Quantitative analysis of Early Campanian calcareous nannofossil assemblages from the southern regions of the Russian Platform

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Abstract: The calcareous nannofossil distribution in the Butovo 100 Borehole (210 m thick marl and chalk section), Belgorod Region, Russia, is described. The section is correlated with the CC18 and CC19 zones. Calcareous nannofossil assemblages from the continuous Lower Campanian – lower Upper Campanian succession were quantitatively analysed. A general tendency to temperature fall is clearly observed in the section. The number of *Watznaueria barnesae* and the warm-water coefficient gradually decreases, supporting temperature decrease during the Campanian. New data on the calcareous nannoplankton from the southern part of the Russian Platform support the global fall in sea surface temperature in the Campanian.

Keywords: Calcareous Nannofossils, Quantitative Analysis, Campanian, Biostratigraphy, Russia, Palaeotemperature

1. INTRODUCTION

Calcareous nannoplankton assemblages widely used in biostratigraphy have been applied to reconstructing main palaeoenviroments (Doeven, 1983; Wagreich, 1987; Watkins, 1992). Some species have been used successfully as indicators for the relative temperature of ocean surface water.

During the Late Cretaceous the climate was rather warm (Teis & Najdin, 1973; Barrera, 1994). The temperature of ocean surface water in the middle latitudes reached its maximum (16–18°C) in the Turonian–Coniacian and minimum (ca. 7°C) in the Maastrichtian (Barrera, 1994). In the Campanian, the average water temperature in the southern hemispere at latitude 47° S reached 12.4–12.6°C (Clarke & Jenkyns, 1999).

Jenkyns et al. (1994) and Clarke & Jenkyns (1999) showed that in the Campanian a gradual decrease in the surface water temperature occurred in the oceans in the southern hemisphere and the territory presently occupied by Western Europe. However, Teis & Najdin (1973), using isotopic compositions of oxygen in belemnite rostra, suggested another temperature pattern for the Russian Platform that lacked definite indications of cooling.

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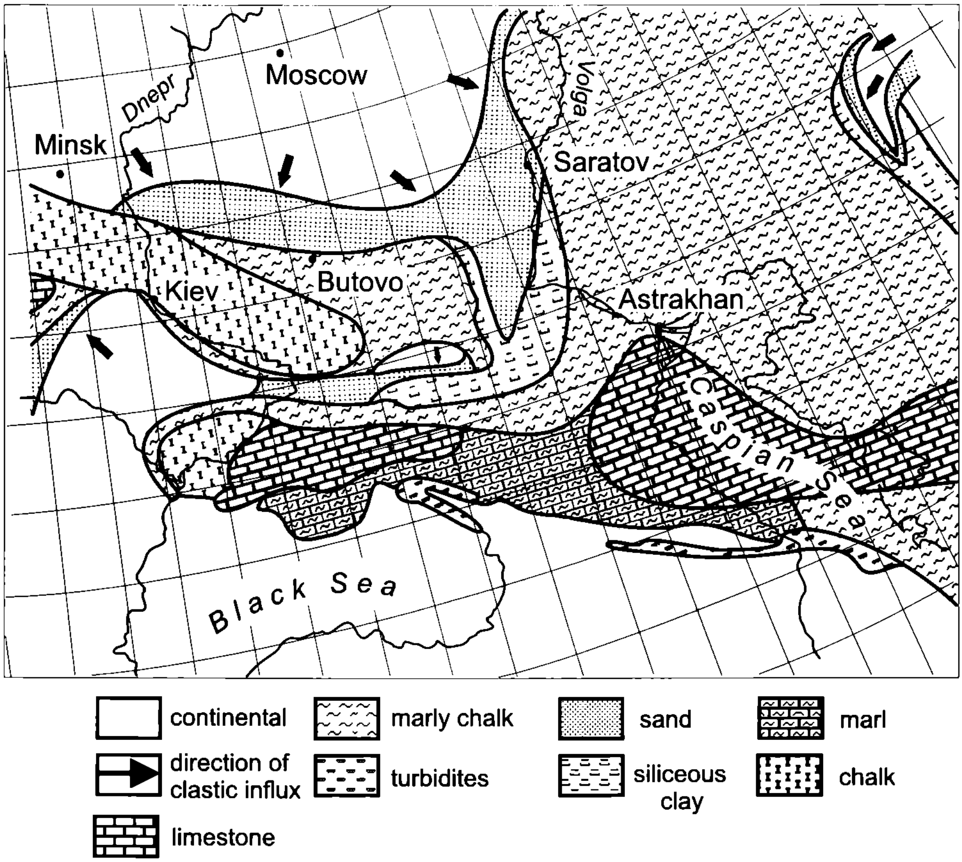

Fig. 1: Palaeogeographic map of east-nothern Peri-Tethys in the Early Campanian.

This paper focuses on the quantitative analysis of calcareous nannofossils and reconstruction of palaeotemperature changes in the Campanian of the Belgorod Region in Southern Russia. Marly Campanian sediments accumulated near the northern margin of the Peri-Tethyan marine basin in the southern regions of the Russian Platform, situated in temperate climatic conditions in mid-latitudes (40°–50° N) (Fig. 1).

A few data on the Late Cretaceous calcareous nannoplankton of the Belgorod Region were published by SHUMENKO (1970, 1976). However, this is the first attempt to analyse the distribution of nannoplankton in the sediments quantitatively.

2. MATERIAL AND METHODS

Material (111 samples) was collected from the Butovo 100 Borehole at intervals of 1.5–2 m. The borehole is located near the village of Butovo in Jakovlevo District, Belgorod Region (50° 46' N, 36° 10' E) (Fig. 2). This borehole was drilled in the area that showed the highest accumulation rate during the Campanian. The succession is 210 m thick and is represented by marls in its lower part (162.0–292.0 m depth) and by marly chalk in the upper part (82.0–162.0 m depth). According to the local stratigraphic zonation (ANTSYPHEROVA & BURYKIN, 1998) this succession spans the interval from the Upper Santonian to lower Upper Campanian (Fig. 3), comprising four lithostratigraphic units (formations) dated by belemnites and benthic foraminifera (ANTSYPHEROVA & BURYKIN, 1998).

Novyi Oskol Formation, Upper Santonian, was recognised in the interval 267.8–292.0 m depth. It consists of white, light grey chalky marls. A bed of light grey bioturbated silty marl is recorded at 275.0–277.0 m depth. The total thickness is 24 m.

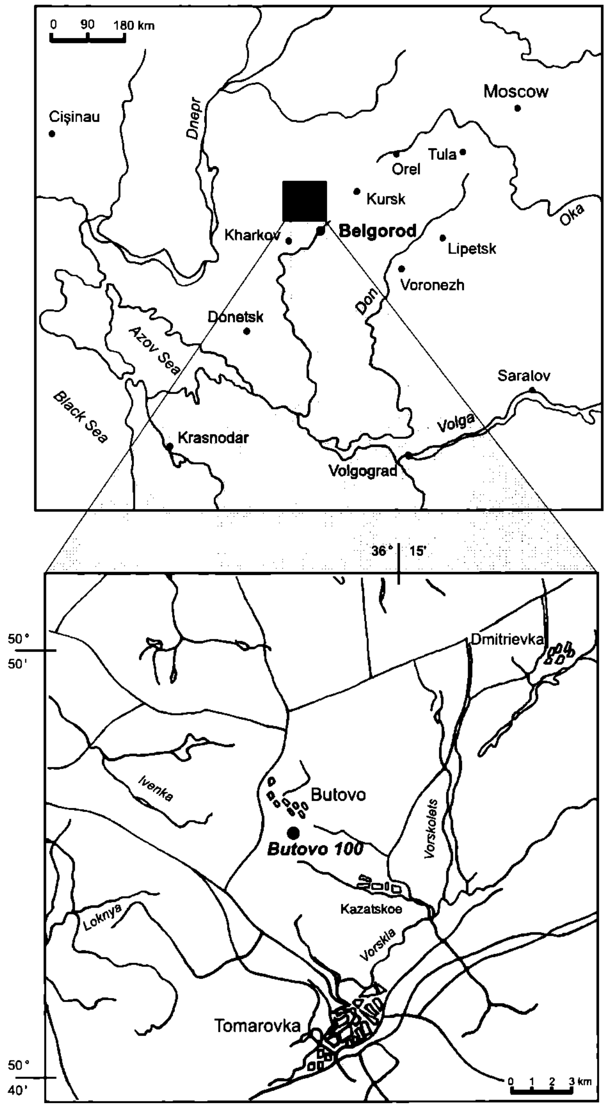

Fig. 2:
Location of the area and the section studied.

Dubenki Formation, lower part of Lower Campanian, was studied in the interval 212.0–267.8 m depth. This formation consists of light to dark grey micaceous bioturbated marls with pyritized burrows ca. 2 mm in diameter. The total thickness is 55.8 m.

Alekseevka Formation, upper part of Lower Campanian, was studied in the interval 162.0–212.0 m depth. This formation consists of light grey soft, micaceous, slightly bioturbated marls with pyritized burrows. The total thickness is 50 m.

Maslovo Formation, early Late Campanian according to the occurrence of the foraminifers *Brotzenella monterelensis* (Marie) and *Globorotalites emdyensis* Vassilenko, was recovered in the interval 82.0–162.0 m depth. It is represented by white and light grey chalky, slightly micaceous marls. The total thickness is 80 m.

Nannofossils from each sample were studied using the standard method of decantation; smear slides were examined under the light microscope (Zeiss Axiolab, x1500 magnification). The SEM photographs were taken by Camscan.

Relative abundances for individual nannofossil taxa are as follows:

very abundant – 6–10 specimens per field of view at x1500;

abundant – 1–5 specimens per field of view at x 1500;

common – 1 specimen per 2–10 fields of view at x1500;

few – 1 specimen per 11–50 fields of view at x1500;

rare – 1 specimen per more than 50 fields of view at x1500.

An average state of preservation was assigned to each sample according to the following criteria:

G – good, most specimens exhibit little or no secondary alteration;

M – moderate, specimens exhibit the effects of secondary alteration from etching and overgrowth (identification of species not impaired);

P – poor, specimens exhibit profound effects of secondary alteration from etching and overgrowth (identification of species impaired but possible in some cases).

Two hundred nannofossils specimens were counted in 56 samples displaying good preservation. One hundred specimens were counted in samples with poorly preserved and less abundant nannoplankton.

The following taxa of nannoplankton were used as the indicators for changes in palaeotemperature. According to Doeven (1983), Wagreich (1987), Watkins (1992), *Watznaueria barnesae* and *Lithraphidites carniolensis* were attributed to the group of warm-water species. The following species were included in the group of cold-water species: *Micula decussata, M. concava, Broinsonia parca parca, B. parca constricta, Arkhangelskiella cymbiformis, A. specillata, Eiffellithus turriseiffelii, E. eximius, Kamptnerius magnificus, Lucianorhabdus cayeuxii, Reinhardtites anthophorus, Thiersteinia ecclesiastica, Tranolithus orionatus, Ahmuellerella octoradiata, Cribrosphaerella ehrenbergii, Biscutum magnum, Prediscosphaera* species (*cretacea, spinosa, intercisa* and *ponticula*). The warm-water coefficient for every sample was calculated as the percentage of warm-water taxa of the total amount of calculated specimens in the sample.

Many nannofossils zonations were proposed for the for the Upper Cretaceous (Sissingh, 1977; Roth, 1978; Bralower et al., 1995; Burnett, 1998). The standard nannofossil zonation introduced by Sissingh (1977) is used in this paper.

3. RESULTS

3.1 Nannoplankton age

Rather poor nannofossil assemblages consisting of 37 species have been recognised in the Butovo 100 core (Fig. 4). The preservation of calcareous nannofossils is mainly moderate, and sometimes good or poor (secondary alteration) (Pl. 1, 2).

Samples provided the following assemblages:

1. *Watznaueria barnesae, Prediscosphaera cretacea, Micula decussata,* and *Eiffellithus turriseiffelii* are relatively abundant throughout the whole section. *Microrhabdulus decoratus, Prediscosphaera intercisa,* and *Cribrosphaerella erhenbergii* are less abundant. *Stradneria crenulata, Lithraphidites carniolensis, Obliquipithonella operculata, Vekshinella angusta, Zygodiscus spiralis, Glaukolithus diplogrammus, Ahmuellerella octoradiata, Tranolithus orionatus, Manivitella pemmatoidea, Lucianorhabdus cayeuxii, Microrhabdulus belgicus,* and *Calculites obscurus* are rare species.
2. *Arkhangelskiella cymbiformis, Kamptnerius magnificus,* and *Prediscosphaera spinosa* are distributed in relatively small quantity in all intervals of the section except for the

STAGE	SUBSTAGE	RUSSIAN PLATFORM BIOZONES			VORONEZH ANTECLYSE
		MOLLUSC ZONES		FORAMINIFERAL ZONES	FORMATION
CAMPANIAN	UPPER	Belemnitella langei	Belemnitella langei najdini	Angulogavelinella gracilis	MASLOVO
			Belemnitella langei langei	Globorotalites emdyensis	
			Belemnitella langei minor		
		Belemnitella mucronata mucronata - Hoplitoplacenticeras coesfeldiense		Brotzenella monterelensis	
	LOWER	Gonioteuthis gracilis - Belemnellocamax mammillatus		Cibicidoides temirensis	ALEKSEEVKA
		Gonioteuthis quadrata quadrata - Belemnitella mucronata alpha			
		Actinocamax laevigatus - Belemnitella praecursor mucronatiformis		Gavelinella clementiana clementiana	DUBENKI
SANTONIAN	UPPER	Gonioteuthis granulata - Sphenoceramus patootensis		Gavelinella stelligera	NOVYI OSKOL

Fig.3: Biozonation of the Upper Santonian and Campanian in the Belgorod Region (after ANTSYPHEROVA & BURYKIN, 1998).

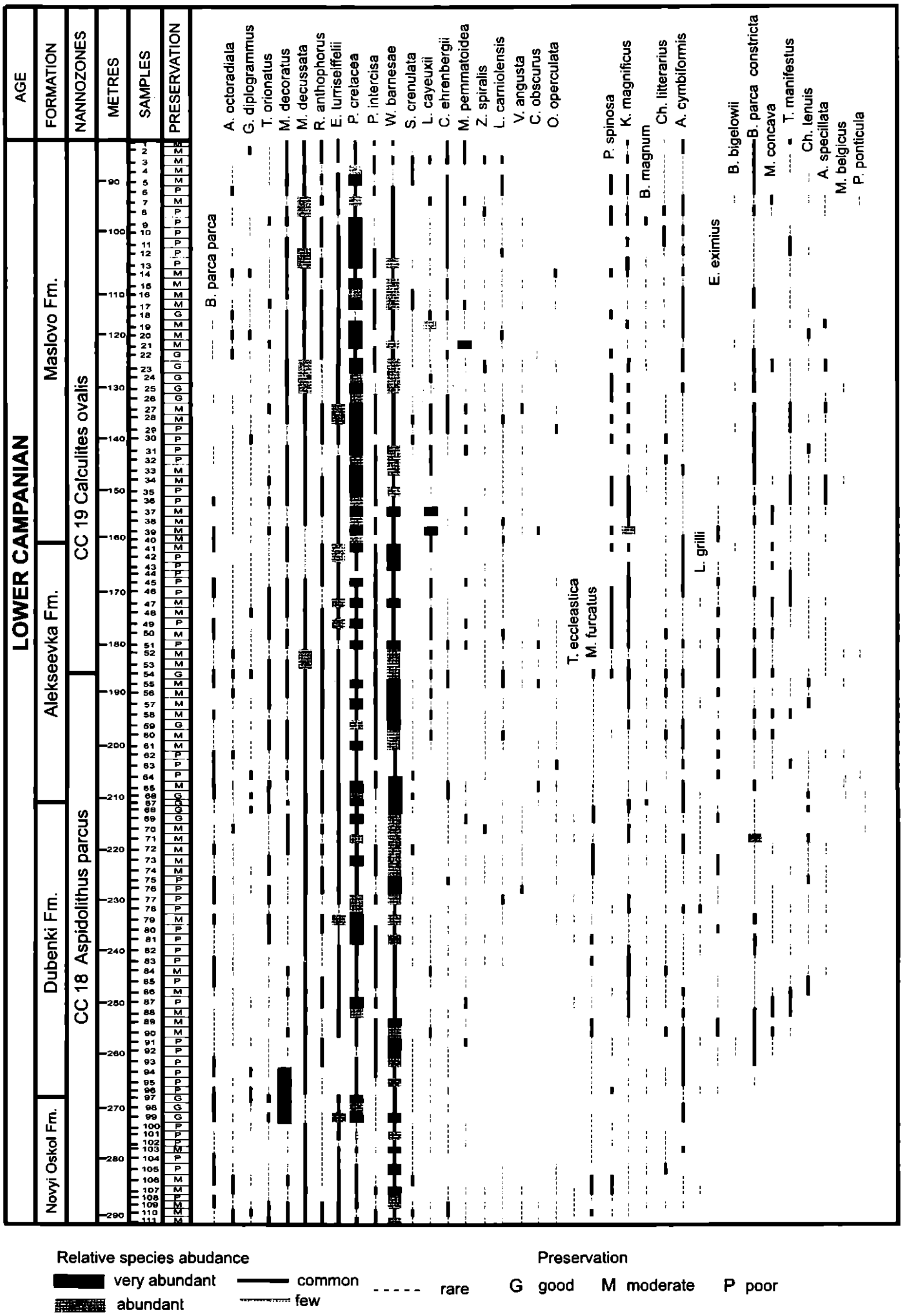

Fig. 4: Stratigraphic distribution of calcareous nannofossils in the Campanian, Butovo 100 section. Nannofossil zonation after SISSINGH (1977).

lower and upper parts. *Chiastozygus litterarius, Biscutum magnum, Eiffellithus eximius* and *Braarudosphaera bigelowii* occur rarely.

3. *Broinsonia parca constricta, Micula concava, Tranolithus manifestus, Chiastozygus tenuis* and *Arkhangelskiella specillata* are found in all intervals of the section except for the lowermost 10 m.
4. *Broinsonia parca parca, Thiersteinia ecclesiastica, Marthasterites furcatus* and *Lithastrinus grillii* are found mainly in the lower part of the section.

The lower part of the section (186.0–292.0 m depth) belongs to the CC18 Aspidolithus parcus Zone. Its upper boundary is established at 186.0 m depth, where the last appearance of *Marthasterites furcatus* in the sample is recorded.

Thiersteinia ecclesiastica, Marthasterites furcatus, Prediscosphaera spinosa and *Kamptnerius magnificus* appear in the lower part of the Novyi Oskol Formation (290.0 m depth). The absence of *Marthasterites furcatus* in the lowermost sample should be explained by rare occurrence of this species in this section. *Biscutum magnum, Arkhangelskiella cymbiformis,* and *Chiastozygus litterarius* first appear at 288.0 m depth, *Lithastrinus grillii* appears at 285.8 m depth and the first occurrence of *Eiffellithus eximius* in the Butovo core is recorded at 277.0 m depth.

The species *Braarudosphaera bigelowii, Broinsonia parca constricta* (266.0 m depth), *Micula concava* (260.0 m depth), *Tranolithus manifestus, Chiastozygus tenuis* (256.0 m depth) and *Arkhangelskiella specillata* (244.0 m depth) were recorded in the Dubenki Formation.

The upper part of the section (82.0–186.0 m depth) may be correlated with the CC19 Calculites ovalis Zone. The absence of *Ceratolithoides aculeus*, which is typical of the succeeding CC20 Zone, enables confirmation of this dating.

3.2 Time resolution

The lower part of the marl (125.5 m, Novyi Oskol, Dubenki and Alekseevka formations) was deposited in approximately 2.3 Ma. This estimation is based on recently published dating of nannofossil zone boundaries as well as nannofossil datum planes for the Late Cretaceous of Western European basins (Hardenbol & Robaszynski, 1998) and the fact that the section is lithologically monotonous. The first appearance of *Broinsonia parca constricta* thus corresponds to ca. 82.2 Ma, and the disappearance of *Marthasterites furcatus* has been recorded at 80.69 Ma (Hardenbol & Robaszynski, 1998). The thickness of this interval is 78 m and the average rate of sedimentation is 5.3 cm per thousand years. One metre of marls was accumulated during 18.9 Ka. The mean distance between the studied samples is 3–4 m, and the resolution for this part of the section is 60–70 Ka.

The deposition rate of the chalk of the Maslovo Formation should be lower because of the slow input of clastic material. We can estimate arbitrarily that the sedimentation rate of this formation was half that of the above formation. The chalk interval (84.5 m) accumulated during 3.14 Ma.

3.3 Quantitative analysis

Quantitative analysis of the calcareous nannoplankton allowed the recognition of the following groups (Fig. 5).

1. The group of dominant species, which occur abundantly throughout the section: *Watznaueria barnesae* (5–45%), *Reinhardtites anthophorus* (2–20%), and species of the genera *Micula* (6–35%), *Prediscosphaera* (7–30%) and *Eiffellithus* (3–20%).
2. The group of species occurring throughout the section, but relatively less abundant: *Broinsonia* (0.5–16%), *Arkhangelskiella* (0.5–10%), *Kamptnerius magnificus* (0.5–10%), *Microrhabdulus decoratus* (0.5–10–15%) and *Tranolithus orionatus* (1–10%).
3. The group of rare species (0.5–6%): *Lithraphidites carniolensis, Stradneria crenulata, Zygodiscus spiralis, Ahmuellerella octoradiata, Cribrosphaerella ehrenbergii, Obliquipithonella operculata, Marthasterites furcatus, Thiersteinia ecclesiastica.* Two species, *Lucianorhabdus cayeuxii* (158.0 and 118.0 m depth) and *Manivitella pemmatoidea* (122.0 m depth), occasionally reach 16.5%.

Watznaueria barnesae is a warm-water species that constitutes about 45% of the assemblage at 268.0–292.0 m depth and 20% at 142.0–267.5 m depth, but its abundance gradually decreases in the upper part of section (82.0–138.0 m depth) to 10%.

The proportion of another warm-water species, *Lithraphidites carniolensis*, does not vary significantly and is usually 1–4 %.

Micula comprises cold-water species and constitutes mainly 20–30%, sometimes decreasing to 6%. The abundance of other cold-water species (*Reinhardtites anthopho-*

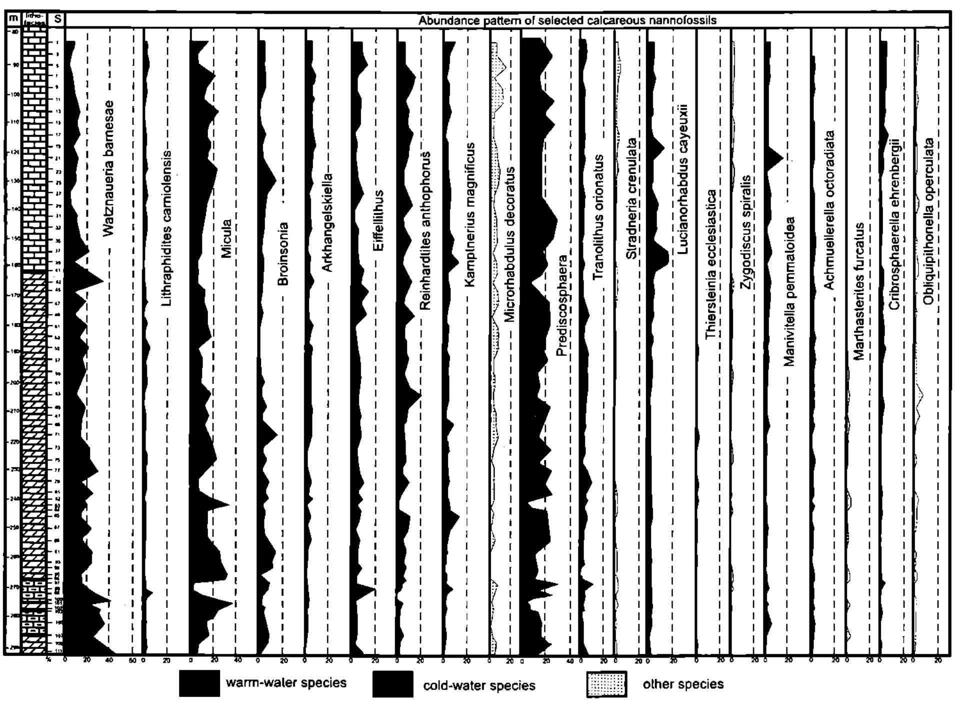

Fig. 5: Quantitative distribution of selected nannofossil taxa in the Campanian, Butovo 100 section.

rus, *Eiffellithus* spp.) changes from 6% to 20%, that of *Prediscosphaera* reaches 3%. The abundance of *Broinsonia* spp. and *Kamptnerius magnificus* changes from 0.5 to 16%. *Lucianorhabdus cayeuxii* is rare, and shows two maxima at 154.0–158.0 m and 114.0–118.0 m depth, where it reaches up to 16.5%.

4. DISCUSSION

According to the standard zonation proposed by SISSINGH (1977), we can distinguish two Lower Campanian zones within the section (Fig. 4).

Based on benthic foraminifera, the Novyi Oskol Formation was attributed to the Santonian. Nevertheless, nannofossil assemblage indicates its younger, Early Campanian, age. *Arkhangelskiella cymbiformis* belonging to this assemblage occurs in the section nearly from its base (282.0 m depth). In the majority of regions this species first appears at the base of Campanian (BURNETT, 1998), as was stated at the Brussels Symposium (HANCOCK & GALE, 1996). Another important species, *Biscutum magnum*, appears at the same level. In the boreal area it first occurs somewhat higher than the base of the Campanian, at 82.6 Ma level, nearly simultaneously with *Broinsonia parca parca* (HANCOCK & GALE, 1996). The last subspecies occurs from the base of the section. In England, *Broinsonia parca parca* appears 10 m above the base of the Campanian (HANCOCK & GALE, 1996). Very rare specimens of pre-Campanian *Thiersteinia ecclesiastica* found in the Novyi Oskol, Dubenki and Alekseevka formations are apparently redeposited. Therefore, according to the calcareous nannofossils it is unlikely that the Novyi Oskol Formation is Upper Santonian. However, a Late Santonian age cannot be completely excluded since the Upper Santonian foraminifera *Gavelinella stelligera* (MARIE), *G. santonica* AKIM., and *Heterostomella stephensoni* CUSHMAN are recorded from the deposits of this formation.

The Maslovo Formation does not contain species such as *Ceratolithoides aculeus*, *Uniplanarius sissinghii*, and *U. trifidus*, which mark the lower boundaries of the CC 20–22 zones. The common absence or extreme rarity of these species were mentioned by PERCH-NIELSEN (1985). SHUMENKO (1976) noted the absence of *Uniplanarius* (*Quadrum*) in the Belgorod Region. However, the benthic foraminifera *Brotzenella monterelensis* (MARIE), *Globorotalites embyensis* VASSILENKO, and others are found in the sediments of this formation. On balance, we infer an early Late Campanian age for the Maslovo Formation.

The newly proposed boreal nannofossil zonation by BURNETT (1998) cannot be applied confidently to the studied section because of the absence of the majority of the marker species of the Campanian UC14 and UC15 zones. The Novyi Oskol Formation may be assigned to the UC14a Zone, judging from the presence of *B. parca parca* in the lowermost samples and the absence of *B. parca constricta*, which appears only in the lower part of the Dubenki Formation.

Palaeotemperatures of the Upper Cretaceous marine basins, and of the Campanian in particular, have been extensively studied (TEIS & NAIDIN, 1973, NAIDIN 1992; JENKYNS et al., 1994; BARRERA, 1994; BARRERA et al., 1997; MILLER et al., 1999; CLARKE & JENKYNS, 1999). CLARKE & JENKYNS (1999) studied the change of $\delta^{18}O$ in the Southern Hemisphere (Fig. 6). The general shape of the curve indicates a progressive temperature fall in the

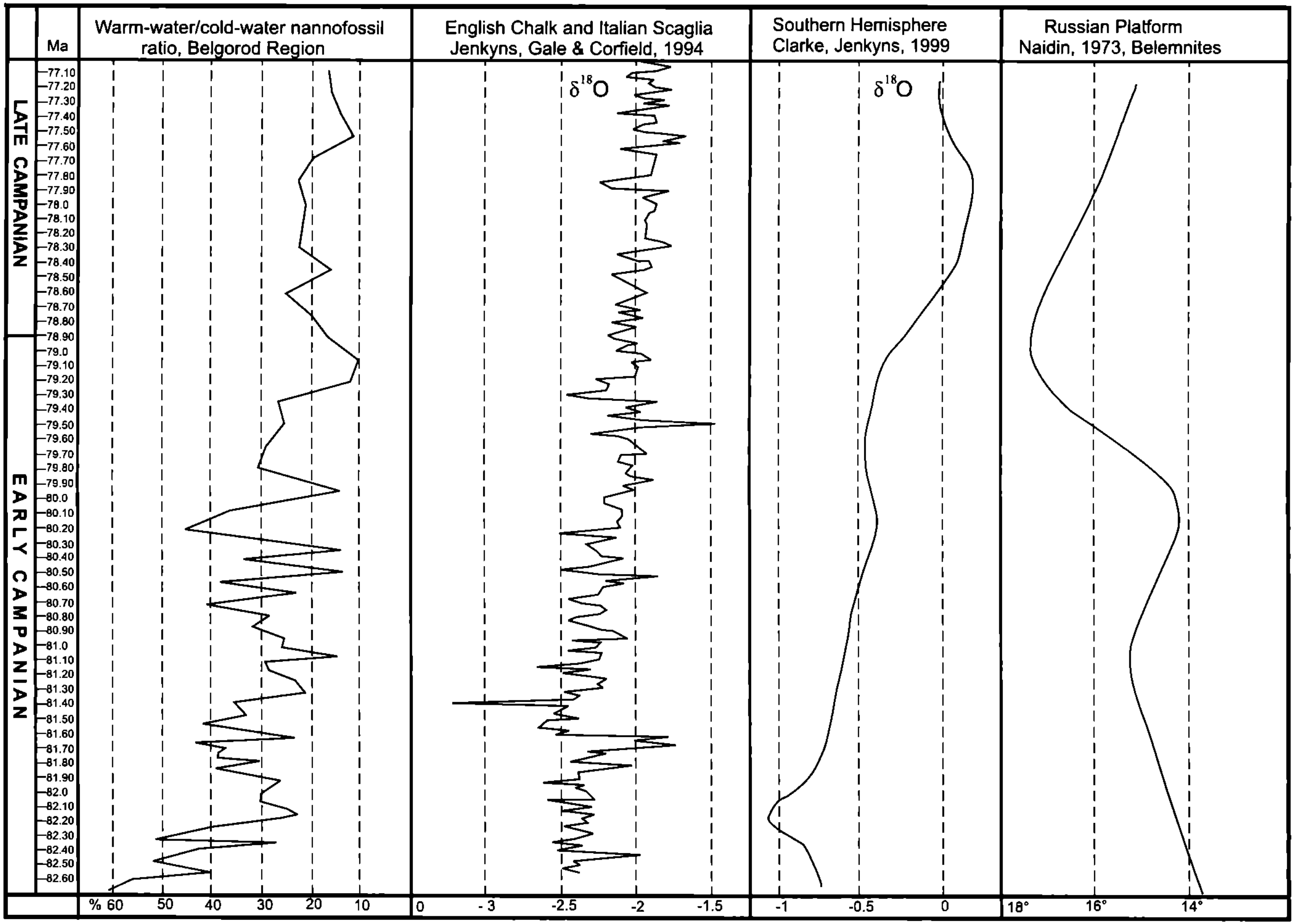

Fig. 6: Palaeotemperature changes in the Campanian in Western Europe, Russian Platform and Southern Hemisphere.

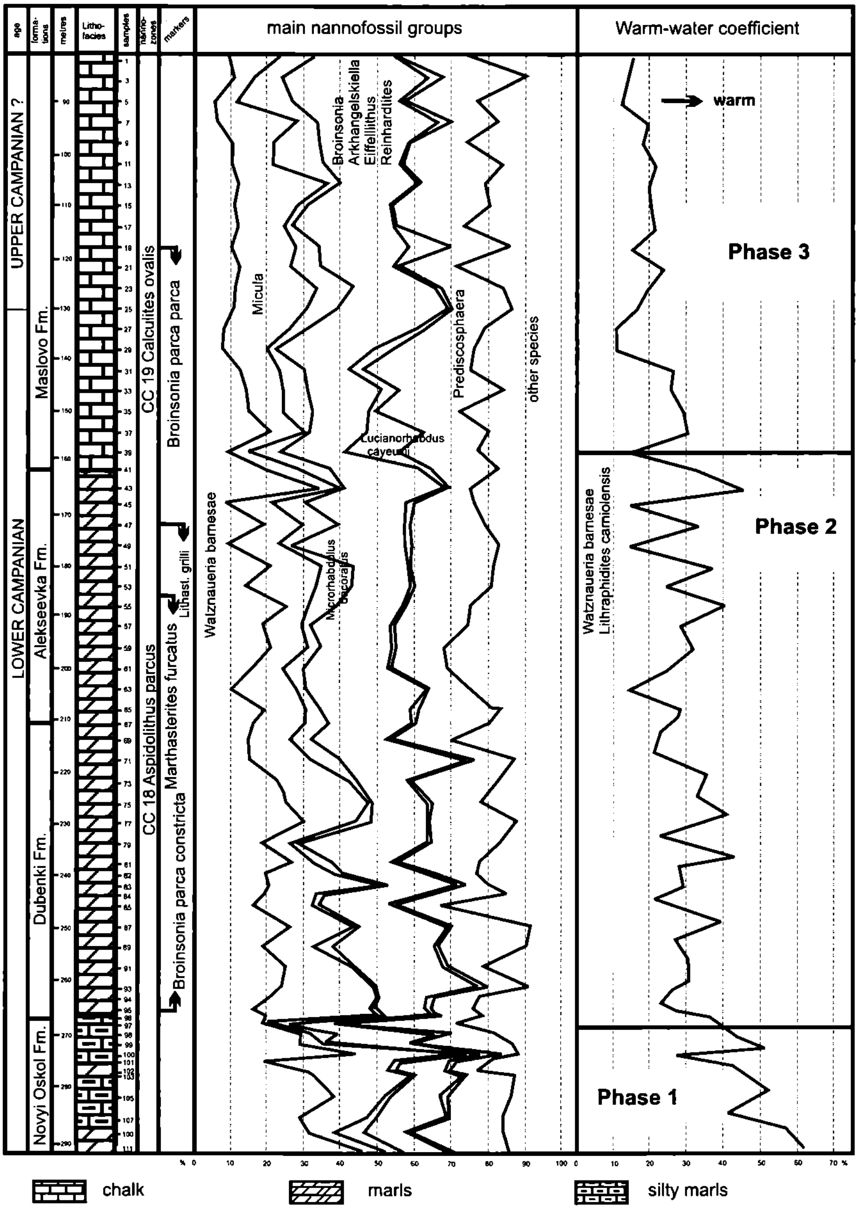

Fig. 7: Quantitative analysis of calcareous nannofossil distribution in the Lower (and Upper?) Campanian, Butovo 100 section. **Phase 1**: This interval is characterized by rather abrupt changes in the abundance of warm- and cold-water species. It corresponds to rather warm conditions. **Phase 2**: Cyclic changes in the abundance of warm- and cold-water species are typical of this interval. This phase shows cyclic "warm-cold" changes. **Phase 3**: The common, predominantly cold-water species, forming up to 60–80%, are characteristic of this phase. This interval reflects relatively cold conditions compared to the other phases.

Campanian with insignificant fluctuations. The surface water temperature reached 9°C 82.2–82.1 million years ago, and about 8°C – 77.8–77.7 Ma ago. JENKYNS et al. (1994) revealed $\delta^{18}O$ and palaeoclimatic changes for the English Chalk and the Italian Scaglia. The shape of their $\delta^{18}O$ curve is similar to that of CLARKE & JENKYNS (1999) and demonstrates the tendency to temperature fall in the Northern Hemisphere. Isotopic temperatures based on Upper Cretaceous belemnites were estimated by TEIS & NAIDIN (1973) for the Russian Platform and adjacent areas. The higher temperatures, mainly from 14° to 17.5°C, were obtained for the Campanian. A general trend to temperature rise has been demonstrated for the Early Campanian and the very beginning of the Late Campanian; the temperature fall started later, approximately 78.9 Ma ago.

Our data on the quantitative analysis of the calcareous nannoplankton demonstrate a general decrease in palaeotemperatures during the Campanian and agree with the isotopic data for both the northern and southern hemispheres (Fig. 6). However, the causes of disagreement between the nannofossil and belemnite data are still unclear and await further investigation.

5. CONCLUSION

Based on the warm-water coefficient, the section can be subdivided into three parts.

The lower part (phase 1) (interval 268.0–292.0 m depth, 82.22–82.69 Ma) corresponds to the Novyi Oskol Formation. Rather sharp uneven fluctuations of warm-water coefficient is characteristic of this interval, but it remains, however, high and ranges from 35.1 to 61.9%.

The middle part (phase 2) (interval 158.0–267.5 m depth, 79.8–82.19 Ma) corresponds to the Dubenki and Alekseevka formations. This interval is characterised by constant cyclic changes in the abundance of the warm-water coefficient, which falls and ranges from 14.4 to 44.2%.

The upper part (phase 3) (interval 82.0–156.0 m depth, 77.0–79.65 Ma) corresponds to the Maslovo Formation. Insignificant changes in quantities of the warm-water species are typical of this formation. The warm-water coefficient gradually decreases from 28.6% in the lower part to 10.95% in the uppermost part of the formation.

The fluctuations in the abundance of species indicative of definitive temperatures, i.e. warm-water coefficient, can reveal changes of surface water temperature of the basin. A general tendency to the temperature fall is clearly observed in the section. The decrease in numbers of *Watznaueria barnesae* and the warm-water coefficient in the 82.22–79.20 Ma interval show that the Campanian sediments were generally deposited during a continuous cooling epoch. The temperature fall was quite rapid in the 82.22–81.55 Ma interval, which that should reflect the rather sharp shift of temperature at the very beginning of the Campanian. Three climatic phases may be recognised (Fig. 7).

Phase 1 (82.22–82.69 Ma, Novyi Oskol Formation) belongs to the CC 18 Zone. This phase is characterised by a rather abrupt change of the warm-water species being 61.9–35.1%. A high abundance, up to 46%, of *Watznaueria barnesae* and *Lithraphidites carniolensis* is typical of this phase, the abundance of *Prediscosphaera* is up to 24%, cold-water species such as *Reinhardtites anthophorus, Eiffellithus* spp., *Broinsonia* spp. and *Arkhangelskiella* spp. form 10–15% of the assemblage, the abundance of *Micula* varies from 10 to 45%. The general predominance of warm-water species indicates rather warm conditions.

Phase 2 (79.80–82.19 Ma, Dubenki and Alekseevka formations) belongs to the CC 18 Zone and the lower part the CC 19 Zone. Cyclic change of the warm-water coefficient is characteristic of this interval. This phase appears to indicate cyclic fluctuations from a warm to a cold environment.

Phase 3 (77.08–79.65 Ma, Maslovo Formation) belongs to the upper part of the CC 19 Zone and, probably, to the CC 20–21 zones. Here the cold-water forms dominate (60–80%), the abundance of the warm-water species *Watznaueria barnesae* and *Lithraphidites carniolensis* decreases markedly from 30 to 10%. This interval indicates a rather cold environment compared to the previous phases.

New data on the calcareous nannoplankton from southern regions of the Russian Platform confirm the global character of the trend toward temperature fall during the Campanian. This trend was more clearly expressed in the mid-latitudes of northern Peri-Tethys.

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Plate 1

Fig. 1: *Prediscosphaera* sp., Lower Campanian, sample 97 (× 8 000)

Fig. 2: *Broinsonia* sp., Lower Campanian, sample 97 (× 10 000)

Fig. 3: *Broinsonia* sp., Lower Campanian, sample 97 (× 10 000)

Fig. 4: *Eiffellithus turriseiffelii* (DEFLANDRE) REINHARDT, Lower Campanian, sample 69 (× 7.500)

Fig. 5: *Broinsonia parca constricta* HATTNER et al., Upper Campanian, sample 25 (× 7.500)

Fig. 6: *Reinhardtites anthophorus* (DEFLANDRE) PERCH-NIELSEN, Lower Campanian, sample 97 (× 10 000)

Fig. 7: *Arkhangelskiella cymbiformis* VEKSHINA, Upper Campanian, sample 25 (× 8 000)

Fig. 8: *Glaukolithus sp. aff. Gl. diplogrammus* (DEFLANDRE) REINHARDT, Lower Campanian, sample 97 (× 19 000)

Fig. 9: *Tranolithus orionatus* (REINHARDT) REINHARDT, Lower Campanian, sample 97 (× 15 000)

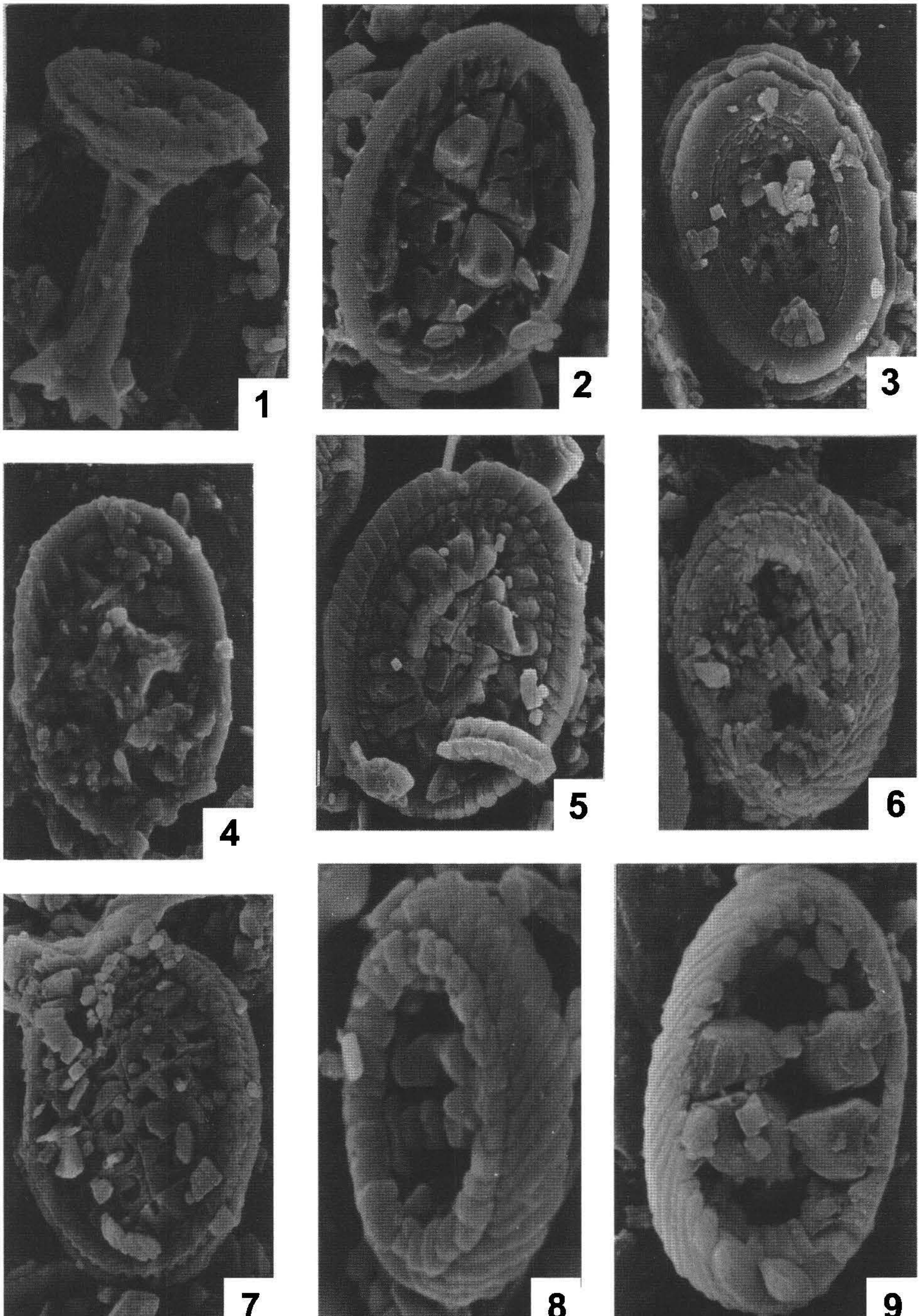
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Plate 2

Fig. 1: *Kamptnerius magnificus* DEFLANDRE, Lower Campanian, sample 97 (× 7 000)

Fig. 2: *Microrhabdulus belgicus* HAY & TOWE, Lower Campanian, sample 97 (× 7 000)

Fig. 3: *Lithraphidites carniolensis* DEFLANDRE, Lower Campanian, sample 97 (× 8 000)

Fig. 4: *Reinhardtites anthophorus* (DEFLANDRE) PERCH-NIELSEN, Lower Campanian, sample 69 (× 10 000)

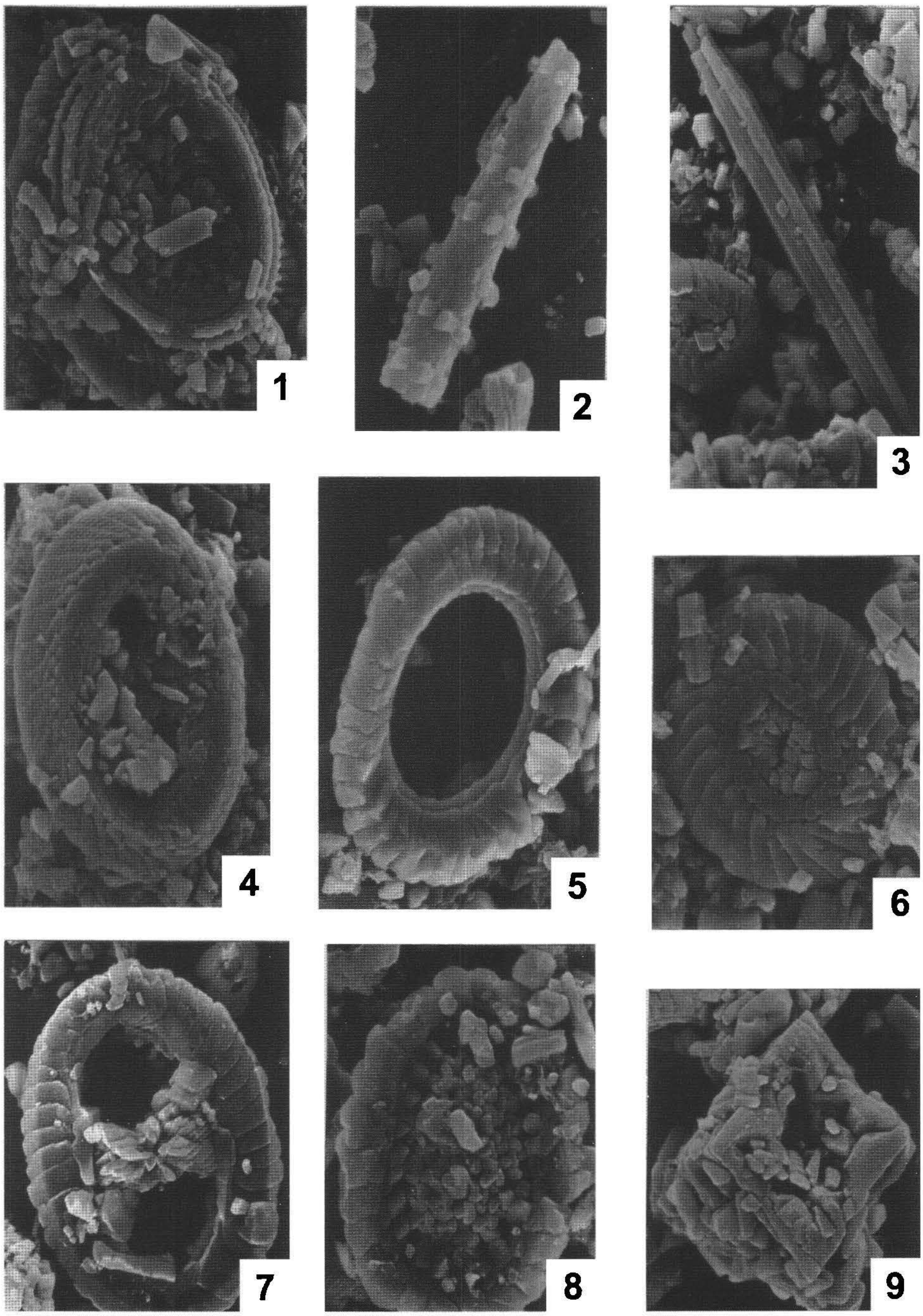
Fig. 5: *Manivitella pemmatoidea* (DEFLANDRE) THIERSTEIN, Lower Campanian, sample 69 (× 9 000)

Fig. 6: *Watznaueria barnesae* (BLACK) PERCH-NIELSEN, Lower Campanian, sample 97 (× 10 000)

Fig. 7: *Zygodiscus spiralis* BRAMLETTE & MARTINI, Lower Campanian, sample 69 (× 8 000)

Fig. 8: *Cribrosphaerella ehrenbergii* (ARKHANGELSKY) DEFLANDRE, Lower Campanian, sample 97 (× 10 000)

Fig. 9: *Micula decussata* VEKSHINA, Upper Campanian, sample 25 (× 9 000)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