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# A new approach to analysing the origin and occurrence of amber-bearing deposits of the Upper Eocene, northern Lublin area, SE Poland

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Eocene sedimentation in the Lublin region reached its peak in the Middle Eocene, followed by a regression in the Late Eocene, which was accompanied by accumulation of significant amber deposits in the North Lublin area. These deposits, located along the southeastern coast of the Eocene, reflect the abundant resin production in diverse forests during the climatic optimum of the Eocene. Recent research has challenged the earlier notion that amber deposits formed in river deltas and linked them to regressive marine facies. Amber is typically found in low-energy, regressive rock layers such as silt and sand, and its distribution could be significantly affected by environmental changes influencing its secondary occurrence. A recent study focusing on the North Lublin region modelled the structural surface of the Upper Cretaceous to identify areas of amber-bearing deposits. Using data from the PITAKA, Bank HYDRO and Central Geological Archive databases, a comprehensive surface of the Upper Cretaceous at the sub-basin scale was created using *ArcGIS* software. This approach enabled a better understanding of the palaeodepositional subsurface of the Paleogene deposits. The analysis identified 84 different amber-bearing fields covering a total area of 891.5 km$^2$, which corresponds to almost 14% of the study area in the northern Lublin region. These results emphasise the influence of the palaeomorphology of the Late Eocene basin on sediment dynamics in amber-bearing areas. This paper describes a new depositional model for the Eocene amber-bearing formations in the Lublin region and indicates potential amber deposits in this region.

Key words: amber, sedimentology, palaeogeography, Paleogene, digital modelling, SE Poland.

## INTRODUCTION

The Eocene succession in the Lublin region formed in part of the eastern branch of the extensive epicontinental basin of the North Proto-Sea (Fig. 1). This basin covered the area of present-day western, central and eastern Europe and was influenced by the slope of the Ukrainian Shield (Akhmetiev and Beniamovski, 2006; Kasiński and Kramarska, 2008; Kasiński and Słodkowska, 2014; van der Boon, 2017; Barrier et al., 2018; Popov et al., 2019). The sea reached its maximum extent in the Middle Eocene and was in a regressive phase in the Late Eocene, which was accompanied by accumulation of numerous amber deposits in the North Lublin area.

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Accumulations of amber *in situ* in Paleogene deposits extending over the northern part of the Lublin area and the neighbouring regions of Belarus and Ukraine have long been known and have been widely described, especially in the vicinity of Parczew and Lubartów (Woźny, 1966a, b; Mojski et al., 1966; Pożaryska, 1977; Kosmowska-Ceranowicz et al., 1990; Kasiński and Tołkanowicz, 1999) and Sarny in Volhynia (Tutsky and Stepanuk, 1999). Small amber deposits have been documented in each of these regions (Tutsky, 2005; Melnichuk and Krynicka, 2018). Similar to those of the Sambia region (Kasiński et al., 2020), these deposits have been associated with deltaic areas thought to have existed along the southern coast of the Eocene sea (Kosmowska-Ceranowicz, 1990).

Advances in the geological study of the Paleogene succession in Europe have contributed to its more precise stratigraphic delineation and enabled the creation of local and regional palaeogeographic maps. The first author (PHK) has produced two palaeogeographic maps based on various sources (Kramarska, 2006; Popov et al., 2004a, b, 2019; Kováč et al., 2016; van der Boon, 2019; Krijgsman et al., 2020) for the Late

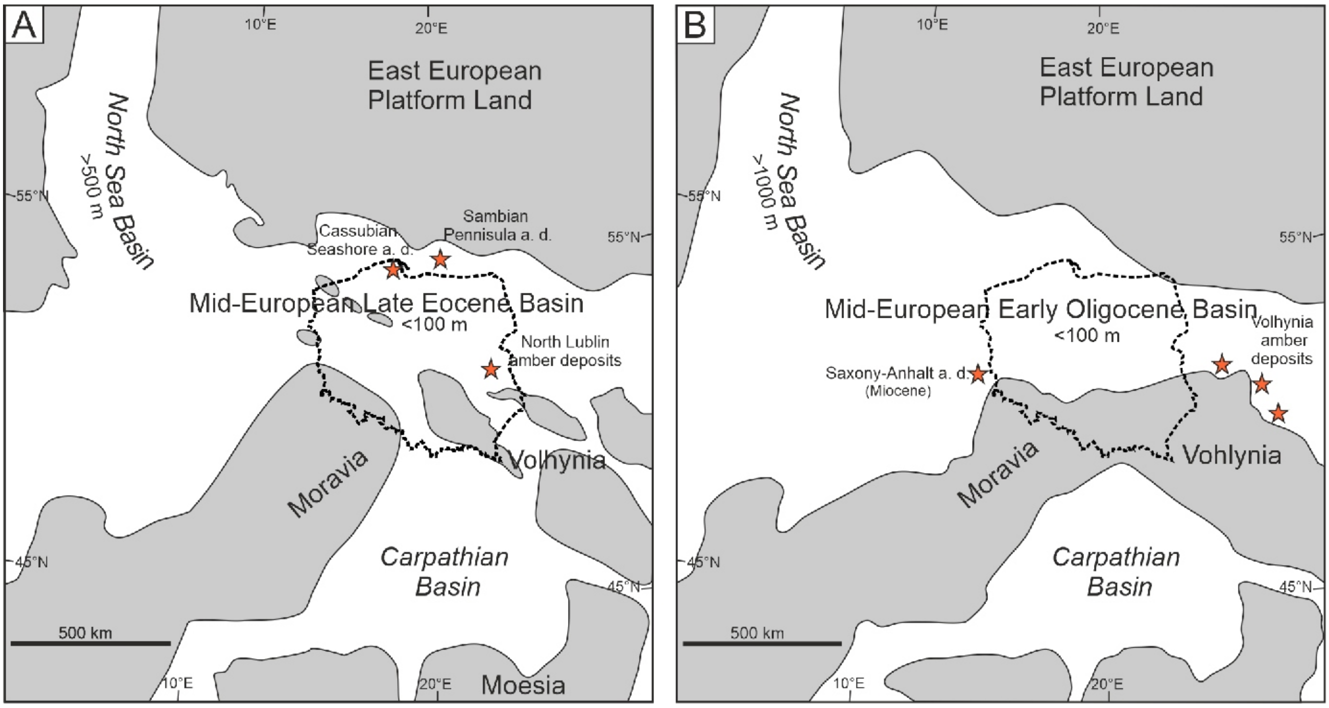


**Fig. 1. Location of amber deposits in relation to the palaeogeography of the Late Eocene (A) and Early Oligocene (B) in Central Europe (maps mainly based on Akhmetiev and Beniamovski, 2006; Kasiński and Kramarska, 2008; Knox et al., 2010; Kasiński and Słodkowska, 2014; van der Boon, 2017; Barrier et al., 2018; Popov et al., 2019; Palcu and Krijgsman, 2023; in the region of south-eastern Poland and Volhynia mainly based on the first author's studies**

Eocene and for the Early Oligocene in Central Europe, showing the transition to the North Sea Basin and to the Carpathian Basin in the south (Fig. 1). A comparison of these maps shows that the formation of the amber deposits in the North Lublin area preceded the formation of most amber deposits in central Europe (Late Eocene). Furthermore, the sedimentation conditions for the Late Eocene deposits were more dynamic than for the Early Oligocene deposits (Knox et al., 2010). A significant reduction of the connections, in the Early Oligocene, between the Carpathian Basin and the Ukrainian Crystalline Shield in the Rivne region and the Gomel Region of Belarus resulted in the amber deposits then being deposited under different conditions than was the case for the Upper Eocene accumulations in the North Lublin area (see Fig. 1). Building on previous successes in identifying Paleogene deposits in the northern Lublin region, particularly regarding the origin of amber in Eocene deposits, this study demonstrates a new model for the deposition of regressive Eocene sediments. Additionally, the study seeks to predict the occurrence of amber accumulations within these deposits. By leveraging modern computational technologies and an extensive database of boreholes in the study area, a standardized methodology was applied across the entire region, yielding promising results.

## GEOLOGICAL SETTING

Accumulations of Baltic amber (succinate) of composite nature are considered as "primary deposits" (initial, rich sedimentary accumulations) associated with fine clastic, including clayey deposits of the Upper Eocene (Piwocki, 2002, 2004; Kasiński, 2015, 2016; Słodkowska and Kasiński, 2016a). The Paleogene amber-bearing association consists of sandy, silty and clayey deposits with scattered amber fragments. A characteristic feature of the association is glauconite. On the basis of palynological and microfaunal studies carried out in the North Lublin area, the age of the amber-bearing deposits was determined as around the boundary between the Middle and Upper Eocene (Bartonian-Priabonian; Gedl, 2012, 2014; Słodkowska and Kasiński, 2016a, b, 2018; Kasiński et al., 2018). The presence of succinate deposits is noted in the area of shallow Eocene sedimentary deposits in the northern Lublin region near the erosional limit of their occurrence (Kosmowska-Ceranowicz et al., 1990; Kasiński and Tołkanowicz, 1999; Kasiński, 2016).

In the northern Lublin region, deposits of Baltic amber are distributed quite evenly in the littoral zone along the eastern coast of the Eocene sea. In the Eocene, the eastern arm of the northern proto-sea extended into the areas of present-day Central Europe, including the northern Lublin region in Poland. It was a shallow epicontinental sea with a chain of islands in the axial part of the basin (Fig. 1). The shores of this sea were covered with lush, diverse forests. On land, the Early Eocene Climatic Optimum (EECO) favoured the development of forests and their great biodiversity, that grew in a tropical to subtropical climate (Bohaty et al., 2009; Jovane et al., 2009; Miller et al., 2009; Lukashina, 2010; Słodkowska and Kasiński, 2016a, b, c; Hutchinson et al., 2021) and produced large quantities of resin. This resin was transformed into amber by complex biochemical and geochemical processes. The factors affecting the increasing resinification could be various (rapid cooling, intense volcanic activity, insect invasion, tree diseases, fires, etc.; Kosmowska-Ceranowicz, 2012; Słodkowska et al., 2013).

## PALAEOGEOGRAPHY AND SEDIMENTARY ENVIRONMENT OF THE AMBER-BEARING DEPOSITS IN THE NORTH LUBLIN REGION

Analysis of lithofacies maps and of the variability of amber content in the deposits (Jurys et al., 2010; Kasiński, 2016) shows that sandy-silty lithofacies associated with amber accumulations occur patchily among the predominant sandy deposits. This architecture of the Eocene succession indicates a sedimentary environment related to barriers or barrier-delta structures in the littoral zone. The clastic barriers migrated northwards consistent with the regressive trend of Eocene sea level. Older barrier areas became land areas and could be partially covered by amber-rich forests. At the same time, they became source areas for clastic material that was deposited on later, younger barriers. This scenario may have been repeated several times (Karnkowski and Kasiński, 2014).

Recent research has called into question the previously accepted view that the amber assemblages in northern Lublin were deposited on the deltas of large rivers (Kosmowska-Ceranowicz et al., 1990). To the contrary, in all accumulations the amber fragments coexist with glauconite, macro- and microfauna (foraminifera, fish teeth, shells) and dinocysts (Woźny, 1977; Kasiński and Tołkanowicz, 1999; Słodkowska and Kasiński, 2016a). These observations indicate that the present-day boundary of the marine Eocene succession has an erosional character, so that the main boundary of the sedimentary basin was undoubtedly located farther south, perhaps in the area of Roztocze (Gedl, 2014). This suggestion is supported by the occurrence of small amber fragments in Badenian deposits in the neighbouring part of the Carpathian Foredeep, where these undoubtedly occur in secondary deposits (Wysocka, 2002). Due to the narrow width of the Meta-Carpathian Ridge and its proximity to the Tethys Ocean basin, the possibility of large rivers developing in such a small area seems very doubtful. Therefore, the occurrence of primary deposits of amber-bearing deposits should be associated with regressive marine facies, and the geometry of the lithosomes suggests that the deposition of amber was associated with periodic slowdowns in regression. The lithofacies analyses carried out indicate that amber occurs in low-energy regressive facies, mainly in fine-grained silts and sands (Czuryłowicz and Sałaciński, 2010; Karnkowski and Kasiński, 2014; Czuryłowicz, 2015). With the increase in the energy of the environment (e.g., due to a minor transgressive episode interrupting the overall regressive trend), the amber was commonly washed out of primary accumulations and redeposited in younger sediments. The present-day distribution of amber is therefore generally associated with several erosional events that affected amber-bearing sediments, with redeposition of amber. Delta deposits also occur secondarily in amber-bearing sedimentary sequences (see Czuryłowicz, 2014; Czuryłowicz et al., 2014), but as regards amber occurrence they are essentially barren.

## CONDITIONS OF OCCURRENCE AND PROPERTIES OF AMBER

Amber-bearing deposits occur at various depths, at shallower depths (2.3 m) in the area of the Siemień pond north-east of Lubartów (Morawski, 1960; Mojski et al., 1966; Woźny, 1966a; Parecki and Bujakowska, 2004; Słodkowska et al., 2022), but most frequently at depths of 15–20 m. In many places, such as in the area of the Siemień pond and in the Firlej region, the Eocene deposits are reduced to a thickness of 1–2 m (see Fig. 2).

With the current state of knowledge, it is difficult to recognise patterns in the spatial distribution of qualitative parameters of the amber. The amber recovered during drilling in the 1990s (Kasiński and Tołkanowicz, 1999) showed a wide variety of grain sizes and qualitative characteristics, but large and high-quality fragments were not very common. At that time, three types of amber were distinguished: transparent, translucent and opaque, in different colours ranging from light yellow to various shades of honey and brown. Some amber clasts had a typical colours, such as lemon-yellow or blood-red. The dark brown grains were usually brittle, a result of advanced weathering. Many clasts retained the original weathered cortex, indicating relatively low transport energy; no amber grains with a high degree of rounding were observed. Numerous grains retained their original shapes associated with the manner of resin accumulation: flake, intermediate and subcortical forms were distinguished.

## HISTORY OF AMBER RESEARCH

The first mentions of the occurrence of major amber deposits in the North Lublin area date from 1931–1938 in unpublished manuscripts by A. Chętnik (*fide* Kosmowska-Ceranowicz and Popiołek, 1981), which focused on the Siemień pond area west of Parczew. From 1959 to 1966, information on deposits of amber-bearing deposits in this area appeared in descriptions of several boreholes and excavation sites for building clays, where Eocene glauconite-quartz sands with phosphorites and amber were encountered at shallow depths (Woźny, 1966a, b; Zalewska, 1971, 1974). In the 1960s, coarse clastic deposits were described in archived records of five deep structural boreholes in the Łuków, Parczew and Lubartów regions as “gravels with amber”, but their exact stratigraphic position is uncertain.

In 1965, a borehole drilled by the Department of Geological Mapping of the Polish Lowlands and Quaternary Research of the Geological Institute in Warsaw confirmed the presence of Eocene amber-bearing deposits on the Wieprz River flood terrace in Luszawa (Mojski et al., 1966). The presence of amber in the Luszawa area was confirmed by a borehole in the 1980s. In the same period, amber from Eocene deposits was also described in a borehole in nearby Wyganów (Kosmowska-Ceranowicz and Leciejewicz, 2005).

In 1974, a borehole drilled by the Oil and Gas Exploration Department of the Oil and Gas Industry Company in Kraków described the occurrence of large amber clasts, some fist-sized, in Leszkowice. Part of this record was stored in the Department of Geology at the Maria Curie-Skłodowska University in Lublin.

In 1989, while documenting a natural gravel deposit in Górka Lubartowska, ~8 km north of Lubartów, the geological company “PolGeol” from Warsaw documented the first deposit in the North Lublin region with amber as an accessory mineral (Strzelczyk and Danielewicz, 1990). The same amber deposit was later formally documented by Bujakowska and Parecki (2004). Currently, the northern part of this deposit is being privately economically exploited. Its primary commodity is glauconite with amber as a secondary raw material. In 1992, the Polish Geological Institute began to develop a methodology for the exploration of amber in Paleogene deposits, to enable more precise determination of prospective areas for amber occurrence and the planning of prospecting work (Kasiński and Tołkanowicz 1999). At that time, a map of prospective areas was created with a forecast of amber occurrence in this area and in southern Podlasie. On the basis of this work, more detailed studies of the amber-bearing sedimentary association in the North Lublin area were carried out in 1994–1997. As part of these studies, the Polish Geological Institute drilled 38 boreholes in the area between the middle Vistula valley and the middle Bug River valley in order to initially explore the amber deposits in this region. The drilling results confirmed the presence of major amber deposits in the central part of this area (between Radzyń Podlaski, Parczew and Lubartów) and allowed an approximate estimation of the mineable amber resources

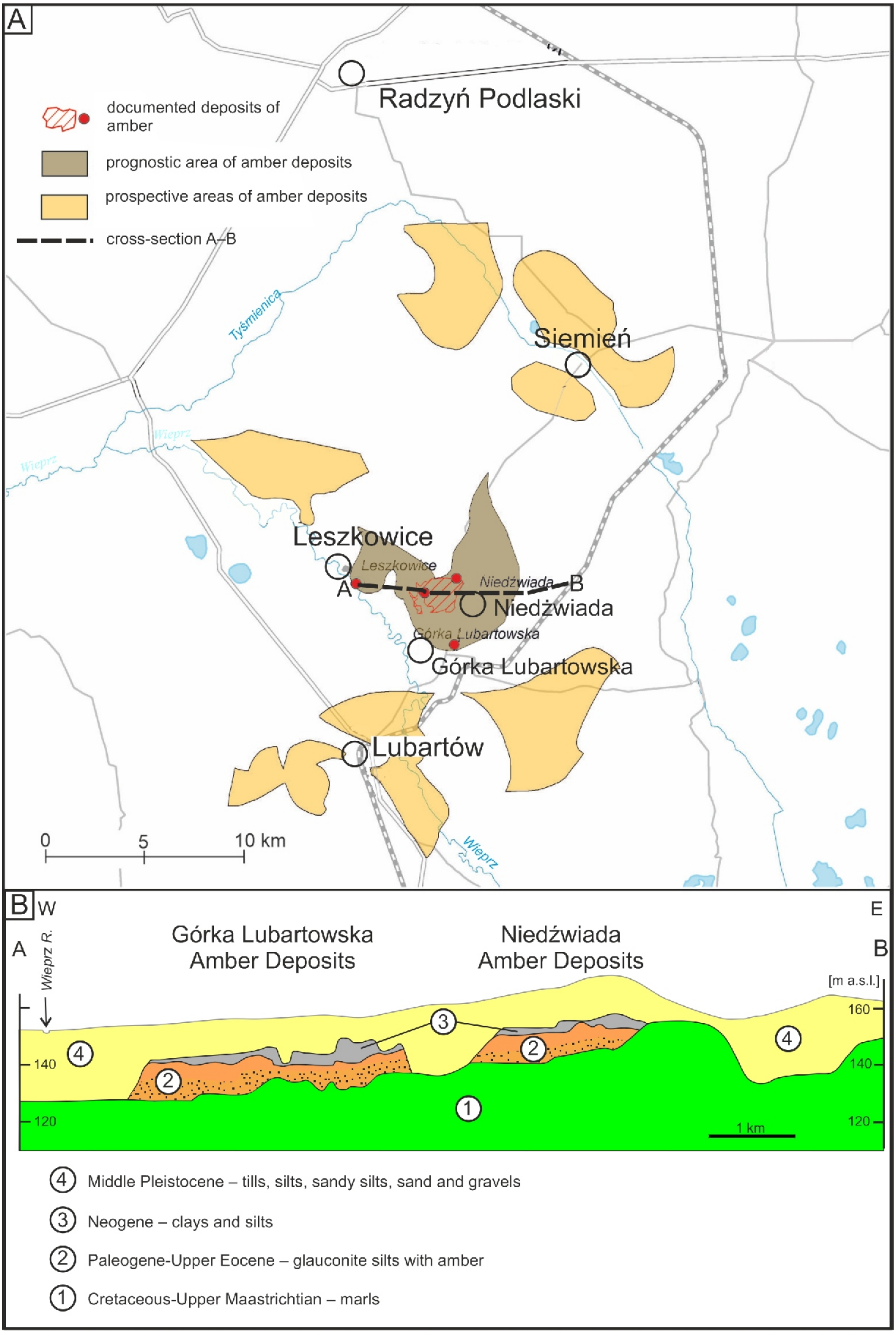


**Fig. 2. Prognostic and prospective areas of amber deposits in the Lubartów-Radzyń Podlaski region (North Lublin area) (A) and geological cross-section of amber deposits in the Górka Lubartowska-Niedźwiada region (B)**

Table 1

**Scientific and industrial activities on amber deposits in the North Lublin region**

| Scientific papers and communications | Years | Reports on amber deposits resources and reserves in the area of Górka Lubartowska-Leszkowice-Niedźwiada |
|---|---|---|
| Woźny (1966a, b); Mojski et al. (1966) | 1960–1969 | |
| Pożaryska (1977) | 1970–1979 | |
| | 1980–1989 | |
| Kosmowska-Ceranowicz et al. (1990); Kasiński and Tołkanowicz (1999) | 1990–1999 | Strzelczyk and Danielewicz (1990) |
| Piwocki (2002); Sałaciński and Łazowski (2008) | 2000–2009 | Bujakowska and Parecki (2004) |
| Nieć et al. (2010a, b); Słodkowska and Kasiński (2013, 2016a, b, c, 2018); Czuryłowicz (2014); Karnkowski and Kasiński (2014); Czuryłowicz et al. (2015); Kasiński (2015, 2016); Kasiński et al. (2018) | 2010–2019 | Zdanowski et al. (2017); Myszka, 2018; Mazurek (2018a, b); Mazurek (2019a, b) |
| Kramarska et al. (2020); Słodkowska et al. (2022) | 2020–2029 | Mazurek (2020a, b, 2021; Szydeł and Gazda (2020); Żarski and Słodkowska (2020); Żembek and Wójcik (2022) |

(Kasiński et al., 1997). Seven potential mining areas with resources of >45,000 tonnes were identified in this area. At that time, a map of potential amber deposits in the North Lublin region was created (Fig. 2A), which was later included in the "Balance of Prospective Mineral Resources of Poland" (Kramarska et al., 2020). This map served as the basis for conducting large-scale exploration work in northern Lublin area and was used by several commercial companies to explore amber deposits with balanced resources (Zdanowski et al., 2017; Szydeł and Gazda, 2020). The largest of these deposits is the Niedźwiada-Górka Lubartowska deposit, which is located north-east of the first, initially recognised Górka Lubartowska deposit (Fig. 2). Basic research has continued until recent years (Kasiński, 2015, 2016a; Słodkowska and Kasiński, 2016b; Słodkowska et al., 2022), also within the framework of international cooperation between Poland and Ukraine (Natkaniec-Nowak et al., 2017; Kasiński et al., 2018; Słodkowska and Kasiński, 2018). In particular, palynological and sedimentological studies were carried out to reconstruct the processes of amber transport and deposition. To constrain the presence of significant amber deposits in the projected area, three research boreholes were drilled in 2019 (Żarski and Słodkowska, 2020).

## PRESENT EXPLORATION ACHIEVEMENTS

Data from the ongoing exploration of amber-bearing deposits has revealed intriguing patterns regarding the likelihood of encountering amber raw material. According to Czuryłowicz (2014), the probability of finding amber quadruples when specific lithofacies are drilled. Statistical analysis of the borehole data has further illuminated some patterns in the occurrence of amber. For example, an upwards trend in amber grade can be observed, which decreases towards the top of the Upper Eocene deposits. This trend is attributed to general hydrodynamic changes caused by progressive marine regression. In addition, amber deposits zones have been identified, probably due to the cyclic supply of sediments during periods of stabilisation in submarine distributary channels. Lenses and other isolated forms of high-grade amber have also been identified. These large- and small-scale forms of amber occurrence, although significant, are considered low-order structures compared to the predominantly random distribution of amber raw material.

The complex spatial distribution of amber provides indirect insights into the interplay of different depositional processes that occur simultaneously at different levels of investigation, some of which are beyond our current analytical abilities. Among the factors influencing amber deposition, the settling of fine amber grains from suspension by gravity and the traction transport of larger grains stand out. Conversely, zones that show increased amber content at the local scale typically display a random distribution within the Upper Eocene deposits.

Following 3D parametric model analysis aimed at reconstructing the internal depositional architecture and the variability structure of the amber content within the "Górka Lubartowska" deposit, several layers of information were calculated to assess the resource potential (Fig. 3B, E and F) and the mining suitability (Fig. 3A and G). Given the inherent uncertainties in resource estimation and the probabilistic nature of the geostatistical simulation results, the evidence map package includes layers that determine the probability of occurrence of the relatively richest lithofacies FSm (Fig. 3C). Geological uncertainty, a fundamental aspect of geological modelling of amber-bearing depositional systems, was taken into account by calculating the Shannon entropy layer (Fig. 3D). An information layer representing the resource potential in relation to the thickness of the depositional facies is provided by the net-to-gross map (Fig. 3F). This coefficient is derived from the vertical column of the grid model and represents the ratio of the total thickness in intervals exceeding a predefined threshold value to the total thickness of the deposit. Additionally, the resource potential can be visualised using a map that indicates the probability that the percentage of amber content exceeds the threshold value. As open-pit mining is the preferred method of exploiting the deposit, the analysis included maps of overburden thickness (Fig. 3A) and gross deposit thickness (Fig. 3B) calculated during the construction phase of the stratigraphic model. The maps presented were created to identify the most economic sectors within the "Górka Lubartowska" deposit area using a knowledge-based approach known as Weighted Overlay. This method enables the adjustment of the influence of individual input maps based on the conceptual deposit model.

A significant correlation between the vertical variations in glauconite silt content and the average amber content calculated from the borehole data of the "Górka Lubartowska" deposit emphasises the close relationship between the processes of amber accumulation and deposition in the shore zone of the

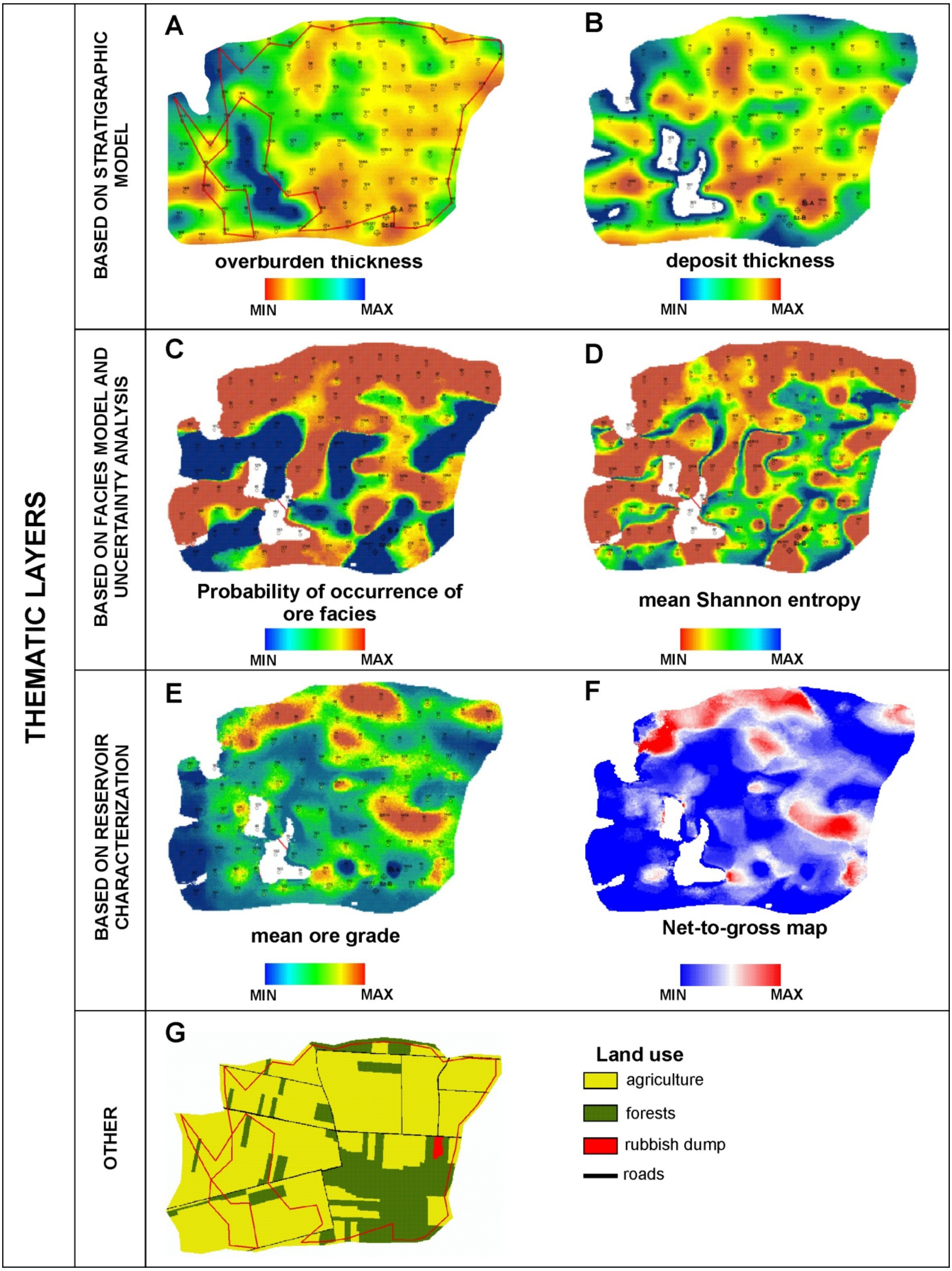


**Fig. 3. Summary of information layers obtained sequentially during model analyses as part of a comprehensive study of the geological conditions of the "Górka Lubartowska" amber deposit (after Czuryłowicz, 2014)**

Late Eocene sea. The peak value of the average amber content closely coincides with the phase in which the probability of the occurrence of glauconite silt is highest.

The sharp increase and subsequent gradual decrease in amber occurrence in vertical profile faithfully reflects the trend of changes in the glauconite silt lithofacies. Further examination of the vertical trends in amber content reveals higher order phase shifts within the sequences when the borehole data are separated on a lithofacies basis. This phenomenon is likely due to the erosion and redeposition of previously concentrated amber originally formed in the silty sediments. As the sedimentary component with the lowest specific gravity, amber is very susceptible to erosion and tends to redeposit into relatively younger sediments. This cyclical process took place at least nine times during the aggradation of the amber-bearing deposits (Czuryłowicz, 2014).

The successive transgressions of the Eocene sequences show a progressive pattern in which their extent gradually increases towards the south. The sequences identified in the profile are characterised by a systematic increase in the proportion of clays and carbonate deposits. The presence of carbonates indicates flood events that correlate with limited inflow of terrestrial sediment. This phenomenon is observed mainly in the northern region and coincides with the phase of maximum increase in the ratio of silts + clays/sands (Czuryłowicz, 2014). This phase of the sedimentary basin development corresponds to the peak of marine transgression and probably extends to the vicinity of today's Lublin Upland.

The deposition of these Upper Eocene strata was closely related to the transition from transgression, which marked the peak of marine expansion in the late Eocene, to marine regression, which initially took place amidst an increased sediment supply. The sediments of the Upper Eocene Siemień Formation were initially deposited within the prodelta zone. Later, as sea level receded, the sediment layers were reworked and the depositional patterns shifted to reflect the progradation of submarine distributary channels (Czuryłowicz, 2014).

## PREVIOUS MODELS OF THE AMBER-BEARING DEPOSIT

Current understanding of the origin of the amber deposits in the Eocene succession north of Lublin has evolved between 1990 and 2014, as analysed by Kosmowska-Ceranowicz et al. (1990), Kasiński and Tołkanowicz (1999), Czuryłowicz (2014), Karnkowski (2014) and Karnkowski and Kasiński (2014). This overview is not organised chronologically, but through analysing the interactions between different perspectives, highlighting the dynamic interdependence between the opinions of various researchers.

In his doctoral thesis on the Paleogene amber deposit "Górka Lubartowska" in the Parczew and Lubartów region (30 km north of Lublin), Czuryłowicz (2014) focussed on various aspects, including the sedimentary conditions, the distribution of lithofacies, the thickness of the amber-bearing deposits, the synsedimentary and post-depositional tectonics, the sedimentary architecture on a local and regional scale, erosional processes and the preservation possibilities of the Eocene sediments. He put forward the thesis that the first phase of the formation of amber-bearing deposits in the Lubartów-Parczew area took place during the transition from transgression, which marks the peak of the expansion of the Late Eocene sea, to regression, which was initially characterised by an enhanced supply of terrigenous material. Czuryłowicz (2014) referred to the concept of the Parczew Delta (Kosmowska-Ceranowicz et al., 1990), in which the amber accumulations are said to have formed. However, Kasiński and Tołkanowicz (1999) had earlier expressed doubts about the existence of this delta and proposed that a system of numerous smaller deltaic fans had developed along the coastline, attributing their formation to the limited land area of the Meta-Carpathian Swell, which was insufficient to support a large, single deltaic system. The contrast between the perspectives is obvious, with the dissertation favouring the concept of a single large delta. Karnkowski (2014) tended to favour the views of Kasiński and Tołkanowicz (1999), who suggested that the formation and development of several smaller fans occurred during the regressive phase of the Eocene basin. As sea level continued to fall, successive generations of deltas developed: those that had previously formed became exposed following sea level fall, and possibly partially eroded to provide material for the subsequent delta sedimentation cycles. These dry areas probably became forested after delta sedimentation and provided amber resin material for the rivers. This cycle was repeated until the end of sedimentation in the Eocene basin. Karnkowski (2014) proposed a multi-stage evolution of the Eocene deltas in the study region, which is in contrast to Czuryłowicz's (2014) single-delta hypothesis. This point of view was then supported by Karnkowski and Kasiński (2014), when the association of amber assemblages with discontinuous occurrences of mud lithofacies sites was emphasised. From a geological and exploratory point of view, the central question remains: where should one look for amber deposits in Eocene deposits in the Lublin region? It seems that the depositional model for amber-bearing deposits in the current, low-energy part of the delta has proved successful.

## PALEOGENE OF THE LUBLIN AREA: STRATIGRAPHY, CLIMATE, TECTONICS, EUSTASY AND PALAEOGEOGRAPHY

A palaeogeographic map of the Late Eocene, i.e. the period in which the amber deposits were formed, is a crucial part of the final plan for the exploration of the amber deposits in the Lublin region. Initially, the map by Kramarska (2006) and Kramarska et al. (2008) was used, which covers a larger area than shown in Figure 4.

The comprehensive compilation of Paleogene and Neogene profiles in the Lublin region required the collation of data from various sources, including the Stratigraphic Table (Kasiński et al., 2008) and others. The summarised lithological-stratigraphic profile is depicted in Figure 5 and shows the position of the Siemień Formation, which may contain amber accumulations. Essentially, the profile shown here covers the entire sedimentary sequence resting on the Cretaceous basement (Jahn, 1956; Harasimiuk and Henkiel, 1981; Świdrowska, 2007; Leszczyński, 2010). The lower part consists of sands and glauconitic conglomerates with phosphate concretions, which indicate a marine origin and are generally not more than 1 metre thick. The faunal biostratigraphy indicates the Paleocene. Higher, the Siemień Formation deposits (Fig. 5) are observed, dated to the upper Eocene.

The palaeogeographic map (Fig. 4) was created specifically for this sedimentation phase. In the Lublin region, the Siemień Formation is currently overlain by thin Pleistocene deposits. The profile depicted (Fig. 5), which consists mainly of the Siemień Formation (~40–34 Ma), therefore represents a geological record spanning 65 My, largely comprising here stratigraphic gaps due to erosion and periods without deposition. The palaeogeographic map of the Late Eocene thus describes a specific phase associated with the transgressive-regressive

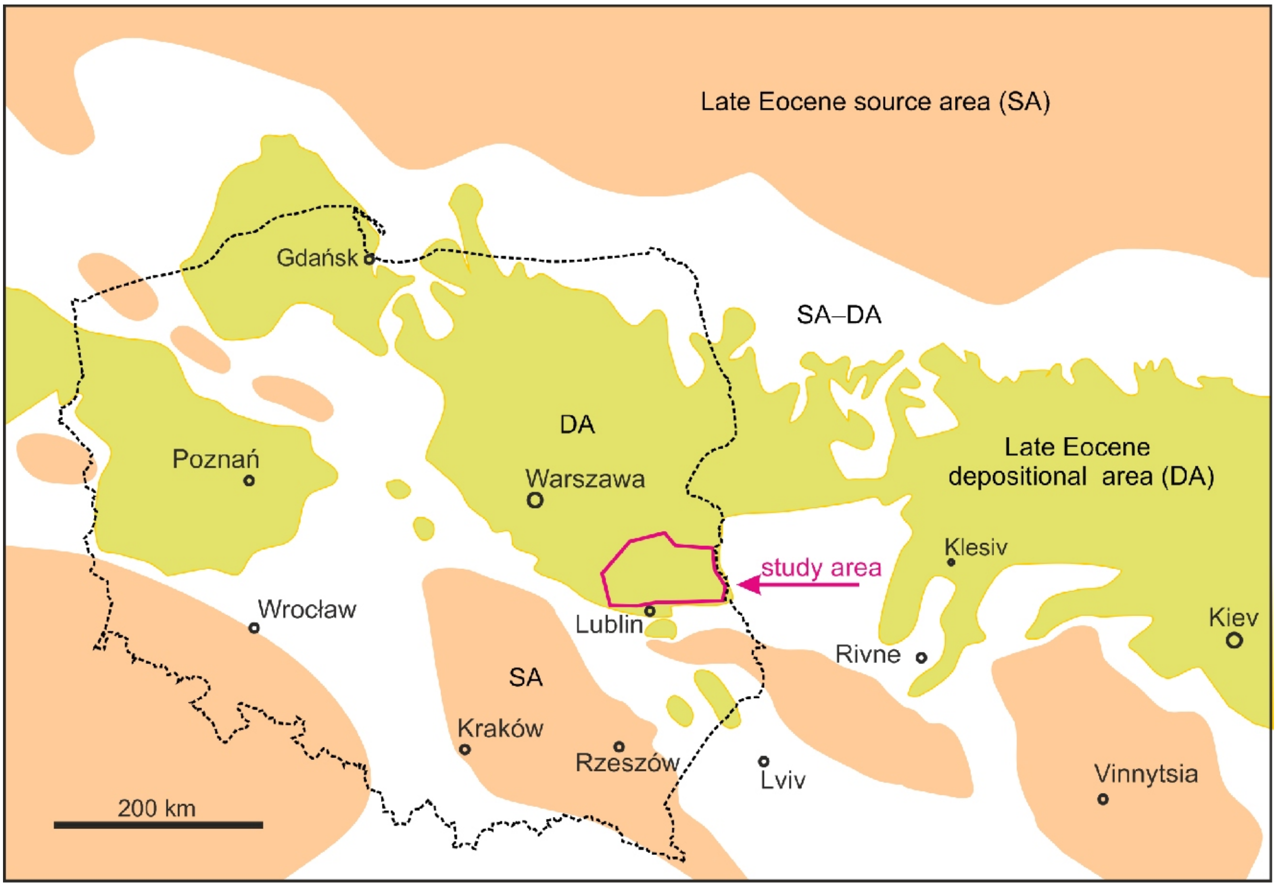


**Fig. 4. Palaeogeographic map during the Late Eocene (mainly after Kramarska, 2006, 2008; considerably modified in the region of southeastern Poland and western Ukraine)**

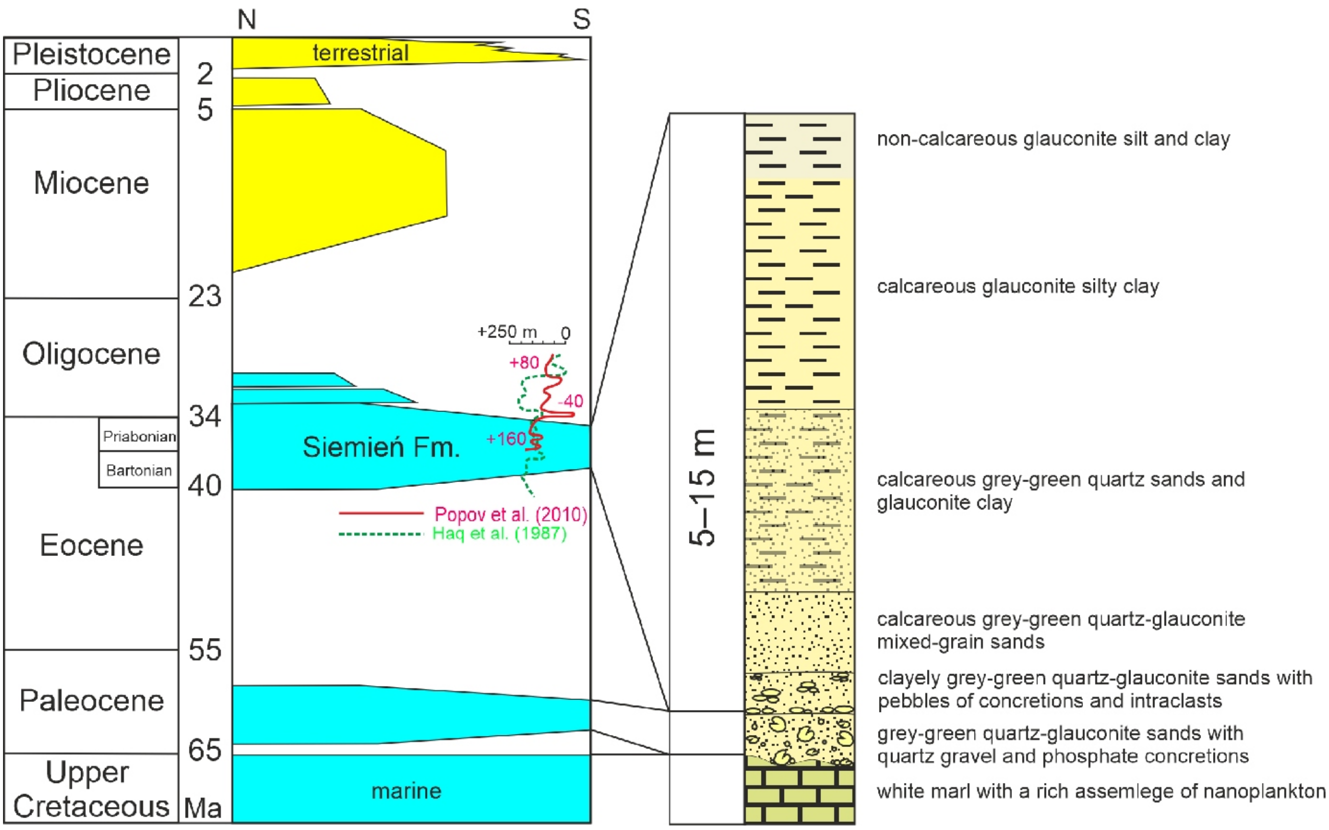


**Fig. 5. The stratigraphic position of the Siemień Formation (amber-bearing deposits) in the chronostratigraphic diagram and its relationship to the older and younger Cenozoic formations (note the eustatic curves in the transition zone from the Late Eocene to the Oligocene)**

cycle of the Late Eocene. Such maps are valuable as they delineate areas of deposition, erosion and transition zones between different palaeogeographic environments. Great efforts have been made to comprehensively update the picture presented (Fig. 4). During the Paleocene, the tectonic inversion in the central part of the Polish Lowland (Poznań – Warsaw area) led to the uplift of the Mid-Polish Swell, which divided the sedimentary basin of the Polish Lowland into two sections (the Poznań and Warsaw-Lublin segments). The Warsaw-Lublin area, which is located entirely east of the Tornquist-Teisseyre (T-T) line, remained relatively unaffected by significant deformation and uplift during the Paleogene, in contrast to the Poznań region. The sea entered the peneplained area from the west during the Middle Eocene transgression and spread eastwards. In the centre of the basin, remnants of the Mid-Polish Swell remained as shoals and a series of islands separating the western basin from the eastern European basin. Amber-bearing sediments developed in some areas of the eastern basin, particularly in the northern Lublin region.

Numerous palaeogeographic reconstructions of the Late Eocene indicate the presence of an extensive Volhynia Massif in southeastern Poland and Ukraine, extending as far as the town of Vinnytsia. However, careful analysis based on various sources has made it possible to refine this representation and divide the Volyn Massif into smaller islands with potential communication channels between them and the basins located south and east of the Lublin region. The study of the substrate of the Carpathian Foredeep indicates a highly diverse Paleogene relief characterised by palaeovalley incisions with depths of >1000 metres (Głowacki and Karnkowski, 1961; Karnkowski, 1989; Połtowicz,1998, 1999; Moryc,1992, 1995, 1997; Karnkowski and Ozimkowski, 2001). In the Rzeszów region, these incisions form small basins with Paleogene terrestrial deposits (Buraczyński and Krzowski, 1994; Moryc, 1995: Gedl, 2012, 2014; Gedl and Worobiec, 2020). Two formations have been identified within these basins: the older Racławówka Conglomerate Formation and the younger Czudec Formation (Moryc, 1995; Gedl and Worobiec, 2020). The Racławówka Formation shows features that indicate localized transport of pebbles, possibly accompanied by gravitational sliding into morphologically depressed valley-shaped areas. The Racławówka conglomerates are overlain by mudstones and subordinate sandstones of the Czudec Formation, indicating a terrestrial sedimentary environment with a considerable supply of organic matter, such as a lake or swamp (Moryc, 1995; Gedl and Worobiec, 2020). In the Late Eocene (Fig. 4), the area around the Rzeszów region had already developed as a land area, which remained flooded by Paratethys seawater until the late Middle Miocene (late Sarmatian age) due to the formation of the Carpathian Foredeep.

The Late Eocene witnessed significant climatic changes, namely the transition from a greenhouse to an icehouse world in which there were no glaciations in this region (Rasser et al, 2008; Ozsvárt et al., 2016; Palcu and Krijgsman, 2023). This climatic change probably contributed to increased resin production in the forests during the transition from the Eocene to the Oligocene, which coincided with the formation of the richest amber assemblages.

From a geotectonic perspective, it is assumed that the collision of the continental plates in the Late Eocene led to the fragmentation and closure of the Tethys Ocean, which was later renamed the Paratethys in its northern section (Schulz et al., 2005; Soták, 2010). The shallowing of the basin in the Late Eocene and the formation of numerous islands and shoals are an indication of changes in sedimentation that signify a transition from an oxygen-rich to an oxygen-poor marine environment from the Eocene to the Oligocene (van der Boon, 2017) . The palaeogeographic map shown (Fig. 4) indicates shallow basins in Ukraine and in the Warsaw-Lublin region, which are bordered by islands and inlets in the south and allow contact between the receding Tethys Ocean (Paratethys) and the Atlantic Ocean. However, this convergence of two large palaeogeographic areas only took place during periods of strong eustatic rise in sea level, which reached values of up to +160 m above present-day sea level; during periods of regression, it occasionally sank to –40 m below present-day sea level. Two eustatic curves, which generally overlap but show interesting differences of detail, address this issue (Fig. 5). While the eustatic curve of Haq et al. (1997, 1988) effectively documents the transgression of the Late Eocene, the curve of Popov et al. (2010), compiled exclusively from data from the Paratethys area, more accurately reflects the eustatic fluctuations corresponding to the sedimentary records in the Warsaw-Lublin and Volhynia regions. Given the occurrence of numerous significant climatic, tectonic and eustatic events in the western Paratethys during the Late Eocene, the palaeogeographic representation shown (Fig. 4) serves as a valuable resource for further research into the origin and distribution of amber-bearing deposits in the northern Lublin region.

## A NEW MODEL OF THE AMBER-BEARING DEPOSIT

### DATA AND METHODS

The traditional "Data and Methods" section in scientific articles, in the case of this paper, pertains to the data and geological modelling. Therefore, two separate subsections are included. The first subsection provides a detailed discussion of the acquisition of structural data from various databases, including their rectification for logical and spatial accuracy. The second subsection describes the applications used for computer modelling and evaluates their effectiveness in solving tectonic and structural problems.

#### INPUT DATA FOR THE MODEL OF THE CRETACEOUS TOP SURFACE IN THE LUBLIN REGION

Between 2016 and 2019, multi-stage scientific studies took place under the supervision of P.H. Karnkowski and R. Kudrewicz at the Department of Georesources and Economic Geology of the Faculty of Geology at the University of Warsaw. These studies focused on spatial analysis using Geographic Information Systems (GIS) to study the Cretaceous deposits of Poland (Fig. 6). One of these works focussed on the Warsaw-Lublin region (Walaszczyk, 2019) and aimed to create models depicting the structural surfaces of both the upper and lower boundaries of the Cretaceous succession. To achieve this, a comprehensive dataset was required, derived from three primary sources: the PITAKA database (Oziembłowski and Karnkowski, 2008), the Bank HYDRO database (Central Hydrogeological Data Bank – CHDB) and the Central Geological Archive (CGA).

The PITAKA database, kindly provided by PGNiG (Polish Oil and Gas Company – POGC), was selected as the primary reference due to its comprehensive coverage and thorough validation. The PITAKA database was originally developed in 1987 from the GEONAFTA Geological Survey's SADOG database and is a cornerstone of geological research. It provides detailed stratigraphic information and precise borehole locations that have been verified multiple times by POGC. This da-

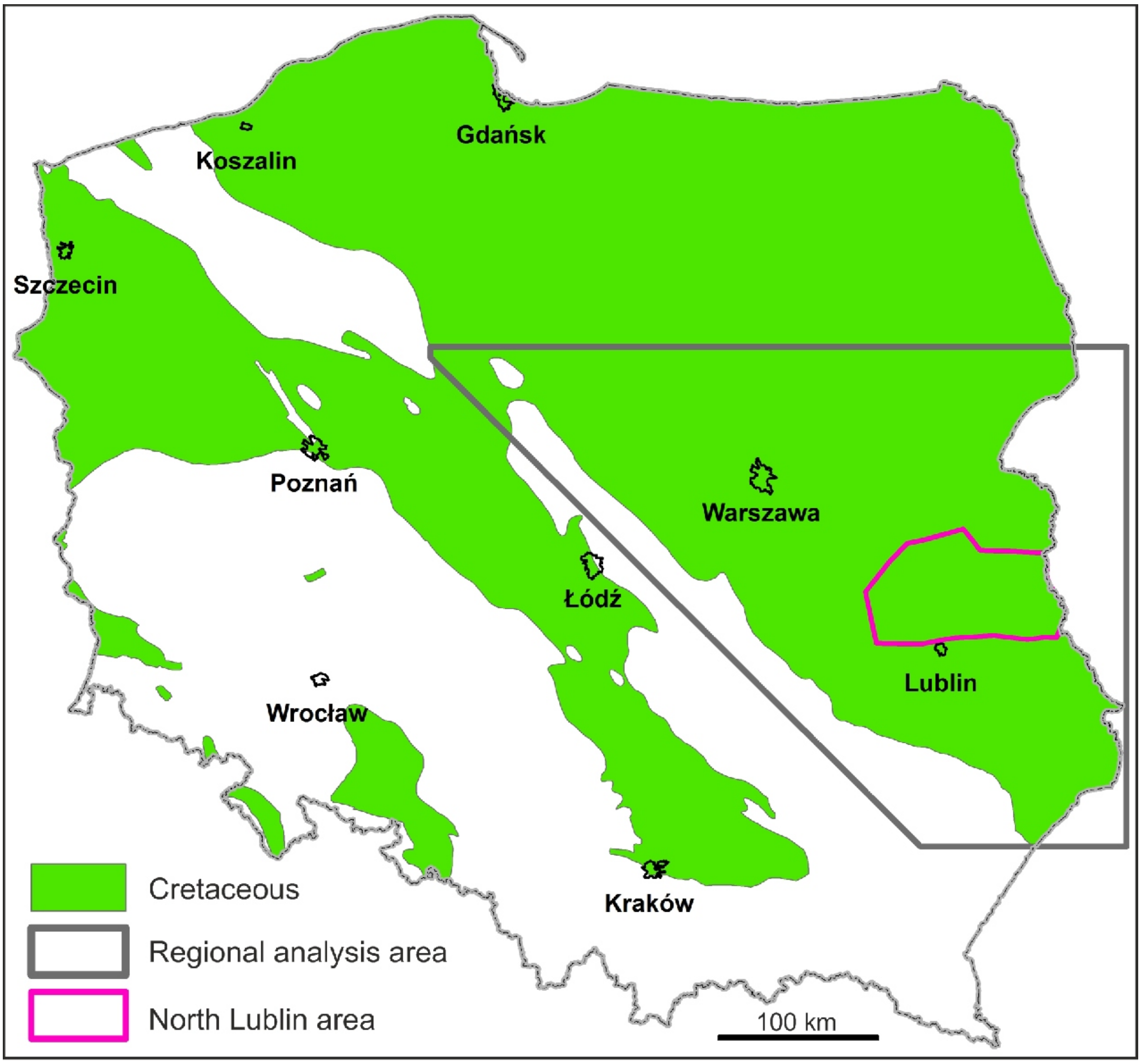


**Fig. 6. The occurrence of Cretaceous deposits in Poland on a map without the Cenozoic showing the marked region of geological modelling in the Lublin-Warsaw zone and the area north of Lublin of direct analyses on digital maps**

The remaining explanations can be found in the text

tabase, which is conveniently available in a shapefile format compatible with ArcGIS, includes only boreholes within the designated research area of the Warsaw-Lublin region, 993 in total.

The Bank HYDRO database, a reservoir of groundwater data, on the other hand, has been carefully maintained by the Polish Geological Institute since the 1970s. It is currently maintained in cooperation with the Central Hydrogeological Database (CHDB) in Warsaw and various Regional Hydrogeological Databases (RHDB). With over 144,000 entries (as of October 2018), this database provides important insights into hydrogeological parameters, including water table depth, lithology and stratigraphy, albeit in CSV format. Despite its richness, the raw format required careful analysis, selection and reorganisation to meet the research objectives (Walaszczyk, 2019).

The process of data refinement began with the conversion of CSV files into a comprehensive database using MS Access. This facilitated the splitting of the data into different columns and allowed the lithological and stratigraphic information to be matched with the borehole locations using RHDB's unique identifiers. Superfluous columns were then deleted, resulting in an optimised dataset of 6,682 records. This refined dataset was then seamlessly integrated into *ArcGIS* for further analysis (Walaszczyk, 2019).

Another indispensable resource is the Central Geological Database (CGDB), which was established by the Polish Geological Institute in 1995. It is managed by the Department of Geoinformation Management and is the most important geological archive in Poland, operated under state supervision. Of particular note is the comprehensive collection of borehole data, which enriches the PITAKA database with lithological and stratigraphic details. This expansion considerably improves the analytical possibilities for the investigation and validation of Cretaceous deposits and facilitates comprehensive studies of sedimentation, palaeogeography and palaeotectonics.

## MODELLING OF THE CRETACEOUS TOP STRUCTURAL SURFACE

This was a pioneering endeavour, as there were no previously published or archived studies on this subject. Consequently, the use of different tools was necessary to carefully

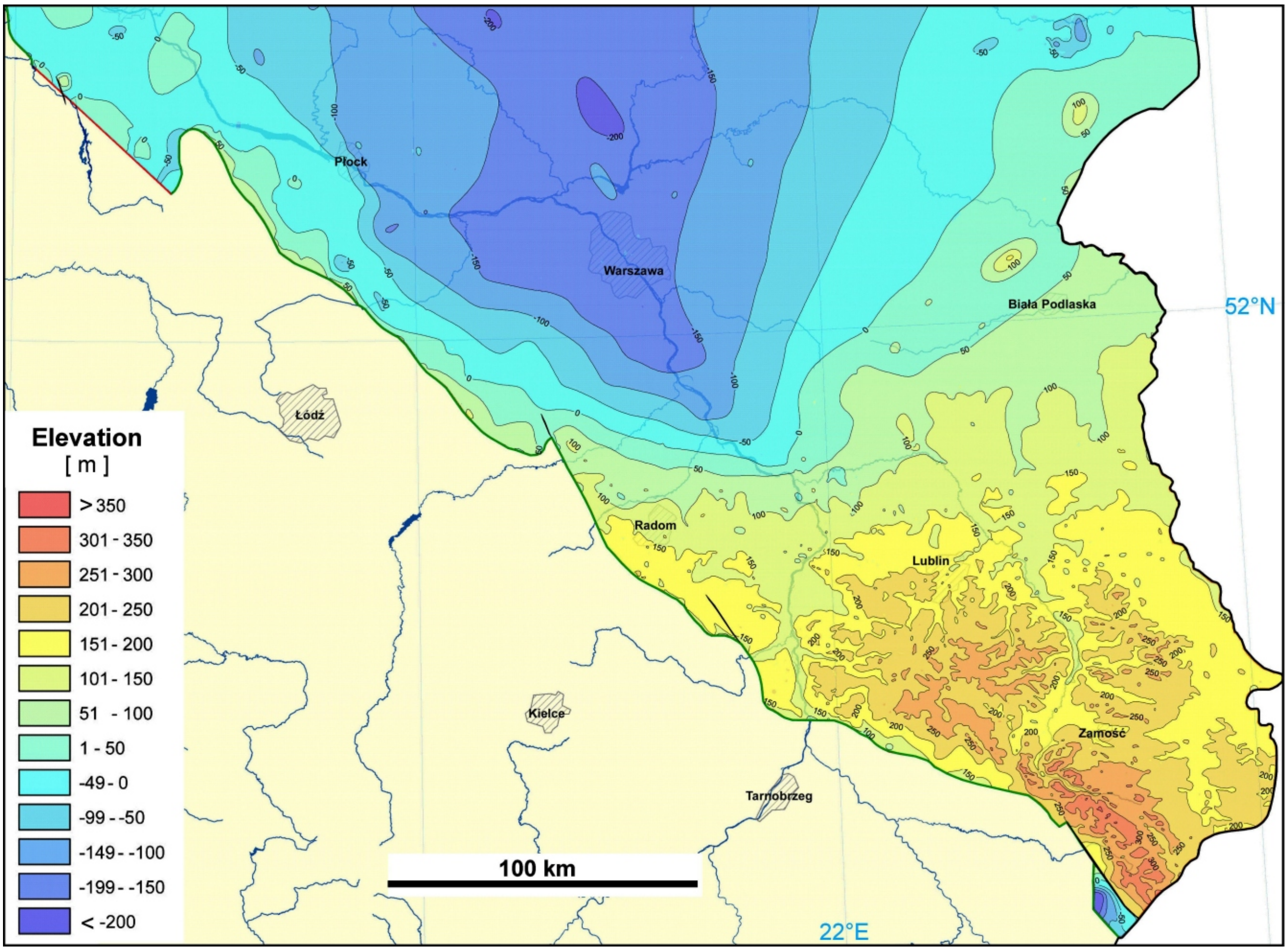


**Fig. 7. Elevation map of the Cretaceous top in the Warsaw-Lublin area**

compare the results obtained and to determine the optimal results. *ArcGIS* software applications were used in turn, employing a cascade of modelling techniques including “Trend”, “Spline”, “Topo to raster”, “IDW”, “Kriging” and “Natural Neighbour” . Detailed insights into the methodology are given by Walaszczyk (2019), which states: “The entire process of modelling the structural surface of the Cretaceous peak involved more than 50 iterative iterations, using mainly the tools ‘Spline’ and ‘Topo to raster’ to determine the developments therein and to identify parameters that lead to optimal results.” In addition, “auxiliary isohips” and “isolines simulating faults penetrating the Cretaceous top surface” were integrated to improve modelling fidelity. With each iteration of the computer simulations, the quality of the models created using the ‘Topo to Raster’ tool gradually and significantly improved. This tool, which works with point and line data, enabled faster modelling than the Spline method, while maintaining or exceeding model fidelity (Walaszczyk, 2019).

In addition to the structural map delineating the Cretaceous top surface, supplementary work was carried out to model the Cretaceous base, to formulate a thickness model for the Cretaceous deposits (using the *Petrel* software Raster calculator) and to produce slope maps for both the Cretaceous top and bottom. Leveraging the modelled maps alongside geological cross-sections a comprehensive geological-spatial analysis of the Cretaceous deposits ensued. Particular attention was paid to faulting and tectonic features to investigate the influence of the Polish Swell inversion on the structural surfaces of the Cretaceous and to describe the tectonic regionalisation resulting from the structural surfaces formulated. Walaszczyk (2019) did not deal with the amber deposits in the Lublin region during his research.

## RESULTS

### A STRUCTURAL MAP OF THE CRETACEOUS SURFACE AND A SLOPE MAP FOR THIS SURFACE

The structural map of the Cretaceous surface in the Warsaw-Lublin region is a pioneering achievement in Poland (Fig. 7). Its creation represents a turning point, as it requires careful geomorphological and structural analyses due to its unprecedented accuracy and the comprehensive data set on which it is based. Remarkably, this map is a digital rendering that has been carefully created using established algorithms of computer software processes. This digital format not only facilitates direct analysis, but also provides an invaluable resource for solving specific challenges by using the underlying database to solve complex geological questions.

Based on this model, a corresponding slope map was created, which depicts the varied terrain of the structural surface in the form of slope inclinations (Fig. 8). These slopes have different inclinations, which are categorised into different classes based on their angular position. The classes range from almost horizontal positions (<0.25°) to inclinations of 8–25° and are characterised by exponentially increasing values, with flat terrain predominating and steeper inclinations being rarer. As an-

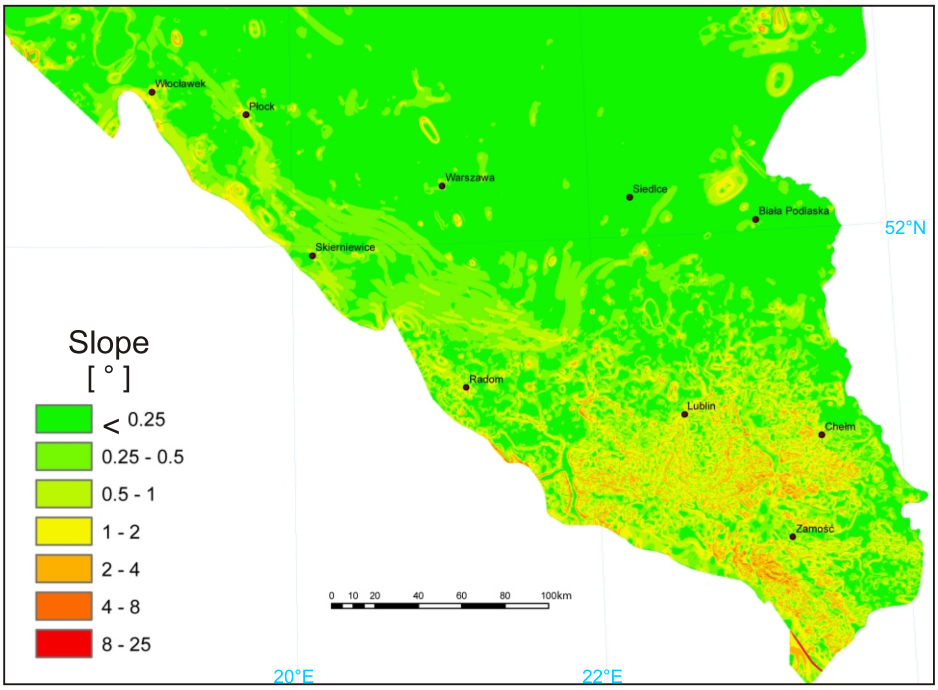


**Fig. 8. Slope map of the Cretaceous top in the Warsaw-Lublin area**

other digital rendition, this map lends itself seamlessly to computational analysis and holds untapped potential for a range of research opportunities. The possibilities offered by such maps are still largely unexplored, so new insights will emerge alongside new challenges. The following study serves as an example of such an endeavour and demonstrates the diverse applications of these resources.

### ANALYSIS OF THE SLOPE MAP IN THE NORTH LUBLIN REGION

The slope map showing the Cretaceous topography in the Warsaw and Lublin area is shown in Figure 8. The northern sector of this map shows predominantly almost horizontal surfaces which lie between 0 and 0.5°, while the southern extension, especially south of Lublin, shows inclinations between 1 and 4°. A detailed analysis of this phenomenon is difficult in the context of this study, as we focus on the occurrence of amber in the Paleogene deposits. Interestingly, Paleogene sedimentary deposits are confined exclusively to the northern areas beyond the Lublin latitude and are absent in the southern terrain, either because they were not deposited or because they were affected by erosion. Attention is therefore focussed only on the northern extent around Lublin (see Fig. 4), and what does this area means in the context of the slope map (Fig. 8).

Our research has shown the importance of considering the context of lithofacies architecture when interpreting the variability of depositional parameters, as isolating these factors can lead to oversimplification. The delineated area has a variety of topographical features, often characterised by closed successions with steeply sloping edges interspersed with flat surfaces with gentle slopes. Our lead investigator (PHK) has studied this representation in detail but has been unable to decipher its intricacies. However, it can be seen that the surface analysed has a regional dip to the north. The elevation profile reaches heights of up to 300 metres above sea level in the southern districts, while in the vicinity of Warsaw it drops to a depth of around –150 metres below sea level (see Fig. 7). Looking only at the region north of Lublin, these differences in altitude are between 200 and 50 metres above sea level. This topographic contour reflects both the hypsometric system of the Paleogene and the residual effects of the tectonic (epeirogenic) phenomena that prevailed during the Miocene, especially during the formation of the Carpathian Foredeep.

Irrespective of the hypsometric nuances of the Paleogene, it is obvious that the topography of the Cretaceous in the defined region shows a regional gradient from the Paleogene to the present day, predominantly towards the north. As the Cretaceous succession is overlain by Paleogene deposits, the slope map can be understood as an approximation of the bottom surface of the Late Eocene basin. It is hypothesised that this surface was originally formed by surface processes primarily triggered by fluvial activity and that it may have been reshaped during the transgressive phase of the Late Eocene. The visible image is thought to reflect the palaeomorphology of the basin, suggesting the adoption of a model that envisages the deposition of the amber from low-energy currents. This scenario is similar to earlier occurrences of amber deposition in small deltas characterised by a belt-shaped distribution of sites dominated by mud lithofacies. The interpretation of a slope map of the Cretaceous topography in this context becomes an attempt to clarify palaeomorphology as a pivotal factor for sedimentation during the regressive phase of the Late Eocene (Fig. 9).

At the beginning of the careful analysis of the slope map, based on the above assumptions, emphasis was placed on identifying low-energy conditions that favour sedimentation and are predominantly located on the northern sides of the slopes. It was also essential that the amber-bearing sediments could move freely, which precluded closed structures. The digital recording of the map analysed allowed practical enlargement on a computer monitor without compromising image quality. Based on these assumptions, the region north of Lublin was subjected to a careful analysis, which revealed numerous sectors that meet the sedimentological criteria for the formation and preservation of amber accumulations. These areas are shielded by

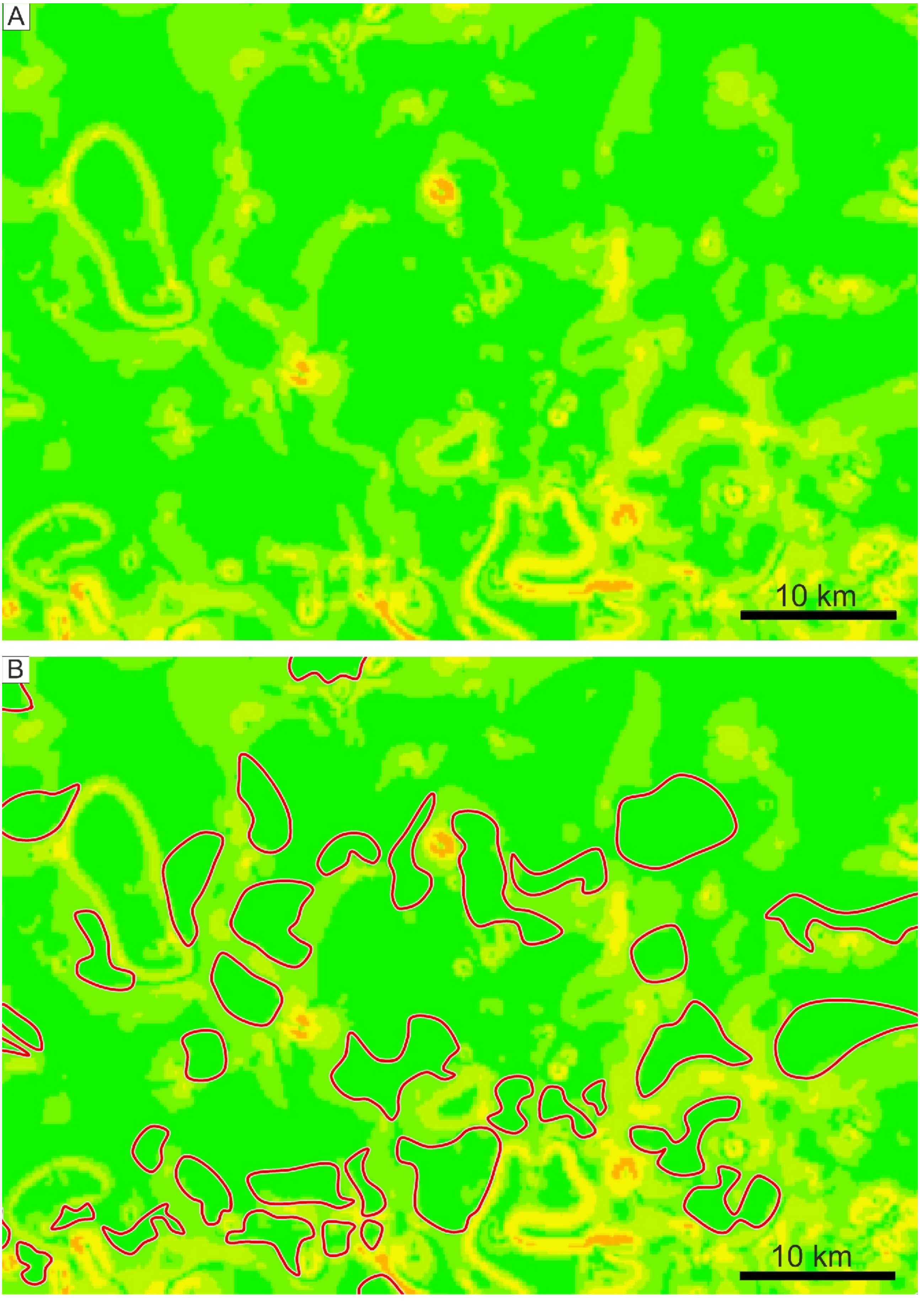


**Fig. 9. Fragment of a slope map of the Cretaceous top in the North Lublin area**

**A** – map without interpretation; **B** – map with highlighted areas of amber-bearing deposits based on the interpretation; further explanations in the text

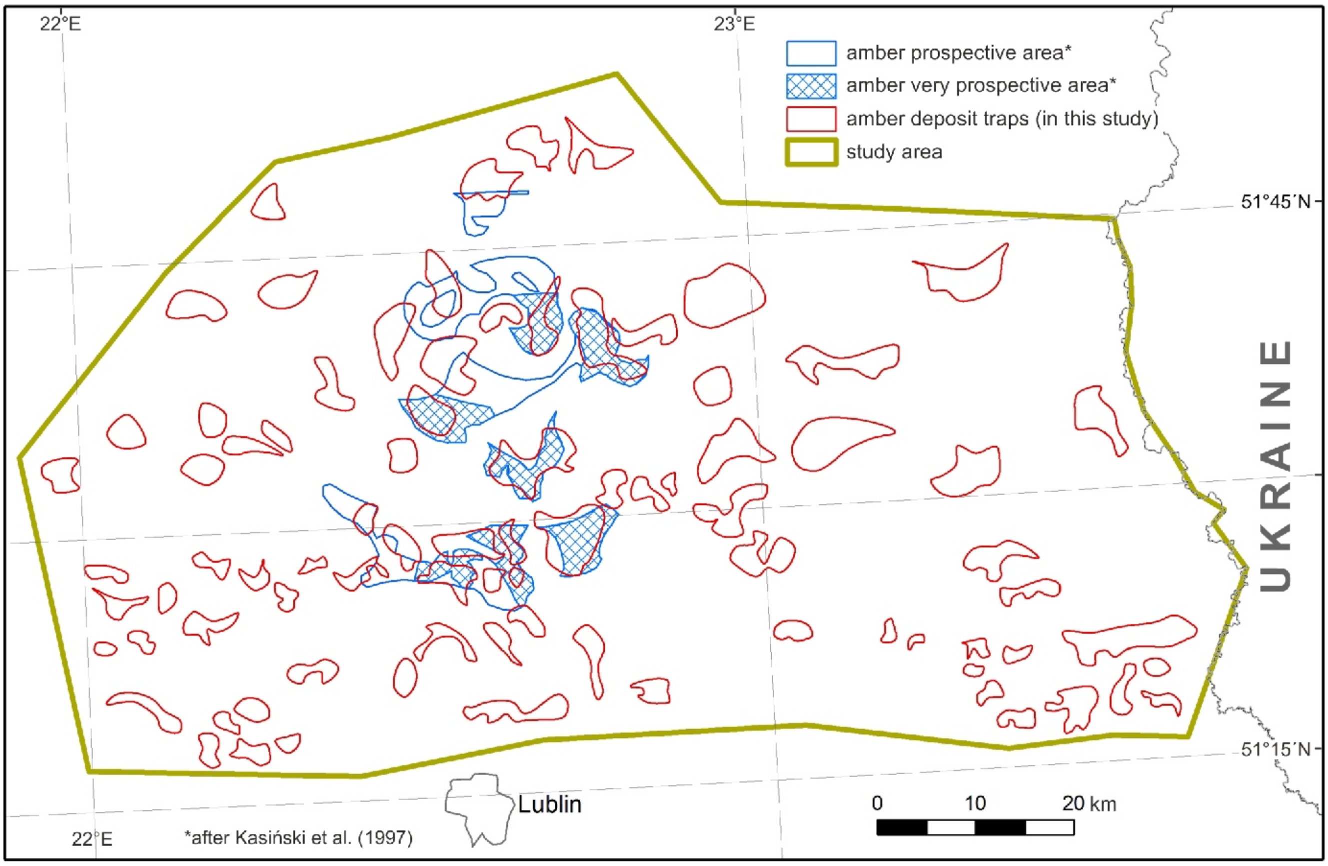


**Fig. 10. Comparison of the amber-bearing fields interpreted on the slope map with the prospective map by Kasiński et al. (1997)**

slopes to the south and open to the north, which is consistent with the direction of marine retreat from the Late Eocene onwards.

The culmination of these efforts can be seen in Figure 9, where the picture clearly corresponds to the postulated assumptions about the belt-like distribution of amber assemblages in the northern Lublin region. Subsequently, the results obtained had to be validated against the map by Kasiński et al. (1997), which served as a pivotal reference point. This map, which was derived from extensive shallow borehole data documenting potential amber deposits, provided a fundamental basis for further analysis of the slope map.

A comparison of the map by Kasiński et al. (1997) with the results of the analysis of the slope map with regard to the delimitation of the low-energy areas within the Late Eocene basin (Fig. 10) shows a clear correspondence between the two representations. This agreement supports the assumption that the palaeomorphology of the Late Eocene basin bottom did indeed have a recognisable influence on sediment dynamics in an amber-bearing environment.

To provide further clarity on this matter, a series of palaeogeographic cross-sections were created to illustrate the stages of amber-bearing sediment formation (Fig. 11). First, the two assumptions underlying the analysis of the slope map are explained: firstly, the northwards dip of the Cretaceous top surface and, secondly, the creation of favourable conditions for the accumulation and preservation of amber-bearing sediments (shown in green in Fig. 11), that embrace the slope from the south and extend northwards into the open expanse. This protective slope also served as a trap for the accumulation of sandy sediments (shown in yellow in Fig. 11), which covered the amber-bearing sediments and thus facilitated their preservation.

The evolving sea level of the Late Eocene was also integrated into the palaeogeographic representations. In the initial phase (Fig. 11A), the amber-bearing sediments accumulated in sheltered areas. Later, with the lowering of the sea level (Fig. 11B), the erosional base changed in favour of the supply of sandy material, that could be transported over short distances and prevented the erosion of the accumulated amber-bearing sediments. The subsequent phase of sedimentation corresponded to the previous model, in which new accumulations of amber-bearing sediments formed and previously deposited accumulations survived even under terrestrial conditions. These were embedded in sand banks that often had oblique layers, indicating strong current activity during the regressive phase or under subaerial conditions due to river currents (Fig. 11C).

The final cross-section (Fig. 11D) shows the terrain without exaggeration, but with a regional dip of 3.5°, while the present dip of the Cretaceous top surface in the northern Lublin region is 0.12°. It is assumed that the slope during the Late Eocene was probably at least half as steep and did not exceed 0.06°.

## ANALYSIS OF THE STRUCTURAL MAP OF THE CRETACEOUS TOP SURFACE IN THE NORTH LUBLIN REGION

Figure 7 shows a digital structural map of the Cretaceous top surface, which not only serves for structural visualisation, but also facilitates palaeomorphological analysis. The structural layout is delineated by isobaths and contours, with one of the isolines presumably delineating the coastline, while the depth ratios correspond to the assumptions made (Fig. 12). In this context, the area 10 metres below the coastline is referred to as the coastal zone (light blue), while depths of >20 metres indi-

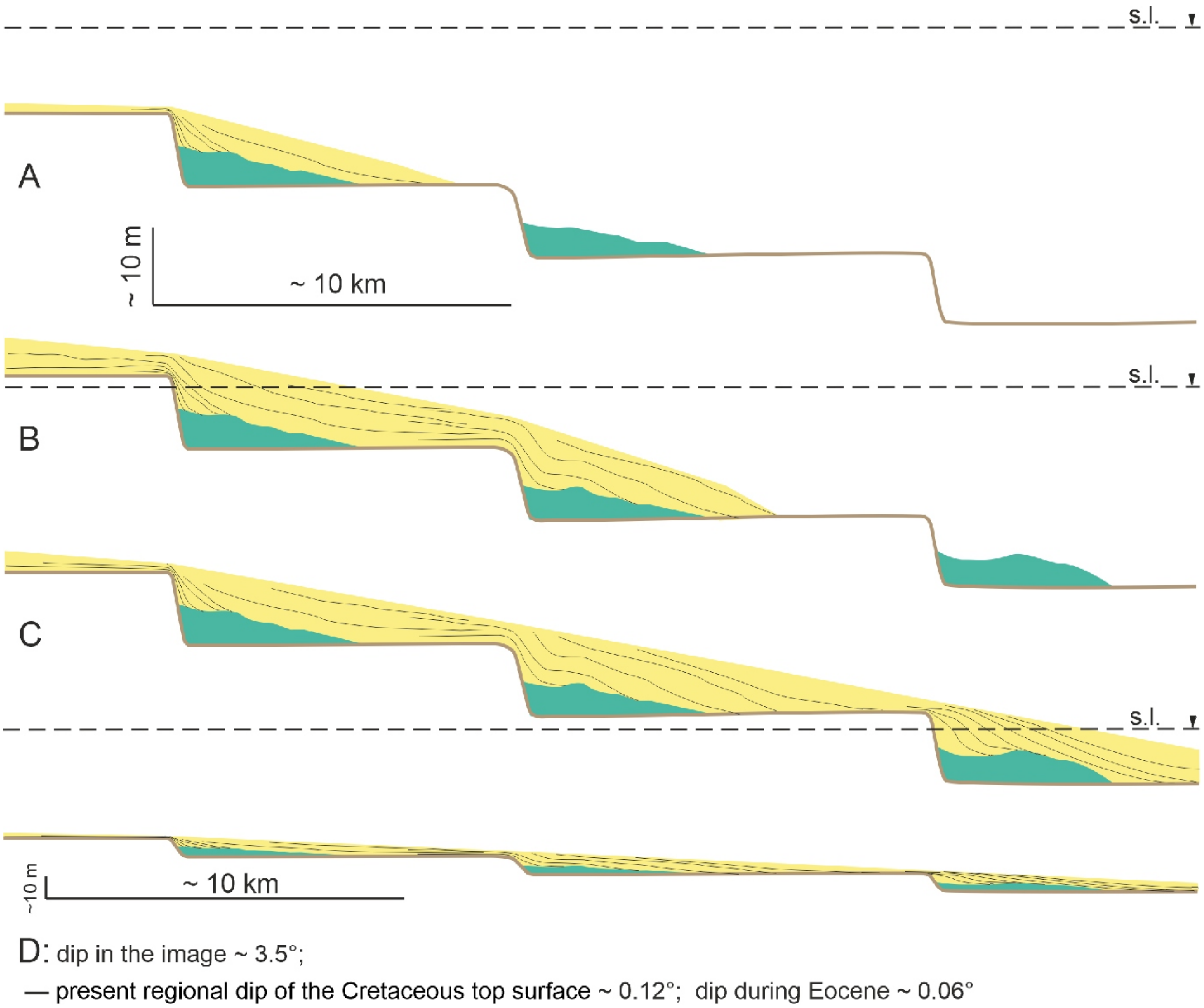


**Fig. 11. Series of palaeogeographic sections explaining the origin and occurrence of amber-bearing deposits (A–C); D – an attempt to approximate the real regional dip of the Cretaceous top in the Late Eocene**

Further explanations in the text

cate a deeper zone (dark blue) with a relatively weakened influence of wave currents. Conversely, land masses above the coastline are shown, with elevations up to 10 metres above sea level marked in green and higher elevations without an upper limit marked in orange. Many such palaeographic schemes were created by shifting the coastline every 10 metres as a reference point. At the same time, the search for amber-bearing fields was started, which were delineated on the basis of the analysis of the slope maps.

Fields located near the transition between the shallower and deeper coastal zones (on the northern side of the 10 metre isobath) were most likely to be amber traps (Fig. 12). In addition, fields in the shallower zone (referred to as amber traps +10 in the annotations) were set aside for additional analysis and comparison. Changing the depth assumptions allows for different analyses due to the versatility of digital mapping techniques.

Following the above analysis, each amber-bearing field identified by analysing the slope maps (Fig. 10) was assigned an arbitrary hypsometric value derived from its location on the palaeogeographic depth map. These values are primarily used to quantify the delineated fields. Consequently, each field has been assigned a depth signature characterised by contour values that provide a comprehensive overview of the chronological sequence of formation of the individual “assemblages” (Fig. 12). Fields with higher signature values are inferred to have been created earlier, with the oldest field signature at 200 and the youngest at –90. These age differences are reflected in the colour-coded signatures, where signatures with the same values are assigned the same colours. This visualisation method not only highlights the belt-like nature of the designated fields, but also describes the sequence of their formation and gives them a stratigraphic character (Fig. 13).

Considering that the present-day position of the Cretaceous top surface is at least twice as deep, the actual palaeobathymetric conditions were probably only half as shallow as shown here, implying a drop in sea level of ~50 metres during the Late Eocene regression phase in the northern Lublin region.

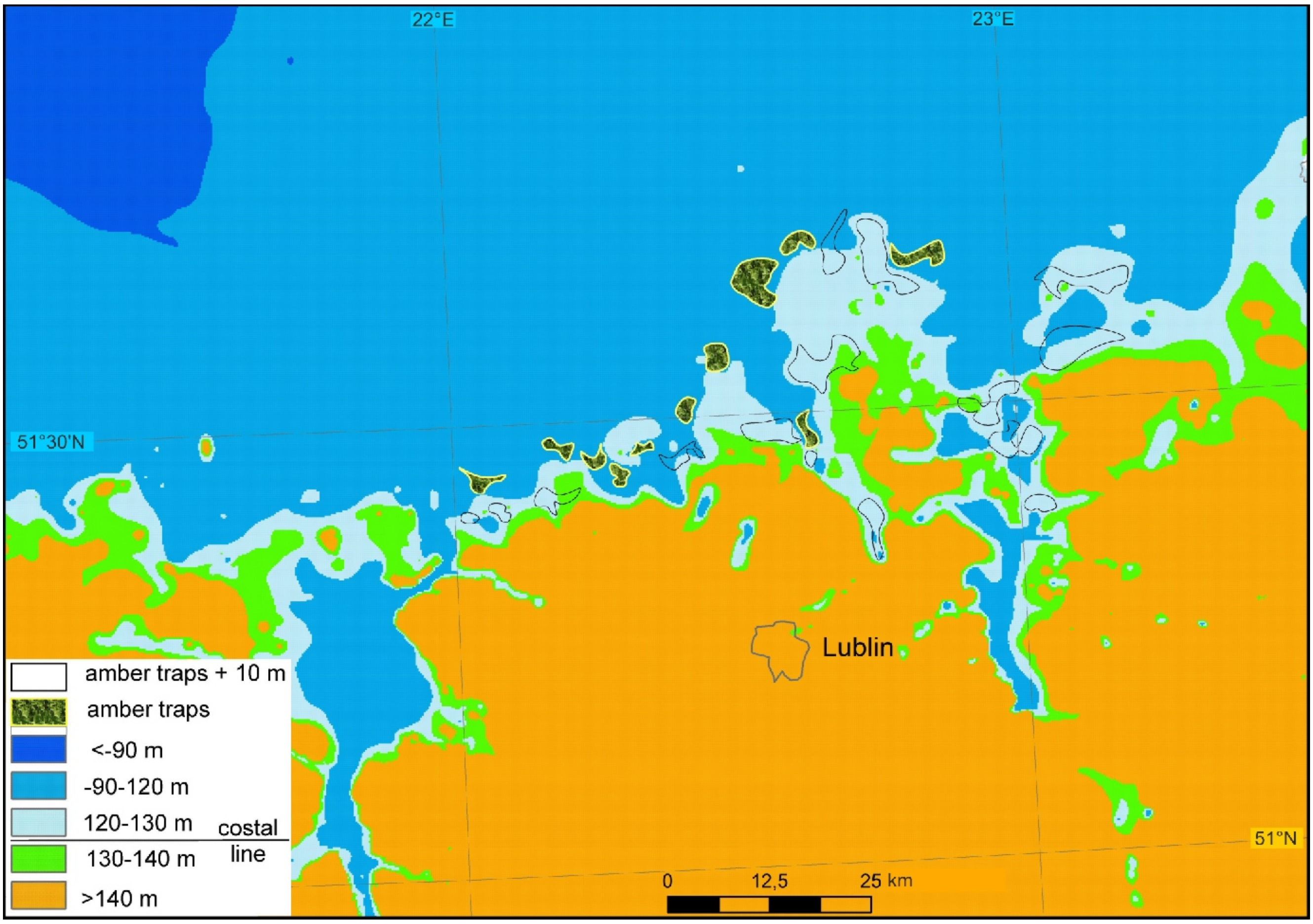


**Fig. 12. Palaeogeographic map of the sedimentary episode (regression phase of the Late Eocene), defined by the extent of the coastline "130"**

Explanations in the text, but here note the location of the amber traps below the isobath "130–20 = 110" and "amber traps + 10", which are already so close to the coastline that nothing stands in the way of a sand supply from the land and the filling of the traps to protect against erosion

## CONCLUSIONS

1. The analysis presented here focuses on the sedimentary conditions of the Late Eocene amber-bearing deposits and establishes that basin morphology was an important factor in the formation and distribution of amber geological resources. The Late Paleocene basin basement in the northern Lublin region consists mainly of Upper Cretaceous deposits.

2. The delineation of amber-bearing fields derived from the analysis of Cretaceous topographic slope maps and quantitative palaeogeographic maps for the Late Eocene showed a strong correlation with the projections of deposits obtained from shallow borehole data.

3. Through our analysis, we have identified 84 different amber-bearing fields (Fig. 13), ranging in size from 1.4 $km^2$ to 38.2 $km^2$. The cumulative area of these fields totals 891.5 $km^2$, which corresponds to almost 14% of the study area in the northern Lublin region.

4. These results underlined the importance of further geological and exploration efforts aimed at validating the results presented in this study.

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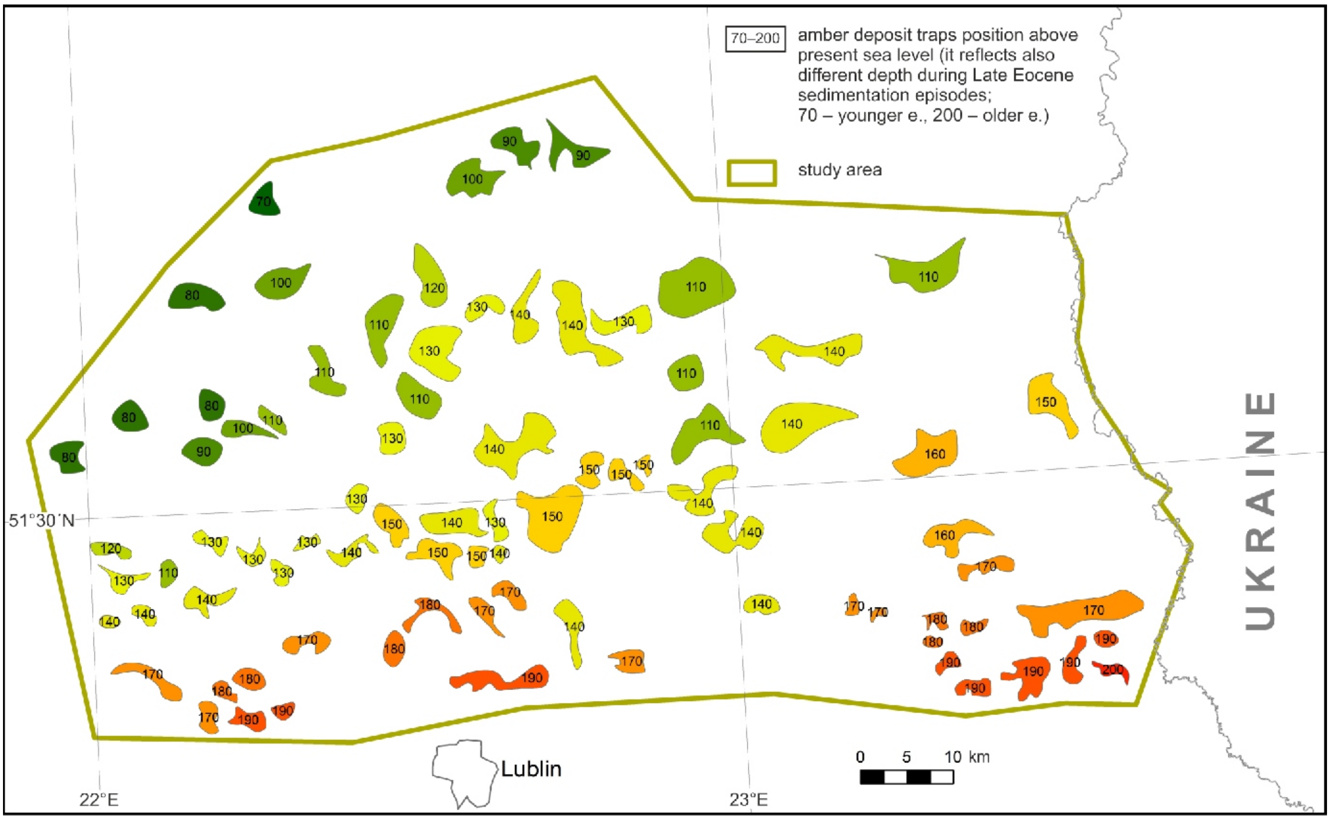


**Fig. 13. Nest strip arrangement of the interpreted amber-bearing fields with assigned signatures and colours showing the sequence of their formation and occurrence**

## REFERENCES


**Akhmetiev, M.A., Beniamovski, V.N., 2006.** The Paleocene and Eocene in the Russian part of West Eurasia. Stratigraphy and Geological Correlation, **14**: 49–72; https://doi.org/10.1134/S0869593806010047

**Barrier, E., Vrielynck, B., Brouillet, J.-F., Brunet, M.F., 2018.** Paleotectonic Reconstruction of the Central Tethyan Realm. Tectonono-Sedimentary-Palinspastic maps from Late Permian to Pliocene. DARIUS Programme, Publisher: CCGM/CGMW, Paris; http://www.ccgm.org

**Bohaty, S.M., Zachos, J.C., Florindo, F., Delaney, M.L., 2009**. Coupled greenhouse warming and deep sea acidification in the middle Eocene. Paleoceanography, **24**: 1–16; https://doi.org/10.1029/2008PA001676

**Bujakowska, K., Parecki, A., 2004.** Geological documentation of the Górka Lubartowska amber deposit in category D (in Polish). Przedsiębiorstwo Geologiczne “Polgeol”, NAG PIG-PIB, 602/2005, Warszawa.

**Buraczyński, J., Krzowski, Z., 1994**. Middle Eocene in the Sołokija graben on Roztocze Upland (in Polish with English summary). Kwartalnik Geologiczny, **38**: 739–753.

**Czuryłowicz, K., 2014.** Geological and depositional conditions of amber accumulations in Paleogene deposits in the Parczew and Lubartów region (in Polish). Ph.D. thessis, Archive of the Faculty of Geology, University of Warsaw.

**Czuryłowicz, K., 2015.** Geological and depositional conditions of amber accumulations in Paleogene deposits in the Parczew and Lubartów region. Spatial analyses in resource prospecting on the example of the Górka Lubartowska amber deposit (in Polish). In: First forum of educational license users of ArcGIS software at the University of Warsaw, Faculty of Geography and Regional Studies, University of Warsaw, conference materials (ed. J. Lechnio): 12–27.

**Czuryłowicz, K., Sałaciński, R., 2010.** Experimental modelling of amber deposition in the coastal zone of a sedimentary basin (in Polish with English summary). Biuletyn Państwowego Instytutu Geologicznego, **439**: 391–398.

**Czuryłowicz, K., Lejzerowicz, A., Kowalczyk, S., Wysocka, A., 2014**. The origin and depositional architecture of Paleogene quartz-glauconite sands in the Lubartów area, eastern Poland. Geological Quarterly, **58** (1): 125–144; https://doi.org/10.7306/gq.1137

**Gedl, P., 2012.** Reworked Eocene–Oligocene dinoflagellate cysts in the Miocene of the Carpathian Foredeep Basin: implications for Paleogene palaeogeography in SE Poland. Geological Quarterly, **56** (4): 853–868; https://doi.org/10.7306/gq.1059

**Gedl, P., 2014.** Eocene dinoflagellate cysts from the Sołokija Graben (Roztocze, SE Poland): biostratigraphy and palaeoenvironment. Geological Quarterly, **58** (4): 707–728; https://doi.org/10.7306/gq.1167

**Gedl, P., Worobiec, E., 2020.** Origin and timing of palaeovalleys in the Carpathian Foredeep basement (Sędziszow Małopolski-Rzeszow area; SE Poland) in the light of palynological studies. Marine and Petroleum Geology, **115**, 104277; https://doi.org/10.1016/j.marpetgeo.2020.104277

**Haq, B.U., Hardenbol, J., Vail, P.R., 1987.** Chronology of fluctuating sea levels since the Triassic. Science, **235**: 1156–1167; https://doi.org/10.1126/science.235.4793.1156

**Haq, B.U., Hardenbol, J., Vail, P.R., 1988**. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. SEPM Special Publication, **42**: 71–108; https://doi.org/10.2110/pec.88.01.0071

**Harasimiuk, M., Henkiel, A., 1981.** Post-Cretaceous tectonics on the northern slope of the Meta-Carpathian Swell near Lublin (in Polish with English summary). Przegląd Geologiczny, **29**: 571–573.

**Hutchinson, D.K., Coxall, H.K., Lunt, D.J., Steinthorsdottir, M., de Boer, A.M., Baatsen, M., von der Heydt, A., Huber, M., Kennedy-Asser, A.T., Kunzmann, L., Ladant, J.-B., Lear, C.H., Moraweck, K., Pearson, P. N., Piga, E., Pound, M.J., Salzmann, U., Scher, H.D., Sijp, W.P., Śliwińska, K.K., Wilson, P.A., Zhang, Z., 2021.** The Eocene-Oligocene transition: a review of marine and terrestrial proxy data, models and model-data comparisons. Climate of the Past, **17**: 269–315; https://doi.org/10.5194/cp-17-269-2021

**Ivanova, A.V., Machulina, S.A., Zaitseva, L.B., 2012**. Epochs of the formation of amber and its distribution in nature. Lithology and Mineral Resources, **47**: 18–22; https://doi.org/10.1134/S0024490212010051

**Jahn, A., 1956.** Geomorphology and Quaternary history of Lublin Plateau (in Polish). Geographical Studies, **7**: 1–493.

**Jovane, L., Coccioni, R., Marsili, A., Acton, G., 2009.** The late Eocene greenhouse-icehouse transition: observations from the Massignano global stratotype section and point (GSSP). GSASpecial Paper, **452**: 149–168; https://doi.org/10.1130/2009.2452(10)

**Jurys, L., Kasiński, J.R., Klich, J., Kramarska, R., Listkowski, W., Łazowski, L., Małka, A., Mucha, J., Nieć, M. (ed.), Sałaciński, R., Saternus, A., Urbański, P., Zieliński, K., 2010.** Principles of exploration and documenting amber deposits – Methodical recommendations (in Polish). Ministerstwo Środowiska, Warszawa.

**Karnkowski, P., 1989.** Deltaic deposits of the Carpathian Foreland (in Polish with English summary). Przegląd Geologiczny, **37**: 28–32.

**Karnkowski, P., Głowacki, E., 1961.** Geological structure of sub-Miocene sediments of the middle Carpathian Foreland (in Polish with English summary). Kwartalnik Geologiczny, **5**: (2) 372–419.

**Karnkowski, P.H., 2014.** Review of Krzysztof Czuryłowicz's doctoral thesis entitled Geological and depositional conditions of amber accumulations in Paleogene deposits in the Parczew and Lubartów region (in Polish): 1–19. Archive of the Faculty of Geology, University of Warsaw.

**Karnkowski, P.H., Kasiński, J.R., 2014.** Paleogeography and architecture of Paleogene formations in the Lublin region (southeastern Poland) (in Polish). In: Challenges of Geology in the Lublin Region in the 21st Century (ed. W. Mizerski). 83rd Meeting of the Polish Geological Society, Polish Geological Institute.

**Karnkowski, P.H., Ozimkowski, W., 2001.** Structural evolution of the pre-Miocene basement in the Carpathian Foredeep (Kraków-Przemyśl region, SE Poland) (in Polish with English summary). Przegląd Geologiczny, **49**: 431–436.

**Kasiński, J.R., 2015.** Amber Lublin region (in Polish). Academia, **41**: 45–47.

**Kasiński, J.R., 2016.** Amber deposits of northern Lublin region: history of exploration, geological structure, perspectives (in Polish). In: Lublin Amber – Findings, Geology, Deposits, Perspectives: 68–93. State Higher Vocational School in Chełm. Ed. Stellarium, Kraków.

**Kasiński, J.R., Kramarska, R., 2008.** Sedimentary environment of amber-bearing association along the Polish-Russian Baltic coastline. Exkursionsführer und Veröffentlichungen für Gesellschaft für Geowissenschaften, **236**: 46–57.

**Kasiński, J.R., Słodkowska, B., 2014**. Amber-bearing sediments of the Eocene eastern margin of the epicontinental North Sea Basin (in Polish). LXXXIII Scientific Congress of the Polish Geological Society 'Challenges of geology in the Lublin region,' Biała Podlaska, abstract: 23.

**Kasiński, J.R., Tołkanowicz, E., 1999.** Amber in the Northern Lublin Region – origin and occurrence. In: Investigations into Amber (eds. B. Kosmowska-Ceranowicz and H. Paner): 41–51. Muzeum Archeologiczne w Gdańsku.

**Kasiński, J.R., Piwocki, M., Saternus, A., Tołkanowicz, E., Wojciechowski, A., 1997.** Implementation of a geological project to determine the prospects for the occurrence of amber deposits in the Eocene formations of the Lublin region (in Polish). Państwowy Instytut Geologiczny, Centralne Archiwum Geologiczne, nr. 2529/99, Warszawa.

**Kasiński, J.R., Oszczypko, N., Piwocki, M., 2008.** Paleogene and Neogene (in Polish). In: Stratigraphic Table of Poland, Poland Beyond the Carpathian Mountains (ed. R. Wagner). Państwowy Instytut Geologiczny.

**Kasiński, J.R., Słodkowska, B., Kramarska, R., 2018.** Amber-bearing sediments of the Polish-Ukrainian border zone stratigraphic correlation. In: 25th International Symposium "Science and Art", Gdańsk, Poland, 22–23.03.2018 (eds. E. Wagner-Wysiecka, J. Szwedo, E. Sontag, A. Sobecka, J. Czebreszuk, M. Cwaliński) Abstracts: 94–98.

**Kasiński, J., Kramarska, R., Słodkowska, B., Sivkov, V., Piwocki, M., 2020.** Paleocene and Eocene deposits on the eastern margin of the Gulf of Gdańsk (Yantarny P-1 borehole, Kaliningrad region, Russia). Geological Quarterly, **64** (1): 29–53; https://doi.org/10.7306/gq.1513

**Kosmowska-Ceranowicz, B., 2012.** Amber in Poland and in the world (in Polish with English summary). Wydawnictwo Uniwersytetu Warszawskiego, wyd. I.

**Kosmowska-Ceranowicz, B., Leciejewicz, K., 2005.** Amber deposits on the southern shore of the Eocene Sea. Amber: views, opinions. Materials from Amberif seminars 1994–2004 (in Polish with English summary) (eds. B. Kosmowska-Ceranowicz and W. Gierłowski): 32–36. International Amber Association.

**Kosmowska-Ceranowicz, B., Popiołek, J., 1981.** About amber deposits in Poland based on unpublished typescripts by Adam Chętnik from 1931–1938 (in Polish with English summary). Prace Muzeum Ziemi, **34**: 3–29.

**Kosmowska-Ceranowicz, B., Kociszewska-Musiał, G., Musiał, T., Miller, C., 1990**. Amber-bearing Tertiary deposits in the vicinity of Parczew (in Polish with English summary). Prace Muzem Ziemi, **41**: 21–25.

**Kováč, M., Plašienka, D., Soták, J., Vojtko, R., Oszczypko, N., Less, G., Ćosović, V., Fügenschuh, B., Králiková, S., 2016.** Paleogene palaeogeography and basin evolution of the Western Carpathians, Northern Pannonian domain and adjoining areas. Global and Planetary Change, **140**: 9–27; https://doi.org/10.1016/j.gloplacha.2016.03.007

**Knox, R., Bosch, A., Rasmussen, E.S., Heilmann-Clausen, C., Hiss M., de Lugt, I., Kasiński, J.R., King, C., Köthe, A., Słodkowska, B., Standke, G., Vanderberghe, N., 2010.** Cenozoic. In: Petroleum Geological Atlas of the Southern Permian Basin Area (eds. H. Doornenbal and A. Stevenson): 212–223. European Association of Geoscientists and Engineers Publications b.v., Houten.

**Kramarska, R., 2006.** Paleogene and Neogene of the southern Baltic Sea and its coastline (in Polish with English summary). Ph.D. thesis, Central Geological Archives of the State Geological Institute, nr. 866/2007

**Kramarska, R., Kasiński, J.R., Sivkov, V., 2008.** Paleogene amber in Poland and neighboring countries – geology, exploitation, prospects (in Polish with English summary). Górnictwo Odkrywkowe, **2–3**: 97–110.

**Kramarska, R., Kasiński, J.R., Słodkowska, B., 2020**. Minerals of the jewelry industry (jewelry stones): amber, succinate (in Polish with English summary). In: Balance of Prospective Mineral Resources in Poland: 371–381. Warsaw.

**Krijgsman, W., Palcu, D.V., Andreetto, F., Stoica, M Mandic, O., 2020**. Changing seas in the late Miocene Northern Aegean: a Paratethyan approach to Mediterranean basin evolution. Earth-Science Reviews, **210**, 103386; https://doi.org/10.1016/j.earscirev.2020.103386

**Leszczyński, K., 2010.** Lithofacies evolution of the Late Cretaceous Basin in the Polish Lowlands (in Polish with English summary). Biuletyn Państwowego Instytutu Geologicznego, **443**: 35–54.

**Lukashina, N.P., 2010.** The Southern Baltic Seas in the Paleogene according to the study of the foraminifera. Oceanology, **50:** 386–396; https://doi.org/10.1134/S0001437010030082

**Mazurek, A., 2018a**. Geological documentation of the natural aggregate and amber deposit "Górka Lubartowska VIII" in category C1 in the location Górka Lubartowska, plot no. 739 and 740, Niedźwiada Commune, Lubartów Poviat, Lublin Voivodeship (in Polish). CAG PIG, Warszawa nr. 4196/2018; G-57/1, Marshal's Office of the Lublin Voivodeship, Geological Archive in Lublin.

**Mazurek, A., 2018b.** Geological documentation of the natural aggregate and amber deposit "Górka Lubartowska-Leszkowice" in category C1 in the location Leszkowice, plot no. 1358 and Górka Lubartowska, plot no. 731, 732, 733, 734, 735. Ostrówek, Niedźwiada Commune, Lubartów Poviat, Lublin Voivodeship (in Polish). CAG PIG, Warszawa nr. 4195/2018; G-58/1, Marshal's Office of the Lublin Voivodeship, Geological Archive in Lublin.

**Mazurek, A., 2019a.** Geological documentation of the deposit of natural aggregate and glauconite-bearing sediments "Brzeźnica Leśna" in category C1 and amber in category D in places Brzeźnica Leśna plot no. 1143 and 1163, Niedźwiada Commune, Lubartów Poviat, Lublin Voivodeship (in Polish). Marshal's Office of the Lublin Voivodeship, Geological Archive in Lublin; CAG PIG, Warszawa nr. 7455/2019.

**Mazurek, A., 2019b.** Geological documentation of the deposit of natural aggregate and glauconito-bearing sediments "Górka Lubartowska IX" in category C1 and amber in category D, plot no. 826, 827, 828, 829, 830, 831, 1149 in the town of Górka Lubartowska, Niedźwiada Commune, Lubartów Poviat, Lublin Voivodeship (in Polish). CAG PIG, Warszawa nr. 5536/2019; G-59/1, Marshal's Office of the Lublin Voivodeship, Geological Archive in Lublin.

**Mazurek, A., 2020a.** Appendix No. 1 to the geological documentation of the "Górka Lubartowska VIII" natural aggregate and amber deposit in category C1, fields B and C, in the town Górka Lubartowska plot no. 738 and 741, Niedźwiada Commune, Lubartów Poviat, Lublin Voivodeship (in Polish). CAG PIG, Warszawa nr. 6288/2020.

**Mazurek, A., 2020b.** Supplement No. 1 to the geological documentation of the natural aggregate and amber deposit "Górka Lubartowska-Leszkowice" in category C1, fields C, D and E, places. Górka Lubartowska, plot no. 727, 730, 736, Niedźwiada Commune, Lubartów Poviat, Lublin Voivodeship. CAG PIG, Warszawa nr. 6291/2020.

**Mazurek, A., 2021**. Geological documentation of the deposit of sands, glauconite-bearing sediments and amber "Niedźwiada III", Niedźwiada Commune, Lubartów Poviat, Lublin Voivodeship. #N-49 (in Polish), Lublin Marshal's Office of the Lublin Voivodeship, Geological Archive in Lublin; CAG PIG, Warszawa nr. 3379/2021.

**Melnichuk, V.G., Krynycka, M.V., 2018.** Burshtyn Polissia (Amber of Polesie) (in Ukrainian). Natsionalnyy Universitet Vodnogo Gospodarstva ta Pyrodokorustovaniya, Rivne.

**Miller, K.G., Wright, J.D., Katz, M.E., Wade, B.S., Browning, J.V, Cramer, B.S., Rosenthal, Y., 2009.** Climate threshold at the Eocene-Oligocene transition: Antarctic ice sheet influence on ocean circulation. GSA Special Paper, **452:** 169–178.

**Mojski, J.E., Rzechowski, J., Woźny, E., 1966**. Upper Eocene in Luszawa on the Wieprz River near Lubartów (in Polish with English summary). Przegląd Geologiczny, **14:** 513–517.

**Morawski, J., 1960.** Characterization of sands from the littoral zone of the Lower Oligocene sea in the Lublin region (in Polish with English summary). Przegląd Geologiczny. **8**: 628–633.

**Moryc, W., 1992.** Geological structure of Miocene substrate formations in Sędziszow-Rzeszów region and their prospects (in Polish with English summary). Nafta-Gaz, **48**: 205–223.

**Moryc, W., 1995.** Terrestrial formations of Paleogene in the area of the Carpathian Foredeep (in Polish with English summary). Nafta-Gaz, **51**: 181–195.

**Moryc, W., 1997.** The Lower Cretaceous in the pre-Miocene substratum of the southern part of the Carpathian Foredeep in Poland. Annales Societatis Geologorum Poloniae, **67**: 287–296.

**Myszka, R., 2018.** Geological documentation of the deposit of sands and glauconites with amber in category C1 in locations. Niedźwiada, Lubartów Poviat, Lublin Voivodeship (in Polish). N-37/2, Lublin Marshal's Office of the Lublin Voivodeship, Geological Archive in Lublin; CAG PIG, Warszawa nr. 435/2019.

**Natkaniec-Nowak, L., Dumańska-Słowik, M., Naglik, B., Melnychuk, V., Krynickaya, M. B., Smoliński, W., Ładoń, K., 2017.** Depositional environment of Paleogene amber-bearing quartz-glauconite sands from Zdolbuniv (Rivne region, NW Ukraine): mineralogical and petrological evidences. Gospodarka Surowcami Mineralnymi, **33**: 45–62.

**Natkaniec-Nowak, L.H., Piestrzyński, A., Wagner, M., Heflik, W., Naglik, B., Paluch, J., Stach, P., 2019.** Górka Lubartowska-Niedźwiada" deposit (E Poland) as a potential source of glauconite raw material. Gospodarka Surowcami Mineralnymi, **35**: 5–30; https://doi.org/10.24425/gsm.2019.128522

**Nieć, M., (eds.), 2010.** Principles of exploration and documentation of amber deposits – methodical recommendations (in Polish with English summary). Ministerstwo Środowiska, Warszawa.

**Nieć, M., Kramarska, R., Sałaciński, R., 2010**. Prospects for the exploration of amber deposits in Poland (in Polish with English summary). Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energii Polskiej Akademii Nauk, **79**: 345–362.

**Oziembłowski, P., Karnkowski, P.H., 2008.** Tectonic regionalization of Poland using the geological PITAKA database (in Polish with English summary). Przegląd Geologiczny, **56**: 936–938.

**Ozsvárt, P., Kocsis, L., Nyerges, A., Győri, O., Pálfy, J., 2016**. The Eocene-Oligocene climate transition in the Central Paratethys. Palaeogeography, Palaeoclimatology, Palaeoecology, **459**: 471–487; https://doi.org/10.1016/j.palaeo.2016.07.034

**Palcu, D.V., Krijgsman, W., 2023.** The dire straits of Paratethys: Gateways to the anoxic giant of Eurasia. Geological Society Special Publications, **523**: 111–139; https://doi.org/10.1144/SP523-2021-73

**Parecki, A., Bujakowska, K., 2004.** Geological documentation of the "Górka Lubartowska" amber deposit in category D (in Polish). National Geological Archive nr. 609/2005. Warsaw.

**Piwocki, M., 2002**. Stratigraphy of amber-bearing deposits in northern Lublin region (in Polish with English summary). Przegląd Geologiczny, **50**: 871–874.

**Piwocki, M., 2004**. Paleogene (in Polish). In: Geological Structure of Poland, Vol. I, Stratigraphy, Part 3a, Cenozoic, Paleogene, Neogene (eds. T.M. Peryt and M. Piwocki). Państwowy Instytut Geologiczny, Warszawa.

**Połtowicz, S., 1998.** Middle-Badenian submarine erosion in the Carpathian Foreland, exploratory implications (in Polish with English summary). Nafta-Gaz. **54**: 209–215.

**Połtowicz, S., 1999.** Badenian olisthostromes and turbidity fans near Tarnów (middle Carpathian Foreland) (in Polish with English summary). Kwartalnik AGH Geologia, **25**: 153–187.

**Popov, S.V., Rögl, F., Rozanov, A.Y., Steininger, F.F., Shcherba, I.G., Kovac, M. (eds), 2004a.** Lithological-paleogeographic maps of Paratethys – 10 maps Late Eocene to Pliocene. Courier Forschungs-Institut Senckenberg, **250:** 1–46

**Popov, S.V., Bugrova, E.M., Amitrov, O.V, Akhmetiev, M.A., Zaporozhets, N.I., Nikolaeva, I.A., Sychevskaja, E.K., Shcherba, I.G., 2004b.** Biogeography of the Northern Peri-Tethys from the Late Eocene to the Early Miocene. Part 3. Late Oligocene-Early Miocene. Marine Basins. Paleontological Journal, **38**: 653–716; https://repository.geologyscience.ru/handle/123456789/39388

**Popov, S.V., Antipov, M.P., Zastrozhnov, A.S., Kurina, E.E., Pinchuk, T.N., 2010.** Sea-level fluctuations on the northern shelf of the Eastern Paratethys in the Oligocene-Neogene. Stratigraphy and Geological Correlation, **18**: 200–224.

**Popov, S.V., Rostovtseva, Y.V., Pinchuk, T.N., Patina, I.S., Goncharova, I.A., 2019.** Oligocene to Neogene paleogeography and depositional environments of the Euxinian part of Paratethys in Crimean – Caucasian junction. Marine and Petroleum Geology, **103**: 163–175; https://doi.org/10.1016/j.marpetgeo.2019.02.019

**Pożaryska, K., 1977.** Upper Eocene foraminifera of East Poland and their palaeogeographical meaning. Acta Palaeontologica Polonica, **22**: 3–54.

**Rasser, M.W., Harzhauser, M., Anistratenko, O.Y., Anistratenko, V.V., Belak, M., Berger, J.-P., Bianchini, G., Čičić, S., Ćosović, V., Doláková, N., Drobne, K., Filipescu, S., Gürs, K., Hladilová, Š., Hrvatović, H., Jelen, B., Kasiński, J.R., Kováč, M., Kralj, P., Marjanac, T., Márton, E., Mietto, P., Moro, A., Nagymarosy, A., Nebelsick, J.H., Nehyba, S., Ogorelec, B., Oszczypko, N., Pavelić, D., Pavlovec, R., Pavšič, J., Piwocki, M., Poljak, M., Pugliese, N., Redžepović, R., Rifelj, H., Roetzel, R., Skaberne, D., Sliva, L., Standke, G., Tunis, G., Vass, D., Wagreich, M., Wesselingh, F., 2008**. Paleogene and Neogene. In: T.McCann (ed.): 1031–1139. The Geological Society London; https://doi.org/10.1144/cev2p.5

**Sałaciński, R., Łazowski, L.,** 2008. Geological and deposit-related premises of amber occurrence in Poland and recognition of the geological conditions for its concentration (in Polish with English summary). Gospodarka Surowcami Mineralnymi. **24**: 325–339.

**Słodkowska, B., Kasiński, J.R., 2016a.** Climatic and environmental conditions of the formation of Baltic amber deposits (in Polish with English summary). In: Amber of Lublin (ed. L. Gazda): 21–41. Kraków.

**Słodkowska, B., Kasiński, J.R., 2016b.** Climatic and environmental factors in the formation of Baltic amber (in Polish with English summary). In: Lublin Amber – findings, geology, deposits, prospects: 22–39. State Higher Vocational School in Chełm. Stellarium, Kraków.

**Słodkowska, B., Kasiński, J.R., 2016c.** Paleogene and Neogene - a time of dynamic climatic changes (in Polish with English summary). Przegląd Geologiczny, **64**: 15–25.

**Słodkowska, B., Kasiński, J.R., 2018.** Amber-bearing deposits of eastern margin of the Pre-North Sea epicontinental basin. 10th European Palaeobotany & Palynology Conference, 12–17.08.2018, UDC Dublin, Program & Abstracts 0159: 113.

**Słodkowska, B, Kramarska, R., Kasiński, J.R., 2013**. The Eocene Climatic Optimum and the formation of the Baltic amber deposits. International Amber Researcher Symposium. Amber. Deposits Collections, The Market, Gdańsk, Poland, 22–23.03.2013: 28–32.

**Słodkowska, B., Kasiński, J.R., Żarski, M., 2022**. Stratigraphic and environmental conditions of the occurrence of amber-bearing deposits in the northern Lublin region (in Polish with English summary). Przegląd Geologiczny, **70:** 50–60; https://doi.org/10.7306/2022.3

**Schulz, H.M., Bechtel, A., Sachsenhofer, R.F., 2005.** The birth of the Paratethys during the Early Oligocene: from Tethys to an ancient Black Sea analogue? Global and Planetary Change, **49**: 163–176; https://doi.org/10.1016/j.gloplacha.2005.07.001

**Soták, J., 2010.** Paleoenvironmental changes across the Eocene-Oligocene boundary: insights from the Central-Carpathian Paleogene Basin. Geologica Carpathica, **61**: 393–418; https://doi.org/10.2478/v10096-010-0024-1

**Strzelczyk, G., Danielewicz, B., 1990.** Geological documentation in category C2 of the natural aggregate deposit (Quaternary building sands) along with the determination of the occurrence of amber in the Tertiary formations in the Górka Lubartowska area (in Polish). National Geological Archive nr. 484/92. Warszawa.

**Szydeł, R., Gazda, L., 2020.** Appendix No. 1 to the geological documentation of the “Niedźwiada II” deposit of glauconite sands and muds in category C1 and amber and phosphorites as co-occurring minerals and quartz sands as an accompanying mineral in category C1 (plot no. 517/2 according to the land register) according to the state of resources as of December 31, 2019, Niedźwiada Commune, Lubartów Poviat, Lublin Voivodeship (in Polish). CAG PIG, Warszawa nr. 3436/2020.

**Świdrowska, J., 2007.** Cretaceous in the Lublin region - sedimentation and its tectonic conditions (in Polish with English summary). Biuletyn Państwowego Instytutu Geologicznego, **422**: 63–78.

**Tutsky, V.O., 2005**. Amber deposits in Ukraine and their use (in Polish with English summary). In: Materials from the “Amberif” seminars 1994–2004 (eds. B. Kosmowska-Ceranowicz and W. Gierlowski): 26–28, Gdańsk.

**Tutsky, V.O., Stepanuk, L., 1999.** Geologie und Mireralogie des Bernsteins von Klesov, Ukraine. In: Amber Investigations (eds. B. Kosmowska-Ceranowicz and H. Paner): 53–60. Muzeum Archeologiczne w Gdańsku, Gdańsk.

**van der Boon, A., 2017.** From Peri-Tethys to Paratethys: Basin restriction and anoxia in central Eurasia linked to volcanic belts in Iran. Doctoral Dissertation. Utrecht Studies in Earth Sciences, **142:** 1–142.

**van der Boon, A., van der Ploeg, R., Cramwinckel, M.J., Kuiper, K.F., Popov, S.V., Tabachnikova, I.P., Palcu, D.V., Krijgsman, W., 2019**. Integrated stratigraphy of the Eocene-Oligocene deposits of the northern Caucasus (Belaya River, Russia): intermittent oxygen-depleted episodes in the Peri-Tethys and Paratethys. Palaeogeography, Palaeoclimatology, Palaeoecology, **536**: 109395; https://doi.org/10.1016/j.palaeo.2019.109395

**Walaszczyk, P., 2019.** Spatial analysis (GIS) of Cretaceous deposits in the Warsaw-Lublin region (in Polish with English summary). Master’s thesis, Archives of the Faculty of Geology, University of Warsaw.

**Woźny, E., 1966a.** Eocene from Siemień near Parczew (in Polish with English summary). Kwartalnik Geologiczny, **10** (4): 843–849.

**Woźny, E., 1966b**. Phosphorites and amber from Siemień near Parczew (in Polish with English summary). Przegląd Geologiczny, **14**: 277–278.

**Woźny, E., 1977.** Pelecypods from the Upper Eocene of East Poland. Palaeontologia Polonica, **22**: 93–112.

**Wysocka, A., 2002.** Clastic Badenian deposits and sedimentary environments of the Roztocze Hills across the Polish-Ukrainian border. Acta Geologica Polonica, **52**: 535–561.

**Zalewska, Z., 1971**. Baltic amber and its deposits (in Polish). Wszechświat, **10**: 261–265.

**Zalewska, Z., 1974.** Origin and stratigraphy of Baltic amber deposits (in Polish with English summary). Biuletyn Państwowego Instytutu Geologicznego, **281**: 139–173.

**Zdanowski, A., Kielczyk, K., Paluch, J., Walczak, K., Bachman, Ł., 2017.** Geological documentation of the deposit of feldspar-quartz sands and accompanying minerals - glauconite and amber “Górka Lubartowska-Niedźwiada”, Lubartów Poviat, Lublin Voivodeship (in Polish). CAG PIG, Warszawa nr. 3309/2017; G-56/3, Lublin Marshal’s Office of the Lublin Voivodeship, Geological Archive in Lublin.

**Zembek, W., Wójcik, L., 2022**. Geological documentation of the “Niedźwiada Kolonia II” deposit of sands and glauconite-bearing sediments with amber, Niedźwiada Kolonia, Niedźwiada Commune, Lubartów Poviat, Lublin Voivodeship. CAG PIG, Warszawa nr. 7095/2022; N-50/1 Lublin Marshal’s Office of the Lublin Voivodeship, Geological Archive in Lublin.

**Żarski, M., Słodkowska, B., 2020.** Documentation for the geological project for the drilling of three research boreholes: Niedźwiada PIG-2019, Leszkowice PIG-2019 and Górka Lubartowska PIG-2019 in Polish). Centralne Archiwum Geologiczne, Państwowy Instytut Geologiczny.