

FACIES DISTRIBUTION OF FUSULINOID GENERA IN THE MYACHKOVIAN (UPPER CARBONIFEROUS, UPPER MOSCOVIAN) OF SOUTHERN MOSCOW REGION

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Abstract. The Moscovian Stage of Central European Russia is represented by a cyclic shallow-marine carbonate succession deposited in a gentle ramp setting part of a vast epeiric sea. Fusulinoids occur in all the marine lithofacies studied including most extreme intertidal grainstones. The ecological tolerance of fusulinoids decreases in the following order: *Fusiella*, *Schubertella*, *Ozawainella*, *Fusulinella*, *Fusulina*, *Reitlingerina* and *Hemifusulina*, *Neostaffella*, and *Parastaffelloides*. The scarcity of *Taitzeoella*, *Beedeina*, *Eostaffella*, *Kamaina*, and *Praeobsoletes* did not allow the reliable estimation of their facies distribution and tolerance.

Three main zones of fusulinoid distribution are revealed. The predominantly autochthonous assemblages of these zones probably correspond to original fusulinoid biofacies. Biofacies 1 contains the most tolerant genera *Fusiella* and *Schubertella* that lived in the most severe conditions of the restricted peritidal zone. The optimal shallow normal-marine settings of Biofacies 2 maintained the highest diversity of fusulinoids (*Fusiella*, *Schubertella*, *Ozawainella*, *Fusulinella*, *Fusulina*, *Reitlingerina*, *Hemifusulina*, *Neostaffella*, *Parastaffelloides*, *Taitzeoella*, *Beedeina*, *Eostaffella*, *Kamaina*, and *Praeobsoletes*). Most abundant were *Fusulinella*, *Fusulina*, and *Schubertella*. The habitats of staffellids (*Reitlingerina* and *Parastaffelloides*) were shifted from a wide normal-marine facies spectrum in Podolskian time to less favourable settings of shoals and fine small-foraminifer sands.

The apparent peaks of some genera in the shoal lithofacies of coarse skeletal-peloidal grainstones must be increased several times as a consequence of much slower net sediment accumulation, but the ratio of different fusulinoid genera in this lithofacies is probably retained. Biofacies 3 contains distal tempestites and skeletal mudstones representing the deepest (considerably more than 20 m) depositional environments.

The fusulinoid assemblage is less diverse than in Biofacies 2. In the Upper Gubastovo tempestites, Biofacies 3 is highly dominated by *Hemifusulina bocki* Moeller. *Fusiella*, *Schubertella*, *Ozawainella*, *Taitzeoella*, *Fusulinella*, and *Fusulina* occur in lesser quantities. Some of these rare fusulinoids may be allochthonous, and the original diversity might have been even lower. *Hemifusulina* in the Upper Gubastovo tempestites tends to form monospecific (*H. bocki* Moell.) concentrations exhibiting the signs of sudden storm burial.

Riassunto. Il piano Moscoviano nella parte centrale della Russia europea è rappresentato da una successione ciclica di carbonati di acque basse deposta su una rampa molto graduale di un vasto mare marginale. I fusulinoidi si rinvennero in tutte le litofacies marine studiate, inclusi i grainstone intertidali. La tolleranza ecologica dei fusulinoidi decresce nel seguente ordine: *Fusiella*, *Schubertella*, *Ozawainella*, *Fusulinella*, *Fusulina*, *Reitlingerina* e *Hemifusulina*, *Neostaffella* e *Parastaffelloides*. La rarità di *Taitzeoella*, *Beedeina*, *Eostaffella*, *Kamaina* e *Praeobsoletes* impedisce di fornire una valutazione affidabile della loro distribuzione nelle diverse facies e della loro tolleranza. Sono state individuate tre zone principali a fusulinoidi.

Le associazioni prevalentemente autoctone di queste zone probabilmente corrispondono alle biozone originali. La biofacies 1 contiene i generi *Fusiella* e *Schubertella*, che vissero nelle condizioni estreme della zona intertidale confinata e pertanto vengono considerati come i più tolleranti. Gli ambienti marini ottimali di bassa profondità sono quelli della biofacies 2, che mantennero la più alta diversità di fusulinoidi (*Fusiella*, *Schubertella*, *Ozawainella*, *Fusulinella*, *Fusulina*, *Reitlingerina*, *Hemifusulina*, *Neostaffella*, *Parastaffelloides*, *Taitzeoella*, *Beedeina*, *Eostaffella*, *Kamaina* e *Praeobsoletes*). Le forme più abbondanti furono *Fusulinella*, *Fusulina* e *Schubertella*. L'ambiente di vita degli staffellidi (*Reitlingerina* e *Parastaffelloides*) migrarono da un più vasto spettro di facies marine normali durante il tempo Podolskiano a condizioni meno favorevoli di litofacies di secca e sabbie fini a piccoli foraminiferi. I picchi apparenti di abbondanza di alcuni generi nei grainstone grossolani a bioclasti e peloidi devono essere cresciuti di diversi ordini di grandezza, come conseguenza della velocità di accumulo più lenta. Si ritiene tuttavia che i rapporti numerici tra i diversi generi di fusulinoidi in questa litofacies si siano mantenuti. La biofacies 3 corrisponde alle tempestiti distali e ai mudstone bioclastici che rappresentano gli ambienti più profondi (significativamente più di 20 m).

La associazione a fusulinoidi è meno diversificata che non nella biofacies 2. Nelle tempestiti dell'unità Gubastovo superiore, la biofacies 3 è marcatamente dominata da *Hemifusulina bocki* Moeller. *Fusiella*, *Schubertella*, *Ozawainella*, *Taitzeoella*, *Fusulinella* e *Fusulina* sono presenti in quantità inferiori. Alcuni dei fusulinoidi meno frequenti possono essere anche alloctoni, per cui la diversità originaria può esser stata ancora inferiore.

Nelle tempestiti del Gubastovo superiore *Hemifusulina* tende a formare concentrazioni monospecifiche (*H. bocki* Moeller) suggerendo seppellimento rapido in seguito ad uragani.

Introduction

The palaeoecological study of Carboniferous foraminifera, and in particularly fusulinoids, has become an important part of foraminiferal research (e.g. Ross 1961, 1969; Gallagher 1998; Villa & Bahamonde 2001). The occurrence of Middle Carboniferous fusulinoids in the Moscow region (genus *Fusulina*) was first described by Fischer de Waldheim (1829) from the limestones of the Myachkovo Quarries. Since that time the Carboniferous fusulinoids of the Moscow Syncline were the subject of considerable systematic and biostratigraphic study (see reviews in Rauzer-Chernousova et al. 1951, 1996). The palaeoecological aspects of the Carboniferous fusulinoids of the Moscow Syncline received much less attention. Only one detailed investigation of the facies distribution of fusulinoids exists in the literature (Rauzer-Chernousova & Kulik 1949) and no papers deal with the palaeoecology of fusulinoids from the type area of the Moscovian Stage. Moreover, the lithological basis tra-

ditionally used for palaeontological studies (Khworowa 1953; Makhlina et al. 2001) is still incompatible with the sedimentological concepts and methods accepted world-wide. We used a new approach in the study of the Upper Moscovian succession of the Moscow region (Kabanov unpubl.). We hope that this approach will revitalize the palaeoecological research of the succession studied and of foraminiferal palaeoecology in particular.

Regional geology and stratigraphic framework

The area studied is situated along the southern flank of the Moscow Syncline which is a gently sloped (less than 1°) and vast zone of subsidence running from the central part of the East European Craton (EEC) to its eastern margin (Fig. 1a; Nikishin et al. 1996). The late Palaeozoic sedimentary basin of the Moscow Syncline was formed during the Middle Devonian (Eifelian) tectonic restructuring of the EEC. During the Permian-Triassic

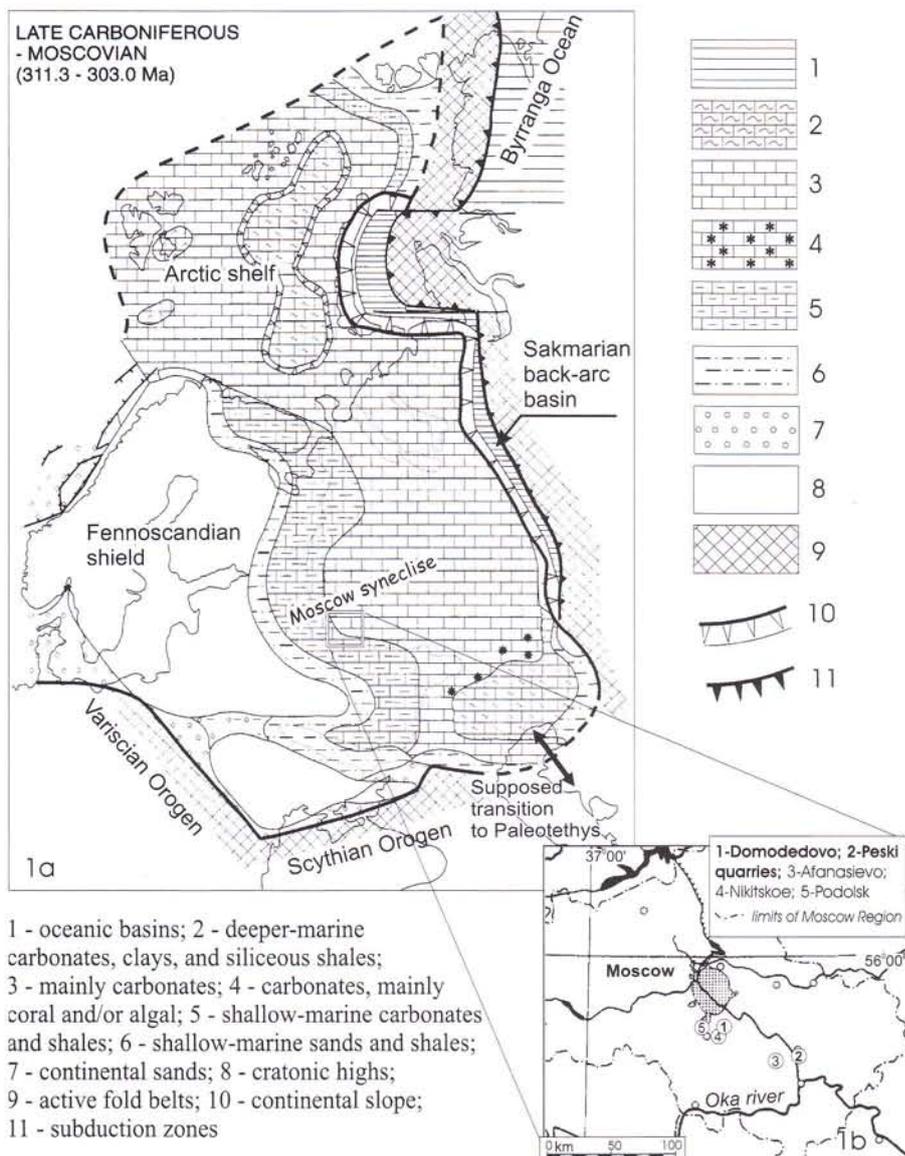


Fig. 1 - Moscovian paleogeography of the European Craton (EEC), slightly modified from Nikishin et al. (1996), and index-map of the studied localities.

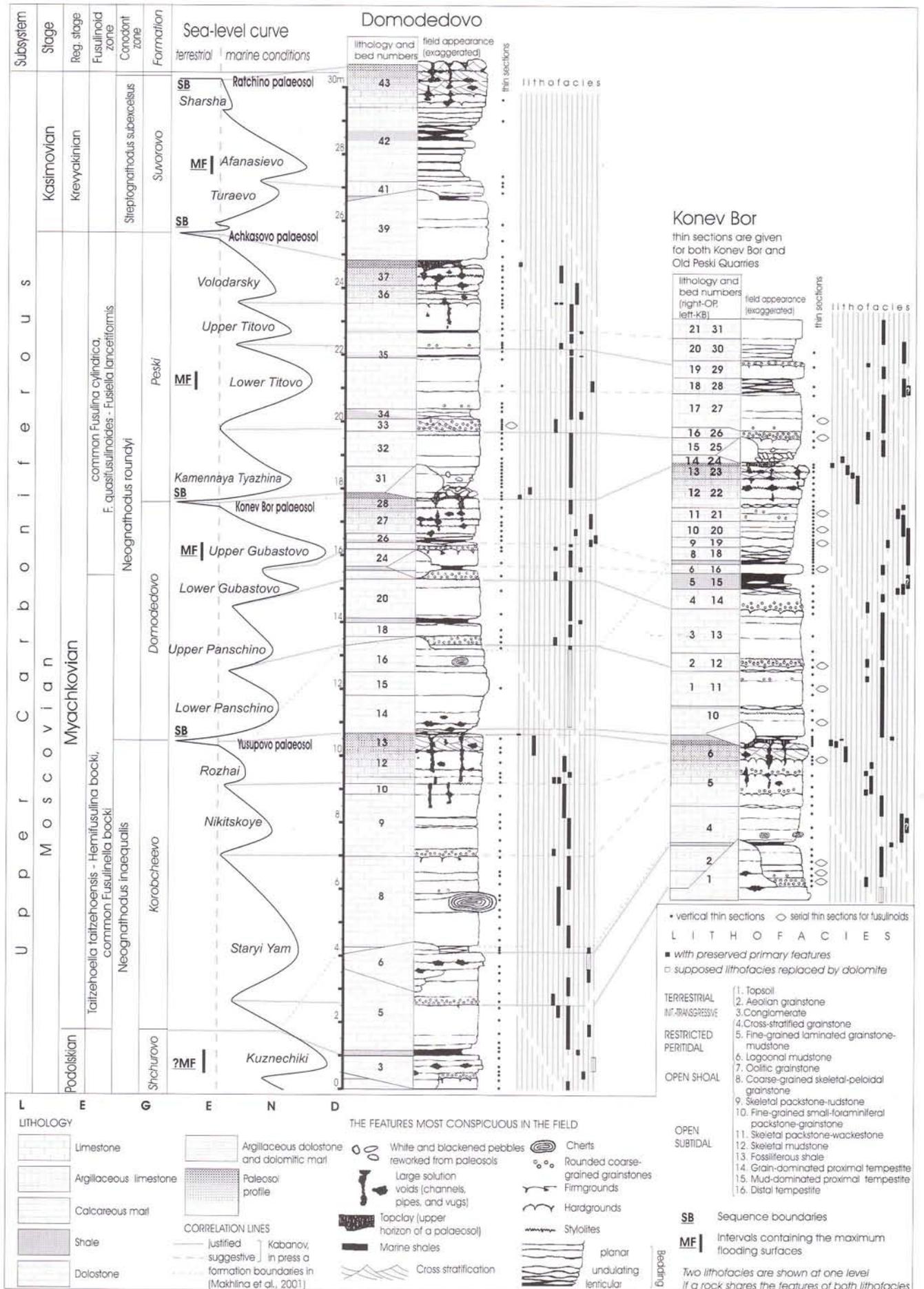
time, the area of sedimentation in the syncline gradually retreated eastward leaving the area studied in a shallow burial state and partly exposed to karstification. The basin development during the Moscovian is reconstructed as a meridionally broad and latitudinally narrow (in modern continent orientation) tongue of a vast, epicontinental sea, with mostly carbonate sedimentation, covering the eastern two thirds of the main part (European) of the EEC. This basin passed northwards to an extensive carbonate Arctic Shelf. The Early Carboniferous collision between Laurussia and Gondwana resulted in the Scythian orogeny along the southern EEC margin. However, the presence of Palaeotethyan taxa suggests a persisting connection with the Palaeotethys, probably through the Pericaspian area (Fig. 1a). The nearly contemporaneous collision with the Kazakhstan and Siberian cratons already occluded the southernmost part of the Ural Ocean leaving its main northern part as a narrow Sakmarian back-arc basin. To the east the Ural Ocean was bordered by a young, actively growing, Ural orogen (Nikishin et al. 1996). The absence of large organic buildups in the main part of the basin and the presence of normal-marine offshore facies of cyclothem cores extending regularly westwards indicate a carbonate ramp depositional system (Burchette & Wright 1992).

The Myachkovian Horizon (= regional stage) is the uppermost subdivision of the Moscovian Stage (Fig. 2). The spectrum of facies ranges from offshore *Zoophycos*-bearing argillaceous wackestones and rhythmic tempestites to lagoonal lime mudstones and intertidal laminated facies, through various shallow subtidal-to-shoal lithofacies (wackestones, packstones, rudstones and grainstones). The Upper Carboniferous of the area contains numerous paleosols with beta-calcretes corresponding to the calcimagnesian paleosols of Wright (1994) and possesses the complex transgressive-regressive cyclicality of more than two orders (Kabanov in press a). Large portions of the rock column are dolomitized. The early generations of dolomite formed pre-compactional dolostone layers and lenses replacing preferentially the marly subtidal lithofacies (Kabanov 2003). The thickness of the Myachkovian generally increases from 10 m at the western and southern rims to 68 m in the axial part of the Moscow Syncline (Makhlina et al. 2001). Accordingly, each cyclothem increases in thickness, becomes generally finer-grained and less argillaceous, palaeosols become less mature, and new cyclothem are introduced (Fig. 2). The degree of dolomitization increases also toward the syncline axis. Kabanov (unpubl.) has advocated a three-fold subdivision of the Myachkovian. This scheme is accepted in Makhlina et al. (2001). The two upper formations (Domodedovo & Peski) are essentially major cyclothem bordered by palaeosols. The Korobcheevo Formation in the lower third of the Myachkovian is the upper regressive part of the largest major Shchurovo-Korobcheevo Cyclothem (Fig. 2).

The Myachkovian Horizon corresponds to the regional fusulinoid zone *Fusulinella bocki*, *Pulchrellula pulchra*, *Fusulina cylindrica*. Makhlina et al. (2001) proposed three regional zones within this interval: *Fusulinella bocki* (spanning the Korobcheevo Fm.), *Fusulina cylindrica* (covering the entire Domodedovo Fm. and the lower third of the Peski Fm.), and *Protriticites ovatus* (upper two thirds of the Peski Fm.) (Pl.1). The formal zonation of the upper Myachkovian became especially controversial in the last decade due to its position in the Middle/Upper Carboniferous transitional interval (Villa et al. 1997; Davydov et al. 1997, 1999). The key question is the first appearance of *Protriticites*. Rauzer-Chernousova et al. (1951) identified, for the first time, *Protriticites* in the Myachkovian of the Moscow Region, although pores in the test walls were not visible due to the poor preservation of the material, making a clear identification of *Protriticites* by these authors quite doubtful. Similarly, our reexamination of the original thin sections of D.M. Rauzer-Chernousova made identification of forms with appreciably recrystallized walls as *Fusulinella ex gr. bocki* Moell. doubtful as well. Davydov (1997, 1999) reported again *Protriticites ovatus* Putrja (and some other species) in the Myachkovian of the type region. Similar forms are presented in our collection (e.g. Pl. 2, fig. 1). However, the evidence of pores is still absent, and the reported *Protriticites* may be the extreme variation of *Fusulinella pseudoboeki* (Lee et Chen), *F. helenae* Rauzer, *F. rara* Shlyk., or *F. fluxa* Lee et Chen. Despite this uncertainty, Makhlina et al. (2001) accepted the presence of *Protriticites* in the upper Myachkovian and erected the zone *Protriticites ovatus*. The use of two traditional Myachkovian zones (Fig. 2) seems to us more valid. The base of the *Fusulina cylindrica* zone (appearance in mass of large *Fusulina*) was detected in 1997 by D. Baranova in the upper part of the Upper Gubastovo cyclothem in the Peski and Domodedovo Quarries. The base of this zone does not coincide with the base of the Domodedovo Fm. as shown in Makhlina et al. (2001). This coincidence arose from mistakes in correlation between sections (Fig. 2).

Material and method

The majority of thin sections studied comes from two localities (Fig. 1, 2). The large Domodedovo quarry, recently chosen as a neostatotype of the Myachkovian Horizon and Moscovian Stage (Makhlina et al. 2001), and the two Peski quarries situated at about 1 km distance from each other, which we prefer to call Old Peski and Konev Bor quarry, respectively. The larger section (Konev Bor) was recently introduced in the literature as Peski (Makhlina et al. 2001) which seems misleading, because at a time at least 6 quarries existed near the Peski station (e.g. Rauzer-Chernousova & Reitlinger 1954), and the present quarry is situated much closer to Konev Bor



than to the Peski railroad station. Additionally, several thin sections from the Afanasievo, Podolsk, and Nikitskoe sections were studied (Fig. 1). The density of sampling in the Peski and Domodedovo sections is shown in Fig. 2. Each black dot represents one vertically oriented thin section of 20-30 cm² mean area.

Fusiform symbols indicate serial horizontal thin sections made for microfaunal identification. The density of sampling in Afanasievo and Podolsk is similar, while in Nikitskoe thin sections are more scattered. About 600 thin sections were examined totally. The bulk of this material was made in the last years by the authors. All data obtained are published for the first time. In addition, the significant material from Konev Bor was kindly lent for study by Dr. T.N. Isakova.

Fusulinoids were counted in thin sections using a transparent 60x60 mm grid made of overhead film. The grid was divided into square cells of 25 mm² area. Each cell was indexed (1a, 1b, 2a, 2b, ...etc.), and glycerol was used to provide adherence of the film to the section to prevent movement.

The grid allowed us to register easily and precisely the number of fusulinoid sections over the measured area of thin section. If n = the number of thin sections; $\Sigma \rho_1 \dots \Sigma \rho_n$ = quantity of tests of a certain genus in a thin

section; S_1, \dots, S_n = thin section area, then the density of this genus in a given thin section is $\rho_{fus} = \Sigma/S$. The average density of a certain genus in a given lithofacies is $\rho_{fus}^{av} = (\rho_1 + \dots + \rho_n)/n$. We restricted the counting results to ρ_{fus}^{av} , which proves to be the most valuable and adequate measure for our purposes (Fig. 4). The data currently obtained allow us to introduce the following gradations. The form is singular if $\rho_{fus}^{av} \leq 0.1$, rare if $\rho_{fus}^{av} = 0.1-0.5$, frequent if $\rho_{fus}^{av} = 0.5-1$, numerous if $\rho_{fus}^{av} = 1-5$, and abundant if $\rho_{fus}^{av} > 5$. In our Myachkovian thin sections, the maximum concentration of fusulinoid tests of one genus does not exceed 11.2 per cm².

The fusulinoid content of each lithofacies was counted in five large 'control' thin sections which were taken, as much as possible, from different levels of the stratigraphic succession. Then the results were checked in other available thin sections which convinced us that the relative abundances of the main fusulinoid genera will not change substantially in new counts. Genera which occur sporadically in the section (*Taitzehoella*, *Beedeina*, and *Praeobsoletes*) could not be counted adequately and are shown in Fig. 4 as a simple line.

In the preliminary report (Baranova & Kabanov 2001) we considered qualitative (abundant-rare-absent) and, therefore, rough facies distribution of fusulinoid

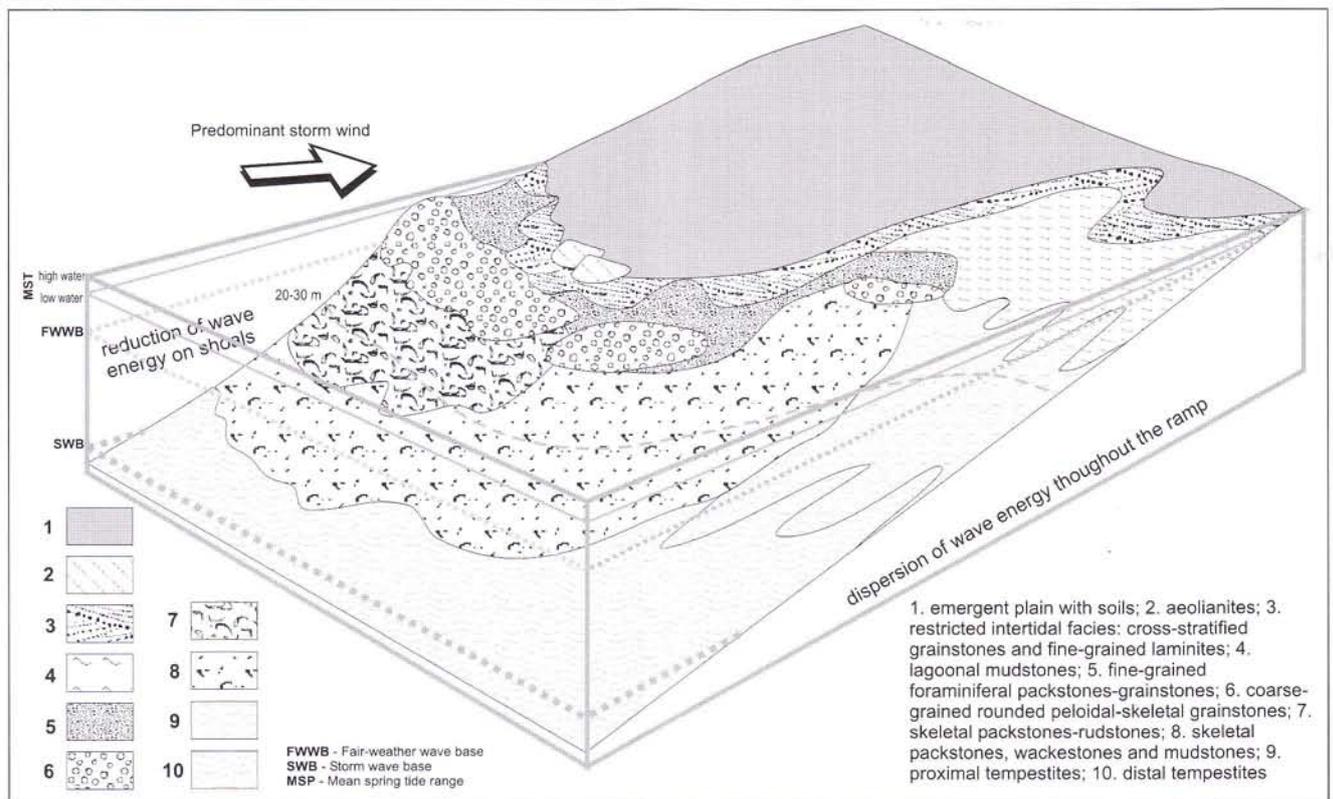


Fig. 3 - A model for environments in the epicontinental basin of the Moscow Syncline during the late Moscovian.

Fig. 2 - Myachkovian stratigraphic scheme and cyclicity; sedimentological features and correlation of the Domodedovo and Konev Bor sections.

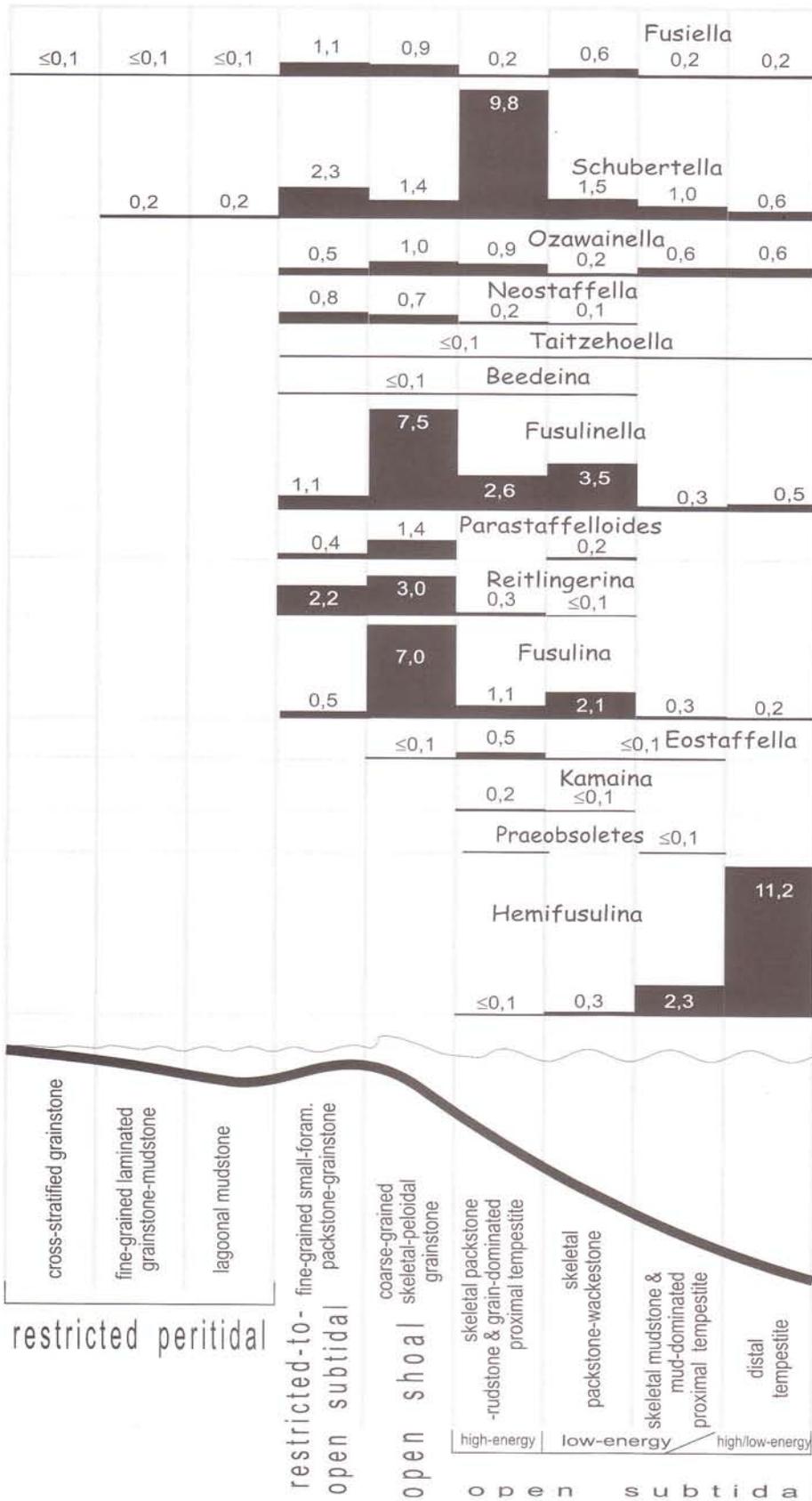


Fig. 4 - Distribution of fusulinoid genera through Myachkovian facies. The relationships are exposed in a rather simplified way; for more details see Fig. 2.

morphotypes. The term 'morphotype' was applied to general shell outline and size of axial test sections. Here, we abandon this term which has different meanings in biology and palaeontology. Moreover, our

'morphotypes' corresponded approximately to genera and had little biological meaning. This paper examines the distribution of 14 genera identified in the Myachkovian in twelve main marine lithofacies.

Sedimentology

The Upper Moscovian rocks are grouped by Kabanov into sixteen lithofacies. Marine lithofacies constitute the bulk of the succession (Fig. 2). Their sedimentary features, stratigraphic relationships, ichnofossil and fossil assemblages indicate three main depositional environments: restricted peritidal, open shoal, and open subtidal (Fig. 4) which is consistent with the general zonation of epeiric basins (Irwin 1965) or ramps (Burchette & Wright 1992). 'Basal conglomerates' are distinct among other lithofacies by the light or blackened pebbles which are the products of palaeosol reworking. We consider these conglomerates as a separate minor initial transgressive lithofacies group, although the real environment of their formation varied from continental to shallow marine. All dolostones in the succession studied appear to be diagenetic (Kabanov 2003). Terrestrial lithofacies (topclays and aeolian grainstones) were not considered. Although shallow-marine limestones can be strongly altered in the palaeosol profile, we used them for identification of lithofacies and fusulinoids unless the primary structure was completely obliterated.

Open subtidal lithofacies (Pl. 2, fig. 8; Pl. 3, figs. 1-6) dominate in the succession studied. They are characterized by the macrofossil assemblage that forms the *Choristites* biofacies, normal-marine relatively diverse parautochthonous and/or autochthonous microfossils, and a relatively high degree of bioturbation (Kabanov unpubl.). Hydrodynamic textures indicate sediment deposition below the fair-weather wave base (FWWB). Most open subtidal lithofacies were soft during sedimentation, and the formation of firmgrounds and hardgrounds was restricted to the shallowest conditions with relatively high water energy. Marly offshore lithofacies (tempestites, some mudstones and wackestones) characteristically contain *Zoophycos*. Some shallow-water wackestones-packstones (Pl. 3, figs. 2-3) and small-foraminiferal packstones-grainstones (Pl. 2, fig. 8) contain simple *Thalassinoides* burrows. The shallow open subtidal skeletal packstones-rudstones (Pl. 3, fig. 1) were apparently most favourable for large skeletal benthos including massive modular tetracorals (*Petalaxis* and *Ivanovia*) and diverse large foraminifera. This lithofacies occurs mainly in the Korobcheevo Fm. which is well known in the literature as a coral-foraminiferal unit (Rauzer-Chernousova & Reitlinger 1954).

Open shoal lithofacies (Pl. 2, fig. 7) comprise the high-energy grainstones commonly with more or less rounded, sorted, and micritized grains, oncoids, lumps, leached grains, and intraclasts. Macrofossils belong to the *Choristites* biofacies and indicate relatively normal-marine conditions. Among the Moscovian lithofacies, open shoal grainstones were the only sites of appreciable isopachous marine cementation (probably aragonitic in original composition) and peloidal micrite development which makes

these facies quite similar to recent beachrocks and shallow hardgrounds (Tucker & Wright 1990). In the Myachkovian, this group is represented only by skeletal-peloidal, coarse-grained grainstones which received among local geologists the idiomatic name 'gorokh', which means 'peastone'.

The characteristic feature of 'gorokhs' is the abundance or dominance of micritized grains and peloids (Pl. 2, fig. 7), with the latter likely being predominantly the ultimate products of micritization. The patterns and products of micritization in the limestones studied are described in Kabanov (2003). Myachkovian products of surface-sediment micritization compare well with the allochems micritized on modern shallow seafloors of tropical carbonate basins (Bathurst 1966; Purdy 1968; Kendall & Skipwith 1969; Alexandersson 1972; Reid & Macintyre 1998). Most fusulinoid tests are characteristically abraded and strongly peloidized, but still retain the remnants of internal septa and chomata (Pl. 2, fig. 7). Such preservation of internal structures suggests that micritization proceeded primarily via recrystallization and internal cementation which is consistent with the observations of Purdy (1968) and Reid & Macintyre (1998). The microendolithic borings and their occlusion by micrite, long considered as a main micritizing agent (Bathurst 1966; Alexandersson 1972; Tucker & Wright 1990), are visible in the centripetally micritized pelmatozoan and brachiopod bioclasts, but rarely dominate in micritic replacements. The peloidization of fusulinoid tests impedes considerably their identification. Micritization of nearly the same intensity is a characteristic feature of fine-grained, small-foraminiferal grainstones. In open subtidal lithofacies the quantity of micritized grains decreases as the lithofacies becomes muddier (mud fraction now represented by the micritic-microbioclastic matrix) and the inferred palaeodepth increases. In modern tropical shallow-water carbonate settings, the micritization generally proceeds at depths of less than 15-20 m (Alexandersson 1972; Tucker & Wright 1990). By analogy, the appearance of substantial quantities of micritized grains and peloids in the Upper Moscovian sections is assumed to be indicative of palaeodepths less than 15-20 m.

Restricted peritidal lithofacies (Pl. 2, figs. 5, 6) include limestones with a depleted microfossil and macrofossil assemblage of the *Meekella* biofacies, suppressed bioturbation, and correspondingly preserved lamination. Normal-marine faunas (*Choristites* and large fusulinoids) are absent. Only one out of three lithofacies is shallow subtidal, while the other two are characterized by intertidal features. Restricted peritidal grainstones often exhibit the relics of isopachous marine cementation. In the Myachkovian, restricted peritidal lithofacies terminate cyclothem and are usually altered in palaeosol profiles.

The stratigraphic relationship between lithofacies in the Domodedovo and Konev Bor sections is shown in Fig. 2. The basin model (Fig. 3) is based on inferred rela-

tive palaeodepths, degree of the facies openness-restrictness, and lateral/vertical relationships of marine lithofacies. In short, lithofacies found in stratigraphical contact and/or grading into each other are shown contacting each other in Fig. 3. Lithofacies separated stratigraphically do not have common boundaries. This model does not reconstruct any particular state of basin evolution, as all lithofacies shown do not co-occur at one stratigraphic level in the area studied. However, this model may approximate to the facies spectrum registered in the Korobcheevo Fm. across the Moscow and northern Ryazan regions (300 km from NW to SE).

Fusulinoid genera and their distribution through Myachkovian facies

The facies distribution of fusulinoids is shown in Fig. 4. We estimated the ecological tolerance of the genus from the facies range where this genus occurs, at least in appreciable quantities, suggesting it is autochthonous and/or flourishing, and heterogeneous in its distribution. In our limited material, the reliable ecological tolerance can be estimated if the $\rho_{fus}^{st.}$ (average density of fusulinoids, see "Material and method") in each facies exceeds or equals 0.5 fus/cm². Therefore we cannot estimate ecological tolerance of singular *Taitzeoella*, *Beedeina*, and *Praeobsoletes* ($\rho_{fus}^{st.} < 0.1$), and rare *Eostaffella* and *Kamaina* ($\rho_{fus}^{st.} = 0.1-0.5$) scattered among more numerous representatives of other genera. However, it seems that at least *Taitzeoella* (Pl. 1, fig. 7), with the widest known

facies range among these genera, is more tolerant than *Kamaina* that has the narrowest known facies range. The Myachkovian fusulinoid genera may be ordered by the decrease of their ecologic tolerance: *Fusiella*, *Schubertella*, *Ozawainella*, *Fusulinella*, *Fusulina*, *Reitlingerina* and *Hemifusulina*, *Neostaffella*, and *Parastaffelloides*. New thin sections from new localities will probably change their facies ranges and correct their abundances.

The facies distribution of fusulinoids shows three distinct fusulinoid assemblages. The selective occurrence of *Fusiella* and *Schubertella* and abrupt disappearance of other fusulinoid genera at the transition to restricted peritidal lithofacies suggests that interfacial transport of fusulinoid tests was insignificant. The same inference can be made from the selective occurrence of abundant *Hemifusulina* in the deepest lithofacies and their scarcity in shallower limestones. Given that the rare/frequent tests of other fusulinoids in distal tempestites could be transported offshore from shallower settings, the original content of fusulinoids in this zone was clearly different. This inferences justify the application of the term 'fusulinoid biofacies' to three main fusulinoid assemblages.

Biofacies 1 possessed most severe conditions with shallow depths, strongly fluctuating salinities and hydrodynamic regimes. No large fusulinoids were found. Small-sized *Fusiella* (Pl. 1, figs. 3, 4) and *Schubertella* (Pl. 1, fig. 2) may have lived on mud lagoon floors, in intertidal ponds, or in intergranular interstices that retained water during ebbs. These forms co-occur with few fossils of the *Meekella* brachiopod biofacies, which were adapted to such extreme environments. Only one brachiopod spe-

PLATE 1

Myachkovian fusulinoids. Scale bars are 0.1 mm; in figs. 9, 10 scale bars are 0.5 mm; the bed number is specified in the specimen number (e.g., AF-1b-1 means Afanasievo Quarry, bed no. 1b).

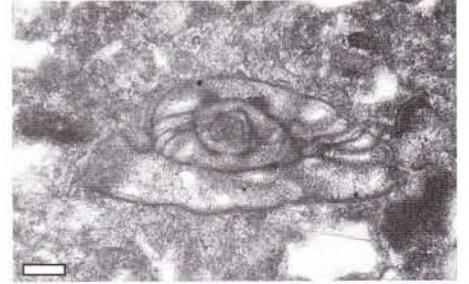
- Fig. 1 - *Eostaffella acuta* Grozdilova et Lebedeva. $\times 50$. Axial section, PIN 4902/AF-1b-1. Afanasievo quarry, Domodedovo Fm., Upper Gubastovo Mb.
- Fig. 2 - *Schubertella subkingi* Putrja. $\times 50$. Subaxial section, 4902/PIN AF-1c. Afanasievo quarry, Domodedovo Fm., Upper Gubastovo Mb.
- Fig. 3 - *Fusiella typica typica* Lee et Chen. $\times 50$. Axial section, PIN 4902/D-5d-1. Domodedovo quarry, Korobcheevo Fm., Staryi Yam Mb.,
- Fig. 4 - *Fusiella sagerdashtiensis* Davydov. $\times 50$. Axial section, PIN 4902/D-35-2. Domodedovo quarry, Peski Fm., Titovo Mb.
- Fig. 5 - *Ozawainella nikitovkensis* (Brazhnikova). $\times 50$. Subaxial section, 4902/PIN D-25. Domodedovo quarry, Domodedovo Fm., Upper Gubastovo Mb.
- Fig. 6 - *Neostaffella sphaeroidea sphaeroidea* (Ehrenberg). $\times 50$. Subaxial section, PIN 4902/KB-1b/c. Konev Bor quarry, Korobcheevo Fm., Staryi Yam Mb.
- Fig. 7 - *Taitzeoella taitzeoensis* Sheng. $\times 50$. Subaxial section, GIN 4740/PS1/17-1-5. Konev Bor quarry, Domodedovo Fm., Upper Gubastovo Mb.
- Fig. 8 - *Beedeina elegans decurta* (Rauzer). $\times 60$. Subaxial section, PIN 4902/PD-35. Podolsk quarry, Korobcheevo Fm., Nikitskoe Mb.
- Fig. 9 - *Fusulinella bocki pauciseptata* Rauzer et Beljaev. $\times 30$. Axial section, PIN 4902/OP-7-52. Old Peski quarry, Domodedovo Fm., Upper Gubastovo Mb.
- Fig. 10 - *Parastaffelloides pseudosphaeroides* (Dutkevich) accumulation in Myachkovian strata. $\times 15$. Axial and subaxial sections of tests, PIN 4902/D-13a-1. Domodedovo quarry, Korobcheevo Fm., Rozhai Mb.
- Fig. 11 - *Reitlingerina bradyi* (Moeller). $\times 50$. Axial section, PIN 4902/D-33b-4. Domodedovo quarry, Peski Fm., Lower Titovo Mb.
- Fig. 12 - *Hemifusulina (Hemifusulina) bocki bocki* Moeller. $\times 60$. Note "keriothecal" wall with coarse pores. Sagittal section, PIN 4902/OP-9. Old Peski quarry, Domodedovo Fm., Upper Gubastovo Mb.



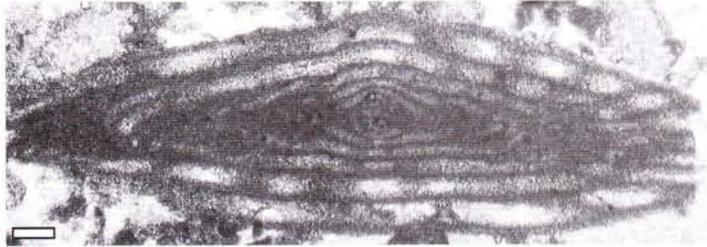
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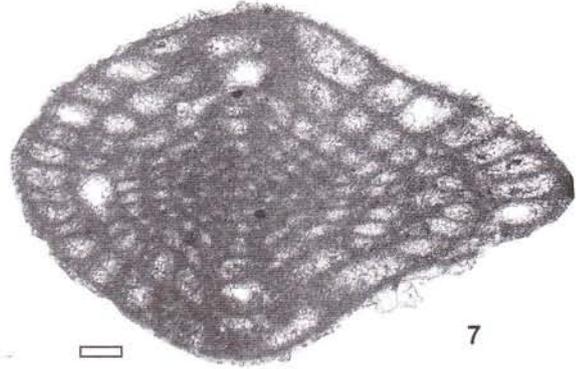
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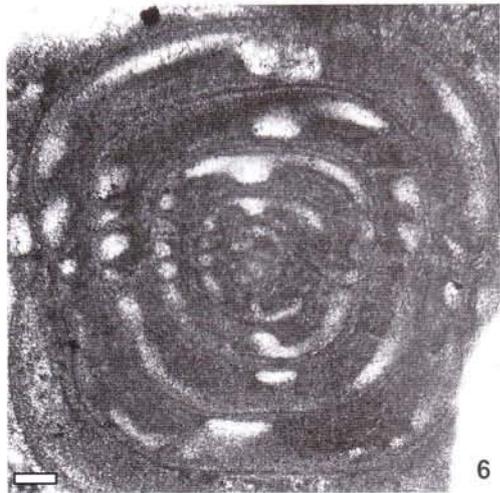
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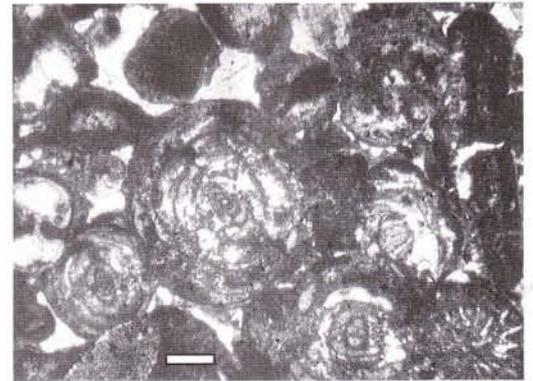
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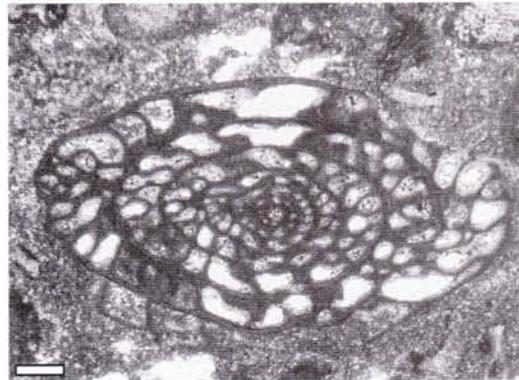
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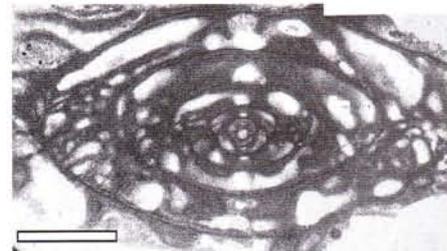
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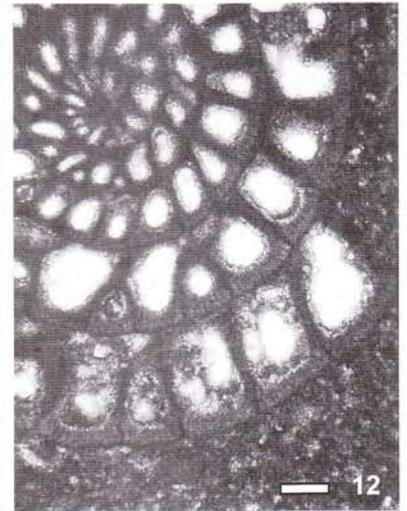
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cies, i.e. *Meekella eximia* (Eichw.), five gastropod species (A.V. Mazaev pers. comm.), fenestellid bryozoans, numerous although monotonous ostracods, and some other micro- and macrofossils were found. Thus, our material suggests that small-sized fusulinoids had a higher tolerance than that revealed by Rauzer-Chernousova & Kulik (1949), who found the shallowest limit of fusulinoid occurrence in oolitic grainstones.

Biofacies 2 is characterized by a high diversity and abundance of fusulinoids which corresponds to the high diversity of other skeletal benthos. Warm insolated settings with normal salinity and seafloors that were stable for periods between storms, were covered by herds of small delicate sphaerical *Schubertella*, large fusiform *Fusulinella* with tests strengthened by chomata, and sub-cylindrical *Fusulina* with thick tests heavily fortified by plicated septa. The genera *Fusulinella* (Pl. 1, fig. 9) and *Fusulina* (Pl. 2, fig. 3) disappear from the studied basin by the end of the Myachkovian. Interestingly, the facies ranges of these genera seem to be extended in the upper Myachkovian, in contrast with the progressive reduction of the habitats of *Neostaffella* (Pl. 1, fig. 6) and staffellids (*Reitlingerina* and *Parastaffelloides* – Pl. 1, figs. 11, 10 respectively). Rauzer-Chernousova & Kulik (1949) assumed that the pre-Myachkovian representatives of the latter three genera had a wide distribution. These authors pointed out that the larger fusiform fusulinoids (including *Fusulinella* and *Fusulina*) had advanced to new biotopes with fine muddy substrates at the end of the Mid Carboniferous, which is consistent with our observations. Staffellids are represented by inflated lenticular *Reitlingerina* (Pl. 1, fig. 11) and nautiloid to subsphaerical *Parastaffelloides* (Pl. 1, fig. 10). Their test wall (luminotheca) is always recrystallized which may be the consequence of

its primary aragonitic composition. In contrast, other fusulinoids possessed primary calcitic, and have, therefore, preserved tests. In the skeletal packstones-rudstones of the Korobcheevo Fm., the diversity of fusulinoids is as high as in other settings of the shallow open-marine zone. The small schubertellids reach their maximum abundance. However, the large fusulinoids *Fusulinella* (Pl. 1, fig. 9) and *Fusulina* (Pl. 2, fig. 3) occur in lesser quantities than in the adjacent packstones-wackestones and, especially, than in the coarse skeletal-peloidal grainstones. Probably this may be explained by the high competitive pressure from such larger “small forams” as *Bradyina*, *Bradyinelloides*, *Climacammina*, and *Palaeotextularia* which occur in large quantities in skeletal packstones-rudstones (Rauzer-Chernousova & Reitlinger 1954). Small drum-shaped *Neostaffella* (Pl. 1, fig. 6) and scarce *Beedeina* (Pl. 1, fig. 8) and *Kamaina* occur only in the second fusulinoid biofacies.

Masses of staffellids are good indicators of shoaling. They are numerous in the two shallowest open marine lithofacies: in coarse-grained skeletal-peloidal grainstones which accumulated mainly above the FWWB and were possibly exposed in the intertidal zone (Fig. 3, 4), and in fine-grained, small-foraminiferal packstones-grainstones which is the most shallow and restricted lithofacies of the open subtidal facies spectrum (Fig. 3, 4). In coarse skeletal-peloidal grainstones, the ρ_{fus} of many genera shows a high peak (Fig. 4). Probably these peaks do not indicate the original flourishing of large fusulinoids in a rather severe shoreface-to-beach setting. Concentrations of fusulinoids were likely increased several times as a consequence of much slower net sediment accumulation. The ratio of different fusulinoid genera may be close to original values, although the smallest fusulinoid tests

PLATE 2

Myachkovian fusulinoids and lithofacies. Scale bars are 1 mm.

- Fig. 1 - *Fusulina cylindrica domodedovi* Rauzer. $\times 33$. Axial section, PIN OP1-17a-1. Old Peski quarry, Domodedovo Fm., Upper Gubastovo Mb.
 Fig. 2 - *Protriticites* (?) cf. *ovatus* Putrja. $\times 15$. Axial section, PIN AF-1-c. Afanasievo quarry, Domodedovo Fm., Gubastovo Mb.
 Fig. 3 - *Fusulinella* (?) sp. $\times 30$. Subaxial sections, GIN PS1/17-139. Konev Bor quarry, Domodedovo Fm., Gubastovo Mb.
 Fig. 4 - Mass *Hemifusulina* (*H.*) *bocki bocki* Moeller of different ontogenic stages in a tempestite unit. $\times 15$. Axial section, PIN 4902/OP-9. Old Peski quarry, Domodedovo Fm., Upper Gubastovo Mb.

Restricted peritidal lithofacies:

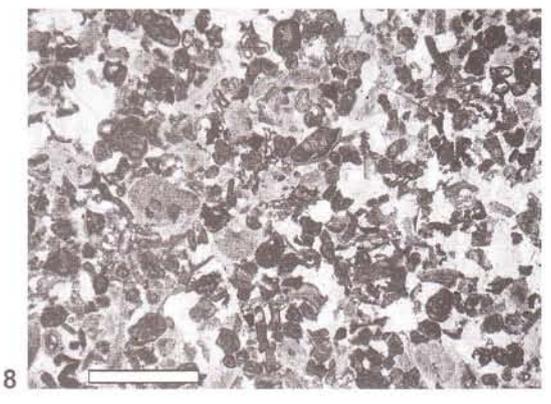
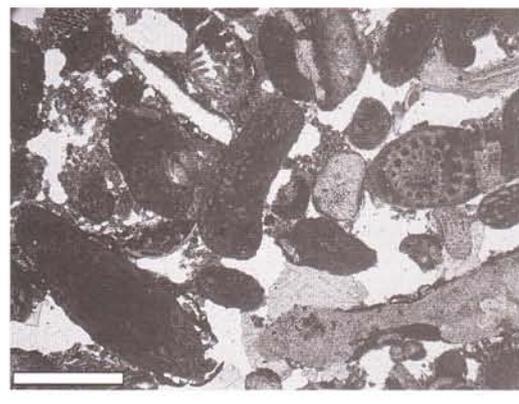
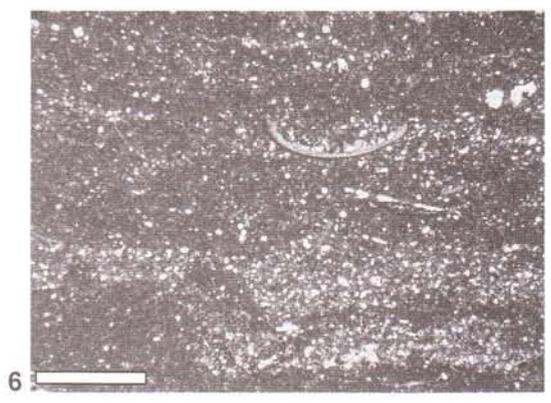
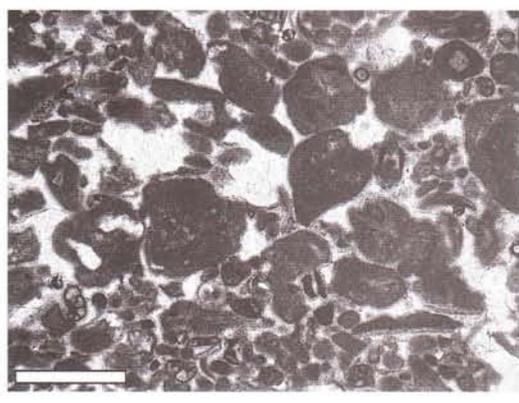
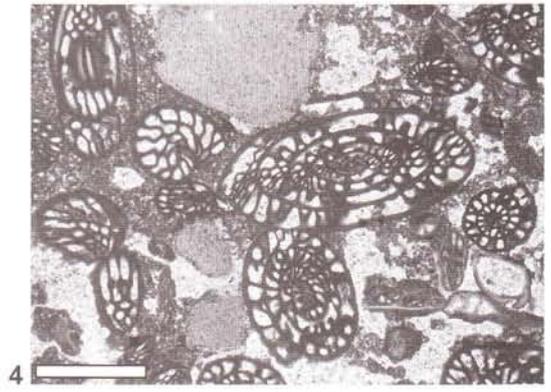
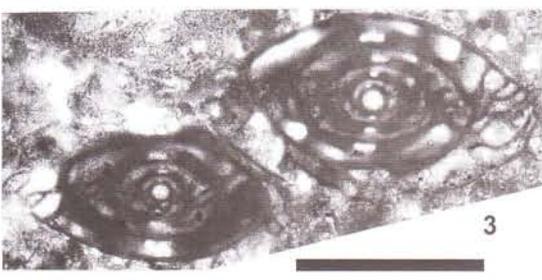
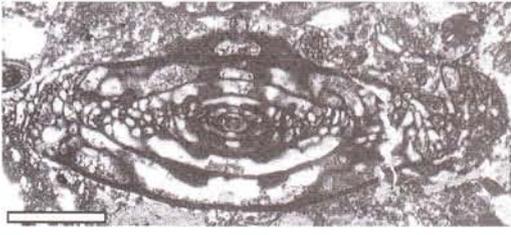
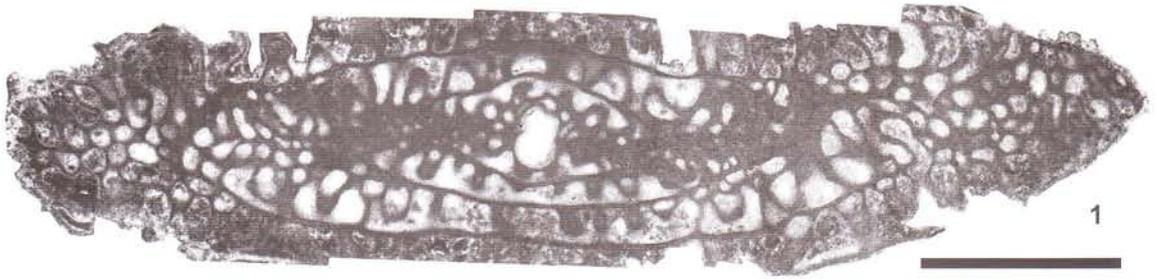
- Fig. 5 - Cross-stratified grainstone. PIN 4902/AF-12-2. Afanasievo quarry, Peski Fm., Volodarsky Mb.
 Fig. 6 - Lagoonal mudstone. PIN 4902/OP-12-5. Old Peski quarry, Domodedovo Fm., Upper Gubastovo Mb.

Open shoal lithofacies:

- Fig. 7 - Coarse-grained skeletal-peloidal grainstone ('gorokh', or peastone). PIN 4902/D-33b-4. Domodedovo quarry, Peski Fm., boundary between Kamennaya Tyazhina and Titovo Mbs.

Open subtidal lithofacies:

- Fig. 8 - Fine-grained small-foraminiferal packstone-grainstone. PIN 4902/NI-4a-4. Nikitskoye quarry, Korobcheevo Fm., Nikitskoye Mb.



may be partly winnowed. As a consequence of slow net sedimentation and long exposure at the sediment-water interface, most grains in this lithofacies are rounded and strongly micritized.

Biofacies 3 occupied the subtidal offshore zone with depths generally exceeding 30 m (micritized grains and siphonacean algae are sporadic). The seafloor was dominated by soft muds, its insolation was shadowed by a thick water column and siliciclastic mud suspension. Rare stronger storms eroded the seafloor, more common weaker storms generated density flows discharged in this setting to form catastrophically buried oryctocoenoses (Kabanov unpubl.). The fusulinoid assemblages are less diverse than in the shallower open subtidal zone. The spectacular late Domodedovo tempestite of the Piski and Afanasievo quarries (Gubastovo Cyclothem; Fig. 2) is strongly dominated by *Hemifusulina bocki* Moeller (Pl. 2, fig. 4). *Hemifusulina* is distinct among large Myachkovian fusulinoids because of their regular ovoid outline, regular septal fluting, pronounced porous wall (Pl. 1, fig. 12), and practically antagonistic facies distribution (Fig. 4). This genus occurs in the Gubastovo tempestites in huge quantities, sometimes comprising monospecific concentrations. The co-occurrence of different ontogenic stages in one tempestite bed indicates a sudden burial (Pl. 2, fig. 4). Their transport from shallower environments by storm-generated compensatory flows seems unlikely because shallower settings, as was already shown, contain clearly different and more diverse fusulinoid assemblages, and even in the proximal tempestite KB-21 immediately overlying the 'core' tempestites KB-18-20 of the Upper Gubastovo Cyclothem, the fusulinoid assemblage has little convergence with the underlying *Hemifusulina* concentrations. Villa & Bahamonde (2001) described similar monospecific concentrations of *Ferganites ferganensis* (Miklukho-Maclay, 1950) and *F. martinezi* Villa, 2001 in the upper Kasimovian-lowermost Gzhelian of NW Spain, but in a different depositional environment. Interestingly, these authors reported the occurrence of abundant *Hemifusulina moelleri* species group in Moscovian fine-grained littoral sandstones. Our apparently autochthonous *H. bocki* from the Gubastovo tempestites thus could be considered as ecological antagonists of Cantabrian Moscovian *Hemifusulina*. If sedimentologic interpretations of both *Hemifusulina* occurrences are correct, it means that different species of *Hemifusulina* with similar test anatomy occupied very different biotopes in the late history of this genus. Besides *Hemifusulina*, subtidal offshore lithofacies contain frequent quantities of *Schubertella* and *Ozawainella*, rare *Fusiella*, *Fusulinella*, *Fusulina*, and singular *Taitzeboella*. Moreover, singular *Praeobsoletes* (Pl. 2, fig. 2) and *Eostaffella* (Pl. 1, fig. 1) are registered in the upper part of Gubastovo tempestites where rare peloids and weakly micritized grains indicate tendency to upward shoaling. The scarcity of these genera suggests that the settings described were rather un-

favourable for them. At least some of these fusulinoids could be allochthonous and redeposited from shallower settings by storms.

Conclusions

1. The new sedimentological approach in the study of type Moscovian deposits shows a consistent pattern in the distribution of fourteen fusulinoid genera recovered in the Myachkovian Horizon. The continuous spectrum of marine rocks was subdivided into fourteen marine lithofacies which in turn are grouped into three main facies zones: restricted peritidal, open shoal, and open subtidal (Figs. 3, 4). About 600 thin sections were analysed and fusulinoids were counted in five thin sections from each main marine lithofacies.

2. The ecological tolerance of fusulinoid genera was estimated from their facies ranges and the heterogeneity of their distribution (Fig. 4). The following are arranged in decreasing ecologic tolerance: *Fusiella*, *Schubertella*, *Ozawainella*, *Fusulinella*, *Fusulina*, *Reitlingerina* and *Hemifusulina*, *Neostaffella*, and *Parastaffelloides*. The genera *Taitzeboella*, *Beedeina*, *Eostaffella*, *Kamaina*, and *Praeobsoletes* occur in negligible quantities which prevent assessment of their tolerance to be made. Fusulinoids apparently inhabited all studied Myachkovian marine environments. The onshore limit of fusulinoid occurrence is the intertidal grainstones with a depleted fossil assemblage indicative of extreme conditions. Extinct at the end of the Moscovian, *Neostaffella* and staffellids (*Parastaffelloides* and *Reitlingerina*) were displaced from the wide facies range where they occur in pre-Myachkovian deposits (Rauzer-Chernousova & Kulik 1949) to the shallowest normal-marine settings. The genus *Fusulinella* exhibits the opposite tendency towards increased ecologic tolerance.

3. The facies distribution of fusulinoids (Fig. 4) exhibits three distinct zones with mostly autochthonous fusulinoid assemblages and must have corresponded to the original fusulinoid biofacies. Biofacies 1 contains only the most tolerant small-sized singular *Fusiella* and rare *Schubertella* and corresponds to most severe conditions of the restricted peritidal zone.

4. Biofacies 2 exhibits the highest diversity of fusulinoids, which corresponds to the high diversity of skeletal benthos. Favourable conditions characterized by warm insolated conditions, normal salinity, and seafloors stable for periods between storms, supported numerous small *Schubertella*, large *Fusulinella* and *Fusulina*, and lesser quantities of all other genera. The habitats of singular to numerous staffellids were shifted to less favourable settings of shoals and relatively restricted fine bahamite-type sands. In the skeletal packstones-rudstones of the Korobcheevo Fm. deposited in most favourable setting for skeletal benthos, large fusulinoids *Fusulinella* and

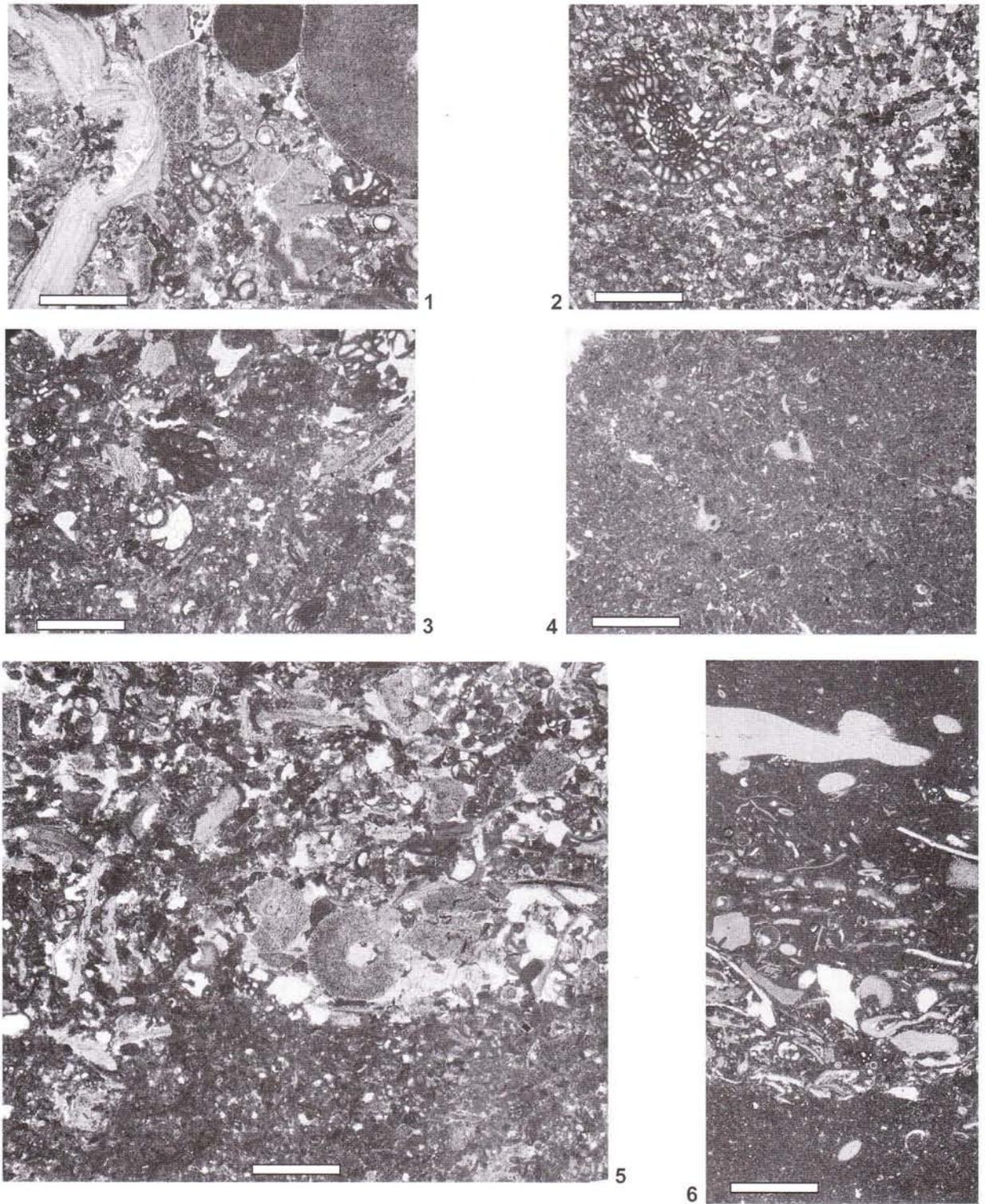


PLATE 3

Myachkovian lithofacies. Scale bars are 1 mm.

Open subtidal lithofacies:

- Fig. 1 - Skeletal packstone-rudstone. 4902/PIN 4902/NI-2c-3. Nikitskoye quarry, Korobcheevo Fm., Nikitskoye Mb.
 Fig. 2 - Skeletal packstone-wackestone; note abnormal *Fusulina* sp. in the upper left. PIN 4902/D-35-5. Domodedovo quarry, Peski Fm., Titovo Mb.
 Fig. 3 - Skeletal packstone-wackestone. PIN 4902/D-35-2. Domodedovo quarry, Peski Fm., Titovo Mb.
 Fig. 4 - Skeletal mudstone. PIN 4902/D-36-4. Domodedovo quarry, Peski Fm., Volodarsky Mb.
 Fig. 5 - Proximal tempestite, thick basal lag dominated by fine bioclastic material. $\times 10$. PIN 4902/PRI-11-1. Prioksky quarry, middle Podolskian.
 Fig. 6 - Distal tempestite. PIN 4902/OP-8c-1. Old Peski quarry, Domodedovo Fm., Upper Gubastovo Mb.

Fusulina are less abundant, which is probably explained by the high competitive pressure from large "small forams" *Bradyina*, *Bradyinelloides*, *Climacammina* and *Palaeotextularia*. Rare to frequent *Neostaffella*, singular to rare *Kamaina* and singular *Beedeina* occur only in this fusulinoid biofacies.

5. The density peaks of some genera in coarse skeletal-peloidal grainstones do not indicate their original abundance. Concentrations of fusulinoids must have been increased several times as a consequence of much slower net sand accumulation. The ratio of different fusulinoid genera, however, may be close to the original. As a consequence of slow net sedimentation and long exposure at the sediment-water interface, most grains in this lithofacies are rounded and strongly micritized. The products of micritization compare well with modern micritized grains from shallow tropical marine carbonates. Myachkovian micritization proceeded via internal micritic cementation and recrystallization with the subsequent role of microendolithic borings.

6. Biofacies 3 contains fusulinoid assemblages less diverse than biofacies 2. This was a subtidal offshore zone with depths generally exceeding 30 m. The seafloor was periodically affected by storms and dominated by soft muds, its insolation was shadowed by a thick water col-

umn and siliciclastic mud suspension. This setting supported large numerous to abundant *Hemifusulina bocki* Moeller and much lesser quantities of *Fusiella*, *Schubertella*, *Ozawainella*, *Taitzeboella*, *Fusulinella*, and *Fusulina*. Singular *Eostaffella* and *Praeobsoletes* are registered in the shallower portion of the Gubastovo tempestite unit. Some of these rare fusulinoids may be allochthonous, and the original diversity might have been even lower. *Hemifusulina* in the Upper Gubastovo tempestites sometimes forms practically monospecific concentrations showing the signs of sudden storm burial. The evidence of mass occurrence of *Hemifusulina moelleri* species group in littoral sandstones (Villa & Bahamonde 2001) suggests that different species of *Hemifusulina* with quite similar test anatomy might have occupied very different biotopes in the late history of this genus.

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