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The Late Jurassic–Palaeogene Carbonate Platforms in the Outer Western Carpathian Tethys—A Regional Overview

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Abstract: The present work focuses on palaeogeographic reconstruction of shallow-water carbonate deposition in the Outer Western Carpathian Tethys. Platform deposits are preserved only as a component of turbidites and olistostromes, and reconstructions of these platforms are based on clastic material redistributed into slopes and deep basins and occurring among the Outer Carpathian nappes. Similar platforms were also present on the Tethys margins. These reconstructions were performed using the global models of plate tectonics. Several ridges covered by carbonate platforms developed in that area during the latest Jurassic–Palaeogene times. Three main shallow-water facies associations—Štramberk, Urgonian, and *Lithothamnion*–bryozoan—could be distinguished. The Tithonian–lowermost Cretaceous Štramberk facies is related to early, synrift–postrift stage of the development of the Silesian Domain. Facies that are diversified, narrow, shallow-water platforms, rich in corals, sponges, green algae, echinoderms, foraminifera, microencrusters, and microbes are typical of this stage. The Urgonian facies developed mainly on the south margin of the Outer Carpathian basins and is characterised by organodetritic limestones built of bivalves (including rudists), larger benthic foraminifera, crinoids, echinoids, and corals. Since the Paleocene, in all the Western Outer Carpathian sedimentary areas, *Lithothamnion*–bryozoan facies developed and adapted to unstable conditions. Algae–bryozoan covers originating on the siliciclastic substrate are typical of these facies. This type of deposition was preserved practically until the final stage in the evolution of the Outer Carpathian basins.

Keywords: carbonate platforms; shallow-water deposits; facies; palaeogeography; reconstructions; Western Tethys; Outer Carpathians; Jurassic; Cretaceous; Palaeogene

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1. Introduction

The Tethys (Neotethys) Ocean appeared as a palaeogeographic element in the Late Triassic, between Eurasian and Gondwanian parts of the disintegrating Pangea supercontinent. The Ligurian-Penninic-Pieniny-Magura Ocean was the tectonic system of the Alpine Tethys, and formed in the western part of the Pangean breakup [1]. Part of the Tethys Ocean that contained the Western Outer Carpathian deposits was formed during the Jurassic–Early Cretaceous synrift–postrift stage of the origin of the basins. Until the Miocene, the Outer Carpathian sedimentary area—separated in several sub-basins as the result of its development and evolution—was filled by a thick series of deposits. Turbiditic sedimentation prevails in this area: calcareous turbidites in latest Jurassic and earliest Cretaceous, and siliciclastic turbidites in later Early Cretaceous, Late Cretaceous, and Palaeogene. Therefore, the Outer Carpathian Mountains, also called the Flysch Carpathians, are built mainly of deep-water clastic rocks, which were deposited in the lower slope and surrounding basinal floor. However, margins of the basin, as well as uplifted ridges separating sub-basins, provided good conditions for development of carbonate platform sedimentation on their shallow banks, so local or regional shallow-water carbonate sedimentation periodically developed. These shallow-water zones were destructed during the final stages of the Carpathian basin's history. Reconstructions of carbonate platforms are based on the material that occurs among the Carpathian clastic deposits and was redistributed into the deep basins as a result of a decay of carbonate platforms. Because our observations are limited to exotic pebbles (rarely—small klippen) only, our reconstructions of these carbonate platforms are automatically limited both in time and space, and that is why reconstructions of their primary architecture are also limited by a scarce field of observations.

The term "carbonate platform" has a few meanings. It was originally used for the areas of shallow-marine, carbonate deposition. They develop on the shelf or in the deeper areas (isolated platforms), and their geometry is characterised by flat tops and steep flanks. The designation "carbonate platform" also has the broad meaning, "Very general term that includes ramps, shelves and various types of flat-topped platforms" [2]. Here, we use this broad meaning of carbonate platforms. The carbonate platforms constitute the main component of the carbonate-deposition system that extends from the area below the tidal zone to the lower edge of the carbonate shelf. Spatial relationships of carbonate platforms mainly refer to the depth of the photic zone and potential of the carbonate factory production (e.g., [3,4]).

The present work focuses on shallow-water environments covered by carbonate-platform sedimentation, namely the margin of the ocean and intrabasinal uplifted elements separating the basinal zones. We present an overview and comparison of carbonate platforms, which developed in the western part of the Outer Carpathian basins through the long history of their evolution. Carbonate platforms are represented by specific deposits, related to well-defined sedimentary environments. Their development and diversity reflects a spectrum of variability of individual environmental factors, therefore their analyses have a fundamental importance for the reconstruction of former marine environments, as well as for recognizing their palaeobiology and evolution (e.g., [2–6]). Fragmented deposits of shallow-water platforms removed to deep sea environments and preserved within turbidites and olistostromes constitute the only material available for such analyses. The original platform sequences have not survived in the Outer Carpathians. Therefore, we used these distracted fragments of platform deposits in order characterize the development and evolution of platform sedimentation in the Outer Western Carpathians. They were collected and subjected to stratigraphic, sedimentological, petrographic, and palaeontological analyses. Our data were supplemented by other published data and results.

2. Material and Methods

The presented overview is based on the numerous published and nonpublished data of the authors, as well as the extensive studies presented in the previous literature. The sources of published data are cited in the appropriate sections. The Jurassic–Palaeogene carbonate clasts were collected by the authors during many years of their field works in the area of all Outer Carpathian nappes (Figure 1). The material was studied macroscopically and investigated microscopically in thin sections using standard microfacies and micropalaeontological methods.

The Outer Western Carpathian plate tectonics and palaeogeography were reconstructed on the basis of global models of plate tectonics [7–12]. The data contained in the electronic databank were processed in the GPLATES software [13]. Information of the carbonate platforms was rotated with the other plate-tectonic elements. This software modelling enabled us to distinguish several basinal and uplifted palaeogeographic elements that were changing shape during the Cretaceous and Palaeogene evolution of the Outer Western Carpathians [8,14].

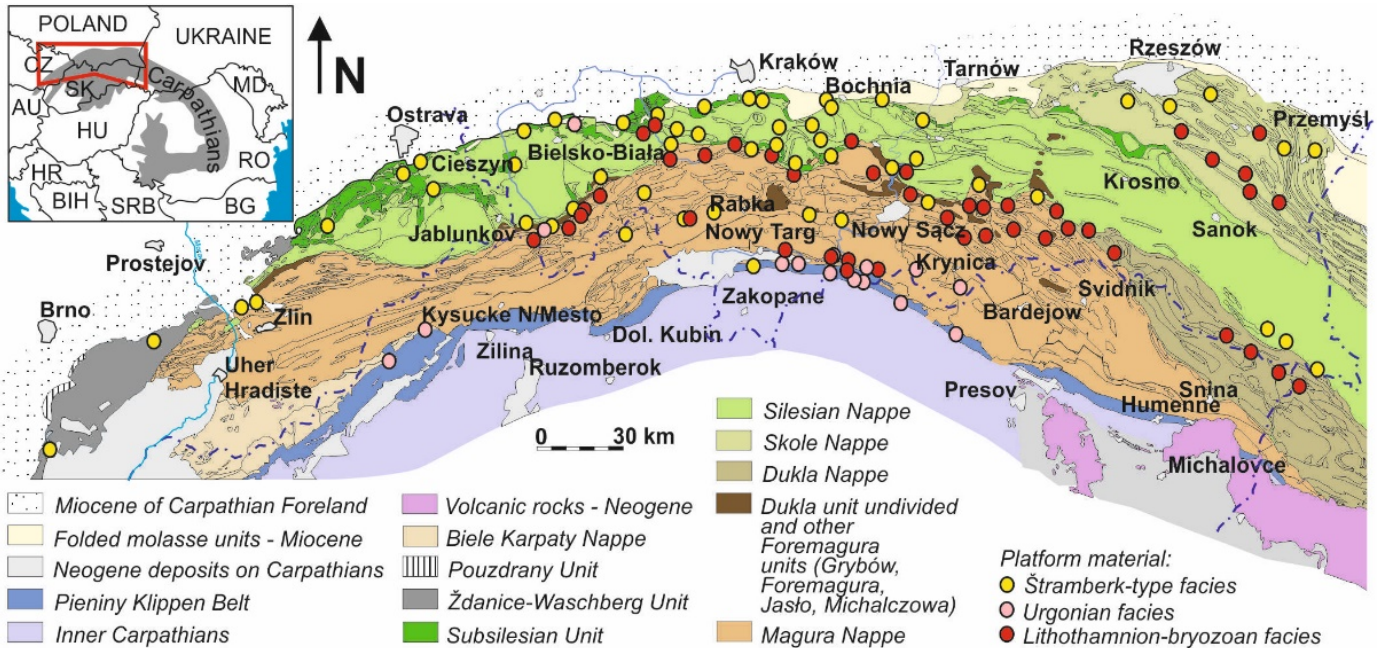

Figure 1. Localizations with platform material in the Outer Carpathians (based on [9]).

3. Geological Background

3.1. Outline of the Outer Carpathian Geology

The Western Outer Carpathians belong to the 1300 km-long Carpathian mountain arc. The Carpathians are generally divided into the Western, Eastern, and Southern Carpathians, surrounding the Pannonian Basin. The Western Carpathian orogen is divided into internides and externides. The Western Outer Carpathians, which constitute the externides that formed as a result of evolution of the Tethys Ocean ending with Neogene folding, thrusting, and uplifting, stretch from easternmost Austria (Vienna Basin) through Czech and Slovak territory to the Polish–Ukrainian border. The Pieniny Klippen Belt separates the Western Outer Carpathians from the internides.

The lithological inventory of the Western Outer Carpathians is the result of the long-lasting history of sedimentation within the Tethys Ocean. The rocks building the discussed part of the orogen were deposited in several basins, which represented more or less clearly individualized water areas in the western part of the Tethys Ocean. The Outer Carpathian basins were separated from inner Tethys by the Czorsztyn Ridge. The Silesian and Magura are the main lithological and structural domains distinguished during evolution of the Western Outer Carpathian basins (e.g., [8,9,14,15] and references therein). The Silesian Domain is related to the Protosilesian, Silesian, and Krosno basins—a succession of basins resulting from geotectonic evolution—while the Magura Domain is related to the Alpine Tethys [16,17]. The Alpine Tethys formed during Middle Jurassic time as an oceanic basin [9,11]. Its deposits are now contained in Western Outer Carpathian Magura and Subsilesian-Ždanice-Waschberg nappes. The Protosilesian Basin originated during the Late Jurassic as rift and/or back-arc basin within the North European Platform (e.g., [7–9,18,19] and references therein). The first ridges in the Outer Carpathian Tethys containing carbonate deposits originated during these times. The latest Jurassic–earliest Cretaceous carbonate deposition took place on the Silesian Ridge, which separated the Magura and Protosilesian basins, as well as on the uplifted areas of the northwestern (Pavlov Carbonate Platform) and northeastern (Baška-Inwałd Ridge) margins of the Alpine Tethys. The basement of the ridges dividing the Outer Carpathian basins consisted of Proterozoic and Palaeozoic crystalline rocks belonging originally to the Protocarpathians (e.g., [20,21] and references therein).

The ridges, basins, and related sedimentary areas existed within these domains as more or less stable elements. The main reorganization of the Outer Carpathian basins started at the end of the Early Cretaceous. The plates at the southeastern margin of Alpine Tethys were moving at that time. The accretionary prism developed in front of the moving plates, gradually closing the southeastern part of the Alpine Tethys. This prism reached the Czorsztyn Ridge at the end of the Late Cretaceous. The new carbonate platform originated at the south margin of the Magura Basin. The Foremagura group of basins (including Dukla Basin) originated within the Magura Domain during Late Cretaceous time. The new uplifted Foremagura Ridge developed between the Magura Basin and the Foremagura basins [9,22]. The Subsilesian Sedimentary Area originated between the Silesian and Skole basins. The Silesian Ridge existed during Cretaceous–Palaeogene time, up to the Eocene–Oligocene. The ridges separating the flysch basins in the Western Outer Carpathians were well developed during the Late Cretaceous–Eocene.

Gravity-flow deposition (mainly turbidity currents) or, subordinately, submarine landslides (e.g., [22–24] and references therein) predominated in this sedimentary area. They covered the lower part of slopes and parts of the basinal floor. During Late Jurassic to early Miocene time, up to 6 km of marine, as well as full oceanic sediments, mostly of turbiditic origin, were accumulated within the western part the Tethys Ocean. Therefore, the Western Outer Carpathians are built of material redeposited in deeper basinal zones, which are relatively well known by palaeofacies and sedimentary analyses. Simultaneously, the shallow-water sedimentation developed on the marginal part of the Tethys Ocean and on the uplifted basinal elements. Carbonate deposits are not preserved as individual units; they were fragmented and included in the clastic deposits.

The general form and morphological shape of the Western Outer Carpathians are an effect of prolonged complicated processes of the Cretaceous–Miocene folding, moving, and uplifting of the deposits sedimented within the Western Tethys Ocean. The Carpathian deposits were deformed during the Neogene. As a result of this orogenic process, a stack of several nappes formed (Figure 1). These nappes were entirely detached from their primary basement during the tectonic movements and thrust over each other and over the European Plate (e.g., [8,9,15]). The thrust direction reflects general verging towards the outer part of the orogene. The Skole, Subsilesian-Ždanice-Waschberg, Silesian, and Magura nappes, as well as the Foremagura group of nappes (including Dukla Nappe), represent the major Western Outer Carpathians structural units from north to south (e.g., [8,9,11,14,15,25–29] and references therein) (Figure 1). The nappes correspond more or less to the aforementioned original sedimentary areas.

3.2. Distribution of the Carbonate Platform Rocks

The occurrence of shallow-water carbonate material in the Outer Carpathian deposits is widely known and noted from the different facies-tectonic units, where it constitutes a component of, e.g., turbidites and olistostromes (Figures 1 and 2). The term “exotics” is often applied for allogenic clasts, especially in the Polish literature, following the 19th-century nomenclature (“exotischen Graniten”, “exotische Blöcke” [30,31]). “Exotic clasts” is a term more popular around the world (e.g., [2]).

The largest fragments of the carbonate platforms—so-called klippen—are very rare, but relatively large. Olistoliths exceeding 1 km in size (e.g., [22,24,32]) are exceptional. Such huge, tens and hundreds of meters and even kilometer-sized olistoliths representing the Late Jurassic–Early Cretaceous carbonate platforms are known from the Silesian, Skole, Subsilesian, Magura, and Waschberg nappes. Fragments of limestones and marls (boulders, cobbles, pebbles) occur in the mélanges deposited by the submarine landslides. Deformation structures, discontinuity of beds, and massive structures observed in some deposits—e.g., the uppermost Jurassic Vendryně Formation of the Silesian Nappe and Popiele Beds connected with Hieroglyphic Formation from the Skole Nappe [33,34]—suggest redeposition of huge, not fully consolidated giant olistoplaques. The carbonate material is much more abundant, but also more shredded, in the turbidites. It is fine, mainly up to few millimeters in size. In some beds it is particularly abundant, and forms the type of allodapic limestones within the turbiditic sequences; e.g., Cieszyn Limestone of Lower Cretaceous [35,36], or Palaeogene Bircza Limestone [37,38], Łużna Limestone [39], and Skalnik Sandstone [40]. Carbonate material also occurs in the Albian to Cenomanian Chlebovice conglomerate and Maastrichtian to the lowermost Paleocene Palkovice Formation [41,42].

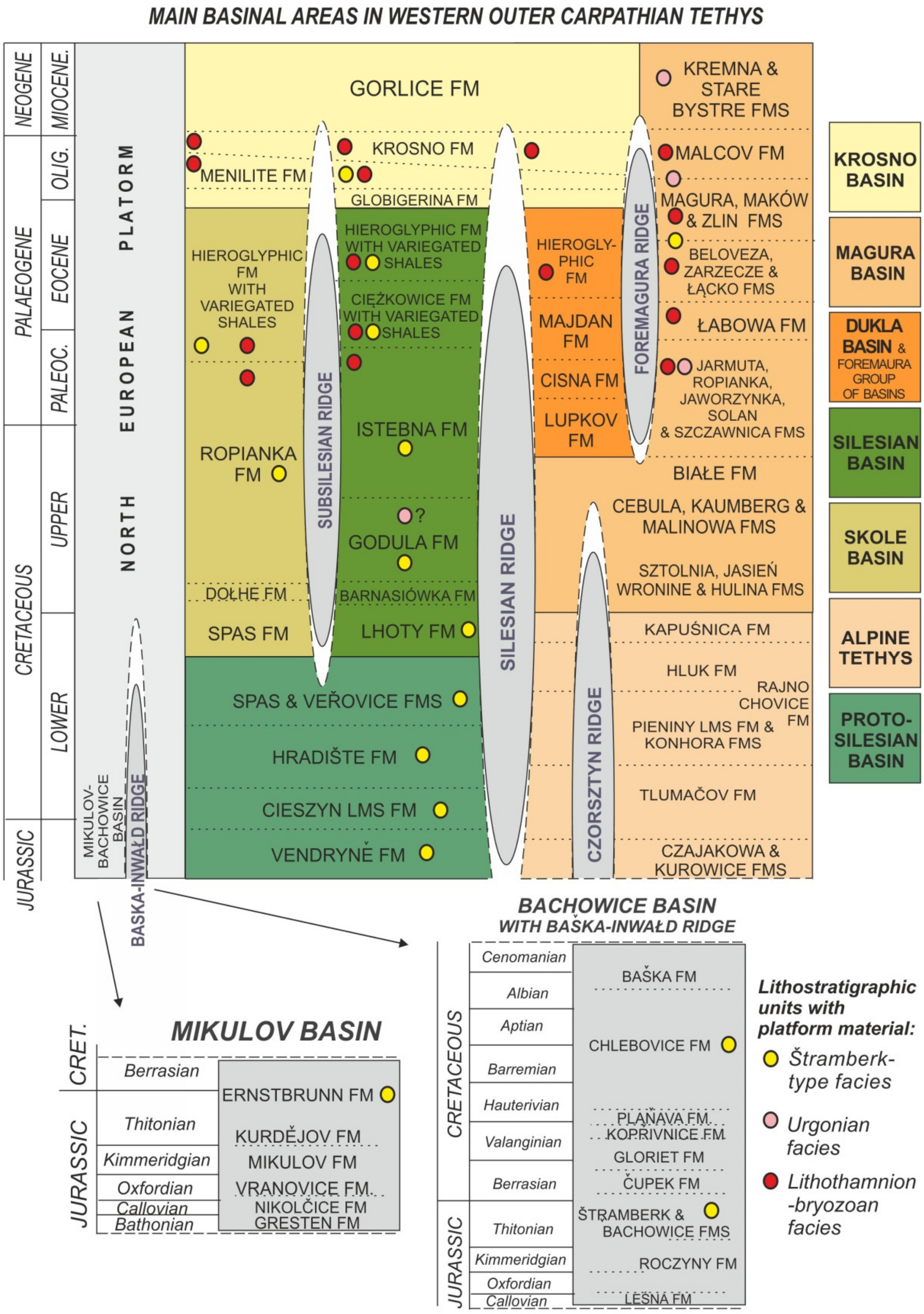

Figure 2. Main basinal lithostratigraphic units with platform material in the Outer Western Carpathians (based on [9]). ?—presumable (poorly documented) occurrence.

The distribution of the remnants of carbonate platforms is not uniform in the Outer Carpathians, even in particular nappes. Their distribution is related to occurrence of coarse-grained deposits. Generally, the larger fragments of carbonate platforms were transported to the deep basins, mainly during the stages of the increased, tectonic-induced activity of the source areas. On the other hand, even taking into consideration particular lithostratigraphic formations, distribution of shallow-water clasts can change spatially. For example, in the Silesian Nappe, it can be explained by several coexisting factors [43]. The western part of the Silesian Ridge emerged first, compared with its eastern parts, so reduction of the sedimentary cover was faster in the western part. Moreover, geometry of the ridge could involve development of various depositional systems. Last but not least, the growth of carbonate platforms could have been nonuniform across the whole ridge. Clasts could be derived from a secondary source: erosion, rework, and redeposition of older, deep-water deposits of the Outer Carpathian basins—so-called "cannibalism" (e.g., [36,43]).

4. Carbonate Platforms in the Outer Western Carpathians

Development of the platforms was connected with some evolutionary stages of the Outer Carpathian Basins. The shallow-water carbonate platforms occurred on margins of the Protosilesian Basin from the earliest stages of its development, and they first constituted continuation of the epicontinental carbonate deposition that took place on the south margin of the North European Platform before its rifting. These pre-Carpathian Middle Jurassic to Kimmeridgian carbonate rocks are known from the Andrychów Klippen and Bachowice area [18,44,45], as well as from smaller exotic clasts found among the Carpathian turbiditic deposits (e.g., [46]). From the Jurassic to Oligocene, the carbonate sedimentation developed locally or regionally in shallow parts of the Outer Carpathian basins. Their character, meaning, and range varied in time as they evolved. The three stages of platform evolution connected with the three main facies associations (simply: facies) can be distinguished in the Outer Carpathians. They belong to the three stratigraphically defined stages: latest Jurassic–earliest Cretaceous, Early Cretaceous (Barremian–Aptian), and Paleocene–Oligocene.

4.1. Štramberk-Type Facies Association (Latest Jurassic–Earliest Cretaceous)

Facies and interpretation: The Štramberk-type limestones are mainly light or grey in colour, usually fossiliferous limestones (Figure 3a–g). Coral-microbial boundstones are found the most typical among Štramberk-type limestones. Microencrusters constituted an important component of these coral-microbial reefs, and they are also one of the main components of microencruster-microbial-cement boundstones. Boundstones dominated by microbialites, siliceous sponges, polychetes *Terebella lapilloides* Münster, and foraminifera *Crescentiella morronensis* (Crescenti) are also found. Reefal components are common in detrital limestones—intraclastic and intraclastic-bioclastic grainstones, rudstones, and packstones—which represent one of the most important facies type. Limestones with foraminifera, algae, cortoids, ooids, and "*Lithocodium–Bacinella*" structures, representing such microfacies as coated grainstone/rudstone, cortoid–oncoid grainstone/rudstone, and foraminiferal-algal grainstone, are also common, as well as limestones with peloids and shallow-water bioclasts: bioclastic-peloidal and peloidal-bioclastic grainstones, packstones, and wackestones. Limestones with ooids and peloids (ooid-peloidal or peloidal-ooid grainstones), peloidal limestones (grainstones or packstones), and limestones (mudstones and wackestones) with calpionellids and/or calcareous dinoflagellate cysts are less frequent.

According to [47], Štramberk-type limestones developed on narrow shallow-water carbonate platforms, but facies were diversified. The inner platform zone was occupied by coral-microbial patch-reefs; moreover, foraminiferal-algal and peloidal-bioclastic limestones were deposited there. Ooid grainstones, occasionally found as exotics, could be related to the platform margin. Microencruster-microbial-cement boundstones were deposited on the upper slope, while carbonate buildups constructed by microbes and siliceous sponges developed in the deeper parts of the slope [47,48]. In peri-reefal zones, accumulation of poorly sorted carbonate detritus took place, but detrital limestones were also deposited in a high-energy environment of the platform margin. Mudstones and wackestones with calpionellids and calcareous dinoflagellate cysts developed in the deepest parts of the carbonate platforms and in the deep basin.

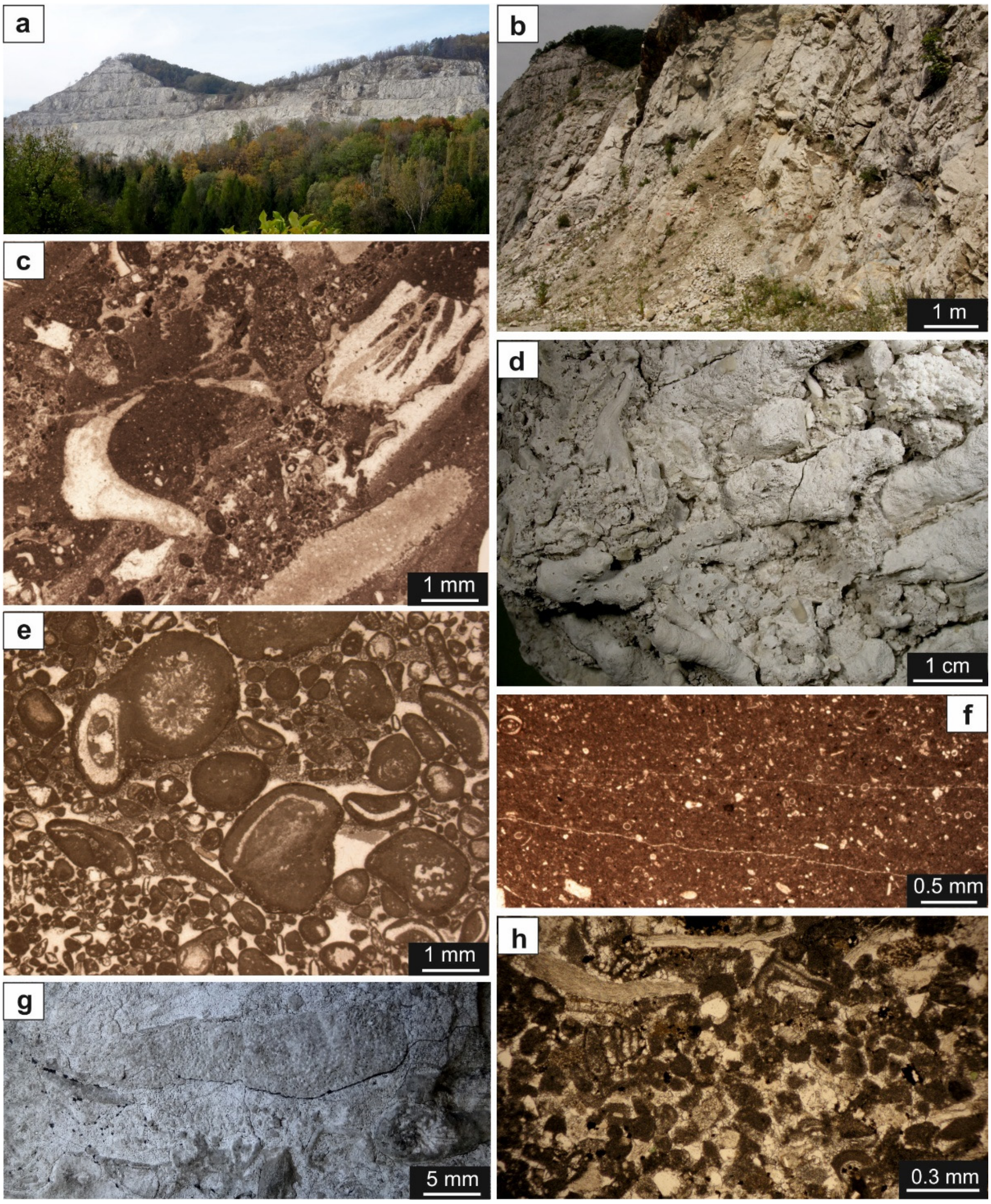

Figure 3. Štramberk-type facies association: (**a**) Štramberk—Kotouč Quarry; (**b**) shallow-water limestones in the Kotouč Quarry; (**c**) bioclastic-peloidal packstone with reefal components, such as fragments of corals and sclerosponges (exotic limestone from Krzyworzeka near Wieliczka); (**d**) reefal limestone with corals in the Kotouč Quarry; (**e**) coated packstone to poorly washed grainstone (exotic limestone from Zarzyce Wielkie near Wadowice); (**f**) wackestone with calpionellids (exotic limestone from Żywiec); (**g**) limestone with corals and calcified sponges (Štramberk—the Castle Hill Quarry); (**h**) allodapic limestone with components from the shallow-water Štramberk-type platforms (Cieszyn Limestone Formation, Goleszów near Cieszyn).

Fossils and age: Environments of the Štramberk-type carbonate platforms were rich in both macro- and microorganisms, such as corals, siliceous sponges, calcified sponges (sclerosponges), bryozoans, crinoids, algae (including dasycladalean green algae), bivalves, brachiopods, crustaceans, gastropods, ammonites, foraminifera, polychetes (including *Terebella lapilloides* Münster), calcimicrobes, and microencrusters. Calcareous and agglutinated foraminifera, calpionellids, and calcareous dinoflagellates are the most stratigraphically significant. Generally, calpionellids and calcareous dinocysts are typical of the deep-water, basinal deposits. However, they are also observed—though not so numerous—in the shallow-water Štramberk-type facies, and they allow the confirmation of the Tithonian–Berriasian age of these platforms (e.g., [45,49–52]. The lower Tithonian is documented by assemblages of calcareous dinocysts, including such species as *Committosphaera pulla* (Borza), *Carpistomiosphaera tithonica* Nowak, *Carpistomiosphaera borzai* (Nagy), and *Parastomiosphaera malmica* (Borza) [44,53]. Early/late and late Tithonian, as well as Berriasian-age, is well documented by calpionellids representing Chitinoidella, Crassicollaria, and Calpionella zones, and, occasionally, the Calpionellopsis Zone [50–52]. However, some foraminiferal data suggests that local continuation of this sedimentation until the Valanginian cannot be excepted [54]. According to Houša (in [55]), sedimentation of the Štramberk Limestone could have started in the latest Jurassic and ended in the early Berriasian (Remaniella ferasini Subzone of Calpionella Zone). Ammonites from the limestone bodies are indicative of the entire Tithonian and the earliest Berriasian [56]. Development of the Štramberk-type platforms was closed by their destruction and drowning, documented by neptunian dykes with deep-water deposits observed in some exotics [47,57]. Data from the Czech Republic indicate that sedimentation on the carbonate platform continued on the Baška-Inwałd Ridge during the Early Cretaceous contributing to the origin of the Berriasian Čupek Formation and Valanginian Gloriet and Kopřivnice limestone formations [9,28,55,58]. In the Kruhel Wielki in Poland Valanginian–Hauterivian, marly limestones with pelagic microfossils also were observed [50].

Occurrence: The discussed limestones occur in the Outer Wester Carpathians as both the exotic clasts among the younger deposits and large fragments of carbonate platforms (klippens). Štramberk Limestone has aroused interest since the 19th century, when the deposits were studied, among others, by Hohenegger (e.g., [31,59]), and they were sedimentary and palaeontologically analysed by numerous authors (for a list of references, see [47]). Fragments of these platform deposits occur from the vicinity of Štramberk, the famous locality in Czech Republic, which gave a name for this kind of rock, and the extent of the reefs is estimated at 400 km [60]. The Štramberk-type limestones are known from numerous locations displaying olistoliths and other exotic limestones. Huge blocks, smaller blocks of Štramberk Limestone, as well as breccias and conglomerates with boulders of these rocks, occur in classic localities around Štramberk. In Poland, the best-known localities with Štramberk-type limestones are in the Western Carpathians in the vicinity of Andrychów near Wadowice (Subsilesian Nappe) (e.g., [31,44,61,62]). Numerous olistoliths and clasts of diverse size are found, especially in the areas of Wadowice and Wieliczka, where they occur among the Lower Cretaceous turbiditic deposits of the Silesian and Subsilesian nappes (e.g., [18,47,63]). The Lower Cretaceous Hradiště Sandstone of the Subsilesian Nappe and northern part of the Silesian Nappe is very rich in shallow-water carbonate material, occasionally even olistoliths. Clasts of up to 2 m are present as part of Chlebovice conglomerates of Cenomanian age in the Rychaltice and Hukvaldy area [64].

Such large fragments as a klippen have not been noted in the Upper Cretaceous and Palaeogene deposits of the Silesian, and, occasionally, Subsilesian nappes, where pebbles and smaller clasts prevail. Exotics occur in the Silesian Nappe, especially in the Lower Cretaceous deposits in Żegocina, Żywiec, and Starý Jičín (e.g., [42,47,63]). They are found in the Upper Cretaceous deposits in the area of Wadowice, Palkovické Hůrky Hill, as well as south of Wieliczka and Bochnia (e.g., [18,42,63]). Exotics are less common in the Paleocene deposits, but were described in the Beskid Mały Mountains and south of Bochnia (e.g., [43,47,53]). They also occur in the Eocene deposits of the Rożnów Lake area and Oligocene deposits of Skrzydlna and Vigantice near Rožnov pod Radhoštěm (e.g., [42,47,53,65]). The Ostravice Sandstone Member of the Godula Formation (Upper Cretaceous) is an interesting example of sandstones and conglomerates rich in calcareous clasts, mostly of the Štramberk-type limestones [66]. The Tithonian–lowermost Cretaceous deposits, such as calpionellid limestones, are known also from the Bachowice succession, but reefal facies are not observed there.

The deposits of such platforms are also known from the Skole Nappe, where the most famous klippen in Kruhel Wielki near Przemyśl were studied since the 19th century (e.g., [50,67,68]). Generally, clasts of the Štrambek-type limestones in the Skole Nappe occur in the Upper Cretaceous and Paleocene deposits (e.g., [47,68–72]). Exotics of the Štramberk-type limestones are very rare in the Magura Nappe, and they are found only occasionally in the northern part of this unit [63]. They are also almost absent in the Dukla Nappe and other nappes of the Foremagura group, but they were observed in the Eocene deposits of the Foremagura Nappe in the Żywiec area [63,73].

Comparison: The terms Štramberk Limestone [31] or Štramberk-type limestones are widely used for the uppermost Jurassic–lowermost Cretaceous shallow-water limestones occurring as exotics and in situ in the Carpathian area, from Austria to Romania ([49] and references therein). Some of them have their own lithostratigraphic names; e.g., Ernstbrunn Limestone ("Calcaire d'Ernstbrunn") [74,75]. The Ernstbrunn Limestone occurs in the Outer Klippen of the Waschberg Unit in the Western Carpathians (northeastern Austria and Czech Republic—southernmost Moravia). The lower part of the Ernstbrunn Limestone is dominated by brecciated organodetritic limestones with a matrix of calcareous shales and occasional large clasts of limestones up to several meters in diameter. These facies may represent a detrital apron of a carbonate platform dominated by gravitational transport, including slides, debris flows, and turbidites. Thick-bedded, partly dolomitized calcarenites (locally oolitic) and micritic limestones, which apparently originated in the shallow-water environment of the carbonate platform, make up the upper part of the Ernstbrunn Limestone. Occasional hardgrounds and karstifications testify to sporadic emergences of parts of the platform. The rich fauna of these limestones includes fragments of corals, stromatolites, calcareous algae, ammonites, belemnites, brachiopods, pelecypods, crinoids, sponges, bryozoans, crustaceans, and fishes. The Ernstbrunn Limestone is Tithonian to Berriasian in age [76–78] and, according to [60], up to Hauterivian (?) in age. The Hauterivian age is documented by assemblages of calcareous dinocysts, including such species as *Cadosina semiradiata olzae* Nowak and *Colomisphaera heliosphaera* (Vogler). Based on ammonites, [79] proposed the mid- to early-late-Tithonian age (Richterella richteri Zone to Micracanthoceras microcanthum Zone, Simplisphinctes Subzone) for the Ernstbrunn Limestone.

The Ernstbrunn Limestone is tectonically incorporated into the thrust sheets of the younger, Upper Cretaceous to lower Miocene sequences in the Washberg sector of northeastern Austria and southernmost Moravia, as tectonic klippen (e.g., [76,80]). These so-called "Outer Klippen" of the Pálava Hills in Moravia and of the Ernstbrunn area in Austria were detached from the underlying European foreland and tectonically integrated into the frontal zones of the Carpathian thrust belt during the last stages of the thrusting. An alternative point of view considers some Ernstbrunn klippen as olistoliths in the Neogene mélange [9,22,24]. At the surface, the Ernstbrunn Limestone occurs within a SW–NE-trending chain of hills that starts at Waschberg north of Stockerau (Lower Austria) and ends at Děvín west of Pavlov in southern Moravia (Czech Republic), thus extending between the Danube and Thaya rivers over ~60 km, and probably even a few kilometers further to the north [81]. The known thickness of the Ernstbrunn Limestone is about 120 m (400 ft).

Gradual destruction of the latest Jurassic–earliest Cretaceous shallow-water platforms provided carbonate material for calcareous turbidites (e.g., [35,82]). The Cieszyn Limestone Formation (Tithonian–Valanginian), the stratigraphic unit of the Silesian Nappe, consists of, among others, detrital allodapic limestones [31,35,60] (Figure 3h). The deposits of the Cieszyn Limestone Formation also contain abundant fossils similar to those known from the Štramberk-type limestones, like green algae and foraminifera, as well as small fragments of corals, sponges, crinoids, bivalves, brachiopods, crustaceans, gastropods, and microencrusters ([35,36,83,84] and references therein).

4.2. Urgonian Facies Association (Early Cretaceous)

Facies and interpretation: Organodetritic limestones (Figure 4) are the most typical rocks of Urgonian shallow-water facies. They most probably represented high-energy environments of the fore-reefs of outer slopes of platforms, and could be an effect of poorly sorted carbonate fragments and their redistribution to a deeper part of the basin. Mass occurrence of fossil remains helps with reconstruction of primary architecture of carbonate platforms that have later been completely destroyed, and are known today by exotics only [85–89]. Rare occurrence of miliolid-rich microfacies may indicate lagoon-type palaeoenvironments, and sporadically distribution of hydrozoans suggests disintegration of core-reef of the Urgonian platform. On the other hand, the presence of fragmented colonial corals suggest occurrence of coral patch reefs at least located on the inner side of the platform. Oolitic grainstone microfacies are very rare, but document extremal shallow-water high-energy regimes of the platform margins. Some coated grains are rare elements of microfacies, but could be connected with the same areas. In some cases, arenitic clastic admixture with chromian and ferroan spinels were observed [86,90–92].

Fossils: Urgonian-type platforms are abundant in invertebrate fossils and algae. The most typical remains of fossils are benthic foraminifera (mainly orbitolinids, miliolids, textularids), bivalves (including fragments of rudists), crinoids and echinoids, brachiopods, ostracods, gastropods, bryozoans, corals, rare annelids and hydrozoans, and dasycladalean algae as well. Biostratigraphical value of orbitolinids are the basis for dating of Urgonian-type exotics and are Barremian–Aptian in age. The assemblage is dominated by *Palorbitolina lenticularis* (Blumenbach), additionally *Mesorbitolina subconcava* (Leymerie), *Praeorbitolina cormyi* Schroeder, *Simpliorbitolina manasi* Ciry and Rat or *Orbitolinopsis reticulata* Moullade & Peybernès are present [86,89,93]. A significant part of association was made up of other benthic foraminifera than orbitolinids (e.g., *Sabaudia minuta* (Hofker), *Patellina carpatica* (Mišík)), calcareous algae (*Carpatoporella fontis* (Patrulius), *Salpingoporella muehlberghii* (Lorenz) [86,91]), microproblematics (*Bacinella irregularis* Radoičić), and calcimicrobes (“Porostromata”) [86,89].

Occurrence: The discussed limestones occur in the Outer Wester Carpathians as clasts among the younger deposits. This facies association is mainly distributed in the Inner Carpathians (Tatra Mountains, Fatra Mountains, etc. [94,95]), and a few occurrences are connected with the Outer Flysch Carpathians, represented here by exotic pebbles only [85–89,93,94]. In between these two units, the Pieniny Klippen Belt is devoid of the in situ Urgonian-type limestones, and that facies is there known by exotics only as well. Opposite to Mišík’s primary suggestion [92] that no Urgonian facies is known from the Outer West Carpathians, the same author [86] observed microfacies, documenting its occurrence within the Magura Nappe (Strihovce conglomerates) of Eastern Slovakia. This observation was also supported by exotic materials from the Polish part of this nappe (Magura Formation of the Krynica Zone [85,87–89]). In several outcrops of this unit, Urgonian-type exotics with variable dimensions (from a few up to over 50 cm) occur, usually within gravelstone debris-flows. Such areas include the following zones: SW of Nowy Sącz (Przysietnica, Kadcza, Tylmanowa [85,87], SE of Nowy Sącz (Piwniczna, Muszyna, Leluchów, Tylicz [87,89], and in the vicinity of Jaworki village near Szczawnica Spa [88,93,96]). In the first two regions, exotic-bearing gravelstones belong to the upper Eocene–Oligocene flysch deposits of the Krynica subunit of the southernmost part of the Magura Nappe, which is in tectonic contact with the Pieniny Klippen Belt. Meanwhile, in the Jaworki village vicinity (Czarna Woda valley), the gravelstones with Urgonian-type exotics belong to the Maastrichtian–Paleocene Jarmuta Formation of the Magura Nappe [96,97], but also to the late Oligocene/early Miocene Kremna Formation of the same nappe [88,98,99]. The green algae *Arabicodium aegrapiloides* Elliot, *Clypeina pejovici*

Radoicic, *Macroporella pygmaea* (Guembel), and *Pianella melitae* (Radoicic), characteristic of the Barremian-Aptian Urgonian limestones, were also found in the single exotic(s?) from the Godula Formation in the Silesian Nappe [100], but without any additional evidence of other Urgonian-type fossils (e.g., orbitolinids).

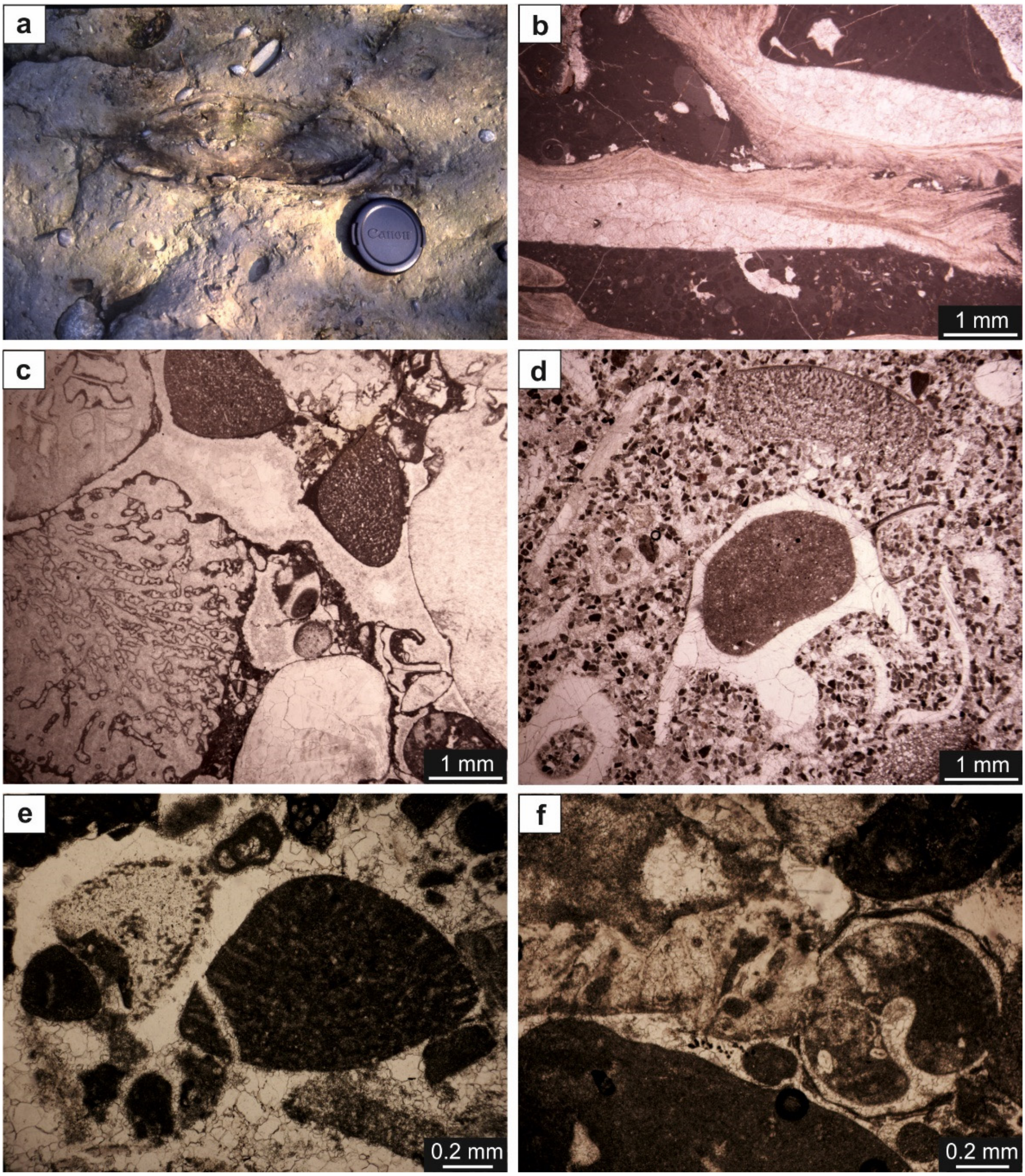

Figure 4. Outcrop of gravelstones of the Kremna Formation of the Magura Nappe (upper Oligocene/lower Miocene) (Czarna Woda stream, Jaworki village) (**a**) with Urgonian exotics (**b**–**f**): (**b**) fragments of rudists shells; (**c**) grainstone with corals and orbitolinids; (**d**) biodetritic sandy limestones with orbitolinids; (**e**) grainstone with benthic forams, including orbitolinids, and echinoderm elements; (**f**) grainstone with bioclasts, including gastropods.

4.3. *Lithothamnion–Bryozoan Facies Association (Paleocene–Oligocene)*

Facies and interpretation: Paleocene–Oligocene carbonate material in the Outer Western Carpathians occurs mainly as bioclasts in carbonate-siliciclastic rocks. Fragments of limestones are less common, and only occasionally reach larger sizes. Analysis of both dispersed material and fragments of limestones indicate that the coralline algae and bryozoans are the main biocomponents of these deposits (Figure 5). Perhaps they occurred mainly as unattached organic elements on the clastic substratum, and can be included in the "maërl" facies [101]. Rhodoids, which are found in some localities [18,65,101–104], also are a typical component of maërl. The algal and algal–bryozoan mats were less common. This facies is known as *Lithothamnion* facies or *Lithothamnion*–bryozoan facies, and less frequently as bryozoan facies. The name of this facies is derived from the genus *Lithothamnion*, the name *Lithothamnium* is also frequently used in literature. Common occurrence of read algae requiring existence of sunlight indicates the shallow-water photic zones for development the *Lithothamnion*–bryozoan facies, including the higher-energetic environment, which is suitable for growing of coated grains and destruction and distribution of organic structures.

Larger foraminifera also constitute a significant component. Locally, they form separate facies, traditionally called nummulitic facies (e.g., [102,103] and citations therein). The bivalve–bryozoan facies [65] and *Lithothamnion*–brachiopod facies [39] occur as subordinate types of sedimentation. The *Lithothamnion*–bryozoan facies is locally represent by organogenic limestones containing crushed skeletal elements. Occasionally, the amount of corals fragments can be significant in such deposits. This is an effect of destruction of the *Lithothamnion*–bryozoan–coral buildups and redeposition on other parts of shelves. Micrite, often marly limestones—mudstones and wackestones with planktonic foraminifera—originated in environments with a limited supply of clastic material. Locally, ooids were also formed [18,65,101–104].

Fossils: Red algae—*Sporolithon*, *Lithothamnion*, and *Mesophyllum*—and bryozoans—Cyclostomata and Cheilostomata—are the main components of the facies association. Additionally, Corallinaceae are represented by *Arhaeolithothamnion*, *Paleothamnium*, *Ethelia*, *Lithoporella*, *Spongites*, *Neogoniolithon*, *Distichoplax*, and *Karpathia* (e.g., [38,45,105,106]). They occur mainly as bioclasts in organodetritic limestones, but also as components of organic buildups. The red algae *Paleothamnium iori* Maslov, *Lithothamnion abrardi* Lemoine, *Lithothamnion andrusovi* Lemoine, *Lithothamnion caucasicum* Maslov, *Lithothamnion contraversum* Lemoine, *Lithophyllum carpathicum* Lemoine, *Lithophyllum densum* Lemoine, *Lithophyllum mengaudi* Lemoine, *Lithophyllum mengaudi* subsp. *carpathica* Lemoine, *Lithophyllum quadrangulum* Maslov, Lithoporella *carpathica* Maslov, *Amphiroa propria* Lemoine, *Distichoplax bisserialis* (Dietrich), *Ethelia alba* (Pfender), and *Jania nummulitica* Lemoine were distinguished in the *Lithothamnion* sandstones in the Magura Nappe.

Foraminifera, including the large forms (such as *Nummulites*, *Discocyclina*, *Orbitoclypeus*, *Haddonia*, *Alveolina*, *Assilina*, *Asterocyclina*, *Operculina*) (e.g., [45,103,107,108]) are very typical of the Outer Carpathian Palaeogene platforms. The dasycladalean green algae (e.g., *Terquemella*) and calcareous red algae *Polystrata* and *Peyssonnelia* are also noticed [45]. The *Lithothamnion*-bryozoa facies association is also constructed by such fossils as corals, mollusks, gastropods, serpulids, and brachiopods. Large corals are known mainly from Danian sandstones of the Stráž type of the Frýdlant Formation (Subsilesian unit) [42,109,110]. The detailed stratigraphy of the Palaeogene platform facies is based mainly on large, as well as planktonic, foraminifera [45,101,103,107,108,111].

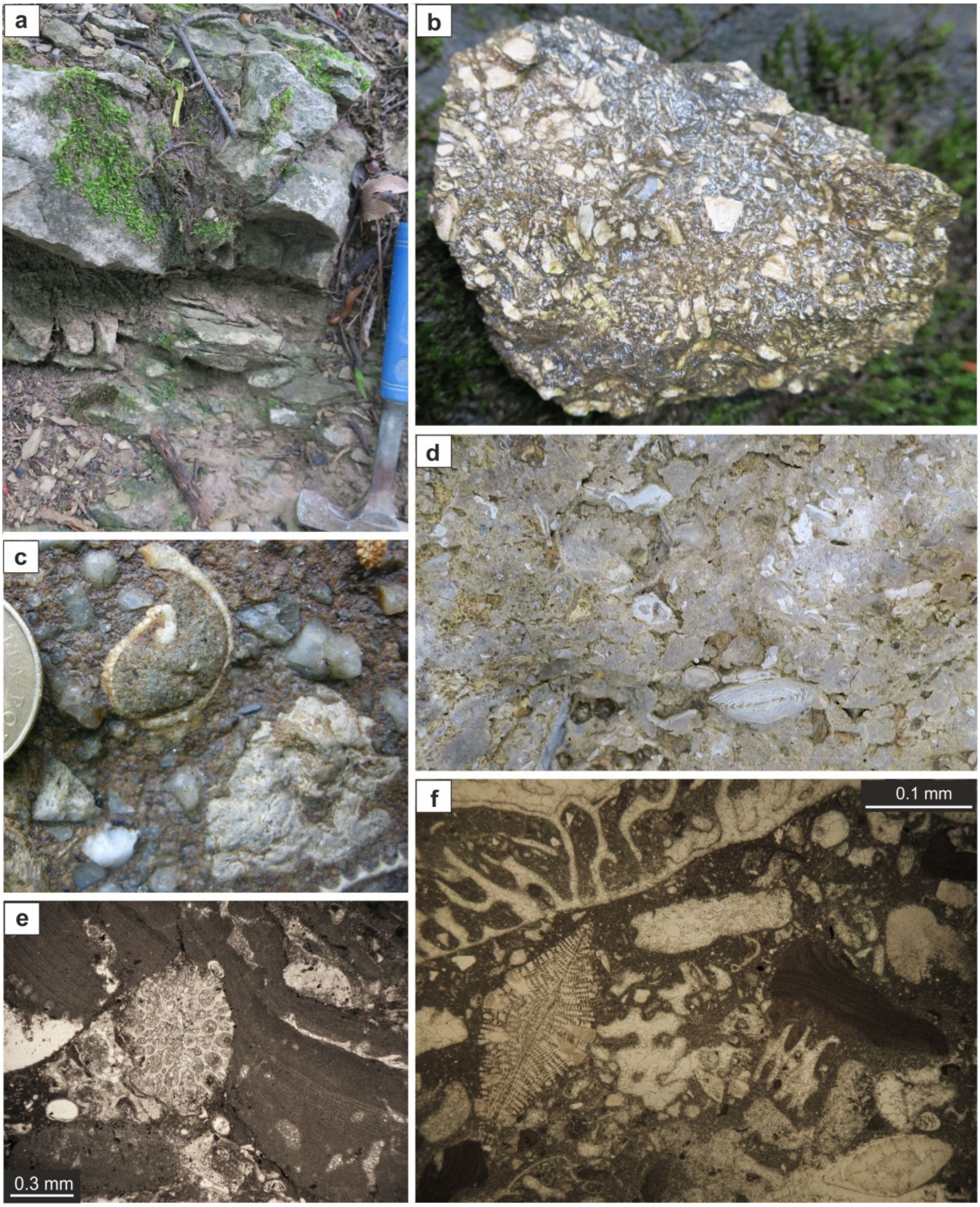

Figure 5. Paleocene–Oligocene carbonate facies: (**a**) the limestone outcrop of the Andrychów Klippen (Pańska Mt. in Andrychów); (**b**) debris flow with bioclasts in Krosno Formation (Bukowiec, Bieszczady Mts.); (**c**) bioclasts in the Ciężkowice Formation sandstone (Melsztyn near Zakliczyn); (**d**) limestone block from Eocene olistostrome (Osielczyk stream in Osielec); (**e**) coralline algae–bryozoan boundstone (Targanice Klippe near Andrychów); (**f**) packstone with fragments of corals, coralline algae, and large benthic foraminifera (block in Osielec near Rabka Zdrój).

Occurrence: The discussed material occurs in the Outer Wester Carpathians, mainly as bioclasts in clastic rocks, while fragments of limestones are relatively rare. Shallow-water material, such as coralline algae, bryozoans, large foraminifera, and others, are a common component of almost all Palaeogene lithostratigraphic units predominated by sandstone and sandstone-conglomerate thick turbidites, and occur as clasts in olistostromes. The largest shallow-water *Lithothamnion*–bryozoan limestone blocks occur in the so-called Andrychów Klippen (e.g., [18,112]). They contain Lower Paleocene–Middle Eocene platform deposits [45]. The relatively large blocks of the *Lithothamnion*–nummulitic limestone with corals occur in the Osielec olistostrome [113]. Slightly smaller blocks are in the Eocene olistostromes of the Silesian Nappe [22,101,114] and Skole Nappe [33,37,38]. Elements of platform carbonate deposition are numerous and broadly distributed in the form of organic detritus (bioclasts) occurring as clastic components of turbidities. They are dispersed among the sandy and conglomeratic clastic material in all the Outer Carpathian lithostratigraphic units deposited from the Paleocene to Oligocene. In some units, such material constitutes even the main clastic component. The large concentrations of the bioclasts were basis for distinguishing "allodapic" limestones (calcareous turbidites) or so-called clastic limestones, such as the Bircza Limestone [37,38], Łużna Limestone [39,65,107,115], Koniaków Limestone [116], and Skalnik Limestone [40,117,118]. So-called *Lithothamnion* sandstones/beds such as Goryczkowiec, Czerwin, Klokočov, and Stráž sandstones [18,42,106,110,119–121] belong to this group. Numerous rhodoids are known from the thick-bedded deposits of the Silesian Nappe [22,101,104,105,122]. Ooids are found occasionally, and are noticed in Eocene and Oligocene strata of the Silesian Nappe [18,65,103]. The innermost Outer Carpathian unit—the Magura Nappe—contains numerous *Lithothamnion* sandstones, as well as conglomerates with pebbles several centimeters in size coming from the Czorsztyn and Foremagura ridges. They were deposited within the uppermost Cretaceous–Oligocene deposits. Similar deposits are known from the Dukla Nappe and other nappes belonging to the Foremagura group.

5. Discussion: Palaeogeography of Carbonate Platforms

The long interval of history of the Outer Carpathian basins was connected with the platform development. During this time, the shallow-water carbonate sedimentation was a component of the Carpathian sedimentary system (Figure 6). It changed in time, and evolved in term of extent, environments, components, and character. Three general facies associations (Table 1)—Štramberk, Urgonian, and *Lithothamnion*–bryozoan (including Kambühel-type)—are distinguished. Each of the distinguished facies associations has its own individual character and defines a specific time interval: latest Jurassic–earliest Cretaceous, Early Cretaceous (Barremian–Aptian), and Paleocene–Oligocene. Platform evolution was controlled by global trends and regional, mainly Carpathian palaeogeography, and by the shallow-water sedimentary regime.

Table 1. Comparison of the existing types of facies associations.

Facies Associations	Age	Typical Components	Distribution in the Western Outer Carpathians
Štramberk-type	Tithonian–earliest Cretaceous	Corals, sponges, benthic foraminifera, microencrusters, microbes, dasycladaceans, green algae	Northern rim of the Carpathian basins, including the Baška-Inwałd Ridge, Silesian Ridge
Urgonian	Barremian–Aptian	Larger benthic foraminifera, bivalves (including rudists), crinoids, echinoids, corals	Southern rim of the Outer Carpathian basins (South-Magura Ridge), Silesian Ridge (?)
Lithothamnion–bryozoan	Paleocene–Oligocene	Coralline red algae, bryozoans, larger benthic foraminifera	Silesian Ridge Foremagura Ridge Northern rim of the Carpathian basins

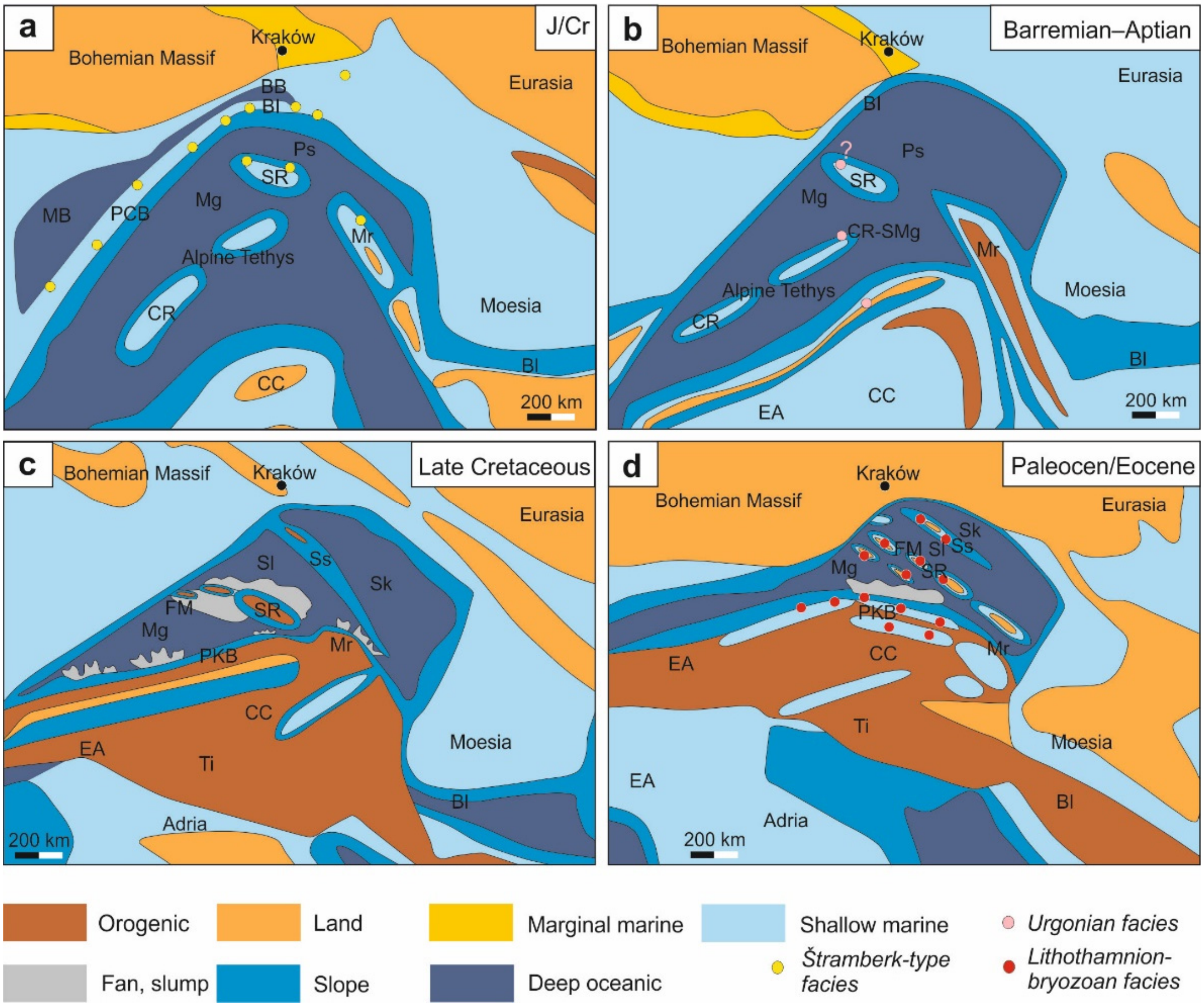

Figure 6. Palaeogeography of the Outer Carpathian Tethys and adjacent areas with the approximate position of the carbonate platforms: (**a**) Latest Jurassic–Early Cretaceous; (**b**) Barremian–Aptian; (**c**) Late Cretaceous, (**d**) Eocene. Abbreviations: BB = Bachowice Basin, BI = Baška-Inwałd Ridge, Bl = Balcans, CC = Central Carpathians, CR = Czorsztyn Ridge, CR-SMg = South Magura Ridge (the most presumable northeastern prolongation of the Czorsztyn Ridge), EA = Eastern Alps, FM = Foremagura Ridge and Basin, MB = Mikulov Basin, Mg = Magura Basin, Mr = Marmarosh Ridge, PCB = Pavlov Carbonate Platform, PKB = Pieniny Klippen Belt, PS = Protosilesian Basin, SK = Skole Basin, Sl = Silesian Basin, SR = Silesian Ridge, Ti = Tisza, ?—presumable (poorly documented) occurrence.

5.1. Latest Jurassic–Early Cretaceous

The most stable and widespread platforms occurred at the first extensional stage of the Outer Carpathian basins. The oldest Štramberk-type facies association of latest Jurassic–earliest Cretaceous age are connected with first stages of the Outer Carpathian development (Figure 6a). Narrow, but facies-diversified shallow-water carbonate platforms developed in the extensive area of the north Tethyan margin and occurred on the margins of the young Protosilesian Basin. Both the climatic conditions and sedimentary regime, with a strongly limited supply of clastic material, favoured the development of limestone formations and reef-forming organisms. The development of the Carpathian Štramberk-type facies followed global trends. The Late Jurassic was generally a time of the widest reef extensions during all the Palaeozoic and Mesozoic, and they were built mainly by corals, sponges, and microbes (e.g., [123]). In the latest Jurassic, carbonate platforms on the northern Tethyan margin formed a belt spreading from Tibet to Florida [124,125], as a result of optimal climatic conditions and a high sea level decreasing the siliciclastic delivery [126]. Algae, foraminifera, echinoids, ooids, and reefal components were the main allochemic material of the platforms. Extension of these carbonate platforms in the Tethyan area was significantly restricted after the tectonic events from the Jurassic–Cretaceous boundary [124].

The Baška-Inwałd Ridge was probably the area with the most intense development of this carbonate sedimentation (Figure 6a). The largest fragments of such deposits—klippen in Štramberk (Czech Republic) and the vicinity of Andrychów (Poland) (Figure 1)—are interpreted as remnants of the sedimentary cover of this ridge (e.g., [44,60,127]). According to the palaeotransport direction analyses, during the early stage of the Outer Carpathian basins development, the material was transported to the Protosilesian Basin mainly from the northern source area [35,36]. The extremely intense erosion of the ridge was a result of the tectonic uplift. The north source area was active mainly in the early stage of the Carpathian basins development, before the end of the Early Cretaceous. In the Late Cretaceous, possibly only occasionally small fragments ("islands") of this ridge emerged, and locally the Upper Cretaceous coarse-grained deposits are observed in the Subsilesian Nappe [128–130].

Since the late Tithonian, the Silesian Ridge also supplied the Protosilesian Basin with the material of shallow-water carbonate platforms [35,36]. The sedimentological studies of the Cieszyn Limestone Formation also indicate that material was derived from the platforms developed both on the northern margin of the Protosilesisn Basin and from the Silesian Ridge ([35,82,84,127,131] and references therein) (Figure 6a).

Fragments of the latest Jurassic–earliest Cretaceous carbonate platforms of the Silesian Ridge occur as clasts in the flysch deposits of the Silesian Nappe. These exotic clasts represent facies and are age-analogous to the Štramberk-type limestones from the Baška-Inwałd Ridge [47,53]. First, the westernmost part of the ridge emerged and the alluvial fan was accumulated by gravity flows in that area of the basin [35]. The activity of the Silesian Ridge as a source area was diachronic, and the uplift of the ridge shifted from west to east [36,131].

In the Skole Nappe, material was transported mainly from the north (e.g., [132]), which suggests development of these facies also on the northern margin of the eastern part of the Carpathian basins. It was the southern margin of the North European Platform, described also the North or Marginal "Cordillera" [127,132]. According to [43], fossil assemblages of the Kruhel Wielki klippen refer to the Jurassic deposits of the Bilcze-Wolica zone from the foredeep of the Ukrainian Carpathians.

The Ernstbrunn Limestone and the underlying Klentnice Formation of the Outer Klippen have been traditionally interpreted as a tectonically detached part of a carbonate succession, which evolved on the rifted passive margins in the Oxfordian and Tithonian. An alternative interpretation by [60] assumed that the Ernstbrunn Limestone represent a pile of carbonate debris derived from a preexisting hypothetical Tithonian Pavlov platform and redeposited into the Ždánice Basin in time of a eustatic drop of the sea level. Equivalents of Ernstbrunn Limestone are preserved in an autochthonous position underneath the Carpathian thrust belt. The Tithonian to Berriasian Ernstbrunn Limestone in the Pavlov Hills and the Waschberg zone are transgressively overlain by the Turonian–Coniacian Klement Formation composed of shales, glauconitic sandstones, and sandy limestones. The position of the Ernstbrunn and the Klement formations documents the existence of a stratigraphic gap, which most likely lasted from the Valanginian to Cenomanian, and is marked by distinct hardgrounds [80]. In that sense, the marginal depositional zone of the Outer Klippen differed from the Štramberk-type limestones of the Protosilesian basin.

5.2. Late Early Cretaceous

The Cretaceous was generally a period of a significant decrease in reef development compared with the Late Jurassic, combined with the unprecedented share of bivalves in their construction (e.g., [123]). On the other hand, it was also a period of a global strong extent of carbonate platforms in general, especially during the Late Cretaceous [133]. Bivalves (rudists) and foraminifera were the most important biocomponents of these platforms [6]. The Urgonian (named after the village Orgon, east of Tarascon, France) is a characteristic shallow-water carbonate facies that accumulated generally along the Tethys northern shelf. The origin of these facies is connected with the Barremian rearrangement of the world ocean [134]. During Barremian and early Aptian time, platforms were again wider expanded in the Tethys, and especially in the early Aptian, transgression over the continental shelves resulted in the reduction of clastic input and development of shallow-water carbonate sedimentation [124]. The Barremian regression uncovered large parts of the shelves. Abundant shallow-water communities flourished there until the mid-Aptian transgression caused their emersion and destruction [93,135].

The Urgonian facies association flourished as different types of carbonate platform palaeoenvironments. Development of these "Urgonian" platforms is observed also in the Carpathian area (Figure 6b); however, an intense siliciclastic deposition strongly dominated the Outer Carpathian basins. This could be related to the reorganization of these basins, which started at the end of Early Cretaceous. In this time, the Carpathian basins changed their character—from postrift basins into synorogenic basins [8,9,11]. Influence of accretionary prism caused an increase of geodynamic activity within the basins. It was connected with the morphological changes of the whole basinal structure—including intrabasinal elements—and with an increase of seismic activity, which resulted in a change in sedimentation type into fully clastic.

The shallow-water carbonate environments occurred mainly in the Inner Carpathians. Their biostratigraphic position within the Early Cretaceous sequences, characteristic fossils, and sedimentary palaeoenvironments are well known [93–95,136–138]. In the Inner Carpathians, the Urgonian facies is represented in the Hightatric units of the Tatra Mountains [136,137] and the Manín Unit of the Váh valley [92,139]. In the Pieniny Klippen Belt, the Urgonian-like facies occurs in the Haligovce Succession [140] (Haligovce Limestone Formation [97]) and as exotic pebbles in the Upper Cretaceous Sromowce Formation, the Upper Cretaceous–Paleocene Jarmuta Formation, and the upper Oligocene/lower Miocene Kremna Formation of the Magura Succession [88,93,97,141–145]. However, the origin and source area of the Urgonian-type exotics within the Outer Carpathians is still matter of hot discussion ([86–88,95] with references therein). Palaeogeographically, their locations indicate without any doubts that they are the northernmost limit of Urgonian facies development within the Western Tethys. According to palaeodirection of submarine currents during dispersion of Urgonian-type exotic-bearing gravelstones, and surroundings turbiditic-type deposits that hosted these gravelstones, we can conclude that the source area of these exotics has been located on the S/SE part of the Outer Carpathian basins (southern part of the Magura Basin), but on the northern front of the Pieniny Klippen Basin. By this reason, [86] created the so-called South-Magura Ridge (the NE end of the Czorsztyn Ridge?—see Figure 6b), which supplied exotic pebbles to the conglomerates/gravelstones of the Krynica Subunit of the Magura Nappe during Eocene–Miocene (?) times (see also discussion—[87,89,146]). The southern part of the Magura Basin—near the northern slope of the Czorsztyn Ridge of the Pieniny Klippen Basin—is a palaeogeographically occupied narrow zone around of the South-Magura Ridge (after nomenclature in [86,90–92]). Most probably, it was a northeasternmost edge of the Czorsztyn Ridge. Recently, contrary to this idea, [88] proposed a location of the source area for gravelstones in Jaworki (Czarna Woda) on the East—from the direction of the Marmarosh Massif.

Additionally, in some cases, arenitic clastic admixture with chromian and ferroan spinels as ophiolitic detritus may indicate erosion of obducted oceanic crust with serpentinitic remains [86,87,90–92,94], most probably of the Meliata Ocean in origin, and later resedimented to Urgonian-type carbonates, which in turn were transported to younger clastic deposits as exotic pebbles (comp. [146]).

In the more northern part of the Carpathian basins, in the Silesian Domain, there is only single, enigmatic evidence for the Urgonian facies. On the other hand, according to, among others, Książkiewicz [127,132] (see also [89,147]), the northern margin—the Silesian Ridge—was traditionally considered as the other source of the exotics in the Magura Basin (Figure 6b). The Marmarosh Massif constituted perhaps the eastern extension of the Silesian Ridge [8,11] (Figure 5b), so there is another suggestion of the presumable existence of the Urgonian Platform on the Silesian Ridge.

5.3. Late Cretaceous

Since the earliest Late Cretaceous, shallow carbonate sedimentation on the Eurasian margin was restricted by increasing siliciclastic deposition [124]. The deposition of the thick turbidite sequences in the Outer Carpathian basins, combined with the lack of evidence of reefal and other shallow-water deposition, follows this trend (Figure 6c). "Mid-" and Late Cretaceous carbonate deposits in the Western Outer Carpathians are represented by marls, marly limestones, and—less commonly—micritic limestones (mudstones and wackestones) with foraminifera (often mainly planktonic), calcareous dinoflagellates, and radiolarians (Figure 7), which can be interpreted as relatively deep facies—mid-shelf to deep basinal deposits (e.g., [18,43,53,148–150]). Such limestones and marls occasionally occur as clasts in coarse-grained Outer Carpathian deposits, but generally the Late Cretaceous marly sedimentation was widely developed on the Subsilesian Ridge, and marly rocks—such as Frydek-type marls or Żegocina Marls—occur in regular sedimentary sequences of the Subsilesian Nappe (e.g., [149,151]). A general downfall of the carbonate-platform development caused by both climatic and oceanographic condition is observed across the Cenomanian–Turonian boundary [152], although, in some Tethyan areas, platform sedimentation continued. The final, latest Cretaceous crisis of platforms in the Tethyan area may be a result of the general regressive trend [124,153].

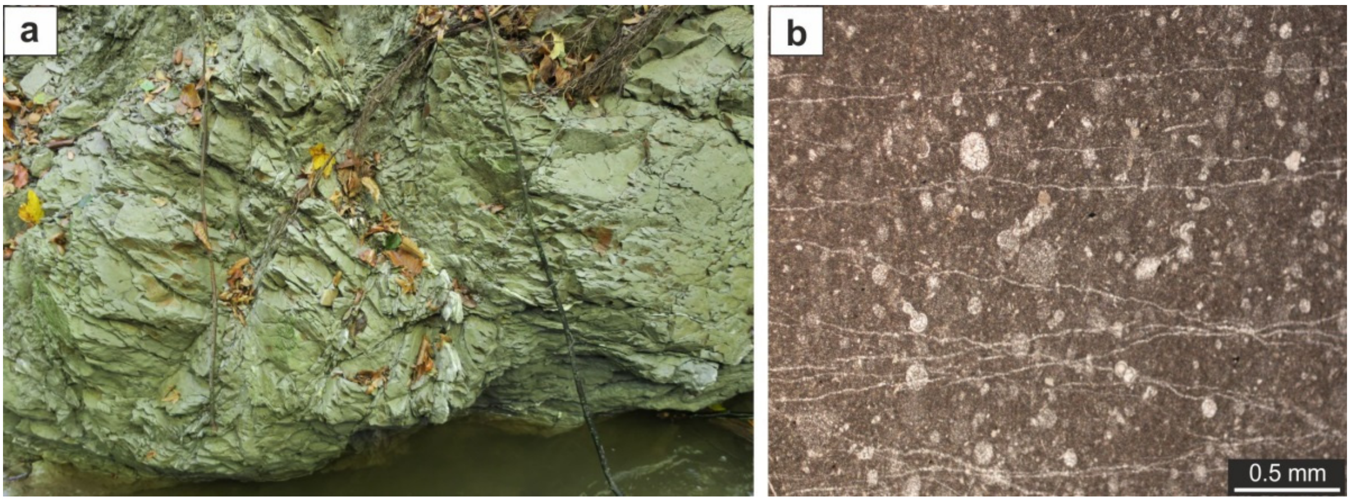

Figure 7. The Upper Cretaceous carbonate deposits in the Western Outer Carpathians: (**a**) Żegocina Marls (Nowe Rybie); (**b**) wackestone with radiolarians and planktonic foraminifera (exotic clast from Rożnów near Nowy Sącz).

Since the beginning of the Late Cretaceous, the Silesian Ridge (Figure 6c) was the main source area for the Outer Carpathian basins, especially the Silesian Basin. The material was transported off the ridge by turbidity currents, and—less often—by debris flows. The Upper Cretaceous Lower Istebna Formation contains carbonate material, mainly older than Late Cretaceous, which—according to palaeotransport direction analyses (e.g., [132,154])—was redeposited from the Silesian Ridge. In the Late Cretaceous, possibly only occasionally small fragments ("islands") of the Subsilesian Ridge emerged, and locally the Upper Cretaceous coarse-grained deposits are observed in the Subsilesian Nappe [110,128–130]. Strong domination of siliciclastic sedimentation was an important limiting factor for the development of carbonaceous facies on the shallow areas of the Silesian Ridge.

5.4. Palaeogene

The significant change in the character of the Outer Carpathian platforms took place with the beginning of the Paleocene. Palaeoenvironmental changes at the end of the Cretaceous caused extinction of the major important biocomponents of carbonate buildups: rudist bivalves and the majority of colonial scleractinian corals. Therefore, the early Paleocene reefs are rare compared with the Late Cretaceous carbonate buildups. The ecologic niches were gradually settled by bryozoans, and at the end of the Early Paleocene, by red algae [155]. Coralline red algae are very abundant in the Cenozoic calcareous rocks. Together with corals, they are the main constructors of the modern reefs. In the Palaeogene, so-called *Lithothamnion* limestones—named after the genus *Lithothamnion*—were widespread. The coralline algae and bryozoans are the main biocomponents of the organogenic shallow-water structures from Paleocene to Oligocene. The mass occurrence of the coralline algae is observed from the late Paleocene, and generally the bryozoans are common in the early Paleocene.

The *Lithothamnion*–bryozoan facies association was widely distributed in the shallow, photic zone of the Outer Carpathian Tethys (Figure 6d). On the one hand, the Outer Carpathian Basins were under favourable climatic conditions, and a new space for platform development appeared. The Silesian Ridge was in emersion in the Paleocene, and tops of the Subsilesian and Foremagura ridges were above the water level (Figure 6d). Surroundings of emerged areas had a shelf character. With a high probability, they were quite narrow and steep shelfs. On the other hand, the platform sedimentation was strongly limited and disturbed by delivery of the clastic material from emerged areas. The carbonate sedimentation was subordinate to clastic, and it developed outside the zones with an intense supply of clastic material. Algae and bryozoan colonies successfully developed on the loose sandy substrate, appearing separately or forming covers, and locally also nummulites, molluscs, and brachiopods were numerous. In fact, platforms of the Outer Carpathian Tethys were unstable since the Paleocene. More stable covers functioned ephemerally in the zones with a low sedimentation rate. The shallow top zones of accretionary prism that crossed the ridges were also occasionally colonized by algae and bryozoans during the intervals of stagnation.

The *Lithothamnion*–bryozoan facies association developed in the early Paleocene on the continental shelf—which was recorded in, among others, the Andrychów Klippen—and on the tops of western part of the Subsilesian Ridge during its maximal development (Figure 1). The Subsilesian platforms occurred only locally, and delivered organogenic material to the Goryczkowiec, Czerwin, and Stráž sandstones. The north source area is indicated by the palaeotransport directions in the Paleocene and Eocene deposits of the Silesian Nappe (e.g., [132,154,156,157]), which are relatively rich in material of the carbonate platforms.

From the Late Paleocene, platforms functioned on the European Platform shelf and southern margin of the Magura Basin, as well as on the Subsilesian, Silesian, and Foremagura ridges (Figure 6d). Sedimentation with an increasing share of *Lithothamnion* began to be common. In the late Paleocene up to the middle Eocene, on platforms at the Silesian Ridge, especially from the northern site, the varied types of carbonate sedimentation developed. Next to the classic maërl facies, the rodoid, ooid, brachiopod, bivalve, and nummulitic facies occurred locally. In the late Paleocene, carbonate platforms also developed on the Foremagura Ridge. At an early stage in the late Paleocene–middle Eocene, the organogenic material was delivered from this source to the central parts of the Magura Basin. In the Eocene, the sources located eastwards activated and supplied the Foremagura (Dukla) Basin. In the Paleocene, the *Lithothamnion*–bryozoan facies with corals (Kambühel limestones) occurred also on the folded Pieniny Klippen Belt at the southern margin of Magura Basin, and delivered organogenic material to that basin [32,158]. The accretionary prism prograding from the south successively crossed the Outer Carpathian ridges. In principle, it should not significantly interfere with the character of shallow-water carbonate sedimentation, and basically took it over, and in its shallow-water areas, deposition continued. However, the intensity of platform sedimentation then decreased. Maërl was still the main facies that could developed on the clastic basement, either with disturbances of its stability, and generally this facies do not need a lot of time for development.

5.5. Decline of Carbonate Platforms

In the Paleocene–Eocene, the ALCAPA block was formed by amalgamation of the Eastern Alps, Inner and Central Carpathians, and several smaller plates [8,159,160]. The Magura Basin was significantly narrowed due to the movement of the ALCAPA slab towards the north [161,162]. The accretionary prism gradually formed, causing the basin axis to migrate northward. The fine-rhythmic turbidites turned into a thick complex of turbidites and fluxoturbidites. The Foremagura (including Dukla), Silesian, and Skole basins remained open, with flysch sedimentation concentrated in their southern parts (Foremagura and Silesian basins) and pelagic facies further north [8].

In the Oligocene, collisions between the ALCAPA and European plate followed the convergence between Africa and Europe. The Western Outer Carpathian accretionary prism was pushed northwards, covering the remains of the Silesian Ridge. After crossing the Silesian Ridge by the prism, the shallow water organogenic carbonates from the prism and destroyed ridges were delivered to the Magura Basin in Eocene time and to the Krosno Basin in Oligocene time. In the more outer parts of the Silesian Domain, a residual basin (Krosno Basin) with sedimentation of the organic-rich shales of the Menilite Formation were formed then [8,9]. The Paratethys Sea was formed in Europe and Central Asia, ahead of the accretionary prism advancing northward [163]. The geodynamic evolution of basins in the Western Outer Carpathian has led to a sedimentary transition from flysch to molasse [8,9]. The destructions of the ridges were a result of the northward movement of accretionary prism and development of the Western Outer Carpathian nappes. This process was completed during Neogene times. Several fragments of carbonate platforms were incorporated as olistoliths in the Oligocene and Neogene mélanges [9,22,24].

6. Conclusions

1. During the evolution of the Outer Carpathian basins, in the shallow-water areas, the carbonate sedimentation was developed apart from the dominating clastic deposition. This is evidenced by the fragments of carbonate rocks preserved among the deep-water deposits.
2. Three main shallow-water facies associations—Štramberk, Urgonian, and *Lithothamnion*–bryozoan—could be divided. These facies are distinct and related to different stages of the Carpathian basins' evolution.
3. The analysis of these facies allows us to distinguish several ridges covered by carbonate platforms within the Outer Carpathian Tethys and correlate them with platforms present on the Tethyan margins.
4. The Tithonian–lowermost Cretaceous Štramberk facies association—the most widespread of the three described facies associations—reflects the most intense carbonate deposition that took place in the Silesian Domain during the early stages of its development. Facies-diversified, narrow, shallow-water platforms, rich in corals, sponges, green algae, echinoderms, foraminifera, microencrusters, and microbes, are typical of this stage.
5. The next stage of the shallow-water carbonate deposition is noticeable in the Magura Domain. The Urgonian facies association developed mainly on the south margin of the Outer Carpathian basins and is characterised by the organodetritic limestones built of such fossils as bivalves (including rudists), larger benthic foraminifera, crinoids, echinoids, and corals.
6. The Late Cretaceous is characterised by domination of siliciclastic sedimentation and limited development of carbonaceous facies on the Outer Carpathian ridges.
7. Since the Paleocene, in all of the Western Outer Carpathian sedimentary area, the *Lithothamnion*–bryozoan facies association, adapted to unstable clastic deposits, devel-

oped. Algae–bryozoan covers originating on the siliciclastic substrate are typical of this facies association. Such type of deposition preserved practically until the final stage in the evolution of the Outer Carpathian basins.

8. The ridges with carbonate platforms were destroyed during Neogene times as a result of development of the Outer Carpathian nappes.

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