late Campanian-Maastrichtian age were documented, exposed along the coast and in river valleys.

Strata cropping out in the Kriljon, Tonino-Aniva and Schmidt peninsulas represent littoral environments and those in the East Sakhalin Mountains correspond to slope settings, whereas the West Sakhalin Mountain sections represent sublittoral environments (ALABUSHEV 1995).

In addition, strata of late Campanian to Maastrichtian age have been recognised in Shikotan Island. This is the largest of the southern islands of the South-Kuril Ridge (Text-fig. 1D). All of the South-Kuril ilands are relatively small. Shikotan Island is 23 km long and about 10 km wide. Its highest peak in the Shikotan Mountain is 412 m high. This is the sole island in the whole of the Kuril Ridge where the Cretaceous is represented by marine rocks, and where it is of relatively simple tectonic structure. Eight sections, all along the coast, have been studied (Text-fig. 1D). A short description of four of these sections was published earlier (YAZIKOVA 1994); the present paper considers the stratigraphy and biostratigraphy of the Shikotan Cretaceous within the framework of regional correlations.

LITHOSTRATIGRAPHY

For a brief historical review of progress in Cretaceous lithostratigraphy of Sakhalin Island, reference is made to Text-figs 3 and 4 with correlation of chrono- and lithostratigraphic divisions and representation of all of the lithostratigraphic units used for the Cretaceous in Sakhalin. This chapter briefly presents the general characteristic of the Cretaceous sequence in the whole area of Sakhalin Island. Most of these data are now published in English for the first time, which should be of prime importance in avoiding any misunderstandings.

In 1929, KAWADA attempted to subdivide the deposits he studied in the Naiba area into three stratigraphic intervals, mainly on the basis of lithological characteristics, namely the Miho Bed for the lowest part of the section (approximately equivalent to the upper Turonian), the Ryugase Bed for the median portion (equating with the lower 'Senonian') and the Shimaiwa Bed for the upper part, equating with the upper 'Senonian'). KRYSHTOFOVITCH (1918, 1920, 1926) was the first to propose a chronostratigraphic scheme for the Cretaceous of all of Sakhalin Island using local series, viz. the Ajnuan, Gyliakian and Orochian series (Text-fig. 3). Subsequently,

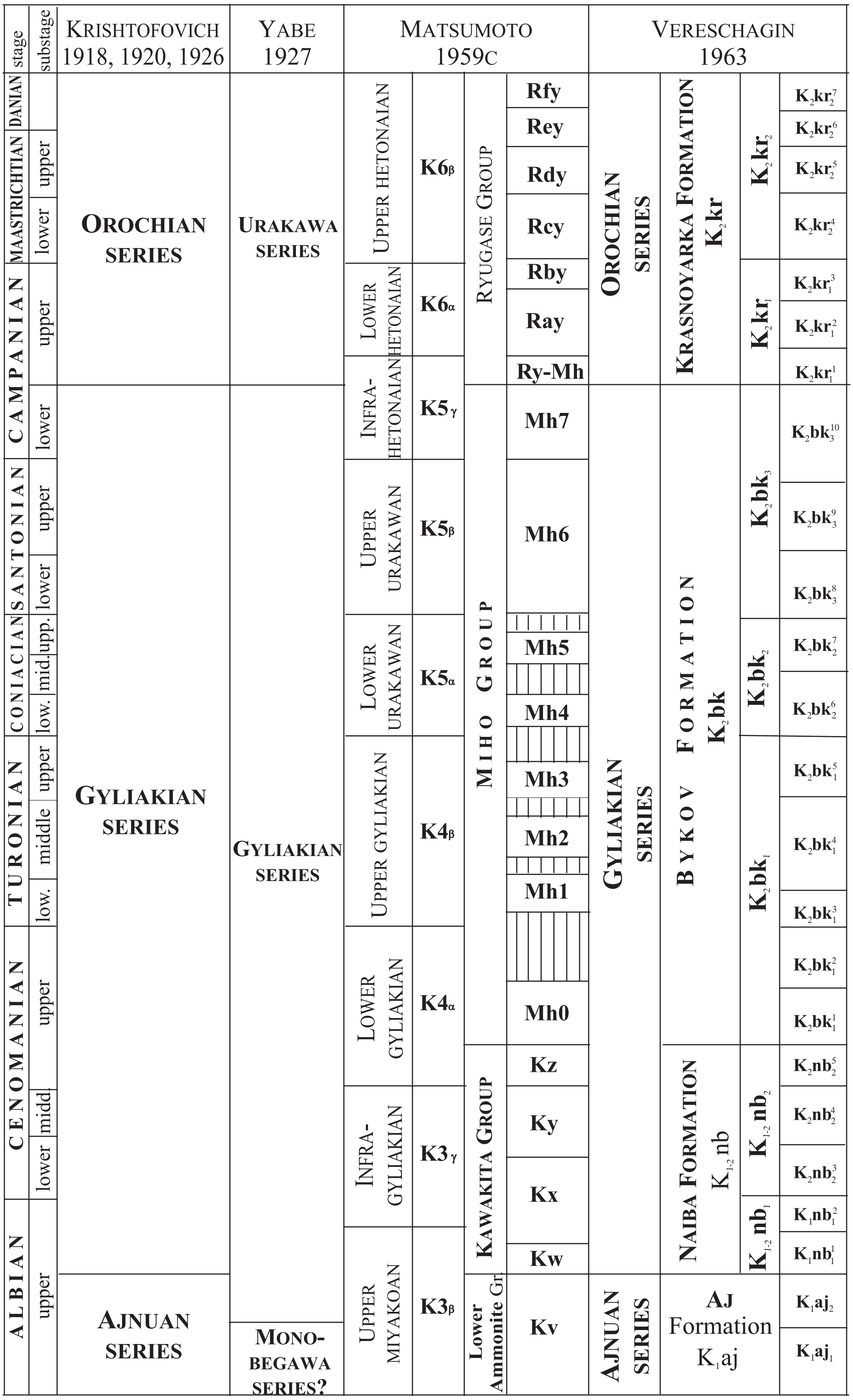

Fig. 3. Historical overview of stratigraphic subdivisions of the Cretaceous of Sakhalin

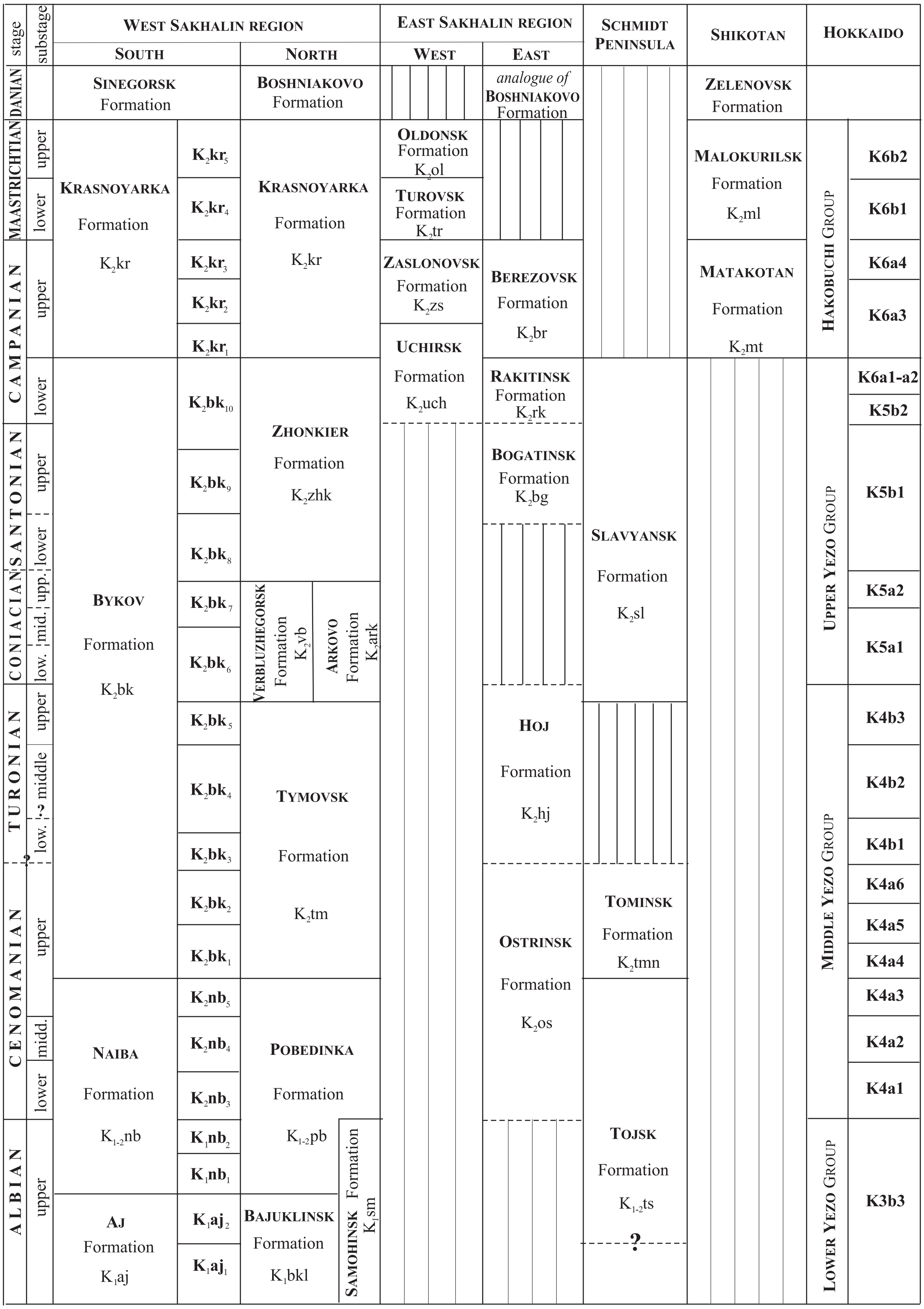

Fig. 4. Correlation between Cretaceous formations of Sakhalin and adjacent areas (Shikotan and Hokkaido)

YABE (1927) applied the Japanese chronostratigraphic division to the succession in Sakhalin, recognising there the Urakawa Series, the Orochian, and the Monobegawa Series. MATSUMOTO (1959c) established a comprehensive litho- and chronostratigraphic scheme for the Sakhalin succession in order to facilitate correlations with the Japanese sequences. In contrast, VERESCHAGIN (1963) introduced a detailed lithostratigraphic scheme, in accordance with KRYSHTOFOVITCH's chronostratigraphic framework (Text-fig. 3), and a detailed lithology of each formation. VERESCHAGIN (1963) provided special indices for formations and units, accepted for mapping. Each formation is subdivided into lithological units based on the dominant rock type. For example, for mapping the Bykov Formation he used the index "K_2bk", where K_2 means Upper Cretaceous and bk – Bykov Formation. In its turn, the Bykov Formation was subdivided into three subformations: K_2bk_1 (lower), K_2bk_2 (middle), K_2bk_3 (upper) and ten members, numbered $K_2bk_1^1$ to $K_2bk_3^{10}$ (Text-fig. 3). SALNIKOV and his group (in POYARKOVA 1987) carefully described the lithologies of the units recognised. At present, subformations are not really useful and, for instance, the index "K_2bk_{10}" refers to Member 10 of the Bykov Formation or Bykov Mudstone Member 10 (Text-fig. 4). The monotonous lithology is well known and has been described many times in the earlier works. The intercalations of mudstone, siltstone and sandstone with rare tuff or tuffaceous layers and numerous carbonate concretions are typical of the whole Cretaceous section here (see Text-fig. 2). The present chapter supplies brief features only of each formation and member, represented through the whole island from south to north and from west to east.

West Sakhalin Mountains and Kriljon Peninsula (The Main Cretaceous Field)

The oldest deposits in the southern part of the Main Cretaceous Field are represented mainly by mudstones and sandy mudstones which have been assigned to the Aj Formation, K_1aj (Text-figs 2, 4), introduced by VERESCHAGIN (1963) and named after the River Aj, with the stratotype along the River Naiba. This formation is represented by the lower sandstone member (K_1aj_1) with rare carbonate concretions and interbedded siltstones, and the upper mudstone member (K_1aj_2). The total thickness of this formation is over 600 m (Text-fig. 2). The radiolarian assemblage from the lower portion of the formation (KAZINTSOVA 2000) and ammonite taxa from the upper part of this unit [*Cleoniceras* (*Neosaynella*) sp., *Anahoplites*, *Sonneratia*, *Brewericeras* ex gr. *hulenense* and *Puzosia andersoni*; see ZHURAVLEV 1969a; TARASEVICH 1971; ZONOVA & *al*. 1986, 1993], document its Albian age.

In the northern part of the West Sakhalin Mountains, on account of strong facies change, the mudstones of the

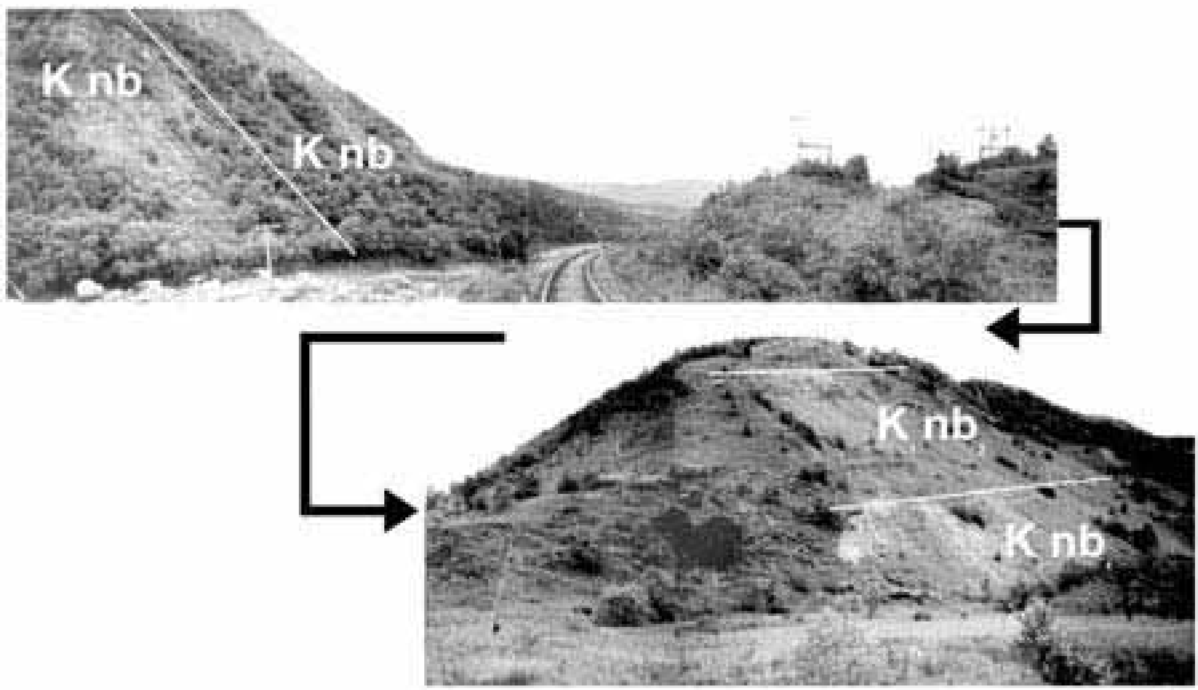

Fig. 5. The Lower/Upper Cretaceous boundary in the River Naiba, section N 1, equating with the boundary between members 2 (K_1nb_2) and 3 (K_2nb_3) of the Naiba Formation on the left-hand side and Upper Albian deposits of members 1(K_1nb_1) and 2 (K_2nb_2) of the Naiba Formation on the right-hand side

upper portion of the Aj Formation has two correlatives (Text-fig. 4), namely the sandstones of the Bajuklinsk Formation, K_1bkl (Text-fig. 1, sections NN19-23), with a thickness of about 500 m, and the lower portion of the Samohinsk Formation (K_1sm), also represented by sandstones (Text-fig. 1, sections NN 24-26). The siltstones of the upper portion of the Samohinsk Formation in the north correlate with the lower part of the overlying Naiba Formation in the south (Text-figs 2, 4).

The Naiba Formation, K_{1-2}nb (VERESCHAGIN 1963), was named after the River Naiba; its total thickness is over 1,100 m (Text-fig. 2). Previously, this unit was subdivided in VERESCHAGIN's scheme (VERESCHAGIN 1963; POYARKOVA 1987) into lower and upper subformations (see Text-fig. 3), but today only members are used (Text-figs 2, 4). Members 1 (predominantly sandstone) and 2 (mudstone and siltstone) are of latest Albian age, based on finds of *Inoceramus anglicus*, *I. aiensis* and *Cleoniceras* (*Neosaynella*) sp. (ZONOVA *& al.* 1993); members 3-5 yield a Cenomanian fauna. The boundary between members 2 and 3 is conformable (Text-figs 2, 5), but Member 3 is characterised by a predominance of sandstones with a few conglomeratic beds and siltstones. Such a lithology illustrates an unstable depositional environment and suggests rapid sea level fluctuations – the regular alternation of siltstone and conglomeratic beds is well illustrated in Text-fig. 2. The northerly correlative of the Naiba Formation (predominance of mudstone and siltstone) in the northern sections of West Sakhalin (sections NN 19-26, Text-fig. 1) is the Pobedinka Formation (K_{1-2}pb), which was differentiated from the Naiba Formation in 1956 by SAYAPINA and PAVLENKO (see VERESCHAGIN 1977, p. 75) on account of facies changes. The lower portion of the Pobedinka Formation correlates with the uppermost part of the Samohinsk Formation (see Text-figs 2, 4). In comparison to southerly sections, the Pobedinka Formation is characterised by a predominance of coarse-grained sandstones and conglomerates (Text-fig. 2). It was named after the Pobedinka River and its total thickness exceeds 1,100 m (Text-fig. 2).

The boundary between the Naiba and Bykov formations is conformable (Text-fig. 2), with the latter having been established by VERESCHAGIN (1961) and named after the village of Bykov. Members 1 and 2 of the Bykov Formation, K_2bk (mainly silstone and sandy mudstone intercalated with sandstone layers), yield a late Cenomanian fauna. The Cenomanian/Turonian boundary is located approximately in the lower part of Member 3 of the Bykov Formation (K_2bk_3, see Text-fig. 2) within the 'barren interval' which is overlain by a green glauconitic sandstone (Text-fig. 6), described in detail by YAZYKOVA & *al*. (2004). In the northerly sections of the Main Cretaceous Field, the upper Cenomanian-Turonian portion of the Bykov Formation equates with the Tymovsk Formation, K_2tm (Text-figs 2, 4), which is characterised by a marked dominance of clayey material (Text-fig. 2). The total thickness of the Tymovsk Formation is in excess of 1,000 m (Text-fig. 2).

The boundary between the Turonian and Coniacian is defined within Bykov Mudstone Member 6 (K_2bk_6). The uppermost Turonian-Coniacian portion of the Bykov Formation has two correlatives in the northerly sections, the Verbluzhegorsk Formation (K_2vb) and the Arkovo Formation, K_2ark (Text-figs 2, 4). Basically, the Verbluzhegorsk and Arkovo formations differ from the Bykov Formation in an absolute predominance of sandstones. In addition, the Verbluzhegorsk Formation contains some coal beds. The concept of the Verbluzhegorsk Formation was based on the 'Werblude Group', as used by YABE & SHIMIZU (1924a) and named after the Werblude Mountain. The thickness of this unit is near 600 m. The Arkovo Formation was defined by KRYSHTOFOVITCH (1937) in the northernmost sections near the village of Arkovo (Text-figs 1, 2); its maximum thickness approximates to 1,000 m.

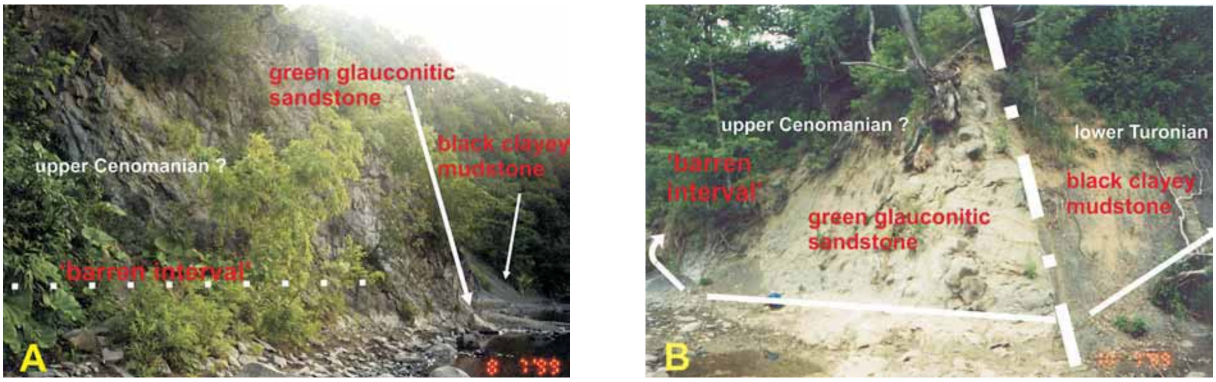

Fig. 6. The Cenomanian/Turonian boundary 'barren interval' and the green glauconitic sandstone within Member 3 of the Bykov Formation (K_2bk_3) on the east bank of the River Naiba, section N1

The Coniacian/Santonian boundary has been placed within Bykov Mudstone Member 8, K_2bk_8, the Santonian-/Campanian boundary within Bykov mudstone Member 10 (K_2bk_{10}) and the lower/upper Campanian boundary at the base of the Krasnoyarka Formation (Text-figs 2, 4). The northerly correlative of this portion of the Bykov Formation is the Zhonkier Formation, K_2zhk (mainly sandstone with coal layers and siltstone), the concept of which was based on the 'Cape de la Jonquière Group' (YABE & SHIMIZU 1924a). The thickness of the Zhonkier Formation is over 1,500 m, that of the Bykov Formation is near 2,000 m (Text-fig. 2).

The Krasnoyarka Formation (K_2kr) can be traced throughout the entire Main Cretaceous Field, from the south to the north. It was established by VERESCHAGIN (1961), and named after the River Krasnoyarka, a tributary of the River Naiba. It comprises strata of Campanian-Maastrichtian age, to a total thickness of 1,000 m (Text-figs 2, 4). The Krasnoyarka Sandstone Member 1 (K_2kr_1) is a very good marker (YAZYKOVA & *al*. 2002), which may be traced from NE Russia through Sakhalin to Japan and which corresponds to the lower upper Campanian. The Campanian/Maastrichtian boundary is placed in the clay bed at the base of Krasnoyarka Sandstone Member 4 (K_2kr_4). The occurrence of these sandstones explains the presence of waterfalls along the River Naiba. However, in the northern sections (sections NN14-18) of the Main Cretaceous Field these sandstones are replaced by a bit more clayey material (Text-figs 2, 7). Member 5 of the Krasnoyarka Formation comprises mudstones of late Maastrichtian age, with typical concretion layers (Text-fig. 2). The Sinegorsk beds were differentiated for deposits of Danian age, whose northerly correlative is the Boshniakovo Formation (Text-fig. 4).

Tonino-Aniva Peninsula

Lower Cretaceous deposits as well as the Naiba, Bykov and Krasnoyarka formations were also established in the Tonino-Aniva Peninsula (section N 12, Text-fig. 1). Unfortunately, any attempts to establish the relationships between these formations here have proved problematic. What is possible to say is that the exposed thickness of Albian deposits amounts to near 150 m, the Naiba Formation is near 70 m thick, the Bykov Formation over 1,700 m and the Krasnoyarka Formation approximately 200-300 m in thickness.

Eastern Sakhalin

Lithologically, the deposits in the eastern Sakhalin area differ from those in the western part of the island in comprising widely distributed volcanic and carbonate-silica rocks. Recently, VISHNEVSKAYA (VISHNEVSKAYA & *al*. 2003) has identified the first Berriasian-Valanginian radiolarian assemblages in eastern Sakhalin. The oldest Upper Cretaceous sediments here are represented by the Uchirsk Formation, K_2uch (Text-figs 2, 4), a thick (over 2,500 m and possibly more) unit of volcanogenic and tuffaceous rocks of late Campanian age, determined on radiolarian evidence and a few finds of *Schmidticeramus schmidti* (MICHAEL), *Sachalinoceramus sachali-*

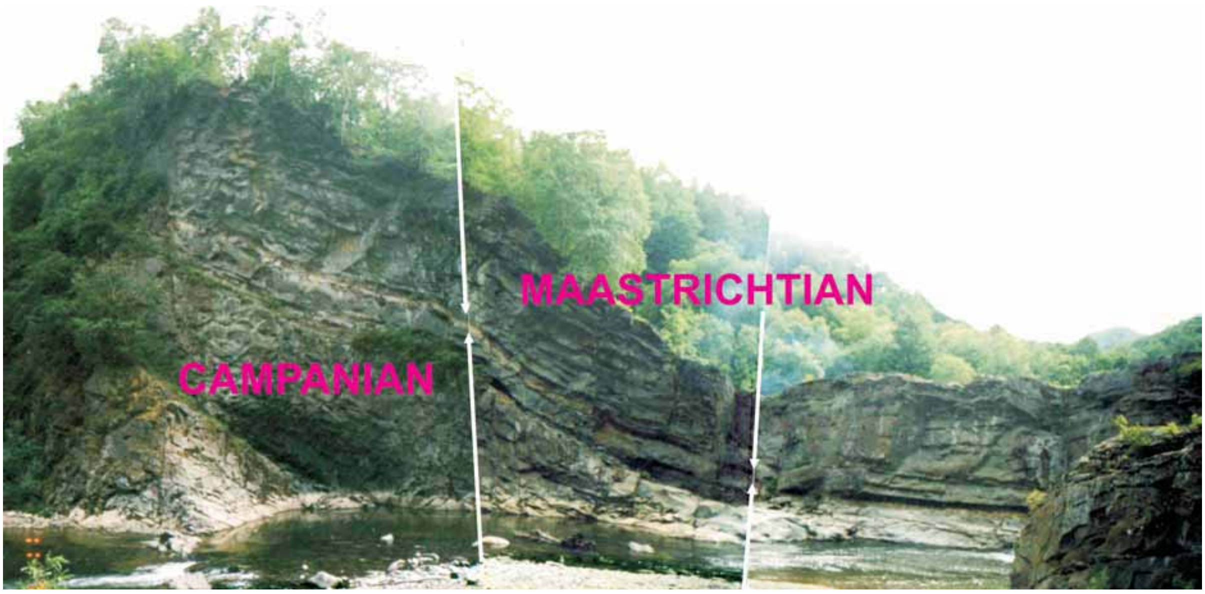

Fig. 7. The contact between members 3 and 4 of the Krasnoyarka Formation, along the River Krasnoyarka, River Naiba Valley, section N 1, which equates with the Campanian/Maastrichtian boundary

nensis (SOKOLOV) and *Anapachydiscus* sp. (SHUVAEV 1965), taxa typical of that interval (YAZYKOVA & *al*. 2002). The overlying unit is the Zaslonowsk Formation (K_2zs, see Text-figs 2, 4), which attains a thickness of more than 1,950 m, and is represented by mudstone and siltstone, with sandstone and tuffa layers. The Turovsk Formation (K_2tr) is over 550 m thick and might correlate with Member 4 of the Krasnoyarka Formation, on the basis of a few finds of inoceramids. Member 5 of the Krasnoyarka Formation correlates well with deposits of the Oldonsk Formation, K_2ol, which was formally introduced by KOVTUNOVICH in 1960 (see VERESCHAGIN 1979) and named after the River Oldon. Specimens of *Gaudryceras hamanakense* (MATSUMOTO & YOSHIDA) and *Neophylloceras hetonaiense* MATSUMOTO collected here by the author have enabled a late Maastrichtian age for these sediments to be established (ZONOVA 1990).

The Ostrinsk (K_2os), Hoj (K_2hj), Bogatinsk (K_2bg), Rakitinsk (K_2rk) and Berezovsk (K_2br) formations form the eastern and northeastern portions of the East Sakhalin Mountains (Text-fig. 4). Here metamorphic, volcanogenic and tuffaceous rocks predominate. Some marker beds of limestones and jaspers have been recorded here, near 10 m in thickness (SHUVAEV 1965). Numerous faults occur as well. The age of these formations has been established on a single specimen of *Schmidticeramus* cf. *schmidti* (MICHAEL) and on radiolarian assemblages (SHUVAEV 1965; ZONOVA & *al*. 1993; KAZINTSOVA 1988, 2000). Each of these formations is also characterised by a great thickness, in excess of 2,000-2,500 m (VERESCHAGIN 1977).

Schmidt Peninsula

The Upper Cretaceous sequence in Schmidt Peninsula is represented by three formations: Tojsk (K_{1-2}ts, ?Albian-Cenomanian), Tominsk (K_2tmn, upper Cenomanian) and Slavyansk (K_2sl, Coniacian-lower Campanian), which attain thicknesses of 700 m, 2,400 m and 1,500 m respectively (VERESCHAGIN 1977). The age of these formations has been established by radiolarian assemblages as well as a few finds of inoceramids and floral remains (RATNOVSKIJ 1960; VERESCHAGIN 1977; ZONOVA & *al*. 1993; KAZINTSOVA 2000). Generally, clastic sediments predominate here. However, a gradual change of lithology between the Tojsk to Slavyansk formations may be observed: the overall predominance of clastic deposits in the Tojsk Formation changes into mudstones and siltstones with numerous tuffaceous sandstones and silica rocks. The Slavyansk Formation is characterised by a predominance of tuffaceous and polymict mudstones, sandstones, and gravelstones, dacite and andesite-basalt porphyries and pyroclastic limestones.

Shikotan Island

The oldest sequences in Shikotan Island are of late Campanian age, and these allow a twofold lithostratigraphic division. The lower unit (Matakotan Formation, K_2mt) is dated as late Campanian, while the upper (Malokurilsk Formation, K_2ml) is of latest Campanian to Maastrichtian age. SASSA (1936) subdivided the former unit, which is represented by volcanogenic rocks, com-

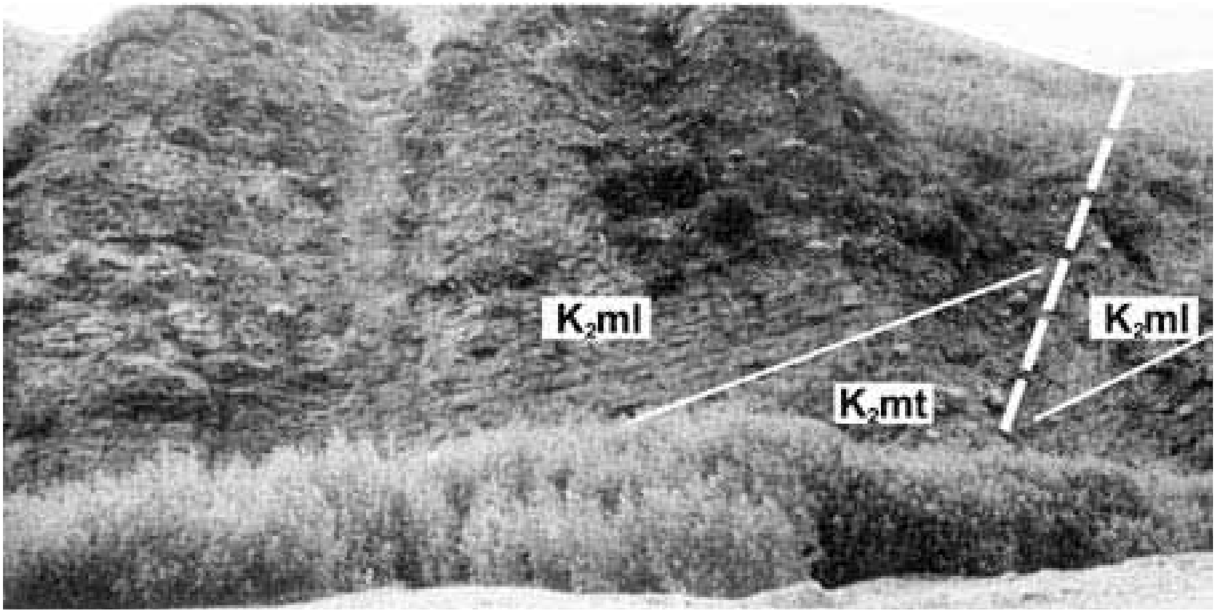

Fig. 8. The boundary between the Matakotan (K_2mt) and Malakurilsk (K_2ml) formations in the Zvezdnaya Bay (section N 37) in Shikotan, equating with the Campanian/Maastrichtian boundary

prising basalts, tuffaceous conglomerates and breccias, occurring along the northwestern coast of the island (Text-fig. 2). This unit generally is poorly fossiliferous; its age was established on the basis of a few finds of the radially ribbed inoceramids, *Sachalinoceramus sachalinensis* (SOKOLOV) and *Schmidticeramus schmidti* (MICHAEL), and of *Inoceramus* aff. *balticus* BOEHM (ZONOVA & YAZYKOVA, 1994b). Recently, the Campanian age has been confirmed by analyses of radiolarian contents (L.I. KAZINTSOVA, pers. comm.). In general, the exposed thickness of this formation is about 300-350 m. Terrigenous deposits of the Malokurilsk Formation overlie the volcanogenic rocks of the Matakotan Formation concordantly (Text-figs 2, 8). The Malokurilsk Formation was defined by ZHELUBOVSKIJ in 1955 (see VERESCHAGIN 1979) and named after the town of Malokurilsk. In general, this unit is represented by mudstones with rare sandstone intercalations and huge carbonate concretions. The exposed thickness is about 150-200 m. In two sections, at Zvezdnaja and Dolfin bays (sections NN 37, 38; see Text-fig. 1D), the author observed the lenticular nature of the tuffaceous sandstone at the base of the Malokurilsk Formation. The Maastrichtian age was first based on inoceramid finds, namely of *Shachmaticeramus shikotanensis* (NAGAO & MATSUMOTO), *Sh. delfinensis* (ZONOVA & SALNIKOVA), *Sh. subkusiroensis* ZONOVA and *Tenuipteria* (?) *awajiensis* MATSUMOTO (NAGAO & MATSUMOTO 1940; TAKAYANAGI & MATSUMOTO 1981; ZONOVA & *al*. 1993). This age assignment has been confirmed by ammonite finds made by the author in Chromova Bay (Text-fig. 9) and Dolfin Bay (ZONOVA & YAZYKOVA 1994; YAZYKOVA 1994). The Cretaceous–Paleogene boundary is not exposed. Only along the eastern coast of Dolfin Bay has the author observed a tectonically induced break at the contact of the Malokurilsk and Zelenovsk formations. The latter unit is part of the Paleogene succession (Text-fig. 4).

The wide distribution of carbonate concretions in the Cretaceous sequences of Sakhalin, Shikotan and Japan is highly typical. They form regular concretion layers in strata assigned to Member 5 of the Krasnoyarka Formation and occur isolated and scattered in the Bykov, Naiba or Pobedinka, Tymovsk and Zhonkier formations and others. The concretions may be of small (up to 10 cm in diameter) to large size (up to 50 cm); occasionally they attain over 1 m in diameter. Following ALBANI & *al*. (2001), carbonate concretions are of prime importance in preserving the original sedimentary record. These concretions contain abundant, well-preserved fossils. The author's field observations have also documented that in a case of numerous isolated concretions or concretion layers, fossils in the host rock (mudstones) are rare and

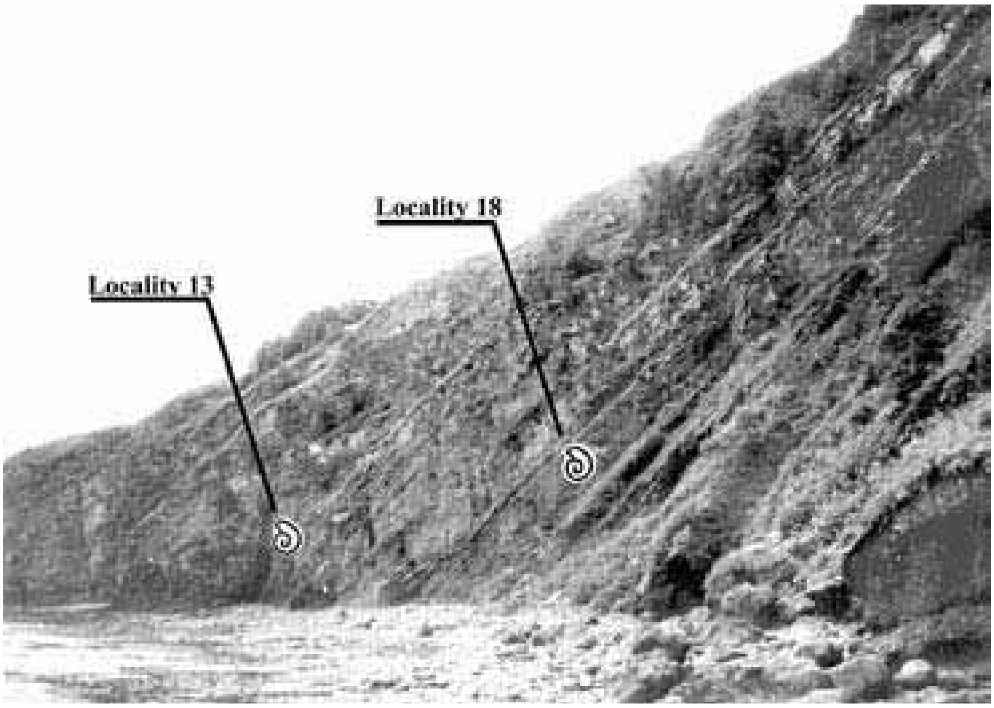

Fig. 9. Provenance of ammonites (author collection N 12757 from field trip of 1988, hosted in the CNIGR Museum VSEGEI in Sankt-Petersburg, Russia) in the Chromova Bay section (N 32), namely *Canadoceras* cf. *multicostatum* Matsumoto, specimen N 3/12757, Locality 13, Malokurilsk Formation; *Canadoceras* cf. *multicostatum*, specimen N 1/12757 and *Pachydiscus* (*P.*) cf. *subcompressus* Matsumoto, specimen N 2/12757, Locality 18, from the 'basal portion' of the Malokurilsk Formation

strongly deformed. In contrast, many fossiliferous levels (e.g., the upper Campanian deposits of Member 1 of the Krasnoyarka Formation) yield no concretions. The concretions are elongated, parallel to the stratification. Single concretions are scattered randomly. The author has been unable to find reworked fossils in sections in the Russian Far East; Japanese scientists noted a few (WANI 2001) but provided evidence that reworked fossils are very rare in carbonate concretions. Thus, for the most part these perfectly preserved fossils occurring in concretions should be considered *in situ*. Moreover, the author's field observations indicate an absence of fossils in host rocks that contain numerous carbonate concretions and an absence of concretions in fossil-rich beds, for example, in Member 1 of the Krasnoyarka Formation. Following ALBANI & *al*. (2001), the difference in fossil abundance between the concretions and host rock is a function of dissolution, rather than of preferential precipitation in fossil-rich areas. Consequently, the carbonate concretions contain the original biological components and are potential tools for estimating the original biological material deposited in the soft sediments. ALBANI & *al*. (2001) noted that the carbonate concretions appear to represent the signal of the natural sediment and the present author agrees with that suggestion. Moreover, it should be noted that these similar features occur in two palaeobasins which are far removed from each other and represented by different host rock lithologics, namely Sakhalin (present paper) and Japan (WANI 2001) characterised by mudstones and sandstones, while the Moroccan sections that are the focus of the study of ALBANI & *al*. (2001) comprise limestones and marls.

All stratigraphic units mentioned above may be fairly easily correlated (Text-figs 2, 4) and can also be traced to northeast Russia and Japan.

AMMONITE BIOZONATION

Amongst Cretaceous macrofossils from Sakhalin, ammonites have proved to be the prime tool for biozonation and correlation. In all, 109 taxa have been identified by the author from sequences in Sakhalin and Shikotan (Text-fig. 10). All available literature sources were taken into consideration and the stratigraphic distribution of some species was updated. The biostratigraphic subdivision of the Cretaceous sequences in Sakhalin and Shikotan based on ammonites corresponds closely to the detailed inoceramid zonation by ZONOVA (in ZONOVA & *al*. 1993 and ZONOVA & YAZYKOVA 1998, 2001) and correlates well with the radiolarian zones by KAZINTSOVA (in ZONOVA & *al*. 1993 and KAZINTSOVA 2000) based on the co-occurrence of representatives of zonal species from these three main groups (Text-fig. 11). A correlation of the ammonite zonation for Sakhalin and Shikotan with that of adjacent areas (NE Russia and Japan) is also presented here (Text-fig. 12).

In total, 24 ammonite zones were distinguished in the Cretaceous of Sakhalin and Shikotan (Text-figs 10, 11), their lower boundaries defined by the first appearance datum (FAD) of the index species. Each of these zones is here briefly characterised. Moreover, in Text-fig. 12 there is a second column with selected associated species. These assemblages work in some cases when the main scheme does not, on account of the absence of index species and greatly facilitate correlation with adjacent areas.

Upper Albian

Upper Albian strata are poorly characterised by ammonites in comparison with younger deposits, with the *Cleoniceras* sp. Zone representing the single ammonite-based biostratigraphic unit in the Sakhalin sections. Two radiolarian zones indicate the Albian age of these deposits (Text-fig. 11).

***Cleoniceras* sp. Total Range Zone** (VERESCHAGIN & *al*. 1972, Proceedings... 1982)

The lower boundary is defined by the FAD of representatives of the subgenus *Cleoniceras* (*Neosaynella*) sp. (Text-fig. 10). Assignable to this zone are Member 2 of the Aj Formation and members 1 and 2 of the Naiba Formation (Text-fig. 11). Co-occurring with *Cleoniceras (Neosaynella)* sp. are *Anahoplites* sp., *Sonneratia* sp., *Brewericeras* ex gr. *hulenense* (ANDERSON) and *Puzosia andersoni* ANDERSON (see Text-fig. 10 and ZHURAVLEV 1969a; TARASEVICH 1971; ZONOVA *et al*. 1986, 1993). All genera are cosmopolitan. *Brewericeras* ex gr. *hulenense* and *P. andersoni* were first documented from the middle-upper Albian of California (ANDERSON 1938). Strata assigned to this biozone are known from sections NN 1-5, 12, 13 and 19-26 (Text-figs 1-2). The upper part of this zone corresponds to members 1 and 2 of the Naiba Formation and the inoceramid zone of *Inoceramus anglicus, I. aiensis*, as based on the co-occurrence of zonal and associated species as mentioned above.

In NE Russia, the same zone has been distinguished; it correlates well with the *Desmoceras dawsoni shikokuense* Zone in Japan based on associated ammonite species and inoceramids (Text-fig. 12). According to KAWABE & HAGGART (2003), *Desmoceras dawsoni shikokuense* is a junior synonym of *Desmoceras poronaicum; D. dawsoni* is endemic to the eastern Pacific.

Stage	Substage	Formation	Member	Inoceramid zones by ZONOVA	Ammonoid zones by YAZYKOVA		Radiolarian zones by KAZINTSOVA
Maastrichtian	upper	Krasnoyarka	5	*Korjakia kociubinskii*; *Shachmaticeramus kusiroensis, Inoceramus hetonaianus*	*Pachydiscus (P.) flexuosus, P. (Neodesmoceras) gracilis*	*Pachydiscus (P.) subcompressus*	*Amphipyndax tylotus*
Maastrichtian	lower	Krasnoyarka	4	*Shachmaticeramus shikotanensis*	*Pachydiscus (Neodesmoceras) japonicus*	*Pachydiscus (P.) subcompressus*	*Pseudotheocampe abschnitta*
Campanian	upper	Krasnoyarka	3, 2	*Inoceramus* aff. *balticus*	*Canadoceras multicostatum*		
Campanian	upper	Krasnoyarka	1	*Schmidticeramus schmidti*	*Pachydiscus (P.)* aff. *egertoni*		*Pseudoaulophacus floresensis -Stichomitra livermorensis*
Campanian	lower	Bykov	10	*Pennatoceramus orientalis*; *Inoceramus nagaoi*	*Canadoceras kossmati*; *Anapachydiscus (Neopachydiscus) naumanni*	*Eupachydiscus haradai*	*Spongostaurus (?) hokkaidoensis - Hexacontium* sp.
Santonian	upper	Bykov	10	*I.* aff. *undulatoplicatus*	*Menuites menu*	*Eupachydiscus haradai*	*Archaeospongoprunum bipartitum-Patulibracchium petroleumensis*
Santonian	upper	Bykov	9	*Inoceramus amakusensis*	*Texanites (Plesiotexanites) kawasakii*	*Eupachydiscus haradai*	*Archaeospongoprunum bipartitum-Patulibracchium petroleumensis*
Santonian	low.	Bykov	8	*Inoceramus amakusensis*	*Texanites (Plesiotexanites) kawasakii*		*Orbiculiforma persenex- Phaseliforma* sp.
Coniacian	upp., mid.	Bykov	7	*Inoceramus mihoensis*	*Peroniceras* sp.; *Forresteria (F.) alluaudi*		*Orbiculiforma vacaensis- Squinabolella putahensis*
Coniacian	low.	Bykov	6	*Inoceramus uwajimensis*	*Jimboiceras mihoense*		*Orbiculiforma quadrata - O. monticelloensis*
Turonian	upper	Bykov	6	*Inoceramus teshioensis, Mytiloides incertus*	*Subprionocyclus* sp.		*Orbiculiforma quadrata - O. monticelloensis*
Turonian	upper	Bykov	5	*Inoceramus hobetsensis*	*Jimboiceras planulatiforme*		
Turonian	middle	Bykov	4	*Inoceramus hobetsensis*	*Romaniceras (Yubar.) ornatissimum*; *Scaphites planus*		*Crucella cachensis - Alievium superbum*
Turonian	lower	Bykov	3	*Mytiloides* aff. *labiatus*	*Fagesia* sp.		*Crucella cachensis - Alievium superbum*
?							
Cenomanian	upper	Bykov	2, 1	*Inoceramus* aff. *tenuis*	*Desmoceras (Pseudouhligella) japonicum*		*Haliomma sachalinica - Dictiomitra multicostata*
Cenomanian	mid.	Naiba	5	*Inoceramus pennatulus- I. gradilis*	*Calycoceras* sp.; *Acanthoceras sussexiense*		*Lipmanium sacramentoensis - Archaeodictyomitra squinaboli*
Cenomanian	lower	Naiba	4	*Inoceramus (Birostrina) nipponica - I. (B.) tamurai*	*Mantelliceras* sp.		*Lipmanium sacramentoensis - Archaeodictyomitra squinaboli*
Cenomanian	lower	Naiba	3	*Inoceramus* aff. *crippsi*	*Desmoceras (D.) kossmati*		
Albian	upper	Naiba	2, 1	*Inoceramus anglicus, I. aiensis*	*Cleoniceras* sp.		*Crolanium quadrangulatum - Spongurus* sp.
Albian	upper	Aj	2		*Cleoniceras* sp.		*Xitus plenus-Pseudo-dictyomitra lodogaensis*
Albian	upper	Aj	1				*Orbiculiforma multangula - Crolanium triquetrum*

Fig. 11. Cretaceous ammonite (YAZYKOVA in YAZIKOVA 1994; ZONOVA & *al.* 1993; ZONOVA & YAZYKOVA 1998; YAZYKOVA 2002 and present paper), inoceramid (ZONOVA in ZONOVA & *al.* 1993; ZONOVA & YAZYKOVA 1998, 2001) and radiolarian (KAZINTSOVA 1988, 2000; KAZINTSOVA in ZONOVA & *al.* 1993) zonations in Sakhalin and Shikotan

Stage	Substage	Sakhalin and Shikotan (by Author): Ammonite zone	Sakhalin and Shikotan (by Author): Selected associated species	NE Russia (by Author): Ammonite zone	Japan (by Toshimitsu & *al.* 1995): Ammonite zone, Desmocerataceae	Japan (by Toshimitsu & *al.* 1995): Ammonite zone, Selected associate
Maastrichtian	upper	*Pachydiscus* (*P.*) *flexuosus*, *P.* (*Neodesmoceras*) *gracilis*; *Pachydiscus* (*P.*) *subcompressus*	*Zelandites japonicus*; *Gaudryceras hamanakense*	*Pachydiscus* (*P.*) *flexuosus*, *P.* (*Neodesmoceras*) *gracilis*; *P.* (*P.*) *neubergicus*, *P.* (*P.*) *gollevillensis*	*Pachydiscus* (*P.*) *flexuosus*; *Pachydiscus* (*Neodesmoceras*) *gracilis*	*Gaudryceras hamanakense*; *Gaudryceras izumiense*
	lower	*Pachydiscus* (*Neodesmoceras*) *japonicus*	*Pseudophyllites indra*	*Pachydiscus* (*Neodesmoceras*) *japonicus*	*P.* (*P.*) *koboyashii*; *Pachydiscus* (*Neodesmoceras*) *japonicus*	*Nostoceras hetonaiense*
Campanian	upper	*Canadoceras multicostatum*; *Pachydiscus (P.)* sp. aff. *egertoni*	*Tetragonites popetensis*; *Anapachydiscus arrialoorensis*	*Tetragonites popetensis*; *Canadoceras* spp.	*Pachydiscus* (*P.*) *awajiensis*; *Patagiosites laevis*; *Anapachydiscus fascicostatus*; *Desmophyllites diphylloides*	*Pravitoceras sigmoidale*; *Didymoceras awajiense*; *Metaplacenticeras subtilistriatum*-*Hoplitoplacenticeras monju*
	lower	*Canadoceras kossmati*; *Anapachydiscus* (*Neopachydiscus*) *naumanni*; *Eupachydiscus haradai*	*Damesites semicostatus*; *Damesites sugata*	*Canadoceras kossmati*; *Anapachydiscus* (*Neopachydiscus*) *naumanni*; *Eupachydiscus haradai*	*Canadoceras kossmati*; *Anapachydiscus naumanni*	*Delawarella* sp.; *Plesiotexanites shiloensis*; *Menabites mazenoti*-*Submortoniceras* cf. *condamyi*
Santonian	upper	*Menuites menu*	*Neopuzosia japonica*; *Saghalinites teshioensis*	*Menuites menu*	*Eupachydiscus haradai*	*Plesiotexanites kawasakii*-*P. pacificus*
	lower	*Texanites* (*Plesiotexanites*) *kawasakii*	*Gaudryceras denseplicatum*	*Texanites* sp.	*Anapachydiscus sutneri*; *Damesites damesi*	*Texanites collignoni*
Coniacian	upper	*Peroniceras* sp.	*Nipponites bacchus*	*Kossmaticeras* (*Natalites*) *penjiensis*	*Kossmaticeras theobaldianum* - *Eupachydiscus keramasatoshii*	*Paratexanites orientalis*
	mid	*Forresteria* (*F.*) *alluaudi*				*Forresteria* (*F.*) *alluaudi*
	low	*Jimboiceras mihoense*	*Nipponites sachalinensis*	*Scaphites* spp.		*Forresteria* (*Harleites*) *petrocoriensis*
Turonian	upper	*Subprionocyclus* sp.; *Jimboiceras planulatiforme*	*Nipponites mirabilis*	*Jimboiceras planulatiforme*	*Damesites ainuanus* - *Tongoboryceras satoi*; *Tragodesmoceras matsumotoi*; *Pachydesmoceras pachydiscoides*; *Tragodesmoceroides subcostatus*	*Subprionocyclus neptuni*; *S. minimus*; *S. bravaisianus*
	middle	*Romaniceras* (*Yubar.*) *ornatissimum*	*Scalarites scalaris*	*Scalarites scalaris*	*Kossmaticeras flexuosum* - *Mesopuzosia pacifica*	*Romaniceras deverianum*; *Collignoniceras woollgari*
	lower	*Scaphites planus*; *Fagesia* sp.	*Zelandites mihoensis*	*Scaphites planus*; *Zelandites mihoensis*	*Pachydesmoceras kossmati* - *Puzosia orientalis*; *Damesites laticarinatus*	*Fagesia thevestensis*-*Mammites* aff. *nodosoides*; *Pseudaspidoceras flexuosum*
Cenomanian	upper	*Desmoceras* (*Pseudouhligella*) *japonicum*; *Calycoceras* sp.	*Anagaudryceras buddha*; *Turrilites costatus*	*Marshallites voyanus*; *Marshallites olcostephanoides*; *Turrilites costatus*; *Desmoceras* (*Pseudouhl.*) *japonicum*	*Marshallites olcostephanoides*; *Wellmanites japonicus*; *Puzosia elegans*; *Desmoceras* (*Pseudouhligella*) *japonicum*- *D.* (*P.*) *ezoanum*	? *Neocardioceras juddii*; *Euomphaloceras septemseriatum*; *Eucalycoceras pentagonum*
	mid.	*Acanthoceras sussexiense*	*Mikasaites orbicularis*	*Marshallites compressus*; *Acanthoceras* sp.	*Marshallites compressus*; *Mikasaites orbicularis*; *Austiniceras nipponicum*	*Calycoceras* (*Newboldiceras*) *asiaticum*; *Cunningtoniceras takahashii*
	lower	*Mantelliceras* sp.; *Desmoceras* (*D.*) *kossmati*	*Parajaubertella kawakitana*	*Mantelliceras* sp.; *Parajaubertella kawakitana*	*Maccarthytes mikasaensis*; *Sounnaites alaskaensis*	*Acompsoceras renevieri*; *Mantelliceras japonicum*; *Graysonites adkinsi* -*G. wooldridgei*
Albian	upper	*Cleoniceras* sp.	*Anahoplites* sp., *Brevericeras* sp.	*Cleoniceras* sp.; *Arcthoplites talkeetnanus*; *Marshallites cumshevaensis*	*Desmoceras* (*P.*) *dawsoni shikokuense*; *Desmoceras kossmati*- *Marshallites cumshevaensis*	*Mortoniceras* (*Cantabrigites*) aff. *subsimplex*

Fig. 12. Correlation between the Cretaceous ammonite zonation for Sakhalin and Shikotan and that for adjacent areas (NE Russia, after Yazykova, present paper; Japan, after Toshimitsu & *al.* 1995)

CENOMANIAN

In the sections studied, five ammonite zones have been distinguished in Cenomanian deposits, ranging from Member 3 of the Naiba Formation to Member 2 of the Bykov Formation (Text-fig. 11). All of them have recently been described in detail (YAZYKOVA & *al*. 2004).

***Desmoceras* (*Desmoceras*) *kossmati* Interval Zone** (MATSUMOTO 1959c)

The Lower/Upper Cretaceous boundary in Sakhalin (Text-fig. 10) is marked by the first appearance of *Parajaubertella kawakitana* MATSUMOTO and *Turrilites costatus* LAMARCK (MATSUMOTO 1959c; POYARKOVA 1987; ZONOVA & *al*. 1993; ALABUSHEV & WIEDMANN 1997; YAZYKOVA & *al*. 2004). Ammonites characterising this zone are *Parajaubertella kawakitana*, *Turrilites costatus, Desmoceras* (*D.*) *kossmati* MATSUMOTO, *D.* (*Pseudouhligella*) *japonicum* YABE, *Zelandites inflatus* MATSUMOTO and *Gaudryceras varagurense* KOSSMAT. *Anagaudryceras buddha* (FORBES) appears in the upper part of this zone; this species was first described from the Cenomanian of India (FORBES 1846). No radiolarian assemblages are established at this level, but, the inoceramid zone of *Inoceramus* aff. *crippsi* is coeval with the ammonite zone as based on joint occurrences (YAZYKOVA & *al*. 2004). The few radiolarian specimens found did not allow the establishment of a radiolarian zone at this level (Text-fig. 11). However, representatives of *Parajaubertella kawakitana* do permit correlation with northeasterly regions (Text-fig. 12).

In Japan, representatives of the index species cooccur with members of the genus *Graysonites* (MATSUMOTO 1959c; TAKAYANAGI & MATSUMOTO 1981), which in Texas is indicative of the lowest Cenomanian (YOUNG 1958).

***Mantelliceras* sp. Interval Zone** (YAZYKOVA in ATABEKIAN & *al*. 1991)

The lower boundary is defined by the FAD in Member 4 of the Naiba Formation (Text-fig. 11) of representatives of the genus *Mantelliceras* (Text-fig. 10), a typical Cenomanian taxon known from many regions in the world (TRÖGER & KENNEDY 1996). Ammonite taxa that make their first appearance in this zone are (Text-fig. 10): *Neophylloceras seresitense* (PERVINQUIERE), *Marshallites olcostephanoides* MATSUMOTO and *Mikasaites orbicularis* MATSUMOTO . Other species range up into this zone, namely *Parajaubertella kawakitana*, *Desmoceras* (*D.*) *kossmati*, *Zelandites inflatus*, *Turrilites costatus, Anagaudryceras buddha*, *Neophylloceras seresitense*, *Desmoceras* (*Pseudouhligella*) *japonicum*, and *Gaudryceras varagurense.* The first appearance of *Mantelliceras* is coeval with the first representatives of *Inoceramus (Birostrina) nipponica* MATSUMOTO and *Inoceramus (Birostrina) tamurai* MATSUMOTO and equates with the lower boundary of *Lipmanium sacramentoensis-Archaeodictyomitra squinaboli* radiolarian zone (Text-fig. 11).

The same zone was established in NE Russia and has been traced to Japan (Text-fig. 12).

***Acanthoceras sussexiense* Total Range Zone** (YAZYKOVA & *al*. 2004)

Following TRÖGER & KENNEDY (1996), the FAD of the ammonite *Cunningtoniceras inerme* is taken as a criterion for recognition of the base of the middle Cenomanian with the entry of *Inoceramus schoendorfi* and the foraminifer *Rotalipora reicheli* as secondary markers. These criteria cannot be applied in Sakhalin because these marker species have never been found here. The local lower/middle Cenomanian boundary in Sakhalin equates with the base of the *Acanthoceras sussexiense* Zone**,** as based on the genus *Acanthoceras* which is generally held to be typical of the middle Cenomanian. Unfortunately, with such limited material we cannot be certain about the specific attribution; note that the specimen illustrated by POYARKOVA (1987, pl. 23, figs 3a-c) is very close to phragmocones described as *Cunningtoniceras* sp. nov. by WRIGHT & KENNEDY (1987, pl. 53, figs. 1-3). For the time being, we adopt the name employed in the volume edited by POYARKOVA (1987). This is the single criterion for the time being. HANCOCK (1960) recognised the *Acanthoceras rhotomagense* Zone in the middle Cenomanian of the Sarthe region, including the stratotype of D'ORBIGNY. *Acanthoceras sussexiense* MANTELL has been found in the uppermost part of Member 4 of the Naiba Formation. Associated are other comparatively long-ranging species such as *Turrilites costatus*, *Neophylloceras seresitense*, *Anagaudryceras buddha*, *Desmoceras* (*Pseudouhligella*) *japonicum* and *Gaudry ceras varagurense.* This zone was described in detail in a previous paper (YAZYKOVA & *al*. 2004).

In NE Russia, an *Acanthoceras* sp. Zone has been distinguished (Text-fig. 12).

***Calycoceras* sp. Total Range Zone** (YAZYKOVA in ATABEKIAN & *al*. 1991)

Some representatives of the genus *Calycoceras* occur in strata assigned to Member 5 of the Naiba Formation (Text-figs 10-11). The FAD of *Calycoceras* is one of several possible criteria for the recognition of the upper Cenomanian. However, no agreement was reached in 1995 on the definition of the base of the substage

(TRÖGER & KENNEDY 1996). The present zone yields *Calycoceras* sp., long-ranging *Gaudryceras varagurense, Neophylloceras seresitense*, *Anagaudryceras buddha*, *Desmoceras* (*Pseudouhligella*) *japonicum,* as well as a new species, *Austiniceras austeni* (SHARPE). For the time being, the middle/upper Cenomanian boundary in Sakhalin is placed at the FAD of *Calycoceras*. The *Calycoceras* Zone correlates with the upper portion of the *Inoceramus pennatulus-I. gradilis* inoceramid Zone and the uppermost portion of the *Lipmanium sacramentoensis-Archaeodictyomitra squinaboli* radiolarian Zone (Text-fig. 11).

Unfortunately, *Calycoceras* is still unknown from NE Russia (Text-fig. 12). In Japan, amongst selected associates, the *Calycoceras* (*Newboldiceras*) *asiaticum* and *Eucalycoceras pentagonum* zones were distinguished (TOSHIMITSU & *al*. 1995). For the time being, the *Calycoceras* Zone in Sakhalin is correlated with the latter of these zones (Text-fig. 12).

Desmoceras (Pseudouhligella) japonicum **Total Range Zone** (MATSUMOTO 1959c)

The *Desmoceras* (*Pseudouhligella*) *japonicum* Zone is dated as Cenomanian based on the stratigraphic occurrence of the index species (Text-fig. 10) and corresponds to the interval from Member 4 of the Naiba Formation to Member 2 of the Bykov Formation. It correlates with the *Inoceramus* (*Birostrina*) *nipponica-I*. (*B*.) *tamurai* Zone and corresponds to two Cenomanian radiolarian zones (Text-fig. 11). This zone has been distinguished in NE Russia and Japan (Text-fig. 12). However, in Japan the FAD of *Desmoceras* (*Pseudouhligella*) *japonicum* was noted in the upper Albian (KAWABE & *al*. 2003). JONES (1967) recorded the index species from Alaska, while HAGGART (1986) recorded it from the Queen Charlotte Islands, British Columbia (Canada), and MURPHY and RODDA (1996) from California.

TURONIAN

In Turonian deposits five ammonite zones are distinguished (Text-fig. 10), on the basis of the first occurrences of the zonal taxa. All of them have recently been described (ZONOVA & YAZYKOVA 1998, YAZYKOVA & *al*. 2004). Thus, the present paper presents only brief characteristics.

Fagesia **sp. Total Range Zone** (VERESCHAGIN in Proceedings... 1982)

The first occurrence of representatives of the genus *Fagesia* typifies the base of the Turonian Stage in many regions in the world (e.g., COLLIGNON 1965; FREUND & RAAB 1969; KHAKIMOV 1970; CHANCELLOR & *al*. 1994, amongst others). In Sakhalin (Text-fig. 5), this taxon cooccurs with *Jimboiceras planulatiforme*, a widely distributed species in the Turonian of the northern Pacific subprovince (MATSUMOTO 1959a, b, 1988; ZONOVA & YAZYKOVA 1998) and of Madagascar (COLLIGNON 1961, 1965). Inoceramids of the *Mytiloides* group have been found to co-occur with *Fagesia* and the first representatives of the *Crucella cachensis-Alievium superbum* radiolarian Zone (Text-fig. 11).

Scaphites planus **Interval Zone** (VERESCHAGIN in Proceedings… 1982)

The “*Scaphites planus* beds” were proposed by VERESCHAGIN (Proceedings… 1982). The *Scaphites planus* Zone (upper lower Turonian – see Text-figs 9-12) was later determined and described by the present author (ZONOVA & YAZYKOVA 1998). This is the level of maximum abundance of Turonian heteromorph ammonites in Sakhalin and in the northeasterly regions of Russia (VERESCHAGIN & *al*. 1965; POYARKOVA 1987; ALABUSHEV & WIEDMANN 1997; ZONOVA & YAZYKOVA 1998; YAZYKOVA & *al*. 2004). The index species (Pl. 2, Fig. 1) is widespread in the North Pacific Province and usually represented by numerous individuals. This typical scaphitid facies is easily traced from NE Russia (Text-fig. 12) through Sakhalin to Hokkaido (TANABE 1979); additional new genera and species appear during this interval (Text-fig. 10). The first representatives of *Scaphites* co-occur with inoceramids of the *Inoceramus hobetsensis* group.

Romaniceras **(*Yubariceras*) *ornatissimum*** **Total Range Zone** (POYARKOVA 1987)

YAZYKOVA first proposed the “*Romaniceras* (*Yubariceras*) *ornatissimum* beds” (in ATABIEKIAN & *al*. 1991). Later, they were transferred to an interval zone; a detailed description was provided by ZONOVA & YAZYKOVA (1998). Locally, the lower/middle Turonian boundary has been established by the FAD of *Romaniceras* (*Yubariceras*) *ornatissimum* (STOLICZKA). Moreover, the index is also known from Europe (MORTIMORE 1986; WOOD & *al*. 1987; GALE 1996; KÜCHLER 1998; WIESE & WILMSEN 1999).

Subprionocyclus **sp. Interval Zone** (YAZYKOVA in ZONOVA & *al*. 1993)

The “*Subprionocyclus* sp. beds” were first proposed by the present author in 1993 (ZONOVA & *al*. 1993), following MATSUMOTO (1977b). Later, they were transferred to an interval zone (ZONOVA & YAZYKOVA 1998). In Japan, the middle/upper Turonian boundary is placed at the FAD of *Subprionocyclus neptuni* (GEINITZ) (see Text-fig. 12). The same species has been reported from Spain (KÜCHLER 1998; WIESE & WILMSEN 1999), and is common in its own zone in the UK and Germany, where its FAD is taken to mark the base of the Upper Turonian (WRIGHT & KENNEDY 1981; ERNST & *al.* 1996). Unfortunately, we cannot be absolutely certain since only single finds of the zonal index are known. Additional investigations are required before this boundary can be placed more precisely. The total number of species decreased slightly but new taxa gradually appeared.

The deposits of this zone correlate well with the *Subprionocyclus minimus* Zone in Japan (Text-fig. 12), as based on representatives of the same associated species, and correspond to the *Inoceramus teshioensis-Mytiloides incertus* Zone based on the co-occurrence of typical ammonite and inoceramid taxa (Text-fig. 11). The lower boundary of the *Subprionocyclus* sp. Zone equates with that of the *Orbiculiforma quadrata-O. monticelloensis* radiolarian Zone (Text-fig. 11).

***Jimboiceras planulatiforme* Total Range Zone** (MATSUMOTO 1959c)

The *Jimboiceras planulatiforme* Zone was described in detail in previous works (MATSUMOTO 1959c; ZONOVA & *al*. 1993; ZONOVA & YAZYKOVA 1998), to which reference is made. This is a well- characterised Zone, encompassing the entire Turonian and perfectly correlating with NE Russia (Text-fig. 12) and Japan, where the index species is a Turonian marker (MATSUMOTO 1954b).

CONIACIAN

Recently, the present author has described the Coniacian zones (ZONOVA & YAZYKOVA 1998). Three subdivisions could be used in Sakhalin. Unfortunately, it is difficult to determine the boundaries of the Coniacian substages at the present time; additional research is needed to establish these. The appearance of new morphological types with coarser shell ornament in the Coniacian is typical of many phylogenetic lineages, for instance in *Jimboiceras* and *Gaudryceras*.

***Jimboiceras mihoense* Total Range Zone** (YAZYKOVA in ZONOVA & YAZYKOVA, 1998)

This zone has recently been established following YU. ZAKHAROV, who proposed "the Beds with *Pachydesmoceras mihoense*" (YU. ZAKHAROV & *al*. 1996), and described in detail in the previous work (ZONOVA & YAZYKOVA 1998). Some confusion has appeared regarding the naming of the index species from Sakhalin, as explained below.

The holotype of *Jimboiceras mihoense* originated from the River Naiba and was described by MATSUMOTO (1954b); this specimen is only moderately well preserved, which explains why specimens collected by the author were erroneously identified as *Pseudokossmaticeras brandti* (REDTENBACHER) (see pl. 70, figs 1-2 and pl. 71, fig. 1 in ZONOVA & *al*. 1993). Subsequently, new finds have enabled rectification of this misidentification (ZONOVA & YAZYKOVA 1998). However, in that paper another mistake crept in since the species was referred to as both *Jimboiceras mihoense* and *Pachydesmoceras mihoense*. Partially causing this problem was the fact that MATSUMOTO (1954b) originally assigned the species to *Jimboiceras* but he later transferred it to *Pachydesmoceras* (MATSUMOTO 1988). ZAKHAROV & *al*. (1996) also published a specimen identified as *Pachydesmoceras mihoense*. However, SHIGETA in KODAMA & *al*. (2002) and HASEGAWA & *al*. (2003) have recently favoured assignment of this material to *Jimboiceras* based on morphological features that are held to be typical of *Jimboiceras* rather than *Pachydesmoceras* (SHIGETA, pers. comm., 2003). The author agrees with that opinion and illustrates this species here again, under its proper name, *Jimboiceras mihoense* MATSUMOTO (Plate 1).

This zone extends to the end of the Coniacian (Text-figs 10-12), and corresponds to two inoceramid zones (Text-fig. 11), viz. the *Inoceramus uwajimensis* Zone and the *Inoceramus mihoensis* Zone, based on the co-occurrence of *J. mihoense* and zonal inoceramids. In Japan, representatives of *J. mihoense* occur in strata of the *Kossmaticeras theobaldianum-Eupachydiscus keramasotoshii* Zone (Text-fig. 12). In NE Russia, the *Kossmaticeras* (*Natalites*) *penjiensis* Zone is proposed in the present paper, because *J. mihoense* has not yet been found there (Text-figs 12). The correlation is based on associated ammonite species, as well as the widespread *Inoceramus uwajimensis* YEHARA and another inoceramid species which characterise the Coniacian of the Far East. The *J. mihoense* Zone corresponds to the upper portion of the *Orbiculiforma quadrata-O. monticelloensis* and *Orbiculiforma vacaensis-Squinabolella putahensis* radiolarian zones (Text-fig. 11).

***Forresteria alluaudi* Total Range Zone** (POKHIALAJNEN 1985)

This Zone was also described in some previous works (ZONOVA & *al*. 1993; ZONOVA & YAZYKOVA 1998), following POKHIALAJNEN (1985), who proposed “the Beds with *Forresteria alluaudi*” and placed it near the middle Coniacian, although it is impossible to give a more precise age assignment now. It clearly corresponds to the *Inoceramus mihoensis* Zone (Text-fig. 11) as based on the joint occurrence of these taxa. The lower boundary of the ammonite zone equates with the base of the *Orbiculiforma vacaensis-Squinabolella putahensis* radiolarian Zone (Text-fig. 11).

***Peroniceras* sp. Total Range Zone** (VERESCHAGIN in Proceedings… 1982)

This zone has been described previously (POYARKOVA 1987; ZONOVA & *al*. 1993; ZONOVA & YAZYKOVA 1998), following VERESCHAGIN, who proposed “the Beds with *Peroniceras*” (Proceedings… 1982). It corresponds to the upper portion of Member 7 of the Bykov Formation, to the *Inoceramus mihoensis* inoceramid Zone and to the *Orbiculiforma vacaensis-Squinabolella putahensis* radiolarian Zone (Text-fig. 11), based on the co-occurrence of all these taxa. It also correlates with the upper portion of the *Kossmaticeras* (*Natalites*) *penjiensis* Zone in NE Russia (Text-fig. 12), on the basis of the similar taxonomic composition of the associated assemblage.

Representatives of *Peroniceras* are typical of the Coniacian in many regions of the world (KLINGER & WIEDMANN 1983). The present zone underscores the global correlation with other biogeographic basins and realms.

SANTONIAN

Three ammonite zones are assigned to the Santonian in the present report (Text-figs 10-11). All of them have already been described in previous works (ZONOVA & *al*. 1993; YAZYKOVA 1996, 2002). Unfortunately, it is difficult to determine the boundaries of the Santonian substages at the present time; additional studies are needed to establish those.

***Texanites* (*Plesiotexanites*) *kawasakii* Interval Zone** (YAZYKOVA in ZONOVA & *al*. 1993)

This Zone was based on “the Beds with *Texanites* (*Plesiotexanites*) *kawasakii*” proposed by ZONOVA & *al*. (1993) and described later in two papers (YAZYKOVA 1996, 2002). This is the oldest Santonian ammonite zone; it contains *Texanites, Yokoyamaoceras, Neopuzosia, Damesites, Tetragonites, Saghalinites, Neophylloceras, Phyllopachyceras* and *Gaudryceras*, as well as the heteromorph genera *Polyptychoceras, Subptychoceras* and *Pseudoxybeloceras* (Text-fig. 10, Plate 2). The percentage of cosmopolitan species is comparatively moderate, approximately 45% (YAZYKOVA 2002). The species of *Yokoyamaoceras, Neopuzosia, Saghalinites* and *Gaudryceras* belong to endemic lineages. *Texanites* appeared in south Sakhalin at the onset of the early Santonian regression. This genus is not known from the northern territories (Koryak Upland, northwestern coast of Kamchatka Peninsula, Anadyr’ Bay) of the Russian Far East. It is possible (cf. COBBAN 1993) that *Texanites* was a migrant from Texas or Mexico, where the genus is common. The *Texanites* (*Plesiotexanites*) *kawasakii* Zone is generally characterised by long-ranging ammonite species, with 15 species appearing at the base of the Santonian. The origination rate is highest during the Santonian (Text-fig. 15) with 26 species in total (Text-fig. 14). The percentage of cosmopolitan species rose to 25% (YAZYKOVA 2002). In contrast, the coeval *Inoceramus amakusensis* Zone is marked by a low percentage of cosmopolitan species and a low origination rate, with only three new, endemic species appearing (YAZYKOVA 2002).

***Eupachydiscus haradai* Total Range Zone** (MATSUMOTO 1959c)

This zone extends to the top of the lower Campanian. Previously, there were many different opinions on the stratigraphic range of this zonal species and consequently on the limits of the zone. This was due mainly to misidentification of specimens that were erroneously referred to *Anapachydiscus* (*Neopachydiscus*) *naumanni* (YOKOYAMA) or to species of *Menuites* because of the closely similar morphology of the juvenile stage in ontogeny. The author of the present paper suggested earlier (YAZYKOVA 1996, 2002; YAZYKOVA & *al*. 2002) that *Eupachydiscus haradai* is the first representative of the Pachydiscidae in Sakhalin, occurring approximately at the lower/upper Santonian boundary and disappearing during the early Campanian. In the latest Santonian, the first representatives of *Menuites* appeared, possibly as immigrants from India, and evolved during a short time before disappearing prior to the *Canadoceras kossmati* Zone. *Anapachydiscus* (*Neopachydiscus*) *naumanni* occurs commonly in lower Campanian deposits (Text-fig. 10).

Based on the co-occurrences of zonal index species, the lower boundary of the *Eupachydiscus haradai* Zone corresponds to that of the *Inoceramus japonicus hokkaidoensis-I*. aff. *undulatoplicatus* inoceramid Zone and of the *Archaeospongoprumum bipartitum-Patulibracchium petroleumensis* radiolarian Zone (Text-fig. 11).

Representatives of *Eupachydiscus haradai* are well known from the same stratigraphic interval in NE Russia and Japan (Text-fig. 12), Madagascar (COLLIGNON 1955, 1966) and British Columbia (JELETZKY in MULLER & JELETZKY 1970).

***Menuites menu* Interval Zone** (YAZYKOVA in ZONOVA & *al*. 1993)

This zone corresponds to the upper portion of Member 9 of the Bykov Formation (Text-fig. 11). As indicated above, *Menuites menu* (FORBES) was a possible immigrant from the Mediterranean Realm. Moreover, endemic representatives of this genus, namely *M. japonicus* (MATSUMOTO) and *M. naibutiensis* (MATSUMOTO) are widespread in the North Pacific. The present zone was also proposed for NE Russia (Text-fig. 12) and described in detail in previous works (ZONOVA & *al*. 1993; YAZYKOVA 1996, 2002).

It corresponds to the upper portion of the *Inoceramus japonicus hokkaidoensis-I*. aff. *undulatoplicatus* inoceramid Zone and of the *Archaeospongoprumum bipartitum-Patulibracchium petroleumensis* radiolarian Zone (Text-fig. 11), based on the co-occurrence of zonal index species.

CAMPANIAN

Four ammonite zones are assigned to the Campanian in this report (Text-figs 10-11), all described previously (ZONOVA & *al*. 1993; YAZYKOVA 1996, 2002).

***Anapachydiscus (Neopachydiscus) naumanni* Interval Zone** (MATSUMOTO 1959c)

This unit was established in Hokkaido (MATSUMOTO 1959c) and described in detail for Sakhalin by YAZYKOVA (ZONOVA & *al*. 1993; YAZYKOVA & *al*. 2002). It occurs within the middle part of Member 10 of the Bykov Formation (Text-fig. 11). The ammonite assemblage is largely endemic, with only seven (out of 31) cosmopolitan species: *Damesites sugata* (FORBES); *Tetragonites epigonus* (KOSSMAT); *Phyllopachyceras forbesianum* (d'ORBIGNY); *Desmophyllites diphylloides* (FORBES); *Subptychoceras vancouverense* (WHITEAVES); *Pseudoxybeloceras lineatum* GABB and *Menuites menu* (Text-fig. 10). The degree of endemism equals or slightly exceeds that of underlying beds. Representatives of the index species are widespread in the northern Pacific province and, as a rule, are well preserved, large and, in some cases, gigantic. *Anapachydiscus (Neopachydiscus) naumanni* is closely allied to *Eupachydiscus levyi* (De GROSSOUVRE) from the lower Campanian in northern and southern Europe.

The same zone is recognised in NE Russia (VERESCHAGIN & *al*. 1965) and in Japan (Text-fig. 12) (TOSHIMITSU & *al*. 1995); it correlates well with the *Inoceramus nagaoi* Zone (Text-fig. 11) based on co-occurrences of the zonal index species. Both of these taxa are the principal criteria for recognition of the Santonian/Campanian boundary in Russian Far East (YAZYKOVA 1996, 2002; YAZYKOVA & *al*. 2002). The zone also equates with the *Spongostaurus* (?) *hokkaidoensis-Hexacontium* sp. radiolarian Zone (Text-fig. 11).

***Canadoceras kossmati* Interval Zone** (YAZYKOVA 2002)

This zone was established in Hokkaido (MATSUMOTO 1977b) and has since been recorded from Sakhalin (YAZYKOVA 2002). It corresponds to the uppermost part of Member 10 of the Bykov Formation (Text-fig. 11). *Canadoceras kossmati* MATSUMOTO is the oldest and most widespread representative of *Canadoceras* in Sakhalin and NE Russia. Within this zone, the degree of endemism is slightly higher than in the underlying *Anapachydiscus* (*Neopachydiscus*) *naumanni* Zone (YAZYKOVA 2002). In total, 22 species in 18 genera have been recorded, including species that are distributed widely in circum-Pacific regions (Text-fig. 10).

The same zone (Text-fig. 12) has been included in the recent biostratigraphic scheme for Japan (TOSHIMITSU & *al*. 1995). Representatives of *Pennatoceramus orientalis* (SOKOLOV) make their first appearance together with species of *Canadoceras* (YAZYKOVA 1996; YAZYKOVA & *al*. 2002). The strata assigned to this zone are well correlated (Text-fig. 11).

***Pachydiscus* (*P.*) sp. aff. *egertoni* Total Range Zone** (YAZYKOVA in ZONOVA & *al*. 1993)

"The *Pachydiscus* (*P.*) sp. aff. *egertoni* beds" were proposed by YAZYKOVA (ZONOVA & *al*. 1993) for a particular level within Member 1 of the Krasnoyarka Formation. This zone is characterised by abundant and comparatively highly diverse ammonite assemblages (20 species, Text-fig. 10), mainly members of the family Pachydiscidae, such as the zonal index, *Canadoceras kossmati, C. yokoyamai* and *C. mysticum* (YAZYKOVA 1996, 2002; YAZYKOVA & *al*. 2002). It correlates with the *Schmidticeramus schmidti* inoceramid Zone (Text-fig. 11) based on co-occurences of the zonal species. The maximum diversity and abundance of representatives of *Canadoceras* equated with the maximum diversity and abundance of inoceramids of the subfamily Sachalinoceraminae (YAZYKOVA 2002; YAZYKOVA & *al*. 2002). This zone is correlated with confidence with the *Anapachydiscus fascicostatus* Zone in Hokkaido (Text-fig. 12) (TOSHIMITSU & *al*. 1995) based on total faunal composition. Representatives of *Anapachydiscus fascicostatus* (YABE) occur also in Sakhalin within the uppermost part of Member 10 of the Bykov Formation and range to the lower part of Member 2 of the Krasnoyarka Formation (Text-fig. 10) (POYARKOVA & *al*. 1987; ZONOVA & *al*. 1993; YAZYKOVA, 1996, 2002; YAZYKOVA & *al*. 2002). Representatives of the genus *Baculites* occur only in the deposits of this zone (Text-fig. 10), although KAWADA (1929) mentioned *Baculites* from the Maastrichtian of Sakhalin, but did not figure any specimens. Finds of *Baculites* from the upper Campanian of Sakhalin were published by ZHURAVLEV (1969b), who also referred to a rich and diverse fauna, traceable over thousands of kilometres within the North Pacific region, i.e. Japan, Sakhalin, Kamchatka, Koryak Upland, and Alaska (see YAZYKOVA *& al.* 2002). The general thickness of the zone, which equates with Member 1 of the Krasnoyarka Formation, is about 100 m (Text-fig. 11).

The zone correlates with the *Schmidticeramus schmidti* inoceramid Zone and the *Pseudoaulophacus floresensis-Stichomitra livermorensis* radiolarian Zone (Text-fig. 11) based on the co-occurrence of the zonal species. In Japan, the *Anapachydiscus fascicostatus* Zone is distinguished at this level, and the *Canadoceras* sp. Zone in NE Russia (Text-fig. 12). The *Pachydiscus* (*P*.) sp. aff. *egertoni* Zone correlates well with these units, based on similar zonal assemblages.

***Canadoceras multicostatum* Interval Zone** (VERESCHAGIN in Proceedings… 1982)

This is the youngest zone of the Campanian in Far East Russia. The *Canadoceras multicostatum* Zone was first established in the Naiba River area and has since been identified in Japan (MATSUMOTO 1959c, 1977a) and described in detail by ZONOVA & *al*. (1993). It occurs within members 2 and 3 of the Krasnoyarka Formation (Text-fig. 11). *Canadoceras multicostatum* MATSUMOTO and *Pseudophyllites indra* (FORBES) have previously been assumed to have appeared and disappeared in the latest Campanian (Text-figs 10). However, two specimens of huge-sized *Canadoceras multicostatum* have been collected by the author at the base of the lower Maastrichtian in Shikotan Island (Text-fig. 9), from deposits referred to the Malokurilsk Formation. Some specimens of *Pseudophyllites indra* are also known from the basal Maastrichtian of Sakhalin (ALABUSHEV & WIEDMANN 1997; YAZYKOVA & *al*. 2002). In total, 20 species in 17 genera are known from the zone, including six cosmopolitan taxa: *Desmophyllites diphylloides* (FORBES); *Phyllopachyceras forbesianum* FORBES; *Saghalinites cala* (FORBES); *Anapachydiscus arrialoorensis* (STOLICZKA); *Ryugasella ryugasense* WRIGHT & MATSUMOTO and *Diplomoceras notabile* WHITEAVES. This zone is coeval with the *Inoceramus* sp. aff. *balticus* Zone (Text-fig. 11) based on co-occurrences of representatives of index species from both groups.

The *Canadoceras* spp. Zone established in NE Russia corresponds to both upper Campanian zones from Sakhalin (Text-fig. 12). Moreover, the *Tetragonites popetensis* Zone in the uppermost Campanian of NE Russia (Text-fig. 12) is well recognised in Sakhalin, where the zonal species is widely distributed at the same level (Text-fig. 9).

At present, two new zones have been adopted in Japan to replace the *Canadoceras multicostatum* Zone (Text-fig. 12), but their faunal assemblages are apparently identical to that of the *Canadoceras multicostatum* Zone in Sakhalin. Representatives of the zonal taxa from Japan, *Pachydiscus* (*P*.) *awajiensis* and *Patagiosites laevis,* have still not been found in Sakhalin. The disappearence of the genus *Canadoceras* in the Pacific is closely related to the demise of radial-ribbed inoceramids of the subfamily Sachalinoceraminae (see YAZYKOVA & *al*. 2002).

MAASTRICHTIAN

The three Maastrichtian zones established in Sakhalin have been discussed on numerous previous occasions (see e.g. YAZYKOVA 1991, 1992, 1993; YAZIKOVA 1994; ZONOVA & *al*. 1993).

***Pachydiscus* (*Pachydiscus*) *subcompressus* Total Range Zone** (VERESCHAGIN in Proceedings … 1982)

This is the first zone to have been proposed for Maastrichtian deposits in Sakhalin (VERESCHAGIN in Proceedings… 1985), following MATSUMOTO (1959c). It ranges to the top of the Maastrichtian and is well traced from NE Russian regions through Sakhalin to Japan. *Pachydiscus* (*P.*) *subcompressus* MATSUMOTO is widespread and abundant in Sakhalin. During almost 25 years (from 1974 onwards; Proceedings… 1982), the general view was that the Maastrichtian deposits in Sakhalin were poorly characterised by fossils. The present author was able to come up with evidence to the contrary, by amassing a large collection which was described in parts in 1990, 1991, 1993 and 1994 (ZONOVA 1990; YAZYKOVA 1991; ZONOVA & *al*. 1993; YAZIKOVA 1994). The two next zones proposed were based on that collection.

***Pachydiscus* (*Neodesmoceras*) *japonicus* Total Range Zone** (YAZYKOVA 1991)

This unit was proposed by YAZYKOVA (1991), following MATSUMOTO (1959c), who proposed the *Neodesmoceras* *japonicum-Damesites hetonaiensis* Zone for the lower Maastrichtian deposits of Hokkaido. It equates with Member 4 of the Krasnoyarka Formation. The zonal assemblage consists of *Pachydiscus* (*Neodesmoceras*) *japonicus* MATSUMOTO, *Pachydiscus* (*P.*) *subcompressus, Pseudophyllites indra, Zelandites varuna* (FORBES), *Neophylloceras ramosum*, *Gaudryceras denmanense* WHITEAVES and *Anagaudryceras matsumotoi* (Text-fig. 10). The percentage of cosmopolitan species is higher in comparison to the end of the Campanian (YAZYKOVA 2002). The zone correlates well with the *Shachmaticeramus shikotanensis* inoceramid Zone and with the *Pseudotheocampe abschnitta* radiolarian Zone (Text-fig. 11) based on co-occurrences of zonal index species. The same zone was established in NE Russia and Japan (Text-fig. 12).

***Pachydiscus* (*Pachydiscus*) *flexuosus-Pachydiscus* (*Neodesmoceras*) *gracilis* Assemblage Zone** (YAZYKOVA 1991)

MATSUMOTO (1977b, see also TAKAYANAGI & MATSUMOTO 1981) proposed this zone for the upper Maastrichtian deposits of Hokkaido. The present author (YAZYKOVA 1991) established it in Sakhalin in Member 5 of the Krasnoyarka Formation. The zonal assemblage consists of *Pachydiscus* (*Pachydiscus*) *flexuosus* MATSUMOTO, *Pachydiscus* (*Neodesmoceras*) *gracilis* MATSUMOTO, *Pachydiscus* (*P.*) *subcompressus*, *Pachydiscus* (*P.*) *gollevillensis* (d'ORBIGNY), *Pachydiscus* (*P.*) *neubergicus* (von HAUER), *Zelandites varuna*, *Z. japonicus* MATSUMOTO, *Neophylloceras ramosum*, *N. hetonaiense* MATSUMOTO, *Gaudryceras denmanense, G. venustum* MATSUMOTO, *G. hamanakense* MATSUMOTO & YOSHIDA, *Anagaudryceras matsumotoi,* and *Diplomoceras cylindraceum* (Text-fig. 10). The Zone corresponds well to the *Shachmaticeramus kusiroensis-Inoceramus hetonaianus* Zone on inoceramid data and *Amphipindax tylotus* Zone on radiolarian evidence (Text-fig. 11).

The same unit has been established in NE Russia (Text-fig. 11). In Japan, the *Pachydiscus* (*Pachydiscus*) *flexuosus* Zone extends to the upper Maastrichtian and the *Pachydiscus* (*Neodesmoceras*) *gracilis* Zone is placed approximately in the middle portion of the Maastrichtian (Text-fig. 12). Amongst associated species, *Gaudryceras hamanakense* is very important in view of its distribution in the East Sakhalin Mountains, where neither *Pachydiscus* (*N.*) *gracilis* nor *Pachydiscus* (*P.*) *flexuosus* occur (ZONOVA 1990).

BASIN EVOLUTION

Deposition of Lower Cretaceous strata is recorded mainly from the northeastern regions of Russia (Text-fig. 1A) and from Sikhote Alin (Text-fig. 1B); it is characterised by a complex evolutionary history (KIRILLOVA & *al.* 2000). Broad connections between the Tethyan and Boreal realms existed during the Berriasian–Hauterivian. Following the Hauterivian regression only in some areas was there marine sedimentation. Marine Hauterivian deposits are known exclusively from the southeastern Primorye, along the Penzhyna Gulf coast (Text-fig. 1A) and from the Pekulnej Ridge in the Koryak Upland (VERESCHAGIN & *al.* 1965; KIRILLOVA & *al.* 2000). The Barremian–Middle Albian time interval is characterised

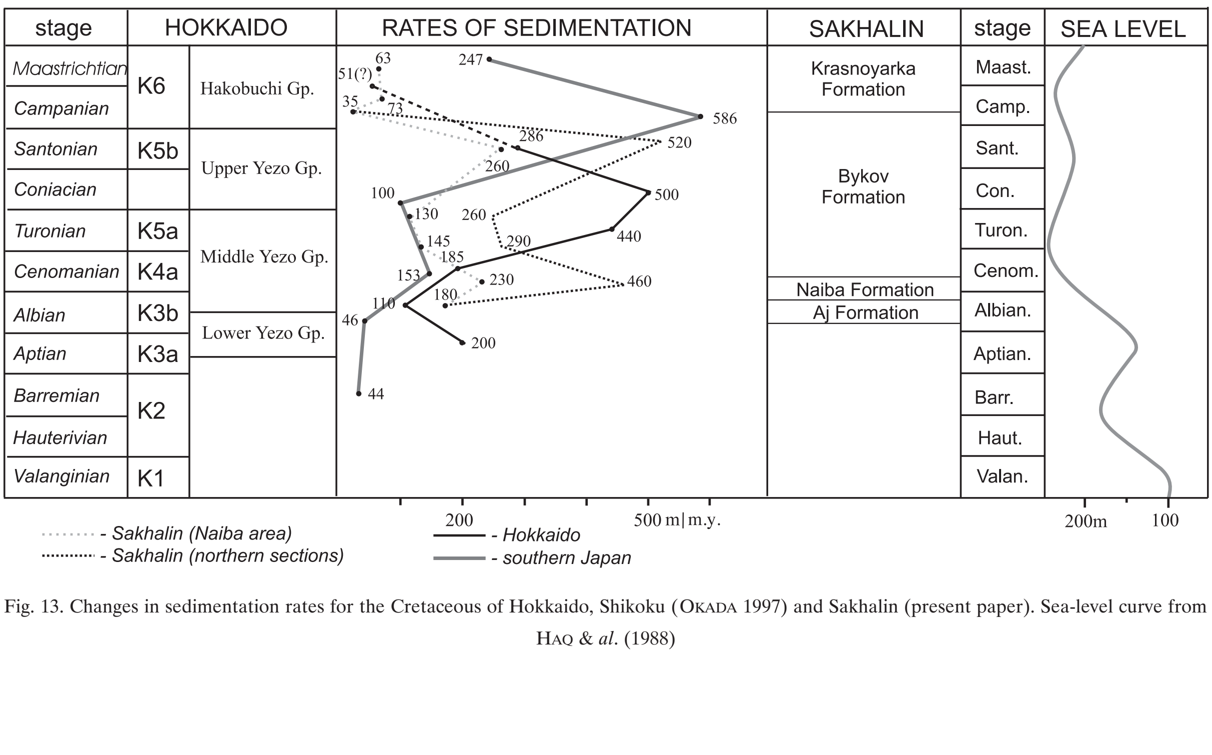

Fig. 13. Changes in sedimentation rates for the Cretaceous of Hokkaido, Shikoku (OKADA 1997) and Sakhalin (present paper). Sea-level curve from HAQ & *al*. (1988)

by a gradual sea-level rise, reflected in deep-water sedimentation in the Sikhote Alin basin, along the Penzhyna Gulf coast and in the Koryak Upland. From the late Albian onwards, the links between the Boreal and Tethyan realms were interrupted by a short-term regression and by active tectonic movements. During the Cenomanian, the Sichote Alin palaeobasin gradually disappeared.

The late Albian palaeobasin occupied part of the territory of Sakhalin Island. Relatively deep-water strata with an extremely high depositional rate (~ 175-180 m/Ma, Text-fig. 13) are reflected in a series of mudstones interbedded with sandstones, with a total thickness of more than 800 m (Text-fig. 2). OKADA (1997) also recorded a high depositional rate for upper Aptian-Albian deposits in Hokkaido (Text-fig. 13), noting 200 m/Ma for the Lower Yezo Group and 110 m/Ma for the latest Albian portion of the Middle Yezo Group.

The Lower/Upper Cretaceous boundary is marked by a global regression and an abrupt environmental change. The lowermost Cenomanian comprises conglomerates and sandstones, about 250 m thick (Text-fig. 2), while the upper portion of the lower Cenomanian is dominated by mudstone and siltstone, totalling some 300 m, documenting an increase in sedimentation rate (Text-fig. 13) to over 200 m/Ma.

The global Middle Cenomanian-Turonian transgression has been recorded for the whole of Far East Russia; it resulted in relatively deep-water sedimentation. In Hokkaido, OKADA (1997) also recorded high rates of clastic sedimentation (> 200 m/Ma) during a sea-level highstand in the late Cenomanian/early Turonian (Middle Yezo Group), reflecting tectonic uplift and highly active magmatism. The total thickness of middle and upper Cenomanian deposits in Sakhalin amounts to about 500 m, thus reflecting a high rate of sedimentation (>145 m/Ma). However, the author's observations in the area between the rivers Lebyazhja, Aj and Firsovka (sections NN 3, 4 and 13, see Text-fig. 1C) document the extreme thickness of upper Cenomanian deposits, up to 1,000 m (rivers Aj and Lebyazhja, Text-fig. 2) and in excess of 2,500 m in the Firsovka River valley (Text-fig. 2). This extremely high sedimentation rate may be explained by tectonic uplift along the East Asian continental margin (OKADA 1997). OKADA recorded two extraordinarily high peaks in depositional rates, which correspond to the global Cenomanian and Campanian sea-level highstands, and show their close links with tectonic activity as well. For instance, sections in the eastern and northeastern parts of the East Sakhalin Mountains typically show an absolute predominance of metamorphic and extrusive rocks and a great thickness of Cenomanian strata, up to 2,000 m. The greatest thickness of Cenomanian deposits is recorded in clastic sediments in Schmidt Peninsula (Text-fig. 1A), reaching up to 3,100 m (VERESCHAGIN 1977).

A brief regressive interval at the Cenomanian /Turonian boundary, connected with active volcanism or tectonics, interrupted this sedimentary regime. The boundary is marked by the occurrence of mudstones interbedded with black, grey and green tuffaceous sandstones and siltstones as well as bentonitic clay. This "coloured" interval is barren of any fossils and generally reaches a thickness of some 40-50 m (YAZYKOVA & *al.* 2004).

The Middle Turonian is characterised by an intercalation of mudstones and siltstones with sandstone, tuff and tuffaceous layers and turbidites, illustrating active volcanics and the predominance of storms. The upper Turonian to Coniacian interval shows a relatively monotonous series of deep-water strata, with a relative decrease in depositional rate (~130 – 140 m/Ma). In Sakhalin, this comparatively stable period is interrupted only by local sea-level changes which are reflected in a series of intercalated mudstones and siltstones with sandstone and possibly slight volcanic activity as evidenced by thin tuff and tuffaceous beds (Text-fig. 2). However, the northerly sections in the West Sakhalin Mountains document a huge thickness of Turonian strata (Text-fig. 2), in excess of 1,000 m, which means the depositional rate must have been high and closely comparable to that documented by OKADA (1997) for the Turonian-Coniacian (Text-fig. 13), up to a maximum of 500 m/Ma in the latest Coniacian. Then, according to OKADA (1997), depositional rates gradually decreased in the Santonian (~ 286 m/Ma) in Hokkaido, but rose again to extreme values in southwest Japan (> 500 m/Ma). In southern Sakhalin, depositional rates were also extremely high during the Santonian (~260 m/Ma, Text-fig. 13) and highest in the north of the Main Cretaceous Field (sections NN 19-26), where Santonian deposits are twice as thick as elsewhere.

The Santonian–Campanian boundary in Sakhalin is characterised by an abrupt regressive pulse which interrupted deep-water sedimentation and triggered notable environmental changes (YAZYKOVA 1996, 2002). During the early Campanian, depositional rates were markedly lower than previously, just 35 m/Ma (Text-fig. 13). An interval of a total thickness of 200 m of mudstones with rare, thin layers of tuffaceous siltstone typifies the lower Campanian in Sakhalin. The lower/upper Campanian boundary is characterised by conglomerates overlain by glauconitic sandstones with thin beds of tuff and bentonitic clay (Text-fig. 2). Based on the presence of conglomerates, an hiatus at this level may be inferred (YAZYKOVA 1996, 2002). Late Campanian sedimentation continued uninterrupted until the Maastrichtian, with a slightly higher sedimentation rate (~ 73 m/Ma). This part of the section comprises relatively shallow-water sandstones with mudstone layers (Text-fig. 2). However, the uppermost Campanian is represented by a predominance of mudstones deposited during a high-stand. It should also be noted that this time interval is characterised by great volcanic activity in the eastern and northern parts of the island, as demonstrated by the predominance of volcanic rocks in sections exposed in the northeastern part of the east Sakhalin Mountains and in Schmidt Peninsula.

Near the end of the late Campanian, the onset of tectonics resulted in an overall uplift of the region (KIRILLOVA in press), with the new regression-transgression pulse leading to global environmental changes. During the early Maastrichtian, the south of the island saw the deposition of shallow-water sandstones. However, a gradual facies change may be observed going from the south to the north. The lower Maastrichtian sequence in the Aleksandrovsk – Sakhalinskij region (Text-fig. 1C, sections NN 19-26) is composed of mudstones and sandy mudstones. In the southern part of East Sakhalin, volcanogenic siliceous rocks of Campanian age are overlain by deep-water mudstones with silica tuffs illustrating strong tectonic activity and the highly complex sedimentary sequence. Possibly, this represented the ultimate interval of strong tectonic 'rearrangements' of the Sakhalin Mountains; the upper Maastrichtian comprises quiet, deep-water sedimentation of mudstones with carbonate concretions, elongated along bedding planes and forming concretion layers in some sections in the south of the island (Text-fig. 2). It seems that the occurrence of such concretions might be linked to storm events during the taphonomic process. WANI (2001) stressed that shell accumulations in the shelf facies in Hokkaido, which are often visible in calcareous concretions, were related to storm events. The total thickness of Maastrichtian deposits in Sakhalin amounts to about 400 m, and thus suggests a depositional rate (~ 63 m/Ma, Text-fig. 13) that is comparable to that of the late Campanian.

The Cretaceous/Paleogene boundary is characterised by a global regression and drastic environmental changes, which is here reflected in the deposition of green-grey clays, 1-2 m in thickness. The East Sakhalin region also shows some volcanic activity that is reflected in glauconitic material in the basal Danian sandstone (SHUVAEV 1965). The Kuril Islands are positioned within the zone of strong tectonic activity and the boundary between Maastrichtian and Paleocene rocks is within the tectonic contact (ZONOVA & YAZYKOVA 1994b). During the Danian, shallow-water sandstones with bentonitic and tuffaceous material were laid down in Sakhalin.

STAGE BOUNDARIES, BIOEVENTS AND GLOBAL CORRELATION

Diversity is a measure of ecosystem 'health'. High diversities are typically associated with more complex communities, and hence are often correlated with ameliorated conditions for biotas. Low diversities, on the other hand, are associated with ecological stress, an element typical of mass extinction events (HARRIES & LITTLE 1999). The commonest trends observed in ammonoid evolution during ecologically stable periods include an increase in shell curvature (e.g. evolute to involute), the development of more complex ornament (flexuosity of ribbing, appearance of coarser elements, e.g. nodes and spines) and a long-term increase in the suture line's fractal dimension. Major turnovers in ammonite evolution occurred during severe extinction events, and were characterised by the sudden appearance of simple, primitive-looking forms which were similar to remote ancestors of their more complex immediate progenitors. Such forms are interpreted as atavistic. According to this hypothesis, homeomorphic species generated during such sublethal stress events may be separated by several millions of years (GUEX 2001).

The position of Cretaceous stage boundaries in Sakhalin and Shikotan has been refined through detailed appraisals of ammonite diversity and of relationships between ammonites and associated faunal groups such as inoceramids and other bivalves, radiolarians, foraminifera, gastropods and echinoids, studies of ecosystem 'health' and integrated biostratigraphy, palaeotemperature data (Yu. ZAKHAROV & *al*. 1999; KIRILLOVA & *al*. 2000), magnetostratigraphy (KODAMA & *al*. 2000), and a preliminary isotope stratigraphy (HASEGAWA & *al*. 2003). In addition, those studies have enabled the characterisation of bioevents on which regional and global correlations of Russian Far East Cretaceous sequences are based, in spite of complex tectonic structure, huge thicknesses of strata, strong facies changes, monotonous lithology and the predominance of endemic faunal elements. Virtually none of the taxonomic elements recommended at the Second International Symposium on Cretaceous Stage Boundaries (Brussels 1995) can be applied in Far East Russia or Japan, since, with few exceptions, the taxa in question have not been recorded from these areas. The problems surrounding global correlation of the Pacific Cretaceous with the stratotype areas are still being discussed to date. The present study provides examples of these problems as based on a detailed study of bioevents across Cretaceous stage boundaries. The dynamics of ammonite development during the Cretaceous in Sakhalin are presented in Text-fig. 14 with oceanic anoxic events (OAE) marked as well. The total origination and extinction rates that have been counted are shown in Text-fig. 15. Following RAUP & SEPKOSKI (1984), the total extinction is the number of species that went extinct during a stage (the total extinction rate = total extinction : stage duration), whereas total origination rate is the number of species that appeared during a stage inclusive of immigrant taxa.

Lower Cretaceous

The comparatively shallow Early Cretaceous seas of the Far East Russia basins were inhabited by representatives of different bivalve groups (e.g., Aucellidae, Inoceramidae, Pectinidae and others) and some brachiopods (VERESCHAGIN & *al.* 1965). In comparison to the numerous bivalves, ammonites are rather rare and occur mostly in central NE Russia, e.g some localities in the Koryak Upland or the Chukotka and Kamchatka peninsulas (VERESCHAGIN & *al.* 1965). ALABUSHEV (in ALABUSHEV & WIEDMANN 1997) noted the occurrence of numerous *Marshallites* and *Neogastroplites* in northwestern Kamchatka. The Early Cretaceous northern Pacific fauna is mostly Boreal in composition. However, the Sikhote Alin palaeobasin at the southern end of this vast area (Text-fig. 1) was unique in that the taxonomic composition of the fauna reflects both the Boreal and Tethyan realms (ZONOVA & YAZYKOVA 2000, 2001; YAZYKOVA 2001). The youngest ammonites in Sikhote Alin are of Cenomanian age.

The first ammonites from Sakhalin were identified as late Albian forms (ZHURAVLEV 1969a; TARASEVICH 1971; ZONOVA & *al.* 1986, 1993). The taxonomic composition of that assemblage is close to the late Albian assemblage from Sikhote Alin mentioned above. It consists of representatives of six genera: viz. *Cleoniceras, Anahoplites, Sonneratia, Brewericeras, Puzosia* and *Pseudhelicoceras* (Text-fig. 10). This assemblage is also composed of Tethyan and Boreal elements; it occurs throughout the Main Cretaceous Field (sections NN 1-4, 13, 24, see Text-fig. 1C) and is mostly dominated by Group A (ornate shell forms) and B (heteromorphs) (*sensu* TANABE 1979) morphotypes. However, representatives of group C (less ornate and smooth shell forms) also exist in this basin. Following SCOTT (1940), TANABE (1979) and MARCINOWSKI (1974) such a combination of morphotypes could point to sublittoral environments.

The Lower/Upper Cretaceous boundary is marked by a complete disruption of links between the Pacific and European realms and coincidently between the Boreal and Tethyan realms. Moreover, a division into a southern and a northern Pacific province is becoming clear at this time. The early Cenomanian to late Maastrichtian interval in the northern Pacific province may be mostly described as Boreal (Far East Russia, Alaska, Japan (Hokkaido), California, Queen Charlotte Islands), whereas the southern Pacific is Tethyan (New Zealand, Australia). However, it should be borne in mind that subsequent Late Cretaceous transgressions offered new opportunities for taxa to migrate.

Albian/Cenomanian

This boundary is very difficult to pinpoint in sections throughout the whole territory of Russian Far East because of a lack of any remarkable lithological changes. Based on personal observations, the present author is of the opinion that a second-order cycle (HAQ & *al*. 1987, 1988) (or the end of a supercycle) unconformity can be established in Sakhalin at this level, while minor local unconformities occur across the lower/middle Cenomanian boundary, and a major regional erosional surface (type 1 unconformity, *sensu* VAIL 1987) has been noted across the middle/late Cenomanian boundary.

An abrupt faunal turnover is suggestive of the placement of the Albian/Cenomanian boundary. In Sakhalin, all Albian taxa disappeared at the boundary (Text-figs 10, 14). A short-term, global turnover in marine biotas following OAE1d (BARNES & *al*. 1995) characterises this level in many regions of the world (Text-fig. 16). Sakhalin is not excluded from this list. The OAE1d (Text-figs 14, 16) has been recorded from Japan and Sakhalin (HIRANO & TAKAGI 1995; HIRANO & FUCUJU 1997; HASEGAWA 1997; TOSHIMITSU & HIRANO 2000; HASEGAWA & *al*. 2003). The disappearance of Albian forms and the first occurrence of new species and even genera as well as of new ammonite and inoceramid morphotypes is also typical of this boundary in the Pacific Realm.

At the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1995) it was recommended (TRÖGER & KENNEDY 1996; see also GALE & *al*. 1996) that the main criterion for the base of Cenomanian should be the appearance of the planktonic foraminifer *Rotalipora globotruncanoides,* with the appearance of *Mantelliceras* as its proxy criterion*.* It is difficult to apply these criteria to the Russian Far East for lack of the index taxon; however, Japanese workers (KAWABE & *al*. 2003) have just demonstrated the occurrence of *Rotalipora globotruncanoides* and *Mantelliceras* in the Oyubari area (Hokkaido) In Sakhalin, *Rotalipora globotruncanoides* has not been found and *Mantelliceras* is restricted to the Naiba Formation. At present, the Albian/Cenomanian boundary in Sakhalin has been placed at the boundary between members 2 and 3 of the Naiba Fomation in the southern sections of the West Sakhalin Mountains, and at the boundary between the Bajuklinsk (or the correlative Samohinsk Formation) and Pobedinsk formations in the northern sections of the West Sakhalin Mountains (Text-figs 2), and at an unconformity which could be seen as a sequence-stratigraphic signature at the top of the *Cleoniceras* sp. Zone. It is characterised by the demise of all Albian ammonites (genera *Cleoniceras, Anahoplites, Sonneratia, Brewericeras, Puzosia* and *Pseudhelicoceras*) and the entry of *Parajaubertella kawakitana, Desmoceras* (*D.*) *kossmati* and *Inoceramus* aff. *crippsi*. Similar features of Albian/Cenomanian boundary bio-events are known from North America (Western Interior Basin; Text-fig. 16), Europe and North Africa (KAUFFMAN & HART 1995). The A/C boundary is associated with OAE1d (Text-figs 14) and a third-order sea-level lowstand with an increased rate of second-order eustatic sea-level rise. It connects with intensive regional volcanism and oceanic tectonic activity associated with the rise of the Pacific Superplume and with accelerated plate spreading (BARNES & *al*. 1995; KIRILLOVA & *al*. 2000; KIRILLOVA in press).

Due to the comparatively high rate of taxonomic origination (Text-figs 15), the recovery stage in the early Cenomanian, post-dating the extinction event, was brief. The new transgression saw the entry of immigrant species (such as *Neophylloceras seresitense, Anagaudryceras buddha, Austiniceras austeni, Acanthoceras sussexiense, Turrilites costatus*) which date these deposits as Cenomanian. During the survival interval (the *Desmoceras* (*D.*) *kossmati* Zone), tetragonitids and desmoceratids, as representatives of group C, dominated. However, following TANABE (1979), representatives of this group were adapted to wider habitats than were the other morphotypes. WARD & SIGNOR III (1983) showed a wide range of morphologic complexity of tetragonitids and desmoceratids which evolved a variety of shapes and highly variable ornament, which suggests their capacity to adapt widely. However, the predominance amongst these of forms with remarkable ornament could point to relatively deep sublittoral environments. The appearance later, during the recovery interval (*Mantelliceras* sp. and *Acanthoceras sussexiense* Zones), of representatives of Group A, and the occurrence of the heteromorph *Turrilites* as well as a maximum diversity of *Pergamentia*-group inoceramids (YAZYKOVA & *al*. 2004) could be indicative of a relatively shallow inshore basin, which did not persist for long. This could possibly be correlated with the so-called Mid-Cenomanian Regressive Trough, which has been documented recently by HANCOCK (2003) for northwest Europe, western Kazakhstan, Texas, Colorado and South

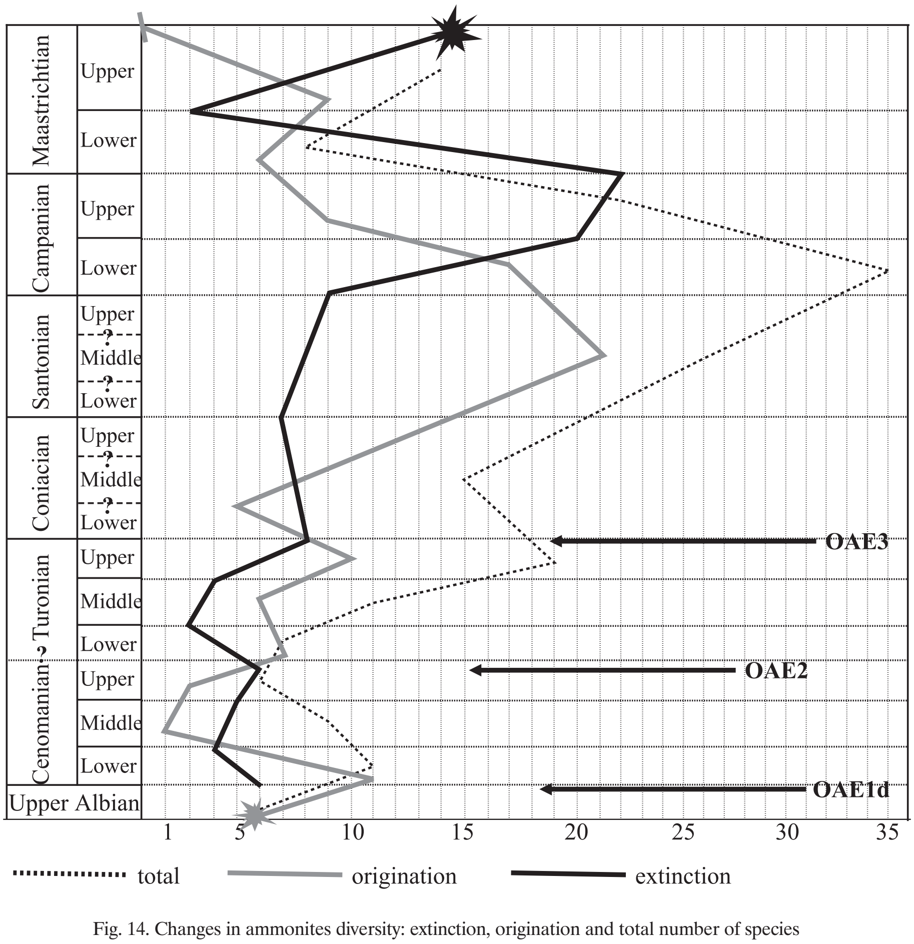

Fig. 14. Changes in ammonites diversity: extinction, origination and total number of species

Dakota. During the late Cenomanian, tetragonitids and desmoceratids dominated again. Generally, the Cenomanian was characterised by a comparatively high diversity of ammonites (Text-fig. 14), a high origination rate and a low total extinction rate (Text-fig. 15). However, the interval of relatively stable development of ammonites was interrupted at the C/T boundary.

Cenomanian/Turonian

This boundary remains one of the best-studied mass extinctions in the world (Text-fig. 16). Recently, a first attempt to analyse that bioevent in Sakhalin has been carried out (YAZYKOVA & *al*. 2004). No Cenomanian taxa survived this crisis. Correlation with the European Realm is based on such features as the extinction of the family Acanthoceratidae at the end of the Cenomanian and the wide distribution of heteromorph ammonites, particularly the development of the *Scaphites* facies in the Turonian, which is well marked during this interval both in the Pacific and European realms (TANABE 1979; KAPLAN & *al*. 1987; HIRANO & *al*. 2000). The disappearance of *Pergamentia*-group inoceramids in Far East Russia can be correlated with the extinction of the *I. pictus* group in European areas and/or the Western Interior of North America (KENNEDY & COBBAN 1991; HARRIES & *al*. 1996; KAUFFMAN & HARRIES 1996; KENNEDY & *al*. 2000). Microfaunal analyses show that the foraminiferal assemblages exhibit no major extinction at the Cenomanian-Turonian boundary but temporary faunal restructuring did take place; the radiolarian fauna appears to have survived this interval without taxonomic change, with the diversity decrease occurring later, near the middle/late Turonian boundary.

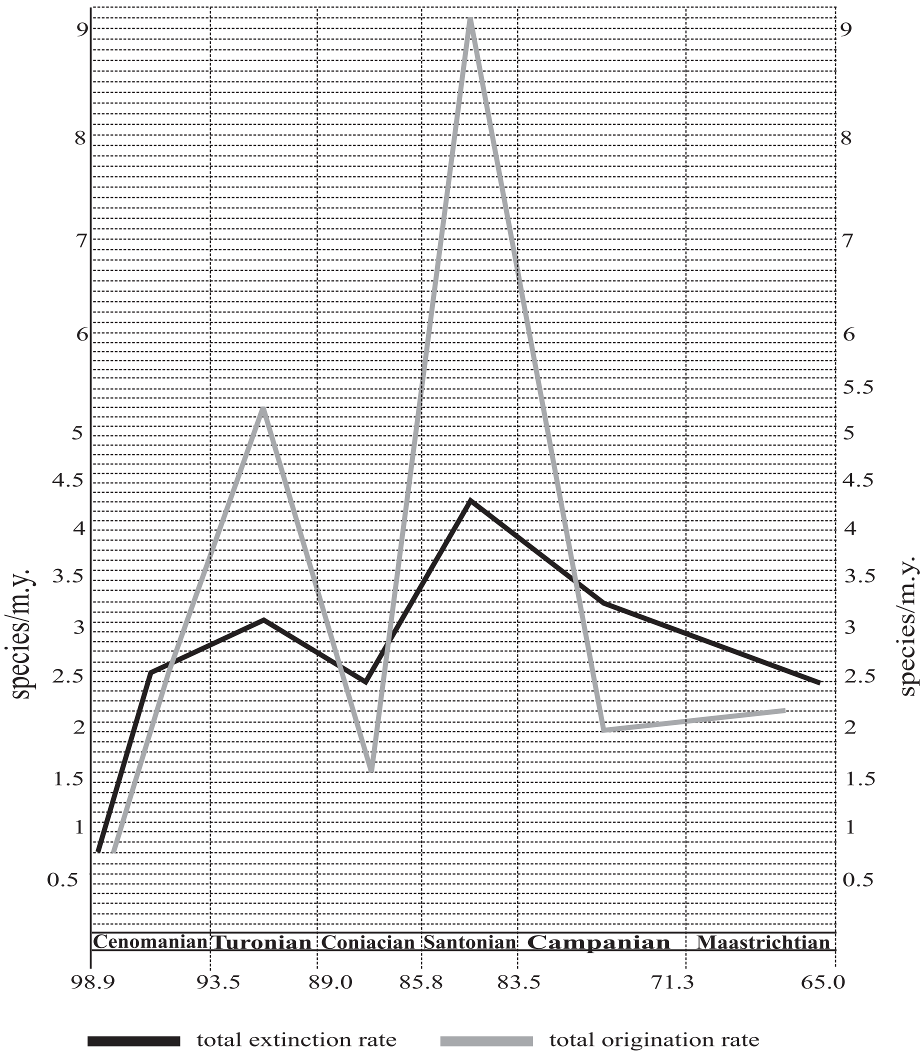

Fig. 15. Total extinction and origination rates following RAUP & SEPKOSKI (1984). The Cretaceous time scale is after GRADSTEIN & *al*. (1999)

At the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1995) it was recommended that the main criteria for the Cenomanian/Turonian and for the lower/middle Turonian boundary are the first appearances of the ammonites *Watinoceras devonense* WRIGHT & KENNEDY and *Collignoniceras woollgari* (MANTELL) respectively (see BENGTSON 1996). In recent years, KENNEDY & *al*. (2000) have suggested an additional event for the base of the Turonian, namely the first occurrence of *Mytiloides puebloensis* WALASZCZYK & COBBAN, 2000. Neither of these species have been recorded from Far East Russia. The correlation of this interval is based on the mass extinction event at this boundary associated with OAE2 (Text-fig. 14), the appearance of the genera *Fagesia*, *Jimboiceras* and *Mytiloides*, and the appearance of new ammonite morphotypes. KAUFFMAN (in BARNES & *al*. 1995) referred to this bio-event to the most dynamic, second-order, stepwise mass extinction during a sea-level highstand.

The survival interval of the lower Turonian (the *Fagesia* sp. Zone) was characterised by maximum flooding and the appearance of new basins in the central part of the island (sections NN 14-18, Text-figs 1C; 2). The ammonite assemblage of this interval consists mostly of Tetragonitidae and the first *Nipponites* and *Jimboiceras,* representing inhabitans of a comparatively deep offshore basin. The situation changed during *Scaphites planus* Zone time with the appearance of *Scaphites* and *Yezoites*. The total origination rate is high in this time. There were diversity and abundance peaks in the late Turonian (Text-figs 14-15). Numerous heteromorphs (morphotypes of Group B), tetragonitids (Group C) and the *Inoceramus teshioensis* group dominated the entire, warm (cf. YU. ZAKHAROV & *al*. 1999) sublittoral basin of the West Sakhalin Mountains. However, towards the end of the late Turonian, a small decrease in taxonomic diversity of the ammonites occurred; in contrast, new forms of inoceramids appeared (YAZYKOVA & *al*. 2004).

Turonian/Coniacian

At the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1995) it was recommended that the main criteria for recognition of the Turonian/Coniacian stage boundary are the first occurrence of *Forresteria* (*Harleites*) *petrocoriensis* for Europe and of *F. peruana* and *F. brancoi* for North America and the first occurrence of *Cremnoceramus rotundatus* (*sensu* TRÖGER *non* FIEGE) (see KAUFFMAN & *al*. 1996), which is now referred to as *C. deformis erectus* (MEEK) (WALASZCZYK & WOOD 1999; WALASZCZYK & COBBAN 2000, WALASZCZYK 2000). Recently, evidence has been put forward to suggest that representatives of the genus *Forresteria* in fact make their first appearance in the uppermost Turonian (KENNEDY & COBBAN 1991, WALASZCZYK & COBBAN 2000, KENNEDY & WALASZCZYK 2004). This means that they can no longer be used as an index for the base of the Coniacian, leaving the first

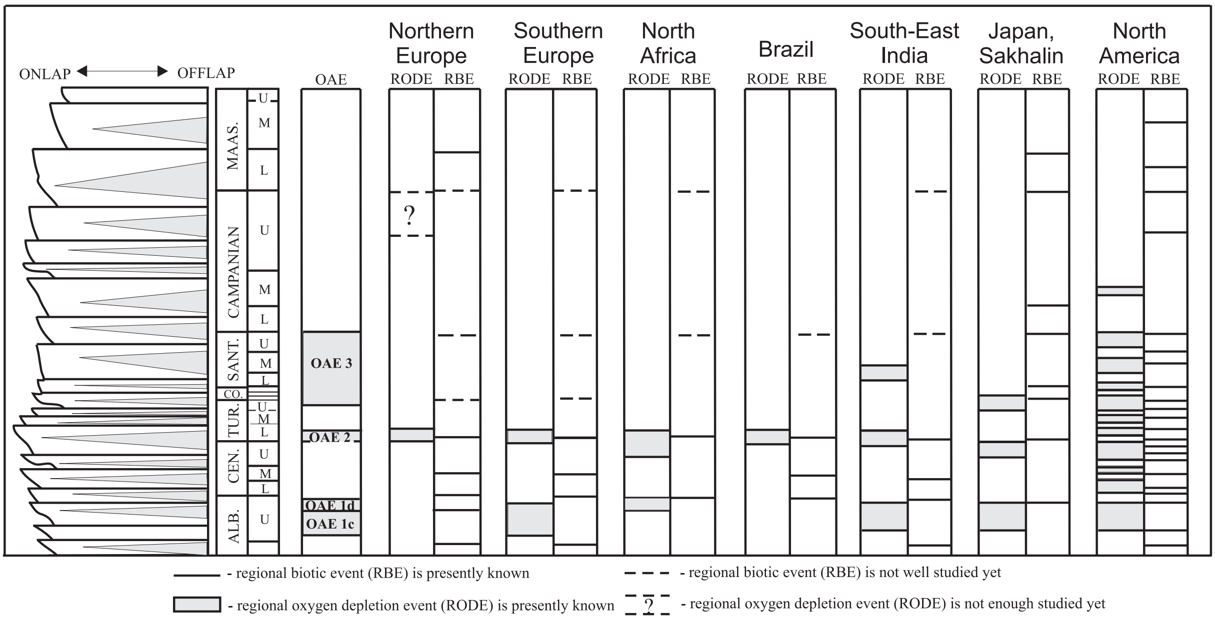

Fig. 16. The global cycle chart of HAQ *& al.* (1987), together with global oceanic anoxic events (OAE), regional oxygen depletion events (RODE), and regional bioevents (RBE) in northern and southern Europe, North Africa, Brasil, southeast India, North America (modified after KAUFFMAN & HART 1995), and Japan (TOSHIMITSU & HIRANO 2000), and Sakhalin (present paper)

occurrence of *Cremnoceramus deformis erectus* as sole criterion (KAUFFMAN & *al*. 1996, WALASZCZYK & WOOD 1999, WALASZCZYK & COBBAN 2000).

The T/C boundary faunal turnover in Sakhalin was marked by the entry of new ammonite morphotypes and by a slight reduction in ammonite taxonomic diversity (Text-fig. 14), with a decrease in total origination rate (Text-fig. 15). However, the total extinction rate decreased as well (Text-fig. 15) and the reduction in taxonomic diversity was not too drastic. The appearance of a coarser type of ornament during the Coniacian in comparison to the Turonian characterised representatives of the genera *Jimboiceras* and *Gaudryceras* (ZONOVA & YAZYKOVA 1998). Moreover, the base of the Coniacian is marked by the occurrence of a new *Scaphites* assemblage in Sakhalin as well as in Europe (KAUFFMAN & *al*. 1996). The appearance of coarser ornament and the abundance of heteromorphs could indicate a relatively shallow-water basin (SCOTT 1940), which would correspond to the strata of a regression and gradual decrease in ammonite diversity. In contrast to the effect on the ammonites, the warm-water up to 17.5°C; cf. YU. ZAKHAROV & *al*. (1999) of the shallow-marine basin was conducive to inoceramid development. This shows a high diversity during the boundary interval (ZONOVA & YAZYKOVA 1998). A noteworthy feature is is the occurrence of numerous small-sized inoceramid species in the uppermost Turonian deposits, namely *Inoceramus multiformis* PERGAMENT, *I. submametensis* ZONOVA, *I. tenuistriatus* NAGAO & MATSUMOTO, *I. teshioensis* NAGAO & MATSUMOTO and others. The appearance of various representatives of the *Inoceramus uwajimensis* YEHARA group (ZONOVA & YAZYKOVA 1998) at the base of the Coniacian in the Russian Far East and Japan might prove coincident with the appearance of *Cremnoceramus erectus* fauna (WALASZCZYK & WOOD 1999; WALASZCZYK 2000) in Europe.

In Sakhalin, the T/C boundary has been placed within Member 6 of the Bykov Formation in the south of the West Sakhalin Mountains and within the upper part of the Verbluzhegorsk Formation (or the correlative Arkovo Formation) in the northern sections NN 19-26 (Text-fig. 2), based on the last appearance of *Jimboiceras planulatiforme* with thin ribs and an evolute shell shape and the entry of *J. mihoense* with coarse ribs (Plate 2), as well as on the first occurrence of *Forresteria alluaudi, Anagaudryceras politissimum*, and *Gaudryceras denseplicatum*. All of the species mentioned are characterised by coarse ornament. Representatives of *F.* (*F.*) *alluaudi* have been found within deposits of Member 6 of the Bykov Formation, together with *Jimboiceras mihoensis* and numerous *Inoceramus mihoensis*. In the uppermost Coniacian, *Peroniceras* sp. has been recognised (Text-fig. 10).

Coniacian/Santonian

In the Naiba reference section, the Coniacian –Santonian boundary as currently understood is placed at the base of Member 8 of the Bykov Formation. At the top of Member 7 there is a good marker, namely a light grey sandstone with abundant plant debris and green-grey tuff intercalations, which is also traceable in Japan (HIRANO & TAKAGI 1995). The last Coniacian ammonite, *Peroniceras* sp., has been found just above these tuffs. Typical Coniacian species, such as *Jimboiceras mihoense*, *Forresteria* (*F.*) *alluaudi* and inoceramids of the *Inoceramus mihoensis* group, occur just below the tuff intercalations.

The first appearance of *Texanites* (*Plesiotexanites*) *kawasakii* and of *Inoceramus amakusensis* are the two best criteria for the base of Santonian in Sakhalin (YAZYKOVA 1996, 2002) in spite of the fact that both are endemic. However, lending support for this is the co-occurrence of these two taxa with the cosmopolitan ammonites *Desmophyllites diphylloides* and *Phyllopachyceras forbesianum*. Unfortunately, the first appearance of *Texanites* was rejected as the main marker for the Coniacian-Santonian boundary at the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1995; see LAMOLDA & HANCOCK 1996). However, the prime marker recommended, i.e. the lowest occurrence of *Cladoceramus undulatoplicatus*, cannot be applied in the Far East of Russia. Isolated occurrences of *Inoceramus* sp. aff. *Cl. undulatoplicatus* are known from the upper Santonian of Sakhalin, co-occurring with *I.* (*Platyceramus*) *kawasakii* (ZONOVA *& al.* 1993). The problems of correlation both within the Pacific Realm and between this region and elsewhere in the world might be facilitated by refined studies of bioevents. The gradual decrease in taxonomic diversity of ammonites and inoceramids, as observed in the Coniacian succession and possibly triggered by a new regression and a slight temperature drop (YU. ZAKHAROV *& al*. 1996, 1999), came to a halt at the beginning of the Santonian. Then, macrofaunal taxonomic diversity increased on account of global sea level rise and a temperature increase. New taxa, representing new morphotypes, appeared. The Coniacian-Santonian faunal turnover, characterised by the same evolutionary trends, has been documented from many places across the globe (HALLAM & WIGNALL 1997).

The Santonian heteromorph ammonite assemblage (Plate 2) consists of six endemic species, two of which disappeared at the local Santonian-Campanian boundary, with four new taxa appearing in the early Campanian (Text-fig. 10). Representatives of Santonian heteromorphs were published in only two previous works

(Poyarkova 1987; Alabushev & Wiedmann 1997). Generally, the Santonian interval is characterised by the highest origination rate and a high diversity of ammonites (Text-figs 14-15). The clear predominance of morphotypes of groups B (heteromorphs) and A (ornate shell forms) (cf. Tanabe 1979) points to a comparatively shallow-water basin. The beginning of the new transgression was marked only at the end of Santonian. In spite of that, the percentage of cosmopolitan species during this time is much higher (Yazykova 2002). However, details of this boundary are in need of additional research.

Santonian/Campanian

The local position of the Santonian/Campanian boundary and the regional faunal turnover during the boundary interval in Sakhalin was studied earlier and discussed in detail in two papers by the author (Yazykova 1996, 2002). Here a brief compilation will suffice. First of all, none of the criteria recommended at the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1955), namely the extinction of the crinoid genus *Marsupites*, the first appearance of the ammonite *Placenticeras bidorsatum* and the first appearance of the belemnite *Gonioteuthis granulataquadrata* (see Hancock & Gale 1996), is applicable neither in Sakhalin, the northeast of Russia nor Japan, because the taxa in question have not been recorded from these areas. The Santonian/Campanian boundary in Sakhalin as currently understood is placed within Member 10 of the Bykov Formation in sections in southern Sakhalin, at the boundary between the Verbluzhegorsk and Zhonkier formations in sections NN 19-26 in central Sakhalin (Text-fig. 2) and marked by the first appearance of the inoceramid bivalve *Inoceramus nagaoi* Matsumoto and the ammonite *Anapachydiscus* (*Neopachydiscus*) *naumanni* (Yokoyama) (see Yazykova 2002); these two criteria are also applicable in Japan (see Text-fig. 12; and Toshimitsu *& al.* 1995). Additionally, the base of the Campanian can be defined, both in Sakhalin and adjacent Hokkaido (Matsumoto 1977a; Toshimitsu *& al.* 1995), by the last appearance of *Texanites* and the first appearance of *Desmophyllites diphylloides* and *Phyllopachyceras ezoense* (Yazykova 1996, 2002).

Recent magnetostratigraphic analyses for Sakhalin, Hokkaido, Shikoku, the Western Interior and California (Kodama 2003) show a good match across the Santonian/Campanian boundary, as well as for two levels within the Campanian.

A few significant bioevents have been identified at the Santonian/Campanian boundary in Sakhalin (Text-fig. 16): a regional extinction event at the boundary as well as maximum ammonite diversity in the early Campanian *Anapachydiscus* (*Neopachydiscus*) *naumanni* Zone (Text-fig. 14), ascribed to a high rate of origination (Text-fig. 15). The early Campanian transgression flooded new areas, as illustrated by the inshore littoral facies developed on the south of Sakhalin Island, in the Kriljon Peninsula basin (sections NN 7-11, Text-fig. 2) and by facies of slope environments formed in the West Sakhalin Mountains. The latter region was characterised during that time by high volcanic and tectonic activity and a wide distribution of metamorphic and volcanogenic rocks, in sections NN 27-30 (Text-fig. 2).

The lower–upper Campanian boundary in southern Sakhalin is placed at the base of the Krasnoyarka Formation. It could be interpreted as the base of a sequence supercycle (type 1 unconformities, *sensu* Vail 1987). It corresponds to the base of the *Pachydiscus* (*P.*) aff. *egertoni* ammonite Zone and coeval *Schmidticeramus schmidti* inoceramid Zone, and is marked by the first occurrence of *Anapachydiscus* (*A.*) *arrialoorensis* (Yazykova 2002; Yazykova & *al*. 2002). This is the level of high ammonite and maximum inoceramid diversity, which in turn provides an excellent stratigraphic marker that may be readily identified in Sakhalin, northeast Russia and Japan (Yazykova 2002; Yazykova & *al*. 2002). This was a comparatively shallow-water inshore basin, based on the predominance of coarsely ornamented ammonites, radially-ribbed inoceramids and *Patella*-like gastropods with radial ribs as well.

Campanian/Maastrichtian

The criterion recommended at the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1955), namely the first occurrence of *Pachydiscus* (*P.*) *neubergicus* (von Hauer) cannot be applied in Sakhalin. There are a few finds of this species in the Russian Far East (Vereschagin & *al*. 1965; Zonova & *al*. 1993; Yazikova 1994) but all of them were made in upper Maastrichtian deposits. It is possible that the Pacific specimens are either not conspecific with *P*. (*P.*) *neubergicus* and previous identifications are erroneous or that they are conspecific but appeared in the Pacific much later. In February 2001, the first occurrence of this taxon to define the base of the Maastrichtian was ratified by IUGS (Odin & Lamaurelle 2001). Instead of using just a single faunal event, an arithmetic mean of twelve biohorizon levels is employed: level 115.2 at Tercis is the recommended level for placement of the GSSP for the boundary. None of these biohorizons (ammonites, dinoflagellates, planktonic and benthic forams, inoceramids and calcareous nannofossils) can be applied in Sakhalin.

This boundary, which appears to correspond to a second-order cycle (*sensu* Haq & *al*. 1987), is best exposed along the River Krasnoyarka (Text-fig. 7). The upper Campanian mudstones of Member 3 of the Krasnoyarka Formation underlie the lower Maastrichtian sandstones of Member 4 of the same formation; the boundary is placed at the base of brown-coloured clays, 20-30 cm thick.

At present, the Campanian/Maastrichtian boundary corresponds to the boundary between members 3 and 4 of the Krasnoyarka Formation in the West Sakhalin Mountains, between the Zaslonovsk and Turovsk formations in the East Sakhalin Mountains and between the Matakotan and Malokurilsk formations in Shikotan Island (Text-fig. 2), based on the disappearance of most Campanian ammonites and inoceramids and on the first occurrence of *Pachydiscus* (*P.*) *subcompressus* MATSUMOTO and *P.* (*Neodesmoceras*) *japonicus* MATSUMOTO, both being widely distributed Pacific species (YAZYKOVA 1991; YAZIKOVA 1994 with references therein). This level is matched by a similar horizon in Japan (Text-fig. 12; and TOSHIMITSU & *al*. 1995). In a sequence-stratigraphic interpretation this boundary could be interpreted in Russian Far East as a second-order cycle or of the next supercycle, which continued into the Paleogene.

During the Maastrichtian, the northern Pacific ammonites again underwent an "explosion" of new taxa, with the evolution of new species in the families Pachydiscidae and Tetragonitidae (YAZIKOVA 1994; YAZYKOVA 1996; HIRANO & *al*. 2000) against the background of a global late Maastrichtian transgression. Some species are immigrants from the European and Mediterranean realms, e.g. *Pseudophyllites indra* (FORBES), *Zelandites varuna* (FORBES) and possibly *P.* (*P.*) *neubergicus* and *P.* (*P.*) *gollevillensis*. These species differ from Campanian tetragonitids and pachydiscids in their smoother ornament. The endemic Pacific representatives of the Pachydiscidae are characterised by a lack of genuine ribs and by more evolute shells. The same trend is seen in the *Gaudryceras* phylogenetic lineage: *Gaudryceras tenuiliratum* is replaced by *Gaudryceras hamanakense* with numerous thin ribs and a thin, delicate shell. This species is widely distributed in the upper Maastrichtian and occurred even in the East Sakhalin Mountains (ZONOVA 1990). The genus *Neophylloceras* comprised long-lived *N. ramosum,* but in the late Maastrichtian *N. hetonaiense* MATSUMOTO appeared. It is morphologically similar to *N. surya* from the Crimea and Caucasus and shows the same character of thin delicate ribs (see ZONOVA *& al.* 1993; YAZIKOVA 1994). The number of ammonites in strata of Member 5 of the Krasnoyarka Formation decreases from the base to the top. Along the River Krasnoyarka, River Naiba Valley (section N 1) almost 2 metres below the Maastrichtian/Danian boundary, only representatives of *Zelandites* have been found (ZONOVA *& al.* 1993; YAZIKOVA 1994). A small-sized, completely smooth involute shell characterises *Z. japonicus* MATSUMOTO, which resembles the late Albian *Cleoniceras*. The first representatives of the genus *Zelandites* appeared in the Cenomanian when the last *Cleoniceras* became extinct. During the whole of the Late Cretaceous, each age was characterised be the presence of species of *Zelandites* which, however, wer not really abundant. Only in the upper Maastrichtian did the author observe numerous specimens of the genus as the last ammonites in Sakhalin. Perhaps these are all homeomorphic taxa generated during such sublethal stress events (GUEX 2001). The last *Cleoniceras* occurred at the end of the Early Cretaceous and the last *Zelandites* occurred at the end of the Late Cretaceous. It is probable that environmental changes triggered this process of adaptation, and resulted in smooth and thin compressed shells. Except for *Diplomoceras cylindraceum,* heteromorphs are absent from the Maastrichtian in Sakhalin and NE Russia. A gradual decrease in temperature (cf. YU. ZAKHAROV & *al*. 1999) may also have influenced the extinction of ammonites. In contrast to the ammonites, the inoceramids do not reveal such a diversity pattern. Taxonomic diversity as well as abundance gradually decreased during the Maastrichtian. However, one adaptational change should be noted. A new genus appeared, *Shachmaticeramus* (ZONOVA & *al*. 1993), with a peculiar chess-board construction of the ligament strip, unknown in any pre-Maastrichtian inoceramids. Nearly all Maastrichtian inoceramids from Sakhalin have this type of ligament strip.

Cretaceous/Tertiary

The Cretaceous/Tertiary boundary in Sakhalin is placed at the base of a 20-cm bed of green clay. 1.5 metres below this bed is a layer of concretions, which yield the last ammonites (*Zelandites japonicus*) and *Tenuipteria* cf. *awajiensis* MATSUMOTO (ZONOVA & *al*. 1993). Above this clay bed, sandy mudstones yield a Danian fauna (spores and pollen, and bivalves; see POYARKOVA 1987). Unfortunately, no data are as yet available on a possible iridium anomaly at this level.

CONCLUDING REMARKS

Rich ammonite faunas collected from Albian to Maastrichtian succession have enabled the establishment of a detailed biostratigraphic framework, which can be easily applied in the field (Text-fig. 10). Contrary to previous studies, the present paper shows new possibilities for correlation and precise local determination of stage boundaries, which have resulted from detailed investigation of bio-crisis intervals. The ammonite biostratigraphic scheme is integrated with two other main faunal groups (inoceramids and radiolarians), based on the co-occurrence of zonal index taxa (Text-fig. 11). The detailed integrated biostratigraphy makes this scheme more reliable. The correlation with adjacent areas has been presented in detail (Text-fig. 12).

Several bioevents, as well as palaeoecological and palaeoenvironmental reconstructions were provided stage-by-stage, based on the evolution of the ammonites (Text-figs 14-15) together with data from other faunal groups and palaeotemperature data.

In summary, all previous studies were based only on finds of cosmopolitan species, which allow global correlations and establishment of Cretaceous stage boundaries. In practice, such a scheme cannot be applied in the Pacific Realm because of the high degree of endemism. The present work shows that in-depth studies of each biotic level render many more opportunities for correlation. A global correlation of bioevents at the Cretaceous stage boundaries is presented here in Text-fig. 16.

The Cretaceous sequences in Sakhalin are still in need of additional investigations, however. It is currently impossible to establish the lower/middle Coniacian, middle/upper Coniacian and lower/upper Santonian substage boundaries. The Coniacian/Santonian boundary also needs additional attention. Detailed study of the sediments is lacking and the sequence stratigraphical interpretations need to be reassessed. The successions throughout the entire region would benefit from a geochemical investigation and a detailed microfaunal microfaunal analysis could also prove very useful.

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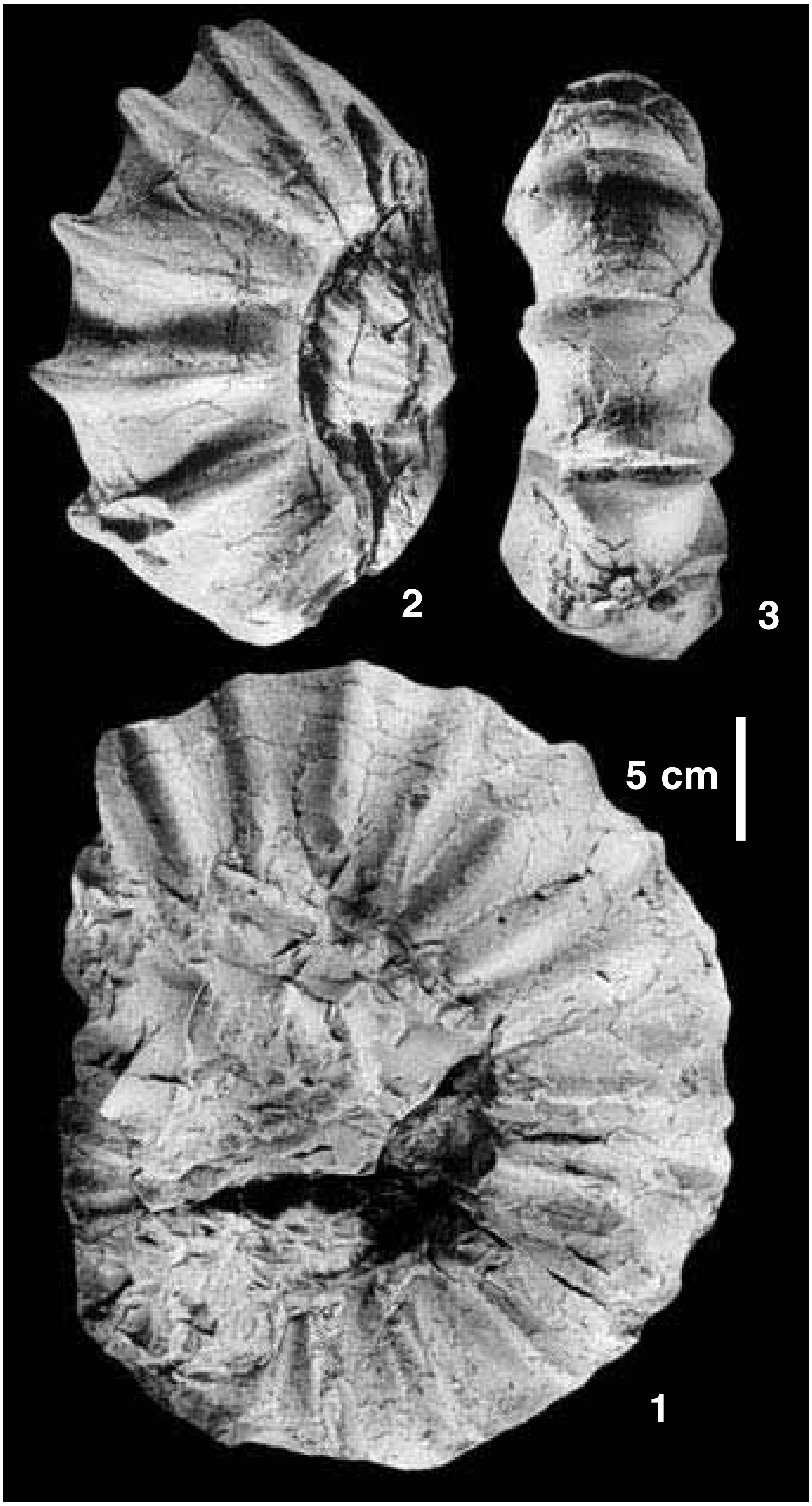
PLATES 1-2

PLATE 1

1-3 – *Jimboiceras mihoense* MATSUMOTO. Localities 550, 551, River Naiba, section N 1, *Jimboiceras mihoense* Zone, Bykov Formation, Member 7, Coniacian.


2
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1

PLATE 2

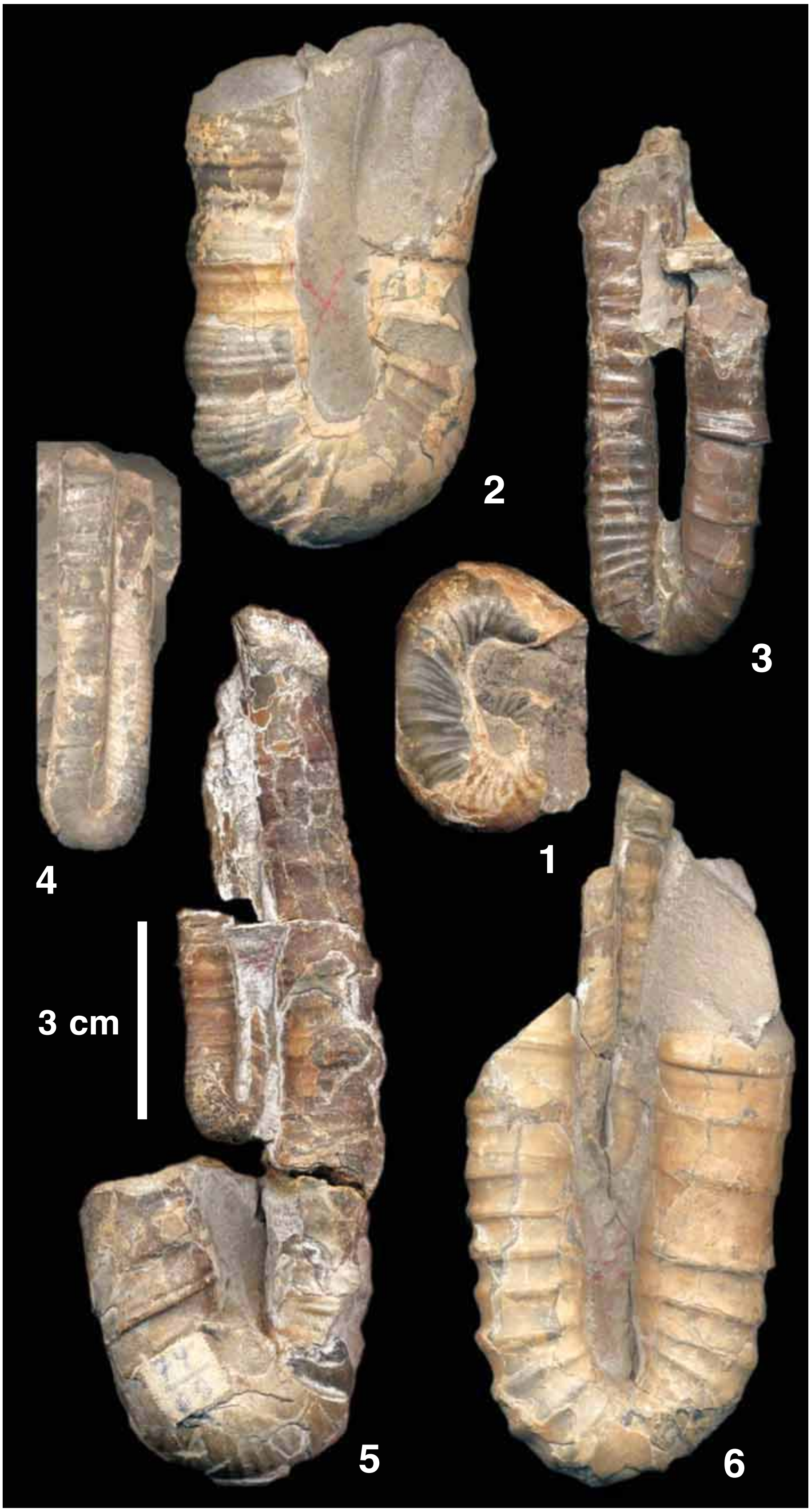
1 – *Scaphites planus* YABE, locality 564, River Lomzha, River Firsovka Valley, section N13, *Scaphites planus* Zone, Bykov Formation, Member 4, Lower Turonian.

2 – *Subptychoceras yubarense* (YABE), River Gorbusha, Kriljon Peninsula, section N 10, *Menuites Menu* Zone, Bykov Formation, Member 9, Upper Santonian.

3, 5 – *Polyptychoceras pseudogaultinum* (YOKOYAMA), **3** - locality 1646, River Bary; **5** – locality 74, River Akacyja, River Pugachevka Valley, section N 15, *Menuites Menu* Zone, Bykov Formation, Member 9, Upper Santonian.

4 – *Subptychoceras* cf. *yubarense* (YABE), locality 3228, *Eupachydiscus haradai* Zone, Bykov Formation, Member 10, Lower Campanian.

6 – *Subptychoceras vancouverense* (WHITEAVES), locality 1015, *Eupachydiscus haradai* Zone, Bykov Formation, Member 10, Lower Campanian.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