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CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY OF PALEOGENE SEDIMENTS OF UKRAINE (HISTORY OF STUDY AND STRATIFICATION)

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The article describes the history of nannofossil research of the Paleogene sediments in Ukraine from the beginning of the end of the XIX century. All available data concerning the significance of this ortho-stratigraphic group for detailed stratification purposes of diverse regional subdivisions and their correlation with International Stratigraphic Chart based on nannofossil biostratigraphy has also been discussed.

Key words: Paleogene, calcareous nannofossils, biostratigraphy, biozonal scales.

БІОСТРАТИГРАФІЯ ПАЛЕОГЕНОВИХ ВІДКЛАДІВ УКРАЇНИ ЗА НАНОПЛАНКТОНОМ (ІСТОРІЯ ВИВЧЕННЯ, СТРАТИФІКАЦІЯ)

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Викладено історію вивчення нанопланктону палеогенових відкладів в Україні починаючи з кінця XIX ст. Проаналізовано інформацію про значення цієї ортостратиграфічної групи для детальної стратифікації різнорангових регіональних підрозділів та їх кореляцію з Міжнародною стратиграфічною шкалою за нанопланктоном.

Ключові слова: палеоген, вапнистий нанопланктон, біостратиграфічне розчленування, біозональні шкали.

БИОСТРАТИГРАФИЯ ПАЛЕОГЕНОВЫХ ОТЛОЖЕНИЙ УКРАИНЫ ПО НАННОПЛАНКТОНУ (ИСТОРИЯ ИЗУЧЕНИЯ, СТРАТИФИКАЦИЯ)

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Изложена история изучения остатков наннопланктона из палеогеновых отложений Украины начиная с конца XIX в. Проанализирована информация о значении этой ортостратиграфической группы для детальной стратификации разноранговых региональных подразделений и их корреляции с Международной стратиграфической шкалою по наннопланктону.

Ключевые слова: палеоген, известковый наннопланктон, стратиграфическое расчленение, биозональные шкалы.

Introduction

Despite the presence of a large number of publications dedicated to the research of calcareous nannofossils biostratigraphy of Paleogene deposits of Ukraine, the degree of their study still remains different, uneven and often controversial. Especially this concerns the Carpathian-Black Sea segment of the Tethys region, in particular the Ukrainian Carpathians, North-Western Shelf, Continental slope of the Western Black Sea Depression, Kerchian Shelf of the Eastern Black Sea Depression and other structural-tectonic units of the East European Platform located within Ukraine. At present, there are many unsolved and debatable issues concerning the Paleogene stratigraphy of these regions. Namely, this is the detailed research of the paleontological age and stratigraphic position of the Dusinska, Turytska and Malovyzhenska formations and Pidgalian flysch, precise biostratigraphy and correlation of the lithostratigraphic units of the Ukrainian Carpathians with neighboring Poland, Slovakia and Romania sections based on calcareous nannofossils.

Within the Black Sea segment, the remaining issue is the detailed calcareous nannofossil biostratigraphy and biozonation of polyfacies terrigenous-carbonate Paleogene deposits of the Azov-Black Sea area, Crimea, the Black Sea region and the joining zone of the Tethys and North-Atlantic (Boreal) provinces within Ukraine and their correlation within the Alpine-Himalayan synclinal zone, with whom several mineral deposits, including hydrocarbons are related with. Subsequent calcareous nannofossil research as part of the microfossil assemblages that are contained in the Paleogene deposits is associated with the perspective of detailed stratification and the justification of the spatio-temporal patterns of their distribution in order to enhance and upgrade the existing stratigraphic schemes.

The research of microfossils has proven the orthostratigraphic importance of calcareous nannofossils assemblages of different ages and they are able to serve as reliable biostratigraphic reference levels for relative geological age dating of sedimentary rocks, regional and interregional correlations and paleobiogeographical reconstructions of relatively short periods of geological time.

Historical view of the calcareous nannofossil biostratigraphy

Calcareous nannofossils have been studied for more than 160 years. Their research is related to a wide list of World known researchers, such as, T. Huxley, H. Lohmann, Tan Sin Hok, G. Deflandre, E. Martini, V.N. Vekshina, D. Noël, W. Hay, M. Bramlette, P. Reinhardt, S. Gartner, D. Bukry, I.A. Shamray, E.P. Lazareva, F. Sullivan, S.I. Shumenko, K. Perch-Nielsen et al. At present, the calcareous nannofossil research is performed by the effort of thousands of scientists called **nannologists**. They deal with a variety of issues that are concerned with the classification, systematic description, geographical and temporal distribution, biozonation and detailed stratification, paleoecology and biostratigraphy of calcareous nannofossils from deposits of different ages.

In Ukraine, the calcareous nannofossil research was initiated in the 1960's. Calcareous nannofossil biostratigraphy was developed by S.I. Shumenko, A.S. Andreeva-Grigorovich, S.A. Lulyeva, M.G. Muzylöv, Ye.M. Bogdanovich, N.A. Savytska, A.M. Romaniv, Dan Dyg Nga, A.V. Matveev, D.D. Waga, E.A. Solyanyk and I.S. Suprun. The main focus of their research was dedicated to study the species content, nannofossil assemblages, biozonation and the generation of biostratigraphic charts of Paleogene based on this group of microfossils.

Paleogene calcareous nannofossils from the southern part of the East European Platform and adjacent areas of the Tethys province in different times were studied by various scientists. In Crimea these are the reports made by A.S. Andreeva-Grigorovich [Андреева-Григорович, 1973, 1980], E.M. Bogdanovich (1985), D.D. Waga [Вага, 2007]; Dnieper-Donets depression – D.D. Nga (1973), S.I. Shumenko and D.D. Nga [Шуменко, Нга, 1973], S.A. Lulyeva (1974); Black Sea basin – S.A. Lulyeva (1977) [Краева, Люльева, 1976], A.S. Andreeva-Grigorovich and Ye.M. Bogdanovich (1979); Ye.M. Bogdanovich (1980, 1985) [Богданович, 1979]; Ukrainian Carpathians – A.S. Grigorovich [Григорович, 1971], A.S. Andreeva- Grigorovich [Андреева-Григорович, Музылёв, Табачникова, 1991], A.M. Romaniv [Романив, 1991] et al. The nannofossils of Paleogene deposits were also studied by foreign scientists, including, M. Wade, H. Mohler and B. Hay (1964) which resulted in the selection of a number of standard zones in the Palaeocene-Eocene sections of the Northern Caucasus. Similarly, E. Martini and C. Ritskovsky (1970) defined the relative age of the Mandrikovka beds of south Ukraine.

The major impetus for nannofossil research within the southern regions of the Eastern European Platform and adjacent areas was contributed by the XII European Micropaleontological Colloquium that took place in Crimea in 1971. Based on the «standard»

biozonation of E. Martini and D. Bukry, the first nannofossil schemes of Paleogene deposits of Crimea, Caucasus, and the Carpathians were developed and approved by the Paleogene Commission of the Interdepartmental Stratigraphic Committee of the former USSR [Андреева-Григорович, 1973; Гавтадзе, 1986; Музылёв, 1980; Шуменко, 1987; Андреева-Григорович, Музылёв, Табачникова, 1991].

The intervals of calcareous nannofossil zonation NP1-NP8 and NP15-NP20 have been discovered within the Northern region of Ukraine (N.A. Savitska [Савицька, 1996] and E.M. Solyanyk (2013)).

M.G. Muzylöv published a monograph «The stratigraphy of the Paleocene of the Southern USSR based on calcareous nannofossils» in which he revised and made some supplements to the existing zonations. He also revised the relative age of the Paleogene stages and determined the stratigraphic volume of the unconformities [Музылёв, 1980].

A comprehensive research of nannofossils from Shelf of the Black Sea was initiated in the early 1970`s when the key biostratigraphic importance of this group of microfossils for biostratigraphy and correlation purposes of carbonate rock formations was realized.

In the Azov-Black Sea region studies were conducted by S.A. Lulyeva, A.V. Shumnyk, A.S. Andreeva-Grigorovich, D.D. Waga and I.S. Suprun. They were chiefly aimed at studying the calcareous nannofossils distribution within the Paleogene samples from the Black Sea shelf derived from well sections drilled at the structures of the West Olenivskaya, Krymskaya, Olympic, Stormova, Selskogo, Gamburtsevo, Golitsinska, Schmidta, Odeska, Beimenna, Subotina, and others alike. On these structures, the biozonation of the Meso-Cenozoic sediments, especially those of the Paleocene, Eocene, Oligocene, Neogene and Quaternary deposits of the Black and Azov Seas that are hydrocarbon productive [Краева, Люльева, 1976; Гожик, Маслун, Плотнікова, Іванік та ін., 2006; Маслун , Андрєєва-Григорович, Іванік, Мінтузова, Трофимович, 2006; Маслун, Іванік, Шумник та ін., 2007; Waga, Andreyeva-Grigorovich, Maslun, 2010; Супрун, 2017].

S.A. Lulyeva presented two monograph works – "Biozonation of the Eocene of the European part of the USSR" and "Zonal biostratigraphy of the Paleocene of the East European Platform" that included the concluding research on calcareous nannofossil biostratigraphy of the Paleocene-Eocene sediments [Зернецкий, Люльева, 1990, 1994].

The Cretaceous-Paleogene calcareous nannofossils from the Ukrainian Carpathian region were first studied by A.S. Andreeva-Grigorovich. Here, calcareous nannofossils belonging to 13 assemblages of the Barremian-Late Eocene interval were determined [Григорович, 1971].

In 1991, A.M. Romaniv [Романив, 1991] published her monograph with a title "Calcareous nannofossils of Cretaceous and Paleogene sediments of the Ukrainian Carpathians". Here she gives the calcareous nannofossils distribution in stratotype and reference sections of the Ukrainian Carpathian region. The substantiation of the biostratigraphy of Cretaceous–Paleogene sediments applying the Standard zonation of E. Martini [Martini, 1971] was also provided.

Calcareous nannofossil research within the Carpathians was performed since the late 1960's enabled to substantiate the age determinations and distinguish a range of calcareous nannofossil biozonal subdivisions beginning from **NP1-Biantholithus sparsus** (lower part of the Danian stage) to **NP25-Sphenolithus ciperoensis** (upper part of the Chattian stage). A vast amount of publications dedicated to the distribution of calcareous nannofossils associated with the Paleogene sediments of Skyba, Dukla, Vezhana and Monasterec nappes (thrusts) and the layers of the transitional Eocene-Oligocene boundary of most tectonic units of the Carpathians [Григорович, 1971; Романив, 1991; Супрун, 2017].

It should be noted that the biostratigraphical validation of the Paleogene scheme of the Carpathian region was performed mainly based on the foraminifera [Мятлюк, 1970; Обоснование..., 1975; Иваник, Маслун, 1977; Грузман, Дабагян, 1979], while the nannofossil biostratigraphy was much less engaged. The Cretaceous/Paleogene boundary (Middle-Striy-Upper-Striy subsuites) in the Skyba and Boryslav-Pokuttya nappes is justified according to the results of the nannofossil distribution research (Андреева-Григорович, 1994). Within the Vezhana nappe of the southern slope of the Carpathians, the calcareous nannofossil biostratigraphy proved the absence of an unconformity between the Yarmut (Maastricht) and the lower parts of the Metova suites [Андрєєва-Григорович, Гнилко, Гнилко, 2012; Супрун, 2017].

Paleoenvironmental research based on calcareous nannofossil assemblages was conducted by S.A. Lulyeva [Люльева, 1978], A.S. Andreeva-Grigorovich (1991), N.A. Savitska [Савицька, 1996], A.S. Andreeva-Grigorovich, N.A. Savitska [Андреева-Григорович, Савицкая, 1998].

Development of calcareous nannofossil zonal biostratigraphic scales

Calcareous nannofossils are a formal group that combines the fossil remnants of single-celled Haptophyte algae and calcareous remains (nannoliths) of unknown origin, whose size is less than 60 microns (<60 μ). Their distribution and productivity depends mainly upon environmental factors, such as temperature (0-30°C) and salinity (3-36 ‰) regimes. Calcareous nannofossils are characterized by rapid evolution, cosmopolitism and high sensitivity to environmental (climate) changes, making them indispensable for purposes of biostratigraphy and correlation of rock units, as well as, during reconstructions of paleoecological environments of the sedimentary basin.

Since the outer skeleton of the nannofossils is carbonate their maximum distribution is typical for the low and medium geographic latitudes. Haptophyte algae are rock forming organisms (see Figure) and generate biogenic carbonate sediments. In some Cenozoic carbonate rocks, the amount of coccoliths can sometimes reach 99 %. Pure coccolith oozes are extremely rare; usually, they are form a combined component with the foraminifera and depending on the quantitative predominance form the coccolith-foraminifera or foraminifera-coccolith varieties of rocks (Лисицын, 1974). Coccoliths are an important component of marine phytoplankton in subpolar and warm waters, and it is in these waters that they are more diverse, while towards the poles this diversity is significantly reduced. Coccoliths are absent in the Arctic and Antarctic waters.

The development of nannofossil biozonation is based on the evolution of Haptophyte algae and

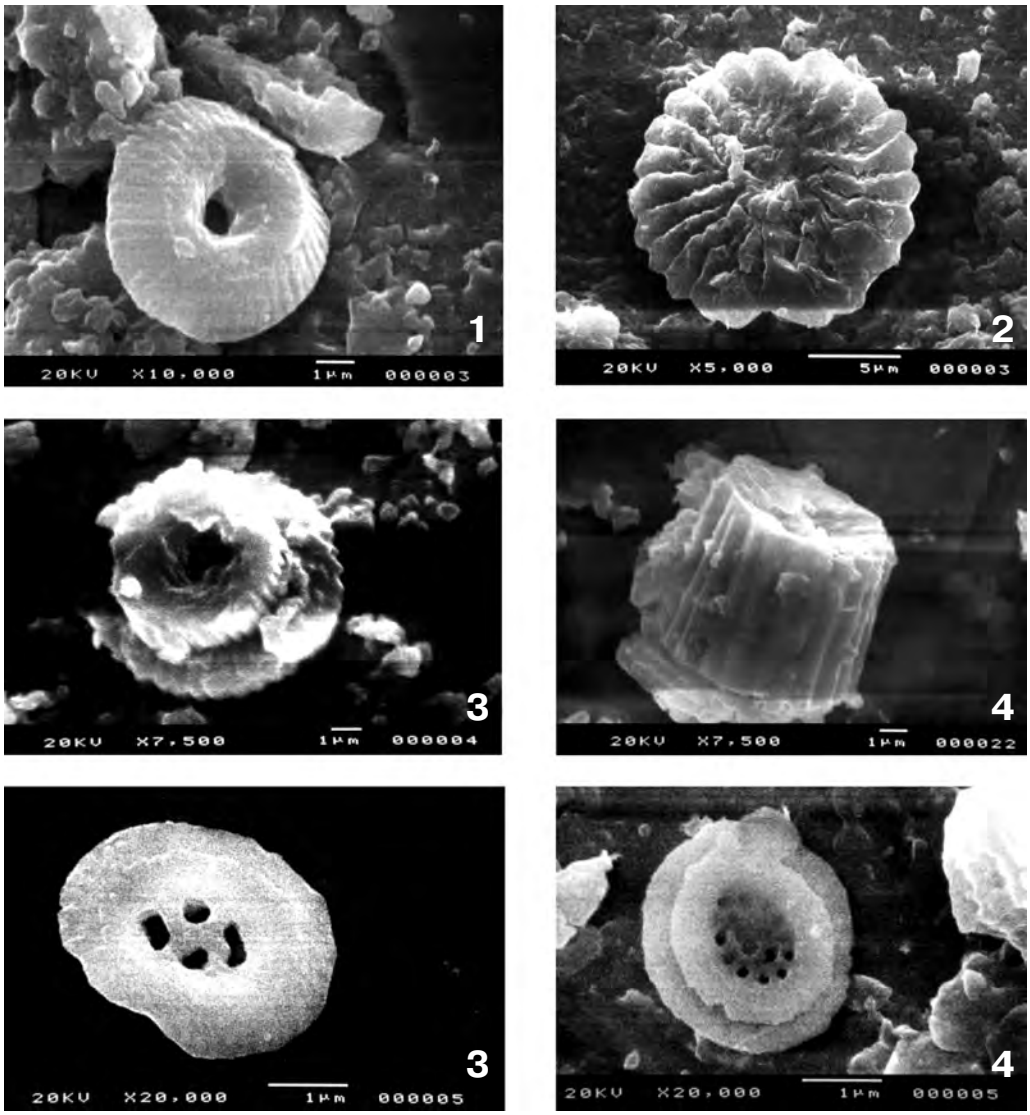

Figure. Typical representatives of Paleogene rockforming nannofossils:
1 — Coccolithus pelagicus, NP2-Extant; 2 — Discoaster multiradiatus, NP9-NP11; 3 — Heliolithus kleinpellii, NP6-NP8; 4 — Fasciculithus tympaniformis, NP5-NP10; 5 — Chiasmolithus bidens, NP6-NP11; 6 — Toweius pertusus, NP4-NP14. Photo by I.S. Suprun

their relation to the changes of hydrological and paleoenvironmental conditions in the Paleogene basins. Paleogene sediments are subdivided into number of nannozones based on which diverse stratigraphic units can become subject for further detailed stratification. A ***biostratigraphic zone*** – is a group of rocks containing an assemblage of fossil organisms (zonal assemblage) that differs from other assemblages specific to the underlying and covering sediments [Стратиграфічний..., 2012].

The most reliable calcareous nannofossil biozonations were developed as a result of the research performed onboard of the scientific vessel «Glomar Challenger» within the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Project (ODP) from the JOIDES Resolution drilling research vessel. Numerous offshore well sections encountered Paleogene deposits which formed under different depths and climatic zones in the Atlantic, Pacific and Indian Oceans and in inland seas enabled to identify each of the selected nannofossil zone. The detail and thoroughness of the correlations of biozonation charts developed on the basis of this group of microorganisms are equivalent to those biozonation charts for planktonic foraminifera, and in some cases they even supplement and detail them.

Local and regional stratigraphic schemes for Paleogene sediments of different areas of the US and Europe based on calcareous nannofossil biostratigraphy have been established (Bronnimann, Stradner, 1960; Bramlette, Sullivan, 1961; Sullivan, 1964, 1965 et al.) This zonation was later included into the biozonation of the Cenozoic of W. Hay, H. Mohler, P. Roth, R. Schmidt and J. Boudreaux (Hay et al., 1967). The Danian-Eocene section of the scheme was developed by H. Mohler and W. Hay (Hay, Mohler, 1967, 1969), while the Lower Oligocene section – by P. Roth and W. Hay. Thus, all known at that time data on the stratigraphic distribution of nannofossils of the Danian-Eocene interval coming from numerous European stratotype sections of Denmark, France, Switzerland, Italy, Austria, Crimea, North Caucasus and United States of America (California, Texas, Mississippi, Alabama), Mexico, Barbados, Trinidad, Cuba were analyzed.

The scheme developed by W. Hay and H. Mohler from the very start had not only a regional, but an intercontinental importance. Due to this, the distribution of nannofossils from many sections of the various regions was examined.

In the zonation proposed by W. Hay and H. Mohler most nannozones had been characterized by representative nannofossil assemblages. However, in all cases the boundary limits of the zones were determined not by general changes in the nannofossils assemblage, but only based on formal levels of first occurrences (FO) or last occurrences (LO) of some index-species.

Subsequently, this approach in establishing biozonal boundaries proposed by W. Hay and H. Mohler, was applied predominantly in all of the next nannofossil biozonal scales: D. Bukry, M. Bramlette (1970), E. Martini [Martini, 1970, 1971], D. Bukry (1971, 1973, 1975), S. Gartner (1971), A. Edwards (1971), P. Roth (1971) which is a reflection of the concept of «datum-levels» («dated levels»). In a sequence of changes in levels established in separate sections, stratification and correlation of Paleogene deposits are performed. It is supposedly assumed that the same name «dated levels» are synchronous within the studied region or regions, but in reality their stratigraphic position in different regions and even in different sections of one region is heavily controlled by many factors, such as, climatic, ecological, facial, palaeobathymetry, structural and tectonic, morphometric, diagenesis et al.

Currently, there are two commonly used calcareous nannofossil standard zonations that have a global status. The first one – the zonation of E. Martini [Martini, 1970, 1971] – is based on the results of the study of sections located on the continents. According to this zonation, the Paleogene is divided into 25 nannozones (NP), of which 9 are of the Paleocene, 11 are Eocene and 5 are Oligocene. The second – the biozonation of D. Bukry (1973) that was developed on the basis of deep-water drilling materials, where 24 zones were selected from the study of the Paleogene from oceanic sections, and subsequently a number of these nannozones were subdivided into subzones (Okada, Bukry, 1980). These zonations intercorrelate well with each other and with the foraminifera zonal divisions, and also with the paleomagnetic scales of the International Stratigraphic Scheme.

The standard zonation of E. Martini [Martini, 1970, 1971] is widely used for biostratigraphic purposes of the Paleogene. Compared with the zonation of W. Hay and H. Mohler (1967) its resolution is much higher as a result of the selection of new units in the Danian stage and in the upper sections of the Middle and Upper Eocene. The succession of zones in the Lower Paleocene and lower portion of the

Eocene was left unmodified. However, the Martini zonation comes with some significant disadvantages, mainly associated with the interpretation of sample data originated from incomplete sections. The conclusions done by E. Martini are based primarily on data from numerous onshore sections located in Europe. These sections are usually presented by an incomplete stratigraphy and those sections that are not always properly correlated, of shallow facies that often display unfavorable conditions for nannofossil preservation. In addition, the nannofossil study was conducted mainly on separate individual samples [Музылёв, 1980].

The zonation proposed by D. Bukry (1973, 1980) is based on a much wider data of calcareous nannofossils distribution obtained from numerous sections of deep wells located and drilled in low latitudes of the Atlantic and Pacific Oceans.

The major advantage of tropical oceanic sections is that they represent open ocean settings and are characterized by constant bionomic environments and facies conditions. Here the stratigraphic distribution of nannofossils in sediments is hardly affected by the influence of local environmental and facies conditions. The latter one is typical for sediments of epicontinental basins.

It is here, in sediments that are developed in low latitudes that a detailed nannofossil biozonation is performed and where the systematic assemblages are dominated by warm-water species (except for a small group of cold-water species). This distribution is associated with the stratification of warm- and cold-water currents. Thus, the Paleogene oceanic sediments can be considered as an ideal research polygon for estimating the spatial and temporal patterns of the nannofossil distribution.

Stratigraphic significance of calcareous nannofossils

The biostratigraphic value of calcareous nannofossils is extremely important, especially for Mesozoic and Cenozoic sediments. The group had its most intensive development during the Late Cretaceous and Eocene Epochs. The rapid change of species assemblages was caused by high rate of evolution. This enabled the application of calcareous nannofossils for biostratigraphic and stratigraphic correlation of sequences. Dramatic changes in the species assemblages took place at the Mesozoic and Cenozoic boundary, i.e., at the Maastrichtian/Danian stages. Significant rates of nannofossil evolution enabled to justify the biostratigraphy of deposits ranging from the Upper Jurassic. Biostratigraphic (zonal) units are subdivisions of the stages and based on the vertical diversity of species, genera and even larger taxa. The taxa of lower level, namely species, and rarely families are applied.

Given the spatial-temporal distribution of microfossils, and calcareous nannofossils in particular, the detailed stratification of regional and local stratigraphic units (regional stages, suites/members, strata, layers, horizon-markers) was performed, as well as their boundaries and diachroneity were substantiated.

Calcareous nannofossils are widely used in generating various stratigraphic models of the Paleogene deposits of Ukraine during various scale mapping of open (outcrop) and closed (borehole) sections. Stratigraphic and sedimentary models, as well as stratigraphic schemes of the Paleogene for Western (Carpathian) and Southern (Black Sea, Crimea, Azov-Black Sea water area) oil and gas regions were also constructed.

Today three regional stage charts for the Paleogene sediments of Ukraine have been developed. Two of these charts are for the Tethyan Province (Carpathian and Southern regions) and one chart is for the North Atlantic Boreal Province (Northern Ukraine) in which the major biostratigraphic group are the calcareous nannofossils by which the several correlation levels are selected.

An integrated biostratigraphical research of sediments (foraminifera, calcareous nannofossil, dinocysts, sponge spicules) provided a interregional correlation of Paleogene sections of various facies that are developed in the Northern, Southern and Carpathian regions. It also enabled to correlate the developed regional scheme with units of the International Stratigraphic Chart [Vandenberghe et al., 2012].

Conclusions

Calcareous nannofossils are one of the ortho-stratigraphic groups that are actively used for biostratigraphy and correlation of Paleogene sediments. One of the most reliable global scales has been developed based on this group of microorganisms. Calcareous nannofossils species, including those of the Paleocene are characterized by rapid evolution, cosmopolitanism, and sensitivity to ecological changes which makes them irreplaceable for biostratigraphy and paleoecological reconstructions of the sedimentary basins. The limits and volumes of the stages of the International Stratigraphic Chart,

regional and local stratigraphic units of remote sections have been substantiated based on this group of microfossils.

According to numerous geological and paleontological data, calcareous nannofossil biostratigraphy enables to perform a wide spectrum of tasks. These include: a) elaboration of the relative geological age; b) substantiation of the diachroneity of the boundaries of diverse stratigraphic units; c) clarification of the biozonal subdivision; d) clarification of the geological position and the conditions of the sediment accumulation of the Paleogene formations; e) The correlation levels that have been allocated from planktonic microorganisms enabled to conduct a direct correlation between the Paleogene deposits of the Carpathian-Crimean and Caspian regions and also with the International Stratigraphic Scale Chart [Vandenberghe et al., 2012].

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