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STRATIGRAPHY

Palynomorphs—Indicators of the Redeposition of Ammonites in the Jurassic—Cretaceous Boundary Interval of the European Part of Russia

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Abstract—The Jurassic—Cretaceous boundary interval of the European part of Russia (the boundary between the Volgian and Ryazanian stages) is associated with regionally developed gaps involving 1—2 ammonite zones and related horizons of redeposition and condensation. By studying palynomorphs separately from the body chambers of ammonites and from host deposits in two reference sections (Kuzminskoye, Ryazan Oblast; Maryevka, Ulyanovsk Oblast), the different ages of ammonites and host rocks have been proven, despite the good preservation of ammonites and lack of visible signs of redeposition. This made possible to establish the re-deposition of Volgian ammonites of the genus *Garniericeras* in the Ryazanian Stage of the Ryazan region, as well as to demonstrate the age discrepancy between the ammonites and host sediments at the Volgian—Ryazanian stage boundary in the Maryevka section.

Keywords: Stratigraphy, Volgian, Ryazanian, dinocysts

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INTRODUCTION

The boundary interval between the Jurassic and Cretaceous systems is currently attracting considerable attention from researchers. The Jurassic—Cretaceous boundary represents the only system boundary in the Phanerozoic for which neither a Global Stratotype Section and Point (GSSP) nor the candidate region, key event, or event type have yet been established. Due to the significant provincialism of faunas at the Jurassic-Cretaceous boundary, two pairs of stages have historically been used in this stratigraphic interval: the Volgian and Ryazanian stages (for mid- and high-latitude sections of the Northern Hemisphere), as well as the Tithonian and Berriasian stages (for other regions) [1, 2].

The type regions for the Volgian and Ryazanian stages are the Moscow area and the Middle Volga region. In all currently known sections of these deposits, the Volgian and Ryazanian stages are separated by a major stratigraphic unconformity involving 1—2 ammonite zones. The study of this stratigraphic interval is complicated by the limited thickness of the deposits (typically the first few meters) and a large number of horizons of redeposition and condensation, with which accumulations of phosphorite concretions are associated, as well as slabs of phosphatic sandstone ranging from 5 to 20 cm in thickness, wherein ammonite moulds are frequently found [3, 4].

Despite the large number of publications devoted to ammonites from the terminal part of the Volgian Stage and the lower part of the Ryazanian Stage, the distribution ranges of key genera and species remain a subject of debate.

One such controversial issue concerns the potential occurrence of ammonites belonging to the typical Upper Volgian genus *Garniericeras* in the Ryazanian stage. An assemblage containing *Garniericeras* and *Riasanites*, typical Ryazanian genus, was identified by Mesezhnikov et al. [3, 5] at the base of the Ryazanian stage in the vicinity of Ryazan. The researchers proposed the "Riasanites riasanensis and Garniericeras subclypeiforme zone." They noted that the finds of *Garniericeras* in this stratigraphic interval suggest the possibility of reworking, but its preservation does not provide grounds for such an assumption.

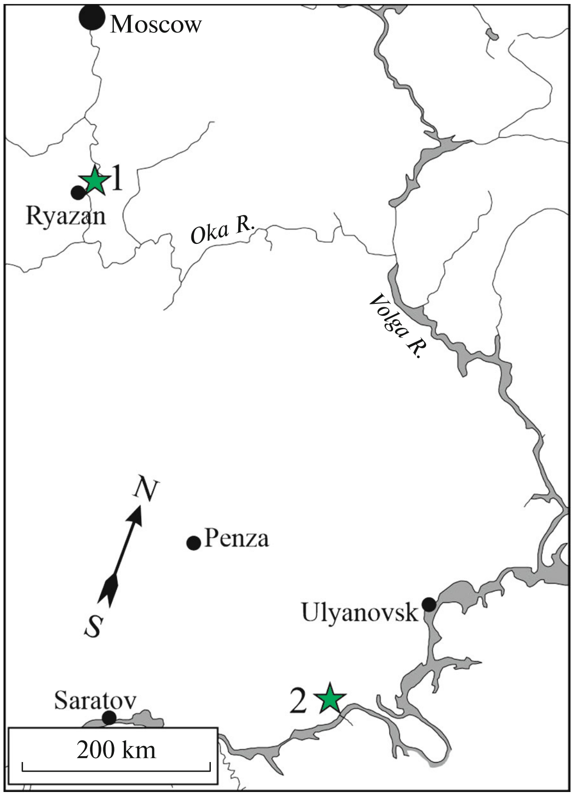

Fig. 1. Location of the sites from which the studied material originates. 1—Kuzminskoye (coordinates: 54.868060° N, 39.637642° E); 2—Maryevka (coordinates: 53.116220° N, 48.163427° E).

This interpretation was challenged by Sazonov and Sazonova [7], who regarded the *Garniericeras* shells as reworked from older deposits. They noted differences in preservation and P_2O_5 content between *Garniericeras* and other ammonites from the same layer.

Subsequently, the sections near the villages of Kuzminskoye and Kostino, where the ammonites in question were found, were visited on multiple occasions by both M.S. Mesezhnikov and I.G. and N.T. Sazonovs, and were included for study in a geological excursion offered to participants of the International Geological Congress held in 1984 in the USSR [8]. Nevertheless, the competing groups of researchers remained firm in their respective opinions, and the question of the occurrence of *Garniericeras* in the Ryazanian Stage has not yet received a definitive resolution.

Later, the section at Kuzminskoye was studied by V.V. Mitta [4], who concluded that findings of ammonites of the genera *Garniericeras* and *Riasanites* are belonged to distinct layers. However, considering the significant lateral variability in the structure of the boundary deposits of the Volgian and Ryazanian stages in the Ryazan region [3, 5], the question regarding the possible co-occurrence of ammonites of the genera *Garniericeras* and *Riasanites* remains open.

MATERIALS AND METHODS

This work is based on a collection of ammonites gathered by M.S. Mesezhnikov at the outcrop near the village of Kuzminskoye (Rybnov District, Ryazan Oblast) in the late 1970s and early 1980s, as well as samples from the Jurassic–Cretaceous boundary interval at the outcrop near the village of Maryevka (Novospassk District, Ulyanovsk Oblast), collected by the authors during fieldwork in 2013–2018 (Fig. 1).

All studied specimens from the M.S. Mesezhnikov's collection (Fig. 2.1–2), were referred to published descriptions of the Kuzminskoye section [3, 5] and field notebooks. They originate from 4 of the Kuzminskoye-1 outcrop (lower part of the Ryazanian Stage, "Riasanites rjasanensis and Garniericeras subclypeiforme zone"). Material from the Maryevka section (Fig. 2.3–6) was collected from an interbed of phosphatized sandstone (Fig. 3) at the top of the Volgian Stage (Bed M23 in [9]), which yielded an ammonite assemblage characteristic of the *milkovensis* biohorizon of the Nodiger Zone of the Upper Volgian Substage: *Craspedites* (*Trautscholdiceras*) *milkovensis* (Strem.) (Fig. 2.3–4), *C.* (*T.*) *kashpuricus* (Trd.) (Fig. 2.5), and rare *Garniericeras subclypeiforme* (Milash.). In the overlying bed M24, ammonites are rare; a single specimen of the Early Ryazanian *Shulginites* was encountered there (Fig. 2.6).

Samples from M.S. Mesezhnikov's collection and the authors' own collections were used for palynological analysis. Two palynological samples originate from bed 4 of the Kuzminskoye-1 outcrop: a sample of host rock with fragments of ammonite shells (sample 4-Kuz), and a intact specimen of *Garniericeras subclypeiforme* (Milash.), from the inner chamber volume of which Sample 8-Kuz was obtained. Samples were collected from the Maryevka section in a similar manner. From bed M23, the following were sampled: a rock sample without faunal remains (sample Mr17-23Eshch), and a intact specimen of *Craspedites* (*Trautscholdiceras*) *milkovensis* (Strem.), from which the contents of the chambers were extracted (sample MK10546). All samples underwent chemical maceration using a method based on on the separation technique of Gritchuk [10]. Microscopic examination was performed using a Carl Zeiss AXIOSTAR (PLUS) light microscope at magnifications of ×400 and ×630; photographs were taken with an ADF PRO20 digital camera. Taxonomic identifications of the dinocysts are provided in accordance with [11].

The studied collection of ammonites is kept at the Aprelevka Branch of the Federal State Budgetary Institution All-Russian Research Geological Oil Institute (except the ammonite shown in Fig. 2.6, which is kept at Yaroslavl State Pedagogical University); the palynological slides are kept in the Laboratory of Paleofloristics at the Geological Institute of the Russian Academy of Sciences (GIN RAS).

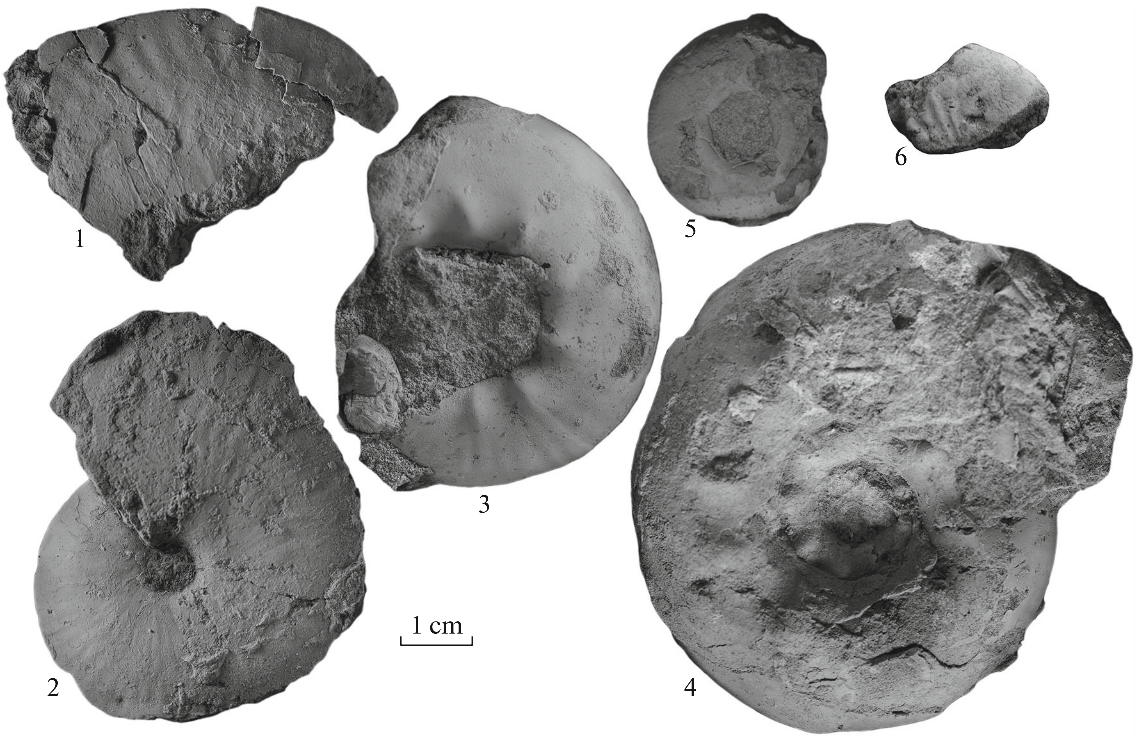

Fig. 2. Upper Volgian (1–5) and Lower Ryazanian (6) ammonites from the studied sections. The specimens were coated with ammonium chloride before photographing. (1, 2) *Garniericeras subclypeiforme* (Milashevich), Kuzminskoye, outcrop 12, bed 4; 1—sp. RMA-66/1 (= [5], Table II, Fig. 7); 2—sp. 122/823 (= [5], Table II, Fig. 5); (3–4) *Craspedites* (*Trautscholdiceras*) *milkovensis* (Strem.), Maryevka, bed M23, 3—sp. RMA-66/2, 4—sp. RMA-66/3; 5—*Craspedites* (*Trautscholdiceras*) *kashpuricus* (Trd.), sp. RMA-66/3, Maryevka, bed M23; 6—*Shulginites* cf. *tolijense* (Nikitin), sp. YarGPU MK7725 (= [19], Table VI, Fig. 8).

RESULTS AND DISCUSSION

A comparative analysis of the palynological samples (Figs. 4–8) showed that in both pairs of samples (4-Kuz/8-Kuz and Mr17-23Eshch/MK10546), the palynomorph associations differ significantly both taxonomically and in terms of the quantitative composition of their components. A detailed taxonomic composition of the associations, with quantitative data expressed as percentages, is presented in Figs. 4 and 5.

The 8-Kuz dinocyst association, extracted from the body chamber of *G. subclypeiforme* (Milash), is characterized by significant species diversity and excellent preservation. The dominant taxa are *Senoniasphaera jurassica* (Gitmez and Sarjeant) Lentin and Williams and *Sentusidinium* spp.; relatively common are *Canningia reticulata* Cookson and Eisenack, *Cribroperidinium* spp., the large *Hystrichodinium pulchrum* Deflandre, and dinocysts with a archaeopyle type 3+4P (*Gongylodinium*? spp.). This association is typical, both taxonomically and quantitatively, for the Upper Volgian *Garniericeras catenulatum–Craspedites nodiger* zones of the Russian Plate [12–14].

The association from the host rock (4-Kuz) is markedly different (Fig. 4). The sample contains dinocysts represented by several generations of various preservation. Along with in situ forms, there are clearly redeposited palynomorphs from the Upper Volgian assemblage. Despite good preservation, these are characterized by specific coloration in shades of brown and yellow. This is consistent with the presence of fossil fragments of various ages in the rock. The evidently

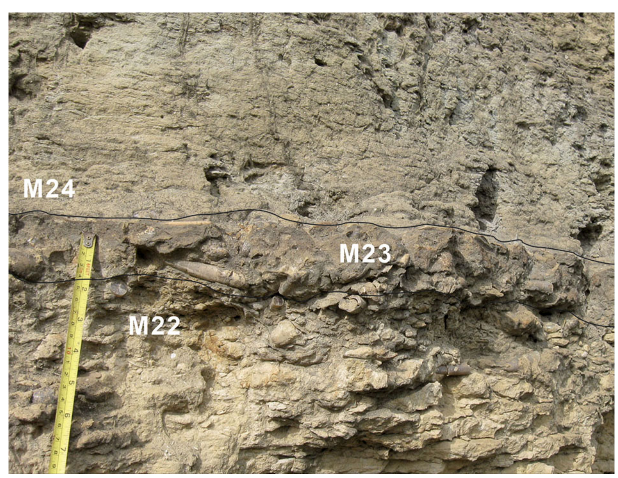

Fig. 3. Boundary deposits of the Volgian and Ryazanian stages of the Maryevka section. Bed M22 belongs to the Upper Volgian substage, bed M24 to the Lower Ryazanian substage. Bed M23 contains Upper Volgian ammonites, but has a matrix of Early Ryazanian age.

Fig. 4. Comparison of the taxonomic and quantitative compositions of palynological assemblages from ammonite body chambers and host sediments of the Kuzminskoye 1 section. The sample 4-Kuz includes redeposited palynomorphs.

in situ dinocysts lack distinct coloration and are represented by numerous *Dingodinium* spp., frequent *Clamydophorella* spp., *Impagidinium* spp., *Stephanelytron membranoideum* (Vozzhennikova) Courtinat, and *Wrevittia? diutina* (Duxbury) Helenes and Lucas-Clark. The Ryazanian age of the sample is confirmed by typical species: *Achomosphaera neptuni* (Eisenack) Davey and Williams, *Muderongia longicorna* Monteil, *Muderongia* sp. I, *Spiniferites* cf. *ramosus* (Ehrenberg) Mantell. Here are the features of the association that deserve special attention. *M. longicorna* Monteil is represented by a morphotype of the species *Muderongia brevispinosa* Iosivova, described by E.K. Iosifova [15] in the Ryazanian palynomorph assemblage at the level of the *Riasanites rjasanensis* ammonite Zone. The 4-Kuz association also includes a form designated as fam. gen. indet. ex Fedorova and Gryazeva, 1984 (Figs. 7.8–7.9), previously mentioned at the level of the *Riasanites rjasanensis* zone [15, 16]. A morphotype, identical to the species *Batioladinium radiculatum* Davey, is noted; this species was described from the Ryazanian Stage of Denmark at the level of the *Praetollia* (*Runctonia*) *runctoni* zone [17] and was subsequently synonymized with *Batioladinium longicor-*

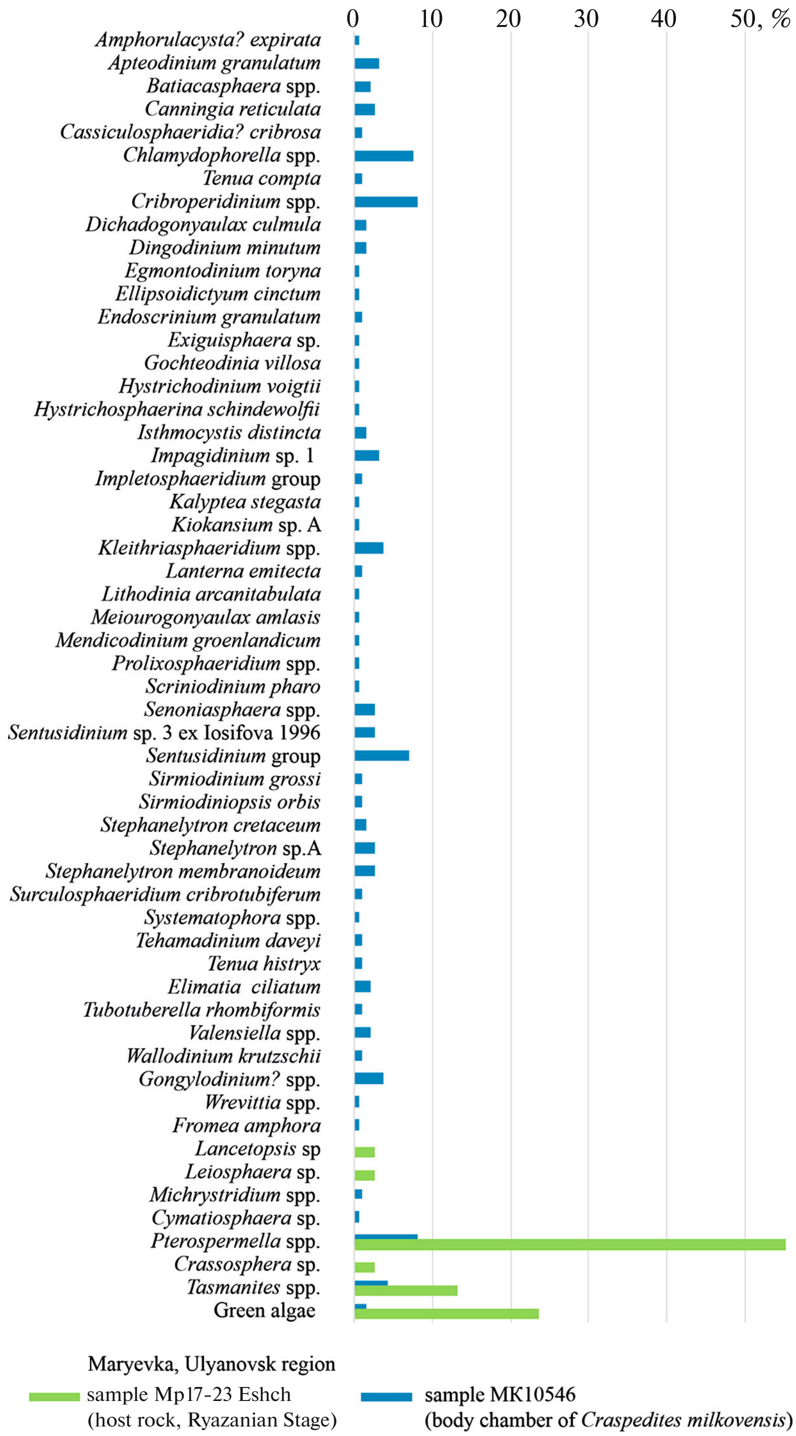

Fig. 5. Comparison of the taxonomic and quantitative compositions of palynological assemblages from ammonite body chambers and host sediments in the Maryevka section.

nutum (Alberti) Brideaux. This morphotype is identified herein as *B.* cf. *longicornutum*, as there are grounds to assert that these species differ morphologically. The species *Palaecysta morondavaensis* Chen, *P. palmula* (Davey) Williams and Fensome, judging by the presence of secondary coloration and predominantly fragmentary preservation, are likely reworked. However, they are not typical of most of the Upper Volgian Substage of the Russian Plate and do not appear earlier than the terminal Upper Volgian *Volgidiscus singularis* Zone [18]. Therefore, we suppose that in the Kuzminskoye-1 section, the complete succession of

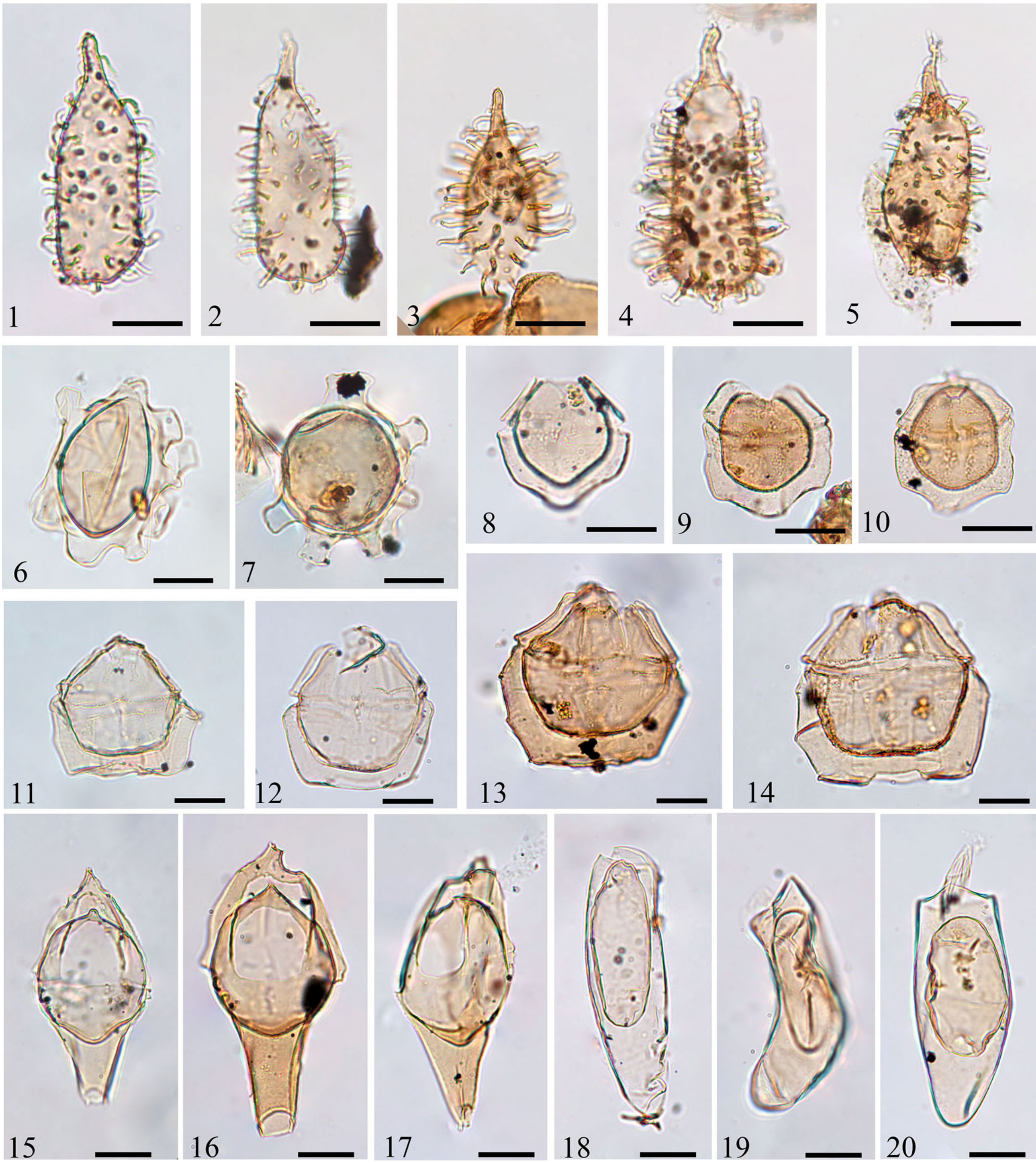

Fig. 6. Comparison of the preservation of dinocysts from the body chamber of *Garniericeras subclypeiforme* (sample 8-Kuz, Upper Volgian substage, Craspedites nodiger zone) and from the host rock (sample 4-Kuz, Lower Ryazanian substage). Scale bar length: 20 µm. Kuzminskoye-1 section, bed 4. (1–5) *Gochteodinia villosa* (Vozzennikova) Norris: 1, 2—sample 4-Kuz, specimens from the host layer, probably in situ; 3—sample 4-Kuz, reworked specimen, cyst fragment with more intense color; 4, 5—sample 8-Kuz, cysts with more intense color but similar wall thickness to in situ specimens; (6, 7) *Riasanodinium fedorovae* Iosifova: 6—sample 4-Kuz; 7—sample 8-Kuz, color intensity differs slightly, mainly on the denser endocyst; (8–10) *Sirmiodiniopsis orbis* Drugg: 8—4-Kuz, likely in situ; 9—sample 4-Kuz, intensely colored specimen, reworked; 10—sample 8-Kuz; (11–14) *Sirmiodinium grossi* Alberti: 11, 12—sample 4-Kuz, specimens in situ?; 13—sample 4-Kuz, Ryazanian Stage, clearly reworked; 14—sample 8-Kuz; (15–17) *Tubotuberella rhombiformis* Vozzhennikova: 15—sample 4-Kuz, in situ; 16—sample 4-Kuz, reworking; 17—sample 8-Kuz; (18–20) *Wallodinium krutschii* (Alberti) Habib: 18— sample 4-Kuz, in situ; 19—sample 4-Kuz, reworking; 20—sample 8-Kuz.

the Upper Volgian Substage was eroded and redeposited.

In the pair of samples Mr17-23Eshch/MK10546 from the Maryevka section, the differences between the palynological spectra are even more manifested (Fig. 5). The body chamber of the ammonite *Craspedites* (*T.*) *milkovensis* (Strem.) (sample MK10546) contains an association of marine phytoplankton

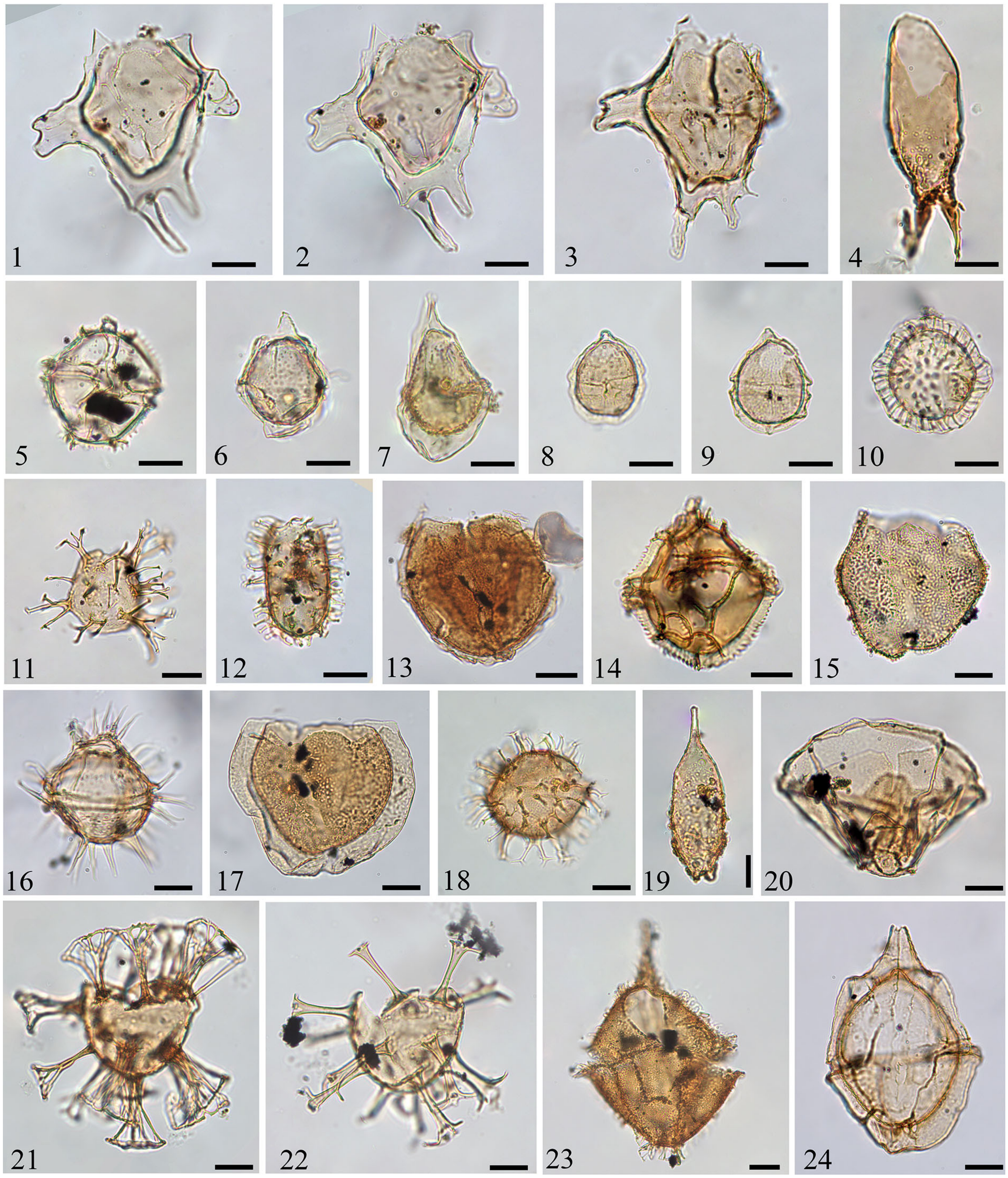

Fig. 7. Dinocysts from the Kuzminskoye section. Scale bar: 20 μm. (1–11) Dinocysts from the Ryazanian palynomorph assemblage, sample 4-Kuz: 1–3—*Muderongia* sp. I; 4—*Batioladinium* cf. *longicornutum* (Alberti) Brideaux; 5—*Wrevittia? diutina* (Duxbury) Helenes and Lucas-Clark; 6—*Dingodinium albertii* Sarjeant; 7—*Dingodinium cerviculum* Cookson and Eisenack; 8—dinoflagellatae fam. gen. indet. ex Fedorova, Gryazeva, 1984; 9—same, another specimen; 10—*Stephanelytron membranoideum* (Vozzhennikova) Courtinat; 11—*Palaecysta morondavaensis* Chen., fragment; (12–14) reworked Volgian dinocysts from, sample 4-Kuz, Ryazanian Stage: 12—*Egmontodinium toryna* (Cookson and Eisenack) Davey; 13—*Senoniasphaera jurassica* (Gitmez and Sarjeant) Lentin and Williams; 14—*Stanfordella fastigiata* (Duxbury) Helenes and Lucas-Clark. (15–24) Dinocysts from the Upper Volgian assemblage, extracted from the body chamber of *G. subclypeiforme*, sample 8-Kuz: 15—*Canningia reticulata* Cookson and Eisenack; 16—*Hystrichodinium pulchrum* Deflandre; 17—*Senoniasphaera jurassica* (Gitmez and Sarjeant) Lentin and Williams; 18—*Dichadogonyaulax culmula* (Norris) Loeblich Jr. and Loeblich III; 19—*Batioladinium* sp. I ex Davey 1982; 20—*Isthmocystis distincta* Duxbury; 21—*Emmetrocysta sarjeantii* (Gitmez) Stover and Evitt; 22—*Oligosphaeridium* sp. 1 (ex. gr. *Perisseiasphaeridium insolitum* Davey); 23—*Cribroperidinium sepimentum* Neale and Sarjeant; 24—*Scriniodinium pharo* (Duxbury) Davey.

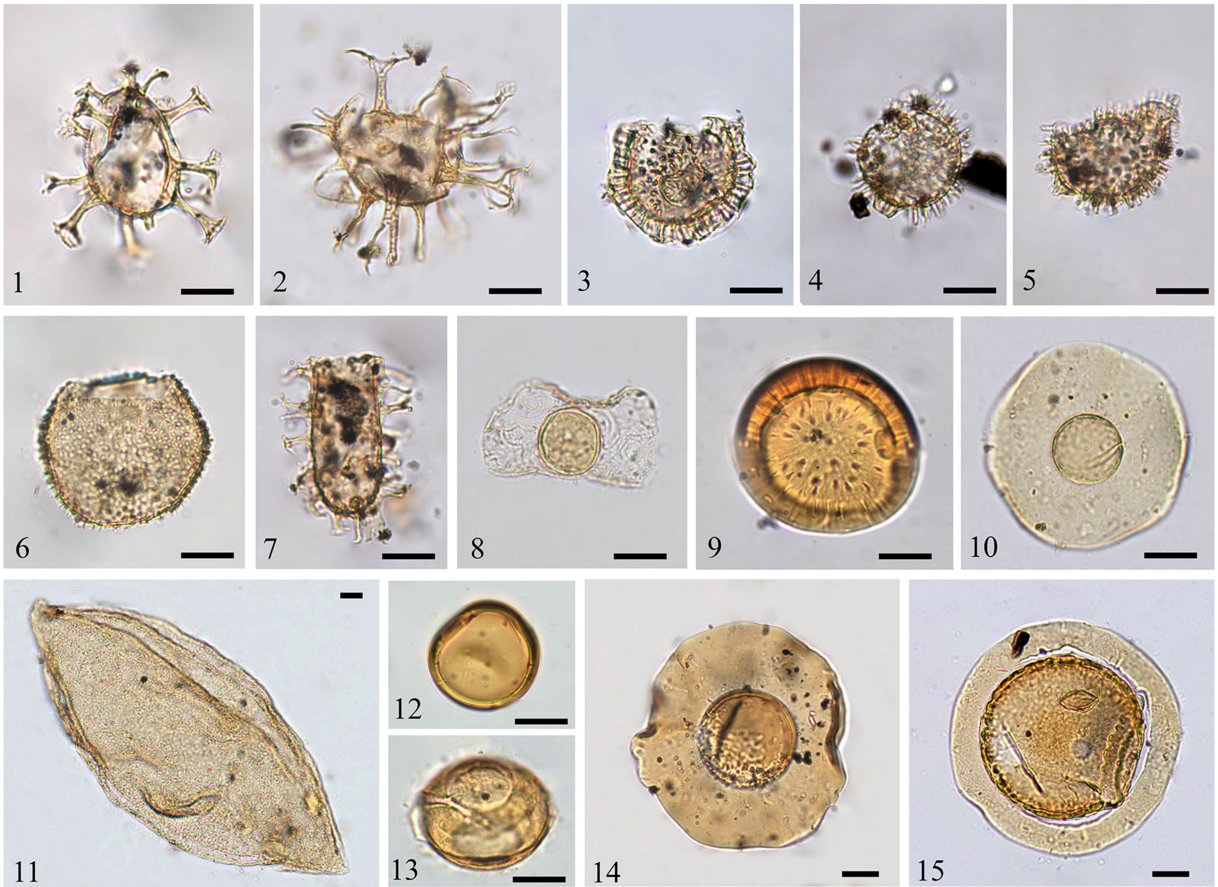

Fig. 8. Palynomorphs from bed M23 of the Maryevka section. Scale bar: 20 µm. (1–8) Dinocysts and prasinophytes from the body chamber of the Upper Volgian ammonite *Craspedites milkovensis*, sample MK10546: 1—*Kleithriasphaeridium porosispinum* Davey; 2—*Surculosphaeridium cribrotubiferum* (Sarjeant) Davey et al.; 3—*Stephanelytron membranoideum* (Vozzhennikova) Courtinat; 4, 5—*Stephanelytron* sp. A; 6—*Tenua hystrix* Eisenack; 7—*Egmontodinium toryna* (Cookson and Eisenack) Davey; 8—*Pterospermella* sp.; (9–15) Palynomorphs from the Ryazanian prasinophyte assemblage of the host rock, sample M17-23Eshch: 9, 12—*Tasmanites* spp.; 10, 14, 15—*Pterospermella* spp.; 11—*Lancetopsis* sp.; 13—phycoma of green algae, possibly the internal body of *Pterospermella* sp.

dominated by dinosysts. In terms of taxonomic composition, this association is typical of the Upper Volgian deposits of the Russian Plate and is generally comparable to the association of sample 8-Kuz described above. It is characterized by common *Sentusidinium* spp., *S. jurassica, Cribroperidinium* spp., and *Gongylodinium?* spp. The preservation of dinocysts is satisfactory to good; the cysts are relatively small, which is likely due to more distal sedimentation conditions. Along with dinocysts, this sample contains prasinophytes, predominantly *Pterospermella* spp. and *Tasmanites* spp.

The palynological spectrum of the host rock (Mr17–23Eshch) differs significantly, with dinocysts almost absent (Fig. 5). The association is dominated by prasinophytes—various Tasmanaceae and *Pterospermella* spp. (over 70%)—as well as phycomata of green algae. The age of the deposits is determined as Ryazanian based on comparison with identical palynological assemblages from the conformably overlying M24–25 beds, which are reliably dated by ammonites [9, 19].

CONCLUSIONS

The palynological analysis showed that comparing palynomorph assemblages from the host rock and from the contents of ammonite shells enables reliable identification of signs of macrofaunal transposition, even in cases, where such reworking cannot be determined due to the excellent preservation of the reworked specimens. In both studied sample pairs, the associations from the ammonite body chambers are represented by taxonomically uniform dinocyst communities typical of the corresponding ammonite zones of the Upper Volgian Substage. At the same time, the palynological association from the host sediments is either mixed, with dinocysts of different varying ages and preservation, or markedly distinct in composition and structure from that of the body chambers, indicating an allochthonous origin for the ammonites. Thus, palynological analysis serves as a practical diagnostic tool for assessing the stratigraphic reliability of ammonite findings in beds with erosion and stratigraphic gaps.

In addition, studying the contents of ammonite chambers from condensed intervals allows us to reconstruct lost data on taxonomic diversity and quantitative composition of microphytoplankton communities. Despite the loss of significant stratigraphic levels due to erosion or compaction, the palynomorphs preserved in ammonite shells retain a synchronous signal and reflect the sedimentation conditions at the time of the shells initial burial. This makes the study of ammonite shell infillings a valuable source of information for reconstructing paleoecological conditions and refining biostratigraphic calibration in sections with gaps and condensation horizons.

Finally, palynological assemblages, extracted directly from ammonites, provide the most reliable synchronization of the dinocyst-based stratigraphic model with the orthostratigraphic scale. Since ammonite scales possess exceptionally high resolution in Jurassic stratigraphy of the Russian Plate, their use as synchronous stratigraphic markers allows us to precisely calibrate dinocyst biostratigraphic zones and to resolve ambiguities. A dinocyst-based biostratigraphic scheme, refined and detailed through such research, could achieve a level of detail approaching the resolution of the ammonite scale.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflict of interest.

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