# TETHYAN/BOREAL CRETACEOUS CORRELATION

## Mediterranean and Boreal Cretaceous paleobiogeographic areas in Central and Eastern Europe

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# 7. UPPER CRETACEOUS INOCERAMID AND DINOFLAGELLATE CYST BIOSTRATIGRAPHY OF THE NORTHERN SIBERIA

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**Abstract:** Two zonal scales are simultaneously proposed for the Upper Cretaceous deposits of Northern Siberia: one on the basis of inoceramids and the other on the basis of dinoflagellate cysts. An inoceramid-based scale provides more detailed division and allows correlation between Upper Cretaceous sequences of Northern Siberia and Europe to the substages. A dinocyst-based scale provides inoceramid-independent correlation with the sections of Great Britain and Northern American Atlantic coast (New Jersey, Eastern Canada). Combined application of the two scales allows Panboreal correlation between Upper Cretaceous stages and substages to be made. Strong predominance of cosmopolitan species in inoceramid assemblages is concurrent with geographical distribution of boreal dinoflagellates, and an increase in species diversity of inoceramids (thanks to new species) is accompanied by marked rise in a number of local species of dinoflagellates. Both events are associated with global rise in sea level during the Late Cretaceous.

**Key words:** Upper Cretaceous, Northern Siberia, Boreal correlation, diversity dynamics, biostratigraphy, inoceramids, dinoflagellate cysts.

## 7.1 Introduction

Marine Upper Cretaceous sediments are present throughout the larger part of northern Siberia and they are overlain by a Quaternary sedimentary cover. The most complete Upper Cretaceous sections are described from the north-east and from the Ust-Yenisey depression. The best (both representative and complete) sections are: along the Agapa River (Cenomanian–Lower Turonian), Chaika River (Upper Turonian), near Vorontzovo village (Upper Coniacian), Yangoda River (Upper Turonian–Coniacian), Tanama River (Santonian–Maastrichtian) (Zakharov et al. 1986, 1989a,b 1991; Zakharov & Khomentovsky 1989) (Fig. 7.1).

The entire succession of 400 m thickness predominantly consists of marine sandy siltstones and argillaceous sediments. Continental and littoral deposits form approximately 10 % of the sequence (Fig. 7.2). The whole succession yielded fossils like ammonites, bivalves, gastropods, dinoflagellate cysts (dinocysts), more rare belemnites, brachiopods, echinoids, foraminifers, ostracods and a few vertebrate remains, such as selachian and ichtiosaur teeth. Bivalves and dinocysts are most frequent.

The zonation of the Cenomanian-Santonian succession in Northern Siberia is based on inoceramids, while the Campanian-Maastrichtian section is barren. Eleven zones were iden-

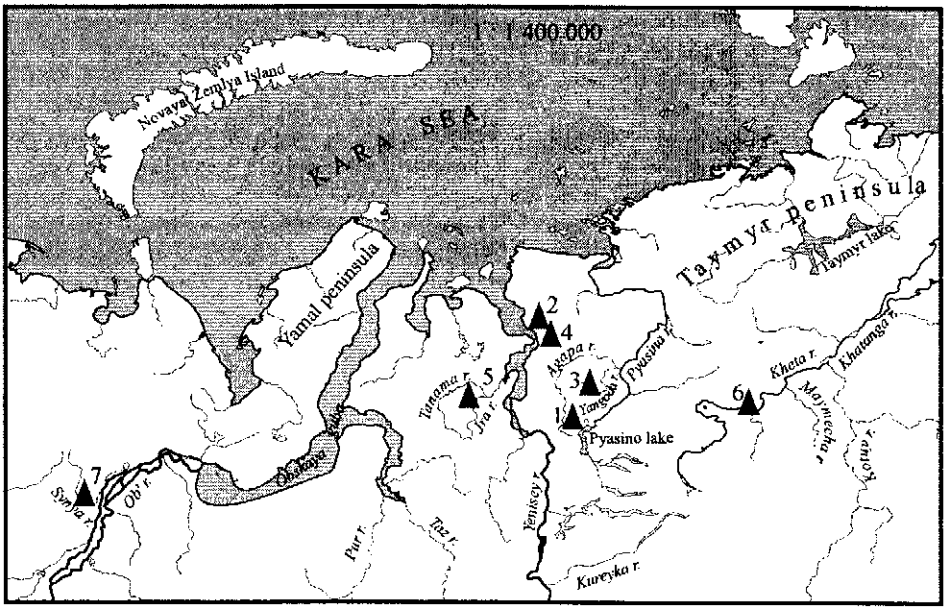


**Fig. 7.1.** Location of the main Upper Cretaceous sections in the northern Siberia. 1 — Lower Agapa River; 2 — Chaika River; 3 — Yangoda River; 4 — Vorontsovo; 5 — Tanama River; 6 — Kheta River.

tified, based on inoceramids including several world-wide recognized indexes like *Inoceramus (Inoceramus) pictus, I. (Mytiloceramus) labiatus, I.(I.) lamarcki, I. (Haenleinia) russiensis, Sphenoceramus cardissoides, S. patootensis,* which allowed interregional stratigraphic correlation (Sahagian et al. 1994).

Other stratigraphic scales were based on dinoflagellates and pollen and spores. Thirteen palynological (dinocysts and sporomorph) units were preliminary defined in the Cenomanian-Maastrichtian sequence of western Siberia by Lebedeva (1991) and they were later incorporated in the study of Ilyina et al. (1994). The Late Cretaceous dinocysts development in northern Siberia is comparable with difficulty with contemporaneous tropical/subtropical developments (Khlonova & Lebedeva 1988). This fact contrasts with the close similarities which exist between Late Cenomanian-Early Turonian assemblages from Northern Europe, Late Coniacian assemblages from Eastern Canada and characteristic constituents in Santonian, Campanian and Maastrichtian assemblages from Arctic Canada.

Sequence stratigraphic analysis of the composite section of the Upper Cretaceous in the Ust-Yenisey depression shows the presence of the majority of the standard sequence of Vail's chronostratigraphic scale for the time interval since 94 to 80 million years (Fig. 7.2) (Haq et al.1987; Zakharov et al. 1991). So, the Northern Siberian section appears to correspond to the lower half of the Late Cretaceous in time scale. The most accurate sequence stratigraphy with coordinate biostratigraphy is established for Late Cenomanian-Turonian. Both lower and upper boundaries of the Turonian Stage are accurately recognized in condensed sections (Sahagian et al. 1994).

## 7.2 Upper Cretaceous stages and substages of Northern Siberia: boundaries and stratigraphic volume

Upper Cretaceous sediments of Northern Siberia contain rock record of all stages of the geochronological scale including Cenomanian, Turonian, Coniacian, Santonian, Campanian, and Maastrichtian (Brussels 1995; Rawson et al. 1996). Ammonites, and sometimes planktonic foraminifers and nannofossils were used in the stage boundaries definition. Some example also of very unusual groups were used in the role of indexes, like the crinoids at the Santonian/Campanian boundary. Unfortunately, the inoceramide scale was not specifically discussed during the symposium, although inoceramid data were used during discussions on some (Cenomanian, Turonian, Coniacian, and Santonian) stage and substage boundaries.

### 7.2.1 The Cenomanian Stage.

The upper part of the Cenomanian sequence is reliable identified only by the presence of *Inoceramus (I.) pictus* Sowerby in the Lower Agapa River section, Northern Siberia (Zakharov et al. 1989). Troeger & Kennedy (1996) argued that the first appearance of *Inoceramus pictus pictus* generally corresponds with the top of the middle Cenomanian ammonite Acanthoceras jukesbrownei Zone that is characterized also by *I. atlanticus* Heinz. According to west-European experts, the Inoceramus (I.) pictus Zone corresponds to the upper Cenomanian. The only Upper Cenomanian section of Lower Agapa River consists of dark grey shaly silts, greenish-gray and gray leptochloritic fine sands, gray bioturbated silts and silty clays, greenish-gray leptochloritic silts with phosphate nodules with thickness about 60 meters, from which about 30 meters was not accessible for observation (Fig. 7.2). It is impossible to determine the stratigraphic volume of the section with *I. (I.) pictus* because it is underlain by non-marine strata. Presence of this species as well as another Cenomanian species *I. (I.) incelebratus* in the Upper Cretaceous section of Yangoda River (Pyasina River Basin) was not confirmed (Efremova & Abramova 1987). Our fieldwork in 1986 and 1988 showed that the base of the Yangoda section consists of Upper Turonian sediments. The older sediments are not present (Zakharov et al. 1989b). Presence of Cenomanian marine beds in Northern Siberia was indirectly identified by *Inoceramus pictus* in a sandstone fragment from moraine on the Yenisey River (Vorontsovo village) (Bodylevsky & Shulgina 1958). Thus, this species was identified for the first time after 30 years (Zakharov et al. 1989a).

In the regional stratigraphic scheme of West Siberia the Cenomanian is represented by the Uvat Beds. It has been believed that these beds contain continental strata only (Papulov 1974). Later, Cenomanian foraminifers and palynomorphs have been found in cores from the clayey and silty upper part of the Uvat Beds (Podobina 1975). In northwestern West Siberia the Uvat Beds were deposited in brackish basin, while the deposition in the eastern part continued on a periodically flooded coastal plain (Galerkina et al. 1982).

### 7.2.2 The Turonian Stage.

The base of the Turonian sequence is identified in Lower Agapa River section by *Inoceramus (Mytiloides) labiatus* (Zakharov et al. 1989a). This is the only section in Northern Siberia where transitional layers between Cenomanian and Turonian are present. The subgenus *Mytiloides* is characterized by a broad geographic distribution in Upper Cretaceous

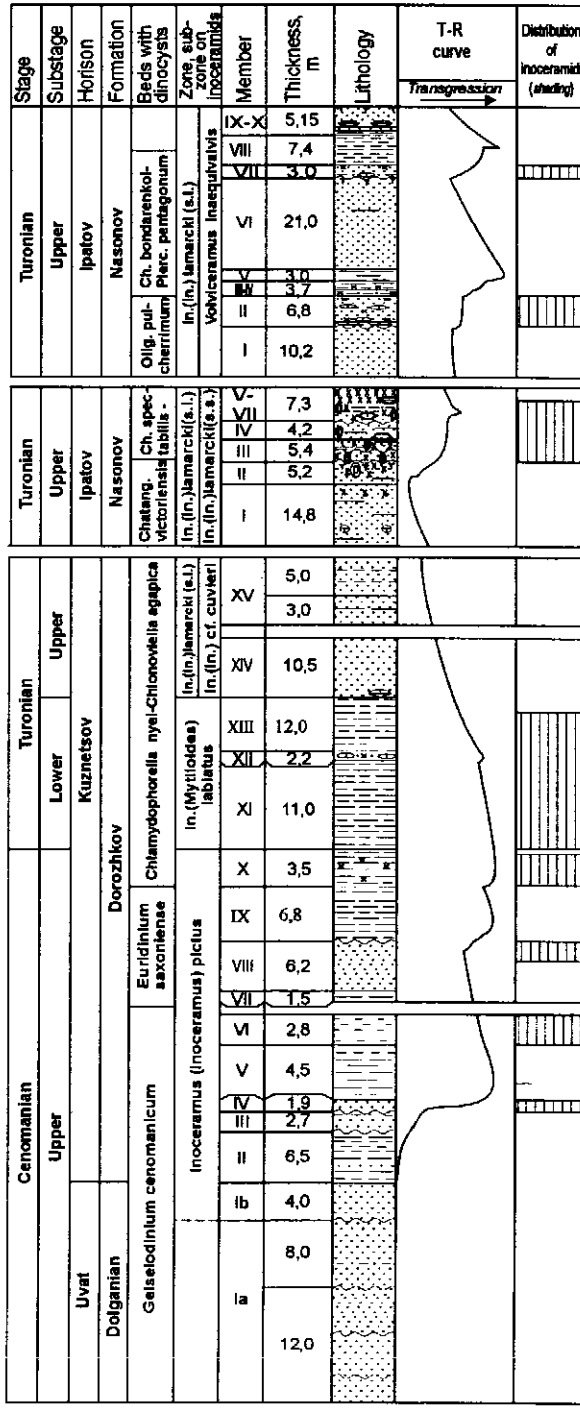


**Fig. 7.2.** *Continued on next page.*

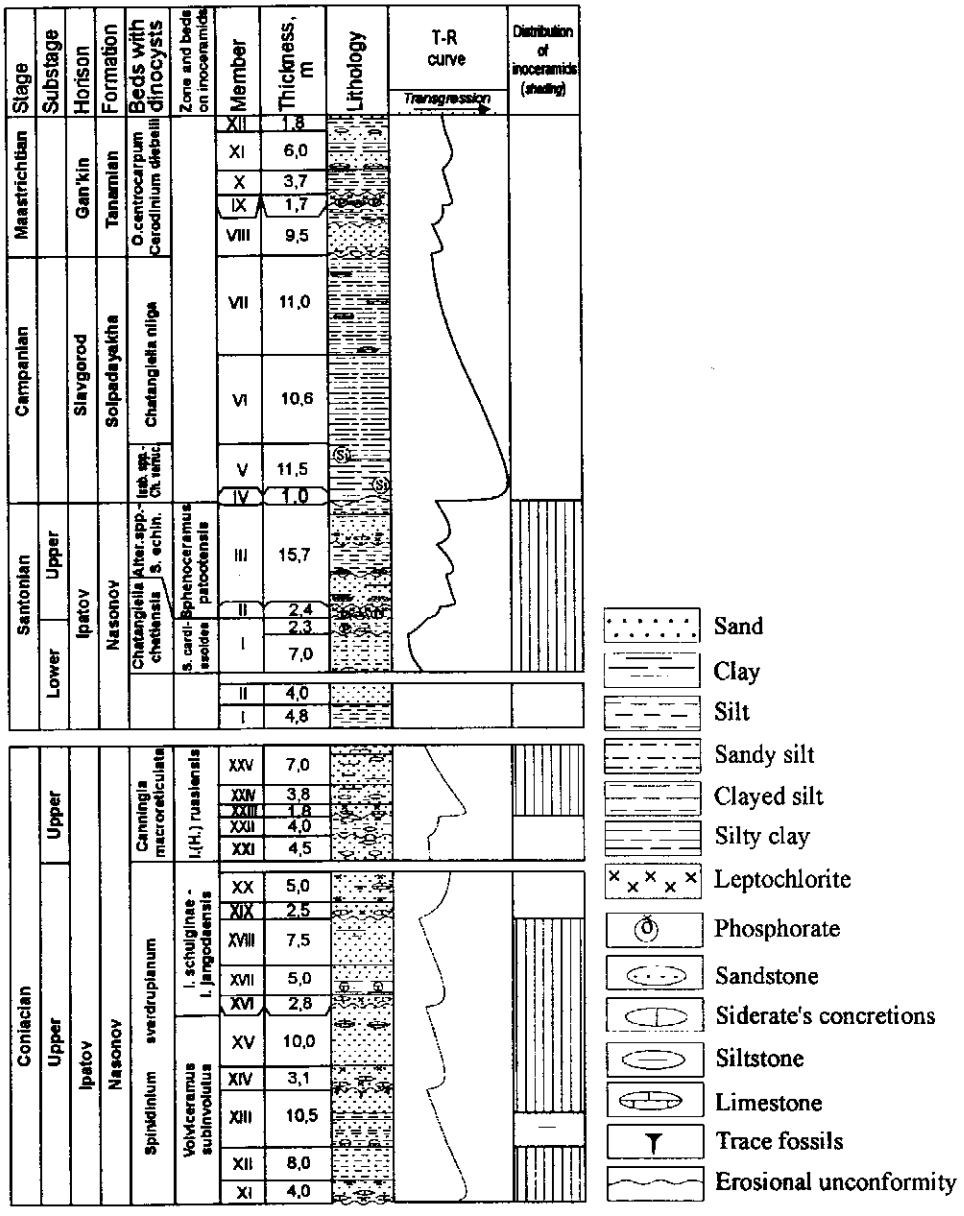


**Fig. 7.2.** Northern Siberian Upper Cretaceous composite section. Inoceramid and dinocyst parastratigraphic scales.

sections of the Northern Hemisphere. The mass appearance of this taxon generally corresponds to the base of the Turonian (Birkelund et al. 1984). In the Rock Canyon Anticline section near Pueblo (Colorado, USA) the subgenus *Mytiloides* (*M. hattini* Elder) is found 1 meter below the bed 86 (stratotype of Cenomanian/Turonian boundary). Abundant *Mytiloides* are present from the level of first appearance of the index-species of the lower zone of the lower Turonian — ammonite *Watinoceras devonense* (Bengtson1996: Text-fig. 5).

*Inoceramus (Inoceramus)* cf. *cuvieri* (Sow.) was found in the upper part of the continuous section of the Lower Agapa River. This suggests that the lower boundary of the middle Turonian (European subdivision) is present in northern Siberia because *Inoceramus (Inoceramus) cuvieri* (Sow.) and *Inoceramus (Mytiloides) hercynicus* (Petrascheck) occur along with the ammonite *Collignoniceras woollgary* (Mantell) at the base of the bed 120 — stratotype (GSSP) of the base of lower zone of middle Turonian (Bengtson1996: Text-fig. 6). *Collignoniceras woollgary* (Mantell) is the index-species of the lower zone of the mid-Turonian. The layers with *Inoceramus (Inoceramus)* cf. *cuvieri* overlie the zone of Inoceramus (Mytiloides) labiatus that in turn lies above the deposits of the Inoceramus (Inoceramus) pictus Zone. As such, the zone of I. (M.) labiatus corresponds to the entire Lower Turonian in North Siberia. The Lower Turonian in Lower Agapa River section is represented by 30 meters of dark-grey clays (at the base) and gray-yellowish fine sands (Fig. 7.2).

The position of the Upper Turonian base is not yet defined in the International Stage Scale. It was suggested to assign it to the level of the first appearance of either *Romaniceras deverianum* (d'Orbigny), or *Subprionocyclus neptuni* (Geinitz). However, both ammonite species are not characterized by broad geographic distribution. At the colloquium on the Turonian Stage (Lyon, France, 1981) the preference was given to the base of strata with *R. deverianum* (Robaszynski 1983). At the present time there is no appropriate section that can be recommended as a global stratotype (GSSP) for the base of the upper Turonian. Discussion on this problem at the International Symposium in Brussels (1995) showed that inoceramids could be more suitable for this purpose compared to ammonites (Bengtson 1996, p. 77). Possibly, the level of first appearance of *Inoceramus (Inoceramus) costellatus* Woods, which is close to that of *S. neptuni* (Seibertz 1995), can be chosen as a lithotype of the boundary between middle and upper Turonian (Seibertz 1995). Thus, the boundary between middle and upper Turonian is not determined yet.

The position of this boundary in the North Siberia sections is not defined either, but due to another reason. The stratigraphic interval between the top of the Lower Turonian and the base of the Coniacian in North Siberia consists of three biostratons: beds with *Inoceramus (Inoceramus)* cf. *cuvieri*, and the I. (I.) lamarcki and Volviceramus inaequivalves Zones. The beds with *Inoceramus (Inoceramus)* cf. *cuvieri* generally correspond to the I. (I.) apicalis Zone on the Russian Platform and Poland (Naidin et al. 1986; Wałaszczyk 1992) and the Inoceramus cuvieri-I. apicalis Zone in German- and Czech sections (Troeger 1989). The I. (I.) lamarcki Zone is accepted to correspond to the homonymous zone of Central Europe because in Northern Siberia and in Germany this zone is overlain by the deposits of the Middle Turonian Volviceramus inaequivalvis Zone. On the Russian Platform and in Poland, the I. (I.) lamarcki Zone is characterized by a greater stratigraphic volume compared to Northern Siberia, because it is overlain by the Upper Turonian I. (I.) costellatus Zone. This species is

missing in North Siberian sections. As a result, the Volviceramus inaequivalves Zone is considered to correspond to most of the middle and entire Upper Turonian. It is not clear if this is related to the incompleteness of the North Siberian section or if it represents a result of endemism of inoceramids from overlying complexes.

### 7.2.3 The Coniacian Stage.

Coniacian deposits in northern Siberia have been identified (by inoceramids) at two localities within the Ust-Yenisey area: along the Yangoda River (left tributary of the Pyasina River), along the right shore of the Yenisey Bay (5 km south of the Vorontsovo settlement) and also at the Syna River (Severnaya Sosva River Basin) (Fig. 7.1). At the Yangoda River the Coniacian Stage is almost entirely exposed and consists of clayey and silty rocks gradually becoming sandy upwards (Zakharov et al. 1989b). The lower Coniacian is recognized by inoceramids from the Volviceramus subinvolutus Zone and complex with *Inoceramus (Inoceramus) schulginae* (Efim.)-*I. (I.) jangodaensis* (Efim.). The upper Coniacian in isolated outcrop is represented by fine sands and sandy silts with numerous sideritic sandstone concretions and phosphorite nodules. Trace fossils (bioturbation) and sedimentary erosion are recorded throughout the sequence of apparent thickness of 18 m. The Coniacian Stage is 78 m thick in total. Near to the Vorontsovo settlement, Upper Coniacian clayey silts crop out at the surface, which yield the complex of the Inoceramus (Haenleinia) russiensis Zone of 27.8 m thickness. At the Synya River the beds with *Cremnoceramus waltersdorfensis* (Andert) are represented by 12 m thick sandstones.

In accordance with the recommendations of the Brussels Symposium (1995) all Coniacian boundaries (those of stage and substages) are suggested to be determined by the first appearance of inoceramid species (Kauffman et al. 1996). The base of the Coniacian (Turonian-Coniacian boundary) is determined by the first appearance of *Cremnoceramus (?) rotundatus*, the Middle Coniacian boundary is defined by the first appearance of *Volviceramus koeneni* and the Upper Coniacian one by the first *Magadiceramus subquadratus*.

The base of the more complete Coniacian sequence at the Yangoda River is determined by the first appearance of *Cremnoceramus inconstans* (Woods) in conjunction with *Volviceramus subinvolutus* (Bodyl.). In the sections of the North American Western Interior and in western Europe *Cremnoceramus* appears at the base (Kauffman et al. 1994; Troeger 1989). *V. subinvolutus* is a local species. Its first appearance in the section is recorded in the member XI, the base of which is represented by an erosional surface (Fig. 7.2). The inoceramid complex of the Upper Turonian underlying the Volviceramus inaequivalves Zone was encountered stratigraphicaly markedly lower, i.e., in member VII. The members VIII-X lack inoceramids (Fig. 7.2). A barren sequence in total thickness of 12.55 m separates the last findings of Turonian inoceramids and the first occurrences of the Coniacian ones. However within this stratigraphic interval in midpart of the member VIII a drastic change of dinocyst assemblage takes place. It should be noted that the nannofossil determination of the Turonian-Coniacian stage boundary in the stratotype section, in the Salzgitter-Salder quarry in Lower Saxony (Germany) is identified (similarly to northern Siberia) stratigraphically lower than that based on inoceramids (Wood et al. 1984). In both the sections one more correlation level (the bed enriched with *Scaphites* spp.) occurs below the microalgae-based boundary but within

the limits of the terminal biozone. Interesting, both beds have nearly the same thickness: in the Salzgitter-Salder quarry the thickness of the bed containing *Scaphites* is 1.6 m and at the Yangoda River (Lomachenkov Creek) 1.7 m.

### 7.2.4 The Santonian Stage.

The inoceramid-based Santonian Stage is known in the Ust-Yenisey and Khatanga depressions and in the Severnaya Sosva River Basin (Subpolar Urals) (Fig. 7.1). Upper Santonian bedrocks are described from the sequences along the rivers of Avam and Chopko (Dudypta River Basin). They are represented by fine-grained, obliquely laminated, greenish-grey and yellow sands with intercalations of coarse-grained sands with siderite concretions, lenses and interlayers of ferruginous sandstones of total thickness up to 20 m. Rocks were dated by the finding of *Inoceramus (=Sphenoceramus)* cf. *patootensis* Lor. (Saks & Ronkina 1957). A restricted interval in the section comprising Santonian–Campanian transitional marine beds is exposed at the Kheta River (Khatanga Depression) (Khomentovsky et al. 1999).

The most complete Santonian sequence represented by shallow water marine friable sandy silts enriched with leptochlorite, embracing numerous breaks and horizons of phosphate and sand concretions and abundant invertebrate trace fossils is exposed on the Sigirte-Nado Plateau (Tanama River, left tributary of the Yenisey River, its lower reaches). Among macrofossils, bivalves are more frequent, whereas gastropods, ammonites, malacostracans and echinoids are more rare. A total apparent thickness of the Santonian deposits is 38 m (Fig. 7.2). Inoceramids from the *Sphenoceramus* genus range are the major indicators of the Santonian age. In the Tanama River section, *Sphenoceramus cardissoides* and *S. patootensis* allowed the recognition of two homonymous zones, which represent the Lower and Upper Santonian respectively according to the Russian interpretation. Such Santonian division does not respond to the west European practice, where the Santonian used to be divided into three substages with the Cladoceramus undulatoplicatus Zone (Lamolda & Hancock 1996) as the lower zone (Brussels 1995). The Santonian base (the Copenhagen Symposium 1983) is placed at the first occurrence of *Cladoceramus undulatoplicatus* (Roemer), which is common and readily identifiable due to its specific shape and sculpture. However no *Cladoceramus* have been found in Russia. North Siberian Santonian inoceramids are represented by a single *Sphenoceramus*. *S. cardissoides* (Goldfuss) and *S. pachti* (Arkhanguelsky) were recommended as indexes of the Coniacian boundary in the northern moderate (Boreal) region (Lamolda & Hancock 1996). Unfortunately, sphenoceramids are very rare to occur outside the region, which makes a direct correlation of Boreal and Tethyan deposits difficult.

Nevertheless, both mentioned species, the latter in particular, are encountered in many localities within the Boreal region, where they overlie the Coniacian volvoceramids or magadiceramids and underlie the beds with *Cladoceramus undulatoplicatus* and *Platyceramus cycloides wegneri* (Boehm). The precise stratigraphic position of first findings of *S. cardissoides* (*S. pachti* previously identified from the same samples assigned by O.V. Khomentovsky to the synonymy of *S. cardissoides*) is uncertain due to incontinuity of sections: a 20 m interval between the highest Coniacian beds and the lowest Santonian beds is covered everywhere (Zakharov et al. 1991; Sahagian et al. 1994). Thus, we estimated the age of the beds with the first sphenoceramids in northern Siberia as Santonian.

### 7.2.5 The Campanian Stage.

In the north of Siberia, a more complete Campanian sequence is uncovered along the Tanama River, left tributary of the Yenisey River (Zakharov et al. 1986). The other regions with known restricted stratigraphic intervals with only Santonian-Campanian boundary beds include the basin of the Severnaya Sosva River (rivers of Synya, Leplya and Nyais) on the eastern slope of the Subpolar Urals and the basin of the Kheta River (rivers of Romanikha, Maymecha, Kheta) in the north of East Siberia (Khomentovsky et al. 1999) (Fig. 7.1). The Campanian was also revealed by drill core from the wells at the rivers of Yakovleva, Bolshaya and Malaya Kheta, however it is defined here by analogy with the Sigirte-Nado section (Saks & Ronkina 1957).

None of the known natural exposures in the Severnaya Sosva River Basin expose a continuous section between the Santonian and Campanian. One of the best Upper Cretaceous exposure at the Synya River (3 km lower of the settlement Tiltim) shows that the Campanian–Maastrichtian opoka-like clayey Leplin Formation overlies with sharp contact a principally sandy Coniacian Ust-Man'ya Formation. The Santonian sequence is crowned here with the beds containing *Sphenoceramus* cf. *lingua* and *Oxytoma* cf. *tenuicostata* (Roem.) (2.8 m), which are made up of fine-grained glauconitic-quartzy dark green sandstones (1.8 m) lying with washout on cherty lumpy dark grey siltstones yielding no macrofossils and their Campanian age is defined by rare foraminifers and dinocysts (Beizel, personal comm.).

In the Antlers ravine of Sigirte-Nado at the Tanama River, the Campanian is represented by opoka-like dark grey clays and clayey siltstones of the Solpadayakha Formation which lies with sharp deep washout on sandy-clayey greenish grey silts of the Upper Santonian Nasonov Formation (Sphenoceramus patootensis Zone) (Fig. 7.2). The total thickness of the Campanian clayey-silty relatively homogeneous sequence is a little less than 35 m. The predominance of clays or silts in the sequence permitted the recognition of 5 members. Tiny carbonate concretions occur throughout the sequence making up persistent interbeds at 3–4 levels. Macrofossils are extremely rare, being represented by ctenodonts and small heterodonts. Inoceramids and ammonites (with the exception of poorly preserved *Baculites* sp. ind.) were not found (Zakharov et al. 1986). Microfossils are dominated by diverse dinocysts which allowed the distinguishing of two members: the lower beds with *Isabelidinium* spp. and the upper ones with *Chatangiella niiga*. Both the beds are correlated very well with two complexes recognized within the Campanian of New-Jersey (Atlantic USA coast; Ilina et al. 1994).

It is impossible to estimate the stratigraphic range of washout between the Santonian and Campanian strata at the Tanama River having no additional evidence. Key materials which made it possible were obtained from Santonian and Campanian boundary marine beds in the basin of the Kheta River (Khatanga Depression) after they were studied in detail. Comparative analysis of inoceramid and dinocyst succession in both sections and biostratigraphic correlation of deposits of Ust-Yenisey and Khatanga regions made on this basis suggested an unambiguous conclusion on the existence of an insignificant temporal break between the Santonian and Campanian in the Sigirte-Nado section (Khomentovsky et al. 1999).

During the Brussels Symposium (1995) at a broadened meeting of Working Group on the Campanian Stage several recommendations were considered for identification of its lower boundary:

1. To follow the classical definition by Grossouvre (1901) to the beds with *Placenticeras bidorsatum* as the lowest level within the Campanian;
2. To stick to the level of extinction of the crinoid *Marsupites testudinarius* Schlotheim, that is recommended for a while as boundary marker at the base of the Campanian Stage;
3. To take into account:
   a) extinction of the planktonic foraminifer *Dicarinella concavata*;
   b) the data on nannofossils, on *Broinsonia parca* in particular;
   c) direct or indirect account of the boundary of magnetic zones 33R/34N.

The position of the lower limit of the Campanian was discussed during the Symposium in context of ammonite, belemnite, inoceramid, crinoid, foraminiferal and nannofossil scales as well as magnetostratigraphy (Hancock & Gale 1996).

Unfortunately, North Siberian material gives no way of applying the suggested diversity in approaches to the placement of the Santonian-Campanian boundary. The boundary beds in the north of Siberia are lacking in ammonites (except for occasional *Baculites*) and belemnites and contain no crinoids, planktonic foraminifers and nannofossils whatever. Magnetostratigraphy has not been applied here yet. The problem of an interstage boundary in natural exposures can be actually discussed based only on the analysis of the stratigraphic range of inoceramids, benthic foraminifers and palynologic remains (spores, pollen, dinocysts).

However, foraminifers are extremely rare in exposures; inoceramids being represented by a single *Sphenoceramus,* the remainders of which disappeared at the Campanian base. *Inoceramus (Endocostea) balticus* Boehm characteristic of Santonian-Campanian transitional beds was not found. Nevertheless, available material provides reason enough to conclude that there is a continuous sequence between the Santonian and Campanian in the north of Siberia and suggests the existence of near-boundary level in the sections of north-western Europe.

In the section at the Tanama River (left tributary of the Yenisey River) the Campanian opoka-like clays lie with washout on the Santonian silts. In the section at the Kheta River (Khatanga River Basin) the Santonian-Campanian boundary runs within homogeneous silty strata. At the Tanama River the highest silt strata yielded the association of *Sphenoceramus patootensis -Oxytoma tenuistriata* supposedly of Upper Santonian age; macrofossils are absent in the overlying opoka-like clays. These clays were dated as Campanian by dinocysts and radiolaria. At the Kheta River *S. patootensis, S. lingua* and *S.* sp. ind. occur jointly with *S. patootensiformis* in the midpart of the marine beds, however the species *O. tenuistriata* was not found. On this basis the beds with *S. patootensiformis* are supposed to be of transitional Santonian-Campanian age. At the Tanama River the following succession of beds with dinocysts was established: *Alterbidinium daveyi* (top of silty strata), *Isabelidinium* spp. (base of opoka-like clays), *Chatangiella niiga* (sandy and silty beds). At the Kheta River the succession of beds within the same interval of section is as follows: *Alterbidinium daveyi-Chatangiella chetiensis* (base of marine beds), *Isabelidinium* spp.-*Chatangiella verrucosa* (midpart of marine beds), *Chatangiella niiga* (roof of marine beds). This succession is most complete in northern Siberia. Taking into account the Santonian age of the top of the silty package at the Tanama River, the transitional Santonian-Campanian age of the beds with *S. patootensiformis* at the Kheta River as well as the very similar succession of beds with dinocysts in both sections, we arrived at the conclusion that the Kheta River section between the Santonian

and Campanian is stratigraphically continuous and that most of the stratigraphic break between these stages at the Tanama River is absent (Khomentovsky et al. 1999).

Lack of inoceramids and important mollusks allows no division of the Campanian into substages.

### 7.2.6 The Maastrichtian Stage.

A single Maastrichtian marine section in the north of Siberia is exposed in the gorges of small rivers and creeks dissecting the Sigirte-Nado Highland on the Tanama River right side (Fig. 7.1). The Maastrichtian sequence is made up of highly variegated essentially friable rocks of sandy composition. Within the section with 32 m in total thickness five members are recognized, which are well traceable over a large distance (up to 8-10 km). The boundaries between the members are clearly visible due to change in rock type and texture. Beds of fine- and medium-grained sands with leptochlorite enclose concretions of sandstone of large size (up to 1.2-1.5 m), which are confined to strictly definite levels. The limits of a number of beds coincide with washout planes, which left their marks within a dark green leptochloritic sand package in the midpart of the section. Alternation of clays and silts of various colour (pseudoflysch), yellow sands, friable greenish grey sands enclosing large concretions, sandstones containing small shells of gastropods may be treated as packages-stratigraphic data. Macrofossils occur throughout the section. Gastropods, ammonites (*Baculites*), bivalves, crabs, and the fragments (vertebrate, teeth) of marine pangolins such as mosasaurids are frequent. Inverterbrate trace fossils are abundant throughout the sequence. The traces of highest crawfishes (?) (ophiomorphs) obliquely or vertically piercing through a sandy bed are particularly common. The Maastrichtian age is dated by incomplete shells of *Baculites* ex gr. *anceps* of frequent occurrence and the bivalve *Tancredia americana* (Meek) as well as through the appearance of a specific assemblage of pollen with *Aquilapollenites quadrilobatus* Rouse (Zakharov et al. 1986; Zakharov & Khomentovsky 1989; Ilina et al. 1994). Inoceramids were not found in the Maastrichtian rocks.

The Working Group on the Maastrichtian Stage that had the meeting during the 2nd International Symposium on the stage boundaries of the Cretaceous System held in Brussels (1995) has decided to confine the stage base to the first appearance of the ammonite *Pachydiscus neuburgensis* (von Hauer) in the section. Of five possible localities to define GSSP, the quarry near the village of Tercis, Landes area (south-western France) was chosen, located between the Basque area in the south and Charentes area (with historical stratotype for the Campanian) in the north (Odin 1996). This selection of the section was convenient because of being located paleogeographically within the Tethys, and due to rich content of fossils which allows its correlation with Lower Boreal sections of North Germany and the Netherlands (Limburg).

## 7.3 Inoceramid zonation

Inoceramids are especially significant for the Northern Siberian zonal stratigraphy because of the rarity and low taxonomic diversity of the ammonites on which the standard scale was established. Inoceramid zones are used for correlation of the Upper Cretaceous sedi-

ments of Northern Siberia with those of Eastern and Western Europe and Northern America as well.

**7.3.1 Development of the inoceramid associations.**

The oldest inoceramids in Western Siberia are known from Upper Cenomanian sediments which were deposited during the period of global Cenomanian-Turonian transgression over the West Siberian Basin. These sediments are mostly characterized by *Inoceramus (Inoceramus) pictus* (Fig. 7.3) in association with its close relatives *I. (I.) tenuis* Mant., *I. (I.) ginterensis* Perg. (which was known before from the Kamchatka Peninsula only), *I. (I.) incelebratus* Per., and the endemic species *I. (I.) agapensis* Khoment. The presence of transitional forms between *I. (I.) pictus* Sow.–*I. (Mytiloides) labiatus* Schlot., which is confirmed by the phylogenetic relation between these two subgenera in the Siberian sections (Lower Agapa River) is remarkable.

An evident change of species associations happened at the Cenomanian/Turonian boundary. At this stratigraphic level the cosmopolitan polymorphic *Inoceramus (Mytiloides) labiatus* Schlot. replaced a diverse Late Cenomanian inoceramid association (Fig. 7.3). The group of *I. (Mytiloides) labiatus* is completely replaced by the morphologically diverse group *I. (I.) lamarcki,* which can be subdivided into four main phyletic branches. The first branch (*Inoceramus* s.str. line) comprises *I. (I.) cuvieri–I. (I.) lamarcki–I. (I.) sachsi.* In the Late Turonian–Early Coniacian, a series of endemic species evolved from the typical *I. (I.) lamarcki* Park. (closely related to the type species). These includes: *I. (I.) pseudocancellatus* Bodyl., *I. (I.) ecostatus* Efrem., *I. (I.) schulginae* Efrem., *I. (I.) septentrionalis* Bodyl., *I. (I.) jangodaensis* Efrem., *I. (I.) monopterus* Efrem. The lamarckoid inoceramids gradually became extinct during Late Coniacian when the gigantic *I. (I.) sachsi* Bodyl. started to dominate (Fig. 7.3) (Khomentovsky 1995).

Another phyletic line — *I. (I.) lamarcki–Volviceramus inaequivalvis–Volviceramus subinvolutus* appeared in the Late Turonian, when nonequal-valved specimens with swollen left valve, *V. inaequivalvis* (Schlut.), evolved. These forms were ancestors of the real involute inoceramids of *Volviceramus* which had arisen at the Turonian/Coniacian boundary. In Siberian sections this taxon is represented by the endemic *Volviceramus subinvolutus* (Bodyl.) (Fig. 7.3). At the same time, the forms with a noticeable change of the valve growth direction, which caused the development of a basal ledge, evolved from the concave *I. (I.) lamarcki* Park. *Cremnoceramus (I. (Cremnoceramus) inconstans* Woods) was a terminal form of this branch of lamarckoid inoceramids.

In the Late Coniacian some species of *Haenleinia* (*I. (Haenleinia) russiensis* Nik.), which are considered to be ancestors of sphenoceramids, evolved from the typical *I. (I.) lamarcki* Park. with their characteristic radial lowering (Fig. 7.3).

There is an evident change of the inoceramid associations at genus level at the Coniacian/Santonian boundary. At this stratigraphic level *Inoceramus* was replaced by *Sphenoceramus.* The well known branch of Sphenoceramids *Sphenoceramus cardissoides–S. patootensis–S. lingua–S. patootensiformis* in Western Europe is present in the Santonian associations of Western Siberia (Fig. 7.3). In Northern Siberia the number and diversity of inoceramids gradually decreased from Late Coniacian to Santonian until their final extinction in the Campanian.

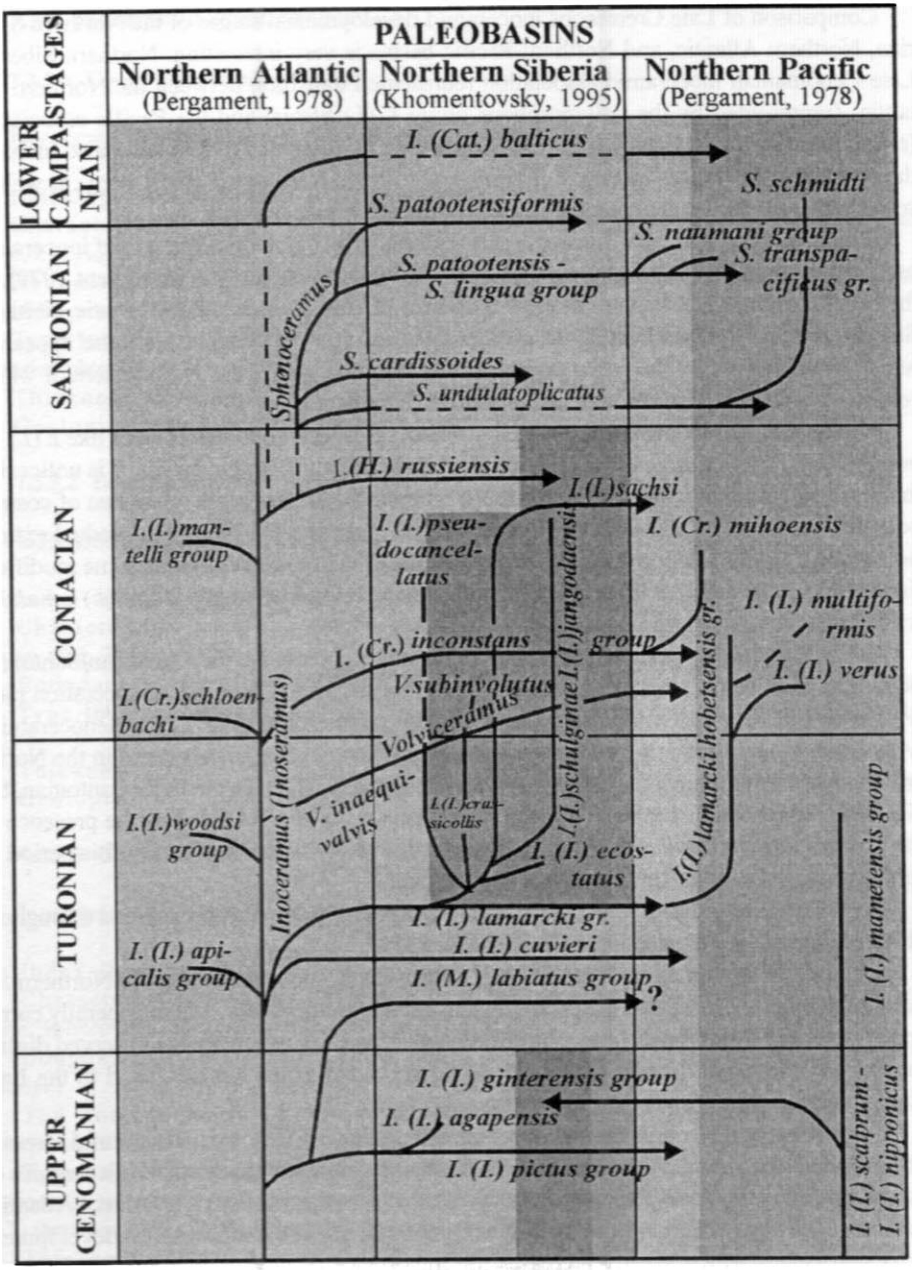


**Fig. 7.3.** Suggested phylogenetic relationships and migrations of the North Siberian inoceramid species, discussed in this paper. The relationships between groups were simplified to emphasize evolutionary history and migration. *Explanation:* The shading indicates geographical range of different inoceramid groups: light — Northern Atlantic; black — Northern Siberian endemic species; medley — Northern Pacific.

Comparison of Late Cretaceous inoceramid developmental stages of the Northern Siberian, Northern Atlantic, and Northern Pacific basins is very interesting. Northern Siberian Late Cenomanian inoceramid association represented transition between the Northern Atlantic- (represented by the polymorphous group *I.* (*I.*) *pictus*) and the Pacific association (represented by the phyletic line *I.* (*I.*) *scalprum*–*I.* (*I.*) *nipponicus*). The latter also includes the cosmopolitan "*pictus*" group: *I.* (*I.*) *ginterensis* Perg., *I.* (*I.*) *incelebratus* Perg., as well as some endemic species which occur in the Kamchatka Peninsula only.

During the Turonian and Coniacian periods, similarity of the development of inoceramid associations in different northern paleobasins significantly increased (Pergament 1979). In the Late Turonian, when the rate of morphogenesis decreased in the Northern Atlantic, Northern Siberia, and the Northern Pacific, the group *Inoceramus (Mytiloceramus) labiatus* appeared, which was followed by the polymorphous *I. (I.) lamarcki* group, the development of which represents a characteristic feature of that period (Khomentovsky 1995).

A large number of endemic species, as well as typical cosmopolitan species like *I.* (*I.*) *lamarcki* Park., was a characteristic feature of all three principal Boreal basins. It is noticeable that the number of endemics in the Northern Siberian Basin was higher than that of cosmopolitans. During the Coniacian, the northern basins were characterized by a gradual extinction of the *I.* (*I.*) *lamarcki* group, and under the influence of local conditions some modifications of species of different branches of lamarckoid inoceramids appeared (e.g. *I.* (*I.*) *lamarcki*–*I.* (*Crem.*) *inconstans*, and others (see above)).

Noticeably, less significant changes of inoceramids occurred at the Coniacian/Santonian boundary. That period of time was characterized by an evident decrease of speciation rates which was followed by a complete replacement of the associations (Fig. 7.3). Sphenoceramids with divergent sculpture (*Sphenoceramus undulatoplicatus* (Roem.) appeared in the Northern Atlantic and Northern Pacific paleobasins (Pergament 1979). In the Early Santonian, the Northern Atlantic and Northern Siberian paleobasins were characterized by the presence of the *Sphenoceramus cardissoides* group, whereas in the Northern Pacific area this period of time was represented by the *I. transpacificus* group.

In the Late Santonian the *Sphenoceramus patootensis* group was widespread throughout all three paleobasins (Pergament 1979; Troeger 1989).

Analyses of stratigraphic distribution of Upper Cretaceous inoceramids in Northern Siberia enable the specification of species maxima and minima phases, which generally correspond to those of the adjacent paleobasins. Phases of species minima were observed during the Early Turonian and Early Santonian; while species maxima are attributed to the Late Cenomanian, Late Turonian and Coniacian (Fig. 7.3).

In conclusion, the compositional development of Upper Cretaceous inoceramid associations in Northern Siberia is similar to the major changes (in the main morphologic features of associations and their composing species) to those of the adjacent basins (Northern Atlantic/Pacific). This observation indicates the synchronous nature of the inoceramids development in Boreal basins which greatly increases the importance of inoceramids for interregional correlation of Upper Cretaceous sequences.

### 7.3.2 Inoceramid zonation.

#### 7.3.2.1 Upper Cenomanian.

Inoceramus (Inoceramus) pictus Zone

Index-species: *Inoceramus (I.) pictus* Sowerby.

Characteristic species: *Inoceramus (I.) pictus* Sow., *I. (I.) tenuis* Mant., *I. (I.) ginterensis* Perg., *I. (I.) agapensis* Khom., *I. (I.)* aff. *incelebratus* Perg. (Fig. 7.4).

Boundaries. Base: the first occurrence (FO) of *Inoceramus (Inoceramus) pictus* Sow. Top: the FO of *Inoceramus (Mytiloides) labiatus* Schloth.

Type locality: Agapa River, members Ib-X; grey silts, silts clay, glauconitic fine sands with septarian phosphorite (Fig. 7.2).

Thickness: 43.9 m.

Geological age: Late Cenomanian.

#### 7.3.2.2 Lower Turonian.

Inoceramus (Mytiloides) labiatus Zone

Index-species: *I. (Mytiloides) labiatus* Schlotheim.

Characteristic species: *I. (Mytiloides) labiatus* Schloth., *I. (I.) pictus* Sow., *I. (I.) agapensis* Khom. (Fig. 7.4).

Boundaries. Base: the FO of *I. (Mytiloides) labiatus*. Top: the FO of *I. (I.)* cf. *cuvieri* Sowerby.

Type locality: Agapa River, members XI-XIII; dark-grey silts, clay with sand partings (Fig. 7.2).

Thickness: 25 m.

Geological age: Early Turonian.

#### 7.3.2.3 Upper Turonian.

Inoceramus (Inoceramus) lamarcki Zone (s.l.)

Index-species: *I. (I.) lamarcki* (s.l.).

Characteristic species: *I. (I.) lamarcki* Park., *I. (I.) pseudocancellatus* Bodyl., *I. (I.)* cf. *cuvieri* Sow., *Volviceramus inaequivalvis* (Schlut.) (Fig. 7.4).

Boundaries. Base: the FO of *I. (I.)* cf. *cuvieri* Sow. Top: the FO of *Volviceramus subinvolutus* (Bodyl.).

The Zone includes: I. (I.) cf. cuvieri Beds; I. (I.) lamarcki (s.s.) Subzone; Volviceramus inaequivalvis Subzone.

Type locality: Agapa River, members XIV-XV; silts, sands. Chaika River, members I-VII; glauconitic green sands with septarians phosphorite, silts with bands of clay. Yangoda River, members I-X; the alternation of green-grey sands with clayey silts (Fig. 7.2).

Thickness: 114 m.

Geological age: Late Turonian.

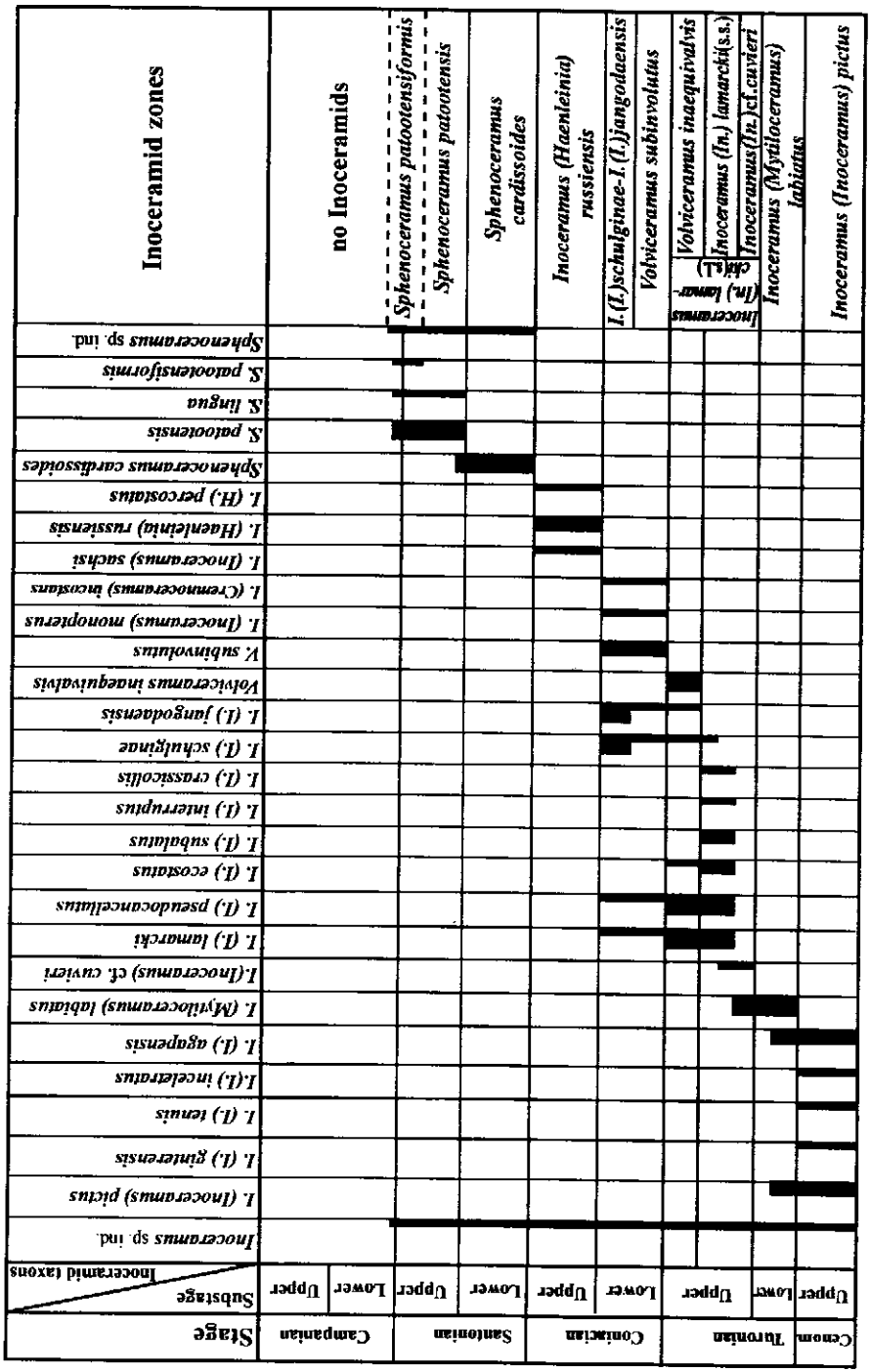


Fig. 7.4. Upper Cretaceous inoceramid zonation of Northern Siberia.

Inoceramus (Inoceramus) cf. cuvieri Beds

Index-species: *Inoceramus (Inoceramus)* cf. *cuvieri* Sowerby.
Characteristic species: *I. (I.)* cf. *cuvieri* Sow., *I. (Mytiloides) labiatus* Schloth. (Fig. 7.4).
Boundaries. Base: the FO of *I. (I.)* cf. *cuvieri*. Top: the FO of *I. (I.) lamarcki* Park.
Type locality: Agapa River, members XIV–XV; silts, sands (Fig. 7.2).
Thickness: 19 m.
Geological age: Late Turonian.

Inoceramus (Inoceramus) lamarcki Subzone (s.s.)

Index-species: *Inoceramus (Inoceramus) lamarcki* Park.
Characteristic species: *I. (I.) lamarcki* Park., *I. (I.) pseudocancellatus* Bodyl., *I. (I.) ecostatus* Efrem. (Fig. 7.4).
Boundaries. Base: the FO of *I. (I.) lamarcki*. Top: the FO of *Volviceramus inaequivalvis* (Schlut.).
Type locality: Chaika River, members I–VII; glauconitic green sands with septarians phosphorite, silts with bands of clay (Fig. 7.2).
Thickness: 36.9 m.
Geological age: Late Turonian.

Volviceramus inaequivalvis Subzone

Index-species: *Volviceramus inaequivalvis* (Schlut.).
Characteristic species: *V. inaequivalvis* (Schlut.), *I. (I.) pseudocancellatus* Bodyl., *I. (I.) lamarcki* Park., *I. (I.) schulgina* Efrem. (Fig. 7.4).
Boundaries. Base: the FO of *V. inaequivalvis*. Top: the FO of *V. subinvolutus* (Bodyl.).
Type locality: Yangoda River, members I–X; the alternation of green-grey sands with clayey silts (Fig. 7.2).
Thickness: 58.1 m.
Geological age: Late Turonian.

**7.3.2.4 Lower Coniacian.**

Volviceramus subinvolutus Zone

Index-species: *V. subinvolutus* (Bodyl.).
Characteristic species: *V. subinvolutus* (Bodyl.), *I. (Cremnoceramus) inconstans* Woods, *I. (I.) schulginae* Efrem., *I. (I.) jangodaensis* Efrem. (Fig. 7.4).
Boundaries. Base: the FO of *V. subinvolutus*. Top: the FO of *I. (H.) russiensis* Nikit.
Type locality: Yangoda River, members XI–XV; sands, glauconitic sands (Fig. 7.2).
Thickness: 33.6 m.
Geological age: Early Coniacian.

Inoceramus (I.) schulginae–I. (I.) jangodaensis Beds

Epibole of *I. (I.) schulginae* Efrem., *I. (I.) jangodaensis* Efrem.
Characteristic species: *I. (I.) schulginae* Efrem., *I. (I.) jangodaensis* Efrem., *I. (Cremnoceramus) inconstana* Woods (Fig. 7.4).

Boundaries. Base: the epibole of *I. (I.) schulginae*, *I. (I.) jangodaensis*. Top: the FO of *I. (Haenleinia) russiensis* Nikit.

Type locality: Yangoda River, members XVI–XX; sands, glauconitic sands (Fig. 7.2).

Thickness: 22.3 m.

Geological age: Early Coniacian.

**7.3.2.5 Upper Coniacian.**

Inoceramus (Haenleinia) russiensis Zone

Index-species: *I. (Haenleinia) russiensis* Nikitin.

Characteristic species: *I. (Haenleinia) russiensis* Nik., *I. (I.) sachsi* Bodyl., *Volviceramus* cf. *subinvolutus* (Bodyl.) (Fig. 7.4).

Boundaries. Base: the FO of *I. (H.) russiensis*. Top: the last occurrence (LO) of *I. (H.) russiensis*.

Type locality: Vorontsovo section, members XXI–XXV; sands, glauconitic sands, silts (Fig. 7.2).

Thickness: 20.1 m.

Geological age: Late Coniacian.

**7.3.2.6 Lower Santonian.**

Sphenoceramus cardissoides Zone

Index-species: *S. cardissoides* (Goldf.).

Characteristic species: *S. cardissoides* (Goldf.) (Fig. 7.4).

Boundaries. Base: the FO of *S. cardissoides*. Top: the FO of *S. patootensis* (Lor.).

Type locality: Tanama River, members I–II; sands, glauconitic sands with septarians phosphorite, silts (Fig. 7.2).

Thickness: 9 m.

Geological age: Early Santonian.

**7.3.2.7 Upper Santonian.**

Sphenoceramus patootensis Zone

Index-species: *Sphenoceramus patootensis* (Lor.).

Characteristic species: *Sphenoceramus patootensis* (Lor.), *Sphenoceramus lingua* (Goldf.) (Fig. 7.4).

Boundaries. Base: the FO of *S. patootensis*. Top: the LO of *S. patootensis*.

Type locality: Tanama River, members III–V; glauconitic sands, sandy silts with septarians phosphorite (Fig. 7.2).

Thickness: 21.2 m.

Geological age: Late Santonian.

**7.3.2.8 Upper Santonian–Lower Campanian.**

Sphenoceramus patootensiformis Beds

Index-species: *Sphenoceramus patootensiformis* (Seitz.).

Characteristic species: *Sphenoceramus patootensiformis* (Seitz.), *S. patootensis* (Lor.), *S. lingua* (Goldf.), *S. pinniformis* (Will.).

Boundaries. Base: the FO of *Sphenoceramus patootensiformis* (Seitz.). Top: the LO of *Sphenoceramus* sp. ind. (Fig. 7.4).

Type locality: Cheta River, clayey silts.

Thickness: 34.3 m.

Geological age: Late Santonian–Early Campanian.

## 7.4 Dinocyst units

Stratigraphic units were deposited on a broad coastal shelf. 328 samples from all section were studied palynologically (101 Santonian-Maastrichtian samples, 57 — Upper Cenomanian-Lower Turonian, 203 — Turonian-Coniacian, 25 — Kheta River section). Numerous and diverse assemblages of microphytofossils were found in the whole sequence. Marine palynological assemblages are composed mainly of dinoflagellate cysts, although acritarchs and prasinophytes are also present. The first and last appearance and abundance of some species have been used for detailed subdivision (Fig. 7.5).

### 7.4.1 Dinocyst Beds.

Geiselodinium cenomanicum Beds

Index-species: *Geiselodinium cenomanicum*.

Characteristic species: *G. cenomanicum*, *Subtilisphaera inaffecta*, *Trithyrodinium rhomboideum*, *Trichodinium castanea*, *Ovoidinium scabrosum*, *Litosphaeridium siphoniphorum*, *Pterodinium cingulatum*, *Pervosphaeridium truncatum* dominate (Fig. 7.5).

Boundaries. Base: the occurrence of the characteristic dinocyst assemblage.

Type locality: Agapa River, members II–VI; grey silts, silty clay.

Thickness: 13 m.

Distribution: Ust-Yenisey region.

Calibration: Lower part of the Inoceramus pictus Zone.

Geological age: Late Cenomanian.

Eurydinium saxoniense Beds

Index-species: *Eurydinium saxoniense*.

Characteristic species: *E. saxoniense*, *Xenascus blastema*, *Canningia rotundata*. *Ginginodinium evittii*, *?Amphidiadema* sp. A are abundant (Fig. 7.5).

Boundaries. Base: the FO of *E. saxoniense*, *?Amphidiadema* sp. A, *Microdinium ornatum*, *Alterbidinium minus*.

Type locality: Agapa River, members VII–IX; silty clay, glauconitic fine sands with septarian phosphorite.

Thickness: 14.5 m.

Distribution: Ust-Yenisey region.

Calibration: Upper part of the Inoceramus pictus Zone.

Geological age: Late Cenomanian.

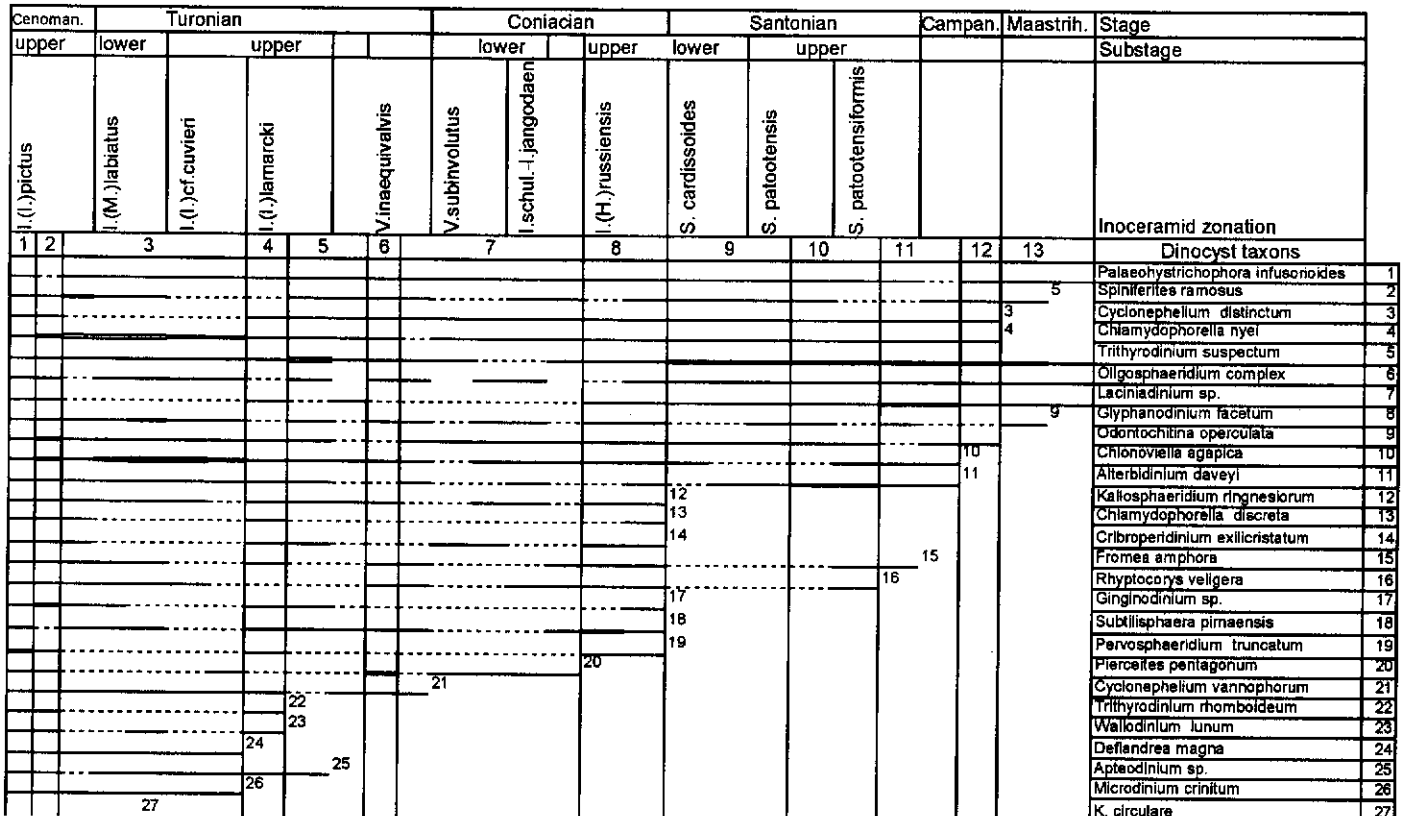


**Fig. 7.5.** *Continued on pages 157 and 158.*

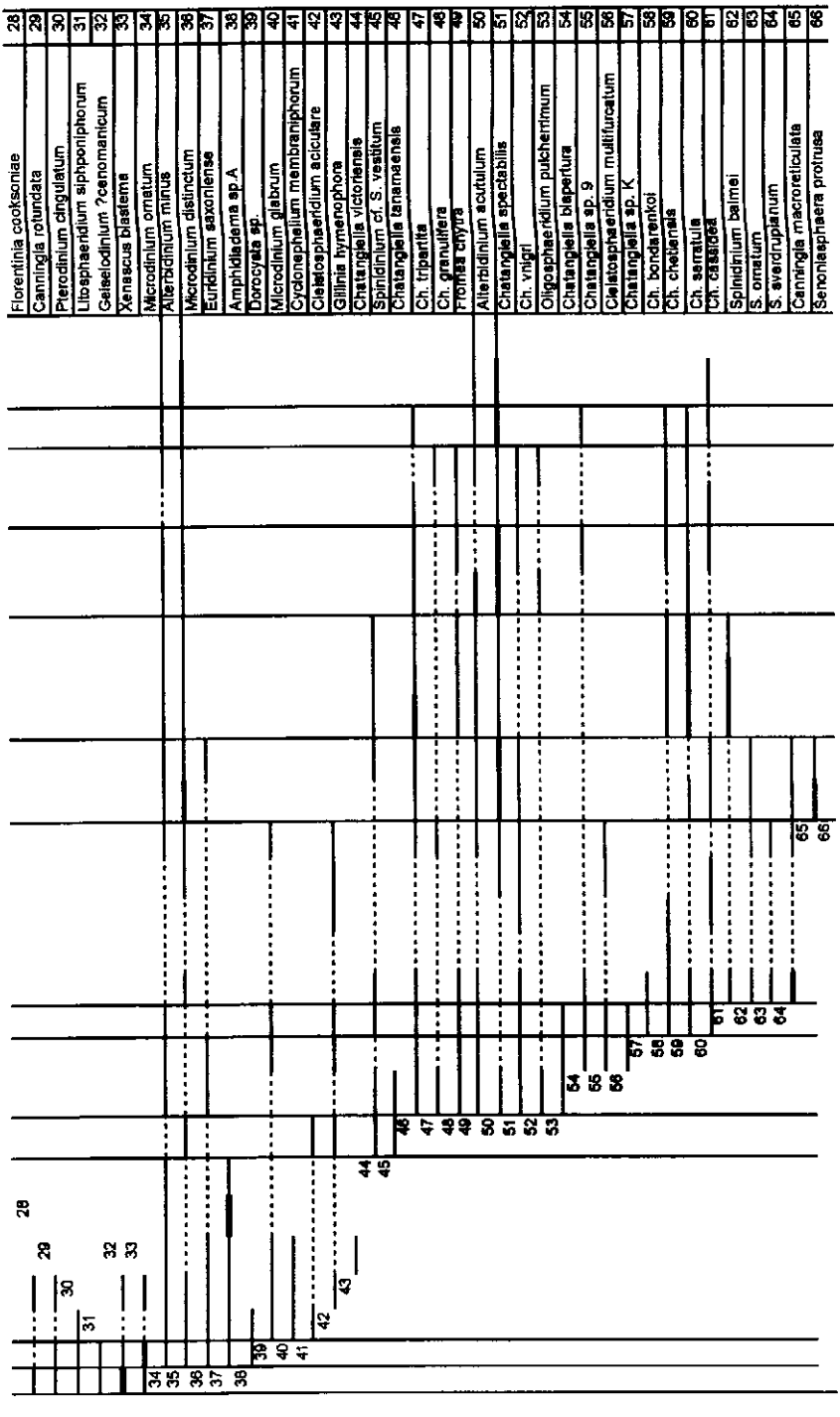


Fig. 7.5. *Continued on page 158.*

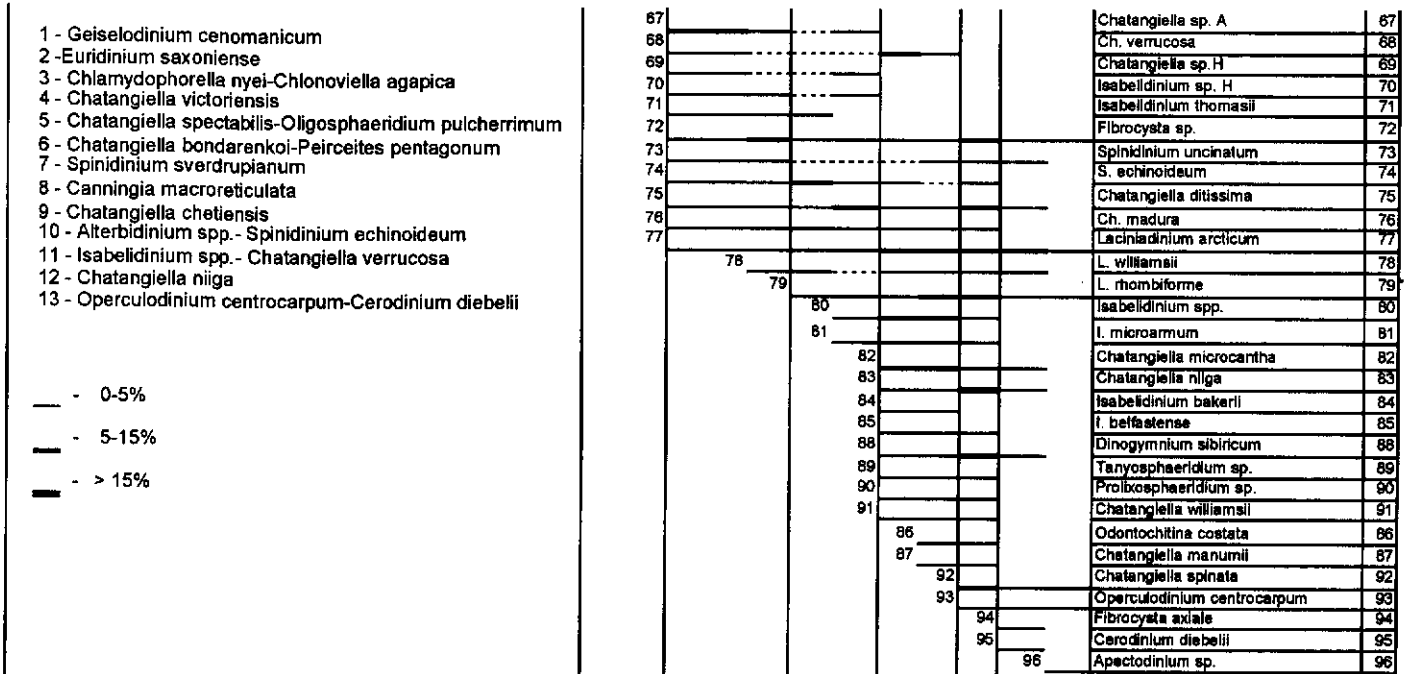


Fig. 7.5. Upper Cretaceous inoceramid zonation of the whole Boreal Realm. *(Fig. 7.5 begins on page 156.)*

Chlamydophorella nyei-Chlonoviella agapica Beds

Index-species: *Ch. nyei, Chlon. agapica.*

Characteristic species: *Ch. nyei, Ch. discreta, Chlon. agapica, Microdinium glabrum, Cyclonephelium membraniphorum, Kallosphaeridium circulare, Glyphanodinium facetum* (Fig. 7.5).

Boundaries. Base: the FO of *Dorocysta* sp., *Cleistosphaeridium aciculare, Microdinium ornatum, Cyclonephelium membraniphorum* and disappearance of *Litosphaeridium siphoniphorum, Geiselodinium cenomanicum, ?Amphidiadema* sp. A.

Type locality: Agapa River, members XI-XV, dark-grey aleuritic clay with sand partings (Fig. 7.2).

Thickness: 47 m.

Distribution: Ust-Yenisey region, Subarctic Ural (well 23-k).

Calibration: Upper part of the I. pictus Zone, I. (Mytiloides) labiatus Zone; I. (I.) cf. cuvieri Beds.

Geological age: Late Cenomanian, Turonian.

Chatangiella victoriensis Beds

Index-species: *Ch. victoriensis.*

Characteristic species: *Ch. victoriensis, Ch. tripartita, Cyclonephelium distinctum, Kallosphaeridium ringnessiorum, Euridinium* sp., *Spinidinium* cf. *vestitum* (Fig. 7.5).

Boundaries. Base: the FO of genus *Chatangiella* and disappearance of *?Deflandrea magna, Eurydinium saxoniense, Pterodinium cingulatum.*

Type locality: Chaika River, members I-II; glauconitic green sands with septarians phosphorite, silts with bands of clay (Fig. 7.2).

Thickness: 20 m.

Distribution: Ust-Yenisey region.

Calibration: I. (I.) lamarcki Zone.

Geological age: Late Turonian.

Chatangiella spectabilis-Oligosphaeridium pulcherrimum Beds

Index-species: *Chatangiella spectabilis, Oligosphaeridium pulcherrimum.*

Characteristic species: *Dorocysta* sp., *Oligosphaeridium pulcherrimum, Cyclonephelium vannophorum, Cleistosphaeridium aciculare, C. multifurcatum, Chatangiella biapertura, Pierceites pentagonum, Florentinia ferox, Microdinium distinctum* (Fig. 7.5).

Boundaries. Base: the FO of *Chatangiella spectabilis, Ch. tripartita, Ch. vnigri, Ch. granulifera, Ch. tanamaensis, Ch. biapertura, Alterbidinium acutulum, Oligosphaeridium pulcherrimum.*

Type locality: Chaika River, members III-VII; Yangoda River, members I-II; sands, glauconitic sands (Fig. 7.2).

Thickness: 34 m.

Distribution: Ust-Yenisey region.

Calibration: Upper part of the I. (I.) lamarcki Zone, lower part of the Volviceramus inaequivalvis Zone.

Geological age: Late Turonian.

Chatangiella bondarenkoi-Pierceites pentagonum Beds

Index-species: *Chatangiella bondarenkoi, Pierceites pentagonum.*

Characteristic species: Dominating *Ch. bondarenkoi* accompanied with *Ch. serratula, Pierceites pentagonum, Chatangiella spectabilis* (Fig. 7.5).

Boundaries. Base: the FO of *Chatangiella serratula, Ch. bondarenkoi, Ch. chetiensis,* the last occurrence (LO) of *Trithyrodinium rhomboideum, Wallodinium lunum, Cyclonephelium membraniphorum.*

Type locality: Yangoda River, members III–lower part of VIII; sands, clay (Fig. 7.2).

Thickness: 37 m.

Distribution: Ust-Yenisey region.

Calibration: Middle part Volviceramus inaequivalvis Zone

Geological age: Late Turonian.

Spinidinium sverdrupianum Beds

Index-species: *Spinidinium sverdrupianum.*

Characteristic species: *S. sverdrupianum. S. balmei, S. ornatum, Subtilisphaera pirnaensis, Palaeohystrichophora infusorioides* dominate (Fig. 7.5).

Boundaries. Base: the FO of *S. sverdrupianum., S. balmei S. ornatum, Chatangiella cassidea,* the LO of *Oligosphaeridium pulcherrimum, Cleistosphaeridium aciculare, Pierceites pentagonum.*

Type locality: Yangoda River, members: upper part of VIII–XIX; sands, glauconitic sands, silts (Fig. 7.2).

Thickness: 61 m.

Distribution: Ust-Yenisey region.

Calibration: The Uppermost part of the Volviceramus inaequivalvis Zone; Volviceramus subinvolutus Zone, Inoceramus schulginae–I. jangodaensis Beds.

Geological age: Late Turonian, Early Coniacian.

Canningia macroreticulata Beds

Index-species: *Canningia macroreticulata.*

Characteristic species: *C. macroreticulata, Alterbidinium minus, Senoniasphaera protrusa* (Fig. 7.5).

Boundaries. Base: range interval of *C. macroreticulata,* the LO of *Pierceites pentagonum, Spinidinium ornatum, Dorocysta* sp., *Cleistosphaeridium aciculare, Chatangiella* sp. 9.

Type locality: Vorontsovo section, members XXI–XXV; sands, glauconitic sands, silts (Fig. 7.2).

Thickness: 20.1 m.

Distribution: Ust-Yenisey region, Subarctic Ural.

Calibration: I. russiensis Zone.

Geological age: Late Coniacian.

Chatangiella chetiensis Beds

Index-species: *Chatangiella chetiensis.*

Characteristic species: *Spinidinium uncinatum. Chatangiella chetiensis, Ch. tanamaensis, Ch. cassidea, Trithyrodinium suspectum* dominate (Fig. 7.5).

Boundaries. Base: the FO of *Chatangiella verrucosa, Ch. madura, Ch. ditissima, Ch.* sp. A, H, *Spinidinium uncinatum, S. echinoideum, Isabelidinium* sp. H, *I. thomasii, Fibrocysta* sp., the LO of *Canningia macroreticulata, Senoniasphaera protrusa, Spinidinium sverdrupianum, S. balmei, Microdinium distinctum.*

Type locality: Tanama River, members I-II; sands, glauconitic sands, silts (Fig. 7.2).
Thickness: 11.7 m.
Distribution: Ust-Yenisey region.
Calibration: Sphenoceramus cardissoides Zone, lower part of Sph. patootensis Zone.
Geological age: Santonian.

Alterbidinium spp.-Spinidinium echinoideum Beds

Index-species: *Alterbidinium* spp., *Spinidinium echinoideum*.
Characteristic species: *A. daveyi, A. acutulum, Sp. Echinoideum, Fibrocysta* sp. dominate over *Chatangiella madura, Ch. ditissima, Microdinium ornatum, M. kustanaicum* Vozzh. Quantity of *Chatangiella* substantionally decreases (Fig. 7.5).
Boundaries. Base: the LO of *Laciniadinium rhombiforme*, the LO of *Chatangiella cassidea, Ch. victoriensis*.
Type locality: Tanama River, members III; Kheta River, members I-III, sands, glauconitic sands, sandy silts (Fig. 7.2).
Thickness: 28 m.
Distribution: Ust-Yenisey, Khatanga regions.
Calibration: Upper part of the Sphenoceramus patootensis Zone, part of the Sphenoceramus patootensiformis Zone.
Geological age: Late Santonian.

Isabelidinium spp.-Chatangiella verrucosa Beds

Index-species: *Isabelidinium* spp., *Chatangiella verrucosa*.
Characteristic species: *Chatangiella verrucosa, Isabelidinium* spp. *(I. cooksoniae, I. microarmum), Chatangiella vnigri, Diconodinium rhombiforme, D. cristatum* (Fig. 7.5).
Boundaries. Base: the FO of *Chatangiella niiga, Ch. microcantha, Ch. manumii, Isabelidinium amphiatum, I. belfastense, I. bakerii*. Top: the LO *Chatangiella granulifera, Ch. verrucosa, Ch. vnigri, Alterbidinium daveyi*.
Type locality: Tanama River, members IV-V; Kheta River — IV-V, clay (Fig. 7.2).
Thickness: 23.1 m.
Distribution: Ust-Yenisey, Khatanga regions.
Calibration: Part of Sphenoceramus patootensiformis Zone.
Geological age: ?Campanian.

Chatangiella niiga Beds

Index-species: *Chatangiella niiga*.
Characteristic species: *Ch. niiga, Ch. manumii, Ch.* sp. G, *Dinogymnium sibiricum, Tanyosphaeridium, Prolixosphaeridium, Fibrocysta* are abundant (Fig. 7.5).
Boundaries. Base: The LO of *Chatangiella verrucosa, Ch. vnigri, Ch. spectabilis, Ch. granulifera, Ch. tripartita, Chlonoviella agapica, Alterbidinium daveyi*. Quantity of *Chatangiella niiga, Ch. manumii, Ch.* sp. G sharply increases.
Type locality: Tanama River, members VI-VII; Kheta River — VI-IX, clay, silty clay (Fig. 7.2).
Thickness: 22 m.
Distribution: Ust-Yenisey, Khatanga region.
Geological age: ?Campanian.

Operculodinium centrocarpum-Cerodinium diebelii Beds

Index-species: *Operculodinium centrocarpum, Cerodinium diebelii.*

Characteristic species: *O. centrocarpum, Chatangiella ditissima, Laciniadinium arcticum, Cerodinium diebelii* (Fig. 7.5).

Boundaries. Base: the FO *C. diebelii, Fibrocysta axiale.*

Type locality: Tanama River, members VIII-XII; glauconitic sands, sandy silts (Fig. 7.2).

Thickness: 22.7 m.

Distribution: Ust-Yenisey region.

Geological age: Maastrichtian.

### 7.4.2 List of dinocysts species.

?*Amphidiadema* sp. A.
?*Deflandrea magna* Davey, 1970
*Alterbidinium acutulum* (Wilson, 1967) Lentin et Williams, 1985
*Alterbidinium daveyi* (Stover et Evitt, 1978) Lentin et Williams, 1985
*Alterbidinium minus* (Alberti, 1959) Lentin et Williams, 1985
*Apteodinium maculatum* Eisenack et Cookson, 1960
*Canningia macroreticulata* Lebedeva, 1994
*Canningia rotundata* Cookson et Eisenack, 1961
*Cerodinium diebelii* (Alberti, 1959) Lentin et Williams, 1987
*Chatangiella biapertura* (McIntyre, 1975) Lentin et Williams, 1976
*Chatangiella bondarenkoi* (Vozzhennikova, 1967) Lentin et Williams, 1976, emend. Lebedeva, 1994
*Chatangiella cassidea* Lebedeva, 1988
*Chatangiella chetiensis* (Vozhennikova, 1967) Lentin et Williams, 1976, emend. Lebedeva, 1994
*Chatangiella ditissima* (McIntyre, 1975) Lentin et Williams, 1976
*Chatangiella granulifera* (Manum, 1963) Lentin et Williams, 1976
*Chatangiella madura* Lentin et Williams, 1976
*Chatangiella manumii* (Vozhennikova, 1967) Lentin et Williams, 1976
*Chatangiella niiga* Vozhennikova, 1967
*Chatangiella serratula* (Cookson et Eisenack, 1958) Lentin et Williams, 1976
*Chatangiella spectabilis* (Alberti, 1959) Lentin et Williams, 1976
*Chatangiella tanamaensis* Lebedeva, 1988
*Chatangiella tripartita* (Cookson et Eisenack, 1960) Lentin et Williams, 1976
*Chatangiella verrucosa* (Manum, 1963) Lentin et Williams, 1976
*Chatangiella victoriensis* (Cookson et Manum, 1964) Lentin et Williams, 1976
*Chatangiella vnigri* (Vozzhennikova, 1967) Lentin et Williams, 1976, emend. Lebedeva, 1994
*Chlamydophorella discreta* Clarke et Verdier, 1967
*Chlamydophorella nyei* Cookson et Eisenack, 1958
*Chlonoviella agapica* Lebedeva, 1994
*Cleistosphaeridium aciculare* Davey, 1969
*Cleistosphaeridium multifurcatum* (Deflandre, 1937) Davey et al., 1969
*Cribroperidinium exilicristatum* (Davey, 1969) Stover et Evitt, 1978
*Cyclonephelium distinctum* Deflandre et Cookson, 1955
*Cyclonephelium membraniphorum* Cookson et Eisenack, 1962

*Cyclonephelium vannophorum* Davey, 1969
*Diconodinium cristatum* Cookson et Eisenack, 1974
*Diconodinium rhombiforme* Vozzhennikova, 1967
*Dinogymnium sibiricum* (Vozzhennikova, 1967) Lentin et Williams, 1973
*Eurydinium saxoniense* Marshall et Batten, 1988
*Florentinia cooksoniae* (C. Singh, 1971) Duxbury, 1980
*Florentinia ferox* (Deflandre, 1937) Duxbury, 1980
*Geiselodinium cenomanicum* Lebedeva, 1994
*Ginginodinium evittii* C. Singh, 1983
*Glyphanodinium facetum* Drugg, 1964
*Isabelidinium amphiatum* (McIntyre, 1975) Lentin et Williams, 1977
*Isabelidinium bakeri* (Deflandre et Cookson, 1955) Lentin et Williams, 1977
*Isabelidinium microarmum* (McIntyre, 1975) Lentin et Williams, 1977
*Isabelidinium cooksoniae* (Alberti, 1959) Lentin et Williams, 1977
*Kallosphaeridium circulare* (Cookson et Eisenack, 1971) Helby, 1987
*Kallosphaeridium ringnessiorum* (Manum et Cookson, 1964) Helby, 1987
*Laciniadinium arcticum* (Manum et Cookson, 1964) Lentin et Williams, 1980
*Laciniadinium williamsii* Ioannides, 1986
*Litosphaeridium siphoniphorum* (Cookson et Eisenack, 1958) Davey et Williams, 1966
*Microdinium distinctum* Davey, 1969
*Microdinium glabrum* Cookson et Eisenack, 1974
*Microdinium kustanaicum* Vozzhennikova, 1967
*Microdinium ornatum* Cookson et Eisenack, 1960a
*Odontochitina operculata* (O. Wetzel, 1933) Deflandre et Cookson, 1955
*Oligosphaeridium complex* (White, 1842) Davey et Williams, 1966
*Oligosphaeridium pulcherrimum* (Deflandre et Cookson, 1955) Davey et Williams, 1966
*Operculodinium centrocarpum* (Deflandre et Cookson, 1955) Wall, 1967
*Ovoidinium scabrosum* (Cookson et Hughes, 1964) Davey, 1970
*Palaeohystrichophora infusorioides* Deflandre, 1935
*Pervosphaeridium truncatum* (Davey, 1969) Below, 1982
*Pierceites pentagonum* (May, 1980) Habib et Drugg, 1987
*Pterodinium cingulatum* (O. Wetzel, 1933) Below, 1981
*Rhiptocorys veligera* (Deflandre, 1937) Lejeune-Carpentier et Sarjeant, 1983
*Senoniasphaera protrusa* Clarke et Verdier, 1967
*Spinidinium balmei* (Cookson et Eisenack, 1962) Ioannides, 1986
*Spinidinium echinoideum* (Cookson et Eisenack, 1960, emend. Sverdlove et Habib, 1974) Lentin et Williams, 1976
*Spinidinium ornatum* (May, 1980) Lentin et Williams, 1981
*Spinidinium sverdrupianum* (Manum, 1963) Lentin et Williams, 1973
*Spinidinium uncinatum* May, 1980
*Spiniferites ramosus* (Ehrenberg, 1838) Mantell, 1854
*Subtilisphaera inaffecta* (Drugg, 1978) Bujak et Davies, 1983
*Subtilisphaera pirnaensis* (Alberti, 1959) Jain et Millepied, 1973
*Trichodinium castanea* Deflandre, 1935
*Trithyrodinium rhomboideum* C. Singh, 1983
*Trithyrodinium suspectum* (Manum et Cookson, 1964) Davey, 1969
*Xenascus blastema* (Davey, 1970) Stover et Helby, 1987

## 7.5 Parallel biozonation

Both zonal scales (inoceramid-based and dinocyst-based) have been independently developed in the same Upper Cretaceous sequences of Northern Siberia. Nevertheless, in seven instances, nine dinocyst boundary beds coincide with inoceramid-based boundaries and in the cases of the Upper Cenomanian and the Upper Turonian the dinocyst-based scale appears to be more detailed than that based on inoceramids (Fig. 7.2). Obviously the paces of inoceramid and dinoflagellate evolution were different. There are good arguments to believe that inoceramid evolution was faster. Therefore, 13 successive dinocyst assemblages are not directly related with 13 successive stages in dinoflagellate phylogeneses, although both reflected environmental changes. It is likely that the temporal changes in the dinoflagellate assemblage structures were affected by regional migration and local ecological successions rather than by taxonogenesis proper. This is because the majority of dinocyst zones established not traceable outside the Siberian region.

Distribution of inoceramids plays another game. The succession of their assemblages is associated directly with phyletic innovations (taxonogenesis) and with long-distance migration in the seas of the Northern Hemisphere (Fig. 7.3). As a result the inoceramid-based zones posess high correlation potential. Six of ten zones and beds with inoceramids can be correlated directly with the zones of the Russian Platform and the species of another three Siberian zones: Volviceramus inaequivalvis, V. subinvolutus, Inoceramus (Haenleinia) russiensis, are encountered in inoceramid assemblages from coeval zones of the Russian Platform (Fig. 7.6). Inoceramid zones provide direct or indirect correlation (through the northern part of Europe) with stage stratotypes in France and Belgium. Thanks to inoceramid-based zones only, it was possible to date the zones and beds with dinocysts. Nevertheless, the beds with dinocysts are advantageous over inoceramid-based zones in oil and gas-prospecting in Western Siberia, as inoceramids are extremely rare in drill cores of the wells. The scale based on dinocysts provides the correlation and is helpful in dating of the formations and regional horizons exposed by the wells at 2–3 kilometers depth. Combined analysis of the two parallel scales (inoceramid- and dinocyst-based) allows more reliable Panboreal correlation of Upper Cretaceous deposits than these could offer separately.

## 7.6 Panboreal correlation

The problem of the Upper Cretaceous Panboreal correlation was discussed recently by Sahagian et al. (1994). Difficulties emerge in zonal correlation between Northern America and Western Europe and Western Siberia, where ammonites are rare. Rather good correlation can be provided by inoceramids. Boreal Upper Cretaceous biostratigraphy has been elaborated thoroughly by numerous authors (Papulov & Naidin 1979; Naidin et al. 1986; Troeger 1989) and is described below (Fig. 7.6). Nine Upper Cenomanian inoceramid zones have been established at the Santonian-Campanian boundary. Inoceramids have not been recognized from the main part of Campanian and Maastrichtian strata (Zakharov et al. 1991).

The Russian Platform serves as a bridge for the Upper Cretaceous stratigraphic correlation of Western Siberia and Western Europe. A very similar succession of inoceramids was

recognized in Western Siberia and the Russian Platform (Fig. 7.6). A good correlation between these two regions has been obtained, based on the recognition of identical index species, such as *Inoceramus (Inoceramus) pictus* (Upper Cenomanian), *I. (Mytiloceramus) labiatus* (Lower Turonian), *I. (I.) lamarcki* (Middle Turonian), *Sphenoceramus cardissoides* (Lower Santonian), and *S. patootensis* (Upper Santonian). For other times, correlation is based on co-occurring species. The occurrence of *I. (Haenleinia) russiensis* (West Siberia) in the Volviceramus involutus Zone of the Russian Platform may be treated as an example of this.

There are some difficulties in correlation with Western and Eastern Europe, since only a few zones are coincident with the West Siberian succession. These embrace the boundary between the I. (I.) pictus and I. (M.) labiatus Zones that marks the Cenomanian-Turonian boundary, the first appearance of *I. (I.) lamarcki* as the base of Middle Turonian, the first appearance of *S. cardissoides*, that determines the base of Santonian, and the S. patootensis

| Stage | Substage | Succession of inoceramids: Northern Siberia | Russian Platform (Naidin et al., 1986) | Poland (Walaszczyk, 1992) | Western and Eastern Europe (Troeger, 1989) | Substage |
|---|---|---|---|---|---|---|
| Campanian | U | | | | impressus | U |
| | | | | | regularis | |
| | L | | balticus | | balticus | L |
| | | patootensiformis | | patootensiformis | patootensiformis | |
| Santonian | U | patootensis | patootensis | pinniformis | pinniformis | U |
| | L | cardissoides | cardissoides | cardissoides | cordiformis | M |
| | | | | | undulatoplicatus | L |
| | | | | | cardissoides | |
| Coniacian | U | russiensis | involutus | subquadratus | subquadratus | U |
| | | | | involutus | subcardissoides | |
| | | | | crassus | involutus | M |
| | | | | deformis | | |
| | L | schulginae - jangodaensis | schloenbachi | brongniarti | schloenbachi-ernsti | L |
| | | subinvolutus | | waltersdorfensis | rotundatus | |
| Turonian | U | lamarcki(s.l.) inaequivalvis | costellatus | incertus | incertus-dresdensis | U |
| | | | | costellatus | costellatus | |
| | | | lamarcki | lamarcki | striatoconcentricus | M |
| | | | | | inaequivalvis | |
| | | lamarcki(s.s.) | | | lamarcki | |
| | | cf. cuvieri | apicalis | apicalis | cuvieri-apicalis | |
| | L | labiatus | labiatus | hercynicus | saxonicus | L |
| | | | | labiatus | subhercynicus | |
| | | | | kossmati | submytiloides | |
| | | | | hattini | labiatus-mytiloides | |
| Cenomanian | U | pictus | pictus bohemicus | | pictus bohemicus | U |
| | | | pictus | | pictus s.str. | |

**Fig. 7.6.** Upper Cretaceous dinocysts range chart with indication of Northern Siberian dinocyst events.

Zone (Upper Santonian). The correlation of the other zones is based on the recognition of identical species from Western Siberia, the Russian Platform, and Western and Eastern Europe, despite the fact that the assemblages strongly vary in composition between these regions. The correlation between the uppermost Turonian and Upper Coniacian is most uncertain. This interval yielded few representatives of the *I. lamarcki* group, which is characterized by marked morphologic variation within species (Fig. 7.6).

The comparison of dinocyst scales of synchronous deposits in various regions shows significant distinctions in detail in the subdivision and composition of the dinocyst assemblages (Fig. 7.7). The regional differences were, among others, caused by different environmental conditions and latitudinally controlled distribution patterns of dinocysts (paleoprovincialism). Nevertheless, the similarity of Late Cenomanian-Early Turonian dinocyst assemblages with those from Northern Europe and Northern Siberia was noted by Ilyina et al. (1994). There are two reference levels, suitable for correlation of Upper Cretaceous sequences of Great Britain and the Ust-Yenisey region, at the top of the Cenomanian and in the middle part of the Santonian (Fig. 7.7). Some similarity between Late Turonian–Early Coniacian dinocyst assemblages from the Ust-Yenisey region and Eastern Canada also exists (Ilyina et al. 1994). The lowest reference level is at the top of the Cenomanian, the second one at the base of Campanian. They are remarkably different, however, due to endemism of dinocysts in the Ust-Yenisey region at this time. Santonian–Maastrichtian assemblages from Arctic Canada are well comparable. The Campanian dinocyst units in the Ust-Yenisey region are similar to those at the Atlantic coast of the U.S.A. Besides there are two reference levels, in the top of the Cenomanian and in the Santonian (Fig. 7.7).

There is a controversy as to the placement of the Santonian-Campanian boundary. Close to the boundary, a very characteristic bivalve dominated member, known as the "Pteria Beds" occurs. Based on foraminifers, Naidin et al. (1984) attributed the "Pteria Beds" to the Lower Campanian. However, Papulov (1974, p. 176) attributed them to the Upper Santonian on the base of inoceramids. Unfortunately, no additional data are available on either the dinoflagellates or the inoceramids of West European and North American sections, to provide definitive placement of the stage boundary.

## 7.7 Discussion

Two features in the development and distribution of inoceramids and dinocysts may be noted: (1) a predominance of cosmopolitan inoceramids is concurrent with a wide geographical distribution of Boreal dinocysts and (2) increase in species diversity among inoceramids is accompanied with a marked rise of Boreal endemic dinoflagellate cysts. The former can be illustrated by the predominance of inoceramid species of the "*pictus*" and "*labiatus*" groups in the Cenomanian-Turonian boundary beds and by the occurrence of merely cosmopolitan *Sphenoceramus* species in the Santonian. Just these stratigraphic levels revealed maximum similarity in dinocyst assemblages within the Boreal Realm (Fig.7.7). Both events are attributed to the existence of sea ways in the Northern Hemisphere due to global high sea level stand (Haq et al. 1988; Sahagian et al. 1996). This conclusion is also collaborated to some extent by the presence of immigrants from the northern Pacific seas (Pergament 1979) (*I. (I.)*

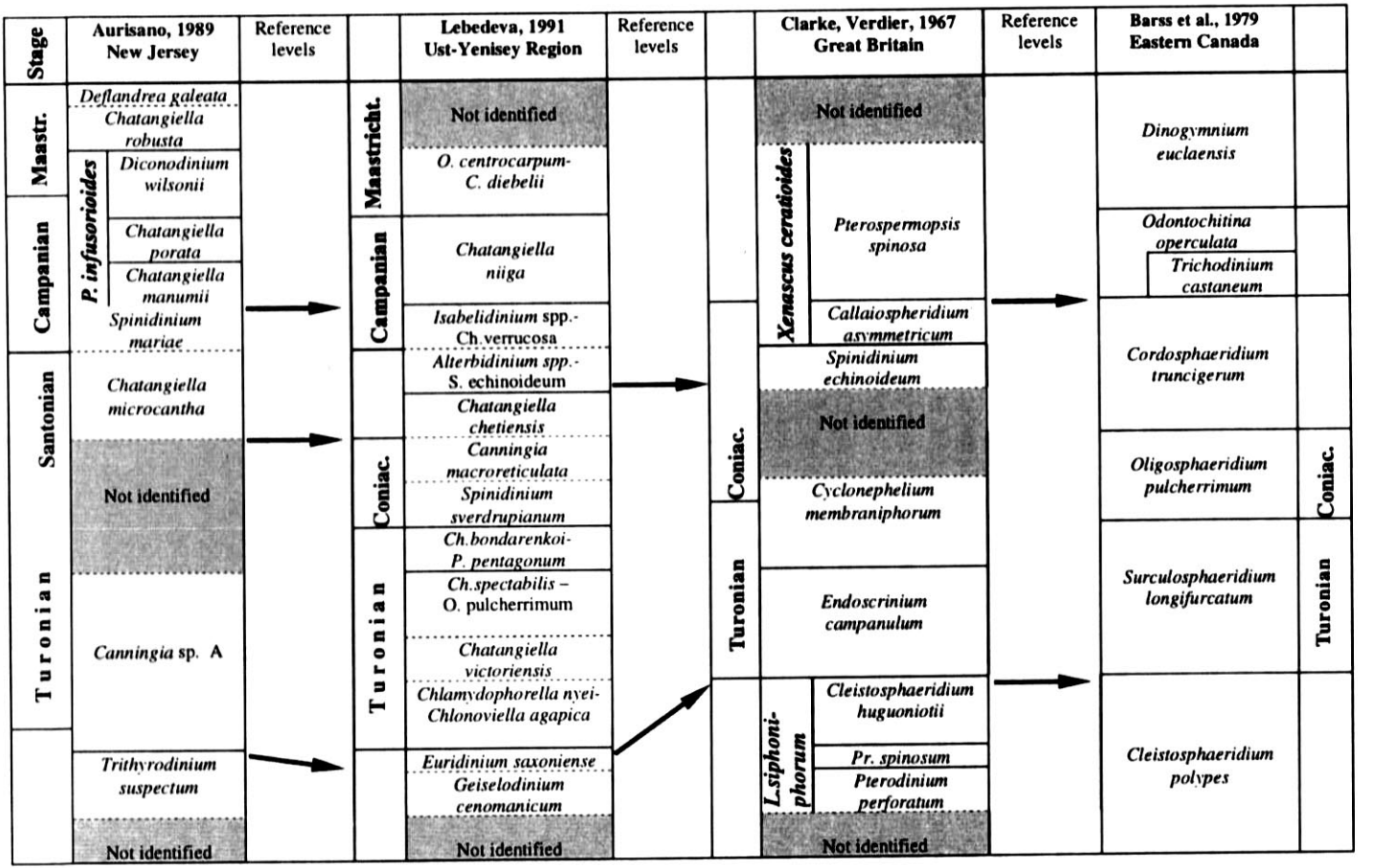


Fig. 7.7. Succession of the Upper Cretaceous dinocyst associations in different provinces of the Boreal Realm. Arrows indicate correlation levels.

*ginterensis* and *I. (I.) incelebratus)* in Cenomanian-Turonian boundary beds (Fig. 7.3). The latter feature can be illustrated by the synchronous appearances of new species of the "*lamarcki*" group in the Late Turonian and Coniacian with an increase in number of endemic *Chatangiella* species. This phenomenon can be explained by the decrease of sea ways and hampered connections within the Boreal Realm.

Reduction of taxonomic diversity of inoceramids in the Santonian is accompanied by decreasing importance of *Chatangiella* among dinoflagellate assemblages. A total disappearance of inoceramids from the Arctic during the Early Campanian testifies that the vanishing of the group began with the reduction of Boreal waters area caused by fall of average annual temperatures (Zakharov 1994). It is well known that the last inoceramids have been found at the Maastrichtian-Danian boundary outside of the Boreal Realm.

One of the problems of Northern Siberian Upper Cretaceous stratigraphy is the evaluation of the extent of a break between the Santonian and Campanian. In the Tanama River section, a clearly defined sedimentary gap is confined to the boundary between these stages (Fig. 7.2). Sequence stratigraphic analysis suggests that the stratigraphic break might comprise the entire Lower Campanian here (Sahagian et al. 1994). However, new data obtained from the section of the Kheta River Basin in the north of East Siberia located 500 km to the East (Fig. 7.1), allow refutation of this conclusion. In the Kheta River section, the Santonian and Campanian marine boundary beds were recognized in a more complete succession of dinocyst assemblages as compared to that of Tanama River (Ust-Yenisey region). Here, above beds with *Alterbidinium daveyi-Ch. chetiensis,* beds with *Isabelidinium* spp.-*Ch. verrucosa* were distinguished, which are overlain by beds with *Ch. niiga* (occurring at the Tanama River section above beds with *Isabelidinium* spp.) (Fig. 7.2). At the Kheta River inoceramid remains have been found throughout this interval including the beds with *Isabelidium* spp.-*Ch. verrucosa.* In addition, *Sphenoceramus patootensiformis,* known from the uppermost Santonian-lowermost Campanian in northwestern Europe (Troeger 1989) was recognized at the Kheta River from the beds with *Alterbidinium daveyi-Ch. chetiensis.* Thus, the correlation of bed succession at the Kheta River and Tanama River shows that the break between the Santonian and Campanian at the Tanama River embraces stratigraphically not more than a part of a dinocyst zone. The present work represents both inoceramid-based and dinocyst-based joint scale for the Ust-Yenisey and Khatanga regions.

This sequence can reflect a gradual cooling of the climate, with the temperature minimum in the Campanian. The warm temperate dinocyst assemblages evolved during the Late Cenomanian-Early Turonian. Faunal data seem to confirm this hypothesis (Zakharov 1994). The assemblages are characterized by dominance of the gonyaulacacean group, the variety of species and genera, and the lack of endemic forms. The dinocyst assemblages from the Santonian-Campanian deposits reflect a cool temperate condition (Khlonova & Lebedeva 1988). The assemblages with a prevalence of peridiniacean cysts, and the abundance of large *Chatangiella* and *Isabelidinium* are most comparable with a Boreal, cool to temperate McIntyre suite (recognized by Lentin & Williams 1980). Results of analysis of Campanian clays and siliceous minerals in the Ust-Yenisey region also testify the cooling and aridization of climate (Zanin et al. 1990).

## 7.8 Conclusions

Two Upper Cretaceous biostratigraphic zonal scales have been integrated in the Northern Siberian area. One is based on inoceramids and the other on dinocysts. The inoceramid-based zonal scale includes datum correlation levels containing *Inoceramus (Inoceramus) pictus* (Upper Cenomanian), *I. (Mytiloceramus) labiatus* (Lower Turonian), *I. (I.) lamarcki* (Middle Turonian), *Sphenoceramus cardissoides* (Lower Santonian), *Sph. patootensis* (Upper Santonian), and *Sph. patootensiformis* (Santonian-Campanian boundary beds) which allow Panboreal correlation on substage level.

The dinocyst-based zonal scale shows a slightly higher resolution than the inoceramid-based scale. However, it permits the correlation of the Upper Cretaceous boreal deposits on a stage level only. Most effective dinocysts datum levels are recognized in the Upper Cenomanian and Upper Santonian.

The penetration of cosmopolitan inoceramid genera to the Arctic at the end of the Cenomanian-Early Turonian and during the Santonian is contemporaneous with Panboreal distribution of Northern Siberian dinoflagellate taxa. These events are attributed to the fact that eustatic sea level reached extreme high levels at the Cenomanian-Turonian boundary and in the Santonian, providing open sea ways for free migration.

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