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GEOLOGY

New Data on Biotic Events during the Santonian–Campanian Transition: Evidence from Microplankton Fossils of the Russian Pacific Margin*

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The Albian–Cenomanian and Cenomanian–Turonian extinctions were among the most significant Cretaceous biotic events. The terminal Albian was marked by the last speciation outburst of the radiolarian genus *Crolanium* that became practically extinct in the early Cenomanian. The total diversity of the Cenomanian radiolarian assemblage was 75 species, which is two times lower as compared with that in the middle Albian [1]. By the end of the Cenomanian, diversity of radiolarians increased to 140–150 species and became again two times lower during the Cenomanian–Turonian boundary period, when half of these species, representatives of the family Rotaformidae included, became extinct. Similar to the ammonoid species *Schloenbachia* with the massive shell, the heavily ornamented radiolarian genus *Godia* also disappeared at that time [2].

The Santonian–Campanian transition was also marked by a significant radiolarian extinction event (Fig. 1). The presence of numerous spherical nasselarians with a submerged cephalothorax in radiolarian assemblages during geological crises may be interpreted as indicator of their adaptation to rapidly changing habitat environments [3]. It is well known that this extinction event also involved other marine organisms, ammonites included. Almost half of ammonoid taxa became extinct at that time. The Santonian *Texanites, Menuites,* and other genera with thick-walled and heavily ornamented shells were replaced by thin-shelled *Canadoceras* and *Pachydiscus*. Several species of the last genus appeared precisely in the early Campanian [4]. The lineage of the radiolarian family Pseudoaulophacidae terminated near the Santonian–Campanian boundary [5] and gave way to prunobrachids, which reflect cold-water environments.

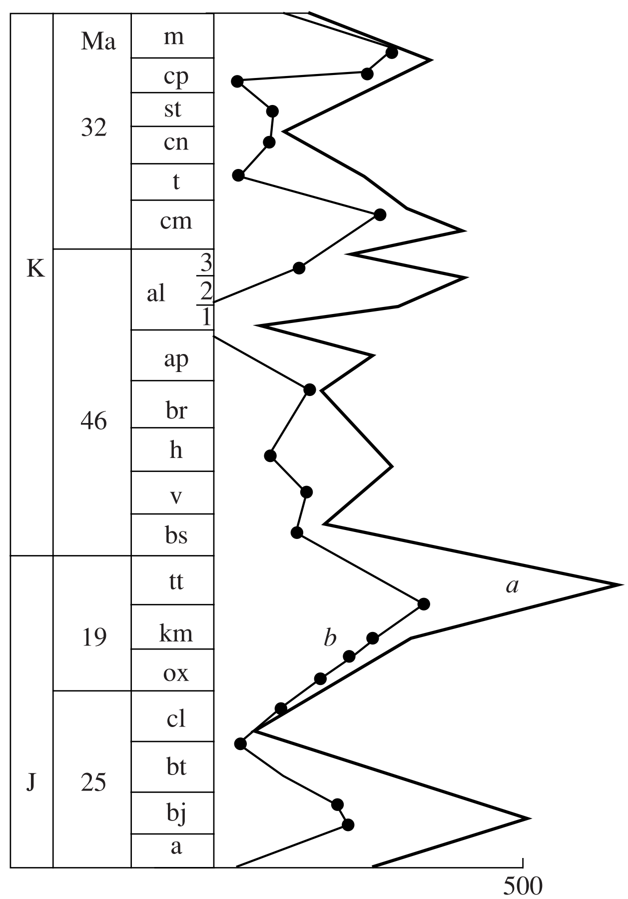

Fig. 1. Species diversity of Cretaceous radiolarians in the (*a*) Tethyan and (*b*) Boreal provinces.

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Nevertheless, the study of development dynamics in ammonoids, inoceramids, and radiolarians from terrigenous sections of western Sakhalin shows that the main extinction event occurred at the Santonian–Campanian boundary rather than in the Campanian [6]. For example, the ammonite assemblage from the uppermost Santonian–lower Campanian strata is highly endemic (17 endemics among the total 22 species) and characterized by progressive gigantism. This period was marked by extinction of the last *Menuites* representatives. Among Santonian inoceramids, all 17 species are endemic. Fifteen species from the lower Campanian *Pennatoceramus orientalis* Zone are also endemic taxa. They are accompanied by five first-appearing radially ribbed forms with the peak development confined to the late Campanian (Schmidticeramus schmidti Zone). In contrast to the impoverished and uniform late Santonian–early Campanian radiolarian assemblage consisting of the predominant 20 taxa with spongy spherical and discoid forms, their late Campanian assemblage is represented by 37 species, more than 50% of which belong to the cyrtoid group. In addition to radiolarians, upper Campanian sediments yielded 72 species of stenobathic benthic foraminifers that point to well-aerated environments [6].

In this communication, we consider manifestation of Santonian–Campanian biotic events [7] in sections located north of Sakhalin, i.e., in the Koryak–Kamchatka region. Here, sedimentary sequences are largely composed of siliceous rocks, which lack ammonites and contain only rare inoceramids and foraminifers [8, 9]. Previously, it was established that the continuous Santonian–Campanian section in the Vatyna River basin (Koryak Highland, northeastern Russia) encloses only radiolarians and scarce foraminifers [8]. In the Kamchatka region, we examined several siliceous sections along the western coast of the peninsula (Palana, Rassoshina, and Tikhaya river basins), where foraminifers and radiolarians were found together in the same layers [9]. It was previously assumed that the boreal zone in high latitudes of the northern hemisphere is indefinable based on foraminifers, while the temperate zone is recognizable only in Polish sections (slightly north of 45° N). Even sections of the Falkland Plateau provided only transitional thanatocoenosis [10, 11]. In this connection, the preliminary analysis of Cetaceous microfaunas from high latitudes of Russia is of particular interest.

The study of Cretaceous–Paleogene sediments from the Koryak–Kamchatka region of Russia based on chemical treatment and scanning electron microscope revealed and confirmed the presence of well-preserved radiolarian and foraminiferal boreal assemblages in the study region. The uniqueness of the study consists in the parallel analysis of two microfaunal groups from Santonian–Campanian boundary strata of the same high-latitude region. As was demonstrated by studies of Cretaceous planktonic foraminifers and radiolarians from different areas of the World Ocean, the structure of their assemblages was determined to a significant extent by surface water temperatures (see, for example, [10, 12]).

In the Vatyna River basin of the Koryak region, the uppermost part of the Santonian section is composed of terrigenous tuffaceous siltstones, whereas the Campanian is represented by pure siliceous rocks [1, 8].

Previously, the single Late Santonian–early Campanian radiolarian complex consisting of 46 species was defined in sections of the southern Koryak Highland [1]. Owing to finds of Santonian radiolarians in the last region and western Kamchatka (together with planktonic foraminifers), this complex is now subdivided into the late Santonian (with *Pseudoaulophacus floresensis*) and early Campanian (with *Prunobrachium crassum*) assemblages characterizing corresponding beds.

The Santonian assemblage consisting of more than 30 species is dominated by spongy spherical and discoid forms. Of significance in this assemblage are *Archaeospongoprunum bipartitum* Pessagno and *Archaeodictyomitra squinaboli* Pessagno that disappear at the base of the Campanian. They are accompanied by characteristic species *Cromyosphaera tschurini* Lipman, *Orbiculiforma persenex* Pessagno, *O. quadrata* Pessagno, *Multastrum flos* Vishnevskaya, *Spongotripus morenoensis* Campbell et Clark, *Pseudoaulophacus floresensis* Pessagno, *Diacanthocapsa euganea* (Squinabol), *Stichomitra manifesta* Foreman, *S. livermorensis* (Campbell et Clark), *Dictyomitra densicostata* Pessagno, and others. Noteworthy is the cooccurrence of the first tiny peculiar Campanian species *Stichomitra manifesta* Foreman and *S. livermorensis* (Campbell et Clark) with *Archaespongoprunum bipartitum* Pessagno, which became extinct in the Santonian [5].

The radiolarian assemblage is accompanied by planktonic foraminifers. In Cretaceous foraminiferal assemblages of the Koryak region, the Santonian foraminiferal assemblage (*Pseudoaulophacus floresensis* radiolarian beds) includes only two species (*Hedbergella* sp. and *Globigerinelloides* sp.) found in the Petr and Pavel Bay section. The coeval foraminiferal assemblage from the Palana section of western Kamchatka consists of eight planktonic species belonging to the genera *Hedbergella, Archaeoglobigerina, Planomalina*, and *Rotalipora* and subordinate benthic *Planularia* and Rotaliidae forms. The late Albian–Cenomanian foraminiferal assemblage from the carbonate–siliceous section of the Koryak region (Vatyna River basin) is represented by three genera: *Hedbergella* (four species), *Globigerinelloides* (two species), and *Heterohelix* (one species).

The early Campanian radiolarian assemblage (Fig. 2) is composed of 27 species with spheroid and cyrtoid groups being represented in equal proportions, while the discoid group occupies the subordinate position. More than half of the middle Campanian taxa are cosmopolitan forms, which appear in the region for the first time: *Theocapsomma brevitorax* Dumitrica, *T. ancus*

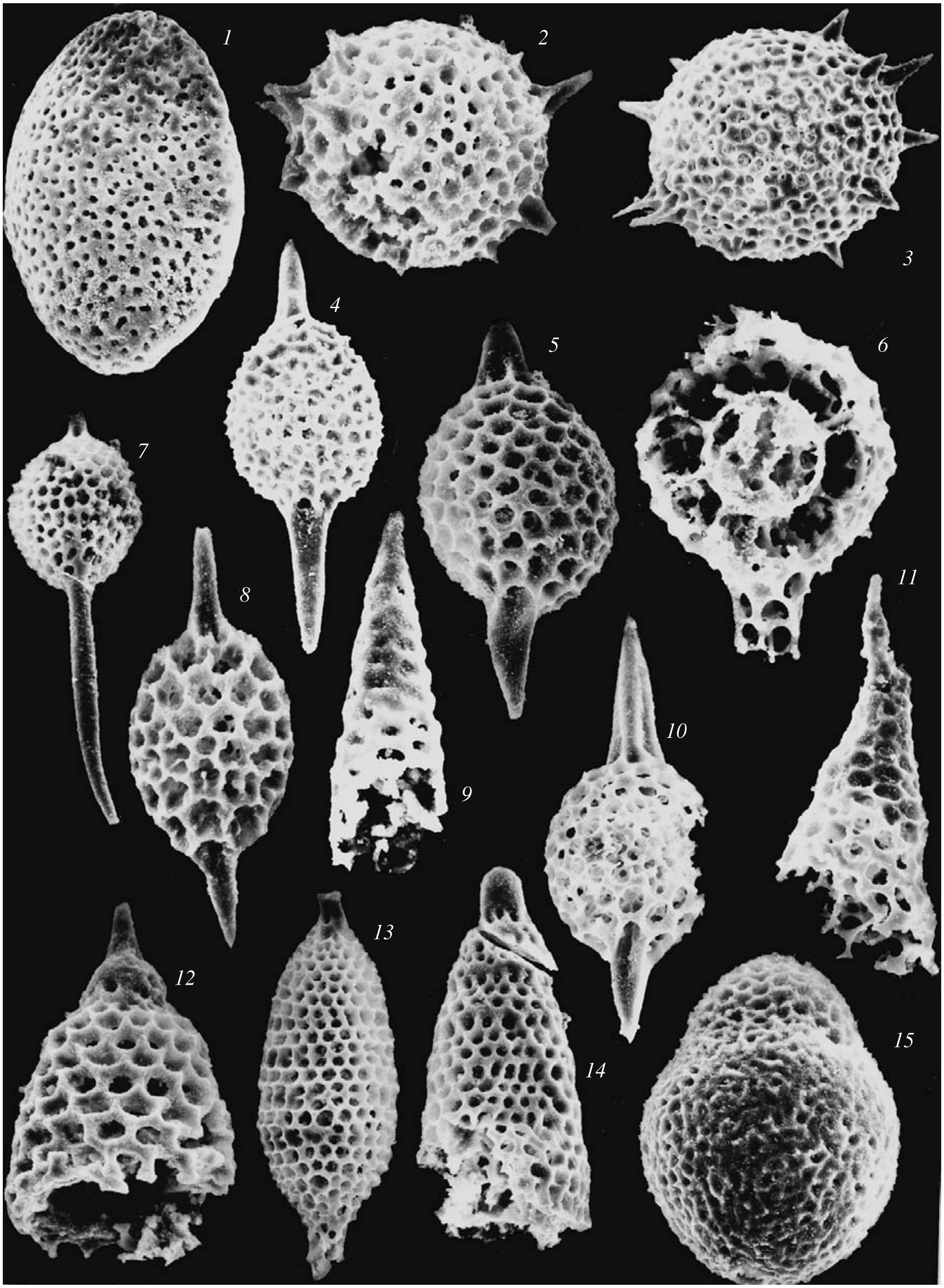

Fig. 2. Campanian radiolarian assemblage from the Ust'-Palana basin (Sample 134/01). (*1*) *Phaseliforma* cf. *subcarinata* Pessagno, 160 × (*2*, *3*) *Lithomespilus* aff. *coronatus* (Squinabol), 270 ×, 160 ×; (*4*, *5*, *10*) *Protoxiphotractus perplexus* Pessagno, 160 ×, 185 ×, 210 ×; (*6*) *Protoxiphotractus* sp. 285 ×; (*7*) *Stylosphaera hastata* Campbell & Clark, 210 ×; (*8*) *Protoxiphotractus kirbui* Pessagno, 250 ×; (*9*, *11*) *Cornutella californica* Campbell & Clark, 330 ×, 285 ×; (*12*) *Coniforma ? antiochensis* Pessagno, 230 ×; (*13*) *Stichomitra livermorensis* (Campbell & Clark), 150 ×; (*14*) *Amphipyndax stocki* (Campbell & Clark), 230 ×; (*15*) *Theocapsomma* sp., 275 ×.

(Foreman), *Amphipyndax conicus* Nakaseko et Nishimura, *Cornutella californica* Capmbell et Clark. This assemblage contains typical cold-resistant species belonging to the genera *Prunobrachium* (six species) and *Excentrosphaerella* (three species): *P. angustum* (Lipman), *P. crassum* (Lipman), *P. mucronatum* (Lipman), *P. sibiricum* Lipman, *P. incisum* Kozlova, *P. longum* Pessagno, *E. kamchatica* Vishnevskaya et Dumitrica, *E. kovalenkovi* Vishnevskaya, and *E. sukhovi* Vishnevskaya. The radiolarian assemblage becomes substantially renewed due to the appearance of Campanian species *Phaseliforma carinata* Pessagno, *Orbiculiforma australis* Pessagno, *Praestylosphaera hastata* (Capmbell et Clark), *Protoxiphotractus kirbui* Pessagno, *P. perplexus* Pessagno, and *Coniforma antiochensis* Pessagno; numerous representatives of high-conical forms of the genus *Amphipyndax*; and *Archaeospongoprunum salumi* Pessagno, which became extinct in the early Campanian. The early Campanian assemblage from the Vatyna River basin also contains several species characteristic only of high latitudes, in addition to representatives of the *Prunobrachium* genus. These are *Heliodiscus borealis* Vishnevskaya, *Spongasteriscus rozanovi* Vishnevskaya, *Prunopyle stanislavi* sp. Vishnevskaya, *Plegmosphaera* sp. 1, and *Cromyosphaera vivenkensis* Lipman [13]. From the last locality (no. 64; 61°40′ N, 172°50′ E), E.A. Yazykova determined *Pennatoceramus orientalis* (Sokolov), which allowed the *Prunobrachium crassum* radiolarian beds to be attributed to the lower Campanian *Pennatoceramus orientalis* Zone [14]. Radiolarians are accompanied by abundant benthic foraminifers *Stensioeina* cf. *exsculpta* (Reuss), *Osangularia* aff. *florealis* (White), and *Hyperammina* cf. *nodosariaformis* (Subbotina), which imply cold bottom waters in the past basin.

In contrast to more diverse Paleogene foraminiferal assemblages of northeastern Russia, early Campanian benthic foraminifers from the Koryak–Kamchatka region are represented by species belonging to genera *Glomospira, Haplophragmoides, Hyperammina, Osangularia, Stensioeina*, and *Silicosigmoillina* well adapted to cold, probably, bathyal and/or abyssal waters.

Thus, similar to the northeastern framing of the Pacific, the Santonian–Campanian boundary in sections of the Northwest Pacific continental margin is recognizable, in addition to lithological changes, based on the composition of microfossil assemblages and the ratio between their relatively thermophilic and cold-resistant constituents. It should be noted that the Santonian assemblages appeared to be more thermophilic than their Campanian counterparts. At the same time, both of them are relatively less thermophilic as compared with coeval Californian assemblages. The Santonian sediments of the northeastern Pacific continental fringing contain abundant representatives of relatively thermophilic radiolarian genera *Alievium, Microsciadiocapsa, Pyramispongia*, and others. For example, the genus *Alievium*, particularly abundant in Santonian sections of California, is characterized by the high stratigraphic and correlation potential of many of its species. Based on the rapid evolutionary development and high abundance of this genus, Pessagno [5] proposed the Turonian *Alievium superbum*, Coniacian *Alievium praegallowayi*, and Santonian *Alievium gallowayi* radiolarian zones, which are valid up to the present time. For the Campanian, he proposed the *Crucella espartoensis* Zone since development of *Alievium* decelerates in the early Campanian and its last two species (*A. gallowayi* Pessagno, *A. murphyi* Pessagno) became extinct by the end of this age, which is, probably, explained by cooling. Radiolarians coexist frequently with foraminifers in Californian sections. Therefore, we can correlate their bioevents. For example, the Santonian *Alievium gallowayi* Zone of California is considered equivalent to the Californian *Globotruncana coronata* or Caribbean *Globotruncana bulloides* foraminiferal zone, while the lower Campanian *Crucella espartoensis* radiolarian zone is correlated with the coeval *Archaeoglobigerina blowi* foraminiferal subzone. In the Koryak–Kamchatka region, the foraminiferal scale is invalid.

It is known that the initial Late Cretaceous is marked by intense erosion in the Pacific with a maximum at the Cenomanian–Turonian boundary. This correlates well with the curve of radiolarian diversity (Fig. 1) and is, probably, related to the tectonic activity accompanied by reorganization of lithospheric plates and a new phase of volcanism in some places. Turonian–Santonian pelagic sediments are rare in the Okhotsk Sea region. The Coniacian–Santonian–lower Campanian tuffaceous gravelstones and agglomerates with fragments of siliceous rocks, inoceramid detritus, and admixture of volcanogenic material [15] probably indicate intensified tectonic activity in the northwestern Pacific region. Stratigraphic hiatuses, dissolution facies, or sediment reworking at the Cenomanian–Turonian boundary are recorded in many deep-sea drilling holes of the Pacific.

The next maximum of erosion in the western Pacific coincides with the Santonian–Campanian transition, which probably resulted from a new tectonic activation phase. This period is marked by the commenced formation of graded volcanic sandstones with members of volcanic breccia, redeposited molluscan shells and large foraminifers [12], and carbonate–siliceous interbeds (DSDP Holes 165, 313, 315, 316). It is conceivable that tuffaceous–siliceous turbidites with detritus of inoceramid shells, which are widespread in Santonian–Campanian sections of the Koryak–Kamchatka region, and frequent olistostromes with the Campanian matrix developed in the Ust'-Palana area are related to these events. Mass accumulations of inoceramid prismatic layers and shell fragments are confined precisely to the uppermost Santonian–basal Campanian siliceous–terrigenous sections in the entire Bering Sea region. This is probably explained by mass extinction of organisms due to sharp paleogeographic changes (cooling, regression, and subsequent regression), which could result in migration or extinction of both benthic and planktonic organisms. Previous researchers noted redeposited cherts with Triassic [1] and Middle Cretaceous [15] radiolarians in the Santonian–Campanian siliceous–terrigenous sediments of the Koryak–Kamchatka region. Abundant Coniacian–Santonian foraminifers recorded in sections along the western coast of Kamchatka indicate relatively shallow-water sedimentation settings (above the CCD level).

New species of the genera *Astrophacus, Heliodiscus*, and *Excentrosphaerella* of the radiolarian family Heliodiscidae, which were previously assumed to appear in the mid-Paleogene (*Astrophacus* and *Heliodiscus*) or Neogene (*Excentrosphaerella*) are found in the reliably dated lower Campanian strata of the Koryak–Kamchatka region. The main distinctive feature of heliodiscids, relative to other radiolarian taxa, is the eccentric position of the microsphere. New species widen substantially the family composition, increase the list of world radiolarian faunas, and characterize the Santonian–Campanian boundary strata in various regions of Russia and the world.

Moreover, it appeared that new representatives of the family Heliodiscidae are confined only to this boundary interval and its genus *Excentrosphaerella* occurs only in sediments corresponding to crisis periods. It is conceivable that such a property may be potentially useful for defining relationships between biotic and abiotic events.

Thus, the Santonian–Campanian boundary is marked by significant change in radiolarian assemblages: the relatively thermophilic Late Santonian assemblage with *Pseudoaulophacus floresensis* is replaced by the cold-resistant early Campanian assemblage with *Prunobrachium crassum.* Similar changes are also observed in foraminifers: the more thermophilic planktonic Santonian assemblage gives way to a cold-resistant early Campanian benthic community.

The main methodological approach, which allowed us to trace the development of Santonian–Campanian radiolarian and foraminiferal assemblages, consists in the extraction of foraminifers and radiolarians from siliceous–tuffaceous rocks from many localities with the help of hydrofluoric acid. Previously, Cretaceous foraminifers were practically unknown from this region, whereas Paleogene microfossils remained ignored because of the impossibility of their extraction from rocks. The further study of the taxonomic composition of Cretaceous radiolarians and foraminifers from new localities can make it possible to define the so-called lesser mass extinction events and specify particular stratigraphic levels.

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