ISSN 1068-7971

RUSSIAN GEOLOGY AND GEOPHYSICS

ГЕОЛОГИЯ И ГЕОФИЗИКА

4

Vol. 40, 1999

Allerton Press, Inc. / New York

Russian Geology
and Geophysics
Vol. 40, No. 4, pp. 494-511, 1999

Geologiya
i Geofizika
UDC 551.7(116.3)(571.511)

THE SANTONIAN-CAMPANIAN BOUNDARY IN NORTHERN SIBERIA

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Santonian-Campanian boundary beds that outcrop in northern Siberia are comprehensively described. In the section of the Tanama River, a left tributary of the Yenisei River, Campanian gaized clays overlie Santonian silts with erosion. In the section of the Kheta River (Khatanga River drainage area), the Santonian-Campanian boundary lies within a uniform silt series. In the Tanama section, an association of *Sphenoceramus patootensis* and *Oxytoma tenuicostata*, presumably of Upper Santonian age, was found at the top of silt beds. Macrofossils are absent from the overlying gaized clays. These clays date from the Campanian by dinocysts and radiolarians. The association present in the lower and middle parts of marine beds of the Kheta section contains *Sphenoceramus patootensiformis*, in addition to *S. patootensis*, *S. lingua*, and *S.* sp. ind., but the species *O. tenuicostata* was not found. This suggests that beds with *S. patootensiformis* are of transitional Santonian-Campanian age. The following succession of dinocyst-containing beds is recognized in the Tanama section: *Alterbidinium daveyi* (top of silt beds), *Isabelidinium* spp. (bottom of gaized clays), and *Chatangiella niiga* (clay-silt beds). In the Kheta section, dinocyst-containing beds in the same range of the section follow the succession: *Alterbidinium daveyi-Chatangiella chetiensis* (bottom of marine beds), *Isabelidinium* spp.-*Chatangiella verrucosa* (middle part of marine beds), and *Chatangiella niiga* (top of marine beds). This succession is more complete than that on the Tanama River. The Santonian age of the roof of the silt member on the Tanama River, the Santonian-Campanian age of beds with *S. patootensiformis* on the Kheta River, and the similar successions of dinocyst-containing beds in both sections suggest that the sequence occurring between the Santonian and Campanian on the Kheta River is stratigraphically continuous and there is no considerable stratigraphic gap between these stages on the Tanama River. The lower boundary of the Campanian is drawn at the bottom of beds with *Isabelidinium* spp.-*Chatangiella verrucosa*.

Santonian, Campanian, boundary, Inoceramus, dinocysts, Upper Cretaceous, northern Siberia

INTRODUCTION

Two symposia of the International Subcommittee on Cretaceous Stratigraphy were devoted to boundaries between Cretaceous stages, a key problem in geochronology. One of them was held in Denmark (Copenhagen, 1983) and the other in Belgium (Brussels, 1995) [1, 2]. The Santonian-Campanian boundary was also discussed at these symposia. This boundary is still one of the least definite. The background and the state of the matter were reported in detail by Naidin [3]. The following benchmarks were recommended at the symposium in Brussels by the working group on the Campanian Stage:

1. Grossouvre's canonical definition [4] of beds with *Placenticeras bidorsatum* as the lowermost level of the Campanian.
2. The level of extinction of the crinoid *Marsupites testudinarius* Schlotheim, recommended as a boundary marker of the bottom of the Campanian.
3. It is also recommended to take into account: (a) extinction of the planktonic foraminifer *Dicarinella concavata*; (b) data on nannofossils, including *Broinsonia parca*; (c) boundary between magnetozones 33R and 34N, directly or indirectly.

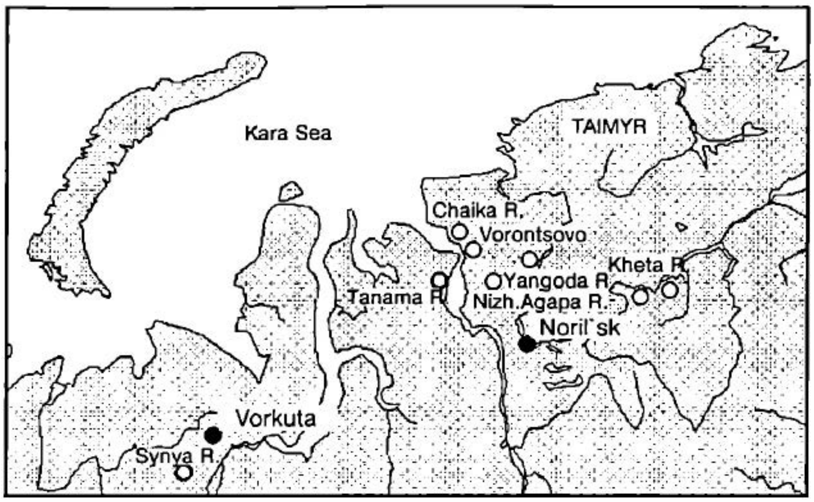

Fig. 1. Location of marine Upper Cretaceous reference sections in natural outcrops in northern Siberia.

The position of the lower boundary of the Campanian was discussed in terms of the ammonite, belemnite, inoceram, crinoid, foraminifer, and nannofossil scales and in the context of magnetostratigraphy [5].

Not all approaches, however, can be used for determining the Santonian-Campanian boundary in northern Siberia. The North-Siberian boundary beds are depleted in ammonites (scarce baculites) and belemnites. Crinoids, planktonic foraminifers, and nannofossils are absent entirely, and no magnetostratigraphic data are available. The boundary between the stages in natural outcrops can be drawn only on the basis of the stratigraphic occurrence of inocerams, benthic foraminifers, and palynological remains: spores, pollen, and dinocysts. Unfortunately, foraminifers are very scarce in outcrops, and inocerams include the single genus *Sphenoceramus*, whose remains disappear from the transitional beds at the bottom of the Campanian. *Inoceramus (Endocostea) balticus* Boehm., typical of the transitional Santonian-Campanian beds, has not been found at all. Nevertheless, the available information suggests the presence of a continuous section between the Santonian and Campanian in northern Siberia and of a near-boundary level in sections in the north of Western Europe.

STRATIGRAPHY OF THE SANTONIAN-CAMPANIAN BOUNDARY BEDS

The sections that, presumably, contain transitional Santonian-Campanian beds are known in three regions of northern Siberia. These are: the drainage area of the Severnaya Sos'va River (Synya, Leplya, and Nyais Rivers) on the eastern slope of the Subarctic Urals; the Tanama River, a left tributary of the lower Yenisei, and the drainage area of the Kheta River (Romanikha, Maimecha, and Kheta Rivers) in the north of East Siberia [6, 7] (Fig. 1).

None of the natural outcrops in the Severnaya Sos'va drainage area exposes a continuous section between the Santonian and Campanian. One of the best Upper Cretaceous exposures on the Synya River (3 km downstream from Til'tim Village) demonstrates that the gaize-clayey Campanian-Maastrichtian Leplya Formation overlies the mainly sandy Coniacian-Santonian Ust'-Manya Formation with a distinct contact. The Santonian section is crowned there by beds with *Sphenoceramus* cf. *lingua* and *Oxytoma* cf. *tenuicostata* (Roem.) (2.8 m thick) containing fine- and medium-grained dark-green glauconite-quartz sandstones (1.8 m thick) overlying (with erosion) siliceous lumpy dark-gray siltstones depleted in macrofossils, assigned to the Campanian by occasional foraminifers and dinocysts.

The best section of transitional Santonian-Campanian beds in the Ust'-Yenisei depression is naturally exposed on the Tanama River in the Sigirte-Nado (Antlers) stow. It was briefly described by Sachs and Ronkina [8]. A closer description was presented by Zakharov et al. [9]. The transition between the Santonian and presumably Campanian deposits can be observed in several outcrops in one section. But even in this section, dark-gray gaized clays of the presumably Campanian Solpadayakha Formation overlie (with erosion) the sand-clayey greenish-gray silts of the Upper Santonian Nasonov Formation (*Sphenoceramus patootensis* Zone) [9, 10]. This boundary is marked by considerable changes in dinocyst assemblages. It is not clear whether these changes stem from age or facies causes [11]. Evaluation of the stratigraphic volume of the erosion demands additional data.

The Upper Santonian and Campanian were also exposed by drilling in the drainage areas of the Yakovlevaya, Bol'shaya Kheta, and Malaya Kheta Rivers but are recognized there only by analogy with the Sigirte-Nado section. Exposures of Upper Santonian bedrocks were described on the Avam and Chopko Rivers in the drainage area of the Dudypta River. They are represented by fine-grained obliquely stratified greenish-gray and yellow sands interbedded by coarse-grained sands with nodules of siderite and lenses and partings of ferruginous sandstones, 20 m in total thickness. The rocks were dated by a finding of *Inoceramus (=Sphenoceramus)* cf. *patootensis* Lor. [8].

The decisive information for evaluation of the stratigraphic gap between the Santonian and Campanian in the section on the Tanama River was obtained by close investigation of the boundary marine beds of the Santonian and Campanian in the Kheta drainage area (Khatanga Depression). Comparison of inoceram and dinocyst sequences in both sections and biostratigraphic correlation performed on this ground between the deposits of the Ust'-Yenisei and Khatanga regions unambiguously pointed to a very small time gap between the Santonian and Campanian in the Sigirte-Nado section.

Here we present a description of the Upper Santonian and bottom-Campanian ranges of the section on the Tanama and Kheta Rivers based on our data during field studies in 1983–89. The description is presented in brief, because its full version has been reported in [9].

Section on the Tanama River (Fig. 2)

Upper Santonian Substage

Zone Sphenoceramus patootensis (18.1 m thick)

Member I (2.4 m thick)

Lithology. Greenish-gray fine- and medium-grained feldspar-quartzy leptochloritic sand. Rests with erosion on silty sands of the underlying member. Light-brown ovate silt-carbonate nodules with phosphate are present at the roof of the member.

Paleontology. Ammonites: *Baculites* sp. (scarce), coiled ammonite (very scarce), bivalves *Sphenoceramus* cf. *patootensis* (Lor.) (common), *S. cardissoides* Goldf. (common), *S.* cf. *lingua* Goldf. (very scarce), and *Oxytoma tenuicostata* Roem. (abundant). Sea urchins (generally common): *Hemiaster* cf. *wetherbyi* Lor., *Holaster* cf. *tanamensis* Schmidt, *Holaster(?)* sp., and *Catopygus(?)* sp. Crustaceans (abundant complete carapaces and traces of activity of crustaceans): *Ophiomorpha* (abundant). Some inoceram valves are up to 1 m long.

Member II (15.7 m thick)

Lithology. Greenish-gray sand-clayey silts enriched in leptochlorite at the bottom of the member. Rest with a minor erosion on the underlying rocks. At the bottom, round concretions of leptochloritic sandstone with carbonate cement up to 0.3 m in diameter, with phosphate and flinty nodules inside. Spherical sandstone concretions in the range 0.9–5.0 m, with abundant shells of diverse bivalves.

Paleontology. Bivalves: *Sphenoceramus* sp. ind. (very abundant), *S. patootensis* Lor. (scarce), *S.* cf. *patootensis* (very frequent), and *Oxytoma tenuicostata* Roem. (very frequent). Ammonites: *Baculites* sp. (frequent).

Campanian Stage (bottom of the section)

The lower boundary is drawn at the bottom of member III, corresponding to the line of erosion of Santonian silts. Contact uneven, the Campanian clay fills pockets (to 0.3 m deep) in the underlying silts and forms nests in the upper part of the silts with admixtures of small pebbles.

Member III (2.2 m thick)

Lithology. Dark-gray clay-silty rock. A deep erosion (reaching 0.3 m) at the bottom. The lower part of the member (0–0.8 m) contains laminated clay with silt lenticles several millimeters thick. The silt contains glauconite grains and occasional, very small gypsum crystals. The clay is overlain by fragmental sand-clayey silts containing 3% glauconite. The clays contain small (to 3 cm) dark-gray ovate carbonate (siderite) concretions.

Paleontology. No macrofauna remains.

Member IV (11.5 m thick)

Lithology. Fine-fragmentary sharply angular brittle solid gaized clay. Light-gray when dry and dark-gray when wet. Contact with the underlying member unclear, gradual. Transition range in the section about 0.5 m.

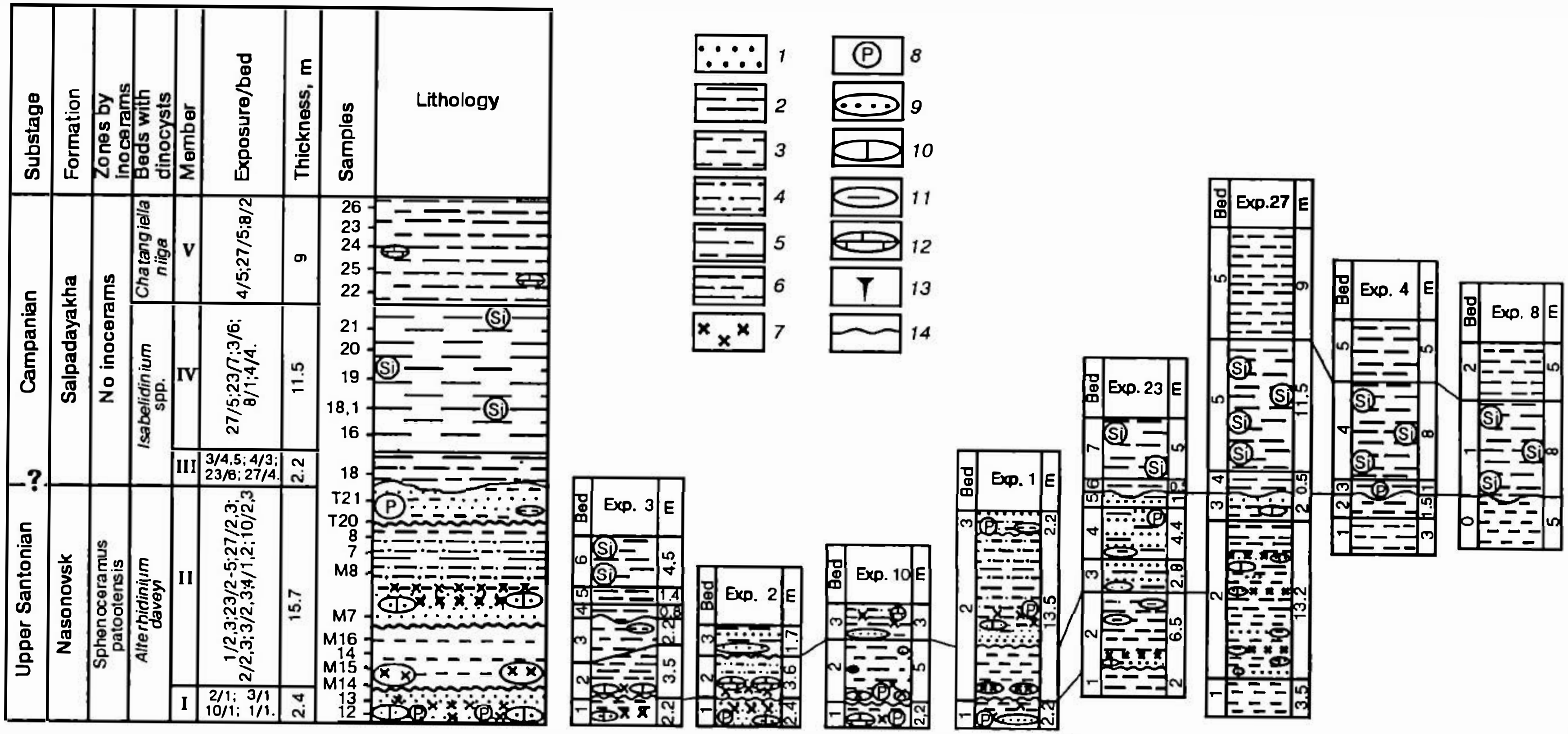

Fig. 2. Composite section of the Santonian and Campanian (Upper Cretaceous) and bed-by-bed correlation of boundary deposits of these stages on the Sigirte-Nado Plateau and the Tanama River (Ust'-Yenisei depression). *1* — sand, *2* — clay, *3* — silt, *4* — sandy silt, *5* — clayey silt, *6* — silty clay, *7* — leptochlorite, *8* — phosphorite, *9* — sandstone, *10* — siderite concretions, *11* — siltstone, *12* — limestone, *13* — worm trails, *14* — erosion boundary.

Paleontology. No macrofauna remains.

Member V (9 m thick)

Lithology. Homogeneous large-lumped dark-gray soft micaceous silty clay. Occasional carbonate (siderite) concretions are present. No distinct contact with the underlying member IV. Transition range about 0.5 m.

Paleontology. No macrofauna remains.

Biostratigraphic data have been comprehensively reported in [9, 10, 12]. Here they are outlined in brief. The Upper Santonian on the Tanama River consists of the single Sphenoceramus patootensis zone. The index species of the zone was identified only in members I and II. The species of sphenocerams were not identified in the overlying member III [13]. Beds with *Alterbidinium daveyi* were found in the Upper Santonian, and beds with *Isabelidinium* spp. and overlying beds with *Chatangiella niiga* were recognized in the Campanian [11, 12].

Section on the Kheta River (Fig. 3)

The marine Upper Santonian and presumably Campanian are exposed in one section 750 km to the east of the Tanama section, in the Khatanga depression on the right bank of the Kheta River. The Upper Cretaceous beds in the Khatanga depression contain mainly continental and lagoon deposits. The outcrops of the Santonian-Campanian Mutinskaya Formation on the Kheta River are the easternmost evidence of a great Late Cretaceous sea transgression in the north of East Siberia. The presence of *Sphenoceramus patootensis* is unambiguously indicative of the Upper Santonian. The Campanian was indirectly recognized owing to similarity of the rocks to the Ust'-Yenisei section [14].

Description of the section

The marine Upper Cretaceous deposits are exposed in the middle reaches of the Kheta River (Mutinskaya Formation). The exposures are biostratigraphically correlated. The combined section is described from bottom to top.

Member I (7 m thick)

Lithology. Small-fragmental brown clayey silt finely alternating with light fine-grained sand. The sand-shale ratio increases up the section.

Paleontology. Spore-and-pollen spectra contain 31–51% moss and fern spores, 29–50% gymnosperm spores, and 9–18% angiosperm pollen. The spores are dominated by *Laevigatosporites ovatus* Wils. et Webs., *Stereisporites* sp., *Cyathidites* sp., and *Leiotriletes* sp. Present are also *Gleicheniidites* sp., *Rouseisporites laevigatus* Poc., *Cicatricosisporites stoveri* Poc., *C. minutaestriatus* (Bolch.) Chlon., *Trilobosporites* sp., *Polypodiaceae* (leguminous, ornamented), *Camarozonosporites insignis* Nor., *Foraminisporis* sp., *Osmundacidites* sp., *Lycopodiumsporites cemiidites* (Ross) Delc. et Sprum., *L. marginatus* Singh., *Densoisporites* sp., *Foveosporites* sp., *Leptolepidites* sp., *Rouseisporites* sp., *Aequitriradites* sp., *A. spinulosus* Cook. et Dett., *Dictyophyllidites* sp., *Appendicisporites* sp., *Lobatia involucrata* (Chlon.) Chlon., and *Osmunda granulata* (Mal.) Chlon. The gymnosperm pollen is dominated by *Taxodiaceaepollenites hiatus* (Pot.) Kremp and poorly preserved saccate conifer pollen. Also, there are *Ginkgocycadophytus nitidus* (Balme) de Jers., *Pinuspollenites* sp., *Sequoiapollenites cretaceus* (Chlon.) Chlon., *Podocarpidites* sp., *Alisporites* sp., *A. similis*, and *Vitreisporites* sp. Of angiosperms, there is much pollen of *Kuprianipollis* spp. and *Parviprojectus* sp. Pollen of *Tricolpites* sp., *Aquilapollenites* sp., *Wodehouseia* sp., *W. gracilis* (Samoil.) Pokrov., *Proteacidites* sp., and *Accuratipollis* sp. is present. Other microphytofossils are represented by scarce grains of *Schizosporis* sp., *Schizocystia nonmarina* Chlon., *Schizocystia laevigata* Cook et Eis., *Leiosphaeridia* sp., and unidentified algal remains. *Trithyrodinium suspectum* (Man. et Cook.) Dav. and *Chatangiella* sp. appear in the upper part.

Member II (4 m thick)

Lithology. Light-gray sand finely alternating with dark silt. Interbeds of concretions of sideritized siltstone containing fauna and sideritized wood are present at the levels 3.1 and 4.1 m.

Paleontology. *Sphenoceramus* sp. ind., *S. patootensis* (Lor.), *S. pinniformis* (Will.), *S. lingua* (Goldf.), *S. patootensiformis* (Seitz), *Modiolus* sp., *Tancredia* sp., *Cucullea* sp., and *Euspira* sp.

Spore-and-pollen spectra contain 6–15% moss and fern spores, 19–40% gymnosperm pollen, 5% angiosperm pollen, and 49–58% microphytoplankton. Compositionally, spores and pollen are depauperated.

The spores are dominated by *Laevigatosporites ovatus*, *Stereisporites* sp., *Cyathidites* sp., and *Leiotriletes* sp. Present are also: *Gleicheniidites* sp., *Rouseisporites* sp., *R. laevigatus*, *Cicatricosisporites* sp., Polypodiaceae (leguminous, ornamented), *Camarozonosporites* insignis, *Osmundacidites* sp., and *Aequitriradites* sp. Of gymnosperm pollen, *Taxodiaceaepollenites hiatus* and poorly preserved saccate conifer pollen are predominant.

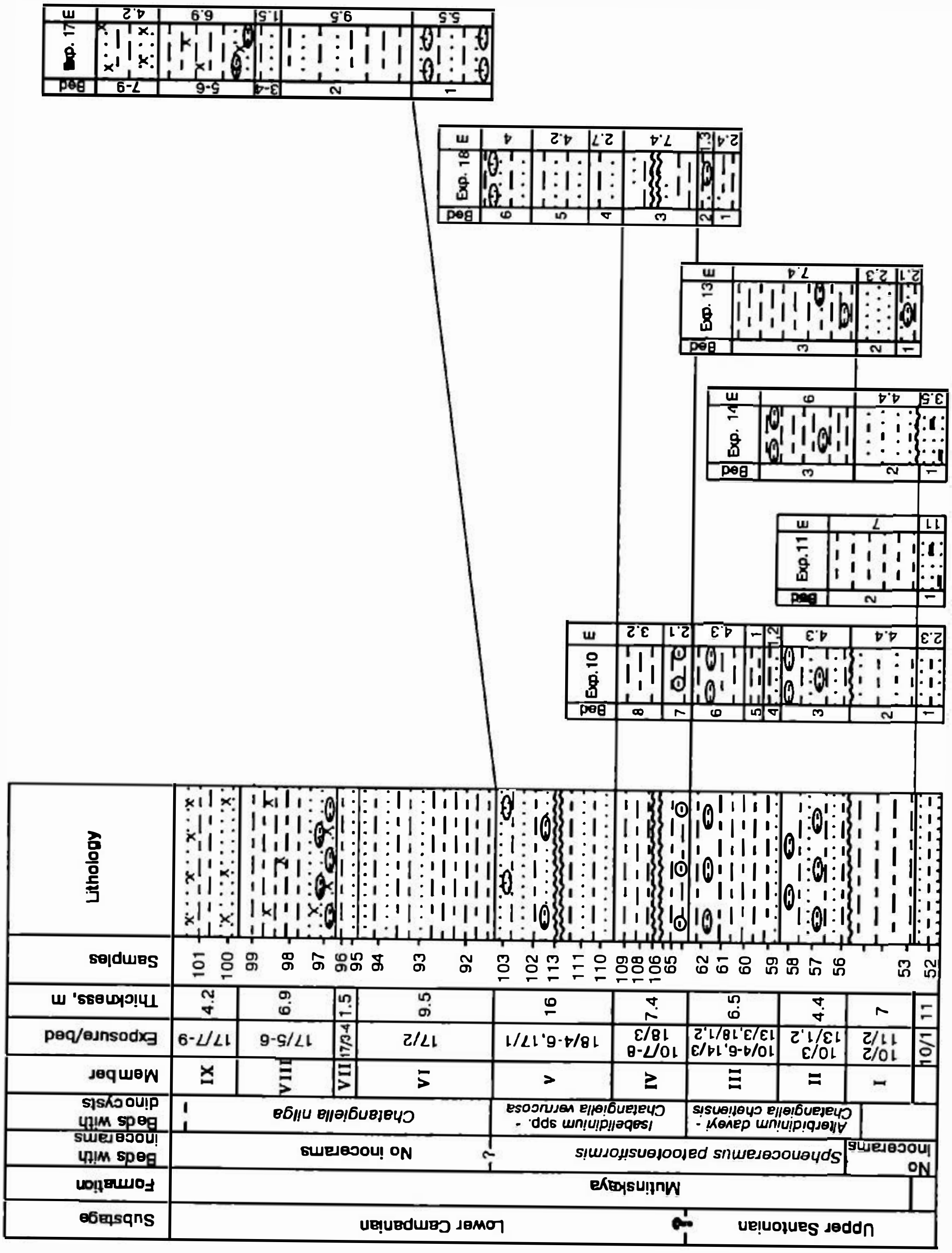

Fig. 3. Section of the Santonian-Campanian boundary deposits and correlation of key marine Upper Cretaceous exposures in the drainage area of the Kheta River (Khatanga depression). Designations follow Fig. 2.

Also, *Ginkgocycadophytus nitidus*, *Pinuspollenites* sp., *Sequoiapollenites cretaceus*, *Alisporites similis*, *Vitreisporites* sp., *Rugubivesiculites* sp., and *Ephedripites costatus* Bolch. occur. Of angiosperms, pollen of *Kuprianipollis* spp. and *Tricolpites* sp. is predominant. Pollen of *Parviprojectus* sp., *Aquilapollenites* sp., *Wodehouseia* sp., and *Proteacidites* sp. is found.

Dinocysts are dominated by *Chatangiella* sp. (*Ch. chetiensis* (Vozzh.) Lent. et Will., *Ch. spectabilis* (Alb.) Lent. et Will., *Ch. tanamaensis* Leb., and *Ch. ditissima* (McIn.) Lent. et Will), *Trithyrodinium* sp., *T. suspectum*, *Alterbidinium* sp. (*A. acutulum* (Wils.) Lent et Will., *A. daveyi* (Stov. et Evitt) Lent. et Will., and *A. minor* (Alb.) Lent. et Will.). Common species are: *Fromea chytra* (Drugg) Stov. et Evitt, *F. fragilis* (Cook. et Eis.) Stov. et Evitt, *Chatangiella* sp., H, A, *Ch. granulifera* (Man.) Lent et Will., *Ch. bondarenkoi* (Vozzh.) Lent. et Will., *Ch. serratula* (Man. et Cook.) Lent. et Will., *Ch. madura* Lent. et Will., *Rhiptocorys veligerum* (Def.) Lej.-Carp. et Sarj., *Elytrocysta circulata* (Clar. et Verd.) Stov. et Helby, *Isabelidinium* spp., I. sp. H, *I. microarmum* (McIn.) Lent. et Will., *Microdinium* sp., *Cyclonephelium distinctum* Defl. et Cook., *Chlonoviella agapica* Leb., *Canningia* sp., *Fibrocysta* sp., *Chlamydophorella nyei* Cook. et Eis., and *Diconodinium arcticum* Man. et Cook. Of other microphytofossils, *Paralecaniella indentata* (Defl. et Cook.) Cook. et Eis., *Palambages* sp., *Leiosphaeridia* sp., *Pterospermella* sp., and *Schizosporis* sp. were found.

Member III (6.5 m thick)

Lithology. Brown, dark-gray clayey silt with lenses of light silt and blue clay. Concretions of sideritized siltstone are present.

Paleontology. *Sphenoceramus* sp. ind., *S. patootensis* (Lor.), *S. lingua* (Goldfuss), *S. patootensiformis* (Seitz.), *Modiolus* sp., *Tancredia* sp., *Cucullea* sp., and *Euspira* sp.

Spore-and-pollen spectra contain 14–18% moss and fern spores, 22–41% gymnosperm pollen, 3–5% angiosperm pollen, and 29–56% microphytoplankton. No changes in spore-and-pollen composition were observed.

Dinocysts are dominated by *Truithyrodinium* sp. and *T. suspectum*. The amounts of *Chatangiella* and *Alterbidinium* decrease. The species available are: *Chatangiella spectabilis*, *Ch. tanamaensis*, *Ch. bondarenkoi*, *Ch. ditissima*, *Ch. chetiensis*, *Ch. biaperura* (McIn.) Lent. et Will., *Alterbidinium acutulum*, *A. daveyi*, *Isabelidinium* sp., *I.* sp. H., *Microdinium* sp., *Fromea* sp., *F. chytra*, *Laciniadinium* sp., *Diconodinium* sp., *D. rhombiforme* Vozzh., *Chlonoviella agapica*, *Canningia* sp., *Odontochitina* sp., and *Chlamydophorella nyei*. Of other microfossils, *Paralecaniella indentata*, *Palambages* sp., *Leiosphaeridia* sp., *Pterospermella* sp., and *Schizosporis* sp. were found.

Member IV (7.4 m thick)

Lithology. Dark-gray clayey silt with interbeds of brown clayey silt. Concretions with inocerams are present in the lower part.

Paleontology. *Sphenoceramus* sp. ind., *S. patootensis* (Lor.), *S. patootensiformis* (Seitz), and *S. lingua* (Goldf.). Spore-and-pollen spectra contain 28–47% moss and fern spores, 32–39% gymnosperm pollen, 3–4% angiosperm pollen, and 10–36% microphytoplankton. No changes in spore-and-pollen composition were observed.

Of spores, *Laevigatospores ovatus*, *Stereisporites* sp., *Cyathidites* sp., *Leiotriletes* sp., *Gleicheniidites* sp., *Rouseisporites* sp., *R. laevigatus*, *Cicatricosisporites* sp., Polypodiaceae (leguminous, ornamented), *Camarozonosporites insignis*, *Osmundacidites* sp., *Densoisporites* sp., *Foveosporites* sp., *Leptolepidites* sp., and *Concavisporites juriensis* Balme are present. Gymnosperm pollen belongs to *Taxodiaceaepollenites hiatus*, *Ginkgocycadophytus nitidus*, *Pinuspollenites* sp., *Sequoiapollenites cretaceus*, *Alisporites similis*, *Vitreisporites* sp., *Ephedripites costatus* Bolch. Conifer pollen is poorly preserved. Angiosperm pollen belongs to *Kuprianipollis* sp. and *Tricolpites* sp. Also, *Parviprojectus* sp., *Aquilapollenites* sp., *Wodehouseia* sp., *W. spinata* Stan., *Proteacidites* sp., and *Mancicorpus* sp. are present.

The proportion of chorate forms among dinocysts increases. They include *Cleistosphaeridium* sp., *Pterodinium* sp., *Fibrocysta* sp., and *Oligosphaeridium* sp. Abundant are *Palaeohystrichophora infusorioides* Defl. Appear: *Chatangiella verrucosa* (Man.) Lent et Will., *Ch. microcantha* (Cook. et Eis.) Lent. et Will., and *Isabelidinium cooksoniae* (Alb.) Lent. et Will. The amount of *Chatangiella* and *Alterbidinium* decreases.

Member V (16 m thick)

Lithology. Thin alternation of light-gray fine-grained sands (sometimes with leptochlorite) and dark-gray silty clays. A concretion interbed of light-gray siltstone 0.10 m in thickness occurs 0.7 m from the roof. The roof contains a concretion interbed of brownish-gray fine-grained sandstone 0.20 m in thickness.

Paleontology. *Sphenoceramus* sp. ind., and *Euspira* sp.

Spore-and-pollen spectra contain 37% moss and fern spores, 23% gymnosperm pollen, 8% angiosperm pollen, and 32% microphytoplankton.

Moss and fern spores: *Laevigatosporites ovatus*, *Stereisporites* sp., *Cyathidites* sp., *Leiotriletes* sp., *Gleicheniidites* sp., *Rouseisporites* sp., *R. reticulatus*, *Cicatricosisporites* sp., Polypodiaceae (leguminous, ornamented), *Omamentifera* sp., *Camarozonosporites insignis*, *Osmundacidites* sp., and *Lycopodiumsporites* sp. Gymnosperm pollen: *Taxodiaceaepollenites hiatus*, *Ginkgocycadophytus nitidus*, *Sequoiapollenites cretaceus*, and poorly preserved saccate conifer pollen. Angiosperm pollen: *Kuprianipollis* sp. and *Tricolpites* sp. The species *Parviprojectus* sp., *Aquilapollenites* sp., *Wodehouseia* sp., *Proteacidites* sp., and *Mancicorpus* sp. are present.

Dinocysts are dominated by *Isabelidinium* sp. (*I. microarmum*, *I. cooksoniae*, *I. belfastense* (Cook. et Eis.) Lent. et Will.), *Chatangiella verrucosa*, *Trithyrodinium* sp., *T. suspectum*, *Alterbidinium* sp. (*A. acutulum* and *A. daveyi*), *Diconodinium arcticum* and chorate forms. There are also: *Fromea chytra*, *Chatangiella* sp., *Ch. granulifera*, *Ch. bondarenkoi*, *Ch. ditissima*, *Ch. chetiensis*, *Ch. serratula*, *Ch. microcantha*, *Ch. madura*, *Laciniadinium* sp., *Diconodinium* sp., *D. rhombiforme*, *Cyclonephelium distinctum*, *Oligosphaeridium* sp., *Spiniferites* sp., *Fibrocysta* sp., and *Chlamydophorella nyei*. The species *Chatangiella niiga* Vozzh. and *Ch. manumii* (Vozzh.) Lent. et Will. appear. Other microfossils are: *Paralecaniella indentata*, *Pterospermella* sp., *Leiosphaeridia* sp. (scarce), and *Schizosporis* sp.

Member VI (9.5 m thick)

Lithology. Finely fragmented dark-gray silty clay. A 0.5–5 cm thick interbed of greenish-yellow sand occurs in the range 4.3–6.5. Sand proportion increases from bottom to top.

Paleontology. Spore-and-pollen spectra contain 31–26% moss and fern spores, 16–15% gymnosperm spores, 3–5% angiosperm pollen, and 64–54% microphytoplankton.

The moss and fern spores are dominated by *Laevigatosporites ovatus*, *Stereisporites* sp., *Cyathidites* sp., *Leiotriletes* sp., *Gleicheniidites* sp., Polypodiaceae (leguminous, ornamented), and *Lycopodiumsporites* sp. No changes in the composition of gymnosperm pollen were observed. Angiosperm pollen belongs to *Kuprianipollis* sp., *Tricolpites* sp., *Aquilapollenites* sp., and *Wodehouseia* sp.

Of dinocysts, *Chatangiella niiga* is predominant. *Isabelidinium* are scarcer. The species *Trithyrodinium* sp., *T. suspectum*, *Chatangiella* sp., *Ch. granulifera*, *Ch. manumii*, *Ch. bondarenkoi*, *Ch. ditissima*, *Ch. chetiensis*, *Ch. verrucosa*, *Ch. serratula*, *Alterbidinium* sp., *Isabelidinium* sp., *I. cooksoniae*, *Laciniadinium* sp., *Diconodinium arcticum*, *Cyclonephelium distinctum*, and *Fromea chytra* are identified. The species *Chatangiella* sp. G. and *Dinogymnium sibiricum* Vozzh. appear. Noteworthy is an increase in the abundance of *Paralecaniella indentata* and, in the upper part of the member, *Leiosphaeridia* sp. Other microfossils are: *Schizosporis* sp., *Pterospermella* sp., and acritarchs.

Member VII (1.5 m thick)

Lithology. Fine-grained brownish-green sand 0.5–0.15 m in thickness. Dark-gray silty clay with lenses of fine-grained yellow sand.

Paleontology. Spore-and-pollen spectra contain 24–26% moss and fern spores, 10–28% gymnosperm spores, 5–6% angiosperm pollen, and 38–61% microphytoplankton.

No changes in spore-and-pollen composition were observed.

The only changes in dinocyst composition are an increase in the abundance of *Isabelidinium* and chorate species and a decrease in the abundance of *Chatangiella niiga*.

Member VIII (6.9 m thick)

Lithology. Fine-grained greenish-gray sand (sometimes with leptochlorite) with lenticles of dark-brown clays with numerous worm trails. The upper part contains fragments of carbonified wood. The member is bottomed by a concretion interbed of light-gray siltstone. A 0.1 m thick horizon of dark-gray siltstone with leptochlorite is at 0.6 m. Thickness 2.3 m. It is overlain by dark-gray silty clay with lenses of light sand and vertical worm trails. An interbed of clays with an admixture of leptochloritic sand is at 3 m.

Paleontology. Spore-and-pollen spectra contain 5–13% moss and fern spores, 10–20% gymnosperm spores, 4% angiosperm pollen, and 67–72% microphytoplankton.

The composition of spores and pollen is very scarce: *Stereisporites* sp., *Laevigatosporites ovatus*, *Osmundacidites* sp., *Leiotriletes* sp., *Polypodiaceae*, *Lycopodiumsporites* sp., *Appendicisporites* sp., *Coniferales*, *Taxodiaceaepollenites hiatus*, *Ginkgocycadophytus nitidus*, *Pinuspollenites* sp., *Tricolpites* sp., *Aquilapollenites* sp., *Parviprojectus* sp., and *Azonia recta*.

Dinocysts: *Chatangiella* sp. (predominant forms are *Ch. niiga* and *Ch. ditissima*), *Ch. verrucosa*, *Ch. granulifera*, *Ch. tanamaensis*, *Ch. chetiensis*, *Ch. madura*, *Ch. spinata*, *Ch. cassidea* Leb., *Ch. manumii*, *Trithyrodinium* sp., *T. suspectum*, *Dinogymnium sibiricum*, *Alterbidinium* sp., *A. acutulum*, *A. minor*, *Isabelidinium* sp., *Diconodinium* sp., *D. arcticum*, *Spinidinium* sp., *Microdinium omatum*, *Spiniferites ramosus*, *Fromea chytra*, and *Cyclonephelium distinctum*. Other microphytofossils: *Paralecaniella indentata* (considerable amount), *Cymatiosphaera* sp., acritarchs, and *Schizosporis* sp.

Member IX (4.2 m thick)

Lithology. Fine-grained dark-green leptochloritic sand, bioturbated with large cross-like worm trails. Thickness 2 m. It is overlain by small-fragmented clayey silt with interbeds of black clays.

Paleontology. The spore-and-pollen spectrum from sample 100 (sands of the lower part) contains 4% moss and fern spores, 3% spores of gymnosperms, 3% pollen of angiosperms, and 85% microphytoplankton.

Spores and pollen: *Stereisporites* sp., *Laevigatosporites ovatus*, *Osmundacidites* sp., *Leiotriletes* sp., *Coniferales*, *Taxodiaceaepollenites hiatus*, *Tricolpites* sp., and *Azonia recta*.

The dinocyst association is the same as in member VIII except for an increase in the abundance of *Paralecaniella indentata*, *Fromea* sp., and chorate cysts and a decrease in the abundance of *Chatangiella*.

The spore-and pollen spectrum of sample 101 (from the silts) contains 38% moss and fern spores, 30% gymnosperm spores, 19% angiosperm pollen, and 8% microphytoplankton.

Moss and fern spores: *Stereisporites* sp., *Laevigatosporites ovatus*, *Osmundacidites* sp., *Leiotriletes* sp., *Polypodiaceae*, *Lycopodiumsporites* sp., *Appendicisporites* sp., *Cyathidites* sp., *Foveosporites cenomanicus*, *Aequitriradites* sp., and *Cicatricosisporites* sp. Gymnosperm pollen: *Coniferales*, *Taxodiaceaepollenites hiatus*, *Ginkgocycadophytus nitidus*, and *Sequoiapollenites cretaceous*. Angiosperm pollen: *Tricolpites* sp., *Aquilapollenites* sp., *Parviprojectus* sp., *Kuprianipollis* sp., and *Mancicorpus* sp.

Microphytoplankton: *Leiosphaeridia* sp., *Chatangiella niiga* (very scarce), and the fresh-water algae *Schizosporis* sp. Dinocysts are scarce, and their genera cannot be identified because of poor preservation.

Biostratigraphic implications

Investigation of the stratigraphic occurrence of species in the Santonian-Campanian boundary deposits allowed recognition of beds with *Sphenoceramus patootensiformis* and three biostrata with dinocysts: beds with *Alterbidinium daveyi–Chatangiella chetiensis*, beds with *Isabelidinium* spp.–*Chatangiella verrucosa*, and beds with *Chatangiella niiga* (Fig. 4).

Beds with inoceramids

Inoceramids appear at the bottom of member II and are observed up to the middle of member IV in the sand-clayey silts and clays of the Mutinskaya Formation (marine part of the Upper Cretaceous section in the Khatanga depression). The assemblage of sphenoceramids, well defined and representative in form and quantitative respect, allows beds with inoceramids to be recognized in the region.

Beds with Sphenoceramus patootensiformis

Index species: Sphenoceramus patootensiformis Seitz (Fig. 5)

Characteristic species: *Sphenoceramus patootensiformis* Seitz, *S. patootensis* Lor., *S. lingua* Goldf., and occasional *S. pinniformis* Will. are found at the bottom of member II.

The lower boundary is marked by the advent of *S. patootensiformis* Seitz and the upper boundary, by the last finding of *Sphenoceramus* sp. ind.

Type section. Located on the Bol'shaya Romanikha River (exp. 10, beds 3–8; exp. 18, beds 1–6; and exp. 17, bed 1). Contains clayey silts. The sand-shale ratio increases at the bottom and the upper part of the section. Concretion interbeds of sideritic siltstone. Thickness ca. 34.3 m.

Occurrence. Bol'shaya Romanikha River (exp. 10, beds 3, 6, and 7); Kheta River (exp. 13, beds 1 and 3); and Maimecha River (exp. 14, bed 3) (Fig. 4).

Distribution and geologic age. Khatanga region, northwestern and eastern Europe — Upper Santonian — Lower Campanian.

Late Santonian sphenoceramids are considered in numerous studies [15–19]. A great number of species and subspecies were recognized mainly on the basis of occasional findings, poorly preserved, with vague stratigraphic correlations. Our materials are much better preserved and stratigraphically correlated. Taphonomic observations were made during sampling to estimate the representativeness of the sample. This permits us to solve taxonomical problems. Paleopopulational analysis of the samples prompted us to revise the volumes of numerous subspecies of *Sphenoceramus patootensis* Lor. and *S. lingua* Goldf. (*S. patootensis angustus* Beyen., *S. patootensis sibirica* Dobr., *S. patootensis tanamaensis* Bodyl., *S. lingua virgata* Pergam., etc.). We consider all of them transitional forms in the variability series of these closely related species. We confirm Seitz's conclusion [18] that *Inoceramus lobatus* Sch. [17] is not valid. This species should be regarded as junior synonym of *S. patootensiformis* Seitz, because our examination of copious samples with representatives of *S. patootensiformis* Seitz from various stratigraphic levels demonstrated that such indications as the size of the

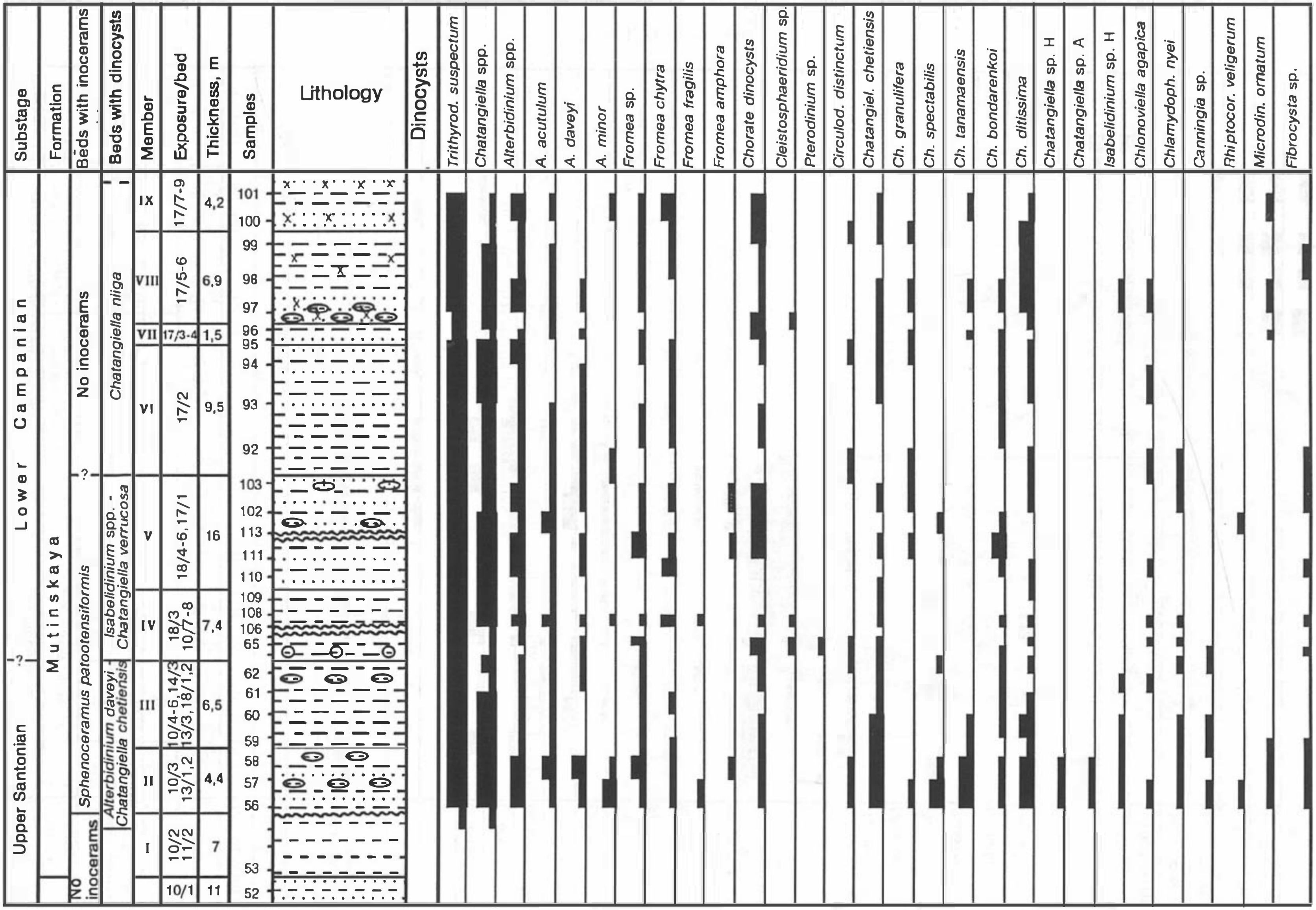

Fig. 4. Stratigraphic location of dinocysts and inoceramids and beds with dinocysts in the section of marine beds of the Santonian-Campanian boundary in the drainage area of the Kheta River (Khatanga depression). Designations follow Fig. 2.

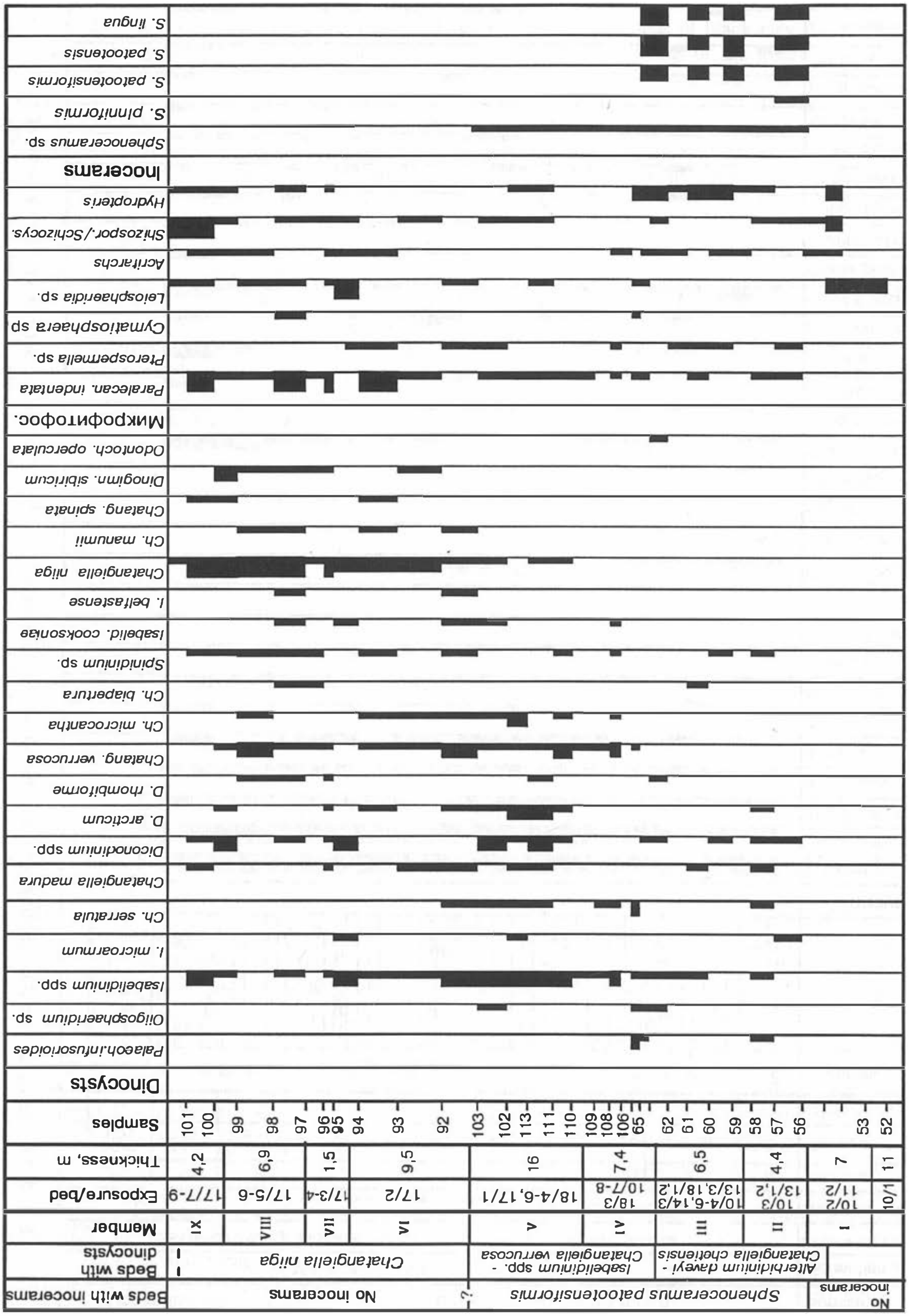

Fig. 4. (Continued)

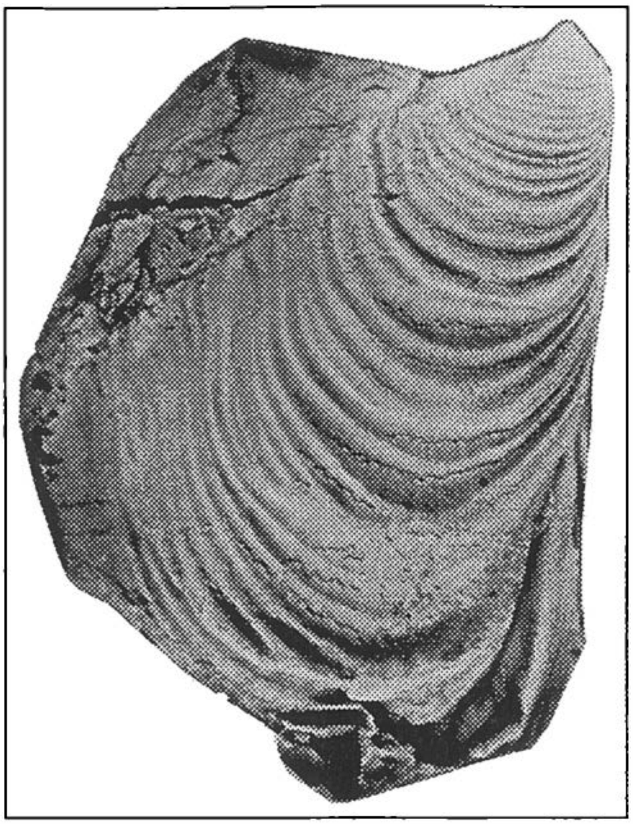

Fig. 5. ***Sphenoceramus patootensiformis*** **(Seitz.); Central Siberian Geological Museum, Novosibirsk, accession 2015. Right-valve view, full scale. Bol'shaya Romanikha River, exp. 10, bed 6. Mutinskaya Formation. ?Bottom of the Campanian. Beds with** ***Isabelidinium*** **spp.–*****Chatangiella verrucosa*****.**

angle between ligament and anterior margin and the degree of equality of shell valves, whose permanence permitted recognition of *I. lobatus*, actually vary significantly.

Beds with dinocysts (Fig. 4)

The first analysis of the palynological composition of the Upper Cretaceous rocks in the Khatanga depression was performed by Bondarenko [20]. She noted unicellular algae in the marine deposits. Samoilovich [21] was first to recognize the most characteristic microalgal taxa in the marine deposits of the Mutinskaya Formation. She extended the list of terrestrial plants and performed correlation of the Upper Cretaceous deposits of the Khatanga, Lena-Vilyui, and Ust'-Yenisei regions.

In the Upper Santonian–Campanian deposits on the Kheta River (Khatanga region), marine phytoplankton is occasionally found in the upper part of member I and is abundant starting from member II. Changes in the composition of dinocysts predominant in the microalgal assemblage are linked with the appearance of new species and variations in their abundance. On this basis, the following biostratons with dinocysts are recognized (Fig. 4).

Beds with Alterbidinium daveyi – Chatangiella chetiensis

Index species: Alterbidinium daveyi (Stover et Evitt) Lentin et Williams and Chatangiella chetiensis (Vozzhennikova) Lentin et Williams

Characteristic species: Predominant are: *Chatangiella*, *Trithyrodinium*, and *Alterbidinium*. Characteristic species: *Chatangiella chetiensis*, *Ch.* sp. H and A., *Ch. spectabilis* (Alb.) Lent. et Will., *Ch. tanamaensis* Leb., *Ch. bondarenkoi* (Vozzh.) Lent. et Will., *Ch. ditissima* (McIn.) Lent. et Will., *Isabelidinium* sp. H, *Trithyrodinium* sp., *T. suspectum* (Man. et Cook.) Dav., *Alterbidinium* sp., *A. acutulum* (Wils.) Lent. et Will., *A. daveyi*, and *Chlonoviella agapica* Leb.

The lower boundary of the beds is arbitrarily drawn according to the appearance of a diversified dinocyst assemblage. The upper boundary is the bottom of beds with *Isabelidinium* spp. — *Ch. verrucosa.*

Type section. Located on the Bol'shaya Romanikha River (exp. 10, upper part of bed 2 — bed 6; exp. 18, beds 1 and 2; and exp. 13, beds 1 and 2). Contains clayey silts and sands thinly alternating with silts containing concretions of sideritized siltstone with inocerams. Thickness is ca. 11 m.

Occurrence. Khatanga region.

Geological age. Lower part of beds with *Sphenoceramus patootensiformis* (Seitz).

Beds with Isabelidinium spp. — Chatangiella verrucosa
Index species: Isabelidinium spp. and Chatangiella verrucosa (Manum) Lentin et Williams.

Characteristic species: *Isabelidinium* spp., *I. microarmum* (McIn.) Lent. et Will., *I. cooksoniae* (Alb.) Lent. et Will., *Ch. verrucosa* (Man.) Lent. et Will., *Ch. microcantha* (Cook. et Eis.) Lent. et Will., *Ch. serratula* (Man. et Cook.) Lent. et Will., *Diconodinium rhombiforme* Vozzh., and *D. arcticum* Man. et Cook. The number of chorate species significantly increases. *Ch.* sp. H and A. disappear.

The lower boundary of the beds is drawn where *Chatangiella verrucosa*, *Ch. microcantha*, and *I. cooksoniae* appear and the upper boundary, at the bottom of beds with *Chatangiella niiga.*

Type section. Located on the Bol'shaya Romanikha River (exp. 10, beds 7 and 8; exp. 17, bed 1; and exp. 18, beds 3–6). Contains thinly alternating light-gray fine-grained sands and dark-gray silty clays. Thickness is ca. 23 m.

Occurrence. Khatanga region.

Age. Upper part of beds with *Sphenoceramus patootensiformis* (Seitz).

Beds with Chatangiella niiga
Index species: Chatangiella niiga Vozzhennikova

Characteristic species: Predominant is *Chatangiella niiga.* **Characteristic species:** *Chatangiella manumii* (Cook. et Eis.) Lent. et Will., *Ch.* G., *Ch. madura* Lent. et Will., *Ch. biapertura* (McIn.) Lent. et Will., *Dinogymnium sibiricum* Vozzh., *Spinidinium* sp., and *Diconodinium* sp. The species *Chatangiella spectabilis* and *Ch. serratula* disappear.

The lower boundary is marked by a dramatic increase in the abundance of *Chatangiella niiga* and predominance of spiny chatangiells. The upper boundary is arbitrarily drawn according to the disappearance of marine microphytoplankton.

Type section. Located on the Tanama River (Ust'-Yenisei region), exp. 4, bed 5; exp. 5, beds 2–4; exp. 8, beds 3–5; exp.7, bed 1. Contains clays and clayey silts. Thickness ca. 26 m.

Occurrence. Khatanga region (Bol'shaya Romanikha River, (exp. 17, beds 2–8). Dark-gray finely fragmented silty clay (bed 2); fine-grained brownish-green leptochloritic sand with interbeds of silty clays. Thickness is ca. 22 m). Ust'-Yenisei region.

Geological age. Presumably, Campanian.

DISCUSSION OF THE LOCATION OF THE SANTONIAN-CAMPANIAN BOUNDARY IN UPPER CRETACEOUS SECTIONS IN NORTHERN SIBERIA

According to inocerams

Though inocerams were not considered to be essential criteria for marking the Santonian-Campanian boundary at either of the International Symposia in Copenhagen and Brussels, we have to invoke data on inocerams because other fossils — crinoids, ammonites, or belemnites — are absent from North-Siberian sections.

Beds with *S. patootensiformis* in the Khatanga region correspond to the composite *S. patootensiformis* Zone in northwestern Europe [22] (beds with *S. patootensiformis* according to Seitz [18]). The inoceram assemblages of these biostratons match perfectly. The *S. patootensiformis* Zone corresponds to beds transitional between the Santonian and Campanian. The problem of the Santonian-Campanian boundary is one of the most intricate in the Upper Cretaceous stratigraphy [18, 23, 24]. Until the boundary is ultimately determined, the lower boundary of the *Gonioteuthis granulataquadrata* Zone is considered to be the bottom of the

Campanian in reference sections in France. *Placenticeras bidorsatum* Romer — index species of the lowermost Campanian zone in Aquitaine is found at the same level. Inocerams do not mark the precise upper boundary of the Santonian, because the range of inoceram species is poor, and inocerams are extremely scarce in the above-lying beds. According to Seitz [25], the boundary between the stages lies within beds with *S. patootensiformis*, whose lower part contains *S. pinniformis* Will. and *Gonioteuthis granulata* Bvl., and whose upper part contains *Gonioteuthis granulataquadrata* (Stoll.). Thus, in the Khatanga section, the lower boundary of the Campanian is arbitrarily drawn in the middle part of beds with *S. patootensiformis* (Fig. 5). The lower part of this biostraton is assigned to the Upper Santonian on the basis of findings of *S. pinniformis* Will.

The continuity of the Santonian-Campanian boundary section on the Kheta River and presence of Santonian beds higher than on the Tanama Rivers is indirectly confirmed by the absence of *Oxytoma tenuicostata* (Roemer) in the Kheta section. This species is known to be present in transitional Santonian-Campanian beds in the south of the Russian Platform. *Oxytoma tenuicostata* are extremely scarce in northwestern Europe [3]. Beds with *S. patootensiformis* on the Kheta River are supposed to occur higher than the *S. patootensis* Zone on the Sigirte-Nado plateau (Ust'-Yenisei depression) [9]. This is confirmed by the absence of *S. patootensiformis* Seitz from the Tanama sections and of *Oxytoma tenuicostata* Roem., from the Khatanga section. Another proof is the complete and ultimate disappearance of inocerams, together with oxytoms. They do not appear again up the section. Thus, the eroded range in the Ust'-Yenisei region and, in particular, on the Sigirte-Nado plateau corresponds to beds with *S. patootensiformis* and involves both the upper Santonian and the lower Campanian (Fig. 6).

The reported data on the stratigraphic distribution of inocerams in northern Siberia allow the "pterid beds" to be localized in this region. The problem of stratigraphic location of "pterid beds" was widely discussed by Soviet scientists [3, 26–29]. In the Ust'-Yenisei region, beds rich in Oxytoma overlie the *S. cardissoides* Zone and underlie the beds with *S. patootensiformis*, from which *Oxytoma tenuicostata* Roem. is absent. Hence, the "pterid beds" in northern Siberia are confined to the Upper Santonian, although occasional *Oxytoma* are present in underlying beds, too*.

According to dinocysts

At the symposia in Copenhagen and Brussels dinocysts were not discussed as a group of actual or potential interest for drawing the Santonian-Campanian boundary. Since the geochronologic scale is universal, it is certainly wrong to disregard this group in solving stratigraphic problems. The goal cannot be achieved if the problem of the Santonian-Campanian boundary is not solved at least for some part of the globe. Santonian and Campanian marine deposits cover millions of square kilometers in Arctic and Subarctic regions. On this enormous territory, particularly in unexposed areas, dinocyst assemblages are sometimes the only tool for solution of stratigraphic problems. Therefore, the example of using dinocysts for solution of the Santonian-Campanian problem on the territory of Arctic or lower Boreal deposits is of great importance.

The succession of dinocyst assemblages established in the marine part of the Khatanga section generally matches that in the Ust'-Yenisei section (Fig. 6). The genera *Chatangiella*, *Alterbidinium*, *Isabelidinium*, *Spinidinium*, and *Diconodinium* are the most important for the stratigraphy of these regions. *Chatangiella* are abundant and diverse in the Tanama section, in beds with *Sphenoceramus pinniformis* and *S. patootensis*. Characteristic are *Chatangiella chetiensis*, *Ch. spectabilis*, *Ch. tanamaensis*, *Ch.* sp. A, and *Ch.* sp. H. *Trithyrodinium* and *Alterbidinium* (*A. daveyi*, *A. acutulum*, and *A. minor*) are also abundant. The above-lying assemblage is marked by disappearance of some of the listed *Chatangiella* species; an increase in the abundance of *Chatangiella verrucosa*, *Ch. microcantha*, and *Ch. granulifera*; an increase in the number of *Isabelidinium* and chorate dinocysts (especially *Fibrocysta*); and appearance of occasional *Chatangiella niiga*. The latter species is predominant, along with other spiny *Chatangiella* (*Ch. manumii* and *Ch. spinata*), in the subsequent assemblage. *Dinogymnium sibiricum*, *Diconodinium* spp., and *Chatangiella ditissima* are also common there.

The differences in the proportion of dinocysts in the assemblages and the contributions of particular species hamper the comparison between the Santonian-Campanian portions of the Khatanga and Ust'-Yenisei sections. These differences may be related to the peculiarities of the structures of the sections. The Ust'-Yenisei section is characterized by clear lithological traits of beds and the presence of erosions. The greatest erosion (between the Upper Santonian and ?Campanian) is marked by a drastic change in lithology and paleontology (see the above description of the section). The section in the Kheta basin is more uniform and demonstrates no distinct boundaries between beds. Sandstone varieties are predominant in this section, including its

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* *Added in proof.* It should be clearly noted that the *Oxytoma tenuicostata* biozone is vertically wider than the "pterid beds". "Pterid beds" include belemnites (*Actinocamax laevigatus*, *Belemnitella* ex gr. *praecursor*, and *Paractinocamax* spp.) and bivalves (*Sphenoceramus* ex gr. *lingua* and *Oxytoma tenuicostata*, which is also found obviously down the section and, occasionally, up the section. Thus, the presence of only *O. tenuicostata* valves is not unambiguously indicative of "pterid beds".

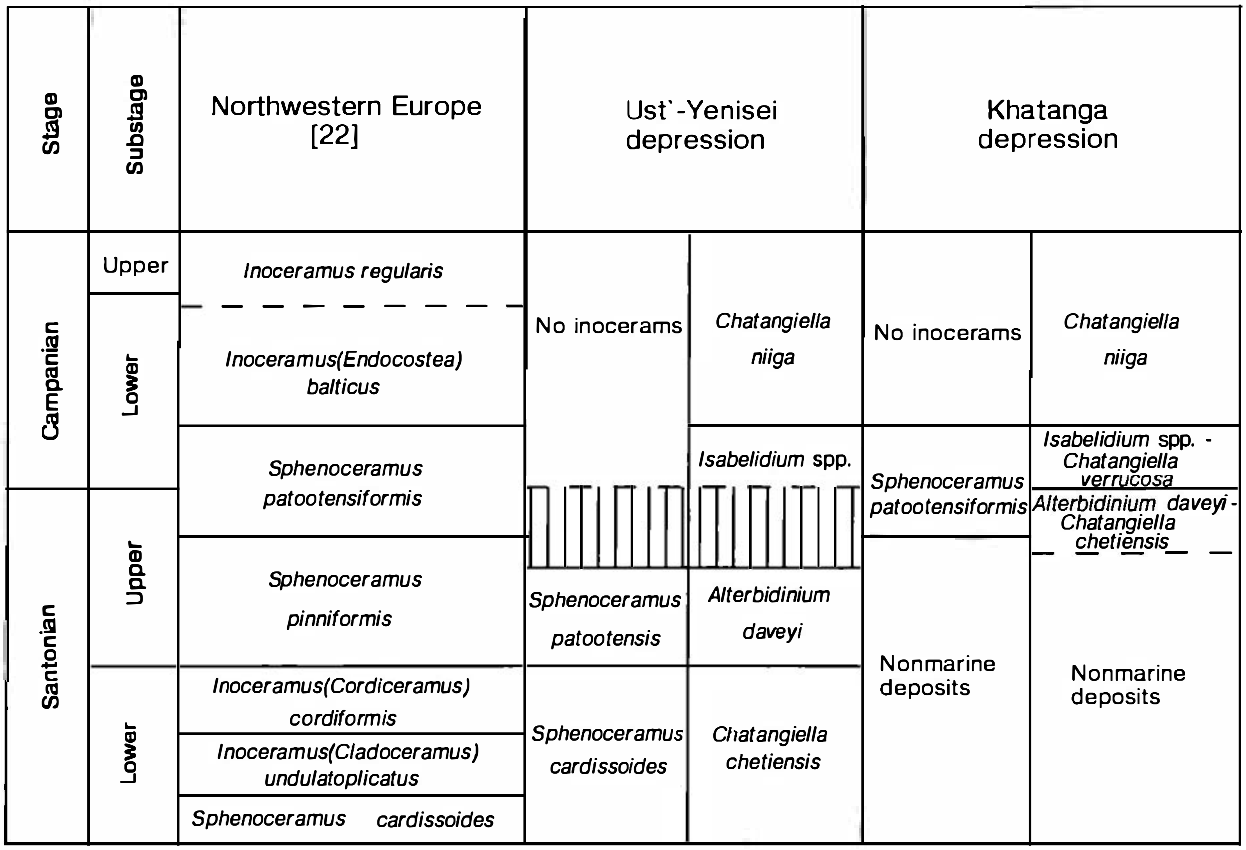

Fig. 6. Biostratigraphic correlation of the Santonian-Campanian in the Ust'-Yenisei and Khatanga depressions and northwestern Europe. Vertical lines demonstrate the supposed extent of the stratigraphic gap in the Ust'-Yenisei depression corresponding to parts of the Santonian and Campanian.

Campanian part. This may determine both the similarity and the difference in the composition and structure of the dinocyst assemblages. For example, *Chatangiella* and *Alterbidinium* are abundant both over the whole Khatanga section (although their range of species is variable) and in the substantially sandstone Santonian part of the Ust'-Yenisei section, whereas their abundance and diversity drastically decrease in the ?Campanian clays, except for spiny species. This confirms the above-noted fact that *Chatangiella* tend to occur in sandy rock varieties [30]. At the same time, *Isabelidinium* and chorate dinocysts are less abundant in the Khatanga section. No abrupt change in the composition of dinoflagellate cysts is observed in the section under consideration. The boundaries of beds with dinocysts are somewhat blurred because the microalgal composition changes more smoothly than in the Ust'-Yenisei section. On this ground, beds with *Alterbidinium daveyi–Chatangiella chetiensis* were recognized. They mostly correspond to the beds with *Alterbidinium daveyi* in the Ust'-Yenisei region. However, the considered interval is substantially clayey in the Ust'-Yenisei section, and the proportion of *Chatangiella* is therefore less, whereas this genus is more abundant and diverse in the silt-clayey part of the Khatanga section. The genus *Chatangiella* becomes less significant, and the contribution of chorate species increases in the upper part of member III and the lower part of member IV, formed by clays (Fig. 6). It appears that the time of formation of members II–V in the Khatanga section corresponds to the maximum transgression, and the boundary between the beds *Alterbidinium daveyi–Chatangiella chetiensis* and *Isabelidinium* spp.–*Chatangiella verrucosa* can be correlated with the boundary between the beds with *Alterbidinium daveyi* and *Isabelidinium* spp. in the Ust'-Yenisei section (Fig. 6). The beds with *Chatangiella niiga*, crowning the Kheta section are well correlated with similar beds in the Tanama section and we compare them with the *Chatangiella manumii* Zone in the Campanian deposits on the Atlantic coast in the USA (New Jersey) [11].

Thus, in spite of some differences in the composition and abundance of dinocysts in the Khatanga and

Ust'-Yenisei sections, related to facies differences, both sections demonstrate identical sequences of dinocyst assemblages. This, in turn, is indicative of the absence of a large time break in the Ust'-Yenisei section at the Santonian-Campanian boundary.

According to foraminifers

Most samples taken from natural outcrops of Upper Cretaceous rocks contained no foraminifer remains. Only few genera (and several new species in open nomenclature) were found in the section from Upper Cenomanian to Maastrichtian in the Ust'-Yenisei and Khatanga depressions. Thus, foraminifers in combination with inocerams and dinocysts cannot be used for solving the problem of the Santonian-Campanian boundary. Data from the literature on foraminifers from borehole cores give a notion of this problem, but definite conclusions cannot be made because of the absence of correlation between these assemblages and inocerams. In addition, foraminifers are of minor importance as markers of the Santonian-Campanian boundary in the West-Siberian plain for two more reasons: (1) There are at least two versions of zonal division of the Santonian and Campanian, and (2) There are two versions of the location of the boundary [31–33]. According to the adopted scheme, the lower boundary of the Campanian should match the bottom of beds with *Spiroplectammina senonana pocurica* and *S. lata*, which overlie the Upper Santonian beds with small anomalinids, beds with a poor assemblage of agglutinated foraminifers, and beds with *Cibicidoides eriksdalensis* [31, 32]. In Podobina's opinion, the lower boundary of the Campanian should be drawn along the bottom of the beds with *Bathysiphon vitta* and *Recurvoides magnificus*, which overlie the *Cribrostromoides cretaceus exploratus* and *Ammomarginulina cripsa* Zones in the west of West Siberia and the beds with *Cibicidoides eriksdalensis luteus* in the east. However, both these boundaries may not match that adopted in Eastern Europe and on Mangyshlak [34–36]. According to three symposia which were held successively in the Aktyubinsk-Mugodzhary region, in the north of the Donets basin, and on Mangyshlak, the lower boundary of the Campanian is drawn much below the bottom of the *Cibicides temirensis* Zone, whose assemblage contains *Bolivinoides decoratus*, placed at the bottom of the Upper Campanian in both West-Siberian schemes [33, 37].

CONCLUSIONS

Close analysis of the Santonian-Campanian boundary beds in natural outcrops in northern Siberia demonstrated that the former notion of the presence of a significant stratigraphic gap at the Santonian-Campanian boundary was erroneous. In the section on the Tanama River, a left tributary of the Yenisei River, the Campanian gaized clays overlie Santonian silts with erosion. In the section on the Kheta River (basin of the Khatanga River), the Santonian-Campanian boundary lies in uniform silts. On the Tanama River, the roof of the silt beds contains the *Sphenoceramus patootensis–Oxytoma tenuicostata* association, presumably Santonian; the overlying gaized clays are free of macrofossils. These clays are dated to the Campanian by dinocysts and radiolarians. In the lower and middle parts of the marine beds on the Kheta River, *S. patootensiformis* is present along with *S. patootensis*, *S. lingua*, and *S.* sp. ind., but *O. tenuicostata* is lacking. This suggests that the beds with *S. patootensiformis* are transitional, Santonian-Campanian. The following succession of beds with dinocysts was found on the Tanama River: *Alterbidinium daveyi* (roof of the silt beds), *Isabelidinium* spp. (bottom of the gaized clays), and *Chatangiella niiga* (sand-silt beds). The succession of beds in the same section range on the Kheta River looks as follows: *Alterbidinium daveyi–Chatangiella chetiensis* (bottom of the marine beds), *Isabelidinium* spp.*–Chatangiella verrucosa* (middle of the marine beds), and *Chatangiella niiga* (roof of the marine beds). This succession is the most complete in northern Siberia. Taking into account the Santonian age of the roof of the silt member on the Tanama River, the transitional Santonian-Campanian age of the beds with *S. patootensiformis* on the Kheta River, and the similarity between the beds with dinocysts in both sections, we concluded that the section between the Santonian and Campanian is stratigraphically continuous on the Kheta River, and there is no considerable stratigraphic gap between these stages on the Tanama River either.

The authors are grateful to D. P. Naidin for critical remarks which helped us to improve the manuscript.

REFERENCES

[1] *Bulletin of the Geological Society of Denmark*, Copenhagen, vol. 33, 1984.

[2] *Bulletin de l'Institut Royal des sciences naturelles de Belgique. Sci. de la terre*, Brussel, vol. 66 Supp., 1996.

[3] D. P. Naidin, *The Santonian-Campanian boundary on the East-European Platform* [in Russian], Sverdlovsk, p. 7, 1979.

[4] A. Grossouvre, *Recherches sur la craie superieure 1: stratigraphie generale. Fasc. 1 & 2. Mem. Pour servir a l'explication d. l. carte geol. Detaillee d. l.*, Paris, 1901.

[5] J. M. Hancock and A. S. Gale, in: *Bulletin de l'Institut Royal des sciences naturelles de Belgique. Sci. de la terre*, Brussel, vol. 66 Supp., p. 103, 1996.

[6] V. N. Sachs, Z. Z. Ronkina, N. I. Shul'gina, et al., *Stratigraphy of the Jurassic and Cretaceous in the north of the USSR* [in Russian], Moscow, 1963.

[7] V. N. Sachs and S. A. Chirva, in: *New data on the stratigraphy and fauna of the Jurassic and Cretaceous in Siberia* [in Russian], Novosibirsk, p. 136, 1978.

[8] V. N. Sachs and Z. Z. Ronkina, *The Jurassic and Cretaceous deposits in the Ust'-Yenisei depression* [in Russian], Moscow, 1957.

[9] V. A. Zakharov, Yu. N. Zanin, K. V. Zverev, et al., *Stratigraphy of the Upper Cretaceous deposits of northern Siberia (Ust'-Yenisei depression)* [in Russian], Novosibirsk, 1986.

[10] D. L. Sahagian, A. L. Beizel, and V. A. Zakharov, *Inter. Geol. Rev.*, vol. 36, p. 359, 1994.

[11] V. I. Il'ina, I. A. Kul'kova, and N. K. Lebedeva, *Microphytofossils and detailed stratigraphy of the marine Mesozoic and Cenozoic of Siberia* [in Russian], Novosibirsk, 1994.

[12] V. A. Zakharov, A. L. Beizel, N. K. Lebedeva, and O. V. Khomentovskii, *Evidence of Upper Cretaceous world ocean eustasy in the north of Siberia*, Geologiya i Geofizika (Soviet Geology and Geophysics), vol. 32, no. 8, p. 8(1), 1991.

[13] V. A. Zakharov and O. V. Khomentovskii, in: *Stage and zonal scales for the boreal Mesozoic of the USSR* [in Russian], Moscow, p. 176, 1989.

[14] V. N. Sachs, I. S. Gramberg, Z. Z. Ronkina, and E. N. Aplonova, *Mesozoic deposits of the Khatanga depression* [in Russian], Leningrad, 1959.

[15] C. Schlueter, *Palaeontographica*, vol. 24, p. 251, 1877.

[16] H. Woods, *Quart. J. Geol. Soc. London*, p. 1, 1912.

[17] S. A. Dobrov, *Uchenye Zapiski MGU, Geologiya*, issue 161, no. 5, p. 100, 1952.

[18] O. Seitz, *Beihefte zum Geol. Jahrb. Hannover*, no. 69, 1965.

[19] M. A. Pergament, *Late Cretaceous inocerams in the Pacific region, Group Inoceramus lobatus-lingua-patootensis* [in Russian], Moscow, 1965.

[20] N. M. Bondarenko, in: *Collection of articles on paleontology and biostratigraphy* [in Russian], Leningrad, no. 7, p. 43, 1958.

[21] S. P. Samoilovich, in: *Microphytofossils in oil geology* [in Russian], Leningrad, p. 113, 1980.

[22] K. A. Troeger, in: *Cretaceous of the Western Tethys. Proc. the 3rd Intern. Cret. Symposium. Tuebingen, 1987*, Stuttgart, p. 911, 1989.

[23] M.-G. Schulz, G. Ernst, F. Schmid, *Bull. Geol. Soc. Denmark*, vol. 33, p. 203, 1984.

[24] F. Schmid, *84-e Congres Soc. savantes Coll. Cretace super.*, Paris, p. 535, 1959.

[25] O. Seitz, *Beihefte zum Geol. Jahrb. Hannover*, no. 75, 1967.

[26] J. A. Jeletsky, *Beihefte zum Geol. Jahrb. Hannover*, no. 33, 1958.

[27] D. P. Naidin, in: *Proceedings of the All-Russian Workshop on refinement of the unified stratigraphical scheme of the Mesozoic deposits on the Russian Platform. Vol. 3. Cretaceous* [in Russian], Leningrad, p. 75, 1961.

[28] G. N. Papulov and D. P. Naidin (Eds.), *The Santonian-Campanian boundary on the East-European Platform* [in Russian], Sverdlovsk, 1979.

[29] G. N. Papulov and E. O. Amon, in: *Problems of Paleozoic, Mesozoic, and Cenozoic stratigraphy* [in Russian], Saratov, p. 3, 1987.

[30] A. F. Khlonova and N. K. Lebedeva, *Microphytofossils and the stratigraphy of the Mesozoic and Cenozoic of Siberia* [in Russian], Novosibirsk, p. 7, 1988.

[31] *Resolutions of the 3rd Interdisciplinary Regional Stratigraphical Workshop on the Mesozoic and Cenozoic of Central Siberia. Novosibirsk, 1978* [in Russian], Novosibirsk, 1981.

[32] *Resolutions of the 3rd Interdisciplinary Regional Stratigraphical Workshop on the Mesozoic Deposits in the West-Siberian Plain* [in Russian], Tyumen', 1991.

[33] V. M. Podobina, *Foraminifers and zonal stratigraphy of the Upper Cretaceous of West Siberia* [in Russian], Tomsk, 1989.

[34] V. S. Akimets, V. I. Baryshnikova, V. N. Ben'yamovskii, et al., *Byul. MOIP, Otd. Geol.*, vol. 53, no. 4, p. 42, 1978.

[35] V. S. Akimets, V. N. Ben'yamovskii, V. I. Gladkova, et al., *Byul. MOIP, Otd. Geol.*, vol. 54, no. 6, p. 112, 1979.

[36] D. P. Naidin, and A. V. Ivannikov (Eds.), *The Santonian-Campanian boundary deposits at the northern margin of the Donetsk Basin* [in Russian], Kiev, 1980.

[37] V. N. Ben'yamovskii, V. I. Gladkova, and L. F. Kopaevich, in: *The Santonian-Campanian boundary on the East-European Platform* [in Russian], Sverdlovsk, p. 31, 1979.

Recommended by A. V. Kanygin Received 29 January 1998