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Levels of changes in the genus *Pinus* Linné in the composition of Mesozoic and Cenozoic flora and vegetation as an additional criterion for the division of sediments by the Mesozoic and Cenozoic of Ukraine

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Abstract. The article presents an analysis of a large array of results of palynological studies of Mesozoic and Cenozoic sediments of Ukraine and adjacent regions of Belarus and Russia. Numerous literature data on the palynological characteristics of Meso-Cenozoic sediments and the materials of the authors are summarized according to the results of spore-pollen analysis of Mesozoic and Cenozoic sediments within the main tectonic structures of Ukraine. It has been established that the genus *Pinus* (Pinaceae) is an integral part of the Meso-Cenozoic flora of Ukraine. Although, the participation in the flora and vegetation of the genus *Pinus* and its species diversity in different periods of geological time were different. Despite the long history and significant achievements of palynological research of Meso-Cenozoic sediments of Ukraine, no attention has been paid to the historical aspect of *Pinus* development in the Meso-Cenozoic flora. This work is presented as the first stem to fill this gap. The genus *Pinus* has a large stratigraphic range, but its species diversity and quantitative changes in the composition of Mesozoic and Cenozoic flora of different ages are markedly different. The analysis of these changes made it possible to trace the emergence and main levels at which the species composition was renewed and the role of *Pinus* in flora increased during the Mesozoic and Cenozoic. According to the results of the research, 5 levels of increasing the participation of the genus *Pinus* and changes in its species affiliation in the Mesozoic flora were established: Aalenian period of the Middle Jurassic (appearance of the first representatives of *Pinus*); Oxfordian time of the Late Jurassic; Valanginian – Early Barremian times of the Early Cretaceous; Albian time of the Early Cretaceous; Late Campanian time of the Late Cretaceous. 5 levels of increasing the role of *Pinus* and its species diversity for the flora and vegetation of the Cenozoic were also established: Oligocene time of the Paleogene, Konkian-early Sarmatian time of the Middle Miocene; early Pontian (Ivankov) time of the Late Miocene; early Kimmerian time (early Sevastopol) of the Early Pliocene and Martonosha time of the Early Neopleistocene. Certain levels have been traced for the similar age of Cenozoic flora of Belarus and Russia.

Keywords: spore-pollen analysis, Mesozoic, Cenozoic, flora, vegetation, Ukraine.

Рівні змін роду *Pinus* Linné у складі мезо-кайнозойської флори та рослинності як додатковий критерій розчленування відкладів мезозою та кайнозою України

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Анотація. У статті представлено аналіз великого масиву результатів палінологічних досліджень мезозойських та кайнозойських відкладів України і суміжних регіонів Білорусі та Росії. Узагальнено як численні літературні дані з палінологічної характеристики мезо-кайнозойських відкладів, так і матеріали авторів за результатами спорово-пилкового аналізу мезозойських та кайнозойських відкладів в межах основних тектонічних структур України. Встановлено, що рід *Pinus* (Pinaceae) є невід'ємною складовою мезо-кайнозойських флор України. Але участь у складі флори та рослинності представників роду *Pinus* та його видове різноманіття у різні відрізки геологічного часу була різною. Незважаючи на тривалу історію та значні здобутки палінологічних досліджень мезо-кайнозойських відкладів України донині не акцентувалась увага на історичному аспекті розвитку *Pinus* у складі мезо-кайнозойських флор. Представлена робота є першим кроком до заповнення цієї прогалини. Рід *Pinus* має великий стратиграфічний діапазон, але його видове різноманіття та кількісні зміни у складі різновікових мезо-кайнозойських флор помітно відрізняються. Аналіз зазначених змін надає можливість простежити появу та основні рівні, на яких відбувалось оновлення видового складу та збільшення ролі *Pinus* у флорах на протязі мезозою та кайнозою. За результатами проведених досліджень встановлено 5 рівнів збільшення участі роду *Pinus* та змін його видової приналежності у складі мезозойських флор: ааленський час середньої юри (поява перших представників *Pinus*); оxfordський час пізньої юри; валанжин-ранньобаремський час ранньої крейди; альбський час ранньої крейди; пізньокампанський час пізньої

крейди. Для флори та рослинності кайнозою також встановлено 5 рівнів збільшення ролі *Pinus* і його видового різноманіття: олігоценний час палеогену, конксько-ранньосарматський час середнього міоцену; ранньопонтичний (іванківський) час пізнього міоцену; ранньокімерійський (ранньосеvastопольський) час раннього пліоцену та мартоносський час раннього неоплейстоцену. Визначені рівні простежено і для одновікових кайнозойських флор Білорусі та Росії.

Ключові слова: спорово-пилковий аналіз, мезозой, кайнозой, флора, рослинність, Україна.

Introduction

Pinus is an integral part of the coniferous and mixed forests of the Northern Hemisphere. An important role in the modern vegetation of Ukraine also belongs to the genus *Pinus*, which refers mainly to *Pinus sylvestris* L. The forests of the western part of Ukraine (Carpathian region) also include *Pinus cembra* L. and *Pinus mugo* Turra.

Palynological studies of Mesozoic and Cenozoic sediments of Ukraine have a long history. First of all, these are the works of E. V. Semenova, G. V. Shramkova, G. G. Yanovska, N. A. Orlova-Turchyna, M. A. Voronova, M. E. Ohorodnik, O. A. Shevchuk on the study of Mesozoic sediments of Ukraine; as well as R. N. Rothman, N. O. Shchekina A. A. Michelis, O. B. Stotland – Paleogene-Neogene sediments; V. Yu. Ochakovskiy concerning Paleogene sediments; O. P. Ahulov, I. B. Maslova, V. S. Sopina, S. V. Syabryaj on Neogene sediments, S. I. Parishkury-Turlo, N. P. Gerasimenko – continental Pliocene – Quaternary sediments; O. A. Sirenko on various facies Upper Miocene-Pliocene sediments; O. T. Artyushenko, G. O. Pashkevich, R. Ya. Arap, L. G. Bezusko, E. T. Lomaeva, T. F. Christoforova, M. S. Komar, O. A. Sirenko, N. Kalynovych – continental Pleistocene sediments. According to research, the genus *Pinus* (Pinaceae) is an integral part of the Mesozoic and Cenozoic flora of Ukraine. However, the participation in the composition of flora and vegetation of the genus *Pinus* and its species diversity in different periods of geological time was different. Despite the long history and significant achievements of palynological research of Mesozoic and Cenozoic sediments of Ukraine, no attention has been paid to the historical aspect of *Pinus* development in the Mesozoic and Cenozoic flora. In this regard, the proposed work is pioneering.

The purpose of this study is to analyze and summarize a large array of literature materials and personal data of authors on palynological studies of Jurassic, Cretaceous, Paleogene, Neogene and Lower Quaternary sediments of Ukraine to identify levels of increasing role and species diversity of *Pinus* in Mesozoic and Cenozoic flora and the use of these levels for stratigraphic and correlation constructions.

The purpose of this study is to analyze and summarize a large array of literary materials and personal data of authors on palynological studies of Jurassic, Cretaceous, Paleogene, Neogene and Lower Quaternary sediments of Ukraine to identify levels

of increasing role and species diversity of *Pinus* in Mesozoic and Cenozoic stratigraphic and correlation constructions.

Materials and methods of research

During the study, materials on the palynological characteristics of various Jurassic and Cretaceous rocks obtained by O. A. Shevchuk for sections of Mesozoic sediments located within almost all major tectonic structures of Ukraine (Fig. 1) (Shevchuk 2004–2013, 2016, 2018, 2020; Dorotyak et al., 2009; Stratigraphy, 2013; Shevchuk et al., 2018), literature data on the results of palynological studies of the most representative sections of Paleogene and Neogene sediments of the northern and southern parts of Ukraine (Fig. 1) (Zosimovich, Savron, Rothman, 1980; Stotland, 1984, 1985; Michelis, 1976; Syabryaj, Shchekina, 1986; Korallova, 1962, 1968; Sopina, 1974; Shchekina 1964a, b, 1974; Shchekina, 1975, 1979), as well as the results of palynological research by O. A. Sirenko of Oligocene, various-facies Miocene and Pliocene, subaerial Eopleistocene and Lower Neopleistocene sediments of platform Ukraine (Fig. 1) (Sirenko, 2000 a, b, 2003 a, b, 2004, 2006, 2007 a, b, 2009 a, b, 2016, 2017 a-c, 2019 a, b, 2021). In order to reconstruct the Mesozoic-Cenozoic flora and perform interregional correlations, the materials of M. A. Voronova, G. G. Yanovska, G. A. Orlova-Turchyna, D. Rekhakova and others according to the results of the study of Jurassic and Cretaceous deposits of Ukraine (Orlova-Turchyna, 1966; Voronova, Yanovska 1973, 1982, 1991; Yanovska, 1973; Shramkova, 1982; Voronova, 1994; Ogorodnik, 2006; Rehakova et al., 2011), as well as results of palynological studies of Paleogene, Neogene and Pleistocene sediments of adjacent regions of Belarus and Russia (Ananova, 1974; Linkina, 2006; Rylova, 1996, 2001, 2002; Tregub, Starodubtseva, 2005; Filippova, 2002; Shpul, 1990, 2004, 2005).

The main research method was palynological: spore-pollen analysis. Stratigraphic, paleoecological and morphological methods are also used in the work.

The main problem in studying the flora of the Mesophyte is that there is currently no generally accepted classification for fossil spores and pollen of the Mesozoic. The issue of systematization and nomenclature of spores and pollen is one of the most relevant, unresolved in Mesophyte palynology. There are a large number of artificial systems that prevail today in the literature on the Mesozoic. As a result, the same taxa in different authors are listed under different

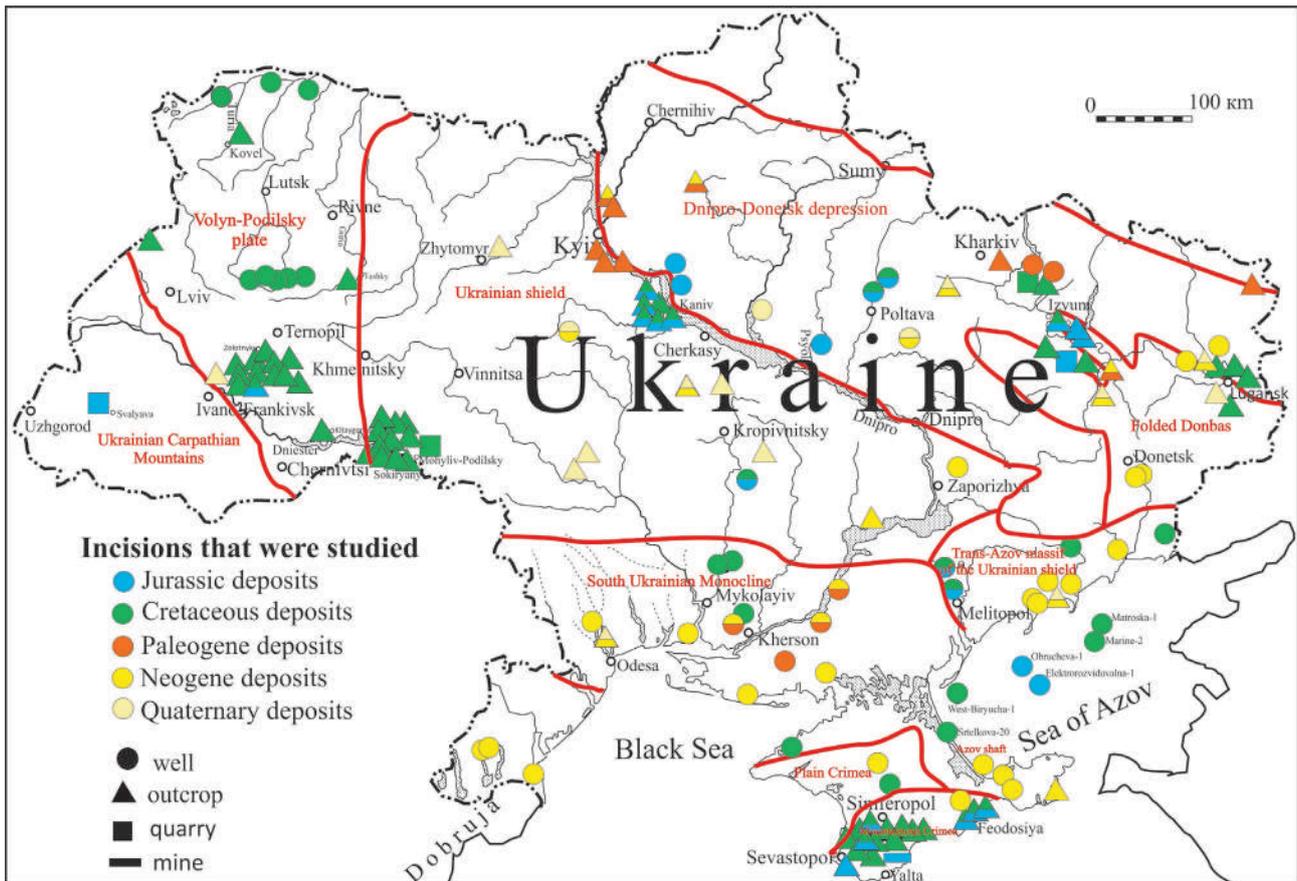


Fig. 1. Map scheme of the studied area. The map of the actual material is made according to the results of palynological researches of the Mesozoic – O.A. Shevchuk, Paleogene – O.B. Stotland, N.O. Shchekina, A.A. Michelis, O.A. Sirenko, Neogene – N.O. Shchekina, V.V. Korallova, A.A. Michelis, O.A. Sirenko and Quaternary – O.A. Sirenko.

generic and species names, and many already known species are described as new. An example of this is the genus *Pinus*. As an example, established and described by N.A. Bolkhovitina species *Pinus divulgata* subsequently described in the artificial classification as *Pinuspollenites divulgatus*. And there are many such examples. In this article, we used primary sources when the species is not re-described by artificial classification.

It is necessary to emphasize a number of important points regarding the reconstructions of the participation of the genus *Pinus* in the Cenozoic flora. The following factors were taken into account during the reconstruction of flora and paleovegetation. The high content of pine pollen in the spectra of certain sections of marine and continental sediments does not always provide an opportunity to reconstruct the level of increase of this genus in the vegetation within the entire region. In particular, it is necessary to take into account in which part of the marine paleobasin the section is located. Since the general increase in tree pollen is characteristic of deep-water sediments (Malyasova, 1976) and, accordingly, the most diverse composition of the spectra is characteristic of sediments of the central part of sea basins and the slope of the shelf. The spectra of shallow sediments are markedly depleted,

and their composition is dominated by 1–2 components. A characteristic feature of these spectra is the significant presence of pollen from aquatic and coastal aquatic plants, which may change the ratio of the main groups of pollen in the spectra. Thus, some decrease in the role of pine pollen in the spectra of the Late Oligocene complex, which characterizes the Berekian deposits of some areas of northern Ukraine, is associated with an increase in the role of Taxodiaceae, which are usually markers of local conditions. N.O. Shchekina (1983) found that fossil spectra from Upper Oligocene – Miocene sediments of the southern part of Ukraine well reflect the distance of the section from the sea shore. The farther from the shore to the depths of the sea, the more gymnosperms with air sacs and the less pollen of angiosperms and gymnosperms without air sacs. When studying subaerial sediments, it is important to take into account the geomorphological location of sections, because in the composition of spore-pollen spectra from section sediments located on river terraces and steep coasts there is always an increased content of *Pinus* pollen (Sirenko, 2017 c). Therefore, during the reconstruction of the levels of *Pinus* changes in the Cenozoic flora, materials were analyzed from sections of age-old sediments located in different parts of Ukraine

and in different geomorphological conditions. Emphasis was made on changes in the species diversity of pines and the ratios in the composition of the pollen spectra of *Pinus* spp. subg. *Haploxylon* Koexne. and *Pinus* spp. subg. *Diploxylon* Koexne. Materials of palynological researches of Cenozoic deposits of adjacent regions of Belarus and Russia were taken into account for the purpose of establishment of levels which would be traced also in the specified territories.

Main results and discussion

Mesozoic

Representatives of the genus *Pinus* originated in the Middle Jurassic period and are clearly recorded according to O. A. Shevchuk is a part of flora of all regions of Ukraine (Carpathians, Dnipro-Donetsk depression, Ukrainian shield – Bajocian, Mountain Crimea – Aalenian).

Ancient representatives of pine *Pseudopinus* spp., *Protopinus* spp. studied in the territory of Ukraine by G.G. Yanovska (Jurassic), S.B. Kuvaeva, H.A. Orlova-Turchyna, M.A. Voronova (Cretaceous) et al. (Orlova-Turchyna, 1966; Voronova, Yanovska 1973, 1982, 1991; Yanovska, 1973; Kuvaeva et al., 1973). A systematic

description of species *Pseudopinus* spp., *Protopinus* spp. is given in the works of N. A. Bolkhovitina (Bolkhovitina, 1953). The results of palynological studies of Mesozoic sediments of Ukraine are compared with the materials of the study of similar age sediments of Russia and Sweden. (Chlonova, 1974; Vajda, 2001; Rostovtseva, 2014).

Aalenian to Bathonian time is famous due to a large number of ancestral forms of *Pseudopinus* spp. and *Protopinus* spp. The most common species are *Pseudopinus pectinella* Bolch., *Pseudopinus pergrandis* Bolch., *Pseudopinus contigua* Bolch., *Pseudopinus oblatinoides* (Mal.) Bolch., *Protopinus subluteus* Bolch., *Protopinus vastus* Bolch., *Protopinus scanicus* Nilsson. At the border of Barremian and Aptian times, some single representatives of the ancestral forms of *Pinus* are noted, and then in the time range starting from the Cenomanian, they are not established (Fig. 2).

Pinuspollenites similis (Balme) M. Petr., *P. minimus* (Couper) Kemp., *P. divulgatus* Bolch. and *Pinus pernobilis* Bolch were noticed in the Middle Jurassic flora. Thus, as the first level of *Pinus* participation in the Mesozoic flora, it is possible to determine the Aalenian time.

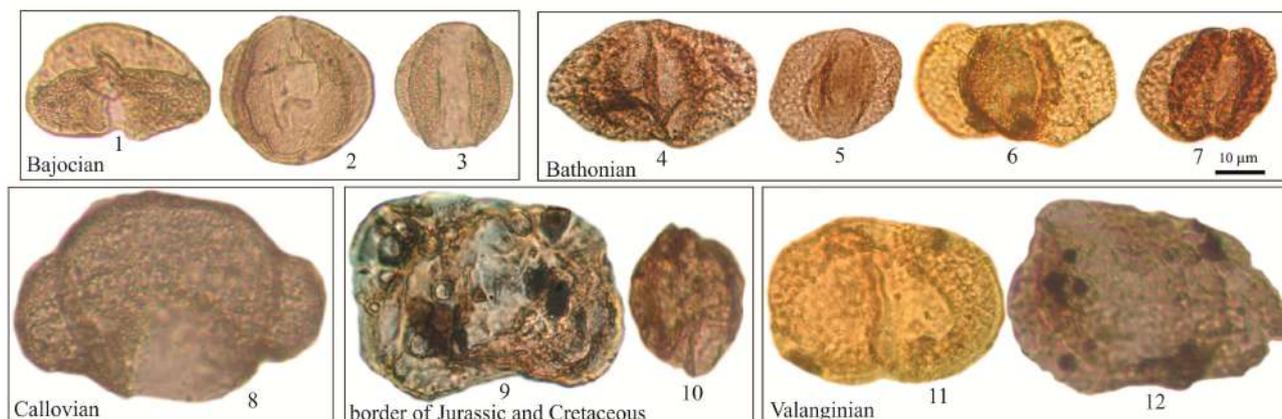


Fig. 2. Ancestral forms of the genus *Pinus* from the Mesozoic. Photos by O.A. Shevchuk. 1. *Protopinus* sp.1, Dnipro-Donetsk depression, well 8561, 191.75 m; 3. *Protopinus* sp.2, Dnipro-Donetsk depression, well 8561, 191.75 m; 2. *Pseudopinus oblatinoides* (Mal.) Bolch., Dnipro-Donetsk depression, well 8561, 191.75 m; 4. *Pseudopinus* sp., North-western outskirts of Donbas, Shevchenko hamlet, Seversky Donets river, sample 0 (1); 5. *Protopinus subluteus* Bolch., North-western outskirts of Donbas, Shevchenko hamlet, Seversky Donets river, sample 1(Б)1; 6, 7. *Pseudopinus contigua* Bolch., North-western outskirts of Donbas, Shevchenko hamlet, Seversky Donets river, sample 0 (1); 8. *Protopinus* sp.3, Ukrainian Shield, Maryanyn Yar, Kaniv, Cherkasy Region, sample 08; 9. *Pseudopinus pergrandis* Bolch., Carpathians, Pryborzhavsky quarry, sample 5; 10. *Protopinus* sp.4, Mountain Crimea, Krasnoselivka township, Kuchuk-Uzen river, pack 7, sample 3; 11. *Pseudopinus* sp., Mountain Crimea, Kuibyshev town, sample 5k; 12. *Protopinus scanicus* Nilsson, Mountain Crimea, Verkhorichcha village, sample 1.

Pinus pernobilis Bolch and *Pinuspollenites divulgatus* Bolch. played a significant role in the composition of the Late Jurassic flora of Ukraine (Fig. 3). The species composition of pines mostly remained unchanged from Oxfordian to Tithonian, except for

some new species *Pinuspollenites verrucosus* Zhang., *Pinuspollenites* spp. It is possible to establish the second level of increase in participation of *Pinus* by emergence of new types of pine as a part of flora of Oxfordian.

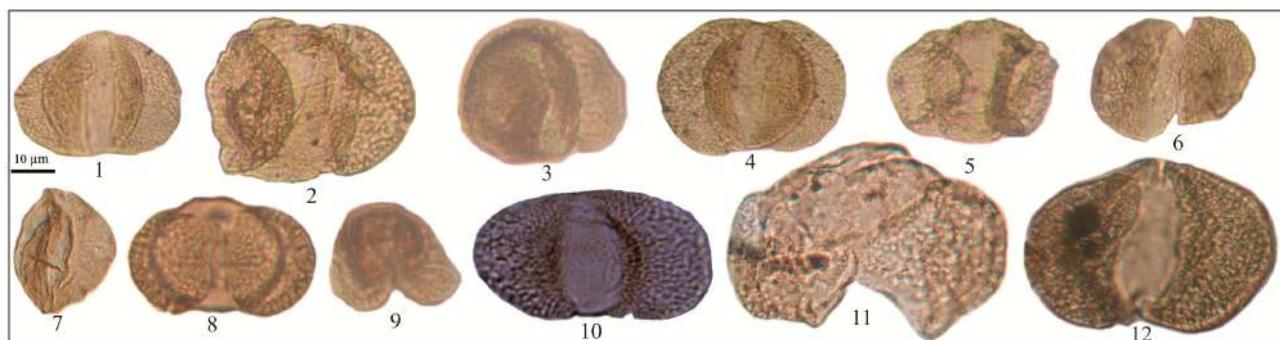


Fig. 3. Typical species of *Pinus* pollen of the Middle-Late Jurassic: Photos by O.A. Shevchuk. 1, 4. *Pinuspollenites similis* (Balme) M. Petr., Dnipro-Donetsk depression, well 8561, 191.75 m, Bajocian; 2, 5. *Pinuspollenites* sp.1, Dnipro-Donetsk depression, well 8561, 191.75 m, Bajocian; 3. *Pinuspollenites* sp., North-western outskirts of Donbas, village of Kamyanka, sample 3k (2), Tithonian; 6. *Pinuspollenites* sp.2, Dnipro-Donetsk depression, well 8561, 191.75 m, Bajocian; 7. *Pinuspollenites divulgatus* Bolch., North-western outskirts of Donbas, Shevchenko hamlet, Seversky Donets river, sample 5a(1), Bathonian; 8. *Pinuspollenites* sp.3, Dnipro-Donetsk depression, well 24673, sample 2016, Bajocian; 9. *Pinuspollenites verrucosus* Levet-Carette, North-western outskirts of Donbas, village of Kamyanka, sample 3k (2), Tithonian; 10, 12. *Pinuspollenites* sp.4, well. 8562, depth. 145,25 m, Callovian; 11. *Pinus pernobilis* Bolch., North-western outskirts of Donbas, Shevchenko hamlet, Seversky Donets river, sample 1a (1), Bathonian.

At the turn of the Jurassic and Cretaceous periods, there was a decrease in the role of pine.

During the Cretaceous, the role of *Pinus* in the flora grew from Valanginian to Barremian. The flora of this time is characterized by the greatest species diversity and number of pines: *Pinus* spp., *Pinus incrassate* Boch., *P. vulgaris* Boch., *P. exequus* Boch., *P. vulandjensis* (Naum.) Bolch. *P. exilioides* Boch., *P. insignis* (Naum.) Bolch., *P. subcohcina* (Naum.) Bolch., *Pinuspollenites divulgatus* Bolch. Therefore, this interval can be considered a surge in the development of *Pinus* and attributed to the third level.

The timing of pine diversification coincides with the evolution of angiosperms, and it is likely that competition between flowering plants and gymnosperms played a role in adaptation, which reduced species diversity and pine participation in the Late Barremian – Aptian period. In the Aptian period there was also a decrease in the participation and the role

of the genus *Pinus* due to their displacement by other important members of the group of gymnosperms – in particular *Cedrus*.

By the middle of the Cretaceous period, morphological features identified two subgenera *Pinus*: *Haploxyylon* and *Diploxyylon* (Millar, 1998). Pines of two subgenera have also been reconstructed for the Albian flora of Ukraine (Fig. 4). Increasing the role of *Pinus* spp. as part of the flora, especially due to the representatives of the subgenus *Diploxyylon* can be traced in the Albian period of the Volyn-Podilska plate, the Ukrainian Shield, the Dnipro-Donetsk basin and the Mountainous Crimea. According to M. A. Voronova, in the Albian period there are representatives of a new species *Pinus aequalis* (Naum.) Bolch. (Voronova, 1994). Therefore, the Albian period can be attributed to the fourth level of *Pinus* participation in the Mesozoic flora.

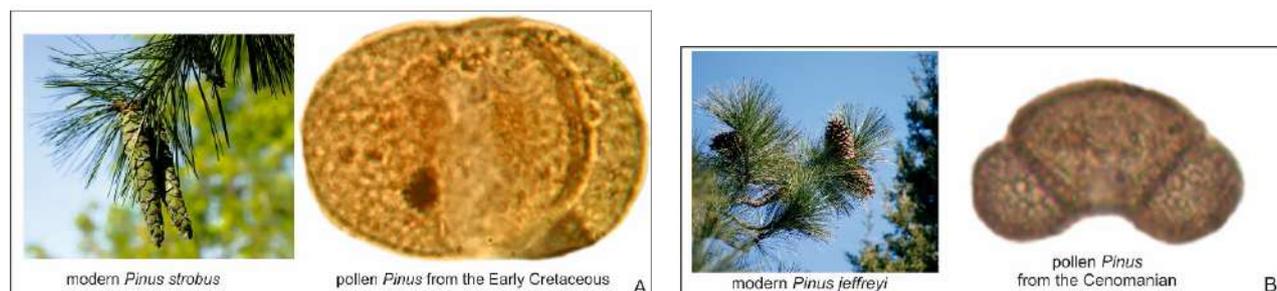


Fig. 4. Two subgenera of *Pinus*: A – *Haploxyylon*, B – *Diploxyylon* (photos by Shevchuk O.A.).

No significant increase of the role of *Pinus* in the flora and vegetation composition of the Cenomanian-Santonian interval was recorded. The following species are characteristic of the Cenomanian flora of Donbas: *Pinus concessa* (Naum.) Bolch., *P. trivialis* Naum., *P. subconcinua* (Naum.) Bolch., *P. minutula* Chl.,

P. vulgaris Naum., *P. pernobilis* Bolch.; Turonian and Santonian flora of the Volyn-Podilska plate: *Pinus trivialis* Naum., *P. vulgaris* Naum., *P. nigraeformis* Bolch., *P. exequus* Bolch. (Fig. 5).

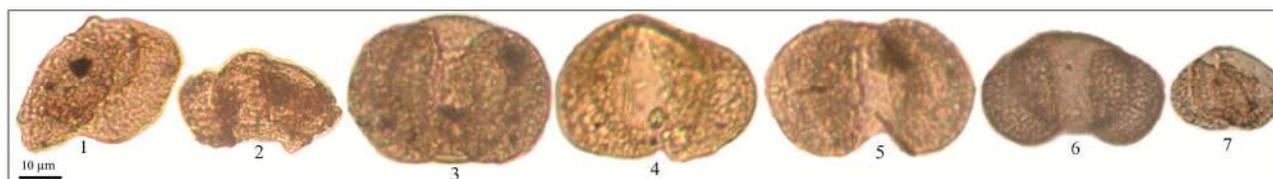


Fig. 5. Typical species of *Pinus* pollen of the Cretaceous: Photos by O.A. Shevchuk. 1. *Pinuspollenites* sp., Ukrainian Shield, Melanchine Stream, Vyrzhivsky layers, sample 6, Albian; 2. *Pinus concessa* (Naum.) Bolch., Ukrainian Shield, Kholodnyy ravine, sample 07, Albian; 3, 5. *Pinuspollenites* sp., Volyn-Podilska plate, well 42, sample 9, Turonian; 4. *Pinus exequus* Bolch., Volyn-Podilska plate, well 42, sample 9, Turonian; 6. *Pinus vulgaris* Naum., Donbas, Glafirovka village, Luhansk region, sample 2, Cenomanian; 7. *Pinus subconcinua* (Naum.) Bolch., Volyn-Podilska plate, well 4606, sample 1, Santonian.

The fifth level of increase in the composition of pines in the Mesozoic flora, as well as a slight change in their species composition is timed to the end of the Campanian. The flora of the Late Cretaceous period is characterized by a significant participation of *Pinus vulgaris* Boch., *P. subconcinua* (Naum.) Bolch., *P. concessa* (Naum.) Bolch. Representatives of *Pinus* cf. *minor* Loudon appeared during the Campanian – Maastrichtian times.

At the boundary of the Cretaceous and Paleogene both the number and the species of pines decreased.

Cenozoic

Studies show that that a significant place in the composition of the Cenozoic flora belonged to the genus *Pinus*, especially in the Late Oligocene, Early and Middle Miocene flora.

The role of *Pinus* in the flora grew from the Early to the Late Paleogene (Stotland, 1974). The beginning of the dominance of this genus corresponds to the Eocene-Oligocene boundary. However, the largest species diversity of *Pinus* is typical for the Oligocene. The flora of this period is characterized by a significant participation of *Pinus* spp. subg. *Haploxyylon*, and among them – *Pinus* sect. *Mirabilis*. Anan. At the same time, it should be noted that the dominant role in the pine forests of Ukraine belonged to the subgenus *Diploxyylon*. However, according to N. O. Schekina (1986), the number of representatives of this subgenus increased from the Oligocene by the end of the Pliocene, and the presence of *Pinus* subg. *Haploxyylon* decreased accordingly in this direction. According to the study of Paleogene and Neogene sediments of the north-western part of the Dnipro-Donetsk depression, as the part of the Late Oligocene flora *Pinus* subg. *Haploxyylon* recorded a significant involvement (Sirenko, 2003 b). The dominance of pines in the Late Oligocene flora of the south-eastern slope of the Voronezh antecline is indicated by V. G. Shpul (2005). According to T. B. Rylova (2001) in the Late Oligocene flora of Belarus is also dominated by various species of *Pinus*, but they belong largely to the subgenus *Haploxyylon*. Analyzing the materials regarding the increasing role

of representatives of thermophilic species *Pinus* subg. *Haploxyylon* in the Oligocene flora of the north-western part of the Dnipro-Donetsk depression (Sirenko, 2003 b) and Belarus in comparison with other regions of Ukraine, it is possible to assume that the number of representatives of this subgenus in the composition of the same age flora increases in the western direction and may be associated with an increase in humidity. We have observed the same pattern for the Pliocene and Early Neopleistocene flora of Ukraine and Belarus (Sirenko, 2017 c).

Thus, the Oligocene time can be determined as the first significant level of *Pinus* participation in the Cenozoic flora. This level is clearly visible, both for the flora of different parts of Ukraine and for adjacent regions. The following representatives of *Pinus* are typical for the Oligocene flora: *Pinus cembraeformis* Zakl., *P. cf. protoembrae* Zakl., *P. cf. sibirica* Mayr., *P. cf. singularis* Mayr., *P. cf. koraiensis* Sieb. at Succ., *P. cf. cristata* Panova, *Pinus* sect. *Mirabilis* Anan., that according to the classification of O. A. Ananova (1974) and T. B. Rilova (1980) includes *Pinus mirabilis* (Rudolph.) Anan., *Pinus tertiaria* (Moreva) Anan. and *Pinus pusillus* Rilov. Dendroflora were also components *P. sp. sect. Cembrae* Spach, *P. sp. sect. Strobis* Shaw., *P. sp. sect. Taeda* Spach.; *Pinus* spp. subg. *Haploxyylon* Koehne., *Pinus* spp. subg. *Diploxyylon* Koehne.

Pinus also played a significant role in the flora of the Early and Middle Miocene. The species composition of pines has largely remained unchanged since the Oligocene, with the exception of some species (for example, *Pinus cf. koraiensis* Sieb. at Succ. was practically absent in the Miocene flora, and *P. cf. cristata* Panova after the Karagian time of the Middle Miocene, was only a single representative of the dendroflora of the middle Sarmatian time).

The second level of significant increase in the composition of pines in the Cenozoic flora, as well as a marked change in their species composition is timed to the end of the Middle Miocene (Konkian and, especially, early Sarmatian times). *Pinus baileyana* Trav., *P. veronica* Anan., *P. gigantea* Anan. appear at the Konkian time. The flora of early Sarmatian times has

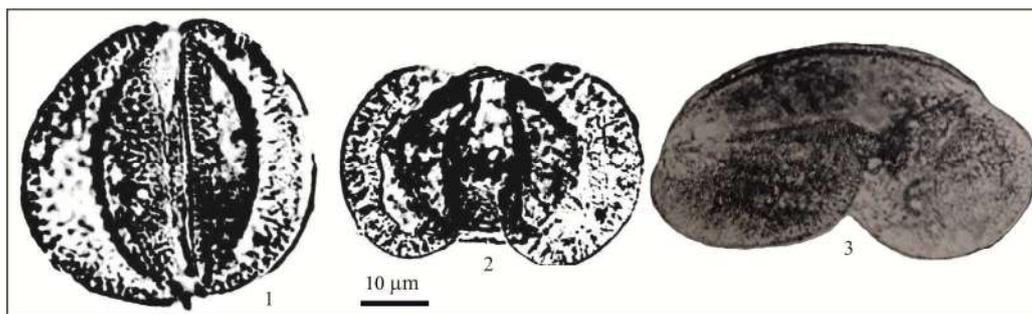


Fig. 6. Typical species of *Pinus* pollen of the Oligocene deposits. Photos by O.B. Stotland: 1. *Pinus* cf. *mirabilis* (Rudolf.) Anan. Dnipro-Donetsk depression, Oligocene; 2. *Pinus* cf. *protocebra* Zakl., Dnipro-Donetsk depression, Oligocene; photos by N.O. Shekina: 3. *Pinus* cf. *sibirica* (Pall) Mayr., South Ukrainian Monocline, Oligocene.

the greatest species diversity and number of pines: *Pinus mirabilis* (Rudolf.) Anan., *P. baileyana*, *P. Ruthenica*, *P. veronica* Anan., *P. minutus* Zakl. (Korallova, 1962; Syabryaj, Shchekina, 1983; Shchekina, 1979). According to N.O. Shchekina in the early Sarmatian pine forests of the subgenus *Diploxylon* belonged to the *Sula*, *Banksia*, *Taeda* sections (Shchekina, 1979). Similar patterns of flora have been observed for the territory of the North-Eastern Priazovye and the Lower Don (Ananova, 1974). According to V.G. Shpul (1990), the flora of the late Ivinsky and early Gurivsky times of Middle Miocene of the Volga-Hopper interfluvium, which correspond to the Konkian and early Sarmatian in Ukraine, is dominated by various *Pinus*, similar in composition to the Konkian and early Sarmatian of Ukraine. This level can also be traced for the Miocene flora of Belarus (late Burnosky time) (Palinozone brns5) (Rylova, 2001, 2002), which corresponds to the early Sarmatian in Russia. Regarding the participation of *Haploxylon* and *Diploxylon* in the flora, the materials of different researchers differ slightly. In particular,

N.O. Shchekina (1979) in the characterization of spore-pollen complexes corresponding to the lower Sarmatian sediments of Ukraine indicated the predominance of pollen of the subgenus *Diploxylon* (which was up to 40%), as well as a slightly lower content of pollen *Pinus* subg. *Haploxylon* (without specifying its percentage). Instead, O.M. Ananova (1974), in characterizing the similar age complexes of the southern part of the Russian plain, noted the predominance of pollen *Pinus* subg. *Haploxylon*, which belonged to 5 species (including *Pinus mirabilis* and *Pinus tertiaria*) in contrast to the three species *Pinus* subg. *Diploxylon*. This conclusion is confirmed by the materials of V.G. Shpul according to the characteristics of the Lamkinska series of the Oka-Don plain (spore-pollen complex III, which corresponds to the Lower Sarmatian deposits of Russia and Ukraine) (Shpul, 2004). The common thing to all analyzed materials is that the flora of early Sarmatian times differed significantly in the number of pine and their species diversity.



Fig. 7. Typical species of *Pinus* pollen of the Middle Miocene deposits (Konkian-lower Sarmatian). Photos by N.O. Shekina: 1. *Pinus* cf. *rutenica* Anan., Ukrainian shield, lower Sarmatian; 2. *Pinus* cf. *tertiaria* (Moreva) Anan., South Ukrainian Monocline, lower Sarmatian; 3. *Pinus* cf. *veronica* Anan., South Ukrainian Monocline, lower Sarmatian; 4. *Pinus* cf. *mirabilis* (Rudolph) Anan., South Ukrainian Monocline, lower Sarmatian; 5. *Pinus* cf. *banksiana* Lamb., Ukrainian shield, lower Sarmatian.

The next level of increase in the role of *Pinus* was traced at the end of the Miocene (Novorossiysk time of the Pontian of the southern part of Ukraine and Ivankiv time – in Northern Ukraine). This period is characterized by the dominance of pines in the flora, as well as their significant species diversity. It should be noted that the species of pines typical for the flora of the Konkian and early Sarmatian times, namely: *P. baileyana*, *P. ruthenica*, *P. veronica*, are no longer typical for the

early Pontian flora. *Pinus mirabilis* Anan. is singly noted only in the dendroflora of the Kerch Peninsula (Sirenko, 2003 a). The flora of these stages was dominated by representatives of the subgenus *Diploxylon*: *Pinus* sp. sect. *Eupitys* Spach (dominated) *P. sp. sect. Sula* Mayr., *P. sp. sect. Taeda*, *P. sp. sect. Pseudostrobus*., *P. sp. sect. Banksia* Mayr., *P. longifoliaformis* Zakl., but the role of *Pinus* spp. subg. *Haploxylon*. in the composition of forests was still quite significant: *P. pusillus*., *P. sp. sect.*

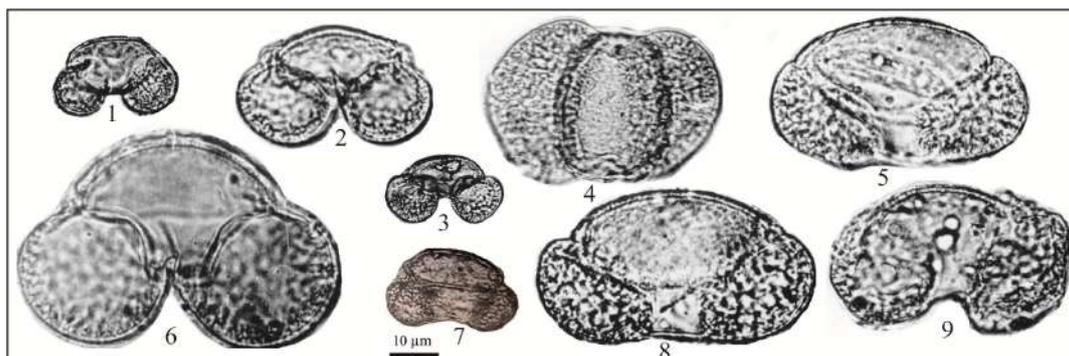


Fig. 8. Typical species of *Pinus* pollen of the Upper Miocene (lower Pontian (Novorossiysk), (Ivankiv)) and Lower Pliocene deposits (lower Kimmerian (early Sevastopol)). Photos by O. A. Sirenko: 1. *Pinus minutus* Zakl., Dnipro-Donetsk depression, Upper Miocene; 2. *Pinus* sp. subg. *Diploxylon* Koehne., Dnipro-Donetsk depression, Upper Miocene; 3. *Pinus* cf. *longifoliaformis* Zakl., Folded Donbas, Upper Miocene; 4. *Pinus* sp. subg. *Haploxylon* Koehne., Dnipro-Donetsk depression, Upper Miocene; 5. *Pinus* sp. sect. *Cembrae* Spach., Folded Donbas, Lower Pliocene; 6. *Pinus* sp. sect. *Strobus* Shaw., Folded Donbas, Upper Miocene; 7. *Pinus* sp. sect. *Sula* Mayr., Dnipro-Donetsk depression, Upper Miocene; 8. *Pinus* sp. sect. *Taeda* Spach., Dnipro-Donetsk depression, Upper Miocene; 9. *Pinus* sp. sect. *Cembrae* Spach., Dnipro-Donetsk depression, Lower Pliocene.

Cembrae., *P.* sp. sect. *Strobus*. This level is well traced both within Ukraine (Shchekina, 1979) and Russia (Taman Peninsula) (Ananova, Volkova, Zubakov, etc., 1985).

The next level of increase in the participation and species diversity of *Pinus* in the flora corresponds to the early Kimmerian Pliocene of southern Ukraine and the early Sevastopolsky time of northern Ukraine. Within the southern and northern parts of platform Ukraine and within the Kerch Peninsula at this time the forest type of vegetation prevailed, the dominant role in the forests belonged to pines, in species composition close to the forests of early Pontian time: *Pinus* spp. subg. *Diploxylon*, *P.* sp. sect. *Banksia*, *P.* sp. sect. *Eupitys*, *P.* sp. sect. *Taeda*, *P.* sp. sect. *Sula*, *P. longifoliaformis*, *P. minutus* Zakl., *P.* sp. sect. *Cembrae*, *P.* sp. sect. *Strobus*. It should be noted that *P.* sp. sect. *Taeda*, *P. minutus* are no longer typical for the flora of the Late Pliocene and Pleistocene of Ukraine. This level is also observed for the early Kimmerian flora of Russia (Taman Peninsula) (Filippova, 2002).

Increasing of the role of *Pinus* spp. as a part of flora, especially at the expense of representatives of the subgenus *Diploxylon* is traced in the early Kuyalnik time of the Late Pliocene of the southern part of Ukraine and the Kyzylar and early Bogdanivka time of its northern and northeastern parts. It should be noted that analogues of the spore-pollen complex from Kyzylar sediments have not been established among the complexes that characterize the lagoon-marine sediments of Ukraine. In the Neogene section of the Trans Asov massif, there is a break in sedimentation between the Kimmerian and Kuyalnik deposits (Semenenko, 1987). The composition of the dendroflora changed dramatically during the

Kuyalnik time. The main component of forests was *Pinus* spp. subg. *Diploxylon*, heat-loving species of the subgenus *Haploxylon* were almost completely absent. This level correlates well with the level of dominance of pine and the general impoverishment of the flora of the early Sokolsky time (SPC VII) of the Middle Volga region. (Linkina, 2006). In the early Bogdanivka time, there was also an increase in the role of pines in the dendroflora, but in the forests dominated by *Pinus* spp. subg. *Diploxylon*, a few members of the subgenus *Haploxylon* already appear. A similar pattern is inherent in the dendroflora of the early Kuyalnik time of southern Ukraine, as well as the middle Sokolsky time (SPC VIII) of the Middle Volga region (Linkina, 2006) and the early Sukhodolsky time of the Volga-Hopper interfluvium (SPC X) (Shpul, 1991). Thus, the established regularity of significant impoverishment of the dendroflora of the Late Pliocene of Ukraine, which also concerns its main component – the genus *Pinus*, is well compared with that for the European part of Russia. According to A. O. Velichko and co-authors (2011) in the landscape of the territory of the European part of Russia clearly records the cooling at the turn of 3.4 million years, which is probably traced in Ukraine in the Kyzylar time. Although, given the lack of analogues of Kyzylar sediments in the marine context of the Pliocene of Ukraine at this stage of research, we consider it appropriate to identify a combined Kyzylar early- Bogdanivka level of changes in the role of *Pinus* in the dendroflora, which generally corresponds to the early Kuyalnik stage of the Black Sea region of Ukraine and the early Akchagylian stage of the Caspian region of Russia.

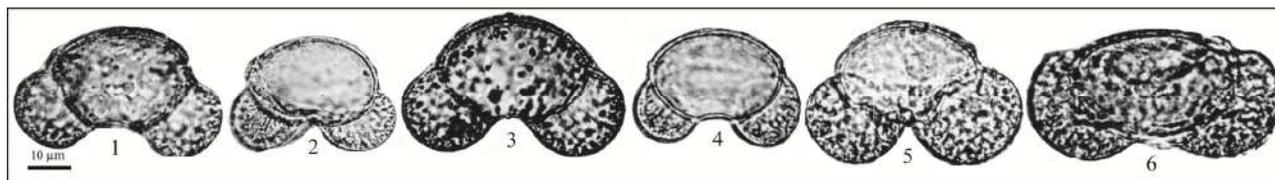


Fig. 9. Typical species of *Pinus* pollen of the Upper Pliocene and Lower Pleistocene deposits. Photos by O. A. Sirenko: 1. *Pinus* sp. sect. *Eupityis* Spach., Dnipro-Donetsk depression, Upper Pliocene; 2. *Pinus* aff. *sylvestris* L., Folded Donbas, Upper Pliocene; 3. *Pinus* sp. sect. *Eupityis* Spach., Folded Donbas, Upper Pliocene; 4. *Pinus* aff. *sylvestris* L. Folded Donbas, Lower Pleistocene; 5. *Pinus* sp. sect. *Strobis* Shaw., Folded Donbas, Upper Pliocene; 6. *Pinus* sp. sect. *Cembrae* Spach., Folded Donbas, Upper Pliocene.

A significant increase in the role of *Pinus* in the composition of flora and vegetation is also recorded in the Kryzhanivka time of the Eopleistocene. However, due to the fact that in Kryzhanivka time there was a fairly pronounced zonation of plant cover and the established pattern was not observed for all regions of Ukraine, we consider it acceptable not to allocate this level as a benchmark.

The next level of increasing the role of *Pinus* in the dendroflora is timed to the first warm stage of the Early Neopleistocene (Martonosha). The vegetation type of the central, north-eastern and western parts of Ukraine was dominated by forest vegetation. Pines played a dominant role in the dendroflora of all, without exception, regions of Ukraine: *Pinus* spp. subg. *Diploxylon* (prevailed), *P. spp.* sect. *Eupityis*, *P. longifoliaformis*, *P. spp.* sect. *Strobis*, *P. spp.* sect. *Cembrae*. This level is well traced both for the territory of Ukraine and adjacent regions of Russia (Tregub, Starodubtseva, 2005) and is characterized by the most significant representation of the genus *Pinus* in the Early Neopleistocene flora, its diversity and noticeable presence of *Haploxylon*.

Conclusions

The genus *Pinus* has a large stratigraphic range, but its species diversity and quantitative changes in the composition of different ages of Mesozoic and Cenozoic flora differ markedly. The analysis of these changes makes it possible to trace the emergence and the main levels at which the species composition was renewed and its role in the flora increased during the Mesozoic and Cenozoic.

The Mesozoic flora has 5 levels, which characterize the increase in the participation of the genus *Pinus* at different ages, among which the two levels are most pronounced. In particular, the appearance of the first representatives of *Pinus*, the Aalenian time (Middle Jurassic), is clearly recorded in the flora of the territory of Ukraine. Also, an important moment in the development of Mesozoic flora – the Albian time (Early Cretaceous), when the representatives of *Pinus* split into two generic groups – subgenus *Haploxylon* and *Diploxylon*.

5 levels of increasing the role of *Pinus* and its species diversity for the flora and vegetation of the Cenozoic were also established: Oligocene time of the Paleogene, Konkian-early Sarmatian time of the Middle Miocene; early Pontian (Ivankiv) time of the Late Miocene; early Kimmerian time (early Sevastopol) of the Early Pliocene and Martonosha time of the Early Neopleistocene.

Participation of representatives of *Pinus* spp. subg. *Haploxylon* and *Pinus* spp. subg. *Diploxylon* in the composition of the Cenozoic flora was different. In general, the tendency to reduce the role of pines of the subgenus *Haploxylon* in the composition of flora from the Paleogene to the Pliocene, established by N.O. Schekina (1986) is traced, but at certain stages of nature development (early Sarmatian and early Pontian of Miocene, early Kimmerian of Pliocene) recorded an increase in the number of representatives of this subgenus and its species diversity compared to the older flora.

A comparison of the composition of the Cenozoic flora of Ukraine and the adjacent regions of Belarus and Russia indicates the existence of a pattern of growth of the role of *Pinus* in the composition of forests from southwest to east and northeast.

The determined levels of changes in the composition of *Pinus* in the development of Mesozoic and Cenozoic flora are well traced not only within different regions of Ukraine, but also typical for the flora of adjacent regions of Belarus and Russia.

The traced levels can be used as benchmarks for stratigraphic divided of Mesozoic and Cenozoic sediments of Ukraine and their correlation with the similar sediments of other regions.

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