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# PALEOGENE AMBER PLACERS IN THE ADJACENT TERRITORIES OF POLAND, BELARUS AND UKRAINE

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*The paper presents the modern geological and genetic model of amber-bearing deposits of Poland, Belarus and Ukraine in combination with the concept of the prognostic and prospecting system of amber. It is determined that this system depends on the modern ideas about the genesis of fossil resins and actual data on the development of the investigated territory in the Paleogene, which has a fundamental influence on the methodological basis of forecasting and searching for new deposits. The results of the field and desk studies of 1991–2020 allowed us to detail the stratigraphic features of amber-bearing deposits and to revise the key sites and reference sections within the study area, to perform correlation analysis of the stratigraphic confinement, geological settings and preconditions of amber deposits formation in the Paleogene deposits.*

## INTRODUCTION

Amber placers of various scale and age have been known for a long time from the territory of Poland, Belarus and Ukraine. A number of attempts have been made to reconstruct their stratigraphic succession, interpret their origin, establish search criteria and determine the scales at which amber raw materials are manifested. The most promising regions have been defined in the three countries and a theoretical base for the solution of local search tasks has been prepared in general. At the same time, according to the leading amber experts of the second half of the 20th century [26; 52; 57; 60], these territories were considered as not very promising for many years due to the alleged accumulation of only secondary repeatedly redeposited placers. According to their opinion, the Baltic Shield territory was the main and only source of amber placers in the area between the Baltic and the Black seas, and the so-called Baltic Paleogene amber tail area became gradually exhausted with the increasing distance from the primary source.

In the 1990s – early 2000s, several amber-producing territories have been recognized in the Paleogene, resulting in distinguishing a large number of separate placers [2; 3; 23; 24; 41; 48]. The Eocene-Oligocene marine transgression was supposed to approach not only from the northwest, but also from the southeast, e.g. along the present-day Dnipro River. These data significantly change our ideas on the paleogeography in the southern part of the world's largest amber-bearing province, the facies regime of amber accumulation, and the prospects for searching new amber placers. This work considers the spatial-temporal and facies diversity of the formation of amber-bearing deposits in the adjacent territories of Poland, Belarus and Ukraine. Productive successions are correlated and the directions of further amber prospecting are substantiated.

## MATERIAL

The authors have analyzed numerous published and archive materials concerning the peculiarities of location of resin accumulations and individual finds, materials of geological survey, exploration and prospecting works, on this basis, paleogeographic reconstruction of the conditions of their formation was performed and the most important search features for resin occurrences of different ages were determined. The research is based on the analysis of data from 38 wells drilled on the territory of Poland, 194 – Belarus, and 45 – Ukraine coupled with author's dataset and literature references [2; 10; 25; 41; 48; 51]. Formation, lithological-facial, paleogeomorphological, mineralogical, petrographic, granulometric methods, as well as basics of lithogenesis theory to reveal sedimentation, diagenesis, catagenesis and peculiarities of formation of granulometric and material composition of continental, transitional and marine deposits were used.

## STRATIGRAPHIC POSITION AND CORRELATION OF THE AMBER-BEARING DEPOSITS

The study area is located within several conjugated units building the sedimentary cover of the East European Platform: the Mesozoic-Cenozoic cover of the Ukrainian Shield (northern and northwest slopes), the Volhynia-Podolia plate (northern part of the Volhynia-Odessa

Homocline, Lviv-Lublin Paleozoic Depression and Volhynia Paleozoic Elevation), the Podlasie-Lublin fault-block zone (Lukówsko-Ratnovsky Horst) being a part of the North-Ukrainian megazone of activation determined by L.S. Haletskyi [16], the Podlasie-Brest Trough and the Polissia Saddle [38; 39; 58]. The North-Ukrainian zone has been dynamically active from the Early Proterozoic till present. Intensive deformation within its limits in the Phanerozoic, which are reflected in a horst-and-graben structure, led to the development of marine transgressions and redistribution of loose material in individual sedimentary basins.

The study area within Ukraine geomorphologically belongs to the Southern Polissia region [50] of accumulation lowlands (subareas of the Prypiat-Volhyn, Zhytomyr and Kyiv moraine-outwash plains), the Volhynia-Podolia area of layered denudation levels and accumulative sandy plains (subareas of the Volhynia denudation plain and Small Polissia alluvial-fluvio-glacial plain). In Belarus [36], the study area is located within lowlands and plains of the Pre-Polissia and Polissia Lowlands (subareas of the Belarusian and, partially, Ukrainian Polissia in the extreme south), and in Poland – within the Middle Polish Lowlands with a denudation moraine, fluvio-glacial and lacustrine-glacial relief and the presence of depressions marking glacier runoff, and within Lublin Polissia to the northeast of Lublin. The long evolution of the landscape has predetermined specific features for the sedimentation of amber-bearing deposits and amber concentration in paleogeomorphological traps. For example, in the Paleogene of the Prypiat-Volhyn subarea of moraine-outwash plains, there were several levels of amber accumulation (Obukhovian, Berekian horizons) in the Volhynia denudation plain; in the Zhytomyr moraine-outwash plain, amber was mainly accumulated in the Mezhyhirian horizon.

Paleogene amber placers in the study area were formed in the Eocene and Oligocene. Deposits of this age were observed in numerous sections and have a complex setting, related with subsequent transgressive and regressive cycles and local deformation. In the Ukraine they include the Kyivian, Obukhovain and Mezhyhirian horizons, in Belarus – the Kyivian and Kharkivian horizons (the latter corresponding to the Obukhovian and Mezhyhirian horizons), and in Poland – the Semen Formation (Figs. 1, 2).

Deposits of the Kyivian horizon are widely distributed, they do not occur only on the elevated parts of the Ukrainian Shield and the Volhynia-Podolia Plate due to washout and exaration during neotectonic processes. The lower part of the horizon comprises green phosphoritized poorly sorted sands of different tints, with pebbles of crystalline rocks, phosphorites and marcasite concretions; the upper part includes light gray, bluish and greenish marls gradually passing into clay limestones, micaceous carbonized clays, glauconite quartz sands and sandstones. The average thickness of these deposits is ~15 m. The Middle Eocene age of the Kyivian horizon is based on pollen assemblages and algal flora. Moreover, it yielded a relatively representative community of foraminifera [12; 13; 19], corresponding to the P12 (*Acarinina rotundimarginata*) and P14 (*Globigerina turcmenica*) zones. Sediments of the Kyivian horizon include abundant and diverse (> 100 species) calcareous nannoplankton including key taxa enabling to relate the sediments to the *Chiphragmalithus alatus* and *Discoaster tani nodifer* nannoplankton zones (NP15–NP16). Joint overlapping of the stratigraphic ranges of the P12–P14 and NP15–NP16 zones points to the Middle Eocene (late Lutetian–Bartonian) age of the Kyivian horizon, which is confirmed by K-Ar geochronology on authigenic glauconite at 38.5–45.0 Ma [37]. The composition of microfauna in deposits comprising the lower part of the Kyivian horizon correlates them to the upper Lutetian; independent age determinations include nannoplankton studies indicating zone NP16 and dinoflagellate studies pointing to zone D9 [64]. Deposits of the Kyivian horizon yield numerous sponge spicules, e. g. *Sterraster fabeformis, Sphaeraster paucus, Amphiaster aculeatus, Ophioxea robusta, Orthomesotriaena ordinaria humila, Protriaena permodesta, Discoides simmetricus, and Plagiotriaena nulla* that point to the upper part of the Lutetian-Bartonian interval. Cornacuspongida, the majority of which lived on tidal marsh soils, prevail. Among Tetraxonida small trienes are predominant. The listed features enabled to easily determine these deposits in Paleogene successions [20].

Deposits of the Obukhovian horizon in the study area are represented by glauconite quartz sands and argillo-arenaceous aleurites, greenish and bluish gray in color, with interlayers of clays resembling the underlying rocks of the Kyivian horizon, and also by non-calcareous glauconite sands, glauconite mica clays, aleurite clays, clay aleurites, reaching a thickness of ~15 m. The contact with the overlying sediments of the Mezhyhirian horizon is defined by an uneven surface, the presence of phosphorite pebbles, gravel and interlayers of coal clays. Mollusks, foraminifera, nummulites, radiolarians, sponge spicules, diatoms, dinoflagellates and palynomorphs have been studied from the Obukhovian sediments. The pollen assemblage is similar to that from the Kyivian horizon; angiosperm pollen dominates and gymnosperms are represented mainly by Pinus, among which the thermophilic species *Pinus mirabilis* Anan, *P. balejana* Travers, *P. cembra* L., and *P.* cf. *ruthenica* Anan have been determined [34; 42].

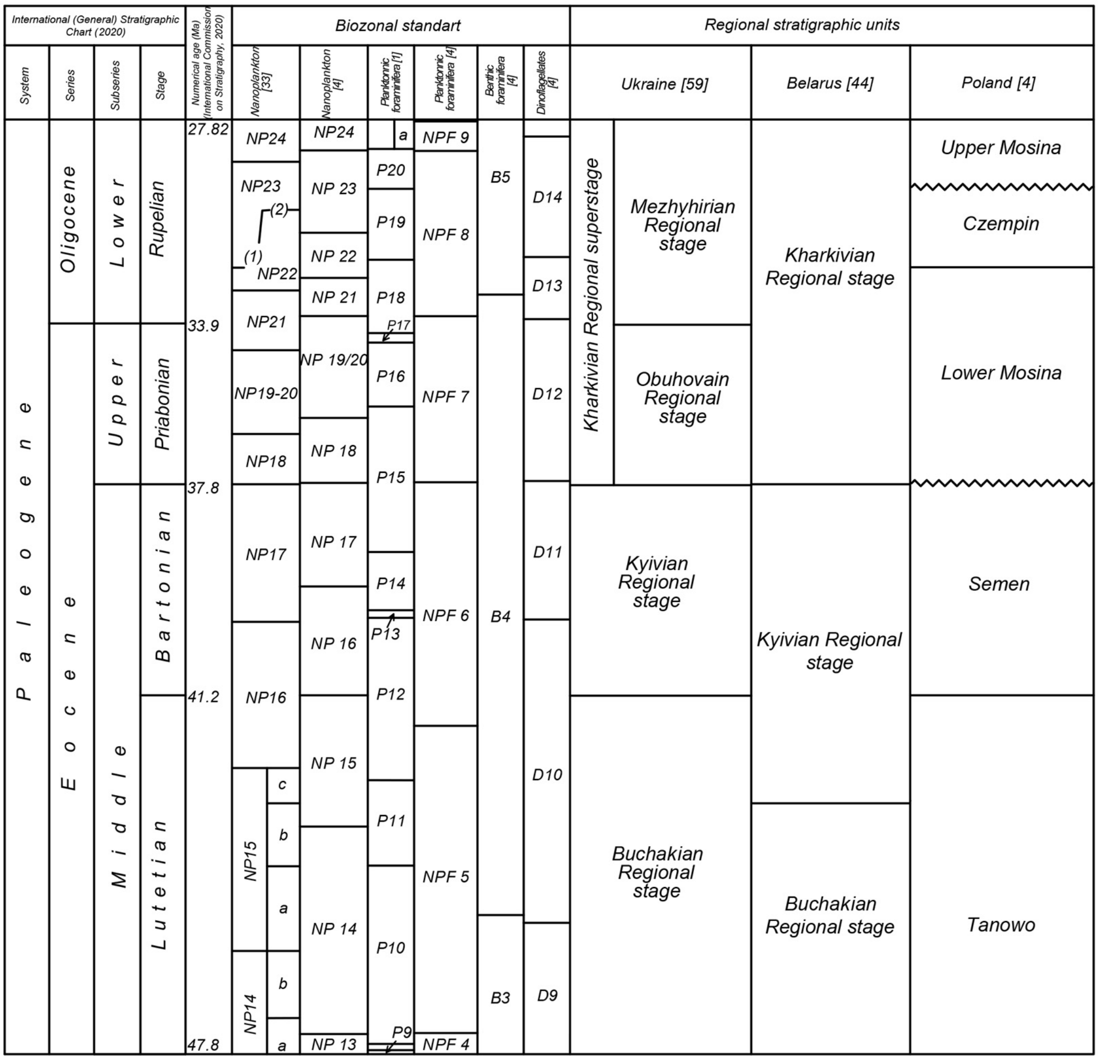


**Figure 1** – Stratigraphic correlation of amber-bearing deposits [1; 4; 33; 44; 59]

Deposits of the Mezhyhirian horizon in the study area are represented by uniform fine-grained glauconite quartz, micaceous non-calcareous sands with insignificant interlayers of sandy aleurites, rarer clays, and with a thickness of ~5 m. In the region of Klesiv village, macrofossils including cones of coniferous trees of the Pinaceae: *Pinus thomassiana* (Goepp), *P. paleostrobus* (Ett.) Heer, *P. parabrevis* Killper, *P. echinostrobus* Sapporta, and *P. spinosa* Herbst have been found in their base [34; 42]. In general, the pollen and spore assemblage in the Mezhyhirian horizon is dominated by representatives of the gymnosperm families Pinaceae [59], Taxodiaceae, and Sciadopityaceae, which contribute to 62–91 % of the assemblages; representatives of angiosperms: *Fagus*, *Castanea*, *Castanopsis*, *Quercus*, and *Carpinus*, etc. have also been noted. On the crystalline rocks of the Ukrainian Shield deposits of the Mezhyhirian horizon representing dinocyst zone D 13 [64] are developed as grey and light grey sands with yellowish, greenish and brownish tints, green aleurites and aleurite clays with glauconite and a large amount of amber, deposited on weathered magmatic rocks overlapped by a thin layer of Quaternary sediments. Interlayers of poorly sorted humus sands with thin interlayers of brown coals and lignites, in places with amber inclusions, often compose the basal part of the horizon. In some cases, the lower part of the succession is composed of poorly sorted sands with numerous phosphorite concretions, interlayers of gravels and ferruginous sands [59]. Average-sized spicules of Tetraxonida with a disintegrated skeleton prevail, the spicules of Hexactina and Pentactina being almost absent. Spicules of Cornacuspongida are not present. The sponge spicules have been noted in the lower part of Mezhyhirian succession comprising clays and aleurites, pointing to shoaling of the basin [20].

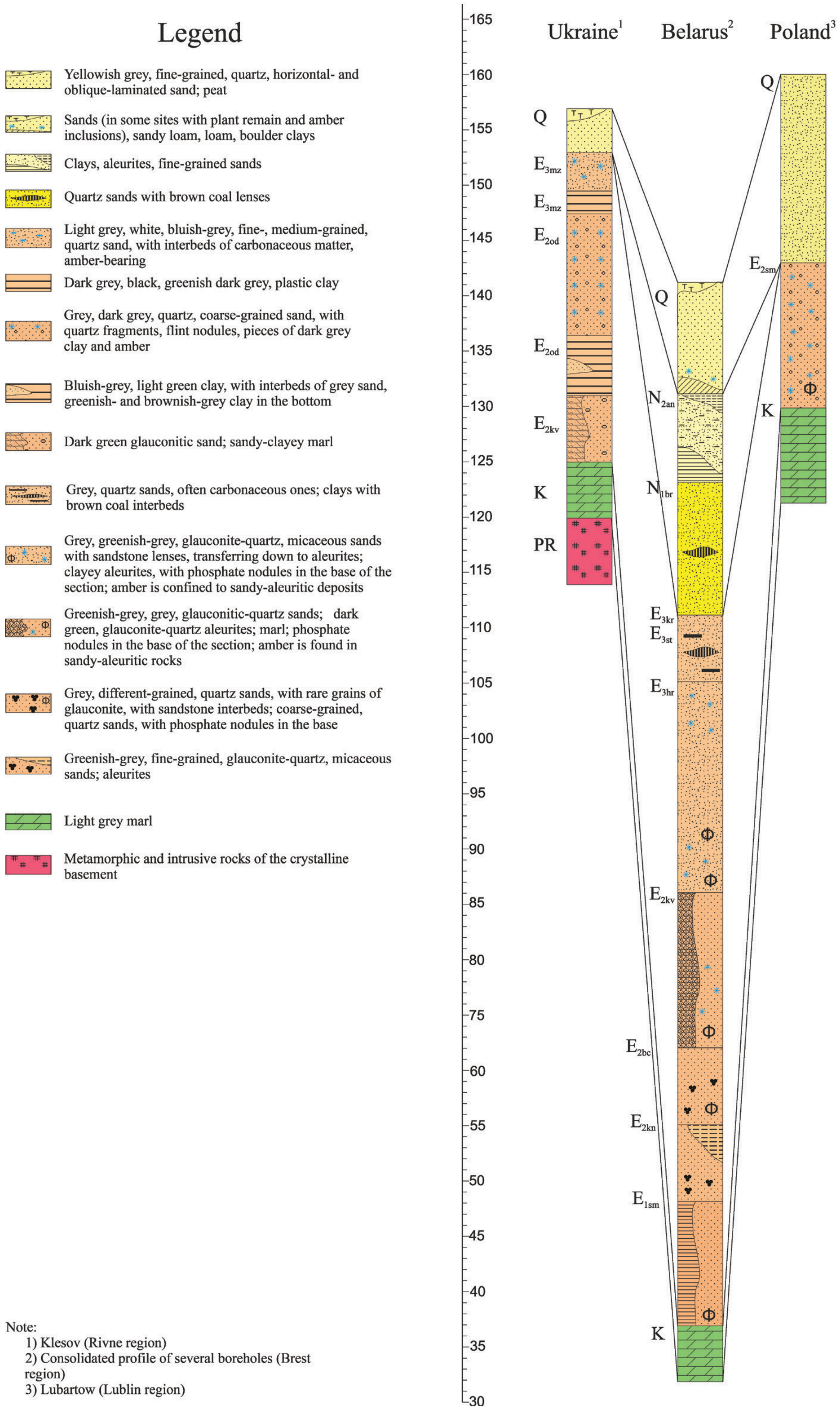


**Figure 2** – Geological structures of amber-bearing deposits in the adjacent territories of Poland, Belarus and Ukraine [2; 10; 25; 51]

In Belarus, deposits of the Kharkivian horizon, whose age was based on the study of spores and pollen, algal flora, mollusks and sponges, and confirmed with isotope geochronometry, correspond to the Obukhovian and Mezhyhirian of Ukraine. Two pollen assemblages were distinguished. The first is characteristic of the lower part of the Kharkivian horizon and is very similar in taxonomic composition to the Obukhovian. The early Eocene (Priabonian) age of deposits in the lower part of the Kharkivian horizon is confirmed by microphytoplankton, diatoms, silicoflagellates [19] and sponges. The isotope age of authigenic glauconite is at 37.0, 37.5 and 38±2 Ma [37]. The second pollen assemblage characterized by the presence of angiosperms and gymnosperms is similar to the assemblages from the Mezhyhirian horizon. Thus, according to paleontological data, the age of the Kharkivian horizon is late Eocene – early Oligocene (Priabonian-Rupelian). The average thickness of the Kharkivian horizon reaches 20–25 m, laterally thinning out to 5–10 m [44].

Deposits of the Semen Formation represented by glauconite quartz sands with quartz gravel, pieces of amber and phosphorites, aleurites and clays with traces of glauconite and amber, and also by calcareous sandy loams with fauna were related to the late Bartonian in the 1960s based on macrofauna [62]. The age of the lower part of the Semen Formation was based on the assessment of planktonic foraminifera *Globirapsis (Globiratheka) semiinvoluta* (zones NPF6–7) and nannoplankton (zones NP16–NP17) [45; 46]. The boundary of the middle and upper Eocene is also confirmed by study of core samples of the Lubartów L-3 and Kostomloty K-1 boreholes performed by experts from the Polish Geological Institute in 1996, when foraminifera represented by the benthic taxa *Pyramidulina minor*, *Vaginulina alzanensis*, *Lenticulina dimorpha* and *L. grodnensis* [17] was described. Microfauna of the upper part of the succession is typical of the *Truncatorotaloides robri* Zone and confirms its early Eocene age [47].

The conducted palynological studies [18; 53; 56] showed that the Semen Formation can be assigned to the uppermost part of the middle Eocene – Bartonian, and partially also to the lowest part of the upper Eocene – lower Priabonian. The presence of a marine microplankton assemblage was confirmed in 1996 in the C-3 well log. It comprises taxa characteristic for the Bartonian, such as *Heteraulacysta parosa*, confirming dinocyst zone D11, and characteristic for the Priabonian *Aerosphaeridium diktyoplokum* and *Rhomboidinium perforatum,* pointing to dinocyst zone D12 [61].

A relatively rich nanoplankton assemblage occurs in the Semen Formation. Studies performed in 1996–1997 in the Kostomloty K-1 borehole established the existence of a nannoplankton assemblage with the key species *Chiasmolithus gigas* and *Dicroaster sublodensis* representing the upper Lutetian zone NP15 [15] being the oldest deposits of this formation. Thus, the beginning of the Eocene transgression in this region should be dated at the middle Lutetian. In the upper part of the succession, the presence of nannoplankton assemblages of zones NP16 and NP17 [30; 45; 46] was established. In the succession of the Sokolian trough on the northern slope of Roztocze (to the south of the study area), deposits of this formation yield a Bartonian nannoplankton assemblage of zone NP16 [15] and directly around the Semen Lake – calcareous nannoplankton of zones NP17 and NP18 [14].

The association of heavy minerals in deposits of the Semen Formation belongs to the tourmaline-zircon complex with andalusite and topaz characteristic of the upper Eocene, with some differences including increase in garnet contribution that reflects the connection of Eocene strata with the source area of the Ukrainian Shield [6]. The studies 2016–2017 have confirmed the similarity of transparent mineral associations from successions of the Semen Formation in Poland and Paleogene sediments (Mezhyhirian, Obukhovian horizons) from the Novi Petrivtsi outcrop in Ukraine [25; 51]. This data shows that the sediments studied were formed from the weathering of pegmatites and metamorphic rocks in the Ukrainian Shield. Results obtained in 1996–1997 [40] have confirmed the age of the minerals in this formation. Radiometric studies of deposits of the Semen Formation [5; 32] indicated the ages of 39.5±3.0 Ma, 41.7±0.4 Ma and 42.2±3.0 Ma pointing to the late Eocene, which is fully concordant with the results of biostratigraphic analysis. The average thickness of the deposits reaches 16 m [4; 58].

## PALEOGEOGRAPHIC SETTING AND CONDITIONS FOR THE FORMATION OF AMBER PLACERS

The development of the study area in the Eocene – Oligocene (Fig. 3) is generally connected with the general paleogeographic evolution of the East European Platform and they resulted from global geodynamic processes and are defined by the position of the area with regard to particular lithospheric plates. In this interval, the disintegration of Pangea II, Gondwana in particular, had already come to an end and the distribution of continents and oceans resembling modern geography had begun to be shaped. On the Eurasian continent, a wide strip of dry land extended from the Central French Massif to the Ukrainian Shield as a result of the formation of Laramian elevations. This landmass separated the North Sea Trough from the troughs adjoining the Tethys Ocean [28].

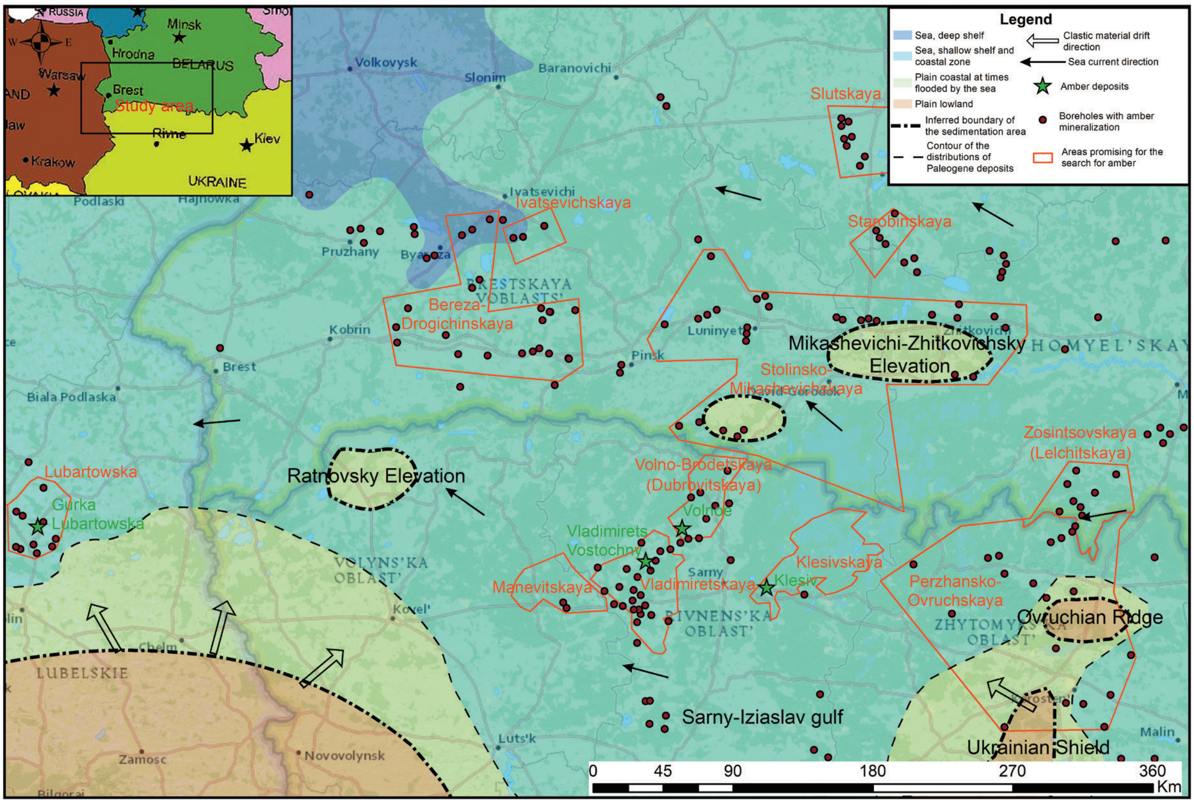


**Figure 3 –** Paleogeographic map of the Kharkivian time (late Eocene – early Oligocene) with forecast of amber-bearing [2; 10; 25; 41; 48; 51]

In Kyivian time (late middle Eocene) the basins located in the Prypiat-Dnipro region and in the west of Belarus became connected for the first time in the Paleogene. A large marine basin that covered a land area near the Ukrainian Shield in the form of the submeridional Sarny-Iziaslav gulf was formed. The northern coastline of this basin reached the present-day latitude of Minsk; in the south the sea occupied the northern slopes of the Ukrainian Shield, with the Ovruchian Ridge and a number of elevations to the west of it as islands. However, a large part of the study area covered by the sea remained rather shallow. The thickness of the Kyivian horizon seldom exceeds 10–15 m. On the other hand, in such considerable large basin, lateral facies variability (sands – clay sands – aleurites – marls) reflecting a transition from coastal areas and elevations to the deepest parts of the shelf is clearly manifested. This succession of facies was often disturbed by sea currents, similar to present-day alongshore currents of inland seas, and by paleorivers. For example, the deltaic sands and pebbles of the large paleoriver flowing from the Ukrainian Shield replaced marine marls and aleurites in the succession on the northern slope of the Ratnovsky Elevation [8]. In depressed lowland areas marls were accumulated at depths of up to 300 m. To the coast they pass into clay glauconite-quartz, often calcareous aleurites. Poorly sorted monomineral quartz sands were accumulated on the sea margins. In the most complete successions, the Kyivian horizon is represented by diverse facies pointing to transgressive, inundation, and regressive settings. The land area surrounding the Kyivian Sea most likely represented a slightly elevated and slightly incised lowland plain.

In Kharkivian time (late Eocene – early Oligocene) the study area was covered by a sea which was the last and most extensive of the Paleogene seas; its appearance was preceded by a short break in sedimentation, as testified by the sharp contact between the aleurites of the Kyivian horizon and the glauconite quartz sandstones of the Obukhovian horizon. The absence of an angular unconformity, and the presence of washout and abrasion traces points to the development of an ingression characteristic of platform regions with a flat lowland relief. The Kharkivian Sea represented a large channel-zone connecting basins of the Dnipro-Donets Depression and Western Europe. The sea basin had a maximum surface area in the late Eocene. In the south, the Kharkivian Sea encroached far into the interior of the Ukrainian Shield. At the end of the Eocene, the sea became much shallower, but remained in the territory of present-day Belarus. In the early Oligocene (Rupelian) it became even shallower and its area was gradually reduced. This process was interrupted by short-term ingressions confirmed by the formation of rhythmic alternations of sand and aleurite (in the regions of Kobryn and Kamenets towns in the Podlasie-Brest Trough) [8]. Despite that, the connection between the basins of the Dnipro-Donets Depression and the Baltic Syneclise through the Polissia Saddle and the Podlasie-Brest Trough was not disturbed till the end of the early Oligocene.

The Kharkivian Sea which occupied a larger area than the Kyivian Sea was considerably shallower (the average depth of the basin was estimated at 60–100 m) [27]. Shallow terrigenous regressive sediments began to develop in place of relatively deep-water marine carbonates of the middle Eocene. They are represented by rather monotonous strata of non-calcareous glauconite quartz sands, with a low mica and a variable clay and iron content, sometimes with a clay-siliceous matrix, and attaining an average thickness of up to 20–25 m. The thickness is reduced to 5–10 m above basement elevations in places of active post-sedimentary washout and exaration. The Kharkivian Sea abounded with shallows and banks. Large islands were exposed above the sea-level in the Mikashevichi-Zhitkovichsky Elevation, Lukówsko-Ratnovsky Horst, Polissia Saddle, and the northern part of the Ukrainian Shield; the Ovruchian Ridge and a series of elevations to the west of it: Dyvlynske, Mykolaivske, Yurovske, Zhubrovychi, etc., were also exposed above sea-level. A set of small islands and submarine highs reaching 40–50 m in height appeared in places where local structures developed. The seabed of the Kharkivian Sea did not contain any significant depressions, characteristic for the middle Eocene Kyivian Sea; which can be connected with the fact that at the turn of the middle and late Eocene these areas experienced some uplift. Individual areas of plunging seabed could have been present near the Ovruchian Ridge from which amber deposits (Koziuli, Syrnytska) are known. Gradual shoaling and shrinking of the sea area in the early Oligocene, interrupted by ingressions, resulted in continuous migration of the coastline. The coastline was also affected by tectonic activity, as marine currents developed in tectonic depressions. Changes in the composition of sponge spicule assemblages testify in favour of this conclusion [20].

The sedimentary conditions in the Paleogene basin of Middle Polish Lowlands, where amber deposits were discovered near Lublin, were specific. Computer modeling has shown that a graben existed here during the late Bartonian – early Rupelian. It was filled with shoreface sand sediments formed along the faults bounding the graben and washed up by littoral waves. Tidal current activity occurred in the axial part of the graben. When tectonic activity of the graben ceased, it became buried with regressive sands overlapping with coastal gravels. Later, the strata were removed by Pleistocene glacial erosion [11].

It should be noted that a reservoir is in the closest connection with the surrounding catchment area, reflecting features of its sediments. The main criterion for the determination of catchment areas supplying material to ancient basins is the petrographic and mineral composition of the terrigenous sediments. Despite differences in the location, size and depth, the stability of debris source areas is characteristic of the Kyivian and Kharkivian seas.

The grain-size composition of coastal sediments represented by poorly sorted sands with low contribution of gravels and pebbles, and also their small thickness testifies for insignificant elevation and a rather flat relief of the eroded land. Lack of breaks in sedimentation in the peripheral parts of the basins and traces of underwater slumps of coastal sediments point to a rather calm tectonic regime.

Intrusive, metamorphic and sedimentary rocks, and weathering crusts developed on these complexes from the early Precambrian to the Late Cretaceous compose the geological structure of the source area. Thick Upper Cretaceous chalk and marl deposits widely covered successively older rocks in most of the study area. Crystalline basement rocks and Proterozoic sandstones were exposed only in the Lukówsko-Ratnovsky Horst, the Mikashevichi-Zhitkovichsky Elevation, and in the NW part of the Ukrainian Shield.

These rocks to a varying degree participated in the formation of sediments of the Kyivian and Kharkivian seas. However, repeatedly washed and redistributed Upper Cretaceous rocks played a key role, as shown by comparative lithological and mineralogical studies [8]. This is confirmed by the poverty of heavy and secondary minerals, a typical homogeneity of accessory minerals common for the Paleogene and Cretaceous rocks, and the degree of increasing the roundness of the rock minerals. Admixture of material from disintegrated crystalline rocks is present during different stages of evolution of the Paleogene seas. The petrographic composition of the gravel-pebble fractions, and also the presence and distribution areas of the non-rounded, especially unstable minerals testify for its origin.

Clasts of gravel-pebble material are of largest interest from this point of view. Therefore, gravels composed of sandstones, Ovruchian quartzites and blue quartz typical of metamorphic and intrusive rocks of the Osnitskyi and Perzhanian complexes of the Ukrainian Shield and rocks of the same age of the Mikashevichi-Zhitkovichsky Elevation appear in the base of the Kyivian horizon. At the same time, small fragments of granites, diorites, quartzites, sandstones, and mica schists appear in deposits along the southern slope of the Belarusian Anteclise. In the clasts, the presence of feldspars represented by plagioclases and microcline may be also observed, which is unusual for Paleogene strata.

Gravel-pebble clasts of crystalline rocks with a significantly high specific weight and therefore with low ability for displacement point to local sources of drift. Apart from them, rocks of the Kyivian and Kharkivian horizons contain also amber derived from the area of active amber formation within the Ukrainian Shield. Amber-bearing deposits are developed along the entire southern sea coast. Based on facies analysis [8], high amber concentrations were genetically connected with deltaic deposits. Within the study area two deltas have been recognized – the Klesiv delta where the amber deposits are connected with the Obukhovian and Mezhyhirian horizons, and the Parchev delta with amber-bearing deposits of the Semen Formation [15; 57]. Following sea-level fluctuations, the resin deposits in deltas and lagoons were washed out by alongshore currents, whose directions were defined mostly by monsoon winds as in the Baltic Region [9]: in winter – by southeast winds, and in summer – by northwest winds. The wide distribution of resins results from their small density and high buoyancy. Amber became concentrated in quiet coastal sites (gulfs) or within seabed hollows.

Limited data on the sources of terrigenous material is provided by the mineralogy of clastic grains in sands and aleurites. Metamorphic rocks of the Ukrainian Shield considerably enriched the marine sediments with sillimanite, staurolite, kyanite, tourmaline, garnets and leucoxenes. A number of specific features clearly distinguishes the sediments of the Kyivian and Kharkivian horizons. The Kharkivian horizon contains double the amount of garnets, triple – of leucoxene and tourmaline, tenfold – of sillimanite, and does not have pyroxenes and amphiboles in the association. Obviously, a replacement of the eroded rocks took place on the Ukrainian Shield at the end of the middle Eocene.

Thus, analysis of the sedimentary basin recharge has shown that the landmass surrounding the Kyivian and Kharkivian seas had a hydrographic network consisting of rivers transporting debris from the Belarusian Anteclise, Ukrainian Shield, Mikashevichi-Zhitkovichsky Elevation, Lukówsko-Ratnovsky Horst, Polissia Saddle and other emerged areas. Sea paleocurrents played a major role in debris distribution during the maximal sea-levels.

The existence of brown coal and lignite interlayers in the lower part of the Mezhyhirian horizon (and its analogs in adjacent areas) indicates the interrelation between the processes of coal formation and evolution of land vegetation. Such interlayers are known in ancient alluvial sediments in the periphery of the Ovruchian Ridge [49]. Three stages of fossil resin transformation have been distinguished: 1) land-marsh, 2) marine, 3) surface and underground catagenesis. Considering the specific paleogeographic conditions in the Dnipro brown-coal basin, in the early middle Eocene (characterized by warm humid subtropical climate, low flat relief, dominance of boggy watersheds and littoral forestlands) soil formation was replaced by bogging and peatland formation where protoamber was formed. Following washout of brown coal and placer formation in the glauconite-bearing setting, protoamber attained the characteristics of amber-succinite [35].

Debris with resin of coniferous trees, growing in the Eocene in a subtropical and warm-temperate climate on vast areas from the Elbe River to the Urals and from Scandinavia to the Black Sea coast, was transported by rivers from the landmasses located in the regions of the Meta-Carpathian Swell and the Ukrainian Shield. In some river mouths small deltas were formed in the area from the present-day Vistula River valley to the Prypiat River sources. In their distal parts, resiniferous protoamber-bearing deposits were accumulated in favorable hydrodynamic conditions [10; 31]. Later, these deposits were eroded and the resins became dispersed by marine alongshore currents. After diagenesis they were redeposited as amber in the barrier facies of regressive upper Eocene and lower Oligocene sediments [22]. This conclusion is drawn from the analysis of the paleogeography of the source areas, in particular a rather narrow neck of land between the epicontinental Eocene sea of Northeast Europe and the Paratethys where there was no place for the development of large rivers. The marginal (distal) parts of alongshore barriers formed by repeatedly redeposited material occur along the Siedlce-Bielsk Podlaski line to the west [23; 24].

Resin diagenesis took place in the littoral zone of a shallow shelf sea with normal salinity [63]. The common glauconite distribution in amber-bearing formations and the finds of marine fauna in all amber manifestation's points to the solely marine environment of amber accumulation. Most likely, areas of primary amber accumulation were located further to the south, as evidenced by a coastal zone in the Eocene confirmed e. g. by the distribution of upper Middle Eocene strata in Roztocze in the Sokolian Trough succession [14]. The presence of redeposited amber in the Miocene sediments of the Fore-Carpathian Foredeep [43] indicates also that amber-bearing deposits were widespread in the Eocene of Roztocze, from where they were removed by erosion.

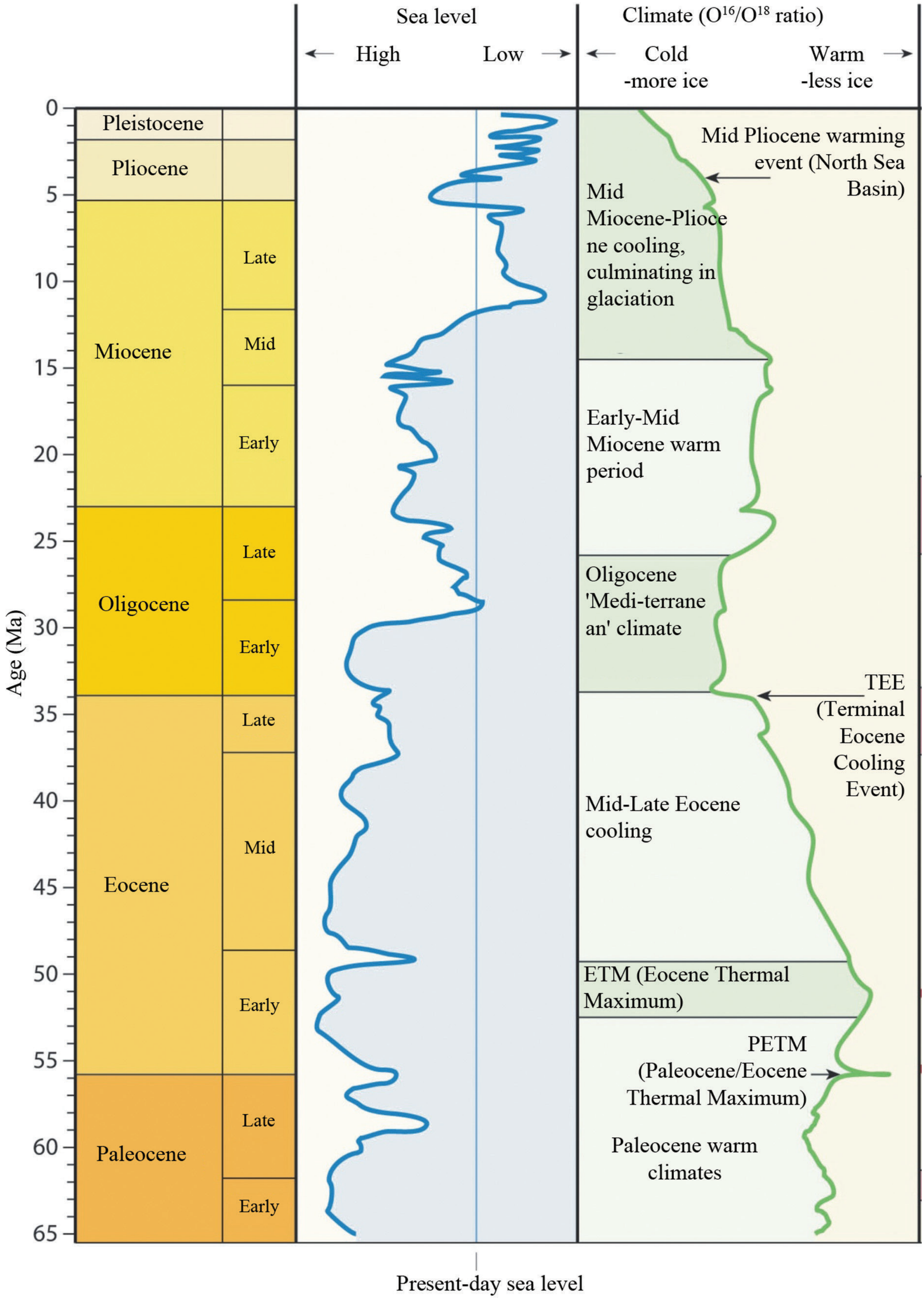


**Figure 4** – Sea-level curve and climate change from the Paleocene to Pliocene [7]

Till now there is no common opinion regarding the causes of profuse resin exudation by plants, which afterwards was turned into amber. According to some views, the process could be promoted by colder climate as a result of gradual glaciation of Antarctica as a consequence of the geotectonic breakup of Gondwana. As displayed on the curve of climate change in the Paleogene (Fig. 4), the rate of climate cooling exponentially increased in the course of time. At the turn of the middle and late Eocene, this cooling was strong enough to overpower the adaptation ability of the existing phytocenoses, i. e. the increase in resin-yielding trees in the Eocene could be one of the plant reactions to increased stress levels. The conifers *Glyptostrobus, Sequoia* and *Metasequoia* are traditionally considered as the main resin producers. Studies of amber and modern resins by Raman spectroscopy [29] have given new results – succinite is most similar to the resins of *Cedrus atlantica* and *Psuedolarix vehri* (Pinaceae) and *Agathis australis* (Araucariaceae), whose resin yielding, however, is not as intensive today. Therefore, different taxonomic groups could be the source of resin, which confirms the external nature of factors causing increased resin-yielding. In addition to climate cooling, the succinosis phenomenon could be also caused by intensified volcanic activity. Together with the progressive transgression of the Eocene sea, volcanic activity undoubtedly exerted direct impact on the late Eocene cooling when considerable volumes of volcanic ash were emitted into the atmosphere, causing the blockage of stomas in plant leaves. The oldest sediments in the amber-yielding region belong to the Bartonian and Priabonian. This means that factors leading to increased resin yielding must have appeared much earlier, most likely in the Lutetian [54]. The latter conclusion corresponds to the beginning of Eocene cooling that apparently points to the interrelation between resin production and climatic change [55]. It is also confirmed by the analysis of the kerogen evolution diagram [21] of amber-like resins of different age (according to the position of particular points on the diagram it is possible to judge the post-diagenetic processes affecting resin transformation).

## DISCUSSION

The required paleogeographic conditions of amber deposit formation were: profuse resin exudation by conifers; introduction of this resin into marine sediments in a reducing geochemical setting after which it turned into amber; and creation of favorable geological settings for placer formation [2; 3]. The fulfillment of these prerequisites was largely provided by the ingression of the Kharkivian Sea on densely overgrown by conifers large landmasses and islands. Subsequent erosion and removal of the non-lithified sediments from the flooded land led to the introduction of resins into marine sediments and was followed by redistribution of the material until placers were formed. Three zones differing in hydrodynamic setting and lithological variability can be distinguished in the present-day distribution of potential amber-bearing deposits: the zone of beaches and coastal strips, the shallow shelf zone, and the relatively deep shelf zone.

The zonation of the grain-size composition in the present-day beach sediments of the Baltic, Barents and Black Seas [26] shows that at clastic material density of about 1.0 g/cm$^3$ the waves displace its largest aggregates which can then be buried among the sand and pebble sediments at close distances from the land. On the contrary, the fine fractions are carried away from the coast into the sea, often in suspension. With regard to the distribution of fossil resin lumps, their zonal accumulation may be observed at a certain distance from the coastline where wave action does not occur. The material washed into the sea is accumulated below the storm-weather wave-base. Therefore, the sand varieties representing the ingressive stage of the Kharkivian Sea and the coastal facies from the period of maximum flooding of this sea (Priabonian) are the most prospective for amber-bearing placers, especially in zones of multiple relative coastline uplift and submergence. The coastal and shallow-water facies of this age are generally located to the south of the Belarus border in Poland and northern Ukraine in the vicinity of the Ukrainian Shield. Considering the above, as well as having analyzed the results of mineralogical sampling for amber, the following promising areas can be identified in the Paleogene sediments of the study area (see Fig. 3).

The regression stage of the Kharkivian Sea (Rupelian) was followed by the accumulation of a belt of coastal marine sediments. In the extended land areas, soil mainly consisting of quartz sands and aleurites was extensively washed out by atmospheric precipitation; resin exudation of renewed vegetation was at a typical scale. Paleogeography did not favor the burial and accumulation of considerable volumes of resin on the land. Because of variable relief of the drying seabed, the coastal zone was characterized by relative resistance to the abrasion activity of waves. Under such conditions the introduction of amber into fresh coastal marine deposits was accomplished by watercourses that developed on land and eroded the earlier accumulated amber-bearing deposits. The most favorable situation for the formation of placers at the regressive stage of the Kharkivian Sea existed in the deltas of paleorivers and on the adjacent shelf areas.

In some cases, the sediments of such zones are overlapped by late liman delta formations and continental deposits of the Upper Oligocene and Neogene. The hypsometric position of the surface of such sites is one of the main reasons for formation of river valleys within their limits in the Neogene. Accumulation of the terrigenous components in the Neogene sediments occurred at that time not only due to the introduction of material from the elevated landmasses and its successive deposition in the sea, but rather due to the processing of the basement rocks. Alluvial sediment processing led to the intensive destruction of placers of marine origin. In this case, the presence of Upper Oligocene and Neogene sediments indicates that the basement rocks are unaffected by erosion; therefore, it is an important search criterion for the identification of amber placers. Kharkivian time deposits that were not subject to erosion and were accumulated mostly in shallow marine conditions have the highest prospects for the detection of new deposits.

## CONCLUSIONS

The formation of amber placers within the study area is defined by the combination of stratigraphic, structural, facies, mineralogical, paleogeographic, geomorphological, geochemical, hydrodynamic, and paleotectonic factors, and also erosional truncation and incision. At the same time, it should be understood that the analysis of the stratigraphic position, structural setting and facies, as well as other cases of possible amber accumulation both in primary and secondary placers should also consider the fact that in the course of resource development even a number of favourable factors cannot compensate the impact of unfavourable parameters in full. It is also necessary to pay attention to structures concentrating amber (paleogeomorphological traps). The reliability of data on the prognostic resources of fossil resins, their assignment to certain formational and genetic types of predictable amber manifestations is the fundamental basis in the development and determination of the priority of future exploration activities. The emergence of new data and ideas on the characteristics of the distribution of amber inevitably requires a reassessment of its resources, control of its reliability, and acquisition of enhanced geological knowledge.

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# ПАЛЕАГЕНАВЫЯ РОССЫПЫ БУРШТЫНУ СУМЕЖНЫХ ТЭРЫТОРЫЙ ПОЛЬШЧЫ, БЕЛАРУСІ І УКРАІНЫ

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У працы прадстаўлена сучасная геолага-генетычная мадэль бурштынаносных адкладаў Польшчы, Беларусі і Украіны ў спалучэнні з канцэпцыяй прагнозна-пошукавай сістэмы бурштыну. Вызначана, што гэта сістэма залежыць ад сучасных уяўленняў аб генезісе выкапнёвых смол і фактычных дадзеных аб развіцці даследуемай тэрыторыі ў палеагене, што аказвае прынцыповы ўплыў на метадычныя асновы прагнозу і пошукаў новых залежаў. Вынікі палявых і камеральных работ 1991–2020 гг. дазволілі ўдакладніць стратыграфію бурштынаносных адкладаў і правесці рэвізію ключавых участкаў і апорных разрэзаў у межах даследуемай тэрыторыі, выканаць карэляцыйны аналіз стратыграфічнай прымеркаванасці, геалагічных абставін і перадумоў фармавання залежаў.

# ПАЛЕОГЕНОВЫЕ РОССЫПИ ЯНТАРЯ СМЕЖНЫХ ТЕРРИТОРИЙ ПОЛЬШИ, БЕЛАРУСИ И УКРАИНЫ

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В работе представлена современная геолого-генетическая модель янтареносных отложений Польши, Беларуси и Украины в сочетании с концепцией прогнозно-поисковой системы янтаря. Определено, что эта система зависит от современных представлений о генезисе ископаемых смол и фактических данных о развитии исследуемой территории в палеогене, что оказывает принципиальное влияние на методические основы прогноза и поисков новых залежей. Материалы полевых и камеральных работ 1991–2020 гг. позволили уточнить стратиграфию янтареносных отложений и провести ревизию ключевых участков и опорных разрезов в пределах исследуемой территории, выполнить корреляционный анализ стратиграфической приуроченности, геологических обстановок и предпосылок формирования залежей янтаря в палеогеновых отложениях.