УДК 561.252:551.781.4(477-17)

PALYNOLOGY OF MARINE BLACK SANDS FROM THE YAROSHIVKA QUARRY, UKRAINE – A CONTRIBUTION TO MIDDLE EOCENE PALAEOGEOGRAPHY OF NORTHERN UKRAINE

ПАЛІНОЛОГІЯ МОРСЬКИХ ЧОРНИХ ПІСКІВ ЯРОШІВСЬКОГО КАР'ЄРУ (УКРАЇНА): ДО ПАЛЕОГЕОГРАФІЧНИХ РЕКОНСТРУКЦІЙ СЕРЕДНЬОГО ЕОЦЕНУ ПІВНІЧНОЇ УКРАЇНИ

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Black sands of the Yaroshivka Beds (Middle Eocene, Lutetian) that directly overlie granitoids exploited in the Yaroshivka Quarry (northeastern peripheries of the Ukrainian Shield) have been studied for palynology. This study was conducted with an aim of palaeoenvironment reconstruction that could contribute to the palaeogeography of Ukraine in the Palaeogene. Deposits studied yielded both marine and continental palynomorphs. The former consist mainly of dinoflagellate cysts, Prasinophyceae algae, and acritarchs. Terrestrial palynomorphs are mainly bisaccate pollen grains. Representatives of both palynomorph groups are immature but they show high degree of mechanical damage. Particularly large specimens of chorate dinoflagellate cysts are almost exclusively preserved as torn-off fragments. Small proximate dinoflagellate cysts and tiny acritarchs are usually complete. Palynomorph assemblages described were interpreted as typical for marine, high energetic sedimentary setting located within a proximal zone of terrestrial influences. Subsequent progression of the Eocene transgression led to a complete inundation of the Ukrainian Shield in the area of our study. As a result, different palaeoenvironmental conditions appeared. They caused pronounced changes in palynofacies and palynomorphs assemblages found in the strata transitional to the overlying Kyiv Fm.
Keywords: palynology, dinoflagellate cysts, palynomorphs, palaeoenvironment, palaeogeography, Eocene, Northern Ukraine.

Проведено палінологічний аналіз чорних пісків, розкритих діючим кар'єром біля с. Ярошівка (північно-східна периферія Українського щита (УЩ)), які відносяться до ярошівської товщі середнього еоцену (лютет). Піски, що залягають безпосередньо на кристалічних породах УЩ, містять як морські (цисти динофлагелят, фікоми празінофітових водоростей, акритархи), так і континентальні (загалом, пилкові зерна хвойних рослин) паліноморфи. Збереженість палінологічного матеріалу нижче задовільної – наявний високий ступінь механічного пошкодження як морських, так і наземних викопних груп. Хоратні диноцисти, особливо крупні, представлені майже виключно розірваними фрагментами. Непошкодженими є лише дрібні диноцисти та дрібні акритархи. Описаний палінологічний комплекс інтерпретується як типовий для морського середовища з високою гідродинамічною активністю (прибережна зона). Подальше нарощування еоценової трансгресії призвело до затоплення УЩ в районі нашого дослідження та зміни палеогеографічних умов, які зафіксовані в палінофаціях перехідних до київської світи шарах.
Ключові слова: палінологія, цисти динофлагелят, паліноморфи, умови існування, палеогеографія, еоцен, Північна Україна.

INTRODUCTION

Palaeogene succession of Northern Ukraine contains a few horizons of black clastic deposits, commonly with brown-coal deposits. Terrestrial origin of these deposits is confirmed by occurrence of sporomorphs, higher plant remains, and lack of marine fossils. However, some black clastic strata, traditionally regarded as continental deposits, could accumulate in a marine environment. Such examples are black sands once exposed in the Yaroshivka Quarry where they lie upon crystalline basement of the Ukrainian Shield. They were treated as continental strata (the so-called sub-Kyiv Sands; Ukrainian name: підкиївські піски), that underlie the marine Kyiv Formation (Kiev Fm., sub-Kiev Sands – translit. from Russian) due to, i.a., occurrence of common coalified plant remains. More recently, however, marine fossils have been found there, including shark and bone fish teeth, and marine turtle remains, that witness for marine sedimentary setting. Our preliminary dinoflagellate cyst studies (Gedl, Shevchenko, 2010) also evidence their marine origin. In this paper, we present our further results of palynological studies of these black sands once exposed at Yaroshivka Quarry.

GEOLOGICAL SETTING

Sedimentary succession of Northern Ukraine is highly diversified as it rests on various structures of older substratum. The most prominent part of this substratum is the Ukrainian Shield built of Precambrian crystalline rocks that occupies most of northern part of Ukraine (Fig. 1). The Ukrainian Shield was since its beginning an elevated structure – its

Fig. 1. Schematic map of Ukraine with main structural geological elements and location of the Yaroshivka Quarry (arrowed).

sedimentary cover consists of Jurassic and Cretaceous (preserved locally only) and Palaeogene-Neogene successions. To the north-east, the Ukrainian Shield borders on the Dnieper-Donets Trough that separates it from another Precambrian rigid structure – the Voronezh Crystalline Massif. The trough begun to form as a rift system separating these two crystalline massifs in the Devonian; it is filled with a thick sequence of sedimentary rocks spanning the Devonian through the Neogene.

The same orographic pattern was in Northern Ukraine during the Palaeogene: the Ukrainian Shield was uplifted, whereas the Dnieper-Donets Trough was a submerged depocenter where the marine Palaeogene section (Lower Paleocene to Upper Oligocene) shows the most complete development and highest thickness (350 m in the axial part) being the type area for the biostratigraphical division of the Palaeogene in epicontinental Ukraine. Towards the Ukrainian Shield, thickness of Palaeogene strata gradually becomes thinner, and it oscillates on the Shield between fifteen to zero meters. This highly incomplete development of the Palaeogene at the Ukrainian Shield makes correlation with the Dnieper-Donets Trough succession problematic, particularly that some intervals of Palaeogene strata at the Ukrainian Shield are continental or shallow marine devoid of fossils.

The Palaeogene succession of Northern Ukraine (known from the Dnieper-Donets Trough) consists of nine informal lithostratigraphical units in the rank of suites/formations: Sumy Fm., Merla Fm., Kaniv Fm., Buchak Fm., Kyiv Fm., Obukhiv Fm., Mezhyhiria Fm., Zmiiv Fm., and Syvash Fm.

Paleocene Sumy (= Psol Fm. according to Stratigraphic Schemes..., 1993) and Merla formations are continental and they are known from the Dnieper-Donets Trough only. The age analogues of the Sumy Fm. on the Ukrainian Shield are marine Polissia Beds, Luzanovka Beds, the Raihorodka Fm., and the lower part of the continental Boltyshka Beds. Continental middle part of the Boltyshka Beds on the Ukrainian Shield is presumably a counterpart of the Merla Fm. The Lower Eocene (Ypresian) Kaniv Fm. is marine (in the Dnieper-Donets Trough); it can be correlated with lacustrine deposits of the Ukrainian Shield (upper part of the Boltyshka Beds). A similar development characterizes younger, lower Middle Eocene (lower and middle Lutetian) strata, which are marine in the Dnieper-Donets Trough (the Buchak Fm.), whereas their possible age counterparts on the Ukrainian Shield are mostly continental (e.g., brown-coal deposits in the Dnieper Brown-Coal Basin). Some others, however, like the Yaroshivka Beds (subject of this paper) – are marine. The overlying marine Kyiv Fm.

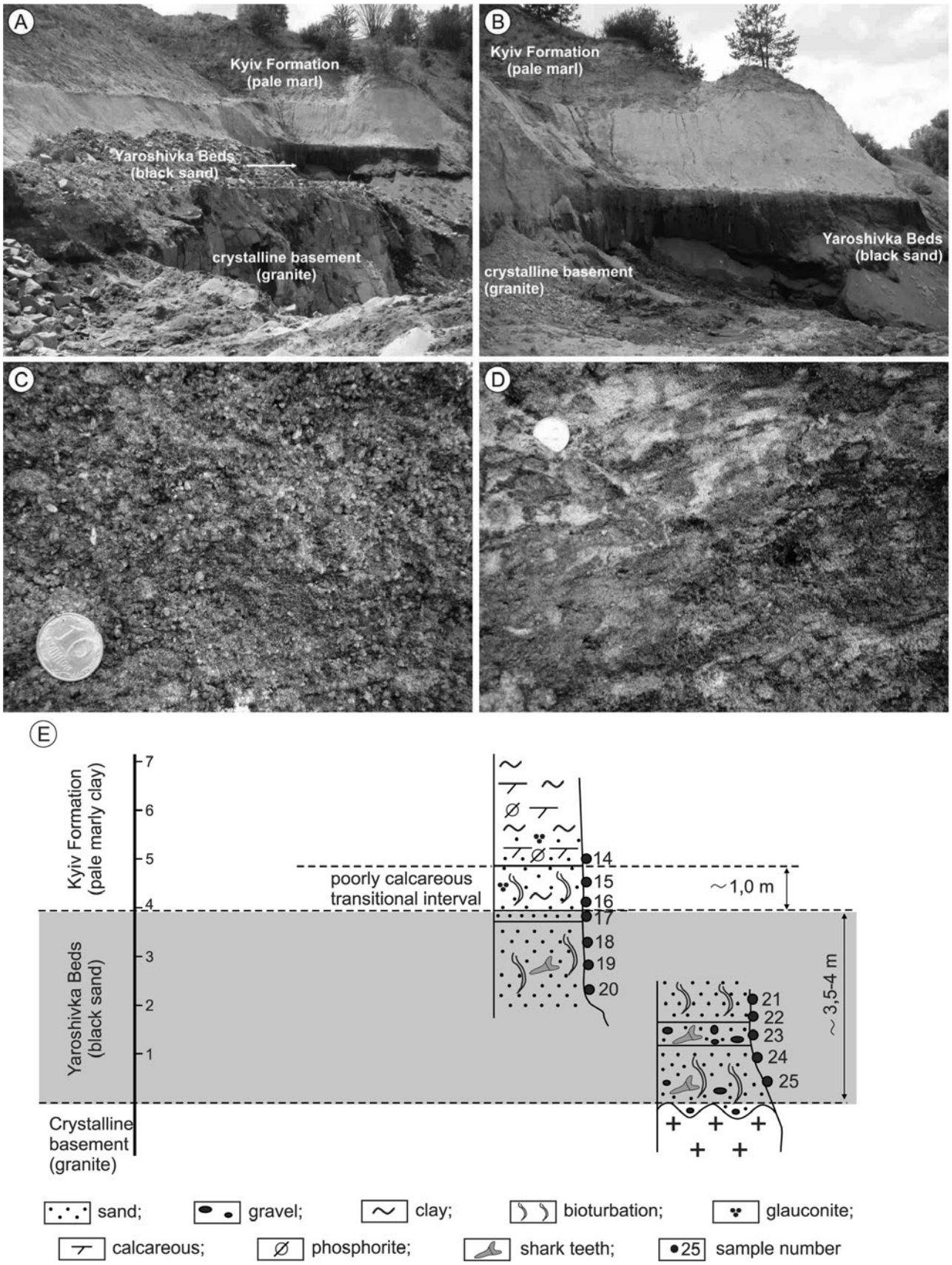

Fig. 2. Yaroshivka Quarry (as of year 2010). A, B – views on uppermost quarry walls showing sedimentary cover of the crystalline (granite) basement; C – coarse-grained sand and gravel from the basal part of the Yaroshivka Beds (coin diameter = 16,3 mm); D – bioturbated sands from the middle part of the Yaroshivka Beds (coin diameter = 16,3 mm); E – schematic sections of the Yaroshivka Beds with positions of the samples studied.

(upper Middle Eocene; upper Lutetian-Bartonian) is the first Palaeogene horizon that uniformly covered the Dnieper-Donets Trough and the Ukrainian Shield). The same refers to the Priabonian Obukhiv Fm. and the Oligocene units (Mezhyhiria, Zmiiv, and Syvash formations), which although show some differences, are generally uniform in both areas.

MATERIALS

The Yaroshivka Beds are dark-brown to black sands and muds, usually quartz with minor admixture of glauconite, that rest directly on Precambrian crystalline basement of the Ukrainian Shield or locally on the Kaniv Fm. Gravel transgressive layers in their base can be observed locally. The Yaroshivka Beds are known from the north-west and central parts of the Ukrainian Shield (Stratigraphic Schem..., 1987, 1993). The best exposures are in granite quarries near Fastiv (at villages of Yaroshivka and Byshiv); they are also known from boreholes (Kaniv and Kamianske region).

At the Yaroshivka Quarry, their *locus typicus*, the Yaroshivka Beds reached up to 5 m thickness (Fig. 2). The basal part contains common gravel and coarse-grained sands (Fig. 2, C). The higher parts contain coarse- to medium-grained black sands with very frequent burrows (Fig. 2, D).

The age of the Yaroshivka Beds at the Yaroshivka Quarry is most likely Lutetian. According to N.I. Udovichenko (pers. comm.), presence of *Carcharocles* cf. *auriculatus* (Blainville) suggests Lutetian age. In another location, a little to the east and south-east (Kagarlyk-Rzhyshchiv area), the same age of the sub-Kyiv Sands is suggested by planktic (Acarinina rotundimarginata Zone) and benthic (Robulus dualis Zone) foraminifera (generalizations T.S. Ryabokon (based on Krajeva et al., 1967)). Calcareous nannofossils found in the interval transitional from the Yaroshivka Beds to the Kyiv Fm. (E.A. Solyanik, comm. pers.) are characteristic of NP16 Zone correlated with the upper Lutetian-lowermost Bartonian (Berggren et al., 1995).

During our fieldtrips in 2010, we collected nine samples from the Yaroshivka Beds exposed in the Yaroshivka Quarry (now, exposures of the Yaroshivka Beds are inaccessible). Three more samples were collected from the strata transitional to the overlying marls of the Kyiv Fm. (Fig. 2, E). The quarry was located 1,5 km east of the village of Yaroshivka near Fastiv (Fig. 1).

METHODS

The samples were processed in the micropalaeontological laboratories of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków, and Institute of Geological Sciences of NAS of Ukraine, Kyiv. The palynological procedure applied included 38% hydrochloric-acid (HCl) treatment, 40% hydrofluoric-acid (HF) treatment, heavy-liquid ($ZnCl_2$+HCl; density 2,0 $g{\cdot}cm^{-3}$) separation, ultrasound for 10-15 s and sieving at 10 μm on a nylon mesh. Nitric-acid (HNO_3) treatment was not applied.

The quantity of rock processed was 250 g for each sample. Palynological slides were made from each sample using glycerine jelly as a mounting medium. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

RESULTS

All samples contain palynological organic matter, although its qualitative content differs throughout the section (Fig. 3). Samples 25–19 from the lower part of the Yaroshivka Beds at the Yaroshivka Quarry yielded high amounts of highly disintegrated, tiny structureless organic particles. A characteristic feature of this interval is frequent occurrence of bisaccate pollen grains, which represent over 90% of all sporomorphs. Spores, although infrequent, are also present (Plate I). Aquatic palynomorphs are represented in this interval by acritarchs, Prasinophyceae algae, and dinoflagellate cysts (Plates I, II). They are all immature (pale coloured) but especially large, chorate specimens of dinoflagellate cysts are preserved as torn-off fragments only.

Acritarchs are represented by frequent *Paucilobimorpha* spp., and less frequent *Cystidiopsis* spp. Prasinophycaea are not so numerous; they are represented by *Cymatiosphaera* spp., and *Tasmanites*. The lowermost sample 25 yielded only fragmentarily preserved dinoflagellate cysts (*Polysphaeridium*?, *Areoligera*?, *Achomosphaera/Spiniferites*). Higher samples yielded dinoflagellate cyst fragments (*Lingulodinium*?, *Homotryblium*?, *Achomosphaera*?, *Areoligera*?, *Hystrichokolpoma*, *Wetzeliella*), complete specimens of *Microdinium* spp., *Lentinia serrata*, and *L. wetzelii*. *Lentinia* specimens become most frequent in samples 22–19.

Two samples, 18 and 17, yielded very low amounts of palynological organic matter, with determinable pollen grains only in sample 17. A different palynofacies occurs in higher samples 16 and 15 collected from the interval transitional to the Kyiv Fm. (Fig. 2, E). Sporomorphs disappear there almost completely, and tiny black opaque particles

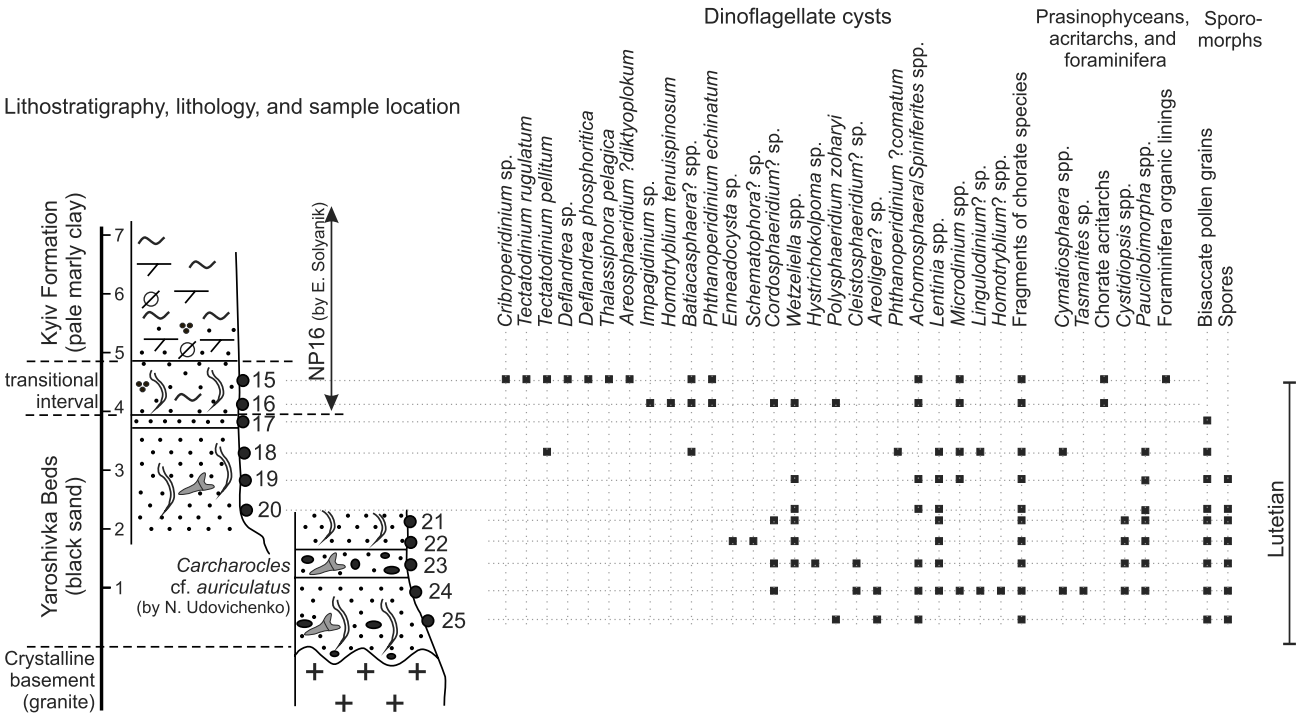

Fig. 3. Distribution of palynomorphs in the Yaroshivka Beds at the Yaroshivka Quarry (for symbol explanations, see Figure 2).

occur frequently. Aquatic palynomorphs undergo a significant change as well: the hitherto dominating acritarchs and Prasinophycae disappear (acritarchs are represented in these two topmost samples by tiny, spiny forms only); among dinoflagellate cysts *Lentinia* disappears, and small subsphaerical proximate species of *Microdinium*, *Batiacasphaera*?, and *Tectatodinium* dominate; *Phthanoperidinium echinatum* occurs. Fragmentarily preserved specimens are also present in these samples: *Polysphaeridium zoharyi*, *Cordosphaeridium gracile*, *Homotryblium tenuispinosum*, *Spiniferites* spp., *Wetzeliella*, *Areosphaeridium*. Impagidinium sp. was found in sample 16, whereas *Deflandrea* (including *D. oebisfeldensis*? and *D. phosphoritica*) occur in sample 15.

INTERPRETATION

Results of our palynological study of the Yaroshivka Beds (the Yaroshivka Quarry), which are presented in this paper, are a record of palaeoenvironmental changes that took place during Middle Eocene transgression on the Ukrainian Shield. This transgression covered the Shield – an area, which up to then was emerged. During the Paleocene and Early Eocene the Ukrainian Shield was a land surrounded to the north-east by a basin where marine strata accumulated (the Dnieper-Donets Trough). During the Lutetian, uprising sea level led to flooding of the Ukrainian Shield and resulted in marine sedimentation in this region that for millions years was land.

Aquatic palynomorphs, especially the fully marine dinoflagellate cyst assemblages found in the Yaroshivka Beds, undoubtedly show these black sands to have accumulated in a marine environment. Presence of frequent acritarchs and Prasinophyceae algae suggests some specific conditions, but as palaeoenvironmental preferences of these microfossils are not precisely known, their nature remains uncertain. Possibly, it may be associated with proximal, shallow marine environment. Subsequent changes in palynological record, detected in the upper part of the studied succession, may confirm our interpretations. We present a following model of palaeoenvironmental changes during accumulation of the Yaroshivka Beds.

Lower part of the section was accumulated during initial stages of the transgression characterized by a high energetic shallow marine environment. Gravels and coarse-grained sands accumulated then. Majority of dinoflagellate cysts from this interval are torn-off, which is another evidence of energetic water conditions that led to cyst damage. Selectivity in cyst preservation relies on the fact that larger specimens, especially those with long processes, i.e., chorate forms like *Enneadocysta*, *Homotryblium*, *Areosphaeridium*, *Cordosphaeridium*, were more susceptible to damage than small subspherical proximate specimens (e.g., *Microdinium*). Begin-

ning of the Yaroshivka Beds accumulation was characterized by proximity of land areas still not flooded by the transgression. Conifers were presumably the main element of vegetation on these islands/lands, although over-productivity of their pollen grains in fossil material is well known due to high productivity of conifer trees and high buoyancy of pollen grains. The Early-Middle Eocene was generally the time of warm and humid tropical climate (e.g., Zachos et al., 2001) so this conifer pollen grain dominance might be indeed a matter of sedimentary processes. Fern spores, although rare in our material, show that thermophilous vegetation was also present on land.

A significant change in palaeoenvironmental conditions took place when the uppermost part of the section, transitional to the overlying Kyiv Fm., was accumulated. Lack of sporomorphs in samples 16 and 15 shows that the alimentary area was either withdrawn or flooded by the progressive transgression. The latter possibility, when the whole neighbouring part of the Ukrainian Shield was flooded is more likely, as pollen grains can be transported from long distances, even by wind. Disappearance of emerged areas resulted also in changes in marine environment. Acritarchs (*Paucilobimorpha*, *Cystidiopsis*) and Prasinophycaea (*Cymatiosphaera*, *Tasmanites*), so frequent in the Yaroshivka Beds – disappeared. Their absence may be a result of increasing water depth (simultaneously with progression of transgression). But it may be also caused by some other factors, hard to determine, due to enigmatic palaeoenvironmental preferences of these microfossils.

Increase in area covered by the sea, indirectly linked with water depth, may be suggested by the appearance of oceanic genus *Impagidinium* (see e.g., Sluijs et al., 2005), which although rare, has been found in sample 16. Other explanations of changes in aquatic palynomorphs assemblages may be related to changes in water temperature and/or sea water chemistry. The latter possibility seems to be more obvious. Our dinoflagellate cyst data show that during accumulation of the Yaroshivka Beds water salinity was fully marine, as their assemblages are composed of stenohaline forms. But disappearance of acritarchs, Prasinophyceae, and peridinioid *Lentinia*, may be related to flooding of land areas. During initial stages of transgression, land areas could influence marine ecosystem by freshwater influx that led to fertilization of marine waters. Peridinioids (in our case *Lentinia*) are known to benefit from nutrient-rich waters (e.g., Sluijs et al., 2005). Cease of nutrient influx after flooding of land areas could lead to shift in trophic conditions from eutrophic (favourable by peridinioids) to oligotrophic (presence of *Impagidinium*).

DISCUSSION

Our interpretations of palaeoenvironmental conditions during deposition of the black sands of the Yaroshivka Beds are consistent with results of previous, partly unpublished studies. Fully marine conditions as based on dinoflagellate cysts are also indicated by occurrence of shark teeth that frequently occur in the basal part of the Yaroshivka Beds at the Yaroshivka Quarry. N.I. Udovichenko (pers. comm.) identified there *Notorhynchus* sp., *Heterodontus* cf. *vincenti* (Leriche), *Heterodontus* sp., *Anomotodon* sp., *Striatolamia macrota* (Agassiz), *Striatolamia* sp., *Brachycarcharias* cf. *lerichei* (Casier), *Hypotodus verticalis* (Agassiz), *Jaekelotodus robustus* (Leriche), *Carcharias* sp., *Odontaspis winkleri* (Leriche), *Carcharocles* cf. *auriculatus* (Blainville), *Physogaleus* sp., *Aetobatus* sp., and *Myliobatis* sp.

Fully marine conditions are also supported by foraminifera that occur in the sub-Kyiv Sands (possible Yaroshivka Beds) of the Kagarlyk-Rzhyshchiv area: planktic (*Pseudohastigerina micra* (Cole), *A. crassaformis simulata* (Kr.), *A. pentacamerata* (Subb.), *A.* ex gr. *interposita* Subb., *A. rugosoaculeata* Subb., and others) and benthic (*Textularia pishvanovae* A. et K. Furs., *Lenticulina dimorpha* Tutkow., *Lenticulina* (*Marginulinopsis*) *fragaria* (Gumb.), *Cibicides biumbonatus* A. et K. Furs., *Bifarina millepunctatus* Tutkow., and others) (determined by E.J. Krajeva (Krajeva et al., 1967, see table 2)).

Calcareous nannofossils have not been observed yet in the Yaroshivka Beds (E.A. Solyanik, pers. comm.). They occur in the strata transitional to the Kyiv Fm. (our samples 16 and 15; see Fig. 2, E), and above. Their absence in the Yaroshivka Beds may reflect either shallow marine conditions and/or high energetic conditions unfavourable for accumulation and preservation of those delicate nannofossils.

The Yaroshivka Beds can be correlated by age with the marine Buchak Fm. Lithology and palynological content of the former show its near-shore shallow marine character. Thus, the proximal marine Yaroshivka Beds is a transitional facies between the brown-coal formation deposited in continental conditions on the Ukrainian Shield and the open marine Buchak Fm. that settled down on the slopes of the Ukrainian Shield and the neighbouring Dnieper-Donets Trough. It occurs along the north-eastern edge of the Ukrainian Shield adjacent to the Dnieper-Donets Trough.

Our conclusion on a complete inundation of the Ukrainian Shield in the area under study in the

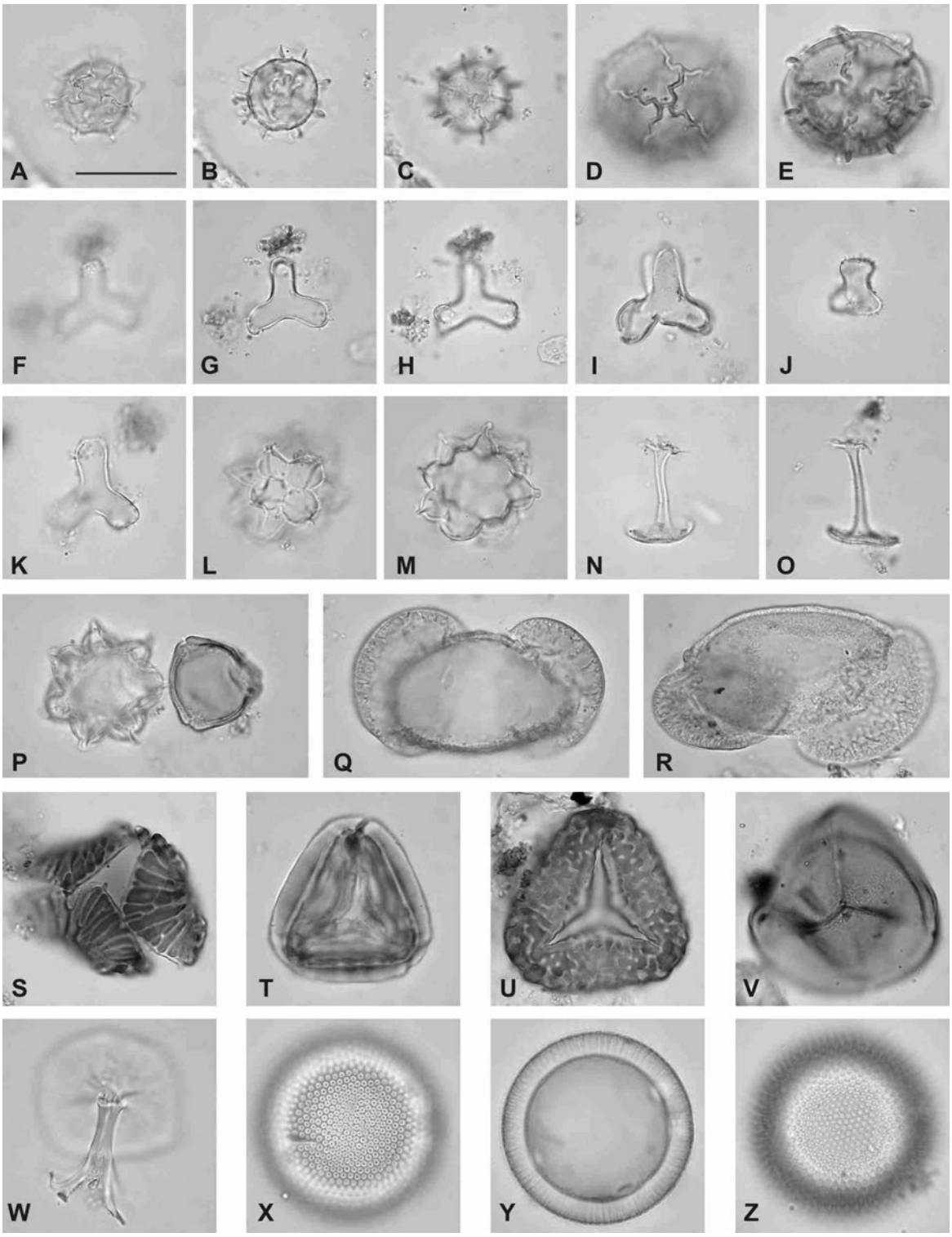

Plate I. Palynomorphs from the Yaroshivka Beds at the Yaroshivka Quarry. Scale bar in A = 15 μm and refers to all other photographs.

A–C – *Cymatiosphaera bujakii* De Coninck, 1986 (sample 24; same specimen, various foci); D, E – *Cymatiosphaera* sp. (sample 24; same specimen, various foci); F–H – *Paucilobimorpha triradiata* (De Coninck, 1986) Prosl, 1994 (sample 24; same specimen, various foci); I – *Paucilobimorpha* (sample 24); J – *Paucilobimorpha* (sample 24); K – *Paucilobimorpha triradiata* (sample 24); L, M – *Cystidiopsis mamellatus* (De Coninck, 1977) Grabowska, 1996 (sample 22); N, O – islolated processes of ?*Homotryblium* (both specimens from sample 24); P – *Cystidiopsis mamellatus* (left) and Myricaceae (right; sample 24) Q, R – bisaccate pollen grains (Q: sample 19, R: sample 23); S-V – fern spores (S, T: sample 23, U: sample 20, V: sample 19); W – isolated process of ?*Cordosphaeridium* (sample 24); X–Z – *Tasmanites concinnus* (Cookson et Manum, 1960) Downie, Evitt, Sarjeant, 1963 (sample 24; same specimen, various foci).

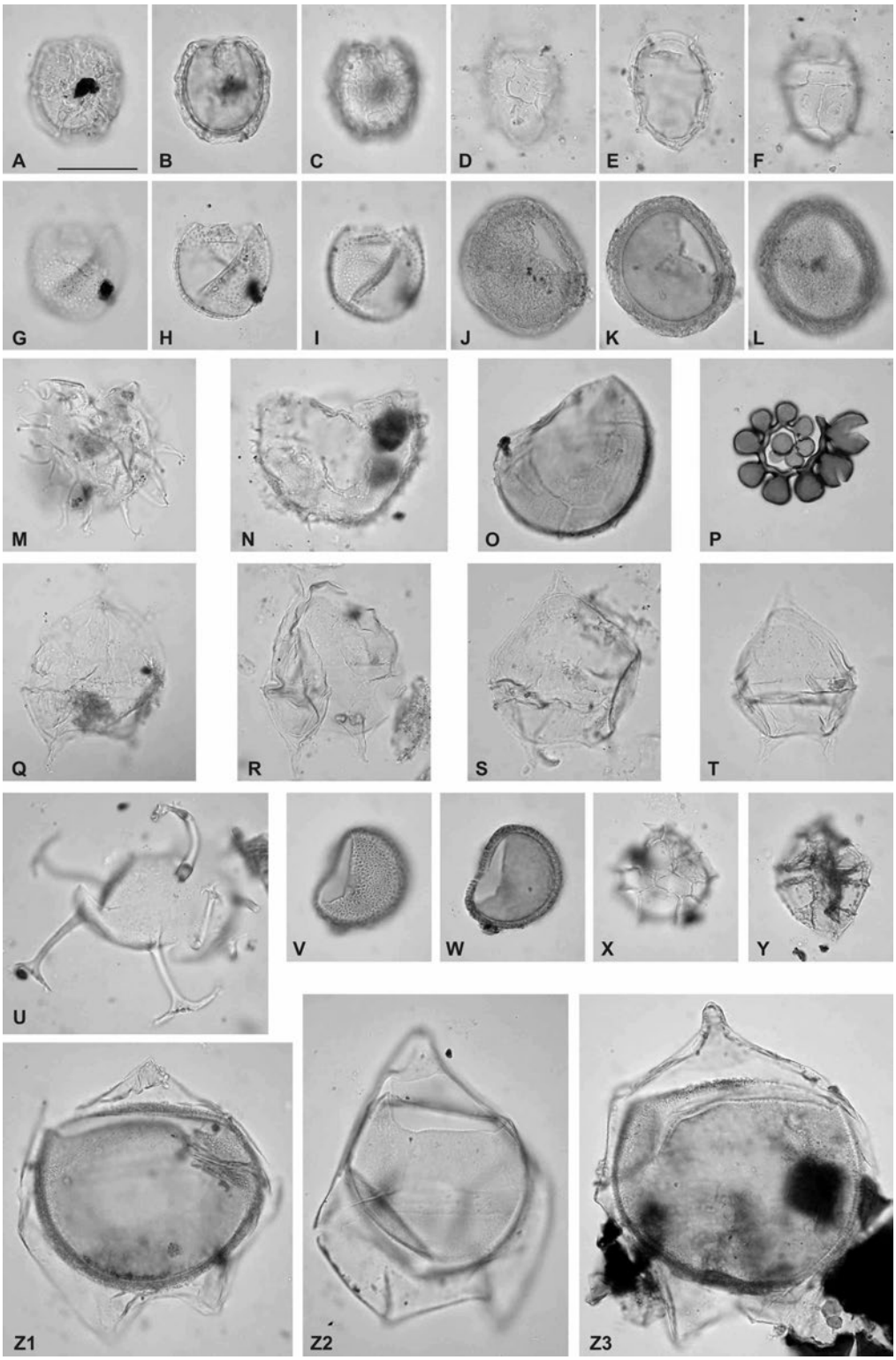

Plate II. Aquatic palynomorphs from the Yaroshivka Beds at the Yaroshivka Quarry. Scale bar in A = 15 μm and refers to all other photographs.

A–C – *Microdinium reticulatum* Vozzhennikova, 1967 (sample 16; same specimen, various foci); D–F – *Microdinium* sp. (sample 19; same specimen, various foci); G–I – *Batiacasphaera* sp. (sample 16; same specimen, various foci); J–L – *Tectatodinium pellitum* (Wall, 1967) Head, 1994 (sample 15; same specimen, various foci); M – *Cleistosphaeridium*? sp. (sample 24); N – *Schematophora*? sp. (sample 22); O – *Cribroperidinium* sp. (sample 15); P – foraminifera organic lining (sample 15); Q–T – *Lentinia* spp. (Q: sample 23, R: sample 22, S: sample 21, T: sample 19); U – incomplete specimen of *Enneadocysta* sp. (sample 22); V, W – *Tectatodinium rugulatum* (Hansen, 1977) McMinn, 1988 (sample 15); X – *Impagidinium* sp. (sample 16); Y – *Phthanoperidinium echinatum* Eaton, 1976 (sample 16); Z1–Z3 – *Deflandrea phosphoritica* Eisenack, 1938 (all specimens from sample 15).

Lutetian is consistent with the hitherto palaeogeographic reconstructions (Krajeva et al., 1967; Radzivill et al., 1987; Zosimovich et al., 2015; Ryabokon, Shevchenko, 2001), which assume a complete submergence of the Ukrainian Shield in the Late Lutetian–Bartonian.

ACKNOWLEDGEMENTS

We would like to thank very much Mr. V.L. Serebryakov, director of the Yaroshivka Quarry, for access to the quarry and sample collection. N.I. Udovichenko is kindly acknowledged for shark teeth determination and permission of his publication. E.A. Solyanik is thanked for sharing us with results of his calcareous nannoplankton studies. T.S. Ryabokon is thanked for correlations of foraminiferal data. We also thank V.Yu. Zosimovich for critical reading our manuscript and valuable comments.

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Manuscript resived 1 November 2016;
revision accepted 30 November 2016

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