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Cretaceous ammonoid succession in the Far East (South Sakhalin) and the basic factors of syngenesis

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Abstract

At the Maastrichtian-Danian boundary in Sakhalin Island radical faunal changes are visible. The repeated influence of three basic factors (drop of temperature, oxygen deficit and enormous eustatic level fluctuation provoked by thermal perturbation at the core/mantle boundary and change in rotation regime of the Earth) seems to be the main reason for a great extinction in many groups of marine and terrestrial organisms during the time of the Cretaceous-Tertiary transition.

Key-words: K/T boundary - faunal changes - stable isotopes - Sakhalin.

Résumé

Dans les dépôts de Sakhalin la transition Maastrichtien/ Danien montre un changement radical dans les faunes. Trois facteurs (diminution de la temperature, un déficit dans la quantité d'oxygène et de fortes fluctuations eustatiques résultant de la perturbation thermique à la transition noyau-manteau et au changement dans le régime de rotation terrestre) semblent être les causes majeures pour une grande extinction dans de nombreux groupes d'organismes marins et terrestres au moment de la transition Crétacé-Tertiaire.

Mots-clefs: Transition K/T - changements fauniques - isotopes stables - Sakhalin.

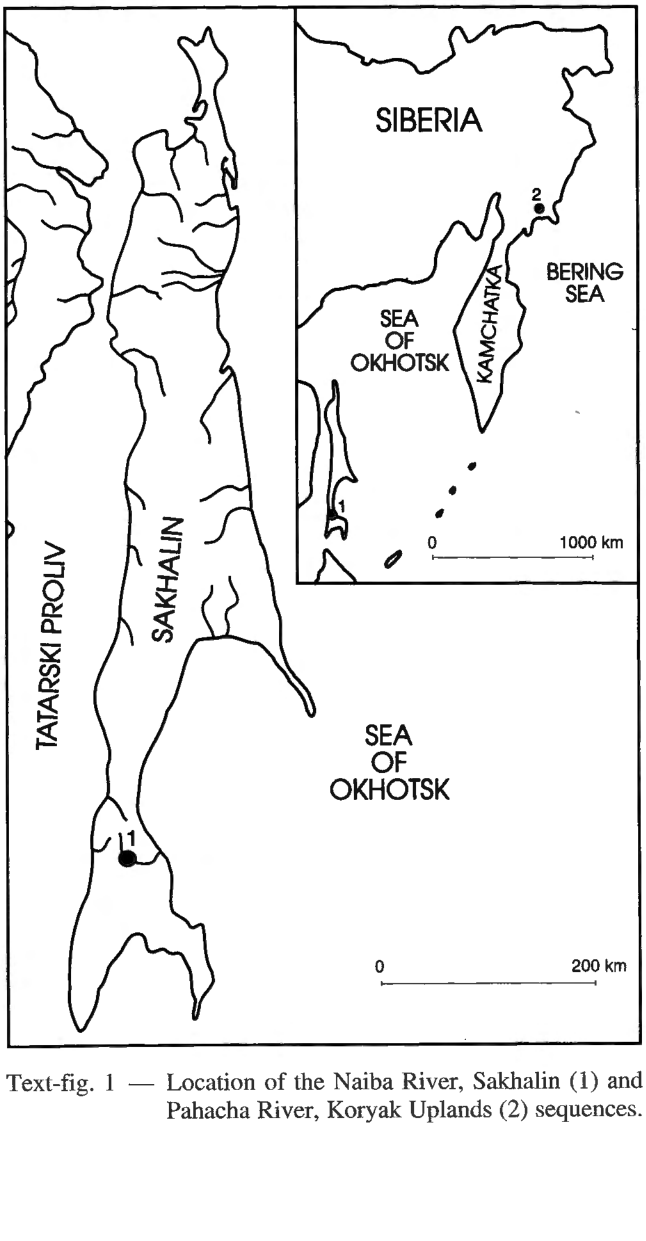
Introduction

A more than 4000 m thick, well exposed late Early Cretaceous - Late Cretaceous - Early Palaeogene sequence is present along the Naiba River in Dolinsk region, South Sakhalin (Text-fig. 1). This famous section (Matsumoto, 1938; Vereschagin, 1977; Zakharov *et al.*, 1978, 1981, 1984a; Salnikov & Tikhomolov, 1987) is considered as the basic section for the Upper Cretaceous in the "Far East". This sequence has been subdivided into four formations : (1) Ai (Albian), (2) Naiba (Albian-Cenomanian), (3) Bykov (Turonian-Santonian), and (4) Krasnoyarka (Campanian-Danian).

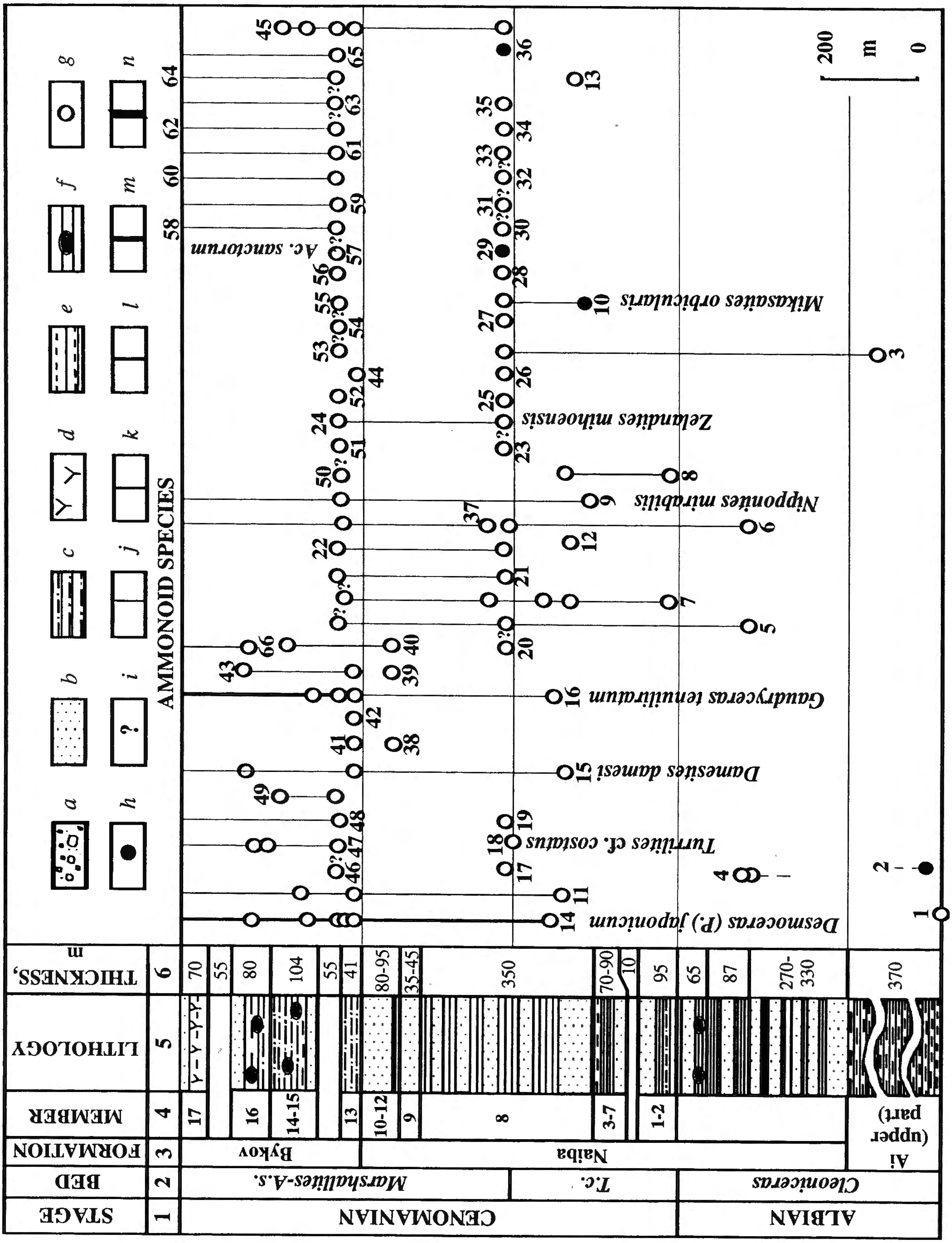
The present work analyses the Cretaceous palaeosuccession of the Far East on the basis of data for the Sakhalin cephalopod fauna and stable isotopes recognized in brachiopod, ammonoid and bivalve shells from South Sakhalin (Naiba, Krasnoyarka and Sary Rivers) and from the Koryak Uplands.

Characteristics of the marine Palaeosuccession

In the Albian-Danian South Sakhalin mollusk succession several phases can be distinguished, reflecting the diversity in the marine communities at that time.



Text-fig. 1 — Location of the Naiba River, Sakhalin (1) and Pahacha River, Koryak Uplands (2) sequences.


STAGE
BED
FORMATION
MEMBER
LITHOLOGY
THICKNESS, m
AMMONOID SPECIES
CENOMANIAN
ALBIAN
Marshallites-A.s.
T.c.
Cleoniceras
Bykov
Naiba
Ai (upper part)
Desmoceras (P.) japonicum
Turrilites cf. costatus
Damesites damesi
Gaudryceras tenuiliratum
Nipponites mirabilis
Zelandites mihoensis
Mikasaites orbicularis
Ac. sanctorum
200 m 0

←

Text-fig. 2 — Lithofacies, distribution and relative abundance of ammonoid taxa for the Upper Ai, Naiba and Lower Bykov Formations (Albian-Cenomanian). Designation of the beds: T.c. = Turrilites costatus, Marshallites - A.s. = Marshallites - Acanthoceras sanctorum. Lithology: a - conglomerate, b - sandstone, c - sandy siltstone, d - tuffaceous siltstone, tuffaceous sandstone, tuffite, tuffs, e - siltstone, f - mudstone with nodules; location: g - Naiba River basin, h - neigbouring territories in South Sakhalin, i - questionably present. Relative abundance of ammonoid species: j - very rare, k - rare, l - occasional, m - common, n - abundant.
Species: 1 - *Brewericeras* ex gr. *hulense* Anderson, 2 - *Cleoniceras (Neosaynella?)* sp. 3 - *Puzosia subcorbarica* Matsumoto, 4 - *Cleoniceras?* sp., 5 - *Desmoceras kossmati* Matsumoto, 6 - *Pachydesmoceras* cf. *denisonianum* (Stoliczka), 7 - *Parajaubertella kawakitana* Matsumoto, 8 - "*Phylloceras*" aff. *tanit* Pervinquière, 9 - *Nipponites mirabilis* Yabe, 10 - *Mikasaites orbicularis* Matsumoto, 11 - *Anagaudryceras sacya* (Forbes), 12 - *Marshallites* sp., 13 - *Epigoniceras* sp., 14 - *Desmoceras (Pseudouhligella) japonicum* Yabe, 15 - *Damesites damesi* (Jimbo) (Pl. 2, Fig. 2-3), 16 - *Gaudryceras tenuiliratum* Yabe, 17 - *Turrilites* cf. *acutus* (Passy), 18 - *T.* cf. *costatus* (Lamarck), 19 - *Puzosia tenuis* Shimizu, 20 - *Desmoceras* aff. *inane* (Stoliczka), 21 - *Puzosia planulata* (J. de C. Sowerby), 22 - *Marshallites* cf. *olcostephanoides* Matsumoto, 23 - "*Phylloceras*" cf. *ellipticum* Kossmat, 24 - *Zelandites mihoensis* Matsumoto, 25 - *Anagaudryceras* sp., 26 - *Puzosia* ex gr. *bhima* (Stoliczka), 27 - *Holcodiscoides popillatus* (Stoliczka), 28 - *Mikasaites matsumotoi* Vereschagin, 29 - *Acanthoceras hippocastanum* (J. de C. Sowerby), 30 - *A. sussexiense* (Mantell), 31 - *A.* cf. *rotomagense* (Defrance), 32 - *Tetragonites* ex gr. *timotheanus* (Pictet), 33 - *Eogunnarites unicus* (Yabe), 34 - *Eucalycoceras* cf. *vergonsense* Collignon, 35 - *Calycoceras asiaticum* (Jimbo), 36 - *Marshallites japonicus* Matsumoto, 37 - *Pachydesmoceras pachydiscoides* Matsumoto, 38 - *Hypophylloceras seresitense* (Pervinquière), 39 - *Microdesmoceras applanatum* Grabovskaya, 40 - *Jimboiceras planulatiforme* (Jimbo), 41 - *Hypophylloceras ononense* (Stanton), 42 - *H. simplificatum* Grabovskaya, 43 - *Metapuzosia* sp., 44 - *Anagaudryceras* cf. *olcostephanoides* Matsumoto, 45 - *Anagaudryceras buddha* (Forbes), 46 - *Puzosia nipponica* Matsumoto, 47 - *Puzosia* sp., 48 - *Phyllopachyceras ezoense* (Yokoyama), 49 - *Hypophylloceras* sp., 50 - "*Phylloceras*" cf. *diegoi* Boule, Lemoine & Thévenin, 51- *Zelandites inflatus* Matsumoto, 52 - *Anagaudryceras utaturense* Shimizu, 53 - *Puzosia* cf. *furnitana* Pervinquière, 54 - *P.* aff. *octosulcata* Sharpe, 55 - *Desmoceras pseudinane* Shimizu, 56 - *Jacobites* sp., 57 - *Acanthoceras sanctorum* Matsumoto & Obata, 58 - *Mesopuzosia pacifica* Matsumoto, 59 - *M. indopacifica* (Kossmat), 60 - *Tetragonites* sp., 61 - *Kossmaticeras* sp., 62 - *Polyptychoceras obstractum* (Jimbo), 63 - *Neophylloceras ramosum* (Meek), 64 - *Epigoniceras epigonum* (Kossmat), 65 - *E. glabrum* (Jimbo), 66 - *Jimboiceras planulatiforme* (Jimbo).

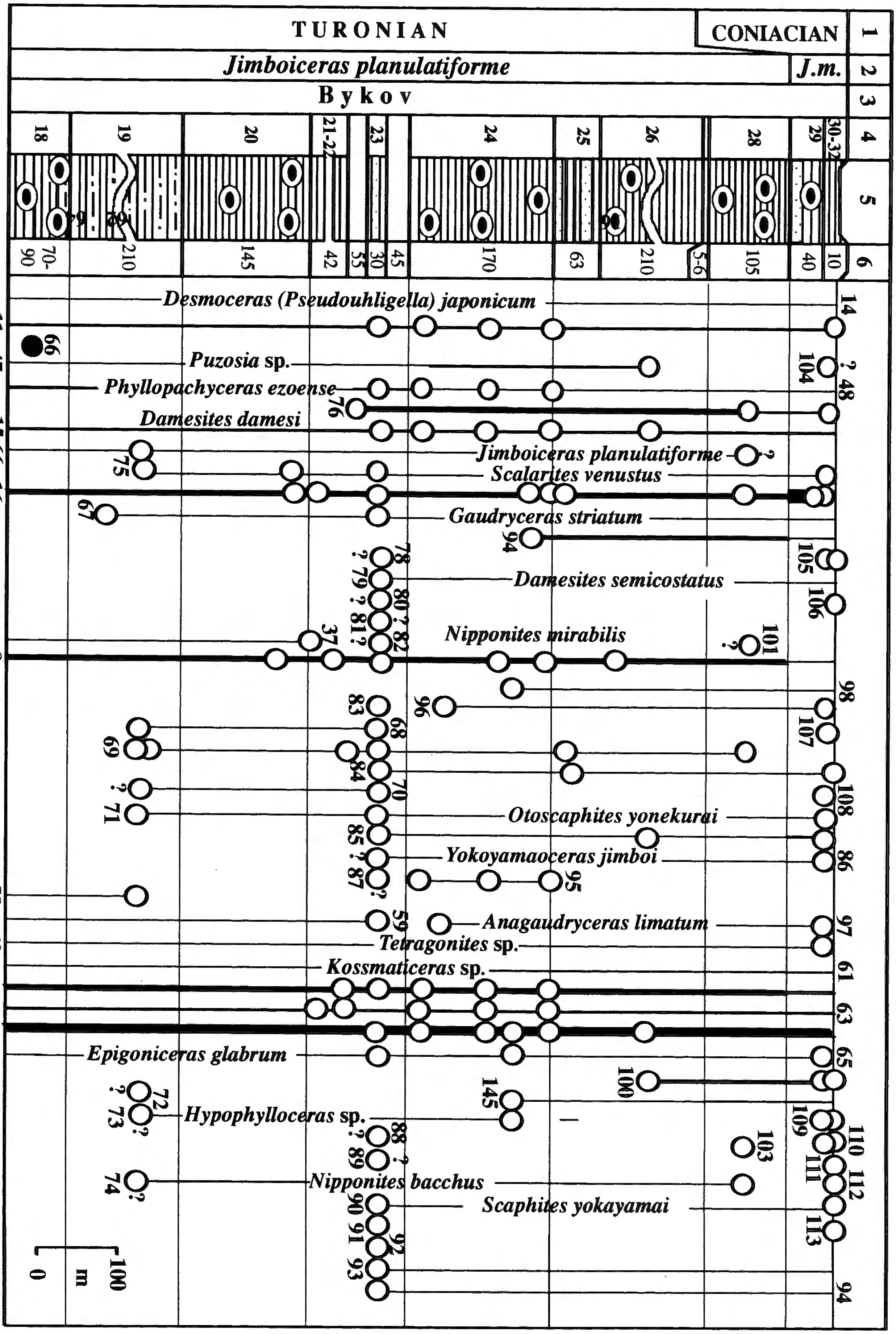
Phase 1

During phase 1 (Ai and Lower Naiba formations, Albian), most marine groups in South Sakhalin were poorly diversified, possibly due to a shallowing marine basin and periodical fresh-water influence during the latest Early Cretaceous. The main body of the community was formed by foraminifers (about 30 species) (Turenko, 1987), radiolarians (about 14 species) (Kazintsova, 1987), crinoids (1 species), echinoids (1 species), bivalves (12 species) (Salnikova, 1987), including some fresh-water taxa - *Anodonta oraria* Kalishevich (Zakharov *et al.*, 1978, 1981), gastropods (2 species) (Poyarkova, 1987), and scarce ammonoids ("*Phylloceras*" aff. *tanit* Pervinquière, *Anagaudryceras*? sp., *Parajaubertella* cf. *kawakitana* Matsumoto, *Puzosia subcarbarica* Matsumoto, *Pachydesmoceras* cf. *denisonianum* (Stoliczka), *Brewericeras* ex gr. *hulense* Anderson, *Desmoceras kossmati* Matsumoto, *Anahoplites*? sp., *Cleoniceras* sp., *Neogastroplites* sp.) (Text-fig. 2) (Zakharov *et al.*, 1978, 1984a; Mirolyubov, 1987).

Phase 2

Phase 2 (Upper Naiba, Bykov, and Lower Krasnoyarka Formations, Cenomanian-Campanian) is characterised by an abundance and high taxonomic diversity of a.o. bivalves (including inoceramids) and ammonoids. This part of the invertebrate succession is represented by foraminifers (about 38 species) (Turenko, 1987), radiolarians (more than 100 species) (Kazintsova, 1987), crinoids (1 species), crustaceans (1 species), bivalves (more than 100 species) (Zakharov *et al.*, 1984a; Salnikova, 1987; Zonova, 1987), scaphopods (5 species), gastropods (25 species) (Poyarkova, 1987), ammonoids (177 species of *Hauericeras, Hypophylloceras, Neophylloceras, Zelandites, Parajaubertella, Anagaudryceras, Gaudryceras, Tetragonites, Saghalinites, Turrilites, Neocrioceras, Anapachydiscus, Puzosia, Pachydesmoceras, Jimboiceras, Mesopuzosia, Microdesmoceras, Marshallites, Holcodiscoides, Eogunnarites, Kossmaticeras, Yokoyamaoceras, Jacobites, Canadoceras, Anapachydiscus, Menuites, Teshioites, Urakawites, Mikasaites, Nipponites, Hyphantoceras, Scalarites, Bostrychoceras, Diplomoceras, Scaphites, Ryugasella, Desmoscaphites, Polyptychoceras, Pseudoxybeloceras, Pseudaspidoceras, Otoscaphites, Peroniceras, Calycoceras, Eucalycoceras, Acanthoceras, Fagesia, Submortoniceras, Schlueterella* (Text-figs. 3-4) (Vereschagin, 1977; Zakharov *et al.*, 1984a; Miroyubov, 1987), nautiloids (7 species), and belemnitoids (1 species).

Within the ammonoid group, a change of dominance took place several times: (1) *Desmoceras (Pseudouhligella) japonicum* (within the *Turrilites costatus* beds and *Marshallites - Acanthoceras sanctorum* beds, Cenomanian - bioevent "a") → *Tetragonites epigonus* (within the *Jimboiceras planulatiforme* beds, Turonian - bioevent "b") → (3) *Gaudryceras tenuiliratum* (within the *Jimboiceras mihoense* beds, *Anapachydiscus naumanni* beds



TURONIAN
CONIACIAN
Jimboiceras planulatiforme
J.m.
Bykov
Desmoceras (Pseudouhligella) japonicum
Puzosia sp.
Phyllopachyceras ezoense
Damesites damesi
Jimboiceras planulatiforme
Scalarites venustus
Gaudryceras striatum
Damesites semicostatus
Nipponites mirabilis
Otoscaphites yonekurai
Yokoyamaoceras jimboi
Anagaudryceras limatum
Tetragonites sp.
Kossmaticeras sp.
Epigoniceras glabrum
Hypophylloceras sp.
Nipponites bacchus
Scaphites yokayamai
100 m
0

and *Canadoceras kossmati* beds (lower part), Coniacian-Early Campanian - bioevents "c-e") → (4) *Baculites zhuravlevi* [within the *Canadoceras kossmati* beds (upper part), Late Campanian - bioevent "f"].

Phase 3

During phase 3 (Middle Krasnoyarka Formation, Maastrichtian), a sharp reduction in taxonomic diversity and abundance of all main groups inhabiting this basin took place. The succession of phase 3 is represented by foraminifers (12 species) (Turenko, 1987), bivalves (about 43 species), scaphopods (2 species), gastropods (14 species), and ammonoids (43 species of *Phyllopachyceras, Neophylloceras, Gaudryceras, Anagaudryceras, Zelandites, Tetragonites, Saghalinites, Baculites, Pachydiscus, Neodesmoceras, Canadoceras, Damesites, Anapachydiscus, Polyptychoceras, Diplomoceras, Pseudoxybeloceras, Neancyloceras*) (Text-fig. 5) (Vereschagin, 1977; Zakharov *et al.*, 1984a; Mirolyubov, 1987). The number of ammonoid species was reduced by about four and the number of bivalve species - increased by 2.3 fold in comparison with phase 2. Within the Early Maastrichtian ammonoid group *Zelandites japonicus* Matsumoto dominated (*Zelandites japonicus* beds). However, it is difficult to decide, which ammonoid species became predominant among the 20 species (belonging to *Neophylloceras, Anagaudryceras, Gaudryceras, Zelandites, Tetragonites, Saghalinites, Baculites, Diplomoceras, Neancyloceras, Pseudoxybeloceras, Neodesmoceras, Canadoceras,* and *Pachydiscus*) found in the restricted Late Maastrichtian group, represented in the *Pachydiscus subcompressus* beds.

The community structure changed radically at the Maastrichtian-Danian boundary which appears in Sakhalin Island at the base of the Sinegorsk horizon (Upper Krasnoyarka Formation).

Phase 4

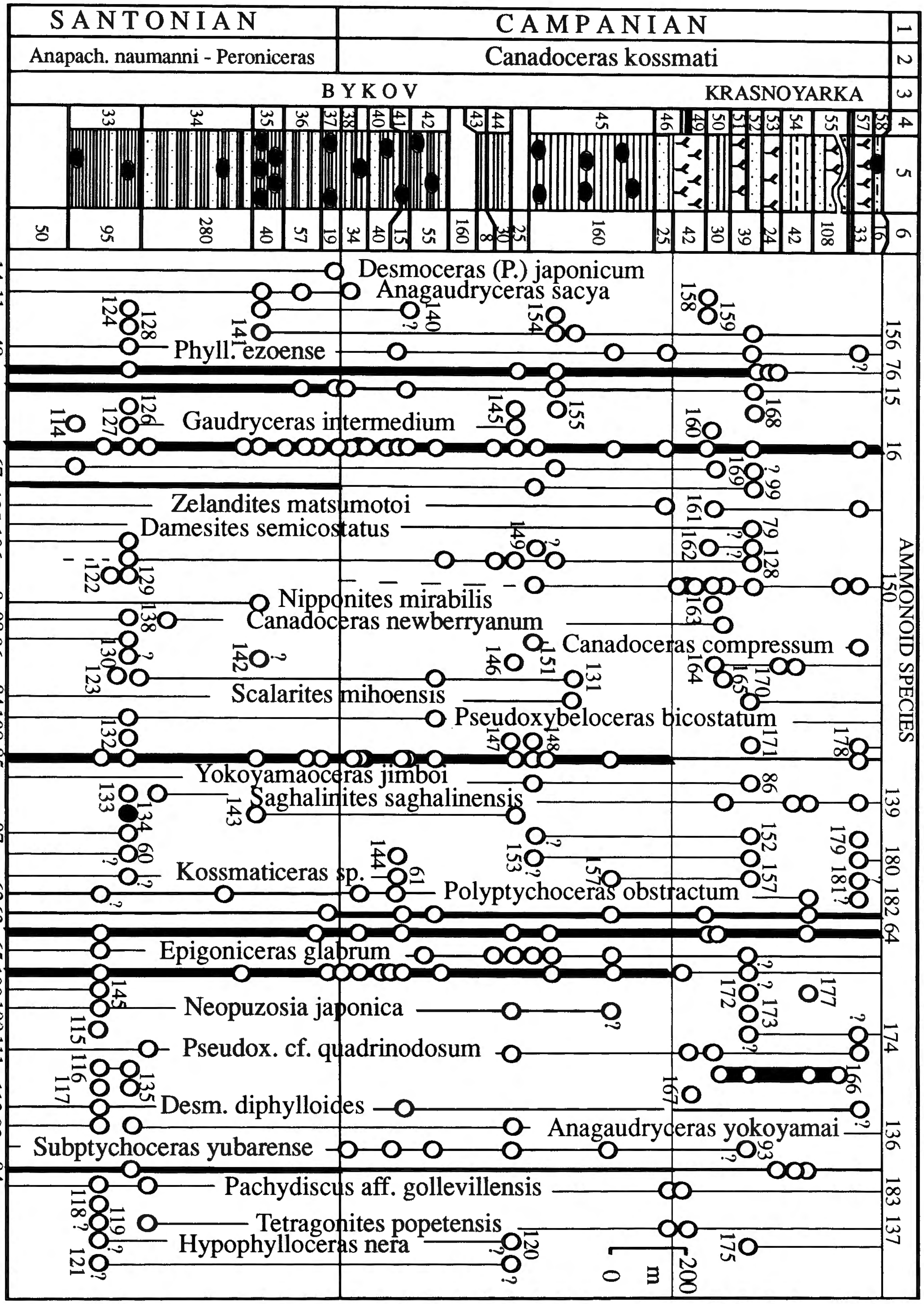
At the beginning of the next (fourth) phase of early Danian time (*Pseudoaphrodina extrema* beds), inoceramid bivalves and ammonoids disappeared. The body of the community was formed by foraminifers (32 species) (Turenko, 1987), bivalves (16 species) (Kalishevich *et al.*, 1981), and gastropods (2 species). Radiolarians have not been recorded. In the middle part of the Sinegorsk horizon (*Thyasira uncinata* beds) a much more diverse bivalve assemblage (38 species) (Kalishevich *et al.*, 1981) was discovered in association with foraminifer, coral, scaphopod, gastropod, and shark remains. Danian radiolarians were possibly absent in this basin.

Plant Palaeosuccession

On the basis of finds of terrestrial plant fossils in marine sediments of the Naiba River region (Zakharov *et al.*, 1981, 1984a) and of some data on floral assemblages

←

Text-fig. 3 — Lithofacies, distribution and relative abundance of ammonoid taxa for the Middle Bykov Formation (Turonian-Coniacian). 1 - Stage, 2 - Bed, 3 - Formation, 4 - Member, 5 - Lithology, 6 - Thickness, m. Abbreviated bed name: J.m. = *Jimboiceras mihoense*.
Species: 67 - *Gaudryceras striatum* (Jimbo), 68 - *Scaphites puerculus* (Yabe), 69 - *S.* cf. *planus* (Yabe), 70 - *Scalarites scalaris* (Yabe), 71 - *Otoscaphites yonekurai* (Yabe), 72 - *Fagesia* sp., 73 - *Hypophylloceras* sp., 74 - *Nipponites bacchus* Matsumoto, 75 - *Scalarites venustus* (Yabe), 76 - *Gaudryceras denseplicatum* (Jimbo), 77 - *Pseudaspidoceras* cf. *armatum* Pervinquière, 78 - *Damesites laticarinatus* Matsumoto (Pl. 2, Fig.4), 79 - *D. semicostatus* Matsumoto, 80 - *Puzosia*? *ambigua* Matsumoto, 81 - *Eupachydiscus haradai* (Jimbo), 82 - *Eupachydiscus* sp., 83 - *Paramammites*? sp., 84 - *Scalarites mihoensis* Wright & Matsumoto, 85 - *Polyptychoceras pseudogaultinum* (Yokoyama), 86 - *Yokoyamaoceras jimboi* Matsumoto, 87 - *Scalarites densicostatus* Matsumoto, 88 - *Romaniceras (Yubariceras) ornatissimum* (Stoliczka), 89 - *Yokoyamaoceras kotoi* (Jimbo), 90 - *Scaphites yokoyamai* Jimbo, 91 - *Otoscaphites teshioensis* Yabe, 92 - *Otoscaphites* sp. indet. Yabe, 93 - *Subptychoceras yubarense* (Yabe), 94 - *Phyllopachyceras forbesianum* (d'Orbigny), 95 - *Otoscaphites pseudoaequalis* Yabe, 96 - *Zelandites kawanoi* (Jimbo), 97 - *Anagaudryceras limatum* (Yabe), 98 - *Hauericeras* cf. *pseudogardeni* (Schlueter), 99 - *Damesites sugata* (Forbes), 100 - *Neopuzosia ishikawai* (Jimbo) (Pl. 1, Fig. 3; Pl. 2, Fig. 1), 101 - *Hauericeras (Gardeniceras) angustum* Yabe (Pl. 2, Fig. 5), 102 - *Bostrychoceras otsukai* Yabe, 103 - *Diplomoceras coscadense* Anderson, 104 - *Tetragonites krystofovitschi* Yabe, 105 - *Zelandites matsumotoi* Grabovskaya, 106 - *Jimboiceras mihoense* Matsumoto (Pl. 1, Figs. 1 - 2), 107 - *Otoscaphites* cf. *puerculus* (Jimbo), 108 - *Pseudoxybeloceras bicostatum* Henderson, 109 - *Neopuzosia japonica* (Spath), 110 - *Polyptychoceras obstrictum* (Jimbo), 111 - *Pseudoxybeloceras* cf. *quadrinodosum* (Jimbo), 112 - *Otoscaphites* cf. *pseudoequalis* Yabe, 113 - *Desmophyllites diphylloides* (Forbes). Other designations as in Text-fig. 2.



SANTONIAN
CAMPANIAN
Anapach. naumanni - Peroniceras
Canadoceras kossmati
BYKOV
KRASNOYARKA
AMMONOID SPECIES
Desmoceras (P.) japonicum
Anagaudryceras sacya
Phyll. ezoense
Gaudryceras intermedium
Zelandites matsumotoi
Damesites semicostatus
Nipponites mirabilis
Canadoceras newberryanum
Canadoceras compressum
Scalarites mihoensis
Pseudoxybeloceras bicostatum
Yokoyamaoceras jimboi
Saghalinites saghalinensis
Kossmaticeras sp.
Polyptychoceras obstractum
Epigoniceras glabrum
Neopuzosia japonica
Pseudox. cf. quadrinodosum
Desm. diphylloides
Anagaudryceras yokoyamai
Subptychoceras yubarense
Pachydiscus aff. gollevillensis
Tetragonites popetensis
Hypophylloceras nera
m
0
200

←

Text-fig. 4 — Lithofacies, distribution and relative abundance of ammonoid taxa for the Upper Bykov - Lower Krasnoyarka Formations (Santonian-Campanian). Abbreviated bed name: *Anapach.. naumanni - Peroniceras = Anapachydiscus naumanni - Peroniceras.*
Species: 114 - *Peroniceras*? sp., 115 - *Hypophylloceras* aff. *hetonaiense* Matsumoto, 116 - *Bostrychoceras oshimai* (Yabe), 117 - *Polyptychoceras haradanum* (Yokoyama), 118 - *P. jimboi* Matsumoto, 119 - *Desmoscaphites* aff. *bassleri* Reeside, 120 - *Hypophylloceras nera* (Forbes), 121 - *H. subramosum* (Shimizu), 122 - *Anapachydiscus yezoensis* Matsumoto, 123 - *A. fascicostatus* (Yabe), 124 - *Scalarites* sp., 125 - *Gaudryceras sachalinense* (Schmidt), 126 - *Bostrychoceras* sp., 127 - *Gaudryceras intermedium* (Yabe), 128 - *Anapachydiscus naumanni* (Yokoyama), 129 - *Kossmaticeras japonicum* Matsumoto, 130 - *Zelandites varuna* (Forbes), 131 - *Anapachydiscus sutneri* (Yokoyama), 132 - *Tetragonites sphaeronotus* (Jimbo), 133 - *Neocrioceras spinigerum* (Jimbo), 134 - *Bostrychoceras otsukai* Yabe, 135 - *B. serpentinum* Matsumoto, 136 - *Anagaudryceras yokoyamai* (Yabe), 137 - *Tetragonites popetensis* Yabe, 138 - *Canadoceras newberryanum* (Meek), 139 - *Saghalinites saghalinensis* (Shimizu), 140 - *Eupachydiscus haradai* (Jimbo), 141 - *Menuites naibutensis* Matsumoto, 142 - *Mesopuzosia campanica* Matsumoto, 143 - *Texanites (Plesiotexanites) kawasakii* (Kawada), 144 - *Scalarites venustus* (Yabe), 145 - *Tragodesmoceratoides subcostatus* Matsumoto (Pl. 2, Figs. 6-7), 146 - *Glyptoxoceras* sp., 147 - *Polyptychoceras susuense* (Yokoyama), 148 - *Damesites* sp., 149 - *Submortoniceras fukazawai* (Yabe et Shimizu), 150 - *Canadoceras kossmati* (Yabe), 151 - *Canadoceras compressum* Matsumoto, 152 - *Gaudryceras ornatum* (Yabe), 153 - *Canadoceras mysticum* Matsumoto, 154 - *Menuites japonicus* Matsumoto, 155 - *Gaudryceras* sp., 156 - *Menuites rotalinoides* (Yabe), 157 - *Bostrychoceras* sp. indet., 158 - *Menuites ryugasensis* (Matsumoto), 159 - *Pachydiscus* aff. *egertoni* (Forbes), 160 - *Ryugasella ryugasensis* Matsumoto, 161 - *Canadoceras multicostatum* Matsumoto, 162 - *C.? yokoyamai* (Jimbo), 163 - *Cymatoceras* sp., 164 - *Damesites* cf. *hetonaiensis* Matsumoto, 165 - *Anapachydiscus subtililobatus* (Jimbo), 166 - *Baculites zhuravlevi* Grabovskaya, 167 - *B.* cf. *chikoensis* Trask, 168 - *Schlueterella kawadai* Matsumoto et Miyauchi, 169 - *Teshioites ryngasense* Matsumoto, 170 - *Anapachydiscus arrialoorensis* (Stoliczka), 171 - *Polyptychoceras ryngusense* (Wright et Matsumoto). 172 - *Urakawaites rotalinoides* (Yabe), 173 - *Brahmaites brahma* (Forbes), 174 - *Baculites occidentalis* Meek, 175 - *Neophylloceras* aff. *surya* (Forbes), 176 - *Pachydiscus subcompressus* Matsumoto, 177 - *Parajaubertella* sp., 178 - *Pseudoxybeloceras lineatum* (Gabb), 179 - *P.* cf. *binodosum* Matsumoto, 180 - *Diplomoceras* sp., 181 - *Neancyloceras* cf. *pseudoarmatum* (Schlüter), 182 - *Neocrioceras (Schlueterella) sachalinicum* Jimbo, 183 - *Pachydiscus* aff. *gollevillensis* (d'Orbigny). Other designation as in Text-figs. 2 and 3.

recognised in terrestrial formations (Lower Arkovo - Coniacian, Upper Arkovo - Lower Santonian, Zhonkyer - Upper Santonian, Avgustovka coal bearing member - Upper Maastrichtian and Boshnyakovo - Danian) (KRASSILOV, 1979) of adjacent regions one can judge the floral succession of the neighbouring sea shore.

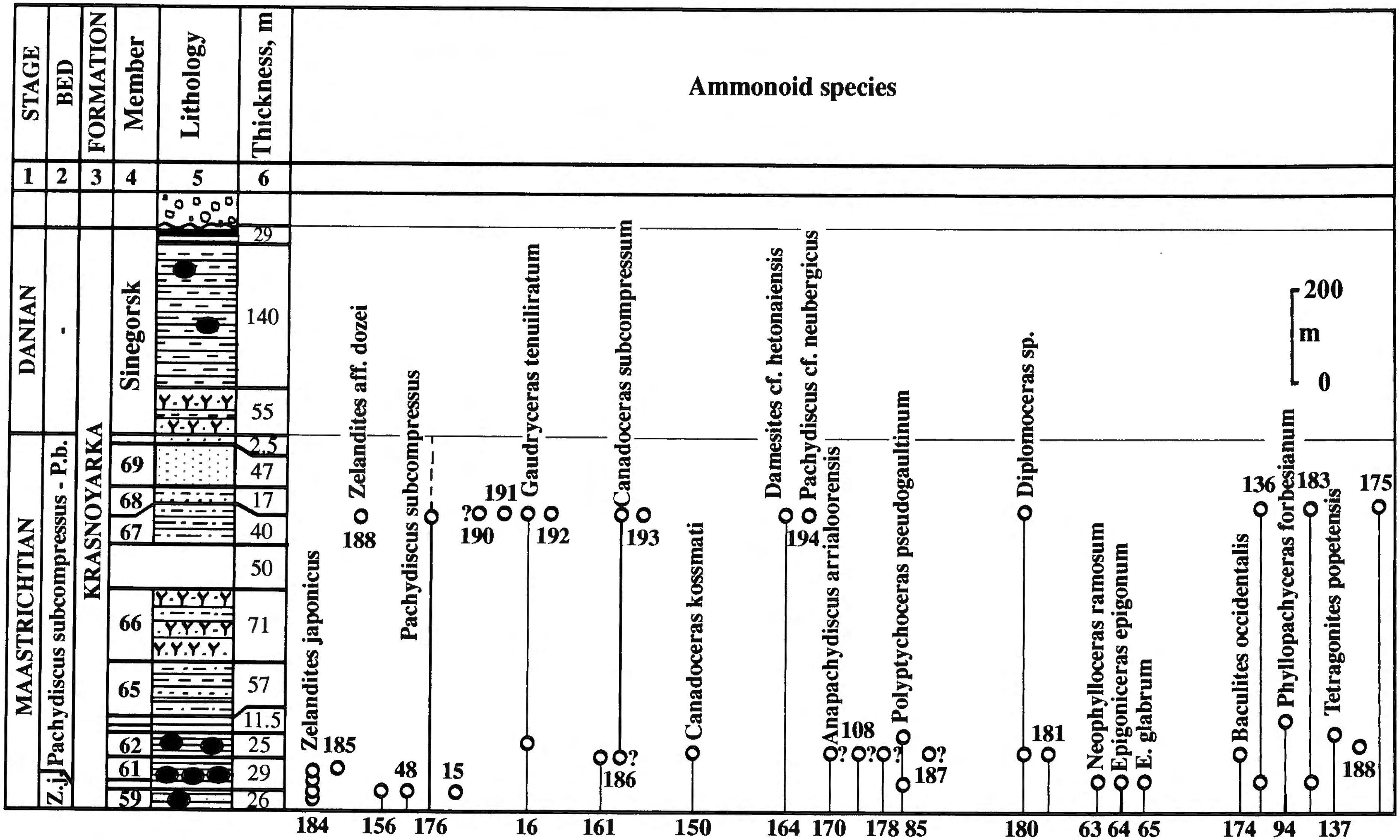
The following plant palaeosuccession can be recognised in the Naiba River region for the Cretaceous: (1) *Ginkgo* and fern (*Gleichenites*) forest - late Albian → (2) predominantly fern (*Sagenopteris, Caytoniales*) forest - Cenomanian → (3) mixed coniferous - *Ginkgo* (*Ginkgoites* ex gr. *adiantoides* (Unger) Seward, *Sequoia* sp.) forest - early Turonian → (4) mixed coniferous-platanophyllous-fern (*Sequoia reichenbachii* (Geinitz) Heer, ?*Protophyllum schmidtianum* (Heer) comb. Krassilov, *Cyathea* sp.) forest - late Turonian - Coniacian → (5) mixed coniferous - *Ginkgo* - ?laurophyllous (*Sequoia reichenbachii, Ginkgo* sp., ?*Araliaephyllum polevoi* (Kryshtofovich) Krassilov, ?*Magnoliaephyllum magnificum* (Dawson) Krassilov, ?*Debeya pachyderma* Krassilov) forest - Santonian → (6) predominantly coniferous (*Sequoia reichenbachii*) forest - early Campanian → (7) fern - laurophyllous - *Ginkgo* (*Oncolea, Ginkgoites*, etc) forest - late Campanian → (8) mixed coniferous - ?platanophyllous (*Sequoia reichenbachii, ?Trochodendroides, ?Protophyllum*) forest - Maastrichtian → (9) mixed coniferous - ?platanophyllous (*Metasequoia, ?Platanus*) forest - early Danian (Text-fig. 6).

Geomagnetic Polarity Sequence, volcanic Activity and eustatic Changes of the Sea Level

On the basis of literature data (IRVING & PULLAIAH, 1976; LARSON, 1976; HARLAND *et al.*, 1982; Geological Time Scale, 1983; MOLOSTOVSKY & KHRAMOV, 1984; LERBEKMO & COULTER, 1985), it is known that the relatively long Aptian-Santonian interval is characterised by a more or less stable normal polarity (Text-fig. 6). The frequent polarity reversals have been predominantly recognised in the Maastrichtian - Lower Danian interval. Judging from data on the Krasnoyarka formation lithology in Sakhalin (characterised by the presence of andesite-dacitic, rarely acidic tuffs, tuffites, tuffaceous sandstones and conglomerates) (ZAKHAROV *et al.*, 1984b; SALNIKOV & TIKHOMOLOV, 1987; UTKINA, 1987) it may be assumed, that the formation was deposited against a background of strong predominantly mediate volcanic activity and regression.

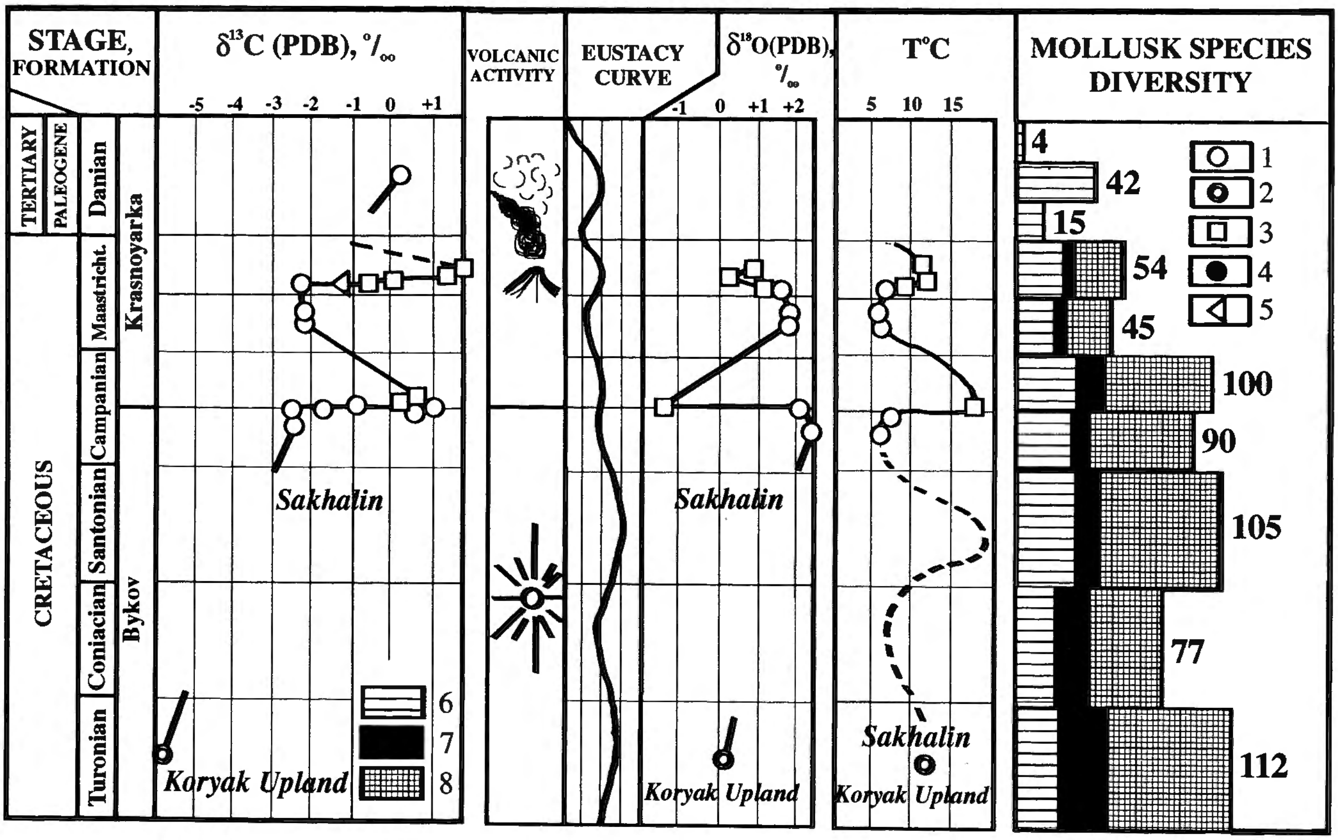
Isotopic Composition of the Cretaceous invertebrate shells from Sakhalin and the Koryak Uplands

Isotopic investigations were made on the basis of the well preserved brachiopod, bivalve and aragonitic ammonoid shells of South Sakhalin (ZAKHAROV *et al.*, 1984b) and on a single aragonitic ammonoid shell from the Koryak Upland (Pl. 1, Fig. 4; Tables 1-3). A low index of $\delta^{13}C$



Text-fig. 5 — Lithofacies, distribution and relative abundance of ammonoid taxa for the Upper Krasnoyarka Formation (Maastrichtian-Danian). Abbreviated name of beds: Z.j. = Zelandites japonicus, Pachydiscus subcompressus - P.b. = Pachydiscus subcompressus - Pleurogrammatodon bykovensis.
Species: 184 - *Zelandites japonicus* Matsumoto, 185 - *Neodesmoceras japonicum* Matsumoto, 186 - *Canadoceras subcompressum* Matsumoto, 187 - *Pseudoxybeloceras quadrinodosum* (Jimbo), 188 - *Saghalinites* cf. *cala* (Forbes), 189 - *Zelandites* aff. *dozei* (Fallot), 190 - *Gaudryceras crassicostatum* Jimbo, 191 - *Gaudryceras hamanakense* Matsumoto et Yoshida, 192 - *Gaudryceras* sp. 193 - *Damesites* sp., 194 - *Pachydiscus* cf. *neubergicus* (Hauer). Other designation as in Text-figures 2 - 4.

GEOLOGICAL TIME SCALE (with magnetic polarity data)				FORMATION	BEDS	PHASE	BIOEVENT	AMMONOID SUCCESSION				T°C	TERRESTRIAL (SEASHORE) PLANT TYPE	BASIC FACTORS OF SYNGENESIS
								DOMINANT	Quantity (genera, species)		N			
TERTIARY	PALAEOGENE	Danian	R_7	Krasnoyarka	-	6		Rare specimens	0	0	0	-	-	Destruction of the marine communities as a result of shallowing and bogging.
			N_7, R_6		*Thyasira uncinata*	5	-	*Multidentata ornata*	0	0	0	-	Mixed coniferous (*Metasequoia*)-platanophyllous forest	Homeostatic development under influence of increase of warmth.
			N_6, R_5		*Pseudaphrodina extrema*	4	-	Rare specimens	0	0	0	-		Destruction of marine communities as a result of temperature fall during early Maastrichtian and Cretaceous-Tertiary boundary time (because of next portions of volcanic activity) and, apparently, fluctuating anoxic conditions.
UPPER CRETACEOUS		Maastrichtian	N_5, N_4		*Pachydiscus subcompressus-P.b.*	3	*h*	*Pachydiscus subcompressus*	17 (16)	26 (17)	N	6.0-9.3	Mixed coniferous (*Sequoia*)-?platanophyllous forest	
			R_3, N_3		*Zelandites japonicus*		*g*	*Zelandites japon.*	19	23	1.2N	5.3		
		Campanian	N_2		*Canadoceras kossmati*	2	*f*	*Baculites zhuravlevi*	(18) 28	(23) 54	10N	18.1	Fern-laurophyllous-*Ginkgo* forest	Homeostatic development under existing conditions of the comparatively fluctuating climate (with maximum of temperature fall during Coniacian and middle Campanian), but normal salinity conditions. The middle Campanian temperature fall is connected with the beginning of volcanic activity, which followed the rise of the unstable palaeomagnetic field. The increase of warmth in late Campanian was probably provoked by the hotbed effect of atmosphere as a result of the increase of carbonic acid concentration of volcanic origin.
			R_1	Bykov			*e*	*Gaudryceras tenuiliratum*	(19) 28	(30) 50	25N	5.4-5.9	Predominantly coniferous forest	
		Santonian	N_1		*Anapachydiscus naumanni-Peron.*		*d*		(26) 33	(37) 63	34N	-	Mixed coniferous-*Ginkgo*-?laurophyllous forest	
		Coniacian			*Jimboiceras mihoense*		*c*		(16) 22 (24)	(28) 39 (29)	15N		Mixed coniferous-platanophyllous-fern forest	
		Turonian			*Jimboiceras planulatiforme*		*b*	*Epigoniceras epigonum*	32	65	15N	11.7	Mixed coniferous-*Ginkgo* forest	
		Cenomanian			*Marshallites-Acanthoceras san.*		*a*	*Desmoceras (Pseudouhligella) japonicum*	(13) 30	(16) 6	7N	-		
LOWER CRETACEOUS				Naiba	*Turrilites costatus*				(3)	(3)			Predominantly fern forest	
		Albian		Ai	*Cleoniceras*	1	-	Rare specimens	5	7	0.3N		*Ginkgo* and fern forest	Destruction of the marine communities as a result of the recurrent fresh-water influence.



Text-fig. 7 — Correlation of isotopic/chemical shifts, volcanic activity intervals, main changes in climate and mass extinction in South Sakhalin and adjacent territory during late Cretaceous - early Tertiary. 1 - ammonoids from South Sakhalin, 2 - ammonoid from Koryak Upland, 3 - brachiopods from South Sakhalin, 4 - bivalves from South Sakhalin, 5 - sedimentary rock from South Sakhalin, 6 - non-inoceramid bivalve species, 7 - inoceramid bivalve species, 8 - ammonoid species. (stable isotope analyses were made in the Far Eastern Geological Institute, FEB RAS, Vladivostok).

was found in the shells from the Turonian (– 5.95%), Lower Campanian (– 2.6%), and middle Maastrichtian (– 2.4%) of the north-west Circum-Pacific. There are grounds to consider that the Maastrichtian-Danian boundary in this region is also characterised by a low index $\delta^{13}C$ (Fig. 7) (ZACHOS *et al.*, 1989). The drop in $\delta^{13}C$ which suggests the reduced biological productivity is probably related to oceanic anoxia (MAGARITZ *et al.*, 1981, 1983, 1988; MAGARITZ & TURNER, 1982; HOLSER & MAGARITZ, 1985; HOLSER *et al.*, 1986, 1989, 1991; MAGARITZ & HOLSER, 1991; BAUD *et al.*, 1989; BERNER, 1989; DELANEY, 1989; GRUSZCZYNSKI *et al.*, 1989; OBERHANSLI *et al.*, 1989; YANG ZUNYI & LIANG-PANG YE, 1992; WIGNALL & HALLAM, 1993; HALLAM, 1994; KOUR, 1994; YIN HONGFU *et al.*, 1994; ZAKHAROV *et al.*, in press), marked in turn by concentrations of iridium and other metals in marine sediments. Anoxia at the Cretaceous/Tertiary boundary is supported by the sulfur isotope record (KAJIWARA & KAIHO, 1992).

A high index of $\delta^{18}O$ was recognised in the shells which were found in Lower Campanian and Middle Maastrichtian. A fall of temperature can be expected at the beginning of the Campanian and in Middle Maastrichtian. Based on the reduction in taxonomic diversity

←

Text-fig. 6 — Faunal and floral succession during the Cretaceous and early Tertiary in South Sakhalin. Normal magnetic polarity is indicated by black colour (Geological Time Scale, 1983). Data in brackets indicate the number of species in common of Sakhalin invertebrates one can also assume the existence of the climatic "pessimum" in Coniacian and the time of the Maastrichtian-Danian boundary beds. The climatic optima in Sakhalin fall during the Turonian, Santonian and Middle Campanian. Relatively low temperature (till 11.7° C) of the near bottom waters of the shelf in Koryak Upland occurred in the Turonian, during a climatic optimum, and may be explained by the climatic zonation existing at least in middle Cretaceous time, also confirmed by palaeobotanical data (KRASSILOV, 1985; NAIDIN *et al.*, 1986). A sharp fall in temperature in the Maastrichtian-Danian transition existed just after a warming during the middle Late Maastrichtian.

Conclusions

An indirect causal link between the mass extinction at the end of the Cretaceous and the massive volcanism, sea-level regressions, reversals of the geomagnetic field, $\delta^{13}C$ and $\delta^{18}O$ fluctuations, as shown below, seems to exist.

In the Santonian phase (bioevent "d"), basic community elements acquire an extremely high diversity (a peak of "Megaclimax", *sensu* ZAKHAROV, 1983, 1986). Data on Santonian $\delta^{18}O$ have not yet been reported from Sakhalin, but some palaeobotany data (the presence of *Ginkgo, Araliaephyllum* and *Magnoliaephyllum* in the forest) confirm the existence of a climatic optimum at that time. The Santonian, in the same way as some previous Cretaceous stages, is characterised by a magnetic field with predominant normal polarity.

During the Early Campanian phase (bioevent "e"), a noticeable reduction in abundance and taxonomic diversity of some ammonoid groups took place. This drop in organic productivity is correlated with a zone of $\delta^{13}C$ values (anoxic conditions) and high values of $\delta^{18}O$. The latter shows that the water temperature was about 5.4° C. The Late Campanian phase (bioevent "g") is characterised by a marked increase in abundance and taxonomic diversity of bivalves and ammonoids which coincide with positive shifts of carbon isotopes, negative oxygen isotope excursion, sea-level regression, rapid polarity changes and the beginning of a strong volcanic activity. The latter fact may have provoked the lower temperature in the first steps of the phase, but during the most of the phase a climatic optimum (with temperature about 18°C) existed, apparently, because of hotbed effect of atmosphere as a result of the increase of carbonic acid concentration of volcanic origin (greenhouse summer).

Table 1.
Carbon and oxygen isotope analysis of a Turonian aragonitic ammonoid shell (*Mesopuzosia pacifica* Matsumoto) from the right bank of the Upper Pakhacha River, Koryak Upland.

Sample	Location (D and H in mm)	Colour	Aragonite contents, %	$\delta^{13}C$ (PDB) ‰	$\delta^{18}O$ (SMOW) ‰	$\delta^{18}O$ (PDB) ‰	T°C
940-1	Septa (D=79; H= 31)	cream-coloured	91	- 2.5	29.6	+0.1	11.56*(14.95**)
940-3	Dorsal wall (D=79; H=31)	id.	95	- 6.0	29.8	+0.3	10.78 (14.09)
940-4	Lateral wall (D=71.6;H=27.8)	id.	95	- 4.1	29.5	0	11.96 (15.39)
940-5	Dorsal wall (D=71.6;H=27.8)	id.	91	- 8.1	29.6	+0.1	11.56 (14.95)
940-6	Lateral wall (D=32.5;H=14.0)	id.	90	- 5.9	29.3	-0.2	12.75 (16.26)
940-7	Lateral wall (D=31.0;H=13.0)	id.	84	- 7.8	29.7	+0.2	11.17 (14.52)
940-8	Lateral wall (D=28.9;H=12.0)	id.	92	- 7.3	29.5	0	11.96 (15.39)
940-2	Ventro-lateral part (D=79;H=31).	cream coloured and brown	15 (admixture α-SiO_2)	-11.4	28.5	-1.0	"T"°C= 16.00 (19.73)

* Anderson & Arthur (1983); ** Grossman & Ku (1986)

Table 2.
Carbon and oxygen isotope analysis of invertebrate shells from the Campanian-Maastrichtian of South Sakhalin.

Sample	Species	Stage, Formation, Locality	Location (H & L mm)	Aragonite %	Calcite %	$\delta^{13}C$ (PDB) ‰	$\delta^{18}O$ (SMOW) ‰	$\delta^{18}O$ (PDB) ‰	T°C
	A.	**Ammonites**							
101.952.1	Pachydiscus (P.) gollevillensis	L. Campanian, Bykov Fm., bed 11.6; Naiba River	L.W. H=80	99	1	-2.3	-	+2.7	2.05*(3.67)**
101.952.2	same shell	"	H=76	99	1	-2.2	-	+1.7	5.55 (8.01)
101.952.9	" "	"	H=70	99	1	-2.5	-	+1.3	7.00 (9.75)
101.952.11	" "	"	H=62	99	1	-2.6	-	+2.0	4.48 (6.71)
101.952.18	" "	"	H=42	96	4	-2.5	-	+1.3	7.00 (9.75)
101.952.20	" "	"	H=30?	-	-	-3.0	-	+1.5	6.27 (8.88)
111.952.50	Pachydiscus (P.) gollevillensis	L.Campanian, Bykov Fm., bed 11.1; Naiba River	L.W. H>45	89	11	-2.6	-	+1.6	5.91 (8.44)
103.952.28	Pachydiscus (P.) gollevillensis	Maastrichtian, Krasnoyarka Fm., bed 5.11; Naiba River	L.W. H=160	99	1	-1.1	-	+1.6	5.91 (8.44)
103.952.31	same shell	"	H>50	99	1	-2.4	-	+1.8	5.19 (7.58)
107.952.36	Pachydiscus (P.) gollevillensis	"	H=70	99	1	-2.8	-	+1.9	4.83 (7.14)
108.952.39	"	"	Septa H>120	99	1	-2.8	-	+1.9	4.84 (7.14)
110.952.45	"	Maastrichtian, Krasnoyarka Fm., bed 5-10; Naiba River	L.W. H=85	98	2	-2.0	-	+1.6	5.91 (8.44)
114.952.50	Pachydiscus (Neodesmoceras) japonicus	Maastrichtian, Krasnoyarka Fm., bed 5-9; Naiba River	L.W.	97	3	-2.2	-	+1.8	5.19 (7.58)
105.952.32	Pachydiscus (P.) sp.	Maastrichtian, Krasnoyarka Fm., bed 5-7; Naiba River	L.W. H>105	99	1	-2.5	-	+1.5	6.27 (8.88)
106.952.35	Pachydiscus (P.) sp.	"	H>106	98	2	-2.5	-	+1.4	6.64 (9.31)

106.952.42	"	"	H>80	98	2	-2.2	-	+1.8	5.19 (7.58)
	B.	**Brachiopods**							
KL10.6.1	Rhynchonellacea (smooth)	U. Maastrichtian, Krasnoyarka Fm. (Krasnoyarka River, just below the mine)	L=13	0	100	+0.6	29.7	+0.2	11.17*
KL10.6.2.	"	"	L=14	0	100	+1.8	30.0	+0.5	10.01
KL10.6.3	"	"	L=11.8	0	100	+1.4	29.0	+0.3	10.78
KL111.1	"	U. Maastrichtian, Krasnoyarka Fm., bed 111.1 (Naiba River)	L=11.5	0	100	+1.1	29.8	+0.3	10.78
KL111.2	"	"	L=12.0	0	100	+1.4	29.8	+0.3	10.78
KL111.3	"	"	L=12.?	0	100	+1.4	29.7	+0.2	11.17
KL6	Rhynchonellacea (coarse ribs)	U. Maastrichtian, Krasnoyarka Fm., loc. 6 (Sary River)	L=11.0	0	100	0	30.5	+1.0	8.12
141.952.65	Rhynchonellacea (coarse ribs)	U. Campanian, Krasnoyarka Fm., bed 5.6 (Naiba River)	few shells	0	100	-0.6	-	+0.7	9.25
6.3	"	U. Campanian Krasnoyarka Fm., bed 6.3 (Naiba River)	L=11.0	0	100	+0.9	28.0	-1.5	18.09

* Anderson & Arthur (1983); ** Grossman & Ku (1986).
L. W.: lateral wall

Table 3.
Carbon and oxygen isotope analysis of diagenetically slightly altered bivalve and brachiopod shells (with natural value for $\delta^{13}C$) from the Campanian-Maastrichtian of Naiba River, South Sakhalin.

Sample	Species (rock)	Stage, formation	Calcite contents %	$\delta^{13}C$ (PDB) ‰	$\delta^{18}O$ (PDB) ‰
7.1	Inoceramus sp.	L. Campanian Upper Bykov Fm., bed 7.1	100	-1.7	-2.4
6.13	"	U. Campanian L. Krasnoyarka Fm., bed 6.13	100	-0.9	-4.2
6.11	"	U. Campanian L. Krasnoyarka Fm., bed 6.11	100	+1.0	-4.1
15.1003	Acila (Truncacila) munda	Danian, U. Krasnoyarka Fm., M. Sinegorsk horizon, bed 108	100	+0.2	-4.3
140.952	Rhynchonellacea (smooth)	U. Campanian, L. Krasnoyarka Fm., bed 6.11	100	+0.3	-3.8
141.952	Marly limestone	U. Maastrichtian, Krasnoyarka Fm., bed 5.6	100	-1.0	+ 0.1

During the Early Maastrichtian phase (bioevent ''g''), the next sharp reduction in abundance and taxonomic diversity of all groups inhabiting this basin took place against a background of a drop in temperature (till 5.2° C) and in conditions of volcanic activity, during fluctuation of the sea level and at a time of rapid polarity changes (volcanic winter). Carbon isotope data from ammonoid shells suggest that there was a sharp drop in organic productivity at that time (including, obviously, terrestrial plant and phytoplankton productivity) which resulted in atmospheric and oceanic anoxia apparently because of photosynthesis reduction.

The Late Maastrichtian phase (bioevent ''h'') was the time of the last diversification of ammonoids under conditions of rising temperature (till 10-11° C), of the continuation of volcanic activity, of fluctuation of sea-level and of rapid palaeomagnetic polarity changes. During the Late Maastrichtian, the mollusk productivity seems to be two times lower in comparison with that of the Late Campanian, but the $\delta^{13}C$ index of Late Maastrichtian organogenic carbonate is relatively high (1.8%). A general high marine organic productivity at this time was compensated, apparently, by a microorganism productivity just before the biodiversity crisis of terminal Mesozoic.

It seems justified to assume that the repeated influence of the three basic factors: drop of temperature, oxygen deficit and enormous eustatic level fluctuation, provoked by thermal perturbation at the core/mantle boundary and a change in rotation regime of the Earth (speed of Earth rotation) (KRASSILOV, 1985; ZAKHAROV, 1986; CANAHAN *et al.*, 1994), as in case of the Permian-Triassic boundary interval, is the main reason for the destruction of epicontinental sea ecosystems at the end of the Cretaceous.

The lower $\delta^{13}C$ (– 2.4%) value found in Late Maastrichtian invertebrates of Sakhalin island, when compared with those from both planktonic and benthic foraminifera of Cretaceous-Tertiary boundary beds in the North Pacific Shatsky Rise (ZACHOS, ARTHUR & DEAN, 1989) can be explained by more strongly expressed anoxic conditions in the epicontinental basins (near the sea floor) than existing in those from the open ocean, due to a weaker water circulation.

Judging from the very low value of $\delta^{13}C$ (– 5.9%) obtained from a Late Cretaceous ammonoid from Koryak Upland, the most oxygen depleted marine waters at that time were spread in high latitudes.

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Explanation of Plates

All the figured specimens are preserved in the collections of the Far Eastern Geological Institute in Vladivostok, Russia.

DVGI: Dal'nevostochny geologicheskij institut = Far Eastern Geological Institute, Far Eastern Branch, Russian Academy of Sciences, Vladivostok

PLATE 1

Figs. 1 - 2 — *Jimboiceras mihoense* Matsumoto: 1 - DVGI 11-27/952, x 1; 2 - 11-12/952, x 1; Sakhalin, Naiba River, Middle Bykov Formation, Coniacian, *Jimboiceras mihoense* beds.

Fig. 3 — *Neopuzosia ishikawai* (Jimbo), DVGI 10-22/952, x 1; Sakhalin, Naiba River, Upper Bykov Formation, Santonian, *Anapachydiscus naumanni* beds.

Fig. 4 — *Mesopuzosia pacifica* Matsumoto, DVGI 1/953, x 1; Kamchatka region, Koryak Upland, Pakhacha River, right bank, 12 km above the Echviyam Creek mouth; Turonian block in deep-sea Vatyn Series (G.I. Popova (Guseva)'s collection).

PLATE 2

Fig. 1 — *Neopuzosia ishikawai* (Jimbo), DVGI 92-4/952, x 1; Sakhalin, Naiba River, Lower Bykov Formation, Turonian, *Jimboiceras planulatiforme* beds.

Figs. 2-3 — *Damesites damesi* (Jimbo): 2 - DVGI 179/952, x 1; Sakhalin, Naiba River, Upper Bykov Formation, Santonian, *Canadoceras kossmati* beds; 3 - DVGI 179/951, x 1; Krasnoyarka River, Upper Bykov Formation, Santonian, Canadoceras kossmati beds.

Fig. 4 — *Hauericeras (Gardeniceras) angustum* Yabe, DVGI 26-1/952, x 1; Sakhalin, Naiba River, Upper Bykov Formation, Santonian, *Anapachydiscus naumanni* beds.

Fig. 5. — *Damesites laticarinatus* Matsumoto, DVGI 116-8/952, x 1; Sakhalin, Kuma River, Upper Bykov Formation, Santonian, *Anapachydiscus naumanni* beds.

Figs. 6-7 — *Tragodesmoceratoides subcostatus* Matsumoto: 6 - DVGI 506/951, x 1; Sakhalin, Krasnoyarka River, Upper Bykov Formation, Santonian, *Anapachydiscus naumanni* beds; 7 - DVGI 57-5/952, x 1; Naiba River, Middle Bykov Formation, Turonian, *Jimboiceras planulatiforme* beds.

Plate 1.

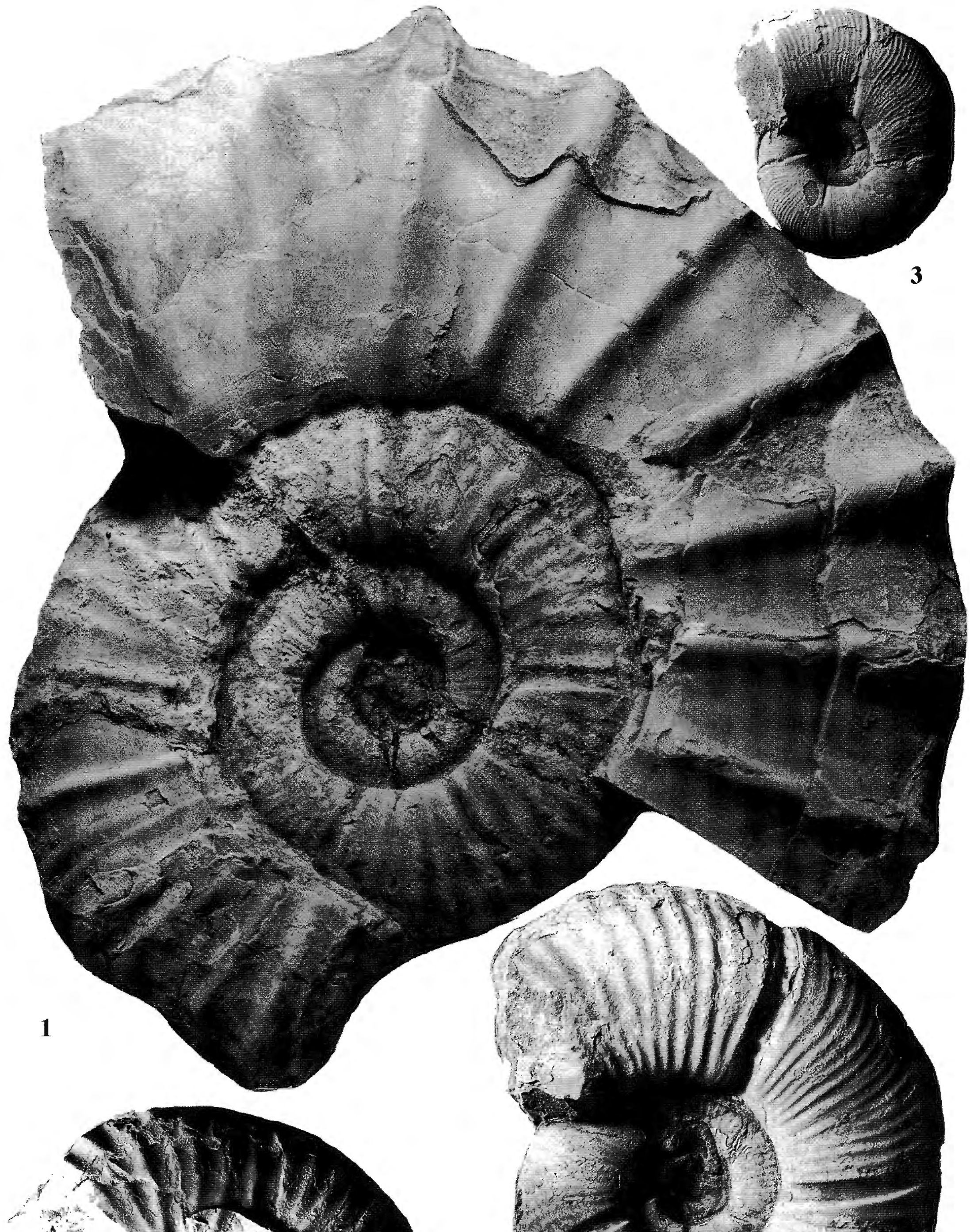

Plate 2.