KOMPLEKSOWE PODEJŚCIE DO ROZPOZNAWANIA I ZAGOSPODAROWYWANIA NIETYPOWYCH ZŁÓŻ BURSZTYNU ORAZ PROBLEMY LEGALNEJ BRANŻY BURSZTYNNICZEJ NA UKRAINIE

A COMPREHENSIVE APPROACH TO THE EXPLORATION AND DEVELOPMENT OF ATYPICAL AMBER DEPOSITS AND THE LEGAL ISSUES OF THE AMBER INDUSTRY IN UKRAINE

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Niniejszy artykuł dotyczy problemów zagospodarowywania złóż bursztynu na Ukrainie. Bursztyn-sukcynit występuje na zboczach tarczy ukraińskiej, a obecnie podlega intensywnej eksploatacji, legalnej i nielegalnej, wyłącznie na terytorium Bursztynowego Dorzecza Prypeci (północne rejony obwodów wołyńskiego, kijowskiego, równieńskiego i żytomierskiego). Na dużych obszarach Polesia ukraińskiego powstały tu eoceńsko-oligoceńskie przybrzeżnomorskie i lagunowo-deltowe złoża bursztynu-sukcynitu pierwszych zbiorników przejściowych, a także złoża rozsypiskowe, wielokrotnie wymywane i redeponowane w późniejszym oligocenie, neogenie i antropogenie. Zalegające pod powierzchnią pokłady złóż bursztynu na Polesiu pozwalają na ich wydobycie metodą odkrywkową, za pomocą odwiertów i metodą hydrauliczno-otworową. Bursztyn łatwo wydobywa się ze skał macierzystych, którymi są piaski, iły piaszczyste i iły, metodą hydromechaniczną z użyciem sit i sit bębnowych. W artykule opisano doświadczenia związane z wykonaniem wykopu poszukiwawczego i przemysłowego na złożu Wołodymyrec Wschodni. Analizowane są różne metody zagospodarowywania złóż bursztynu w zależności od warunków geologicznych, a także nakreślane są nowe zadania dla geologów. Zgodnie z ustawą nr 2240 (2019) wprowadzono jednolite zezwolenia na badania geologiczne zasobów bursztynu z późniejszym wydobyciem surowca przez pięć lat na działkach o powierzchni do 10 ha. Ustawa reguluje kwestie związane z dostępem do złóż bursztynu, wprowadza odpowiedzialność za niespełnianie wymogów rekultywacji gruntów oraz obowiązek rekompensaty za szkody.

Słowa kluczowe: *bursztyn-sukcynit, przybrzeżnomorskie i lagunowo-deltowe złoża rozsypiskowe, wykop, wydobycie metodą odkrywkową*

The paper addresses the problems of the development of amber deposits in Ukraine. Amber-succinite (AS) is found in the slopes of the Ukrainian Shield and is currently being intensively extracted, both legally and illegally, exclusively in the territory of the Pripyat Amber Basin (northern districts of the Volyn, Kyiv, Rivne, and Zhytomyr regions). Eocene-Oligocene coastal-marine and lagoon-deltaic deposits of AS of the first intermediate reservoirs had been established here over large areas of Ukrainian Polesia, alongside the placers repeatedly washed out and re-deposited in the later Oligocene, Neogene and Anthropogene. The near-surface bedding of amber deposits in Polesia allows them to be mined through open pits, pit-holes and boreholes by hydro-lifting. AS is easily extracted from amber matrix, which is sands, sandy clays and loam, hydromechanically using screens and colanders. The article describes the experience of digging an exploratory and industrial trench at the East Volodymyrets deposit. The different modes of development of amber deposits depending on geological conditions are analysed and new tasks for geologists are outlined. Bill No. 2240 (2019) introduces uniform permits for the geological survey of amber deposits with the subsequent extraction of amber for 5 years on allotments up to 10 ha. The Bill regulates land issues of access to amber deposits; it also introduces liability for non-compliance with land reclamation requirements and the obligation to compensate for damage.

Keywords: *amber-succinite, coastal-marine and lagoon-deltaic placers, trench, open pit mining*

Introduction

In the productive horizons of Ukrainian amber occurrences and deposits, amber lies extremely unevenly both crosswise and in the strike direction and also on bore log. There are single inclusions, as well as inconsistent layers and lenses. The most common pieces of amber are up to 100 g, the mass of individual large pieces is predominantly up to 1 kg, and those that exceed 1 kg – 5 kg are rare and unique [3].

Amber exploration work determines the geological structure and stratigraphic position of amber-bearing horizons, the quantity, quality and nature of the occurrence of a useful constituent, the mining and mineral processing conditions. A preliminary, detailed and operational stage of work is foreseen.

Geology of amber deposits

Amber-succinite (AS) is found exclusively in placers. Crucially, in the geology of placer deposits, all mineral types therein are of secondary nature and have formed solely due to the destruction of more ancient (primary) sources [4]. In terms of the mode of formation, methods of identifying, studying, testing, forecasting, exploration and development, AS placer deposits are significantly different from placers of precious metals (gold, platinum), ore minerals (ilmenite, wolframite, cassiterite, magnetite), the combination of ore elements (monazite), as well as precious and semiprecious stones (diamond, ruby, agate) (Tab. 1).

Tab. 1. The most important distinguishing features and characteristics of placers of heavy minerals and amber-succinite
Tab. 1. Najważniejsze cechy charakterystyczne i właściwości złóż rozsypiskowych minerałów ciężkich i bursztynu-sukcynitu

Deposit feature	Gold and other minerals	Amber
Primary source	Deposits or concentrations which are spread over relatively small areas	Resin deposits (proto-amber) – swampy areas of growth of "amber forests," peatlands at the stage of conversion to brown coal, over a large area of the East European Platform
Placers	Placers of heavy minerals (gold, platinum, cassiterite and others)	AS placers and accompanying light minerals
Types of commercial placers	Eluvial-deluvial, alluvial, deluvial-proluvial	Lagoon, coastal, marine
Facies	Coastal zone and channel alluvium – sand-gravel-pebble	Coastal and relatively deep-water parts of the shelf – glauconite sand-silt-clay sediments ("blue earth")
Placer detection methods	Heavy mineral sand sampling	Layer-by-layer testing of the light fraction of sand by sieving and flushing

All the properties of AS, as well as of other mineral species of fossil resins, are caused by their organic origin and formation in the process where the exuded resin fossilized in terrestrial and marine conditions at the stage of transition from living to non-living (mineral) nature [1].

The density of AS is 0.97 – 1.10, which means that it floats in salt water, and sinks in fresh water. The flattened form, the weathered protective crust and numerous air voids contribute to the amazing durability and lack of susceptibility to abrasion of the gem which has undergone extensive erosion, redeposition and reburial for tens of millions of years.

In Ukraine, the initial formation of AS placer deposits occurred due to the erosion of the Buchak paleo-peat bog and the transfer of erosion products (resin deposits – protoamber) to the marine basin from the end of the Middle Eocene (Sea of Kyiv) to the Lower Oligocene (Mezhyhirsk Sea). AS placers of the first (intermediate) reservoir or primary placers were formed in the quartz-glauconite deposits of the Paleogene (post-Buchak Sea) intensively developed on the north-western slopes of the Ukrainian Shield (Fig. 1). They are represented by coastal, coastal-marine and lagoon-delta facies with low commercial AS content (up to 50 kg/m^3). The Lower Oligocene Mezhyhirsk deposits of AS are the main type of deposits being developed in Ukraine. The existence of rich commercial placers in the distant parts of the Eocene-Oligocene seas paleoshelf in Ukraine is yet to be established (Fig. 2). Over a 100-year period of drilling operations in the Dnipro-Donetsk and Black Sea basins, core material from productive quartz-glauconite sand and silts of Eocene-Oligocene has not been tested by the washing and sifting of amber [2].

Continental AS placers were formed due to the repeated erosion and redeposition of original Eocene-Early Oligocene placers in the Late Oligocene, Neogene and Pleistocene. In terms of amber size and resources, they are significantly inferior to those from the Eocene and Oligocene, but in general have better qualities jewelry-wise. It has been proven that even occasional finds of amber in the sediments of the Berek and Novopetrovsk horizons of the Neogene, fluvio-glacial, interglacial and other Neopleistocene Holocene deposits almost always indicate the spatial proximity of the main placers or the presence of such deposits in the deeper horizons of the Paleogene section. Of course, the methods of detection (predicting), exploration and development of these atypical amber occurrences are significantly different from how this kind of work in done in the development of the commercial marine and mineral-marine deposits of AS [5].

Research methods

In order to determine whether amber deposits are attractive for investment, geological description and sampling of AS occurrences and deposits in the Pripyat Amber Basin are used, alongside studies of archive data and geological reports

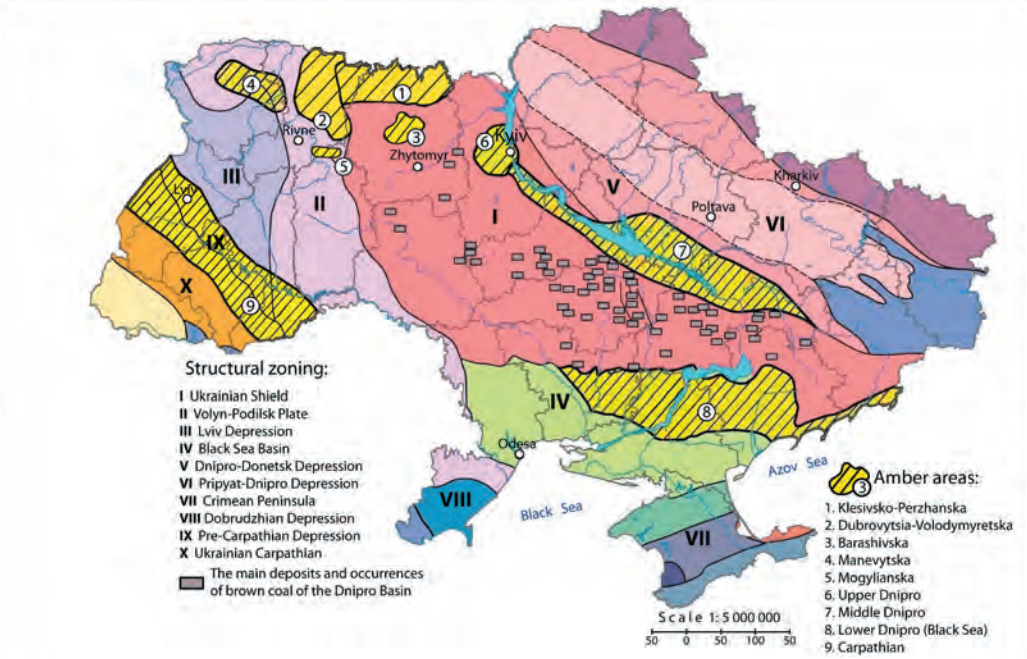

Fig. 1. Overview map of amber zones in Ukraine
Rys. 1. Przeglądowa mapa stref występowania bursztynu na Ukrainie

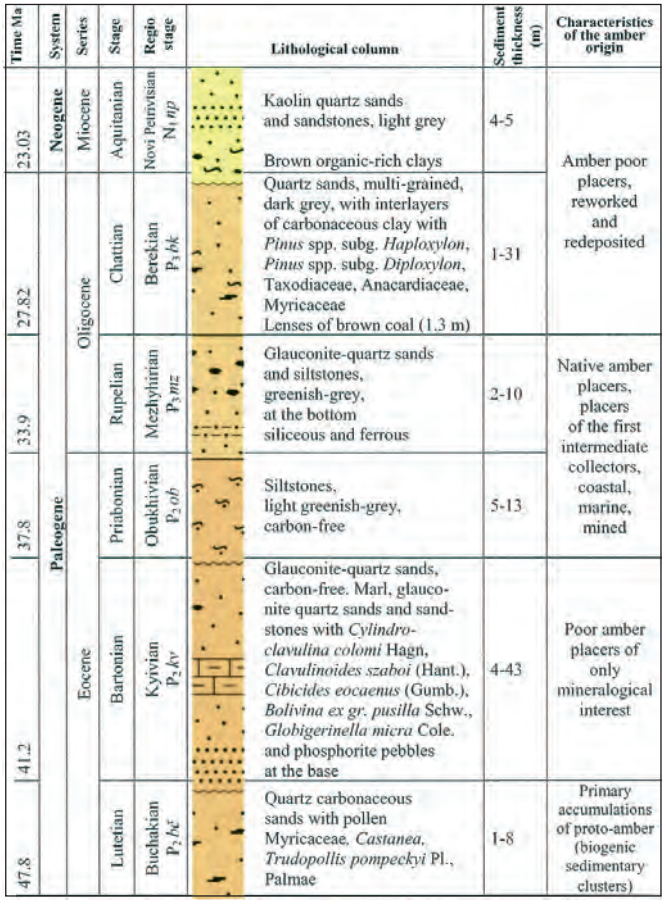

Fig. 2. Stratigraphic-lithological column of amber-bearing deposits
Rys. 2. Profil stratygraficzno-litologiczny złóż bursztynonośnych

from previous years. A map of most important amber finds was produced for the Zhytomyr, Rivne and Volyn regions. Paleogeomorphological methods were used to detect amber traps. Based on this, the background for the development of amber deposits was elaborated. These results were used by mining companies for AS deposit exploration in Ukraine.

Commercial development of Ukrainian AS

The investment attractiveness of Ukrainian amber is based on the large number of promising areas, the poor undeveloped lands of Polesia, the high quality of AS and the presence of unique specimens, as well as favourable mining and geological conditions in which placers occur: shallow depths (from 1-2 to 10-15 m), friability (looseness) of the rocks which make up the productive horizon and overburden, with high prospects for the discovery of new commercial deposits.

The development of Ukrainian AS deposits began in the twentieth century, seven centuries after the decline of Kievan Rus. In the Soviet period, it was still believed that there was no amber in the depths of the earth in Ukraine, and the Soviet geological service paid attention only to the Baltic deposits. With the collapse of the USSR and the declaration of independence of Ukraine, the state's interest in domestic amber and the issues of its prospecting, production, processing and use did not change significantly. If anything, there came only new problems associated with industrial exploration, environmentally sound and cost-effective mining of deposits, the development of modern technologies, the processing of raw amber, the use of AS and its processed products in various industries, medicine, agriculture, etc.

The beginning of the development of AS deposits in the Pripyat Amber Basin was preceded by scientific studies conducted in the previous century. In the early 20th century, P.A. Tutkovsky et al. [7] laid the foundations for modern ideas about the geology of Ukrainian AS. He collected and summarized the available information about the amber finds before the beginning of the twentieth century (including those in archaeological excavations) in the Kyiv, Zhytomyr, Rivne and Volyn regions, described the amber-bearing deposits of the Kyiv and Kharkiv layers of the Paleogene (placers of the first intermediate reservoirs), glacial, water-glacial, alluvial, lacustrine and other genetic types of Neogene placers.

General prospecting, evaluation and exploration work on AS in Ukrainian Polesia, carried out by the Quartzsamotsvety joint-stock company (based in the town of Volodarsk-Volynskyi, now Khoroshiv) at the end of the previous – beginning of the current century, were focused exclusively on areas previously indicated by P.A. Tutkovsky as having amber occurrences or as places of solitary "erratic finds" – Klesiv, Dubrovytsia, Barashi, Gulianka and many others.

The first specialized geological exploration project in Ukraine was carried out under the direction of P.I. Vasylenko [8] on the right-hand bank of the Dnieper over a distance of 70 km, from the village of Novi Petrivtsi to the village Trypillia, where amber had been gathered in the Paleolithic, Neolithic and Middle Ages. The average content of AS was found to be 2.14 g/m^3, with the maximum at 6.68 g/m^3. Extraction of amber was deemed unprofitable.

Quartzsamotsvety JSC has studied the boundary layers of the Eocene-Oligocene and carried out prospecting and exploration works. The reserves of the Vilne deposit in the Dubrovytsky district of the Rivne region were calculated and, subsequently, its operation began.

In 1980, geologists at the Zapadkvartszamotsvety production association (now Quartzsamotsvety JSC) in the Klesivsky district began calculating the reserves. The deposit consists of 5 allotments. Detailed exploration was carried out at the Pugach allotment. The amber content in the Eocene-Oligocene deposits varies from 1-5 to 420 g/m^3 with an average yield of 58 g/m^3. Industrial development of the field began in 1989.

Since the end of the previous century, exploration work in the north-western part of the Pripyat Amber Basin has been carried out by the Rivne Geological Expedition. It has explored and calculated the reserves of AS in the sections of Vyrka, East Volodymyrets, Volodymyrets, Kanonychi, Dubivka, Zhovkyni, etc., and also conducted an audit of the areas of illegal amber mining in the Rivne region.

Simultaneously with the discovery and development of AS deposits in the 1980s–1990s, amber production in Polesia has continued to experience an ever-increasing environmental burden caused by negative economic activity, i.e. unsanctioned amber mining. With the help of heavy equipment (hydro-motor pumps, bulldozers, excavators, etc.), illegal miners deplete vast areas in the northern regions of Volyn, Rivne, Zhytomyr and Kyiv regions. Sometimes in the forests one can find deep pits and hills made up of the weathered crust with crushed stone and kaolin clay, taken by "prospectors" to be amber-bearing rocks. Revealed by the "prospectors," the new amber finds are also worked by them.

In Ukraine, the industrial development of amber deposits and the calculation of reserves are carried out by means of open--pit mines: quarries, trenches, hydraulic enlargement of the hole, pits and boreholes, and through illegal "prospecting": by pitting and underground flushing. Mining operations on the deposits are carried out by draglines, **bucket chain excavator (BCE); bucket-wheel excavator (BWE)**, wheel tractor-scrapers and other hydro-mechanical methods (Fig. 3.). The amber-bearing rock is taken out with an excavator onto a truck that delivers it to the washing unit. Two types of trenches, stripping line and finished trench, are used.

A stripping line is an open pit mine that serves to remove the overburden, form the primary front of work and to deploy mining transport equipment during the construction of the quarry. The depth of the stripping line corresponds to the height of the horizon, and it is the height of the pit bank. The slope angles of the walls are set depending on the properties of the short-term stability of the sands that make up the opening horizon. In the conditions of Polesia the angles are 50-70 degrees (Fig. 4). The finished trench is designed to open the working contours of the quarry. It serves for a long time and is used to accommodate mining equipment and transport.

Fig. 3. Amber mining on Olexiivka open pit (Klesiv group of deposits, Rivne region). Photo by O. Remezova
Rys. 3. Wydobycie bursztynu w odkrywce Oleksijewka (klesowska seria złożowa, obwód rówieński). Fot. O. Remezova

The amber reserves within the contours of the open pit are the most important indicator to determine the possible extent of its production, the size and lifetime of the strip mine, as well as its economic development. The reserves within each pit bank (horizon) and the quarry area as a whole are established during the exploration of the deposit. They are specified and listed in the contours of the quarry during its design and operation and are periodically updated according to the current conditions.

Fig. 4. Trench revealing the (dark-grey) amber-bearing sands on East Volodymyrets deposit [6]
Rys. 4. Wykop odsłaniający (ciemnoszare) piaski bursztynonośne w złożu Wołodymyrec Wschodni [6]

Stripping operations on Polesia amber deposits are carried out with draglines, bucket-wheel and chain excavators, scrapers and hydro-mechanical equipment. Amber-containing rocks are

taken out by an excavator. The excavated rock is transported by truck to a washing unit located at the industrial site. The amber matrix passes through a series of vibrating screens with holes of various dimensions (Fig. 5).

At the Klesiv deposit, starting from 1980, more than 100 kg of amber has been extracted annually, 95% of it is of the gem quality.

The amber-bearing gravel mix obtained from the screens is subjected to further gravitational **enhancement** by separating the pieces of amber from rock gravel and sorting them by grain

Fig. 5. Washing unit on Olexiivka open-pit and extracted amber. Photo by O. Remezova
Rys. 5. Myjnia w odkrywce Oleksijewka i wydobywany bursztyn. Fot. O. Remezova

size into fractions provided for in the standard. This **enhancement** process is based on the gravitational separation of matrix particles with different specific gravities in water. Amber, which has a relatively low specific gravity (about 1 g/cm3), and rock fragments do not get soaked, float to the surface of the water, and those that are get soaked, sink to the bottom.

The extraction of amber by borehole hydro-flushing consists in the erosion of the productive horizon of amber-bearing sand deposits with high-pressure jets and the removal of amber to the surface by rising streams of water. The method of hydraulic mining of amber from boreholes is accompanied by the removal of mineral soil to the surface of the deposit; it does not provide a complete extraction of the amber from the deposits, is energy-intensive, leads to a change in the soil structure, the formation of voids and, in consequence, has a significant negative technogenic and ecological impact on the environment. However, in terms of economic efficiency, it is cheaper than the mechanical mining of amber deposits in quarries and the extraction of amber with the use of screens.

The manual method of AS gathering from the depths of the earth is used both by individuals and usually by groups of illegal prospectors. They use both the old extraction methods, originating and known from ancient times, and modern hydraulic flushing. The simplest and most harmless method is gathering and shallow removal of soil on the slopes of river valleys, gullies and ravines.

The most unacceptable and environmentally destructive audacious method of extracting amber is underground hydro-flushing (using a motor pump), and that is due to the disintegration and destruction of the productive amber-bearing stratum by a descending pressurised stream of water with the subsequent transfer of the floating pieces of amber to the surface. The hydro-motor pump method of AS mining came to Ukraine from neighbouring Poland in the early 1990s and is currently the main tool for illegal mining.

The application of a specific method is determined by the combination of the following factors:

1) the overburden thickness above the amber-bearing deposits,
2) the depth of the groundwater table and the presence of heaving sand,
3) susceptibility of the amber-containing deposits to erosion,
4) the content of amber in the matrix.

As a rule, pits are used to mine shallow amber deposits (on average up to 5 m deep) in the aeration zone, where there is less heaving sand, as well as rich placers in water-resistant clay deposits that are not amenable to hydraulic erosion. Deposits that lie deeper, among the permeable sediments covered by heaving sand, are extracted using the underground hydraulic flushing method.

On average, amber mining by pitting accounts for about 55% of all productive amber-bearing Oligocene strata covered by non-industrial mining. This method consists in sinking of vertical workings – which have different cross-sectional shapes and configuration – from the surface in Quaternary and Oligocene sediments, aimed at revealing the amber-bearing horizons inside (partial or on full thickness) and in mechanically removing amber lumps from the rock mass outcrops. Most pits are manually dug with spades, square-faced shovels and other simple tools. That is why this method pioneered the prospecting of amber in Ukrainian Polesia [6].

The most important tasks of geologists in Ukraine are:

1. Forecast and develop new large commercial deposits of AS associated with the remote part of the marine paleoshelf, similar to the Sambia deposit 40 km from Kaliningrad.
2. Carry out an additional study and re-evaluation of the amber potential in the area of intensive contemporary amber mining (Pripyat Basin) in the Volyn, Rivne and Zhytomyr regions in order to assess their prospects for legal mining.
3. Determine the forecasted resources and prospects of the Dnieper basin for AS and the Carpathian range of fossil resins.

From the experience in the digging of an exploratory and industrial trench at the East Volodymyrets deposit, which was carried out in accordance with the "Instruction on the Application of the Classification of Reserves and Resources of Minerals of the State Subsoil Fund for the Amber Deposits" of the State Reserves Committee of Ukraine, p. 12.5, 2003, the digging was carried out with the aim of studying the type of amber occurrence and assessing the reliability of the drilling results by means of a prospecting pit using a "prospector" self-propelled drilling rig (УБСР-25-М) and by further comparing the results of small (pit) and large (trench) samples, the quality and grading of amber deposits. The trenching was carried out with the permission of the local authorities and the consent of land users in accordance with the requirements of the law. The trench was dug in stages in three sections, 50 m long each (the total length of the trench is 150 m). The trench opened up the following sequence (from bottom to top): 1. The footwall: siltstone, clay; 2. The productive horizon of the Mezhyhirsk suite: dark gray quartz-glauconite sands with remnants of carbonated plant organic matter – 1.8-2.6 m; 3. Overburden rocks: sandy deposits of the Upper Oligocene – 1.5-2.2 m and Pleistocene – 1.2-1.8 m, overlain by the soil and plant layer (Fig. 6). When digging the trench, the soil and plant layer was first removed with a Д3-27-С bulldozer and transported over a distance of about 30 m. Overburden rocks were excavated with an E-652 dragline excavator with a bucket capacity of 0.8 m3 with one open pit bench. The width of the excavation on each side of the trench was 10 m (20 m in total), the radius of the discharge of the stripped rock reached 12 m. After the excavation, the stripped rock mass was subsequently moved to spoil heaps with a Д3-27-С bulldozer over a distance of 15 m.

The depth of the rock stripped off the trench as a whole ranged from 2.4 to 3.1 m. Above the rocks of the productive stratum there remained a pillar with a thickness of 0.1 m in order to prevent the loss of amber. The total volume of the mining trench rock amounted to 7,148 m^3 and the rock of the productive Mezhyhirsk stratum amounted to 3,080 m^3. The excavation of the productive strata, as well as the cutting of the rock, was carried out from the sides with removal onto a spoil heap. In addition, the underlying clays of the Obukhiv Formation with a thickness of 0.1 m were extracted. The slope angles of the trench of the productive stratum averaged 35 degrees. Of course, after the first compartment of the trench was dug out, and the raw amber was flushed and extracted from the productive stratum, the bottom of the trench was backfilled in the reverse sequence, topped with a soil and plant layer. The trench within the boundaries of the C_2 amber reserves calculation block at the East Volodymyrets deposit was completed, thoroughly studied and fully reclaimed from October 2007 to March 2008.

Conclusions

The issue of amber prospecting and mining is complex and is being addressed at the state level. It affects many aspects of the country's socio-economic, cultural, scientific and political life. Unfortunately, in the first years of the 21st century in independent Ukraine, ill-considered and extremely erroneous legislative decisions were made to give amber-succinite the status of a gemstone of national importance. According to these decisions, amber is exclusively state's prerogative. These governmental regulations have slowed the development of the amber industry for many years to come and continue to have a negative impact to this day [4].

First of all, this has a negative impact not only on the production and processing of raw amber, but also on the prospects of using AS and its processed products in various industries, culture, art, medicine, as well as on the sales of amber products in the domestic and foreign markets.

In addition, the opportunities and prospects for using AS are substantially limited by the absence of the domestic stone in free trade. After all, an amber market has not yet been created

Fig. 6. Geological section on the East Volodymyrets deposit, Rivne region. The productive horizon of the Mezhyhirsk suite, i.e. dark gray quartz-glauconite sands, is at the bottom of the exploratory pit. Photo by O. Remezova

Rys. 6. Przekrój geologiczny złoża Wołodymyrec Wschodni, rejon Równego. Poziom produktywny horyzontu mieżgorskiego, czyli ciemnoszare piaski kwarcowo-glaukonitowe, znajduje się na dnie wyrobiska. Fot. O. Remezova

in Ukraine, while the grey economy production is ten times higher than the state production.

At the same time, the presence of abundant resources of AS in Ukraine makes it possible to establish a modern industrial development of amber deposits and occurrences. According to unofficial data, the annual grey economy export of AS outside Ukraine reaches 20 tons or more.

However, to date, there are no tangible results in the attempt to solve the amber problems in Ukraine, as there is no substantial support from the state in raising the amber industry to the current international level. In December 2019, the Verkhovna Rada (Supreme Council) adopted Bill No. 2240 in its entirety, in the second reading, providing for the introduction of uniform permits for the geological survey of amber resources with the subsequent extraction of amber for 5 years on allotments of up to 10 hectares. In particular, the bill regulates land issues of access to amber deposits, introduces liability for non-compliance with land reclamation requirements and the obligation to compensate for damage. There will be significantly increased penalties for illegal amber production, as well as for any illegal sale, purchase, storage, transfer, shipment, transportation or processing of amber, if its legality is not confirmed by the relevant documents [9].

The time has come to really change the situation and specifically start to create a sustainable amber brand in Ukraine on the way to establishing a highly productive amber industry which covers a whole range of scientific and industrial work from forecasting amber deposits and occurrences, their comprehensive and waste-free development to mastering modern raw amber processing technologies and implementing the obtained results in various industries.

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