

Spores, Pollen, and Organic-Walled Phytoplankton from Neogene Deposits of the Zheleznyi Rog Reference Section (Taman' Peninsula)

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Abstract—Ten spore-and-pollen assemblages and nine phytoplankton assemblages (dinocysts, green algae, acritarchs) are distinguished in upper Sarmatian–lower Kimmerian deposits of the reference section situated in the Zheleznyi Rog area of the Black Sea region. Palynological spectra of two types (forest and forest–steppe) were found to alternate throughout the section. Their composition and structure reflect climatic fluctuations, primarily the humidity changes. During humid phases, conifer (*Pinus*, Taxodiaceae) and mixed broad-leaved (*Carya*, *Ulmus*, *Quercus*) forests dominated, whereas xerophilous herbaceous–fruticose vegetation (Chenopodiaceae, Artemisia, Gramineae) prevailed during the more arid phases. A temperature decrease, most considerable in the studied stratigraphic interval, is recorded in the early Kimmerian that is evident from the increased percentage of *Sphagnum* spores and *Betula* and Ericaceae pollen in the spectra. The decrease did not exceed however thermal parameters characteristic of the warm-temperate climate and did not change it. Most significant changes in assemblages of the organic-walled phytoplankton are distinguished at two levels: in the lowermost and uppermost Pontian. The Pontian assemblage of organic-walled phytoplankton taxa *Galeacysta etrusca*, "*Gonyaulax digitalis*," *Spiniferites bentorii* and peculiar *Impagidinium*, is found to appear 8–10 m above the top of coupled diatomite layer, along which most geologists draw the boundary between the Maeotian and Pontian in the section. The assemblage is correlative with the dinocyst association from an upper part of the Messinian deposits in Italy (Lago Mare facies). In addition to taxa mentioned above, new forms, which are tentatively referred to the *Komewuia* genus, appear in the organic-walled phytoplankton assemblage of the upper Pontian and lower Kimmerian deposits. Data on salinity changes in paleobasins are discussed as well.

Key words: Black Sea region, Taman Peninsula, Zheleznyi Rog section, Sarmatian, Maeotian, Pontian, spores, pollen, dinocysts.

INTRODUCTION

Cape Zheleznyi Rog is situated on the southern (Black Sea side) coast of the Taman Peninsula. It is the site of one reference section in the northeastern Black Sea region (Fig. 1), which has been used along with others to elaborate the palyno-climatostratigraphy and regional Neogene schemes based on organic-walled phytoplankton at the Laboratory of Paleofloristics, Geological Institute RAS. The comprehensive analysis of data on palynomorphs and phytoplankton can be used to reconstruct simultaneously parameters of a basin and surrounding land, to trace dynamics of their evolution with time, to reveal synchronism and interactions of various events, and to correlate them with events in other parts of the Paratethys and Mediterranean region.

The organic-walled phytoplankton (dinocysts, green algae, acritarchs, and others) has been used in the Upper Cenozoic stratigraphy during recent decades, since the 1980s. The group is proved to be applicable for examining deposits of oceanic areas, for which zonal schemes elaborated on this basis are widely

usable in practice (Williams and Bujak, 1985; Bujak and Matsuoka, 1986; Mudie *et al.*, 1990; de Verteuil, 1996; and others). In contrast to other plankton groups (nannoplankton, diatoms, and others), the organic-walled phytoplankton inhabits waters of a wide salinity range. Being independent of carbonate and silica content, it occurs in various sedimentary facies that is essential for the effective application of the group in the Upper Cenozoic stratigraphy of epicontinental, partly or completely closed basins with their specific sedimentation environments. The Paratethys (Western and Eastern) and Mediterranean Sea represented this kind of basins in various geochronological time intervals. Despite the long investigation history of studying, correlation of regional stratigraphic subdivisions in these regions is still a principal problem of their Upper Cenozoic stratigraphy.

At present, there is a great demand for elaborating zonal stratigraphic scales based on the organic-walled phytoplankton for the regions mentioned above. Work in this line is now underway, but the progress is not of equal value in different regional areas, because some of

them are under state of acquiring initial data on distribution of these microphytofossils, while in others the local stratigraphic schemes are already elaborated (Baltes, 1971; Sütő-Szentai, 1985, 1989; Ananova *et al.*, 1985; Corradini and Biffi, 1988; Al-Azhani, 1994, and others). The organic-walled phytoplankton is most purposefully studied in the central part of Western Paratethys, especially in Hungary, where a detailed subdivision of Neogene deposits is substantiated (Sütő-Szentai, 1985, 1989) (Table 1). In Eastern Paratethys, the study of the Upper Cenozoic organic-walled phytoplankton is at the initial stage. Ananova *et al.* (1995) reported pioneering data on this group and tried to subdivide the Miocene–Pliocene deposits using data obtained in the Black Sea region, namely in the section between the Kutrya Balka and Cape Panagiya, the southern coast of Taman' Peninsula.

A keen interest to the Zheleznyi Rog section that is located on the same coast 5 km southeastward, between the Pekla Hill (Kruglaya Gora) and Cape Zheleznyi Rog, is understandable, because it is well-studied and often considered as the reference one (Andrusov, 1961b; Popov, 1996; Popov and Zastrozhnov, 1998, and others). It is also significant that data on palynology and phytoplankton can be reliably attached here to the regional stratigraphic scheme elaborated on the basis of molluscan fauna evolution. It should be pointed out as well that Neogene deposits of the Taman' Peninsula, the Zheleznyi Rog section included, are mainly represented, in contrast to other areas of the Black Sea region, by argillaceous facies most favorable for studying both paleontological groups.

Andrusov (1961b) was the first to describe the Zheleznyi Rog section in 1899. Since that time, it attracted a considerable interest, but there is still a number of problems to be solved. The principal one concerns the boundary between Pontian and Maeotian. Andrusov pointed out that it is difficult to establish boundary between these "stages," since the Pontian "Valenciennesia" Clay rests on shales usually barren of molluscan remains (Andrusov, 1961a, p. 295). He described Maeotian deposits of the section (from top downwards) beginning from a thin-laminated clay member that encloses three tripoli interlayers in the upper part and a peculiar white fine-grained layer located a bit lower, resembling sand, and composed of ground volcanic glass. The member is located directly below the last clay layers, which bear small *Paradacna abichi* shells and manganese nodules and are referred to the Pontian (Andrusov, 1961a, p. 295). Thus, Andrusov places the boundary, according to fauna distribution, at the top of the mentioned member. Many of contemporary geologists prefer to place the Pontian–Maeotian boundary at the top of the first reference diatomite (tripoli) interlayers (two are well traceable along strike and third pinches out). In opinion of Yu.O. Gavrilov, it is more natural to displace the boundary 5.5–6.0 m below this level down to a thin (0.1–0.3 m) interlayer of brecciated clay ferruginate in places.

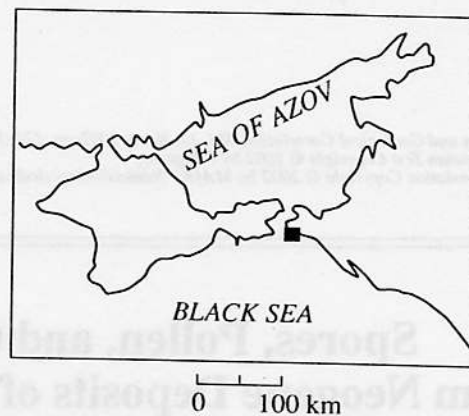


Fig. 1. Geographic location of the Zheleznyi Rog section (black box).

According to Andrusov, Pontian deposits in the Zheleznyi Rog section are about 120 m thick and can be divided in two horizons separated by a layer of *Congeria subrhomboidea* shell detritus that is 0.5–1.0 m thick; in his assessment, the upper horizon is about 40 m thick and the lower about 80 m thick (Andrusov, 1961a, p. 296; Andrusov, 1961b, p. 616). He attributed underlying deposits, without mentioning their thickness, to the Maeotian pointing to presence of *Scrobicularia tellinoides* in their lower part and emphasizing that they resemble the upper Sarmatian shales so much that they could easily be taken for the latter, because the section lacks the Maeotian demarcation horizon of bryozoan limestone (Andrusov, 1961b, p. 642). Nothing

Table 1. Subdivision of Middle–Upper Miocene deposits of Hungary on the basis of organic-walled phytoplankton (Sütő-Szentai, 1989)

Regional stage	Regional substage	Organic-walled phytoplankton zonation	
Pannonian	upper	<i>Mougeoita laetevirens</i>	
		<i>Dinoflagellata–Zignemataceae</i>	
		<i>Spiniferites validus</i>	Subzone <i>Spiniferites validus</i>
	Subzone <i>Spiniferites paradoxus</i>		
	lower	<i>Spiniferites bentorii</i>	Subzone <i>Pontiadinium pecsvaradiensis</i>
			Subzone <i>Spiniferites bentorii oblongus</i>
Subzone <i>Spiniferites bentorii pannonicus</i>			
		<i>Pleurozonaria ultima</i>	
Sarmatian s. str.		<i>Spiniferites bentorii budajcnoensis</i>	

more detailed is reported in his book about subdivision of Maeotian deposits in the Zheleznyi Rog section.

Kimmerian deposits ("ore beds") underlying Pontian strata are described by Andrusov (from the base upward) beginning from a layer of dark brown, highly ferruginate marl (limestone in this work) that underlies a layer of bluish gray clay and next "layer of a very friable bluish gray matter" with yellow ferruginate nodules. All are overlapped by a brown iron ore bed.

FACTUAL MATERIAL

In this study, I use materials (rock samples, section description) cordially donated by S.V. Popov (Paleontological Institute, RAS), and I am very grateful to him.

According to published data (Popov, 1996; Popov and Zastrozhnov, 1998), the Zheleznyi Rog section is about 500 m thick in total. It is composed of upper Sarmatian (130 m), Maeotian (370 m), Pontian (90 m), and lower Kimmerian (10 m) deposits. A brief description of the section (Fig. 2) is presented below.

Sr₃ Member 1: gray calcareous clay alternating with yellow-gray porous limestone of vermicular texture (30 m thick).

Member 2: brown non-calcareous clay with gypsum, jarosite, and volcanic ash; the rock is exposed fragmentarily and resembles the Maikop variety; landslide marks in the lower and upper parts (100 m thick).

M₁ Member 3: gray calcareous clay with interlayers (2–3 m) of non-calcareous clay with jarosite (120 m thick).

M₂ Member 4: brecciated clay or "blocky" olistostrome (2–10 m thick).

Member 5: light gray massive calcareous clay (40 m thick).

Member 6: darker low-calcareous clay with a brownish tint (16 m thick).

Member 7: light gray thin-laminated silty high-calcareous clay, probably diatomaceous (4–5 m thick).

Member 8: light gray to greenish gray calcareous clay, brecciated at the base (23–25 m thick).

Member 9: dark gray clay with a greenish tint (5 m thick).

Member 10: light yellow thin-laminated silicified diatomite with lenses of hard limestone at the base (4.5 m thick).

Member 11: gray calcareous clay with two interlayers of diatomaceous shale and a layer (0.01 m) of gray volcanic ash 20 m above the base (40–50 m thick).

Member 12: gray to greenish gray clay with an interlayer (0.1–0.3 m) of brecciated clay at the base, in places ferruginate. Two diatomite interlayers occur 5.5–6.0 m above the base; the lower one is 0.10–0.13 m thick, and the upper is 0.03–0.06 m thick (7.0–7.5 m thick in total).

P₁ Member 13: dark gray to bluish thin-laminated calcareous clay. First *Limnocardina* appear 3 m above the base and abundant *Paradacna abichi* occur 8 m above the base (11 m thick).

Member 14: gray massive thick-laminated clay with a reference bed of light gray diatomite (0.6 m thick) enclosing many ferruginate interlayers 2.0–2.5 m above the member base (11–12 m thick).

Member 15: dark gray banded silty clay under talus, through which some fragments are visible (13–16 m thick).

Member 16: dark gray clay with a greenish brown tint; the rock is slightly silty and calcareous (10–15 m thick).

Member 17: light to greenish gray, highly calcareous clayey siltstone (4 m thick).

Member 18: greenish gray clay with a brownish tint (2 m thick).

Member 19: Greenish lumpy to amorphous clay with whitish stains of shell detritus (1 m thick).

P₂ Member 20: greenish gray clay overfilled with shells of *Congeria novorossica*, *C. subrhomboides*, and others. The contact surface with the underlying strata is wavy; the upper boundary is of erosion type, distinct owing to coloration (0.35–0.50 m thick).

Member 21: shell detritus varying in coloration from yellowish to light gray (0.15–0.23 m thick).

Member 22: greenish gray to gray clay of banded structure; bands (1–2 cm) are ferruginate, and the lower boundary is uneven (2.4 m thick).

Member 23: dark gray banded calcareous clay with brownish interlayers 0.1–0.5 m thick (9–11 m thick in total).

Member 24: lighter, brownish yellow to gray banded calcareous clay (8 m thick).

Member 25: dark gray compact calcareous clay with ferruginate brick-red interlayers responsible for banded structure (14–15 m thick).

Km₁ Member 26: dark gray limestone with a brownish tint, hard, sideritized, having uneven lower boundary (0.2–0.3 m thick).

Member 27: variegated (tobacco-green to gray) gypsum-bearing clay with ferruginate stains (0.6–0.8 m thick).

Member 28: Oolitic iron ore (3–4 m thick).

Member 29: gray, poorly calcareous clay (7–10 m thick).

It should be pointed out that due to irregular sampling some intervals of the Zheleznyi Rog section are characterized not as detailed as it is desirable. Nevertheless, the results obtained elucidate taxonomic composition of palynological and phytoplankton assemblages in separate stratigraphic units and in the whole range of studied deposits. They reveal as well the dynamic changes and main boundaries of phytoplankton renewals.

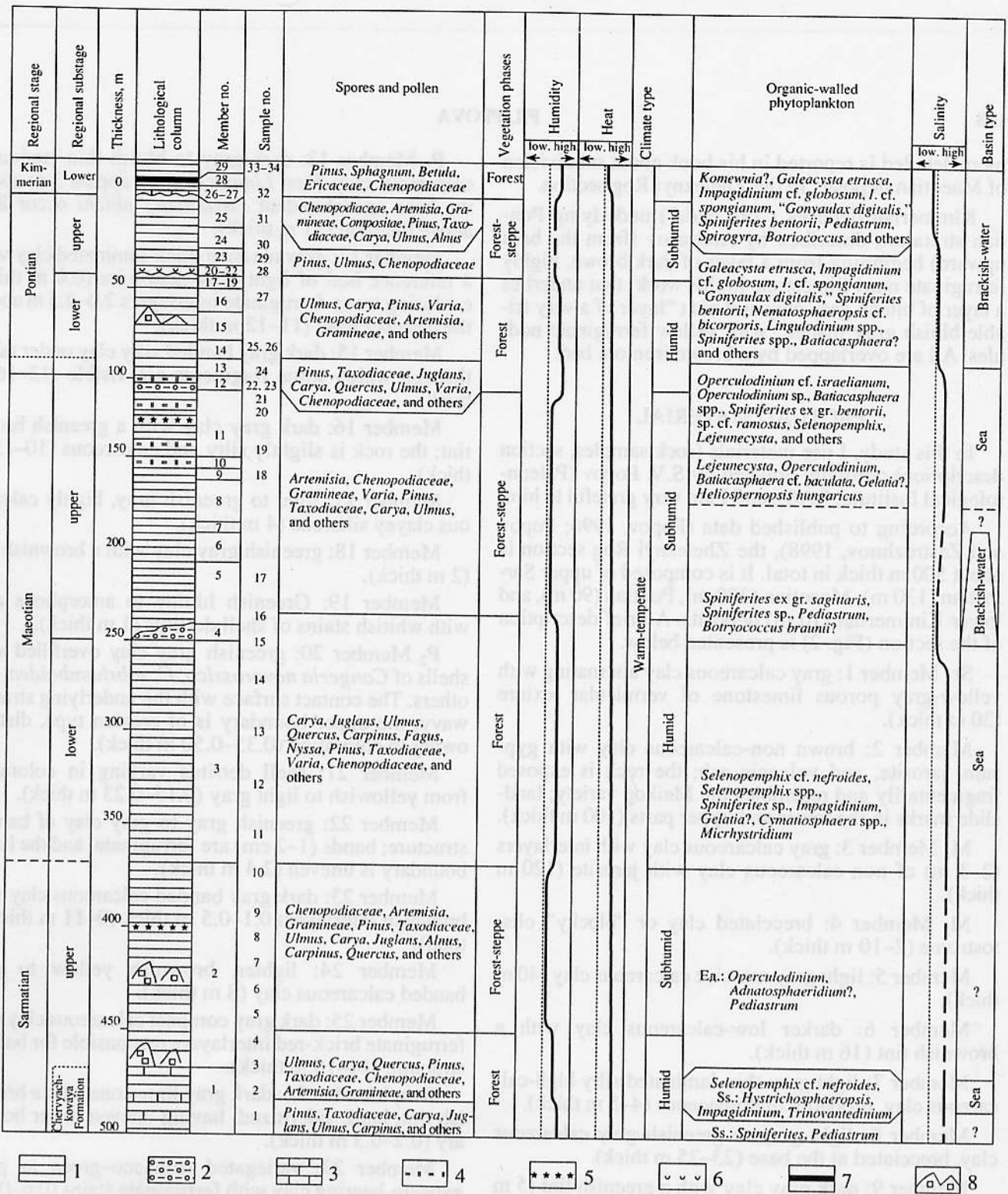


Fig. 2. Lithology and biostratigraphy of Neogene deposits in the Zheleznyi Rog section: (1) clay; (2) brecciated clay; (3) limestone; (4) diatomite; (5) volcanic ash; (6) shell detritus; (7) oolitic iron ore; (8) talus and landslides with fragmentary exposed bedrocks. Abbreviations: (ss) single specimens.

During the Seminar on Reference Neogene Sections of Eastern Paratethys that was held in August, 1998, in the Taman' Peninsula, and in field seasons of 2000–2001, the Zheleznyi Rog section was additionally sampled in more detail by a group of geologists, I belonged to. These samples will be studied in the immediate future in order to complement and verify the data available.

SPORES AND POLLEN

Ten intervals differing in palynological characteristics are distinguished in upper Sarmatian–lower Kimmerian deposits of the Zheleznyi Rog section.

The palynological assemblage from the lowermost part of the section (20 m thick, Sample 1) mostly consists of arboreal pollen; dominant here are gymnosperms: *Pinaceae* (*Pinus* subgen. *Diploxylon*, *Pinus* subgen. *Haploxylon*, *Abies*, *Picea*, single *Cedrus* grains), and *Taxodiaceae*.¹ Pollen of *Juglandaceae* (*Carya*, *Juglans*, *Pterocarya*), *Ulmaceae* (*Ulmus*, *Zelkova*), and *Betulaceae* (*Carpinus*, *Corylus*, *Alnus*, *Betula*) dominate among that of deciduous taxa, whereas pollen of *Moraceae*, *Liquidambar*, *Nyssa*, *Quercus*, *Acer*, *Salix*, *Tilia*, and *Oleacea* is rare. Infrequent pollen of herbaceous plants represents mainly *Chenopodiaceae* and less abundant *Ephedra*, *Artemisia*, *Asteraceae*, *Cichoraceae*, *Gramineae*, *Polygonaceae*, *Cruciferae*, *Umbelliferae*, *Ranunculaceae* and others. Single spores of *Sphagnum*, *Polypodium*, and *Lycopodium* cf. *clavatum* are also present.

Climate during the corresponding interval of the Sarmatian was warm-temperate and humid. Pine–*Taxodiaceae*–elm–hickory forests were widespread.

The dominating role of arboreal pollen is also characteristic of overlying upper Sarmatian deposits about 40 m thick (samples 2–4), where structure of the pollen spectrum slightly changes however. Pollen of coniferous and deciduous species is of equal abundance here, and role of elm and oak pollen increases. *Chenopodiaceae* still dominate among pollen of herbaceous plants, but abundance of *Artemisia* and *Gramineae* increases in this group. Spores are rare, representing *Polypodiaceae* and *Sphagnum*; individual grains belong to *Ophioglossum*, *Osmunda*, *Gleichenia*, *Lycopodium*, and *Pteridium*. Accordingly, climate was less humid as compared to the previous time interval.

In the overlying upper Sarmatian sequence about 70 m thick, the percentage of herbaceous and fruticose pollen sharply increases up more than 50% of the spore-and-pollen assemblage. In this group, *Chenopodiaceae* are dominants, *Artemisia* pollen is common, and abundance of *Gramineae* slightly decreases. Gymnosperms (*Pinus* subgen. *Diploxylon*, *Taxodiaceae*, *Abies*, *Picea*, *Podocarpus*, *Tsuga*) prevail among arboreal taxa. *Ulmaceae* and *Juglandaceae* (*Carya*, *Juglans*,

Pterocarya) are dominant among deciduous forms and associate with less abundant *Betulaceae* (*Alnus*, *Carpinus*, *Betula*) and *Fagaceae* (*Quercus*, *Fagus*). Spores of *Polypodiaceae*, *Sphagnum*, and *Gleichenia* are rare.

At that time, climatic conditions markedly changed towards the higher aridity, and open landscapes occupied the extended areas.

Pollen of arboreal plants again plays a leading role in the lower part of Maeotian deposits (about 120 m thick; samples 11–16), where representatives of broad-leaved *Juglandaceae* (*Carya*, *Juglans*, single grains of *Pterocarya* and *Engelhardtia*) are dominant, elm pollen is somewhat less abundant, pollen grains of oak, hornbeam and beech are common, while *Nyssa* and other forms are frequent. *Pinus* subgen. *Diploxylon* prevailing among gymnosperms coexists with rather abundant *Taxodiaceae*, *Abies*, *Picea*, and with rare grains of *Podocarpus*, *Cedrus*, and *Tsuga* genera. Herbage elements (*Varia*) dominate in the herbaceous–fruticose group, where *Chenopodiaceae* are less abundant. Spores of *Polypodiaceae* and *Sphagnum* are rare. Consequently, climate was more humid during this time interval. Broad-leaved forests of elm–hickory type were widespread, and herbaceous–fruticose community was of a more mesophilic nature.

The upper Maeotian deposits (about 150 m thick; samples 17–23) are characterized by a palynological assemblage with prevailing pollen of herbaceous–fruticose vegetation. *Artemisia* and *Chenopodiaceae* were leading elements of the latter and associated with less abundant grasses and herbage. *Pinus* subgen. *Diploxylon* prevails in the arboreal group, where *Taxodiaceae*, *Carya*, and *Ulmus* are fairly abundant, commonly associated with *Quercus*, *Fagus*, *Juglans*, *Carpinus*, *Alnus*, *Picea*, *Tsuga*, and others. Spores of *Polypodiaceae* and *Sphagnum* are rare. Climate aridity grew in the late Maeotian, and widened areas of open landscape were occupied by steppe plant groupings, which included wormwood, *Chenopodiaceae*, grasses, and other elements.

The arboreal pollen with prevailing gymnosperm taxa (*Pinus* subgen. *Diploxylon*, *Taxodiaceae*, *Picea*, *Abies*, *Pinus* subgen. *Haploxylon*, *Sciadopitys*, *Tsuga*, *Cedrus*, *Podocarpus*, and others) again becomes dominating in spectra of lower Pontian deposits (about 10 m thick; samples 23, 24). At this level, *Juglandaceae* (*Juglans*, *Carya*, *Pterocarya*), oak, and elm prevail among deciduous plants, whereas alder, hornbeam, filbert, *Zelkova*, maple, holly, sweet gum, tupelo, linden, and others are less abundant. Herbaceous and fruticose pollen represents herbage, *Chenopodiaceae*, *Artemisia*, grasses, and others. Amount of *Sphagnum* spores sharply increases against the background of common *Polypodiaceae* and *Lycopodium*. Climate of this phase was more humid than before. Pine and mixed broad-leaved forests, which included hazel nut, hickory, oak, elm, and others, dominated in the vegetation cover; swamp cypress forests grew in places.

¹ Underlined are prevailing taxa.

The palynological assemblage with prevailing arboreal pollen is also characteristic of the overlying lower Pontian deposits (about 50 m thick; samples 25–27). Leading elements of this assemblage are broad-leaved taxa *Ulmus*, Juglandaceae (*Carya*, *Pterocarya*), and *Quercus*. *Pinus* subgen. *Diploxylon* dominates among coniferous elements and associates with Taxodiaceae and *Abies*. The herbaceous–fruticose group includes herbage, Chenopodiaceae, wormwood, and grasses. Rare spores belong to *Sphagnum* and Polypodiaceae. As compared to the early Pontian, climate was less humid. Broad-leaved oak–hickory–elm forests were widespread.

Deposits of the uppermost Pontian, (about 25 m thick; samples 28–30), except for the top bed, are characterized by a low percentage of spores and pollen. *Pinus* subgen. *Diploxylon* is dominant taxon, whereas *Ulmus* and Chenopodiaceae are less abundant, and Taxodiaceae, *Abies*, *Tsuga*, *Picea*, *Carya*, *Pterocarya*, *Juglans*, *Quercus*, *Artemisia*, and others are accessory. The assemblage likely indicates the increasing aridity of climate in the second half of the Pontian.

The percentage of spores and pollen slightly increases in the topmost Pontian bed (10–15 m thick; Sample 31). Arboreal and herbaceous–fruticose pollen taxa occur here in equal proportions. The herbaceous–fruticose pollen represents Chenopodiaceae, *Artemisia*, Gramineae, Compositae, and others. *Pinus* subgen. *Diploxylon* dominates among arboreal taxa and coexists with less abundant Taxodiaceae, *Carya*, *Ulmus*, *Alnus*, and with common *Pinus* subgen. *Haploxylon*, *Abies*, *Tsuga*, *Picea*, *Pterocarya*, *Juglans*, *Quercus*, *Salix*, *Ilex*, *Carpinus*, *Betula*, and others. Polypodiaceae are main sporogenous plants, whereas spores of *Sphagnum*, *Pteris*, and *Gleichenia* are found as single specimens.

The prevalence of pollen *Pinus* subgen. *Diploxylon* is characteristic of the Kimmerian palynological spectra (samples 32–34). It is also remarkable that the percentage of *Betula* pollen increases at this level, whereas that of Taxodiaceae decreases. Grains of other taxa are rare, representing *Picea*, *Abies*, *Carya*, *Juglans*, *Quercus*, *Fagus*, *Alnus*, *Ulmus*, and others. Chenopodiaceae dominate in the herbaceous–fruticose group, where *Artemisia* and Gramineae are less abundant. The Ericaceae pollen is frequently occurring. Percentage of *Sphagnum* spores sharply increases in this interval against the background of *Lycopodium*, Polypodiaceae, and *Pteris* spores commonly present.

The increased percentage of *Betula* pollen and *Sphagnum* spores, along with the sharp decrease of Taxodiaceae and broad-leaved species, and presence of Ericaceae pollen may be considered as indications of certain cooling and relatively high humidity, although this assumption must be supported by additional data.

ORGANIC-WALLED PHYTOPLANKTON

Phytoplankton has not been found in the upper Sarmatian interval (about 130 m thick; samples 1, 3–10) of the Zheleznyi Rog section. Only single dinocysts *Spiniferites*, *Operculodinium*, *Adnatosphaeridium*? and green algae *Pediastrum* were encountered. A level with *Selenopemphix* cf. *nephroides* associated with single specimens of *Hystrichosphaeropsis*, *Impagidinium*, *Trinovantedinium*, and infrequent *Pediastrum* is distinguished in the uppermost parts of the “Chervyachkovaya Formation” (about 10 m thick; Sample 2).

As compared to upper Sarmatian deposits, Maeotian beds are richer in phytoplankton. Proximate cysts *Selenopemphix* cf. *nephroides* and *Selenopemphix* spp. dominate in the lower Maeotian interval (about 120 m thick; samples 11–15), where proximochorate cysts, e.g., smaller stunted *Spiniferites* sp. and *Impagidinium*? are also common. Green algae *Gelatia*?, *Cymatiosphaera* spp. are abundant here, and acritarchs *Micrhystridium* sp. are also present.

The lower part of the upper Maeotian deposits (about 80 m thick; samples 16, 17) yields the phytoplankton assemblages of abundant small stunted *Spiniferites* ex. gr. *sagittarius* with reduced spines, *Spiniferites* spp., and rare *Impagidinium*. Other forms frequently occurring here are *Pediastrum* and *Botryococcus braunii*?

Another assemblage from the overlying interval (30–35 m; samples 18, 19) consists of rare *Lejeunecysta* spp. and single representatives of *Operculodinium* sp. and *Batiacasphaera* cf. *baculata*. Green algae *Gelatia*? are abundant here, and *Heliospermopsis hungaricus* is encountered.

The upper Maeotian–lower Pontian boundary interval (40 m thick in total; samples 20–24) is characterized by the assemblage, in which larger *Operculodinium* cf. *israelianum* dominate and associate with less abundant *Operculodinium* sp., *Batiacasphaera micropapillata*?, *B. sphaerica*?, and *B. baculata*?. Dwarfed *Spiniferites* cf. *bentorii*, *S.* cf. *ramosus*, *S.* cf. *cingulatus*, *Spiniferites* spp., *Cleistosphaeridium*?, *Lingulodinium*, *Selenopemphix* sp., *Lejeunecysta* sp., *Impagidinium*, and *Achomosphaera* ex gr. *sagenata*? are common in this interval. Other taxa abundant here are green algae *Gelatia*? and *Cymatiosphaera*. *Pediastrum*, *Botryococcus*, *Micrhystridium* sp. are less abundant, while *Pterospermopsis*, *Heliospermopsis*, and *Spirogira* with ornamented surface are found as single specimens.

The phytoplankton assemblage from overlying layers of lower Pontian deposits (Member 14) is remarkably different. It marks the appearance level of *Galeacysta etrusca* and of a new group of peculiarly sculptured *Impagidinium* forms (*I.* cf. *spongianum*, *I.* cf. *globosum*, *Impagidinium* sp.), which have reduced sutural crests (septae). The last group dominates in phytoplankton assemblages of the whole Pontian interval (about 65 m thick; samples 25–30), except for its lowermost (8–10 m thick) and uppermost parts. Associated

Plate I. Organic-walled phytoplankton from Neogene deposits of the Zheleznyi Rog section (magnification $\times 750$ for figures 1–3, 5–10, and $\times 500$ for figure 4)

(1, 2) *Impagidinium* cf. *globosum* Sütő-Szentai, 1985, Sample 25, Pontian; (3) *Impagidinium* cf. *spongianum* Sütő-Szentai, 1985, Sample 25, Pontian; (4) *Gonyaulax digitalis* (Pouchet, 1883) Kofoed, 1911 (see Footnote 2), Sample 25, Pontian; (5) *Spiniferites bentorii* (Rossignol, 1964) Wall and Dale, 1970, Sample 29, Pontian; (6) *Spiniferites* cf. *ramosus* (Ehrenberg, 1838) Mantell, 1854, Sample 30, Pontian; (7) *Spiniferites* sp., Sample 15, Maeotian; (8) *Spiniferites* sp., Sample 30, Pontian; (9) *Galeacysta etrusca* Corradini and Biffi, 1988, Sample 32, Kimmerian; (10) *Galeacysta etrusca* Corradini and Biffi, 1988, Sample 25, Pontian.

taxa are "*Gonyaulax digitalis*,"² *Spiniferites bentorii*, *Nematosphaeropsis* (including *N. cf. bicorporis*, *Nematosphaeropsis* sp.), *Lingulodinium* spp., various *Spiniferites* forms (*S. ex gr. cornutus*, *S. ex gr. elongatus*, *S. ex gr. perforata*, *S. ex gr. ramosus*, *S. aff. frigidus*), and *Batiacasphaera?* species (*B. sphaerica?*, *B. micropapillata?*, *B. baculata?*). *Selenopemphix*, *Adnatosphaeridium* cf. *multispinosum*, *Hystrichokolpoma* spp., *Impagidinium* cf. *pallidum*, *Cannosphaeropsis?*, *Cerebrocysta?*, *Achomosphaera*, *Apteodinium*, *Hystrichosphaeridium*, *Hystrichosphaeropsis* sp., *Operculodinium* are present as single specimens. *Pediastrum* occurs frequently in contrast to less common smooth *Spirogyra*.

In the upper Pontian deposits (about 15 m thick; Sample 31), the phytoplankton assemblage again substantially changes in composition. New taxa appearing here are similar to "*Diconodinium inequicornutum*"³ from Pontian deposits of Hungary (Baltes, 1971) and to "*Pontiadinium*"⁴ forms from the mid-Pannonian boundary deposits of Hungary (Sütő-Szentai, 1985). This group of taxa is characteristic, along with *Galeacysta etrusca* and peculiar *Impagidinium* forms, of the overlying Kimmerian deposits (about 10 m thick; samples 32–34). The assemblage of the late Pontian–early Kimmerian time also includes "*Gonyaulax digitalis*," *Spiniferites bentorii*, *Nematosphaeropsis* sp., *Spiniferites ex gr. cornutus*, *S. ramosus*, *Spiniferites* spp., *Hystrichosphaeropsis*, *Batiacasphaera?*, *Lingulodinium*, *Hystrichosphaeridium*, *Achomosphaera?*, *Leptodinium?*, *Apteodinium*. Representatives of *Pediastrum*, *Spirogyra* (ornamented and smooth morphotypes of the latter), and *Botryococcus*.

DISCUSSION

As a result of palynological study, ten palynological assemblages have been established in upper Sarmatian–lower Kimmerian deposits of the Zheleznyi Rog section.

² Name *Gonyaulax digitalis* is used to denote a recent dinoflagellate species in its mobile stage, and it is not legitimate to apply this name for morphologically similar fossil cysts, that is why it is used with quotation marks. The cyst species under consideration likely bear no relation to *Gonyaulax digitalis* at all, and *Spiniferites bentorii* can be a fossil analog of the latter (Dodge, 1989).

³ At present, this species is attributed to the genus *Komewuia* (Chen, 1982; Williams *et al.*, 1998).

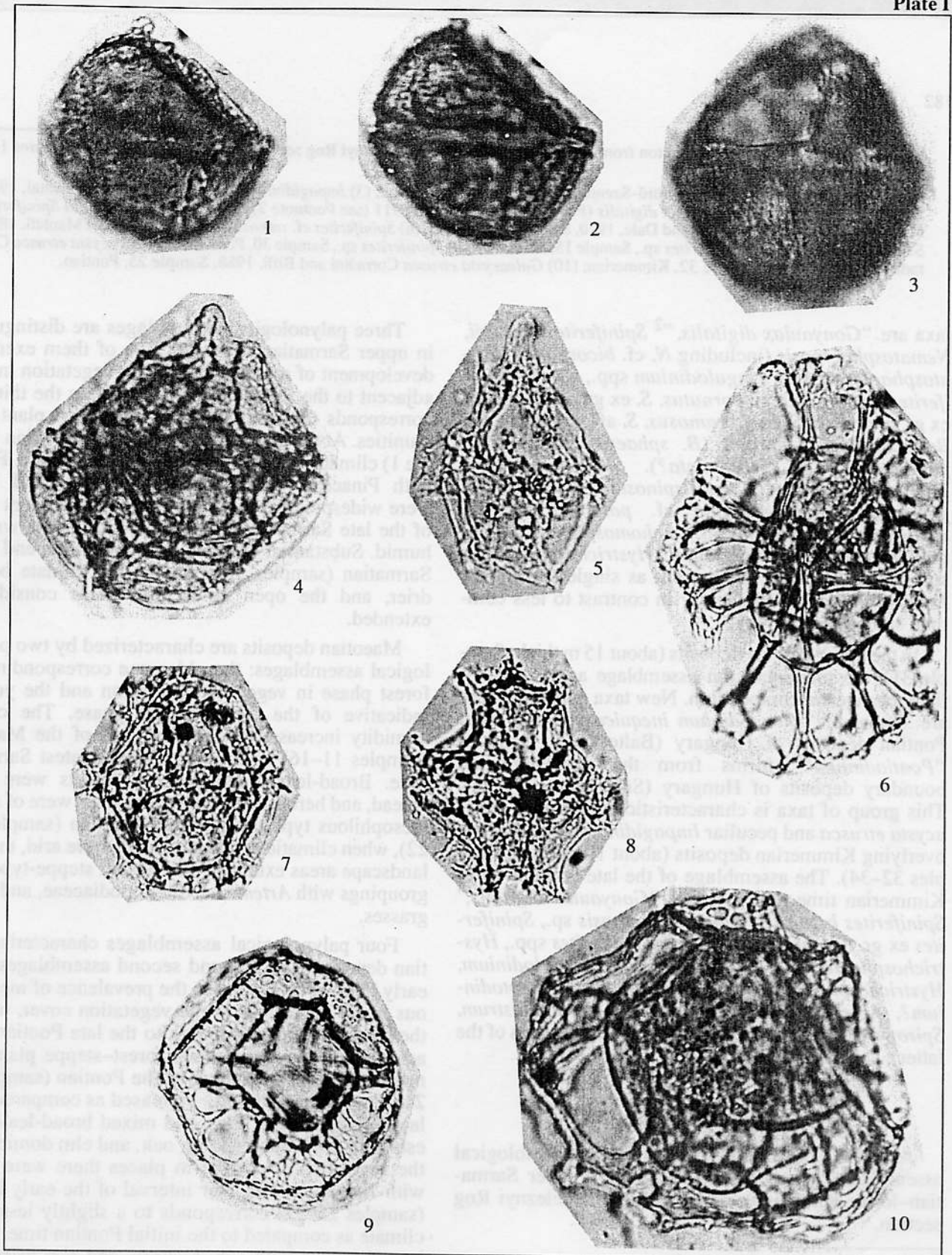
⁴ "*Pontiadinium*" is recognized as a later synonym of *Komewuia* (Chen, 1982; Williams *et al.*, 1998).

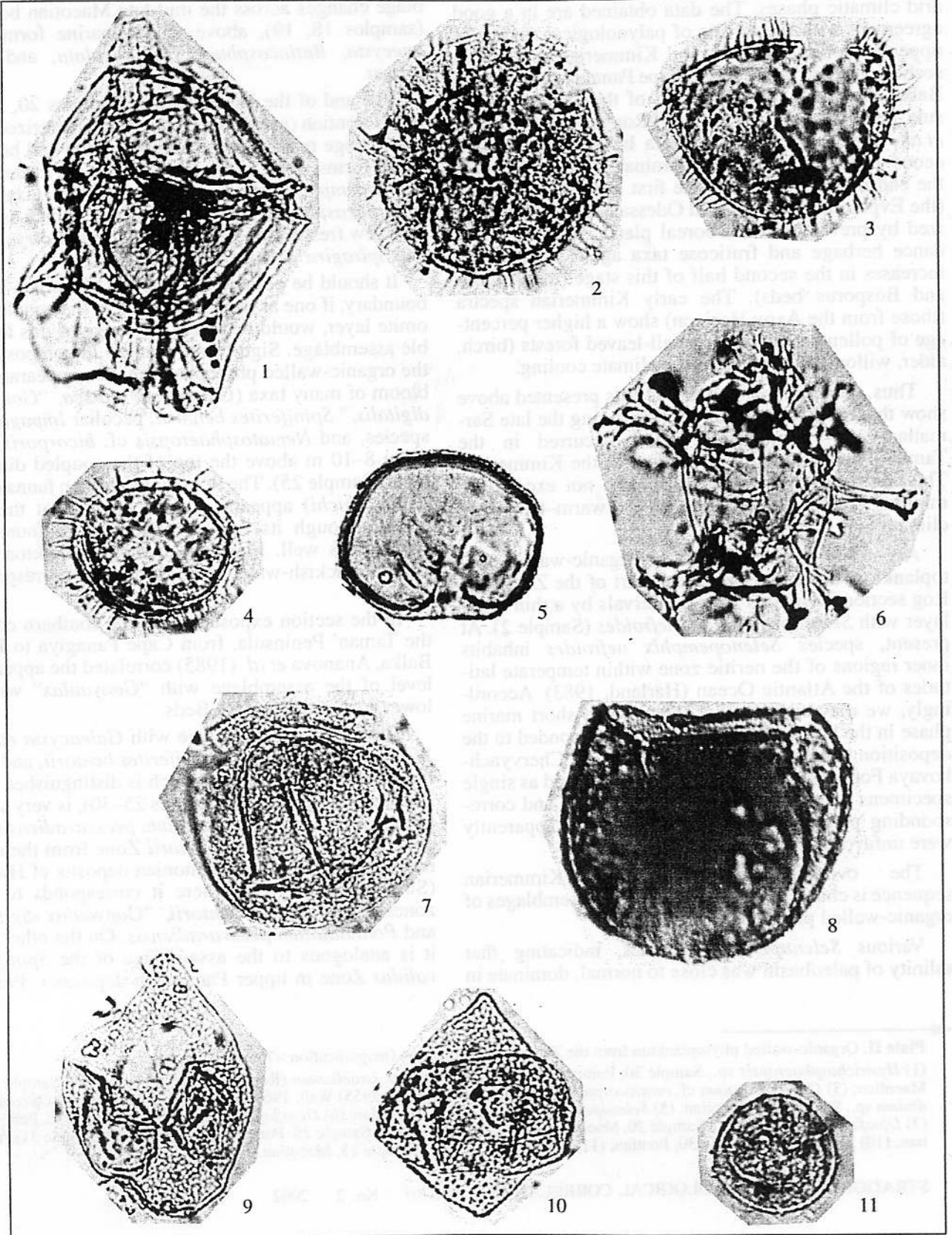
Three palynological assemblages are distinguished in upper Sarmatian deposits. Two of them exemplify development of mesophilous forest vegetation in areas adjacent to the Euxinian Basin, whereas the third one corresponds to xerophilous forest–steppe plant communities. At the beginning of the late Sarmatian (Sample 1) climate was warm–temperate and humid. Forests with Pinaceae, Taxodiaceae, Ulmaceae, and *Carya* were widespread at that time. In the subsequent epoch of the late Sarmatian (samples 2–4), climate was less humid. Substantial changes occurred at the end of the Sarmatian (samples 5–10) when the climate became drier, and the open landscapes areas considerably extended.

Maeotian deposits are characterized by two palynological assemblages: the older one corresponding to a forest phase in vegetation evolution and the younger indicative of the forest–steppe phase. The climate humidity increased in the first half of the Maeotian (samples 11–16) as compared to the latest Sarmatian time. Broad-leaved elm–hickory forests were widespread, and herbaceous–fruticose plants were of a more mesophilous type. In the late Maeotian (samples 17–22), when climatic conditions were more arid, the open landscape areas extended and hosted steppe-type plant groupings with *Artemisia*, Chenopodiaceae, and others grasses.

Four palynological assemblages characterize Pontian deposits. The first and second assemblages of the early Pontian time point to the prevalence of mesophilous forest formations in the vegetation cover, whereas the other two, corresponding to the late Pontian, characterize a more xerophilous forest–steppe plant communities. At the beginning of the Pontian (samples 23, 24), the climate humidity increased as compared to the late Maeotian time. Pine and mixed broad-leaved forests with hazel nut, hickory, oak, and elm dominated in the vegetation cover, but in places there were forests with *Taxodium*. The later interval of the early Pontian (samples 25–27) corresponds to a slightly less humid climate as compared to the initial Pontian time. Broad-leaved forests with oak, hickory, and elm were widespread at that time. It is likely that climate was drier in the second half of the Pontian (samples 28–30), and herbaceous–fruticose formations occupied larger areas.

One palynological assemblage of the early Kimmerian time indicates prevalence of arboreal vegetation with dominating pine formations. Judging from the leading role of sphagnum moss, heath, and birch, whereas abundance of *Taxodium* and broad-leaved spe-





cies decreased, the early Kimmerian climate was likely more cold and humid, although this assumption needs to be verified.

Hence, this study revealed alternation of forest and forest-steppe palynological assemblages within the late Sarmatian-early Kimmerian interval and, respectively, the regular change with time of humid and more arid climatic phases. The data obtained are in a good agreement with the results of palynological studies of upper Maeotian, Pontian, and Kimmerian deposits in sections located between the Cape Panagiya and Kutrya Balka along the southern coast of the Taman' Peninsula, southwest of the Zheleznyi Rog section (Ananova *et al.*, 1985). According to data by Ananova, herbaceous-fruticose plants also dominated in vegetation at the end of the Maeotian. The first half of the Pontian (the Evpatoria, Ingulets, and Odessa beds) is characterized by prevalence of arboreal plants, whereas abundance herbage and fruticose taxa again significantly increases in the second half of this stage (the Portafer and Bosphorus beds). The early Kimmerian spectra (those from the Azov Horizon) show a higher percentage of pollen produced by small-leaved forests (birch, alder, willow) that indicates the climate cooling.

Thus, data by Ananova and results presented above show that most substantial cooling during the late Sarmatian-early Kimmerian period occurred in the Taman' Peninsula at the beginning of the Kimmerian. This temperature decrease likely did not exceed the minimal critical value typical of the warm-temperate climate.

According to new data on the organic-walled phytoplankton, the upper Sarmatian part of the Zheleznyi Rog section is divided in two intervals by a thin interlayer with *Selenopemphix cf. nefroides* (Sample 2). At present, species *Selenopemphix nefroides* inhabits inner regions of the neritic zone within temperate latitudes of the Atlantic Ocean (Harland, 1983). Accordingly, we may suggest that there was a short marine phase in the late Sarmatian, which corresponded to the deposition time of uppermost beds of the "Chervyachkovaya Formation." Phytoplankton was found as single specimens below and above this interlayer, and corresponding periods of the upper Sarmatian apparently were unfavorable for its development.

The overlying Maeotian-lower Kimmerian sequence is characterized by six diverse assemblages of organic-walled phytoplankton.

Various *Selenopemphix* species, indicating that salinity of paleobasin was close to normal, dominate in

the lower Maeotian assemblage (samples 11-15). Dwarfed *Spiniferites* species and frequent occurrence of fresh-water phytoplankton (*Pediastrum*, *Botryococcus braunii*?) in the assemblage from the lowermost part of upper Maeotian (samples 16, 17) are indicative of a certain freshening at the beginning of the late Maeotian. The taxonomic composition of the assemblage changes across the mid-late Maeotian boundary (samples 18, 19), above which marine forms *Lejeunecysta*, *Batiacasphaera cf. baculata*, and others appear.

The end of the late Maeotian (samples 20, 21) and initial Pontian (samples 22-24) are characterized by the assemblage mainly consisting of marine and brackish-water forms, such as *Operculodinium cf. israelianum*, *Selenopemphix*, *Lejeunecysta*, *Spiniferites*, taxa similar to *Batiacasphaera* species, and others, which associate with few freshwater forms (*Pediastrum*, *Botryococcus*, and *Spirogira* with ornamented surface).

It should be pointed out that the Maeotian-Pontian boundary, if one assumes to trace it in the coupled diatomite layer, would be inside the range of this indivisible assemblage. Significant changes in composition of the organic-walled phytoplankton, i.e., appearance and bloom of many taxa (*Galeacysta etrusca*, "*Gonyaulax digitalis*," *Spiniferites bentorii*, peculiar *Impagidinium* species, and *Nematosphaeropsis cf. bicorporis*), took place 8-10 m above the top of the coupled diatomite layer (Sample 25). The Pontian molluscan fauna (*Paradacna abichi*) appears in mass roughly at the same level, although its first specimens were found 5 m below it as well. Mollusks and phytoplankton populated a brackish-water basin during the corresponding period.

In the section exposed along the southern coast of the Taman' Peninsula, from Cape Panagiya to Kutrya Balka, Ananova *et al.* (1985) correlated the appearance level of the assemblage with "*Gonyaulax*" with the lower part of the Odessa Beds.

The dinocyst assemblage with *Galeacysta etrusca*, "*Gonyaulax digitalis*," *Spiniferites bentorii*, and peculiar *Impagidinium* forms, which is distinguished in the Zheleznyi Rog section (samples 25-30), is very similar to that of the upper *Pontadinium pecsvariensis* Subzone of the *Spiniferites bentorii* Zone from the uppermost part of the lower Pannonian deposits of Hungary (Sütő-Szentai, 1985), where it corresponds to acme zones of *Spiniferites bentorii*, "*Gonyaulax digitalis*," and *Pontadinium pecsvariensis*. On the other hand, it is analogous to the assemblage of the *Spiniferites validus* Zone in upper Pannonian deposits ("Postpan-

← **Plate II.** Organic-walled phytoplankton from the Zheleznyi Rog section (magnification $\times 750$ for all figures).

- (1) *Hystrichosphaeropsis* sp., Sample 30, Pontian; (2) *Operculodinium cf. israelianum* (Rossignol, 1962) Wall, 1967, Sample 21, Maeotian; (3) *Operculodinium cf. centrocarpum* (Deflandre and Cookson, 1955) Wall, 1967, Sample 21, Maeotian; (4) *Operculodinium* sp., Sample 21, Maeotian; (5) *Selenopemphix* sp., Sample 21, Maeotian; (6) *Dinoflagellate* gen. indet., Sample 30, Pontian; (7) *Dinoflagellate* gen. indet., Sample 20, Maeotian; (8) *Palaeostonocystis*?, Sample 28, Pontian; (9) *Komewuia*?, Sample 31, Pontian; (10) *Komewuia*?, Sample 30, Pontian; (11) *Cymatiosphaera* sp., Sample 15, Maeotian.

Table 2. Correlation of late Miocene–early Pliocene organic-walled phytoplankton assemblages from the Black Sea region, Western Paratethys, and Mediterranean region

Eastern Paratethys		Western Paratethys		Mediterranean Sea	
Black Sea Basin (after Filippona)		Hungary (after Sütő-Szentai, 1985, 1989)		Romania (after Baltes, 1971)	
				Italy (after Bertini and Corradini, 1998)	
Lower Kimmerian	<i>Komewuia?</i> , <i>Galeacysta etrusca</i> , <i>Impagidinium</i> cf. <i>globosum</i> , <i>I. cf.</i> <i>spongianum</i> , and others		Assemblage of the <i>Mougeotia laetevi-</i> <i>rens</i> Zone ----- Assemblage of the <i>Dinoflagellata-</i> <i>Zygnemataceae</i> Zone	Pontian	<i>Diconodinium</i> <i>ineuicornutum</i> * and others
Pontian	<i>Galeacysta etrus-</i> <i>ca</i> , <i>Impagidinium</i> cf. <i>globosum</i> , <i>I. cf. spongianum</i> , and others	Upper Pannonian (Pontian)	Assemblage of the <i>Spini-</i> <i>ferites validus</i> Zone (<i>Impagidinium glo-</i> <i>bosum</i> , <i>I. spongianum</i> , <i>S.</i> <i>paradoxus</i> , and others)		upper Messinian (Lago Mare)
					<i>Galeacysta</i> <i>etrusca</i> , <i>Impagidinium</i> sp. ("pitted"), and others

* See Footnote 3 in the text.

nonische neogen Sedimente," "Oberpannonische Unterstufe," "pontischen Bildungen") of Hungary (Sütő-Szentai, 1985, 1989), where this zone is distinguished at the appearance level of *Spiniferites validus*, corresponds to *Impagidinium globosum* and *I. spongianum* acme zones, and also yields "*Gonyaulax digitalis*," *Spiniferites bentorii*, "*Pontiadinium*" species, and other forms.

At this stage in my research, I tend to correlate the indicated assemblage from the Zheleznyi Rog section with the upper Pannonian assemblage of the *Spiniferites validus* Zone, taking into account abundance of *Impagidinium cf. globosum* and *I. cf. spongianum* (Table 2) at this level. This assumption needs, however, to be verified.

In the Mediterranean region (Italy), the assemblage with *Galeacysta etrusca* and "pitted" *Impagidinium* forms (Bertini and Corradini, 1998) appears in the upper part of the Messinian (Lago Mare facies) and is correlative with the Pontian dinocyst assemblage of the Black Sea region.

One more appearance level of new taxa, which are similar to *Komewuia* species (see Footnote 2), is found in the Zheleznyi Rog section at the top of Pontian deposits (Sample 31). They associate here with peculiar *Impagidinium*, *Galeacysta etrusca*, "*Gonyaulax digitalis*," and *Spiniferites bentorii* inherited from the previous assemblage. The same assemblage is characteristic of lower Kimmerian layers as well. The above taxa developed most likely under brackish-water conditions. Judging from the presence of freshwater forms (*Pediasstrum*, *Spirogira*, *Botryococcus*), the paleobasin became slightly freshened at the beginning of the Kimmerian that might have been related to the increase of river runoff and climatic cooling that is inferable from palynological data on that interval of the Kimmerian.

Two levels of changes in the organic-walled phytoplankton composition, which are established in the lowermost and uppermost parts of the Pontian in the Zheleznyi Rog section, are traceable as well in the section located eastward of the Kuban superdeep borehole.

CONCLUSION

Hence, ten spores-and-pollen assemblages of the forest and forest-steppe type, which reflect alternation with time of corresponding vegetation phases, are established after palynological analysis of upper Sarmatian, Maeotian, Pontian, and lower Kimmerian deposits in the Zheleznyi Rog section. In the entire studied interval, the assemblages are nearly identical in taxonomic composition (at the level of families and genera) and differ only in proportions of those components, which reflects climatic fluctuations.

At the early phases of the late Sarmatian, Maeotian, and Pontian, climate was warm-temperate and humid with coniferous (of pine and *Taxodium* types) and mixed broad-leaved forests (elm-hickory, oak-hickory-elm, and others) dominated. During later phases of the mentioned ages, climate was more arid, and areas of xerophilous herbaceous-fruticose plants, mostly of *Chenopodiaceae*, *Artemisia*, and other grasses, widened. Judging from a considerable increase in the abundance of such taxa as *Sphagnum*, *Ericaceae*, and *Betula*, climatic conditions became more cool and relatively humid at the beginning of the Kimmerian.

Palynological data reveal most clearly the rhythmic changes in the humidity. Alternating forest and forest-steppe vegetation phases corresponded to humid and subhumid conditions, respectively. Variations in temperature developed in other way, showing a general tendency of gradual cooling that is evident from a steadily

decreasing percentage of spores and pollen of thermophilic plants upward in the section. During the entire studied period, climate was likely warm-temperate. The most remarkable decrease in the temperature apparently did not exceed the minimal values typical of the warm-temperate climate.

Nine assemblages of the organic-walled phytoplankton (dinocysts, green algae, acritarchs) have been established in the course of paleoalgalogical study of rocks from the Zheleznyi Rog section.

The late Sarmatian is poorly characterized by phytoplankton, and only one short interval of a definite marine regime is distinguishable here. The basin salinity in the early Maeotian was close to normal and decreased at the beginning of the late Maeotian. The marine regime recommenced in the second half of the late Maeotian, but water salinity likely deviated from normal at that time. Brackish-water conditions were characteristic of the Pontian and early Kimmerian, and the lowest salinity parameters are recorded by the uppermost Pontian and lowermost Kimmerian phytoplankton assemblages. Freshening events at the early late Maeotian, terminal Pontian, and earliest Kimmerian likely reflected activation of the river runoff. The last event could be also connected with the temperature decrease inferable from palynological data.

Most radical changes in composition of phytoplankton assemblages, which are marked by appearance of many new taxa within the late Sarmatian-early Kimmerian interval, took place in the lowermost (*Galeacysta etrusca*, peculiar *Impagidinium*, and other forms) and uppermost (*Komewuia*?) Pontian. These levels are good stratigraphic markers traceable in easterly areas of the Black Sea region (Kuban superdeep borehole).

According to distribution patterns of organic-walled phytoplankton, the Maeotian-Pontian boundary in the Zheleznyi Rog section is actually traceable 8-10 m above the top of the coupled diatomite layer, to which it was conventionally attributed.

The results of correlation of the late Neogene organic-walled phytoplankton assemblages from the Black Sea region with coeval assemblages from the Mediterranean region and Western Paratethys are quite significant. They imply that the Pontian assemblage with *Galeacysta etrusca* and peculiar *Impagidinium* forms, which are characteristic of the greater interval of Pontian deposits in the Black Sea region (except for its lowermost and uppermost parts), is correlative with the late Messinian assemblage (Lago Mare facies) of the Mediterranean region and, most likely, with the assemblage of the late Pannonian (Pontian) *Spiniferites validus* Zone of Hungary. The assemblage of organic-walled phytoplankton from uppermost Pontian and lower Kimmerian deposits of the Black Sea region exhibit similarity with the Pontian assemblage of Romania.

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