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Biostratigraphy and conditions of formation of Albian and Cenomanian deposits on the south-western slope of the Ukrainian Shield (Middle Dnister region)

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abstract

Data from a comprehensive study into the lithological composition and lateral distribution of Albian and Cenomanian deposits in the Middle Dnister region (Ukraine), in the watersheds of the Smotrych–Tarnava–Studenytsia–Ushytsia–Kalyus–Zhvan–Lyadova–Nemiya–Murafa–Rusava–Markovka rivers, are presented in the paper. Cretaceous deposits of Volyn-Podillia are part of the terrigenous-carbonate subformation of the Jurassic-Cretaceous carbonate formation (J_3–K_1) and the glauconite Cretaceous formation (K_1al_3–K_2), which includes gaizeous (K_1al_3–K_2s_1), siliceous-chalk (K_2s_2–K_2k) and marl-gaizeous (K_2sn–K_2m) subformations. Cretaceous deposits of the Middle Dnister region are represented by the lower (Albian stage) and upper parts (Cenomanian stage).The study is focused on the distribution of micro- and macrofauna (e.g. molluscs, calcareous nannoplankton) in the Albian and Cenomanian deposits and their facies affiliation, as well as on the quantitative analysis of organic remains and palaeoecological conditions. Differences in homogeneous conditions of sedimentation within the epicontinental sea basin of the modern Middle Dnister region at the Early-Late Cretaceous boundary were insignificant. Due to a study of Cretaceous macro- and microfauna, its facies distribution, quantitative analysis, and palaeoecological conditions, it is possible to trace slight differences between close homogeneous conditions of sedimentation within the relatively homogeneous sea basin of the Middle Dnister region on the verge of the Early and Late Cretaceous. This shallow epicontinental sea was characterized by normal salinity and well-aerated warm waters with temporary strong bottom currents within shallow water and with maximum depths up to 150–200 m in some areas and soft muddy bottom of deep-water areas. Phosphatisation of the early-middle Cenomanian fauna is evidence for the important role of the Carpathian upwelling at that time. Geochemically active phosphorus is concentrated on shelf due to changes in salinity, temperature, pH, CO_2 content and other parameters of the aquatic environment, which were characteristic for this region of Volyn-Podillia.

Біостратиграфія та умови формування відкладів альбу і сеноману на південно-західному схилі Українського щита (регіон Середнёього Подністер'я)

Леонід Киселевич, Олександр Ковальчук

Резюме. У статті представлено результати комплексного дослідження літологічного складу та латерального розподілу альбських і сеноманських відкладів у Середньому Подністер'ї (Україна), на вододілах річок Смотрич-Тарнава-Студениця-Ушиця-Калюс-Жван-Лядова-Немія-Мурафа-Марківка. Крейдові відклади Волино-Поділля є частиною теригенно-карбонатної підформації юрсько-крейдової карбонатної формації (J_3-K_1) та глауконітової крейдової формації (K_1al_3-K_2), що включає опокову (K_1al_3-K_2s_1), кременисто-крейдяну (K_2s_2-K_2k) і мергельно-гезову (K_2sn-K_2m) підформації. Крейдові відклади Середнього Подністер'я представлені нижньою (альб) та верхньою частинами (сеноман). Дослідження зосереджено на розподілі мікро- та макрофауни (молюсків, нанопланктону) у відкладах альбу і сеноману та їх фаціальної приналежності, а також кількісного аналізу органічних решток та палеоекологічних умов. Відмінності в однорідних умовах седиментації в епіконтинентальному морському басейні сучасного регіону Середнього Подністер'я на межі ранньої та пізньої крейди були незначними. Завдяки вивченню крейдової макро- і мікрофауни, її фаціального розподілу, кількісного аналізу та палеоекологічних умов можна простежити незначні відмінності між близькими однорідними умовами осадконакопичення у межах морського басейну. Це мілководне епіконтинентальне море характеризувалося нормальною солоністю і добре аерованими теплими водами з тимчасовими сильними донними течіями на мілководді та максимальною глибиною до 150–200 м у деяких районах і м'яким мулистим дном на глибоководді. Фосфатизація фауністичних решток раннього та середнього сеноману є свідченням великої ролі карпатського апвелінгу. Геохімічно активний фосфор концентрується на шельфі внаслідок зміни солоності, температури, pH, вмісту CO_2 та інших параметрів водного середовища, характерних для Волино-Поділля.

Ключові слова: стратиграфія, біохронологія, палеоекологія, море, крейда, Україна.

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Introduction

In the Early Cretaceous, most of the territory of modern Ukraine was a landmass with a weakly dissected relief, local depressions comprising continental terrigenous formations, and coastal-lagoon deposits in its outskirts. Shallow temporary epicontinental isolated seas with sandy, sandy-clayey, clayey-carbonate or siliceous sediments existed on the periphery (in the Dnipro-Donets Depression, Crimea, Black Sea region, Moldavian Depression, and Volyn-Podillia). The Early Cretaceous was characterized by the appearance of mostly continental formations, except for Valangian and Albian, when the accumulation of marine sediments took place. Because of a rather complex palaeogeographic situation in Volyn-Podillia during the Cretaceous, in particular numerous transgressions and regressions associated with ocean eustatic processes, there is a mosaic lateral distribution of lithological facies of different stratigraphic units. Sediments of the Cretaceous system in Volyn-Podillia with a clear stratigraphic inconsistency transgressively lie on the blurred surface of geological formations of different age — Neoproterozoic, Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Jurassic.

The surface of pre-Cretaceous formations is inclined from east to west and gradually deepened, having a sharp bend on the border with the Pre-Carpathian Depression, which causes an increase in thickness of Cretaceous deposits in this direction: from several tens of centimetres within Volyn-Podillia to 1000–1400 m within the Lviv Depression and further to the west.

The study of the palaeogeographic situation during the Barremian–Early Albian shows that clay-carbonate sediments have formed in shallow bays of the palaeoshelf within Volyn-Podillia and in the adjacent part of the modern Pre-Carpathian Depression as a result of water runoff from land, which supplied terrigenous material to the branched isolated basin on the northern mainland outskirts of the Tethys. The almost complete absence of Berriasian-Aptian deposits on the south-western slope of the East European platform, including Volyn-Podillia, is due to global regression associated with a significant amplitude of falling ocean levels.

Analysis of earlier biostratigraphic studies and previous publications

Eichwald (1830) published the first paper containing specific data on the Cretaceous deposits of the Middle Dnister region, in particular the description of outcrops with Upper Cretaceous rocks. Kner (1848, 1852) studied fossils in this area, including Cretaceous molluscs from the Seret River basin. The age of fossils is not clearly defined, although *Ammonites varians* Sow. described by the author indicates the Cenomanian stage of fossil-bearing rocks.

Zaręczny (1874) analysed faunal remains from the Seret and Stryp rivers in more detail. In the geological part describing the scheme of the Cretaceous system, the author attributed sandy marls and sandstones to the Cenomanian and distinguished four horizons of different age. Dunikowski (1888) also studied the Cenomanian fauna, although he considered the horizons proposed by Zaręczny as facies of the same age. Radkevich (1891, 1897, 1898) allocated the northern and southern parts of this area. South of the Dnister–Southern Bug watershed, there are widespread Cenomanian deposits with faunal remains of all biozones, including *Actinocamax plenus*. Large species lists were presented by this researcher along with comparing the Cenomanian lithology and fauna of Podillia with those of Western Europe.

In the first half of the 20th century, Cretaceous deposits of the Middle Dnister region were studied by Vyrzhykivsky (1927, 1931, 1932), and the results were presented in a number of publications. Kokoszyńska (1920, 1928, 1931, 1939) provided fauna lists and a description of numerous Cenomanian outcrops. Based on the study of rocks in this area, she identified five facies some of which are important stratigraphic horizons (sandstones, calcareous sandstones with sea urchins, green sands, marls, and white limestones), three lower of which the author refers to the Lower Cenomanian, and the two upper — to the Middle and Upper Cenomanian, respectively. The section of Cretaceous rocks near Soroky (Moldova) was studied by Vascautanu (1923), who collected fossils from each layer and described the Cenomanian part of the outcrop. O. V. Savchynska studied the fauna of the Middle Dnister region from 1939 and concluded that there is '... a fairly strong confirmation of the presence of Albian deposits.'

Despite the many studies, several issues of the stratigraphy of Cretaceous deposits of the Middle Dnister region remained unknown or required clarification. The most important of them were the following: identification of the full thickness of the Upper Cretaceous in general and of its individual stages, the study of the lithological nature of sedimentation, and facial changes within each stage. Complete lists of fauna have not yet been compiled making it difficult to compare and correlate with already studied areas. Earlier outcrops were studied only along the Dnister valley and its tributaries, but the wide application of drilling works allowed passing full section wells of Upper Cretaceous rocks, to study Cretaceous formations in continuous sections, to clarify the lateral distribution of sediments, and to study the microfauna.

In the late 1940s, research covered the Southern Bug basin. It was found that the Upper Cretaceous section begins with the lower Cenomanian formation; visible traces of the break between the Cenomanian and Turonian stages are not observed. Cenomanian deposits are absent in the raised areas of Palaeozoic rocks. In general, Cenomanian sediments are represented by various rocks: coarse-grained glauconite sandstones, marls, spongioliths, sandy limestones, and others. Pasternak (1957, 1959, 1962a, 1962b, 1966) studied Cretaceous formations of the Middle Dnister region, in particular the section from Volodymyr-Volynskyi to the Dnister River (Pasternak 1956a), the distribution of Albian and Cenomanian deposits and biostratigraphy of the Upper Cretaceous of the Volyn-Podillia Plate (Pasternak 1956b, 1957, 1966; Pasternak & Gavrylyshyn 1956, 1964). Pectenids are widespread in Upper Cretaceous deposits of the Middle Dnister region. Their ecology and taxonomy was considered and studied by Sobetsky (1961).

The lithological specificity of the Upper Cretaceous rocks drew the attention of researchers to the issues of lithogenesis (Senkovsky 1962, 1963a, 1963b, 1977; Sergeev 1964).

Mineralogical and petrographic characteristics of the Albian and Cenomanian stages were provided along with the discussion of genesis of sillicites. The issues of biostratigraphy of Cenomanian deposits of the Middle Dnister region are considered in detail by Kyselevych *et al.* (1987, 1988), Yakushyn (2006), Leshchukh *et al.* (2012), Ivanik *et al.* (2013), and others. Based on a list of fauna collected (Pasternak *et al.* 1987; Maryash & Kurepa 2013; Maryash 2015; Kyselevych & Ogienko 2018; Maryash 2019), the conditions of formation of these deposits were clarified (Kyselevych 1991, 1992, 1999; Danyliv 2017, 2019). Zonal biostratigraphic dismemberment of three substages of Cenomanian deposits in the Middle Dnister region was carried out, and they were correlated with formations of the same age of Western Europe and Central Asia.

Results and Discussion

Cretaceous deposits of Volyn-Podillia are part of the terrigenous-carbonate subformation of the Jurassic–Cretaceous carbonate formation (J_3-K_1) and the glauconite-Cretaceous formation (K_1al_3–K_2), which includes gaizeous (K_1al_3–K_2s_1), siliceous-chalk (K_2s_2–K_2k) and marl-gaizeous (K_2sn–K_2m) subformations (Chebanenko *et al.* 1990). Cretaceous deposits of the Middle Dnister region (Fig. 1) are represented by the lower (Albian) and upper (Cenomanian) parts.

Cretaceous system K
Lower section K_1
Albian stage K_1al
Middle Albian substage K_1al_2

Stratigraphy. The sandy facies of coastal zone of the middle Albian sea has been preserved in small areas of the south of Ternopil Oblast and is mainly distributed in depressions of the pre-Cretaceous relief. Lithologically, it is represented by clayey sands and sandstones with admixtures of glauconite, gravel, black flint and quartz, phosphorites, and pebbles of Silurian argillites in contact with Silurian rocks. Undoubted middle Albian fauna was found only near Melnytsia-Podilska in outcrops on the banks of the Dnister River (Pasternak *et al.* 1968).

On the blurred surface of Silurian rocks (near Khudykivtsi) it forms a thin layer of conglomerate (0.1–0.2 m), the saturation of which with washed and phosphatized faunal remains in some places reaches more than 50% of the cementing rock. The following taxa were identified in the conglomerate[1]: *Nucula pectinata* Sow., *Leda bergi* Arkh., *L. baueri* Noetl., *Arca dupiniana* (Orb.), *Barbatia marullensis* Park., *Cucullaea glabra* Park., *C. mailleana* (Orb.), *Grammatodon carinatus* (Sow.), *Glycymeris sublaevis* (Sow.), *Limopsis mulleri* Holzapf., *Pteria* sp., *Entolium orbiculare* (Sow.), *Chlamys* cf. *hispida* (Goldf.), *Lima rhotomagensis* Orb., *L.* sp., *Plicatula gurgitis* Pict. et Roux, *Lopha carinata* (Lam.), *Amphidonte conicum* (Sow.), *A. lateralis* (Nilss.), *Linotrigonia* cf. *spinosa* (Park.), *Cardita tenuicostata* (Sow.), *Cyprina ligeriensis* Orb., *C. lineocostata* (Sow.), *Lucina downesi* Woods, *Thetironia laevigata* (Sow.), *Cyprimeria faba* (Sow.), *Cardium proboscideum* (Sow.), *Dosinopsis caperata* (Sow.), *Panope gurgitis* (Bron.), *Pleurotomaria ewaldi* Tissen, *Littorina lubrica* Woll., *Turrilites* sp., *Confusiscata* cf. *dupiniana* (Orb.), *Gyrodes gaultina* (Orb.), *Natica ervina* Orb., *N.* sp., *Ringinella inflata* (Sow.), *Avellana* cf. *incrassata* (Sow.), *Fustiaria strehlensis* (Gein.), *Nautilus* sp., *Puzosia mayoriana* (Orb.), *Hoplites dentatus* (Orb.), *H. latesulcatus* Spath, *H. bailey* Spath, and *Anahoplites planus* (Mant.). In addition, there are phosphated sponges, shark teeth, sea urchin needles and tree fragments. The given faunal assemblage, in particular hoplites (species-index *Hoplites dentatus*) evidenced the middle Albian

[1] Here and further—fossils were identified by L. Kyselevych.

Fig. 1. Study region with collection points of paleontological material. 1 — Bilche-Zolote; 2 — Mykhalkiv; 3 — Khudykivtsi; 4 — Melnytsia-Podilska; 5 — Hrynchuk; 6 — Malynivtsi; 7 — Demshyn; 8 — Bakota; 9 — Velyka Kuzheleva; 10 — Stara Ushytsia; 11 — Tsykove; 12 — Nova Ushytsia; 13 — Kucha; 14 — Struga; 15 — Sloboda Shcherbovetska; 16 — Balabanivka; 17 — Zhytnyky; 18 — Murovani Kurylivtsi; 19 — Khonkivtsi; 20 — Yaryshiv; 21 — Sloboda-Yaryshivska; 22 — Mohyliv-Podilskyi; 23 — Ataky; 24 — Otach; 25 — Oklanda; 26 — Mykhailivka; 27 — Oksanivka; 28 — Dzhyhiv Brid; 29 — Porohy; 30 — Soroky.

Рис. 1. Регіон дослідження з точками збору матеріалу. 1 — Більче-Золоте; 2 — Михалків; 3 — Худиківці; 4 — Мельниця-Подільська; 5 — Гринчук; 6 — Малинівці; 7 — Демшин; 8 — Бакота; 9 — Велика Кужелева; 10 — Стара Ушиця; 11 — Цикове; 12 — Нова Ушиця; 13 — Куча; 14 — Струга; 15 — Слобода-Щербовецька; 16 — Балабанівка; 17 — Житники; 18 — Муровані Курилівці; 19 — Хоньківці; 20 — Яришів; 21 — Слобода-Яришівська; 22 — Могилів-Подільський; 23 — Атаки; 24 — Отач; 25 — Окланда; 26 — Михайлівка; 27 — Оксанівка; 28 — Дзихів Брід; 29 — Пороги; 30 — Сороки.

age of the conglomerate layer. It should be noted that some researchers (Sobetsky 1978; Rozumeiko 1988; Leshchukh 1992; Leshchukh & Maryash 2009) doubt the presence of middle Albian deposits within the Middle Dnister region and suppose re-deposition of the faunal content in younger formations (Maryash 2007; Bakayeva 2010). According to I. Maryash (pers. comm.), remains of the middle Albian index species *H. dentatus* were most likely re-deposited. In the current stratigraphic scheme for the Lower Cretaceous of Volyn-Podillia, the phosphorite layer from Khudykivtsi is referred to the upper part of the upper Albian substage, upper part of the *Mortoniceras inflatum* zone — the *Stoliczkaia dispar* zone (Ivanik *et al.* 2013).

Palaeoecology. The coastal zone of the middle Albian sea received a sufficient amount of organic detritus, and the bottom waters were quite rich in oxygen and food, which were necessary for the existence of a number of benthic organisms. The systematic composition of faunal remains is represented by 40 species (Pasternak *et al.* 1968). Taxonomic composition and species richness indicates the highest distribution of bivalve molluscs (92.0% of the processed specimens), of which 56.0% are Taxodonta. The portions of other groups are as follows: gastropods — 5.5%, cephalopods — 1.1%, sponges — 0.8%, sea urchins and fishes — 0.6%. *Cucullaea glabra* Park. and *Glycymeris sublaevis* (Sow.) predominate by the number of individuals. Among the ecological groups, there are mobile benthos (92.3%, of which 13% are free-floating organisms (mainly ammonites and less often belemnites), and sedentary benthos (7.6%) represented by sponges, some species of *Ostrea*, *Lopha*, and *Amphidonte*. In addition, there were lithophagous organisms, the quantification of which is difficult, but common drilling traces in Silurian argillites indicate their widespread distribution and abundance. A number of bivalve shells have holes drilled by zoophagous gastropods (*Natica*).

The nature of the burial and the state of preservation of organic remains indicate that they were washed, re-deposited and represent an orictocoenosis. Almost all of the fossils are phosphatised, rolled and partially broken. Molluscs have remained in the form of nuclei. Significant clusters of fauna are often found, which are cemented with phosphate substance, and together with phosphorite pebble and phosphated wood remains form a phosphorite layer.

Based on ecological characteristics of certain groups of the fauna, in particular molluscs, as well as the lithological composition of rocks, it is possible to conclude on the physical and geographical conditions of this part of the Albian sea: the middle Albian fauna developed under favourable conditions — sufficient light, good bottom water aeration, favourable gas regime, normal salinity, high water temperature, etc. The normal water salinity is indicated by the large number of stenohaline species represented by numerous *Glycymeris*, *Limopsis*, etc., which do not tolerate any deviations from normal salinity. The large number of thermophilous forms (e.g. *Exogyra*, *Ostrea*, *Glycymeris*, and *Chlamys*) indicates that water temperature was not lower than +17...+20°C. High water temperatures are also confirmed by oxygen isotope analysis in calcite rosters of belemnites. The presence of molluscs capable to drill bottom rocks indicates a slow sediment accumulation at the initial stages of development of the Albian sea basin, or a significant hydrodynamic activity of waters and the presence of strong bottom currents that removed the newly formed sediments.

Upper Albian substage K_1al_3

Stratigraphy. Upper Albian deposits are lithologically diverse, well characterized by fauna and widespread in the Middle Dnister region, where they are exposed (Pasternak *et al.* 1968). Separate layers with faunal remains are allocated in their structure (from bottom to top):

quartzose-glauconitic sands, containing gravels, sometimes conglomerates, and in eastern Podillia — re-deposited phosphorite Neoproterozoic nodules in the lower part. The fauna is poor and represented mainly by *Amphidonte conicum* (Sow.), *A. lateralis* (Nills.), *Lopha* cf. *carinata* (Lam.), *Plicatula gurgitis* Pict. and Roux, etc. *Neohibolites* cf. *minimus* (Miller) was found near Mikhalkiv, and phosphatized nuclei of *Aucellina gryphaeoides* (Sow.), *A. krasnopolskii* Pavl., and *A. stuckenbergi* Pavl. in Mohyliv-Podilskyi. The basal sands of the upper Albian form separate lenses (up to 2 m thick) on the surface of the Neoproterozoic or Lower Palaeozoic deposits. Presumably, this horizon includes glauconite-quartz sandstone of Yavoriv district;

bryozoan-echinoderm, organogenic-detrital limestones composed mainly of fragments of bryozoans, sea urchins, and molluscs with an admixture of quartz and glauconite grains. Molluscs suitable for identification are very rare. Among them are *Amphidonte conicum* (Sow.), *A. lateralis* (Nills.), *Lopha* sp., *Entolium orbiculare* (Sow.), and *Chlamys puzosiana* Woods. Colonial and solitary corals are relatively frequent. The rocks are quite varied, contain terrigenous material (sand grains) and often turn into calcareous sandstones, in places with oblique stratification (Bilche-Zolote village). In the eastern regions, they contain chalcedony pseudoconcretions and flint (Ustya and Kolodribka), as well as sand layers (Mykhalkiv). In Pylypche village, limestones are represented by coarse- and medium-grained, often re-crystallized deposits with fragments of bryozoans and impurities of glauconite and fragmentary quartz grains.

These limestones ('sea urchin limestones,' according to Zaręczny 1874) form a wide 8–10 m thick lens in Podillia. They are common near the mouth of the Seret River, but also known in Bilche-Zolote, Horodenka, and Horodnytsia. Their total thickness reaches 28 m in Pidluby;

gaizes and opal spongioliths, often containing chalcedony contractions, and in some places flints (Hrynchuk, Malynivtsi, and Bakota). The fauna is not phosphatised and is represented mainly by *Amphidonte conicum* (Sow.). Less common are *Entolium orbiculare* (Sow.), *E.* cf. *balticum* (Dam.), *Chlamys hispida* (Goldf.), *C.* cf. *puzosiana* (Math.), *Lima* cf. *gaulnina* Woods, *Dosinopsis* cf. *subrotundata* (Sow.), *D.* cf. *parva* (Sow.), and *Linotrigonia spinosa* (Park.). The latter is quite often observed in the lower opal sillicites (Malynivtsi, Darabany, and Melnytsia-Podilska). In addition, single specimens of *Parahibolites tourtiae* were found in the outcrops of Melnytsia-Podilska and Khudykivtsi (Weigner 1910). Gaizes and opal spongioliths (0-18 m) are distributed mainly in the Middle Dnister region. Senkovsky (1962) also reported these rocks from near Zaboloty. Late Albian sillicites were found near Kamyanka-Buzka.

Based on previous observations, it can be stated that Albian deposits are distributed almost exclusively on the western and south-western edges of the Volyn-Podillia Plate and in adjacent depressions. In the part of Volyn-Podillia with the highest uplifts of the Palaeozoic surface, no marine Albian deposits were found and some signs indicate the presence of Lower Cretaceous continental formations that occur in the form of small lenses.

Upper section K_2

Cenomanian stage K_2s

Stratigraphy. The Late Cretaceous epoch was generally marked by the development of large-scale transgression and an increase in the depth of marine epicontinental basins. It is evidenced by the wide lateral distribution and facial features of Cenomanian formations in the composition of mainly shallow terrigenous sediments (early Cenomanian). At the early-middle Cenomanian boundary, regression took place, which manifested in breaks of sedimentation and in the appearance of phosphorite facies. The accumulation of carbonate sediments began in the second half of the Cenomanian age. The Carpathian Basin with a moderately deep-water zone and a deep shelf developed along the periphery of the south-western edge of the East European platform. Carbonate-clayey, silt, silty-siltstone deposits with sands formed there. The presence of inoceram remains indicates good water aeration and normal salinity.

At that time, there was no large landmass near the Volyn-Podillia Sea. In the east, the surface of the Ukrainian Shield, levelled by prolonged denudation, rose above the water in the form of large islands. In the southwest, the Volyn-Podillia Sea bordered the Carpathian Sea, separated from the Carpathian folded region by a shaft. In the north, there were several small islands. As a result, little terrigenous material entered the water basin and sedimentation occurred mainly due to erosion and processing of the weathering crust by the water mass.

Cenomanian deposits were formed under conditions of active hydrodynamic regime of the shallow epicontinental sea, which developed and caused significant vertical and horizontal lithological-facial variability of its sediments under the influence of rather intense bottom currents.

Two sedimentation areas are allocated in the Cenomanian sea basin (Sobetsky 1961): north-western shallow zone with terrigenous sediments (sublittoral) and south-eastern, relatively deep-water zone with carbonate-clayey and carbonate sediments. The boundary between these lithofacial zones is indistinct and the lithological change of sediments occurs as a result of sequential-pulsating (transgressive-regressive) 'wedging' and wedge-shaped layering of marls with sands (Vorobiev *et al.* 1971). This was reflected in the gradual increase in the clay content of marls towards the Ukrainian Shield until their transition into carbonate clay, and then, as a result of increasing sand and glauconite content, into dense quartz-glauconitic sands.

In the north-western part of the Middle Dnister region, west of the Kalyus-Zhvan watershed, Cenomanian sediments lie directly on the blurred surface of Silurian deposits and are represented by coarse-grained sandstones and clayey shales. Dark green glauconitic sand with basal conglomerates lies in the base of the Cenomanian section. There are wood fragments (Struga) and re-deposited phosphorite nodules (Rudkivtsi) in basal conglomerates. The sand is fine-grained and dense with remains of sponges and bryozoans. Small clumps of grey flints are evenly scattered throughout the section. The thickness of the basal formations is 0.3–3.0 m.

Upward in the section, there are sandy gaizes interbedded with opal-glauconite-quartz sands and opal-chalcedony spongioliths. Opals comprise rare *Entolium orbiculare* Sow., *E. balticum* (Dam.), *Chlamys hispida* (Goldf.), and *Parahibolites tourtiae* (Weign.). In some places (Malynivtsi, Darabany, and Stara Ushytsia), there is a limestone layer (0.5–1.0 m), in which *Amphidonte conicum* (Sow.), *Trigonia pavlovi* Strem., and *Lima* sp. were found. The thickness of sandstone is about 10 m. *A. conicum* (Sow.), *Venericardia tenuicosta* Sow., *Cucullaea* aff. *mailleana* (Orb.), *Parallelodon carteroni* (Orb.), and *Chlamys* cf. *hispida* (Goldf.) were identified from deposits of the same age exposed near Demshyn. Further upward, there are sands (Kalius river basin: Nova Ushytsia, etc.) and marls (Verbivka river basin: Balabanivka).

There are uniform fine-grained, greenish-grey glauconitic-quartz sands (0.2–1.0 m) on the watershed between Kalius and Studenytsia. This sandy layer is enriched with numerous phosphatised remains of molluscs, detritus, and shark teeth. Sands are often interbedded with gaizes, formed due to secondary separation of carbonate rocks (Senkovsky 1973). Fossilization of remains is due to groundwater, which had reached this level (Vorobiev *et al.* 1971).

The lower border of glauconitic-quartz sands is clear. At the very contact with the underlying formations, there is a layer (0.1–0.15 m) of viscous olive-green clay with a small admixture of sand. The roof of sands is wavy and apparently reflects the relief of the seabed. The upper part of the sand section (0.5 m) is enriched with fragile iron contractions of semi-circular shape. In this part, along with faunal remains, a chain of shallow lenses of greyish-cream marls is observed. From above, in a layer of greenish-grey glauconitic-quartz sands, finger-like flints enter to a depth of 0.5 m. The thickness of glauconitic-quartz sands is 15–20 m.

The most complete set of the fossil fauna was collected in greenish-grey glauconitic-quartz sands near Nova Ushytsia: *Cyprimeria faba* (Sow.), *Cucullaea mailleana* (Orb.), *C. subglabra* (Orb.), *Venericardia tenuicosta* Sow., *Avellana cassis* Orb., *Trigonia aliformis* Park., *Plicatula inflata* Sow., *Pl. gurgitis* Pict. et Roux, *Myoconcha cretacea* Orb., *Natica lyrata* Sow., *Trigonarca orbigniana* (Math.), *Chlamys* cf. *hispida* (Goldf.), *Ch.* (*Merklinia*) *aspera* (Lam.), *Ch.* cf. *fissicosta* (Eth.), *Amphidonte conicum* (Sow.), *Grammatodon carinatus* Sow., *Terebratula striatula* Reuss, *Cretirhynchia subhercynica* (Tsn.), *Rhynchonella grasiana* d'Orb., *Nairiella* cf. *tenuicosta* Plamad., *Nodosiella* cf. *nodosa* (Roem.), *Neithea* sp., *Donax* sp., *Pleurotomaria* sp., numerous fragments of belemnites, bryozoans, corals, vertebrae and teeth of *Platypterygius*? sp. (Kyselevych & Ogienko 2018), and shark teeth. A scale of the ganoid fish *Scheenstia* (Actinopterygii, Holostei) was also found there (Kyselevych & Kovalchuk 2019). Phosphatization has led to good preservation of fossils and their structural details.

The best preserved in this section are cephalopods represented by *Cymatoceras deslongchampsianum* (Orb.), *Turrilites costatus* Lam., *Hypoturrilites* aff. *tuberculatus tuberculatus* (d'Orb.), *Puzosia mayoriana* Orb., *P. planulata* (Sow.) var. *odiensis* Kossm., *Arrhaphoceras variabile* Renz, *Acanthoceras* cf. *rhotomagense* (Defr.), *Sharpeiceras* aff. *schluteri* Hyatt., *Mantelliceras mantelli* (Sow.), *Schloenbachia varians* Sow., *S. varians subvarians* Spath, *S. varians subtuberculata* (Sharpe), *S. varians ventriosa* Stiel., *S. coupei quadrata* Spath, *Ammonites* sp., and *Turrilites acutus* Passy. In addition to these species, *Gryphaeostrea canaliculata* (Sow.), *Trajanella* aff. *muniari* Popov-Hatzeg, *Chlamys robinaldina* (Orb.), *Entolium noetlingi* Sob., *E. orbiculare* (Sow.), *Neithea quiquecostata* (Sow.), *Hypoturrilites mantelli* (Sharpe), *S.* aff. *coupei trituberculata* Spath, and *Spondylus* sp. were identified in Balabanivka. *Parallelodon carteroni* (Orb.) and *Lima podolica* Sob. were found in Sloboda Shcherbovetska, *Drilluta curta* Pčel. near Kucha, while *Neithea cometa* (Orb.) and *Lima rhotomagensis* Orb. were identified in materials from Velyka Kuzheleva.

The closest to the faunal assemblage of Nova Ushytsia is that from Lysyachy Yar (Tsykove), which, in addition to the previously listed species, includes *Opis bicornis* (Gein.), *Gryphaeostrea canaliculata* (Sow.), *Capillithyris* ex gr. *capillata* (Arch.), *Mariella* aff. *essenensis* (Gein.), and *Turrilites* aff. *acutus* Passy. To the west of the Zhvan River, the section of Cenomanian sediments ends with white fine-grained trifles and marls with chalcedony flints.

In Balabanivka, flint lies in a sandy marl with a thickness of 5 m. The marl is very sandy in the lower part (1.5 m), up to the formation of dense carbonate sands. The number of flints increases upwards. In the lower part of the section, flint layer lies in greenish, viscous, carbonate, sandy clays. The thickness of flints increases westward and varies from 5 to 10 m.

To the southeast of the Zhvan River, the section of Cenomanian sediments changed — there is a sand-carbonate stratum on basal conglomerates, which corresponds in age to spongioliths and glauconitic-quartz sands (Kraeva & Lypnyk 1958; Senkovsky 1963b). Some changes occur in the thickness of basal formations — they are represented in Mohyliv-Podilskyi by glauconitic-sandy limestones with *Amphidonte conicum* (Sow.), *Entolium orbiculare* (Sow.), *Neithea sexcostata* Woodw., *Plicatula gurgitis* Pict. et Roux, and *Neohibolites* cf. *ultimus* (Orb.).

A 42 m thick layer of greyish-white dense sandy chalk-like marls with numerous black flints lies on basal formations (glauconitic sands with pebbles of Palaeozoic sandstones and mica clay shales) in Murovani Kurylivtsi. These marls yield the following fossils: *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., *Chlamys fissicosta* (Eth.), *Ch.* cf. *elongata* Lam., *Ch.* (*Aequipecten*) *aspera* (Lam.), *Neithea quinquecostata* (Sow.), *Plicatula inflata* Sow., *Venericardia tenuicosta* (Sow.), *Trigonarca* aff. *orbignyana* (Math.), *Amphidonte conicum* (Sow.), *Cyprimeria faba* (Sow.), *Parallelodon carteroni* (Orb.), *Avellana cassis* Orb., *Pleurotomaria* cf. *panderi* Gofm., *Trochus duodecimcostatus* Gofm., *Neohibolites ultimus* (d'Orb.), *Rotularia damesii* Noetl., *Aucellina* sp., and bone fragments. Cephalopods with outer shell (*Nautilus laevigatus* d'Orb., *Puzosia* aff. *chivensis* Arkh.(?), *Schloenbachia varians varians* Sow., *S. varians subvarians* Spath, *S. varians subtuberculata* (Sharpe), *S. coupei costata* (Sharpe), and *S. coupei quadrata* Spath.) are also widely represented in this section.

The species list of Cenomanian cephalopods from a new section near Murovani Kurylivtsi was recently supplemented with *Schloenbachia sharpei* Semenov, *S. ventriosa* Stieler, *Phylloceras* sp., *Forbesiceras* sp., *Hyphoplites* cf. *costosus* Wright et Wright, *Mantelliceras mantelli* (Sow.), *M. tuberculatum* (Mantell), *M. cantianum* Spath, *Acompsoceras* cf. *inconstans* (Schlüter), *Puzosia mayoriana* d'Orb., *Puzosia* sp., *Austiniceras* cf. *austeni* (Sharpe), *Mariella* sp., *Turrilites scheuchzerianus* Bosc, *Stomohamites simplex* (d'Orb.), *Sciponoceras baculoides* Mantell, *Pseudocenoceras fittoni* (Sharpe), *Eutrephoceras sublaevigatum* (d'Orb.), *Praeactinocamax plenus* Blainville, and *Praeactinocamax* sp. (Maryash & Kozlovsky 2019). Among them, *Mantelliceras mantelli* is an index species of the lower part of the lower Cenomanian (Ivanik *et al.* 2013), while *Praeactinocamax plenus* represents the Upper Cenomanian zone within the entire subtier for Volyn-Podillia (Maryash & Kozlovsky 2019).

In Yaryshiv, 20–25 m thick greyish-white, dense, homogeneous marls with iron inclusions and a gradually increasing number of flints lie on basal conglomerates. The marls are significantly clayey in the lower part of the section, being sandier in the middle part. The entire layer contains rare fragments of sponges and small pectenid shells.

Numerous fossil faunal remains were found 1–2 cm of the marl roof. This part of the section contains rare grains and small black flint pebbles. The fauna is numerous and diverse: *Chlamys* (*Aequipecten*) *aspera* (Lam.), *Ch. robinaldina* Orb., *Ch. fissicosta* (Eth.), *Ch.* aff. *elongata* Lam., *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., *Neithea quinquecostata* (Sow.), *Venericardia tenuicosta* (Sow.), *Cyprimeria faba* (Sow.), *Trigonarca orbignyana* (Math.), *Plicatula gurgitis* Pict. et Roux, *P. inflata* Sow., *Parallelodon carteroni* (Orb.), *Cucullaea* cf. *subglabra* (Orb.), *Myoconcha cretacea* Orb., *Amphidonte conicum* (Sow.), *Gryphaeostrea canaliculata* (Sow.), *Ostrea* aff. *vesicularis* Reuss, *Exogyra lateralis* Nills., *Trigonia pavlovi* Strem., *T.* cf. *aliformis* Park., *Terebratula striatula* Reuss, *Terebratulina podolica* Zar., *Avellana cassis* Orb., *Cyathophyllum articulatum* Wahl., *Scyphya fenestrate* Goldf., *Ventriculites coewicornis* d'Orb., *Rhynchonella grasiana* d'Orb., *Inoceramus crippsi* Mant., *Ceprina ligeriensis* d'Orb., *Spondylus striatus* (Sow.), *S.* aff. *dutempleanus* d'Orb., *Parsimonia* ex gr. *antiquate* (Sow.), *Serpula* aff. *ampullacea* Sow., *Pleurotomaria* sp., *Dentalium* sp., *Cymatoceras deslongchampsianum* (Orb.), *Mantelliceras mantelli* (Sow.), *Puzosia planulata* (Sow.), *Forbesiceras largilliertianum* (Orb.), *Turrilites costatus* Lam., *Schloenbachia varians subvarians* Spath, *S. varians subtuberculata* (Sharpe), *S. varians ventriosa* Stiel., *S. coupei quadrata* Spath, *S. coupei trituberculata* Spath, and *Sharpeiceras* sp. In addition, *Natica lyrata* Sow., *Arcuatothyris arcuata* (Roem.), and *Lima podolica* Sob. were found in Khonkivtsi.

Chlamys (*Aequipecten*) *aspera* (Lam.), *Trigonia pavlovi* Strem., *Cyprimeria faba* (Sow.), *Venericardia tenuicosta* (Sow.), *Schloenbachia varians subvarians* Spath, and *Ostrea* sp. were identified along with shark teeth from 17 m thick limestones of Mohyliv-Podilskyi.

Light gray marls with glauconite are exposed on the right bank of the Dnister River near Otach (Republic of Moldova). Pebbles of Palaeozoic rocks are found in the lower part of the section (0.25 m). Fossils found in this layer represent *Inoceramus crippsi* Mant., *Lima gaultina* Woods, *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., *Isocardia* ex gr. *karabakhensis* Bobkova, *Chlamys elongata* Lam., *Chlamys* (*Merklinia*) *aspera* (Lam.), *Spondylus striatus* (Sow.), *Plicatula gurgitis* Pict. et Roux, *Ostrea* sp., and *Schloenbachia* aff. *coupei quadrata*.

Glauconite content is sharply decreased 5 m upwards. Marls of this part of the section comprise *Entolium orbiculare* (Sow.), *Plicatula inflata* (Sow.), *Inoceramus crippsi* Mant., *Neithea quinquecostata* (Sow.), *N. cometa* (Orb.), *N. sexcostata* (Woodw.), *Chlamys robinaldina* (Orb.), and *Lima gaultina* Woods. In 3 m above, the marl is enriched with numerous inoceram fragments indicating a significant mobility of waters within the sedimentation basin. *Inoceramus crippsi* Mant., *I. orbicularis* Noetl., *Neithea quinquecostata* (Sow.), *Plicatula inflata* Sow., *Entolium orbiculare* (Sow.), *Gryphaeostrea canaliculata* (Sow.), *Chlamys* cf. *fissicosta* (Eth.), *Terebratula* cf. *striatula* Reuss, and *Rhynchonella* sp. were collected there. The upper part of marls (15 m from the base) with numerous flint concretions contains *Entolium noetlingi* Sob., *E. orbiculare* (Sow.), *Plicatula inflata* Sow., *Lima podolica* Sob., *Neithea quinquecostata* (Sow.), *Chlamys* (*Aequipecten*) *aspera* (Lam.), and *Inoceramus crippsi* Mant. The Cenomanian section in Mohyliv-Podilskyi area ends with inoceram (5 m) and siliceous (6 m) limestones and trepels (5 m) with flint. Their age is confirmed by findings of the Cenomanian fauna. The presence of *Turrilites* cf. *scheuchzerianus* Bosc., *Schloenbachia varians* Sow., *S. subvarians* Spath, *S.* cf. *scharpei* (Sem.), *S.* cf. *ventriosa* Stiel., *Turrilites costatus* Lam., and *Schloenbachia* sp. in the assemblage allows to refer these deposits to the lower part of the Middle Cenomanian.

In the southern part of the Middle Dnister region, Cenomanian deposits are observed in the outcrops of Okland-Soroky, where they lie on the blurred surface of Riphean and Palaeozoic rocks, and are represented by pebbles and fragments of underlying rocks (0.4–0.5 m), dense quartz-glauconitic, clayey, fine-grained sands (1.5 m), and clayey marls (1.0 m). Greyish sandy marl (visible thickness 3.5 m) in Kobzhanka ravine near Soroky comprises *Inoceramus crippsi* Mant., *I. orbicularis* Noetl., *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., *Gryphaeostrea canaliculata* (Sow.), *Chlamys puzosiana* (Math.), *Ch. robinaldina* Orb., *Ch. fissicosta* (Eth.), *Lima podolica* Sob., *Plicatula inflata* (Sow.), *Neithea quinquecostata* (Sow.), and *Cyclothyris* cf. *schloenbachi* (Dav.). This marl upwards gradually turns into a very dense, chalk-like marl with a thickness of 2 m with small-sized *Entolium noetlingi* Sob., *E. orbiculare* (Sow.), *Chlamys fissicosta* (Eth.), *Ch. robinaldina* Orb., *Ch. puzosiana* (Math.), *Neithea quinquecostata* (Sow.), *Plicatula gurgitis* Pict. et Roux, *Lima podolica* Sob., and *Inoceramus* sp. This marl is covered by 4 m thick dense, fine-grained, essentially clayey marl containing *Inoceramus crippsi* Mant., *I. orbicularis* Munst., *Entolium noetlingi* Sob., *E. orbiculare*, *Chlamys fissicosta* (Eth.), *Ch. robinaldina* Orb., *Neithea quinquecostata* (Sow.), *Plicatula gurgitis* Pict. et Roux, *Lima podolica* Sob., *Gryphaeostrea canaliculata* (Sow.), *Ostrea* sp., and *Mantelliceras mantelli*.

There is a 5 m thick greyish, fine-grained, sandstone-like marl lying upward. The following fossils were collected there: *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., *Gryphaeostrea canaliculata* (Sow.), *Lima gaultina* Woods, *L. podolica* Sob., *Neithea quinquecostata* (Sow.), *N. sexcostata* (Woodw.), *N. cometa* (Orb.), *Chlamys* aff. *fissicosta* (Eth.), and *Ch. robinaldina*.

This layer is covered by a 10 m thick dense oolithic marls with nest-like clusters of fossil fauna represented by *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., *Gryphaeostrea* sp., *Neithea quinquecostata* (Sow.), and *Chlamys robinaldina* Orb. In the upper part of the section, there are *Gryphaeostrea canaliculata* (Sow.), *Amphidonte conicum* (Sow.), *Parsimonia antiquata* (Sow.), *Plicatula inflata* (Sow.), *Chlamys* aff. *robinaldina* Orb., *Entolium orbiculare* (Sow.), and *E. noetlingi* Sob. The sandy marl gradually turns into an olive-green clay-carbonate rock with traces of bioturbations and containing *Gryphaeostrea canaliculata* (Sow.), *Entolium orbiculare* (Sow.), *Neithea quinquecostata* (Sow.), and *Plicatula inflata* (Sow.). The Cenomanian section ends with 5 m thick dense, slightly silicified white marls with rare brown-grey flints the number of which increases upward. Two specimens of *Inoceramus* sp. were found in this layer.

Further north (between Soroky and Kobzhanka ravine, Moldova), there is a Cenomanian section, which is similar to the previous one. The following taxa were found in its lower part: *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., *Lima gaultina* Woods, *Plicatula inflata* (Sow.), *Inoceramus* sp., *Ostrea* sp., and *Terebratulina* sp. Somewhat higher, there are *Plicatula inflata* (Sow.), *Inoceramus* sp., *Ostrea* sp., small fragments of belemnites and poorly preserved brachiopods. *Chlamys robinaldina* Orb., *Ch.* (*Aequipecten*) *aspera* (Lam.), *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., *Amphidonte conicum* (Sow.), *Gryphaeostrea canaliculata* (Sow.), *Plicatula inflata* (Sow.), *Parsimonia* ex gr. *antiquata* (Sow.), *Neohibolites ultimus* (d'Orb.) were collected in the upper part of the section. Similar faunal remains were identified north of Soroky, in Dzyhiv Brid, Porohy, Oksanivka, and Mykhailivka. In addition to the above species, *Cucullaea mailleana* (Orb.), *Venericardia tenuicosta* (Sow.), *Trigonarca orbignyana* (Math.), *Avellana cassis* Orb., *Cyprimeria faba* (Sow.), *Schloenbachia varians subvarians* Spath, fragments of sponges, characteristic of the northern, shallower part of the Middle Dnister region, were found in Okland (Moldova). South of Soroky, Cenomanian sediments are represented by ash-grey fine-grained marls with a thickness of 20–25 cm (corresponding to fine-grained marls with marcasite in Kobzhanka ravine), containing *Neohibolites ultimus* (d'Orb.), *Plicatula gurgitis* Pict. et Roux, *P. inflata* (Sow.), and *Inoceramus crippsi* Mant.

Age and biostratigraphy of the Cenomanian of the Middle Dnister region

Lower Cenomanian K_2s_1

Lower Cenomanian deposits are widespread almost everywhere in the Middle Dnister region, and numerous outcrops are known from the Ternava River in the west to the Markovka River in the east, which led to the most complex paleontological characteristics of this region.

Lithology. In the Middle Dnister region, there is a lithological change of facies: from shallow glauconitic-quartz sands of the littoral zone of open shallow shelf in the northwest to deep carbonate-clayey formations of the middle and upper sublittoral in the southeast.

Molluscs. Cephalopods with external shells are widespread in lower Cenomanian deposits of the Middle Dnister region, especially in its north-western part — on the Ushytsia-Liadova watershed. Mass gatherings of this fossil fauna were made in vicinities of Nova Ushytsia, Tsykove, Velyka Kuzheleva, Verbivtsi, Struga, Kucha, Balabanivka, Zhytnyky, Murovani Kurylivtsi, Khonkivtsi, and Yaryshiv. In the south-eastern direction, there is a sharp reduction in species and quantity of cephalopods, and isolated findings are known in Mohyliv-Podilskyi and in the Republic of Moldova — in Ataky, Okland, and Soroky. The following taxa are the most common among the ammonoids (Kyselevych 1991): *Schloenbachia varians varians* (Sow.), *S. varians subvarians* Spath, *S. varians subplana* (Mant.), *S. varians subtuberculata* (Sharpe), *S. varians ventriosa* Stiel., *S. coupei quadrata* Spath (Nova Ushytsia), *S.* aff. *coupei trituberculata* Spath (Balabanivka), *S. varians varians* (Sow.), *S. varians subvarians* Spath, *S. varians subtuberculata* (Sharpe), *S. varians quadrata* Spath (Murovani Kurylivtsi), *S. varians subvarians* Spath, *S. varians subtuberculata* (Sharpe), *S. varians ventriosa* Stiel., *S. coupei quadrata* Spath, and *S. coupei trituberculata* Spath (Yarishiv). In the south-eastern part of the Middle Dnister region, there are isolated *Schloenbachia varians subvarians* Spath in Mohyliv-Podilskyi, *S.* aff. *coupei quadrata* Spath in Ataky, and *S. varians subvarians* Spath in Okland.

In the north-western part of the Middle Dnister region, *Schloenbachia* is confined to a thick layer of glauconitic-quartz sands with a large number of phosphated mollusc remains. Phosphatization of remains led to their good preservation in the fossil state with details of the external sculpture and internal structure. Near Nova Ushytsia, *Schloenbachia* was found together with *Mantelliceras mantelli* (Sow.) — an index species of the upper zone of the lower Cenomanian — and with *Turrilites costatus* Lam., which is characteristic for the middle Cenomanian. Balan (1973) suggested that representatives of *Schloenbachia*, due to the presence of transitional forms and the high rate of prochoresis, were probably ecological subspecies. Atabekyan (1985) believed that in the south of the former USSR they are characteristic only for the upper zone of the lower Cenomanian. However, Marcinowski (1983) provided data about lower Cenomanian sections, which shows that the nominative and other subspecies of *Schloenbachia varians* (Sow.) were common in the lower and middle Cenomanian, and the first representatives of *S. coupei* (Brongn.) appeared only during the Middle Cenomanian.

Mantelliceras mantelli (Sow.), an index species of Lower Cenomanian (Kyselevych *et al.* 1987; Kyselevych 1992; Ivanik *et al.* 2013), is widespread in the Middle Dnister region. Its findings are known in the sandstones of Nova Ushytsia and Yaryshiv (our data), in the marls of the Soroky district (Kobzhanka ravine, Republic of Moldova), as well as in Bernadivka, Butsniv (Maryash 2016) and Murovani Kurylivtsi (Maryash & Kozlovsky 2019). The allocation of *Mantelliceras mantelli* zone in the Lower Cenomanian deposits of the Middle Dnister region is also tentatively confirmed by findings of *Hypoturrilites* aff. *tuberculatus tuberculatus* (d'Orb.) in Nova Ushytsia, *H. mantelli* (Sharpe) in Balabanivka (both these species have the same stratigraphic distribution according to Monnet & Bucher 2002) and *Mariella* aff. *essenensis* (Gein.) (Tsykove). According to Atabekyan (1985), all three these species are characteristic for the Cenomanian of England and France, as well as for the middle and upper parts of *Mantelliceras mantelli* zone of the North Caucasus, Mangyshlak, Tuarkir, and Kopet-Dag. In addition, the lower Cenomanian of the Middle Dnister region is characterized by the presence of poorly preserved *Sharpeiceras* aff. *schluteri* Hyatt., *S.* sp., and *Forbesiceras largilliertianum* (Orb.). *Arrhaphoceras variabile* Reuz, known from the upper Albian deposits of Turkmenistan, was found, apparently, in a re-deposited state near Nova Ushytsia (Kyselevych *et al.* 1987).

The oldest ammonites known in the Late Cretaceous seas of the eastern Central European province (Balan, 1973) represented the genus *Puzosia* Bayle, 1878. In the early Cenomanian sea of the Middle Dnister region, there were *P. planulata* (Sow.) (Yarishiv), *P. mayoriana* d'Orb. (also recorded from the middle Cenomanian of Volyn-Podillya; Maryash & Kurepa 2014), *P. planulata* (Sow.) var. *odiensis* Kossm. (Nova Ushytsia), *P.* aff. *chivensis* Arkh. (Murovani Kurylivtsi). In addition to their distribution in Turkmenistan, species of the genus are known in the sediments of the lower Cenomanian Anglo-Paris and Polish-German basins, North Africa, Madagascar and Japan. Next to them, *Nautilus* *laevigatus* d'Orb. and *Cymatoceras deslongschampsianum* d'Orb. of the same age were found in the Middle Dnister region.

Most fossil molluscs are confined to the phosphatized faunal layer in the north-western part of the Middle Dnister region. In this area, many groups have varying degrees of importance, but, in general, it is possible to note certain patterns. The most common among bivalves are *Cyprimeria faba* (Sow.), *Cucullaea mailleana* (Orb.), *C. subglabra* (Orb.), *Venericardia tenuicosta* Sow., *Trigonia aliformis* Park., *Plicatula inflata* Sow., *P. gurgitis* Pict. et Roux, *Myoconcha cretacea* Orb., *Grammatodon carinatus* Sow., *Parallelodon carteroni* (Orb.), *Trigonia aliformis* Park., *Amphidonte conicum* (Sow.), *A. canaliculata* (Sow.), and *Lima* sp., while *Avellana cassis* Orb., *Natica lyrata* Sow., *Pleurotomaria* sp., and *Trochus* sp. predominate among gastropods. There are rare *Nodosiella* cf. *nodosa* (Roem.), *Nairiella* cf. *tenuicostata* Plamad., *Trajanella* aff. *muniari* Popov.-Hatzeg, known in western Europe, India, and Japan. Among brachiopods, the most common member of assemblages is *Terebratula striatula* Reuss.

Bivalves and gastropods are represented by phosphatised nuclei, often with preserved carbonate shells with their outer sculpture, less often with phosphatised nuclei. Forms that are partially or completely buried in the living state in the bottom substrate (*Cyprymeria* and others) are represented in the fossil state by whole nuclei with remains of shells. They did not acquire any lifelong orientation, except *Amphidonte conicum* (Sow.) which formed oyster banks near Stara Ushytsia. Much less common in the northwest are *Chlamys* (*Aequipecten*) *aspera* (Lam.), *Ch.* cf. *hispida* (Goldf.), *Entolium* cf. *noetlingi* Sob., and *Neithea* sp.

A decline in species composition of bivalves is observed in the south-eastern direction. In the Yaryshiv area, pectenids are quite common — *Chlamys* (*Aequipecten*) *aspera* (Lam.), *Ch. fissicosta* (Eth.), *Ch. robinaldina* Orb., *Ch. elongata* Lam., *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., and *Neithea quiquecostata* (Sow.). Large Pectinacea shells indicate favourable living conditions. Of the pectenids, the most common are large *Syncyclonema noetlingi* Sob. and smaller *S. orbiculare*. Further to the southeast, there are only *Entolium orbiculare* (Sow.), *E. noetlingi* Sob., *Chlamys fissicosta* (Eth.), *Ch. robinaldina* Orb., *Chlamys elongata* Lam., *Ch. puzosiana* (Orb.), *Neithea quiquecostata* (Sow.), *N. sexcostata* (Woodw), *N. cometa* (Orb.), *Lima gaultina* Woods, *L. podolica* Sob., *Plicatula inflata* (Sow.), *P. gurgitis* Pict. et Roux, *Inoceramus crippsi* Mant., *I. pictus* Sow., *I. orbicularis* Munst., and *Ostrea* sp.

In general, this faunal assemblage is characteristic for the lower Cenomanian. The *Mantelliceras mantelli* zone is reliably distinguished by the findings of the index species and characterized by the presence of the nominal species *Schloenbachia varians* (Sow.) and its subspecies.

Calcareous nannoplankton. Lower Cenomanian deposits of the Middle Dnister region contain *Manivitella redimiculata* (Stov.), *Zygodiscus diplogrammus* (Defl.), *Lithastrinus floralis* (Str.), *Biscutum constans* (Gorka), *Eiffellithus turriseiffeli* (Defl.), *Watznaubereria barnesae* (Black), *Cribrosphaerella ehrenbergi* (Arkh.), *Parhabdolithus emdergeri* (Noel.), *Chiastozygus amphipons* (Braml. et Mart.) and others, which are characteristic for *Chiastozygus amphipons* zone. This calcareous nannoplankton assemblage, in general, is common for all sections of the lower Cenomanian of the Middle Dnister region. It correlates with those of the Dnipro-Donetsk Basin, Caucasus, France, USA, and the oceans.

Palaeoecology. The facies of the lower Cenomanian glauconitic-quartz sands and sandstones is characterized by gravel impurities and insignificant thickness. Sponges with a silicon skeleton (genus *Triaxonida*) played a significant role in sedimentogenesis. Moderate water mobility and good aeration contributed to the formation of a rich fauna (bivalves, cephalopods and brachiopods, sponges, oysters, sea urchins, and corals). Mobile benthos predominated among the fauna (76%; Atabekyan 1985). Detritophagous *Turbo* were numerous, and *Natica* was typical among zoophages. Brachiopods were non-abundant, mainly rhynchonellids and terebratulids, being represented by shell fragments. The species composition of foraminifera from these sediments is poor. Benthic foraminifera (78–84%) are represented by numerous genera (*Arenobulimons*, *Cidicides*, *Gavelinella*, and *Plectina*), and planktonic (16–22%) — by members of the genus *Hedbergella*. This palaeocoenosis was buried in sediments of the coastal part of open sea at a depth of about 50 m. Shallow water is also evidenced by the lithological composition of sediments, as well as the findings of *Cucullaea*, *Cardita*, and *Cyprina*, occupying shallow habitats (10–80 m) of warm seas with good water aeration, mobility, and light.

There are mixed yellow-granular nodules of phosphorites in the early and middle Cenomanian sublittoral sediments of Volyn-Podillia, which were transferred from the Vendian deposits as a result of washing by later transgressing seas. Granular phosphorites were formed under calmer conditions of the sublittoral and relatively calm shallow shelf. The low seabed relief and structural-tectonic positions also contributed to the re-deposition processes.

Middle Cenomanian K_2s_2

Lithology. Faunistically characterized middle Cenomanian deposits are widespread in the Middle Dnister region. In the second half of the Cenomanian, the basin became deeper and the character of sedimentation had also changed due to the formation of carbonate-detrital deposits. New faunal groups appeared in the sea, in particular inoceramids, whose shells later became a rock-forming material for detrital limestones. Within the north-western part of the Middle Dnister region, quartz-glauconitic sands dated back to the middle Cenomanian, are replaced southward by detrital facies, with glauconite admixtures, limestones, which turn into marls and chalk near Soroky. The upper part of marls and limestones belongs to the middle Cenomanian.

The lower border of the middle Cenomanian deposits is determined by the results of the analysis of fossil fauna. In the northwest (Nova Ushytsia–Balabanivka) — the accumulation area of sublittoral Cenomanian deposits — it is confined to the upper part of glauconitic-quartz sands with phosphatized fauna. In the central part (near Yarishiv), this border is in the upper part of sand marls, whereas near Ataky–Mohyliv–Podilskyi — at the base of inoceram limestones; it is confined to the base of marls and chalk in the southeast (near Soroky).

Molluscs. Middle Cenomanian deposits of the Middle Dnister region are distinguished by the presence of *Turrilites costatus* Lam. (Nova Ushytsia, Yaryshiv, Tsykove), which was common in the Anglo-Paris and Polish-German basins, as well as in North Africa during the middle Cenomanian; *Acanthoceras rhotomagense* (Defr.) (Nova Ushytsia, Sloboda-Yaryshivska); *Turrilites acutus* Passy (Nova Ushytsia), which are characteristic for the upper middle Cenomanian in the south of Eastern Europe (*Cunnigtoniceras inerme* zone for the lower middle Cenomanian), found in the Cenomanian of Western Europe, the Caucasus, and the Fore-Caspian area (*Acanthoceras rhotomagense* zone of the mid-middle Cenomanian).

In addition, the first representatives of *Schloenbachia coupei* (Brongn.) appeared in the middle Cenomanian (Kyselevych 1991), i.e. *S. coupei quadrata* Spath (Nova Ushytsia, Yaryshiv, and Otach), *S. coupei trituberculata* Spath (Balabanivka and Yaryshiv), *S. coupei costata* (Sharpe) (Murovani Kurylivtsi), as well as *S.* cf. *scharpei* (Sem.), and *S.* cf. *ventriosa* Stiel. These taxa were widespread in the Cenomanian of Western Europe, Ukraine and, especially, in the middle Cenomanian of Turkmenistan (Mangyshlak and Tuarkir).

Calcareous nannoplankton. The middle Cenomanian age of deposits in the north-western part of the Middle Dnister region could not be confirmed by the calcareous nannoplankton, as its remains were not found in glauconitic-quartz sands near Nova Ushytsia. Further to the south, the middle Cenomanian is distinguished by the appearance of *Chiastozygus anceps* (Gorka), *Ch. cuneatus* (Lulj.), *Prediscosphaera cretacea* (Arkh.), etc. Middle Cenomanian sediments near Yarishiv contain the richest assemblage of coccoliths: *Watznaueria barnesae* (Black), *Discorhabdulus ignotus* (Gorka), *Chiastozygus amphipons* (Braml. et Mart.), *Ch. cuneatus* (Lulj.), *Ch. litterarius* (Gorka), *Zygodiscus diplogrammus* (Defl.), *Z. bussoni* (Noel.), *Eiffellithus turriseiffeli* (Defl.), *Prediscosphaera cretacea* (Arkh.), *Lithastrinus floralis* (Str.), *Microrhabdulus attenuatus* (Defl.), *Manivitella pemmatoidea* (Defl. et Maniv.), *Cretarhabdus crenulatus* (Braml. et Mart.), *Parhabdolithus embergeri* (Noel.), and *Bidiscus ignotus* (Gorka) (Kyselevych *et al.* 1987), which are characteristic for the *Chiastozygus cuneatus* zone.

The middle Cenomanian calcareous nannoplankton assemblages of the Middle Dnister region are identical to those in the stratotype sections of the Anglo-Paris Basin.

Palaeoecology. The facies of the middle Cenomanian inoceram limestones of open shallow epicontinental sea basin is widespread almost throughout the Volyn-Podillia Plate and is represented by light grey marl limestones with a large number of destroyed inoceram shells. The limestones are well clayey in its lower part, with an admixture of glauconitic and quartz sand. Phosphorites are scattered throughout the section, but mostly concentrated in the lower part of the sediments. The amount of carbonates increases upward (from about 70% to 93.5%). In the western regions, inoceram limestones turn into Turonian deposits, and in the east of the Volyn-Podillia Plate (Mohyliv-Podilskyi Transnistria) they are covered with siliceous limestones. The saturation of facies deposits with faunal remains is uneven and, usually, they are less common in the upper part of the stratum, and most often occurred in its lower part.

The systematic composition of the fauna, its origin, and the degree of preservation in different areas has its own characteristics. The exception are widespread inocerams, shell prisms of which have formed entire limestone strata. The saturation of facies deposits near Sloboda-Yaryshivska is low. Together with the phosphorites, the fauna is concentrated within the layer, which is located approximately 1–1.5 m above the bottom. This fossil assemblage is an orictocoenosis, and the systematic composition of its fossil remains (407 specimens) is represented by 45 species. The most numerous are bivalve molluscs (49.4%), among which *Venus* (*Cyprimeria*) *faba* (Sow.), and *Chlamys* (*Aequihecten*) *aspera* (Lam.) predominate. The second largest group are cephalopods (39.3%) with a predominance of members of the genus *Schloenbachia*. Gastropods make up 6.9%, sponges — 2.7%, serpulids — 0.7%, brachiopods — 0.3%, fishes and others — 0.7%. According to the number of individuals, this faunal assemblage can be called as Cyprimerio-Schloenbachian complex. The state of preservation of faunal remains indicate that most organisms were buried at the site of their existence and phosphated, some were re-deposited and preserved both in the form of nuclei and shell fragments (even a mother-of-pearl layer preserved on nuclei of *Schlenbachia*). The specimens collected are weakly or almost not rolled, which indicates low hydrodynamic activity of the bottom waters of the sea basin.

Ecologically, mobile benthos is dominant (57%), in particular the percentage of remains belonging to free-floating organisms is 6.4%. This group is dominated by forms that were buried in the bottom substrate (representatives of *Cyprimeria*, *Tapes*, *Natica*, etc.). Sedentary benthos is 10%, and it is represented by sponges, oysters, serpulids, and rare brachiopods.

Near Rukomyshyn, Ternopil Oblast the saturation of rock with remains of organisms is uneven and almost all of them are located in the basal (0.5 m) layer, and are rare upward the section. They are represented by 67 species (460 specimens), of which 57.8% are bivalves (dominated by *Opis coquandiana* Orb. and *Cucullaea mailleana* (Orb.)), cephalopods reached 16.7%, gastropods — 13.8%, brachiopods — 3.9%, sponges — 3.6%, sea urchins — 1.5%, scaphopods — 1.5%, serpulids — 0.6%, solitary corals — 0.4%, and fishes — 0.2%.

The nature of the burial and the degree of preservation indicate that almost the entire fauna is phosphated, washed, partially re-deposited and preserved mainly in the form of nuclei. Some species of the family Ostreidae and partially Pectenidae remained unphosphatized.

Among the ecological groups, mobile benthos reached the largest number (91.5%), with a predominance of *Tracia*, *Cardium*, *Corbula*, *Natica*, etc., which were buried in the bottom substrate. Free-floating organisms, mainly ammonites, are numerous there (16.8%). Sedentary benthos is 8.6% represented by sponges, solitary corals, serpulids, brachiopods, and oysters.

In Loshinivka, located 32 km northeast of Rukomyshyn, the number of systematic groups, in particular cephalopods, gastropods, brachiopods, etc., is greatly reduced compared to all outcrops in the southwest. At the same time, pectenids (e.g. *Entolium*, *Chlamys*) acquired a larger number. Their shells are found throughout the stratum of inoceram limestones.

The state of preservation indicates that the organisms were buried at the place, except for the basal layer complex, and to some extent represent the biocoenosis of the Middle Cenomanian sea. Pectenid shells are thin-walled, completely preserved, do not bear traces of movement and rolling, as evidenced by a thin sculpture of well-preserved shells. According to the number of individuals, this assemblage can be called a pectenid biocoenosis.

Some differences are observed when comparing the systematic and ecological groups of the fauna of the western and eastern parts of inoceram limestones. In the western part, the percentage of sedentary benthos is larger. In the Rukomyshyn Raion, it is represented by five systematic groups. In the eastern regions, the distribution of inoceram limestones is greatly reduced and, for example, in Sloboda-Yaryshivska only one *Terebratula* was found among more than 400 specimens. Solitary corals are also almost absent in the eastern areas. *Cucullaea mailleana* (Orb.) and *Opis coquandiana* Orb. reached a larger number in Ternopil Transnistria, while in Vinnytsia Transnistria the first species is represented only by several specimens, and the second one is absent. On the contrary, *Venus* (*Cyprimeria*) *faba* (Sow.) is numerous in the east, while rare in the west, and *Trigonarca orbignyana* (Math.) is completely absent there.

These differences can be explained by the difficult connections of shallow waters, and possibly by the isolation (at certain stages of development) of these parts of the Middle Cenomanian sea dissected by islands or capes. This is also confirmed by the fact that currently in large areas between the mentioned areas (Khmelnytskyi Transnistria) there are no inoceram limestones. Their small thickness could be probably blurred by younger marine transgressions.

Based on the lithological composition of rocks and the remains of organisms, we suggest that the sediments of this facies were formed at the beginning of the middle Cenomanian in a shallow open sea basin, in which the terrigenous material was demolished from the adjacent land parts of the Ukrainian Shield, and, probably, from small islands within the basin.

The bottom clear waters were relatively well warmed, enriched with oxygen and organic detritus, which contributed to the good development of the fauna. Later (approximately in the mid-middle Cenomanian), the transgression intensified, the sea basin deepened, as evidenced by the gradual decrease of the amount of terrigenous material entering the sea basin. It led to changes in bottom waters, which adversely affected the further development of the existing biocoenosis. There was a gradual extinction of entire faunal groups.

Almost complete phosphatization of the early–middle Cenomanian fauna is an evidence for the great role of the Carpathian upwelling at that time — the inflow of cold waters with dissolved phosphorus, silicon, nitrogen and other nutrients from the depths of the ocean. Geochemically active phosphorus is concentrated on the sea (ocean) shelf due to changes in salinity, temperature, pH, CO_2 content and other physicochemical parameters of the aquatic environment, which were characteristic for this region of Volyn-Podillia. In addition, upwelling is also interpreted as a rise of deep waters, enriched with gases; redistribution of exogenous mineralised water masses by sea currents over long distances; the appearance of redoxycline zones (favourable environment for sorption and desorption of elements). It is possible that the identified patterns took place in this region during the mass phosphatization of the early–middle Cenomanian organic remains with the preservation of details of the structure of their solid exoskeletons.

Upper Cenomanian K_2s_3

Lithology. The presence of upper Cenomanian deposits in the Middle Dnister region was established only in the Mohyliv-Podilskyi-Otach region (Republic of Moldova). This time was characterized by transgression increase with the formation of carbonate-clay sediments. Based on the lithological composition and organic remains (*Gavelinella cenomanica* (Brotz.), *Lingulogavelinella globosa* (Brotz.), *Gavelinella vesca* Vass., *Brotzenella berthelini* (Kell.), and *Amphidonta* sp.), the sea basin had normal salinity and optimal hydrodynamic regime.

Calcareous nannoplankton. A rather rich calcareous nannoplankton assemblage was identified by G. P. Kalinichenko from the deposits of this age (Kyselevych *et al.* 1987): *Watznaueria barnesae* (Black), *Eiffellithus turriseiffeli* (Defl.), *Cribrosphaerella ehrenbergi* (Arkh.), *Biscutum constans* (Gorka), *Lithastrinus floralis* (Str.), *Cretarhabdus coronodventis* (Reinh.), *Vagalapilla elliptica* (Reinh.), *Zygodiscus diplogrammus* (Defl.), *Z. variatus* (Carat.), *Chiastozygus litterarius* (Gorka), *Ch. anceps* (Gorka), *Manivitella pemmatoidea* (Defl. et Maniv.), *Parhabdolithus embergeri* (Noel.), *Microrhabdulus* aff. *decoratus* (Defl.), etc.

Palaeoecology. Macrofauna is very scarce in these sediments, being represented by *Praeactinocamax plenus* Blainville known from Murovani Kurylivtsi (Naidin 1952; Maryash & Kozlovsky 2019) and inoceram molluscs (Pasternak *et al.* 1968). The upper Cenomanian formations are well distinguished by calcareous nannoplankton (Kyselevych *et al.* 1987), the composition of which is closer to associations known from the same age in the Tethys and adjacent regions. The upper part of the Cenomanian section in the Middle Dnister region has a reduced carbonate and an increased silica content. It is possible that this is due to underwater and surface volcanism in the Steppe Crimea (Kyselevych 1999), the maximum of which was manifested in the middle and early late Albian. The increased content of silica of volcanic origin in the epicontinental sea basin promoted the development of organisms with siliceous skeleton. North-western sea currents promoted their migration and supplied increased portions of silica first to the Black Sea coast, where the upper Albian and lower Cenomanian spongioliths and gaizes were formed, and then to the Middle Dnister region with the accumulation of sillicites. The waters of the Carpathian upwelling could also have a significant impact on this process.

Climate. Data on the Cenomanian climate and the entire Late Cretaceous cycle of geological development of Ukraine are insufficient, because palaeovegetation, which could provide relevant information, is almost not preserved and practically not studied in Ukraine.

According to Krassilov (1985) and Vakhrameev (1988), during the Late Cretaceous Ukraine was a part of the European subtropical region and experienced fluctuations in temperature and humidity, which could be caused by transgressive and regressive phases of palaeobasin development. In the late Albian–Cenomanian, at least during the first half of this phase, the climate in the territory of modern Ukraine was warm and humid, as evidenced by the spread of terrigenous-glauconitic facies with phosphorites and by the presence of volcanic ash (Kyselevych 1999) indicating volcanic activity and possible greenhouse effect.

The water temperature in sea basins of that age in the Crimea was about 20°C (Yasamanov 1978). According to Krassilov (1985), there was a slight cooling during the late Albian and early Cenomanian compared to pre-Albian times and the middle Cenomanian, which is evidenced by the absence of thermophilous cycadophytes among the floristic remains.

The results of the study of the late Albian and Cenomanian marine fauna allow to suggest that the climate in the south and north of Ukraine was slightly different being typical subtropical in the Black Sea region and in the Crimea, while moderately warm and arid in the Dnipro-Donets Basin, northern slopes of Donbas and Volyn-Podillia, as evidenced by a mixture of cold- and warm water faunal elements, and the mineral composition of autogenic formations.

Due to a detailed comprehensive study of Cretaceous macro- and microfauna, its facies distribution, quantitative analysis, and paleoecological conditions, it is possible to trace slight differences between close homogeneous conditions of sedimentation within the relatively homogeneous sea basin of the Middle Dnister region on the verge of the Early and Late Cretaceous. It was found that this shallow epicontinental sea was characterized by normal salinity and well-aerated warm waters (+17 °C...+20 °C) with temporary strong bottom currents within shallow water and with maximum depths up to 150–200 m (average 10–80 m) in some areas and soft muddy bottom of deep-water areas.

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