

LATE VENDIAN (NEOPROTEROZOIC III) MICROBIAL AND ALGAL COMMUNITIES OF THE RUSSIAN PLATFORM: MODELS OF FACIES-DEPENDENT DISTRIBUTION, EVOLUTION AND REFLECTION OF BASIN DEVELOPMENT

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Riassunto. Le comunità algali e microbiche furono dominanti nei bacini marini e non marini del tardo Vendiano della Piattaforma Russa. Gli ecosistemi del tardo Vendiano erano molto diversi da quelli del Fanerozoico, dominati dagli Invertebrati. Vengono costruite per la prima volta carte delle principali località secondo sette intervalli di tempo del tardo Vendiano, utilizzando la distribuzione del plancton, del phytobenthos, dei distruttori e dei consumatori. Per ogni intervallo di tempo sono distinte le zone dei paleobacini con popolamenti ed ambienti diversi, nonché le modificazioni delle comunità durante l'evoluzione degli ecosistemi e dei bacini. Viene dimostrata la connessione tra evoluzione delle comunità e lo sviluppo dei bacini. Per due intervalli di tempo tra i più significativi, l'inizio della trasgressione e della regressione, sono proposte ricostruzioni degli ambienti e delle popolazioni.

Abstract. Microbial and algal communities dominated in the Late Vendian marine and non-marine basins of the Russian Platform. The Late Vendian ecosystems differed very much from the Phanerozoic invertebrate-dominated ecosystems. Maps of key localities with distribution of plankton, phytobenthos, destructors and consumers for seven time-slices of the Late Vendian of the Russian platform are constructed for the first time. Zones of the paleobasins with different population and environments are isolated for each level. Stability and alteration of communities during ecosystem and basin evolution are traced. The connection between the communities evolution and the basin development is demonstrated. Reconstructions of environments and population are proposed for two time-slices of a major interest, the onset of transgression and regression.

Introduction.

Late Precambrian was the age of Prokaryotes and lower Eukaryotes. Virtually complete lack of information about animals (except for those of the enigmatic Ediacara fauna and worm-like organisms) prevents application of standard models of facies-dependent distribution of organisms for the Late Precambrian. The application of information concerning extant lower organism distribution cannot be correct because present-day Prokaryote and lower Eukaryote dominated communities

exist only where higher organisms "allow" them to do so. Today, prokaryote-dominated communities predominantly inhabit extreme biotopes, while during the Precambrian their distribution was evidently wider.

Reconstruction of Precambrian ecosystems and elaboration of model of facies-dependent distribution of microorganisms and communities in ancient paleobasins has been based on the silicified microfossils distribution (Knoll et al., 1991). This kind of fossils is characterized, as a rule, by *in situ* burial that makes easier the reconstruction of communities and facial sequences, but chert formation in the Precambrian was restricted mainly to extreme shallow-water environments (Maliva et al., 1989) and the reconstruction appears to be available only for populations that inhabited marginal shallow-water parts of paleobasins.

Efforts to reconstruct the population of Precambrian paleobasins from organic-walled Siberian Riphean microfossils (Weiss & Petrov, 1994) have given a picture of burial (taphonomic) condition distribution in paleobasins rather than of communities, even though detailed lithofacies analyses were made. This is because the following problems were not considered: 1) ecological interpretation of microfossils; 2) reconstruction of communities from scattered remains; 3) analysis of preservation that reflects both the degree of bacterial activity and transport by waves and currents before the burial in zone of fine mud deposition.

The Upper Vendian (Neoproterozoic III) paleobasin of the Russian Platform is very suitable for reconstruction of communities and construction of facies models based on the distribution of organic-walled fossils. It possesses the following merits: 1) large area of facies development and continuity; 2) wide development of clays that give organic-walled fossil preservation; 3) notably low-degree of thermal alteration of rocks; 4) com-

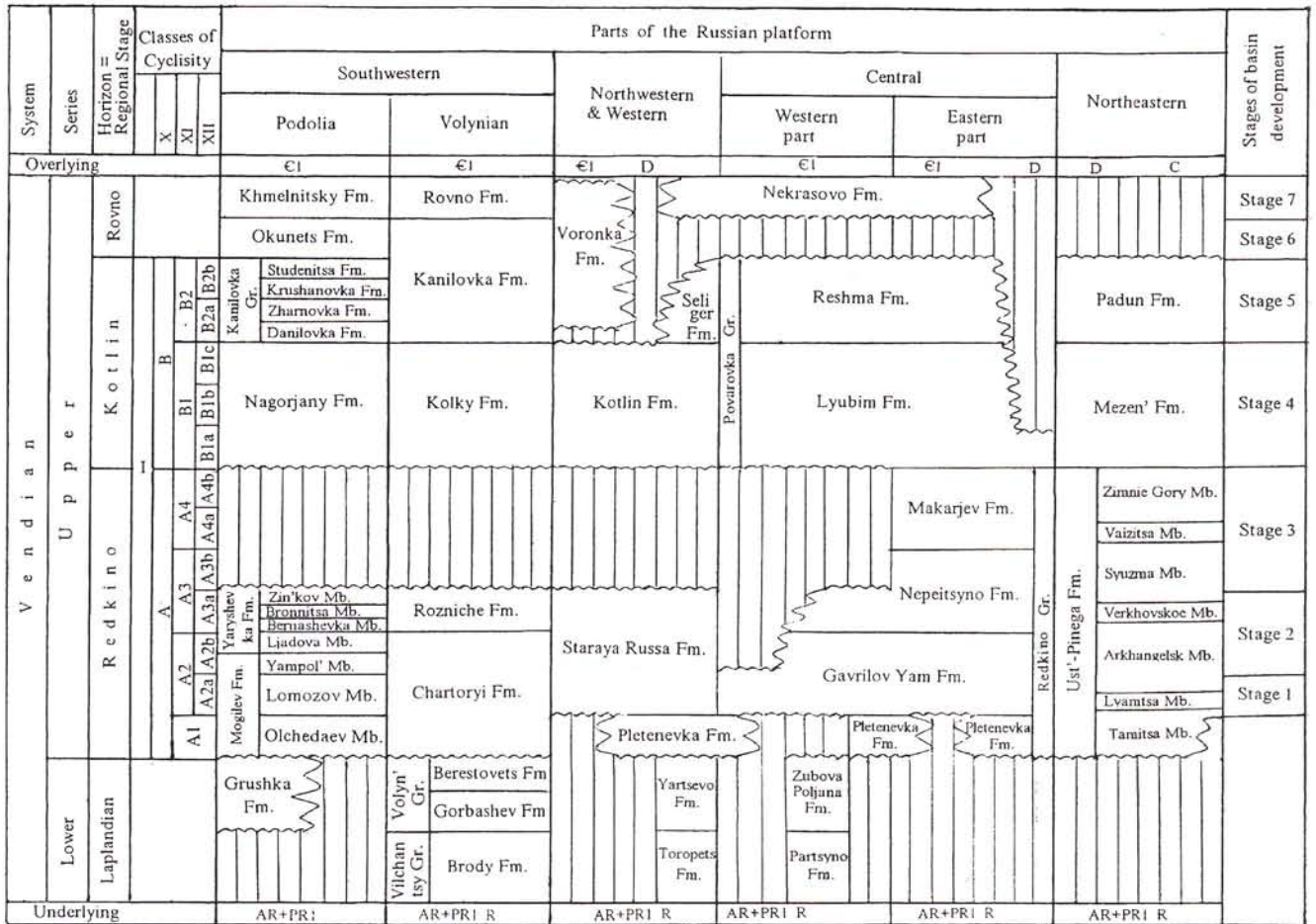


Fig. 1 - Stratigraphic chart of the Vendian of the Russian Platform.

plete sequence of paleobasin development stages (from the initial stage of transgression to regression and beginning of new transgression); 5) recently developed comprehensive stratigraphy (Fig. 1); 6) rich findings of organic-walled microfossils and carbonaceous macroscopic remains (so-called carbonaceous "macrofossils") that became widely distributed both laterally and stratigraphically, and are readily sampled from bore-hole material. Microbial and algal communities dominated in the Late Vendian marine and non-marine basins of the Russian Platform. The Late Vendian ecosystems differed very much from the Phanerozoic invertebrate-dominated ecosystems. A large number of non-oxidized organic matter made these vast basins an important factor influencing the atmosphere composition prior to the beginning of the Cambrian and the radiation of skeletal organisms.

Methods and Materials.

Using the lithological-paleogeographical maps for Ust'-Pinega (Fig. 2, a-c) and Lyubim time (Fig. 2, d-f) created by E.M.Aksjenov (The Vendian System, 1990),

and map for Rovno time (Fig. 2, g) resulted from Joint Polish-Soviet investigations of the Upper Precambrian and Cambrian deposits of the East European platform (Keller & Rozanov, 1980) as a base, special maps were constructed for the first time for seven time-slices (indicated on Fig. 1) of the Late Vendian of the Russian Platform in order to reconstruct basin population and its evolution.

Representatives of major ecological groups of organisms are indicated on the maps as symbols on flags (one flag for each locality, see legend on Fig. 2) with four stripes: symbols for probable planktonic organisms (mostly phytoplankton) are on the highest stripe, phyto-benthos - on the second, destructors (with no division into planktonic or benthonic) - on the third, and animals-consumers - on the fourth one. Methods and principles of ecological interpretation of the Upper Vendian organic-walled microfossils have already been described (Burzin, 1993a, b, 1995a).

Materials investigated by the author from bore-holes and outcrops are indicated on the maps. In addition, data from the Pavlovsky Posad no. 1 borehole were obtained by the author from investigation of palynological

slides from E.D. Schepeleva's collection. Materials from the Redkino borehole was supplemented with revised data from N.A. Volkova (Volkova, 1973; The Vendian System, 1990). Information from the Lezha no. 1 borehole came from V.V. Kirjanov. Revised data from the Dniester River Podolia belong to E.A. Assejeva (Assejeva, 1988; Velikanov et al., 1983), and A.A. Istchenko and M.B. Gnilovskaya (Gnilovskaya et al., 1988). The data from Finnish boreholes belong to R. Tynni and co-authors (Tynni & Donner, 1980; Tynni & Uutela, 1985). The data from Cis-Urals peri-cratonic depressions (eastern part of platform) are not indicated on the maps since they are poorly understood and only information about microplankton is available.

Results and Discussion.

The patterns of organism distribution are examined according to the stage of basin development (see Fig. 1), from older to younger.

Stage 1 (Fig. 2, a).

Early Gavrillov-Yam time (Late Vendian, the beginning of the Redkino Horizon) was marked by marine transgression over peneplaned crystalline basement, Riphean sediments in aulacogenes, and adjoining areas of Lower Vendian deposits (some depressions of the peneplane were filled up prior to transgression by proluvial-deluvial and lacustrine-lagoonal deposits of the Pletenevka Formation) (The Vendian System, 1990). The transgression very quickly covered the widest area of Upper Vendian deposits.

A zone of extremely shallow-water conditions was situated to the west of the central part of the platform. Benthonic cyanobacterial mat-like communities (dominated by oscillatorian filamentous forms) flourished there, and less abundant solitary plankters are also present.

The zone south-east and east of the central part can be reconstructed as an estuary (Afanasieva et al., 1995; Burzin, 1996). It was inhabited by diverse solitary (micro- and meso-sized), colonial coccoidal and filamentous plankters, but the tangle-forming dendroid filamentous algae *Eoholynia* Gnilovskaya, 1975 was the only known benthonic vegetation. One can suppose that *Eoholynia*, like the extant green alga *Cladophora* Kutzing, 1847, was able to form large interlaced mass of branching filaments that were detached from the substratum and transported by waves and currents. This interpretation is based on: 1) occurrence of this alga as allochthonous remains in fine clayish argillites, i.e. they lack attachment and reproductive structures, complete bushes are unknown and only clusters of filaments and their fragments are found; 2) sapropelization of remains

has obscured details of cell walls or filament envelopes. No evidence of *in situ* burial was found.

The major part of the organic matter in sediments of this zone occurs not as microfossils, but as orange and red films and disk-like bodies (= *Spumosina* Naumova, 1968) of sapropel-like matter containing a large number of pyrite framboids (Afanasieva et al., 1995; Burzin, 1996). Assuming that pyrite framboids in extant cyanobacterial mats are diagenetic innovations around sulphur granules intracellularly accumulated during vital activities of colonial sulphur bacteria (Krumbein, 1978), one can suppose that the films and disk-like bodies in this context are the remains of clusters of sulphur bacteria, growing on a necromass of plankton and dendroid filamentous algae, settled on boundary between water layers with different density and salinity (Fig. 3, a). The assumption of water stratification and planktonic mode of life of those sulphur bacteria is based on the following concepts:

1) A considerable amount of time has to pass between algal death and burial by silty-mud sediments to obtain a high degree of destruction and transformation of organic remains into sapropel-like matter, that leaves no relicts of the initial structures.

2) It is unlikely that destruction of organic matter occurred at the sediment-water interface, because films are homogeneous and lack lamination typical of bacterial mats and pertaining to oxygen-reduction and other gradients on the water/sediment boundary or to some extent within sediments (Zavarzin, 1993).

3) The lack of Ediacara-type metazoan remains and utter rarity of trace-fossils testify either to non-marine conditions in this part of the basin, or to bottom water pollution by hydrogen sulphide. Enigmatic Sabeliditidae-like *Saarina* Sokolov, 1965 (preserved as pyritized cylindrical or conical tubes) were the only animals inhabiting this zone.

Shallow-water quiet marine conditions prevailed on the northwest part of the platform. There grew the tangles of the filamentous alga *Striatella* Assejeva, 1982 and the macroscopic ribbon-shaped *Vendotaenia*-like algae (the ancient forms known from the Russian Platform, not yet described). The inferred animal *Beltanelloides* Sokolov, 1972, preserved as jelly-fish-like imprints, and worm-like organisms that possessed cylindrical but non-pyritized tubes related to *Saarina* also lived there.

The southwest part of the platform was characterized by shallow-water. However, rougher-water marine conditions probably were responsible for the poor benthonic vegetation (or unfavorable conditions for preservation of organic-walled microfossils and carbonaceous films). Those conditions favoured burial and preservation of diverse metazoan remains. Pyritized remains of colonial sulphur bacteria are scarce in both areas with shallow-water marine conditions.

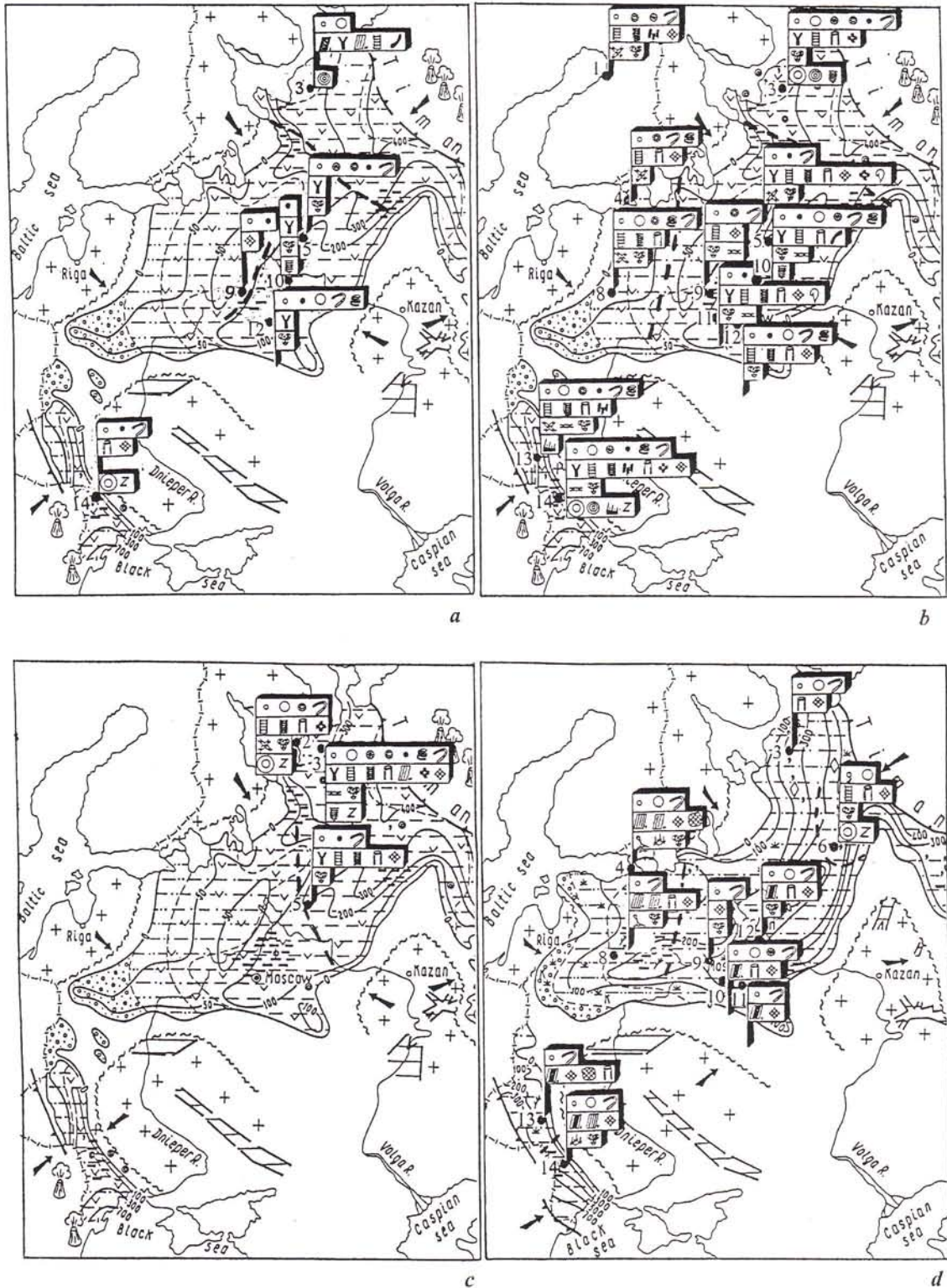
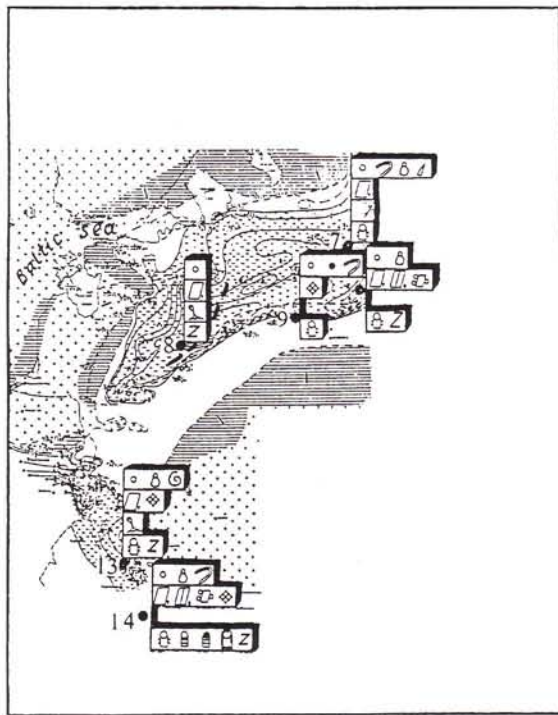
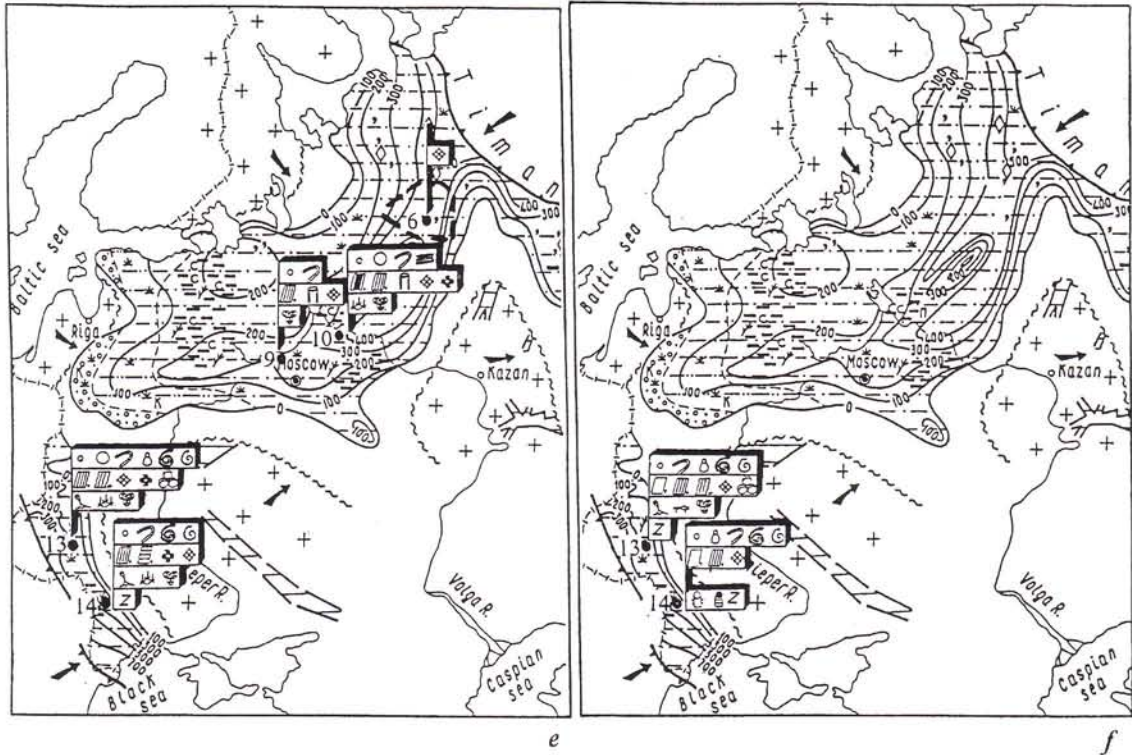


Fig. 2 - Maps of distribution of major ecological groups of organisms constructed for seven time-slices of the Late Vendian of the Russian Platform: a - Early Gavrilov-Yam time; b - Late Gavrilov-Yam-Early Nepeitsyno time; c - Late Nepeitsyno-Makarjev time; d - Lyubim time; e - Reshma time; f - Early Rovno time; g - Late Rovno time. Key localities: 1 - Finland Hailuato no. 1 & 2, and Taivalkoski no. 5 bore-holes (see text for references); 2 - outcrops of White Sea Winter Coast; 3 - no. 775 & 776 bore-holes of 17th Expedition of Commercial Amalgamation "Nevskgeologia"; 4 - outcrop pit C-1 of Leningrad Flood-Protection System, and C-270 bore-hole of Commercial Amalgamation "Sevzapgeologia" on Kotlin island; 5 - Soligalich no. 1 bore-hole; 6 - Kotlas no. 1 bore-hole; 7 - Lezha no. 1 bore-hole; 8 - Nevel' bore-hole; 9 - Redkino bore-hole; 10 - Gavrilov Yam no. 1-5 bore-holes; 11 - Moscow Hydrogeological P-4, P-7 & P-9 bore-holes; 12 - Pavlovsky Posad no. 1 bore-hole; 13 - no. 1512, 1547 & 1562 bore-holes of Rovno Geological-Prospecting Expedition of Commercial Amalgamation "Sevukrgologia"; 14 - outcrops in Podolia on the Dniester River. Symbols on flags: 1-10 - plankton: 1-2 - solitary coccoidal: 1 - microplankters (diameter 50-500 mkm), 2 - mesoplankters (0.5-5 mm); 3-4 - colonial coccoidal: 3 - *Symplassosphaeridium*, 4 - *Tynnina*; 5 - disk-like bodies of sapropel-like matter (= *Spumosina*); 6-8 - filamentous cyanobacteria: 6 - solitary straight and curved, 7 - colonial, 8 - helicoidal *Volyniella*; 9 - vase-shaped microfossils *Teophipolia*; 10-11 - chitinous spirals of



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Cochleatina: 10 - *C. canilovica*, 11 - *C. rara*; 12 - *Ceratophyton*; 13-31 - phytobenthos: 13-20 - macroscopic ribbon-shaped algae: 13 - ancient *Vendotaenia*-like forms (yet undescribed), 14 - *Aataenia*, 15 - *Vendotaenia*, 16 - *Kanilovia*, 17 - *Tyrasotaenia*, 18 - *Dvinia*, 19 - cuticular tubes, 20 - *Vanavarataenia*; 21-24 - problematics: 21 - *Caudina*, 22 - *Chuarina*, 23 - non cyanobacterial tubular sheaths, 24 - *Tawuia*; 25 - dendroid filamentous alga *Eoholynia*, 26-27 - tangle-forming filamentous algae: 26 - *Striatella*, 27 - *Palaeolyngbya*; 28 - colonial helicoidal filamentous cyanobacteria *Obruchevella*; 29-31 - mat-forming filamentous cyanobacteria: 29 - unitrichomal oscillarian filaments, 30 - polytrichomal filaments, 31 - filaments with colonial mucus; 32-37 - destructors: 32 - chytridiomycetes fungi *Vendomyces*, 33-34 - actinomycetes: 33 - *Primoflagella*, 34 - new undescribed form; 35-37 - sulphur bacteria: 35 - colonial coccoidal, 36 - solitary filamentous straight *Zinkovioides* and helicoidal *Spirilliopsis*, 37 - mats of *Zinkovioides*; 38-46 - consumers: 38 - Ediacara fauna, 39 - *Redkinia*, 40 - *Beltanelloides*, 41 - *Saarina*, 42 - trace-fossils; 43-46 - Sabellitidae: 43 - *Sabellidites*, 44 - *Parasabellidites*, 45 - *Sokoloviina*, 46 - undescribed small smooth forms. Dashed lines separate zones of paleobasins. Legend for paleogeographic environments for Fig. 2, a-f see The Vendian System (1990, Vol. 2, fig. 11), and for Fig. 2, g, see Keller & Rozanov (1980, fig. 3, 6).

Stage 2 (Fig. 2, b).

During Late Gavrilov-Yam and Early Nepeitsyno time the transgression reached its maximum. Fine clayish sediments were deposited everywhere in the basin.

Normal marine conditions prevailed on the northeast part of the platform. Diverse plankton lived there, the tangle-forming filamentous eukaryote-like and eukaryotic size algae *Striatella* and *Palaeolyngbya* domi-

nated the phytobenthos, ancient ribbon-shaped *Vendotaenia*-like forms disappeared, and cyanobacterial vegetation was not abundant. Animals occur as Ediacara fauna and *Saarina*. Colonial sulphur bacteria were the main destructors.

An approximately similar composition of plankton and phytobenthos is observed at the center of the platform, but consumer composition is markedly depleted. Only *Saarina* is known in some localities and

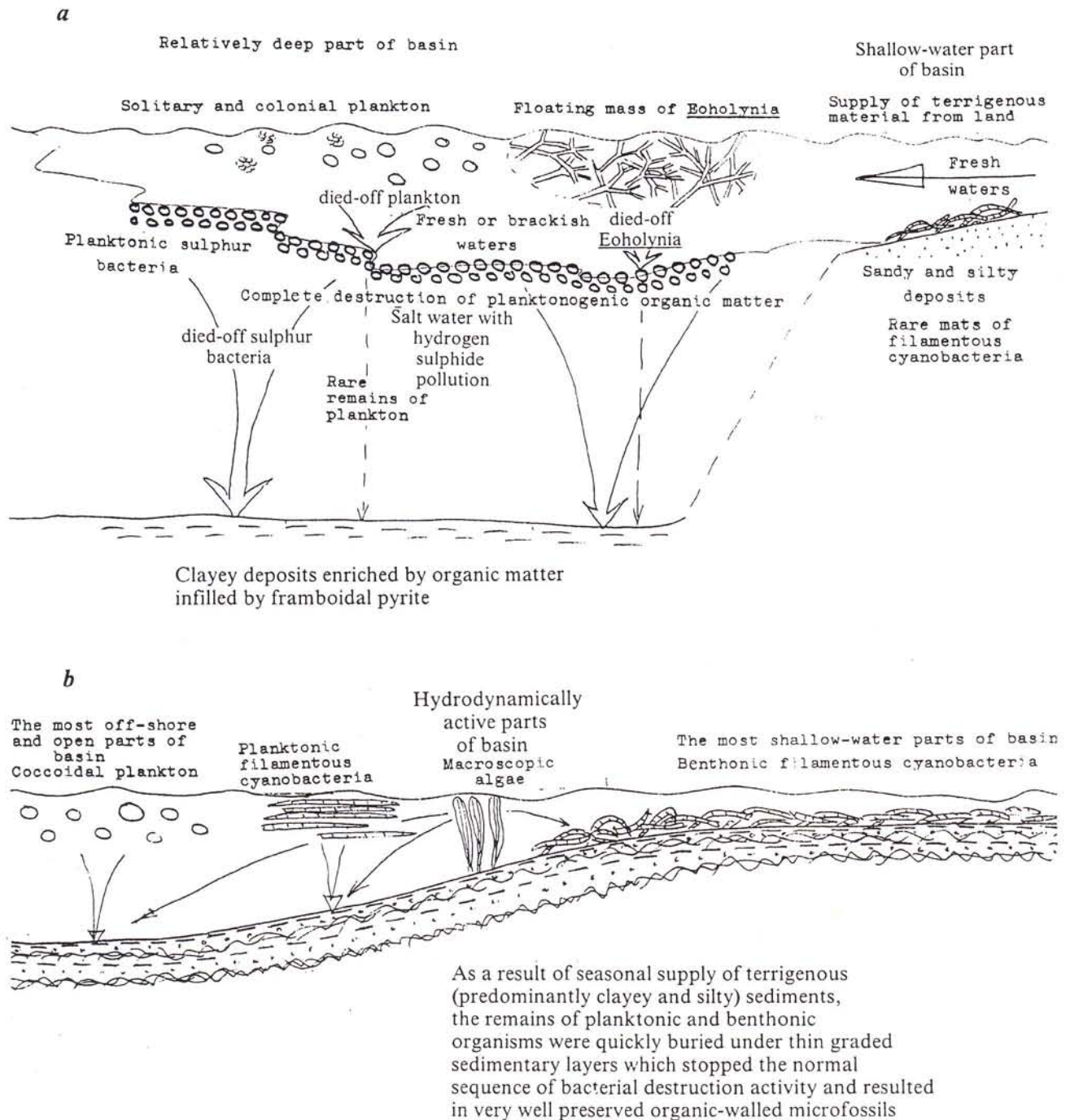


Fig. 3 - Reconstructions of environmental and ecological conditions and populations for central parts of the Russian Platform for: a - Early Gavrilov-Yam time, b - Reshma time.

jaws of *Redkinia* Sokolov, 1977 have been found at one locality at the south-east of this area (Nepeitsyno borehole; however, the composition of the plankton, phyto-benthos and destructors is not indicated on the map because was not investigated for this locality). It is the lack of consumers that possibly accounts for the appearance of a new kind of destructor: the filamentous sulphur bacteria *Zinkovioides* Hermann, 1986. The latter is morphologically similar to extant Beggiatoaceae, lying flat on the bottom detritus (Burzin, 1993b, 1995a).

At the west of the platform, plankton composition remained the same as in the center and northeast parts, but the composition of the phytobenthos was enriched by the appearance of a new kind of cyanobacterial vegetation: tangles of helicoidal filamentous form *Obruchevella* Reitlinger, 1948 emend. Burzin, 1995. Mats of the filamentous sulphur bacteria *Zinkovioides* covered some areas of the bottom surface where algal detritus and planktonic remains were concentrated, and the solitary helicoidal form *Spirilliopsis* Burzin, 1995 grew there as well. The local mass development of these destructors in the west can be explained both in terms of a lack of consumer in this area, and much lower rates of sedimentation. As a result, organic remains occurred on the seafloor (or in the uppermost layer of sediments) for a long period of time (possibly a season?) (Burzin, 1993b). South of this area, animals of the Ediacara fauna and *Redkinia*-bearing organisms appeared again in the basin.

Stage 3 (Fig. 2, c).

During Late Nepeitsyno and Makarjev times, the area of the basin was reduced, and deposits of this age are only known from the east of the central and the northeast parts of platform. Normal marine conditions occurred throughout the area, but the Ediacara fauna is known predominantly from shallow-water facies where event sedimentation favoured burial of soft-bodied organisms. No significant changes in plankton and phyto-benthos composition took place, but the distribution of mats of filamentous sulphur bacteria *Zinkovioides* switched to the east of the basin, where they were developed on algal detritus and metazoan remains during periods of low sedimentation rates.

Stage 4 (Fig. 2, d).

During Lyubim time (Late Vendian, the Early Kotlin Horizon) waters again covered the area with extension nearly equal to the earlier Redkinian basin at the maximum of the transgression. But there are lithological and geochemical data, such as lamination, lack of pyrite and glauconite and presence of siderite, absorbed ion complexes, etc. (Pirrus, 1986), that together with virtual

lack of Ediacara-type remains and trace-fossils (except at the northeast corner of the platform), that indicate that the basin had no, or limited connection with the open sea and had abnormal salinity conditions. Considering the siliciclastic composition of the sediments, the interpretation of a humid climate, and the mid-high latitudinal position of the basin during the Vendian (The Vendian System, 1990), it would appear reasonable to suppose that the ingress of large volume of fresh waters into the basin resulted in freshening its waters. Marine environments were only preserved to the northeast corner of the platform, where Redkinian-type tangles of the filamentous alga *Striatella*, Ediacara-type soft-bodied metazoans, and trace-fossils are known. Basin population was essentially different for the rest of the area (Burzin, 1990). Tangles of filamentous eukaryote-like and eukaryotic size algae were absolutely lacking. Cyanobacterial mat-like communities became a dominant kind of benthonic vegetation supplemented by oligotaxonic bushes of the ribbon-shaped macroscopic algae *Aataenia* Gnilovskaya, 1976 in the center and southwest of the platform, and *Vendotaenia* Gnilovskaya, 1971 in the west, northwest, and extreme southwest of the platform. Colonial coccoidal forms and the solitary helicoidal filamentous form *Volyniella* Assejeva, 1974 emend. Burzin, 1995 are lacking in basin plankton population. Radically new kinds of destructors appeared in the west of the platform like the aquatic chytridiomycete fungus *Vendomyces* Burzin, 1993 and the actinomycete *Primoflagella* Gnilovskaya, 1979, which grew on algal detritus (Burzin, 1993a, b). Colonial sulphur bacteria are known only from remains of mats and from sapropel-like films, filamentous sulphur bacteria are absolutely lacking.

Stage 5 (Fig. 2, e).

During Reshma time the previously unified non-marine basin (it can be referred to as a sea-lake) broke into poorly connected or isolated parts. Thin gray-colored layers observed within red-colored and, possibly, continental deposits at the center of the platform reflect short-term episodes of sea-lake environment, inhabited by benthonic cyanobacterial mat-like communities in coastal and mostly shallow-water conditions. Oligotaxonic bushes of the ribbon-shaped macroscopic alga *Vendotaenia* developed in hydrodynamically more active conditions, whilst solitary coccoidal and filamentous plankters flourished in open spaces of the basin (Fig. 3, b). Destructors were represented by colonial sulphur bacteria in mats and sapropel-like films, and the actinomycete *Primoflagella* on algal detritus. The northeast part of the basin evolved in lagoons, populated by cyanobacterial communities with oscillatorian forms dominant, and rare plankters.

The southwest of the platform was characterized by stable sea-lake conditions. Oligotaxonic bushes of *Vendotaenia* and new alga *Kanilovia* Istchenko, 1983 flourished in this zone. *Kanilovia* thallus carried chitinous spirals of *Cochleatina* Assejeva, 1983 emend. Burzin, 1995 which, possibly, served for reproduction under subaerial conditions (Burzin, 1995b). Destructors were represented by forms known from the center of the platform, and the chitridiomycete *Vendomycetes* continued to exist. Trace-fossils *Harlaniella podolica* Sokolov, 1972 are known from this area.

Stage 6 (Fig. 2, f).

During Early Rovno time (Late Vendian or ?Early Cambrian, the Rovno Horizon) sedimentation only continued at the southwest side of the platform. Changes in population composition of the sea-lake involved appearance of the ribbon-shaped macroscopic alga *Tyrasotaenia* Gnilovskaya, 1971 formed oligotaxonic bushes and disappearance of mesoplankters (diameter 0.5 - 5 mm), as well as wider distribution of trace-fossils and the appearance on the Dniester river (Podolia) of the oldest representatives of true Sabelliditidae, *Sokoloviina* Kirjanov, 1968.

Stage 7 (Fig. 2, g).

During Late Rovno time, a new marine transgression started, but the area of the basin was significantly smaller than the one of the earlier Redkinian basin. Similar environments were established over nearly the entire territory of the basin, as indicated by compositional and wide distributional resemblance of oligotaxonic bushes of the ribbon-shaped macroscopic algae *Tyrasotaenia*, *Dvinia* Gnilovskaya, 1979 and *Vanavarataenia* Pjatiletov, 1985, as well as almost universal distribution of *Sokoloviina* except in the west of the platform (Nevel' borehole). Different genera and species of not figured and described Sabelliditidae are indicated in the list of fossils from Podolia on the Dniester River (Velikanov, 1990).

During Late Rovno time the fossil record became inadequate to allow community composition, as in the case of destructors (chitridiomycetes fungi), which are known only from the west part of the platform, while for the rest of the basin the remains of this important ecological group are obscure. Plankton remains became rare and of low diversity.

During Lontova time (Early Cambrian, ? Tommotan Stage) inadequacy of the fossil record actually increased: remains of benthonic algae become rare, plankton diversity is further decreased, and there are no data on destructors, so the ecosystem of that age (judging from the fossil record) appears to consist of consumers (Sabelliditidae, *Platysolenites*, *Onuphionella* etc.) alone, as if the latter were the only organisms of that time. Thus, the fossil record is unsuitable for direct analysis of basin populations.

Conclusions.

Close connection between the evolution of algal-microbial communities and basin evolution for the Russian platform is revealed for the Late Vendian. Extension to which the basin was connected with the open sea, salinity, hydrodynamic activity, rates of sedimentation, and presence of animal-consumers were the factors that controlled the communities composition and distribution. The most drastic changes in this evolution were due to basin isolation from the open sea and assumed freshening. Under these conditions, changes in dominant benthonic vegetation and destructors occurred. Vendian/Cambrian ecosystem changes were related to increasing of consumer activity, and the latter caused bias of the fossil record.

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