Geodynamics of ridges and development of carbonate platforms within the Outer Carpathian realm in Poland

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Abstract. The Mesozoic and Cenozoic paleogeography of the Outer Carpathians reflects the series of continental break-ups, rifts and collisions (Golonka et al., 2000, 2003, Golonka, 2004). The Magura Basin originated as part of the Penninic-Pieniny Klippen created during Mesozoic time between Tethyan terranes and Eurasia. The other Outer Carpathian basins had developed in the process of rifting and fragmentation of the European platform. During the Cretaceous tectonic reorganization the new Outer Carpathian realm was formed. Within this realm in the foreland of the folded Inner Carpathians area, several basins divided by ridges and underwater swells became distinctly separated. In Paleogene the movement of Adria and Alcapa terranes resulted in gradual closing of the flysch basins and development of an accretionary prism. The ridges dividing the flysch basins in the Outer Carpathians became more distinguished providing favorable conditions for development of shallow banks with the carbonate platform sedimentation. These platforms have been destroyed during the orogenic process. The platform deposits formed numerous carbonate fragments that have been found in the Outer Carpathians flysch and olistostromes. These fragments were transported with the turbidity currents to the flysch, forming the organodetritic limestones and sandstones. Their distribution provides significant help in an attempt to find the original location of carbonate platforms and finally, to make proper palinspastic reconstruction of the Northern Outer Carpathian realm.

Keywords: Outer Carpathians, plate tectonics, paleogeography, carbonate platform, Mesozoic, Cenozoic.

Introduction

The Northern Carpathians are subdivided into an older range known as the Inner Carpathians and the younger ones, known as the Outer or Flysch Carpathians. At the boundary of these two ranges the Pieniny Klippen Belt (PKB) is situated. The Outer Carpathians are built up of a stack of nappes and thrust-sheets changing along the Carpathians built mainly of flysch. All the Outer Carpathians nappes are overthrusting onto the European platform covered by Miocene deposits of the Carpathian Foredeep. These nappes have mainly allochtonous character, and originated in basins situated outside their present location. On the other hand, traditionally (e.g. Pescatore and Ślączka, 1984) the following sedimentary basins have been distinguished within Northern Outer Carpathians from south to north: the Magura Basin, the Dukla and Fore-Magura set of basins, the Silesian Basin, the Sub-Silesian Ridge and the Skole Basin.

The complex Mesozoic and Cenozoic tectonics of the Outer Carpathians produced series of ridges separating deep water basins. These ridges were providing favorable conditions for development of shallow banks with the carbonate platform sedimentation. The orogenic processes in the Northern Outer Carpathians produced an enormous amount of the clastic material that started to fill the basins. The material was derived from the northern and southern margins as well as from the inner ridges and swells. Each basin had the specific type of clastic deposits, and sedimentation commenced in different time.

The Mesozoic and Cenozoic shallow water carbonate platforms have been destroyed during the orogenic process. The numerous carbonate fragments have been found in flysch and olistostromes within all the Outer Carpathian subbasins. These fragments were transported with the turbidity currents to the flysch, forming the organodetritic limestones and sandstones. Their distribution allows tan attempt to reconstruct the original location of carbonate platforms within the Northern Outer Carpathian realm.

The origin of Czorsztyn Ridge

The Alpine Tethys (Fig. 1) was formed during the Jurassic time. This Alpine Tethys constitutes the extension of the Central Atlantic system (Golonka, 2004) and includes Ligurian, Penninic Oceans and Pieniny/Magura Basin. Bill et al. (2001) date the onset of oceanic spreading of the Alpine Tethys by isotopic methods as Bajocian. According to Winkler & Ślączka (1994) the Pieniny data fits well with the supposed opening of the Ligurian-Penninic Ocean. The orientation of the Pieniny/Magura Ocean was SW-NE (see discussion in Golonka and Krobicki, 2001, 2004, Golonka et al., 2003). This Ocean was divided into the northwestern and southeastern basins by the mid-oceanic Czorsztyn Ridge (Cr, Fig. 2). According to Birkenmmajer (1986) the Czorsztyn Ridge could be traced from the vicinity of Vienna trough Western Slovakia, Poland, Eastern Slovakia to Transcarpathian Ukraine and perhaps northernmost Romania (Bombiţă et al., 1992). Plašienka (2003) postulated the thermal uplift above the distal, subcrustal part of detachment fault. The origin of the Czorsztyn Ridge is coeval with the spreading phase of the Pieniny/Magura Ocean. However it should be stressed that existence of the oceanic crust beneath the Magura basin could be disputable (Winkler & Ślączka, 1994). The occurrence of the mafic (basalt) intrusions in the eastern termination of the Czorsztyn Ridge in Novoselica Klippen (Lashkevitsch, 1995, Golonka et al, 2004) seems to support the thermal origin of the ridge related to the oceanic spreading.

The triple-junction zone was probably formed somewhere in the present day Eastern Carpathian. The Silesian presumably formed the one arm, the second one was represented by its extension into the Rahiv-Sinaia zone and the third one by the Pieniny Klippen Belt-Magura oceanic realm. The exact location and character of this triple-junction and associated volcanism is one of the subjects of the research undertaken by our team (Krobicki et al., 2004).

The research work on geodynamic evolution and on paleogeography of the Polish part of Carpathian during Neo-Cimmerian time (Golonka et al., 2003) showed, that Mesozoic volcanism of the area could be related to complicated development of rift and subduction environments. A setting associating features of both of them is back-arc basin. Evolution of back-arc basins includes magmatic activity showing rift characteristic (inducted by rising mantle diapir) as well as subduction characteristic. The first possibility is supported by some of the volcanic sequences displaying pattern similar to MORB (Lashkevitsch et al., 1995, Varitchev 1997). On the subduction-related magmatism could point the LILE behavior in some other sequences occurring in the Eastern Carpathians (Lashkevitsch et al., 1995, Varitchev 1997). The LILE behavior could result from melting process induced within mantle wedge above subducted slab, metasomatised by fluids released from the slab. The process could be more intensive acting jointly with hot spot.

The shallowest ridge sequences are represented by the dark Early Jurassic marly (Fleckenkalk/Fleckenmergel-type) facies followed by Bajocian-Tithonian crinoidal and nodular limestones (*Ammonitico rosso* type) and Cretaceous variegated marls (*Scaglia rosa* facies). The transitional slope sequences are known from outcrops south and north of the Czorsztyn Ridge in Poland. Several successions were distinguished within the slope deposits. The exact position of these sequences is uncertain due to the strong tectonic deformations. Ridge sequences as well as transitional slope sequences are also called "the Oravicum" by Slovak geologists (e. g. Maheľ, 1974, Plašienka, 1999). The initial movements during Toarcian-Aalenian had to precede the appearance of the Czorsztyn Ridge which did not exist as the main paleogeographic unit before Bajocian (e.g., Aubrecht et al., 1997).

The rapid change of sedimentation within Pieniny Klippen Basin from dark shales of oxygen-depleted environment (Fleckenkalk/Fleckemergel facies – Aalenian to earliest Bajocian) to overlying light crinoidal grainstones (crinoidal-type facies) corresponded to an important geodynamic event that took place during Early Bajocian – the origin of the mid-oceanic Czorsztyn Ridge (Krobicki & Wierzbowski, 2004).

This ridge emergence was connected with the postrift phase of the basin evolution (Golonka and Ślączka, 2003). The sedimentation of the younger, red, nodular Ammonitico Rosso-type limestones was an effect of Meso-Cimmerian vertical movements, which subsided Czorsztyn Ridge (Fig. 2 – Cr) and produced tectonically differentiated blocks, neptunian dykes and scarp-breccias (e.g. Birkenmajer 1986, Krobicki, 1996, Aubrecht et al. 1997, Wierzbowski et al. 1999, Aubrecht 2001, Aubrecht & Túnyi 2001, Golonka et al., 2003, Krobicki et al, 2003).

During Jurassic – Early Cretaceous time the Czorsztyn ridge was submerged and did not supply clastic material into the Pieniny and Magura basin. This observation provides an argument against the origin of ridge as the rifted away fragment of the European platform.

The origin of Silesian Ridge

The Outer Carpathian rift (proto-Silesian Basin) had developed with the beginning of the Uppermost Jurassic - Lower Cretaceous calcareous flysch sedimentation (Słomka, 1986). The Jurassic – Early Cretaceous Silesian Ridge (Książkiewicz, 1977a, b) originated as a result of the fragmentation of the European platform in this area (Olszewska & Wieczorek, 2001). The proto-Silesian basin was formed during the synrift process wit a strong strike-slip component. The complex system of rotated block was born. The emerged fragment of these blocks supplied material to the basin. The opening of the basin is related to the propagation of the Atlantic rift system (Golonka et al., 2003). The Silesian ridge separated the proto-Silesian basin from the Alpine Tethys. The Eastern Carpathian (Sinaia or „black flysch") as well as to the Southern Carpathian Severin zone (Sandulescu, 1988, Kräutner, 1996) are somehow related to this proto-Silesian basin. The direct connection is obscured however by the remnants of the Transilvanian Ocean in the area of the eastern end of Pieniny Klippen Belt Basin. These remnants are known from the Iňačovce-Krichevo unit in Eastern Slovakia and Ukraine (Soták et al., 2000). In this area existed a junction of the different basinal units – Alpine Tethys, Transilvanian Ocean and Outer Carpathian Basin. The Bucovino-Getic microplate (Golonka et al. 2003) constitutes a fragment of the East European Platform. It includes Precambrian, Early Paleozoic (Caledonian) granites and metamorphic rocks, Late Paleozoic (Variscan) metamorphic rocks as well as the late Paleozoic and Mesozoic sedimentary cover. The connection of this Bucovino-Getic microplate with the Silesian Ridge is uncertain because of existence of transform faults related to the Jurassic opening of Alpine Tethys (Fig. 1).

The Cieszyn Beds (Kimmeridgian-Hauterivian) are the oldest stratigraphic unit of the Silesian Nappe in the Outer Carpathians. It consists mainly of detrital and pelitic limestones, calcareous sandstones, marls and marly

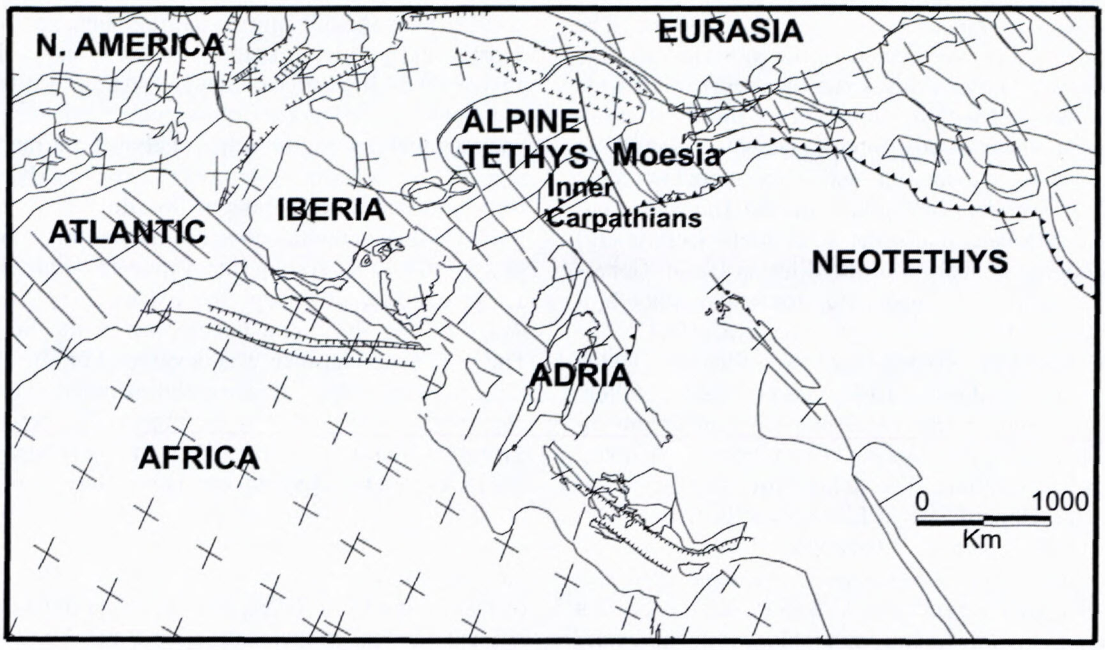

Figure 1. Position of Atlantic, Neotethys and Alpine Tethys. After Golonka, 2002, 2004.

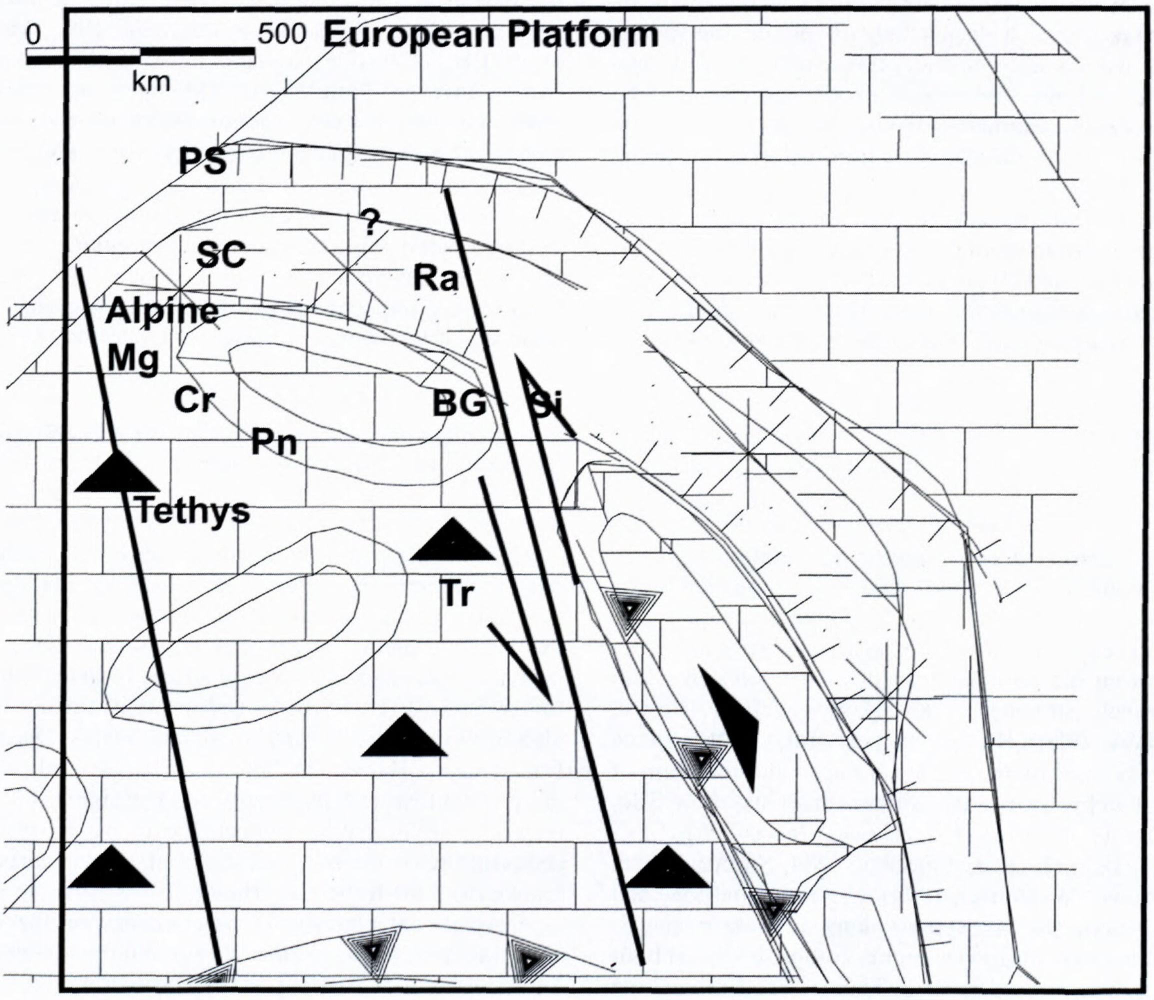

Figure 2. Paleogeography of the Outer Carpathian basins during latest Jurassic – earliest Cretaceous. BG = Bucovinian-Getic, Mg = Magura basin, Pn = Pieniny Basin, PS = proto-Silesian basin, Ra = Rakhiv, Si = Sinaia, SC= Silesian ridge (cordillera), Tr = Transilvanian Ocean.

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shales. Maximum thickness attains above 800m. The subsidence in the proto-Silesian Basin was accompanied by the extrusion of basic lavas (teschenites) which were probably connected with development of initial rifting in this basin (Narębski, 1990). Simultaneously the shallow-water carbonate sedimentation with coral reefs (so-called Štramberk limestones) took place on the Eurasian platform. The carbonate platforms with reefs (Štramberk) developed along the margin of the Silesian Basin. Generally, reef complexes formed patch-reefs and other biogenic carbonate bodies (Eliáš & Eliášová, 1984). The carbonate platform existed on the Silesian Ridge (Matyszkiewicz & Słomka, 1994) and provided excellent conditions for organic life, represented by calcareous algae, sponges, corals, bryozans, brachiopods, bivalves, ammonites and crinoids. The debris-flow sediments belonging to the Upper Cieszyn Limestone (Berriasian) include clasts of bioclastic limestones (boundstones) of microbial-sponge mud mounds and coral-algal reef with the microencruster assemblage *Lithocodium aggregatum - Bacinella irregularis.* This assemblage unequivocally proves the presence of shallowing-upward reefal sequences on the Silesian Ridge (Matyszkiewicz & Słomka 1994, 2004). According to Matyszkiewicz & Słomka (1994), two belts of carbonate buildups were present on the Silesian Ridge: a deeper belt of microbolite-sponge buildups and a shallower one, represented by coral-algal reefs. The last new findings of exotics provide foundations for a new, alternative model of carbonate buildup distribution on the Silesian Elevation (Matyszkiewicz & Słomka, 2004). The age of the exotics is difficult to establish because of the lack of index fossils. However, the presence of the microbial megafacies suggests that the clasts are not older than Late Jurassic and represent a higher, Kimmeridgian-Tithonian part of the Jurassic or earliest Cretaceous (cf. Darga & Schlagintweit 1991, Moshammer & Schlagintweit 1999, Schlagintweit & Ebli 1999, Schlagintweit & Gawlik 2003). This model accepts the presence of only one belt of the buildups, which underwent transformation from microbolite-sponge mud mounds to coral-algal reefs (Matyszkiewicz & Słomka, 2004). The development of the coral-algal reefs was probably a consequence of intense aggradational growth of microbolite-sponge mud mounds, accompanied by intense uplift movements of the Neo-Cimmerian phase.

The clastic material for Cieszyn Beds were generally derived from the northern margin of the Silesian Basin (e.g. Kruhel, Štramberk) (Książkiewicz, 1960, Peszat, 1967, Malik, 1986). However, a part of the clastic source area was situated on the islands at the southern margin of this basin and related to the northern margins of the Silesian Ridge (Cordillera) (Książkiewicz (ed.), 1962, Ślączka (ed.), 1976, Eliáš & Eliášová, 1984, Słomka, 1986, Matyszkiewicz & Słomka, 1994). Cieszyn Limestone and Upper Cieszyn Shales, exposed along the Soła river valley in the vicinity of Żywiec region comprise several bodies of debris-flow deposits. Their thickness in the particular outcrops oscillates from 2,5 up to 30 meters. The share of the clast framework does not exceed 30%. These sediments correspond to the facies A1.3 after Pickering *et al.* (1986) and facies GyM after Ghibaudo (1992). They include numerous fragments and pebbles of detrital and pelitic limestones of the Cieszyn Beds, organodetrital limestones, marly shales, Carboniferous sedimentary and metamorphic rocks: granitic gneisses, gneisses and crystalline schist. Pebbles are randomly arranged in a mass of structureless, hard marly silt. Both clays and embedded lumps of limestone have bends and folds closing generally towards the north, which would suggest that the sliding mass moved from the south. These deposits document the existence of the Silesian Ridge during the initial developing of the Silesian rift. The carbonate platform was developed on the submarine ridge. Covering the Paleozoic sedimentary and metamorphic rocks. The rift was a subject of latest Jurassic-earliest Cretaceous uplift. Part of the Cieszyn Beds, which originally covered the basin floor was also uplifted. These beds were again eroded and redeposited by debris flows. The existence of coarse-grained facies of the Upper Cieszyn Limestones as well as the appearance of mass-movement debris-flow deposits indicate the significant vertical movements during the Neo-Cimmerian activity. Alternatively, the formation of such allodapic rock beds are also interpreted as an effect of eustatic events (litohorizone Be-7) and correspond very well with the Berriasian part of the Nozdrovice Breccia within Inner Carpathians (Reháková & Michalík, 1992, Michalík *et al.*, 1995, 1996) developed as scarp breccias along active submarine fault slopes (Michalík & Reháková, 1995). On the other side, the eustatic changes are perhaps connected with the global plate reorganization which took place during Tithonian-Berriasian time (Golonka, 2000). This global plate reorganization is also related to the Tethyan Neo-Cimmerian tectonic activities. The Early Cretaceous development of the Silesian Basin, perhaps from rifting into spreading phase, as suggested by the presence of teschenitic magmatism (Narębski, 1990, Lucińska-Anczkiewicz et al., 2000) was probably another effect of this Neo-Cimmerian activity.

The black marls pass gradually upwards into calcareous turbidites (Cieszyn limestones – Sinaia beds) which created several submarine fans (Słomka, 1986). Occurrence of deep-water microfauna (Geroch & Olszewska, 1990) indicates that subsidence of the basins must have been quite rapid (Poprawa *et al.*, 2002). During the early part of the Cretaceous the calcareous turbidites gave way to black calcareous shales and thin sandstones passing upwards into black, commonly siliceous shales (the Věřovice Shales). This type of sediments is already known also from the other Outer Carpathians basins. During the Hauterivian, Barremian and Aptian several coarse-grained submarine fans developed. The supply of clastic material was probably connected with the Early Cretaceous uplift of internal and external source areas, that known from the Bohemian Massif.

Insignificant changes in assemblages of the corresponding deep sea agglutinated foraminifera (generally to *Recurvoides* zone of Haig, 1979) through the Early Cretaceous suggest lack of pronounced changes of depth of basins. It implies generally continuos tectonic subsidence of the basins during that period. This subsidence was equal to the rate of sedimentation. Periodical occurrence

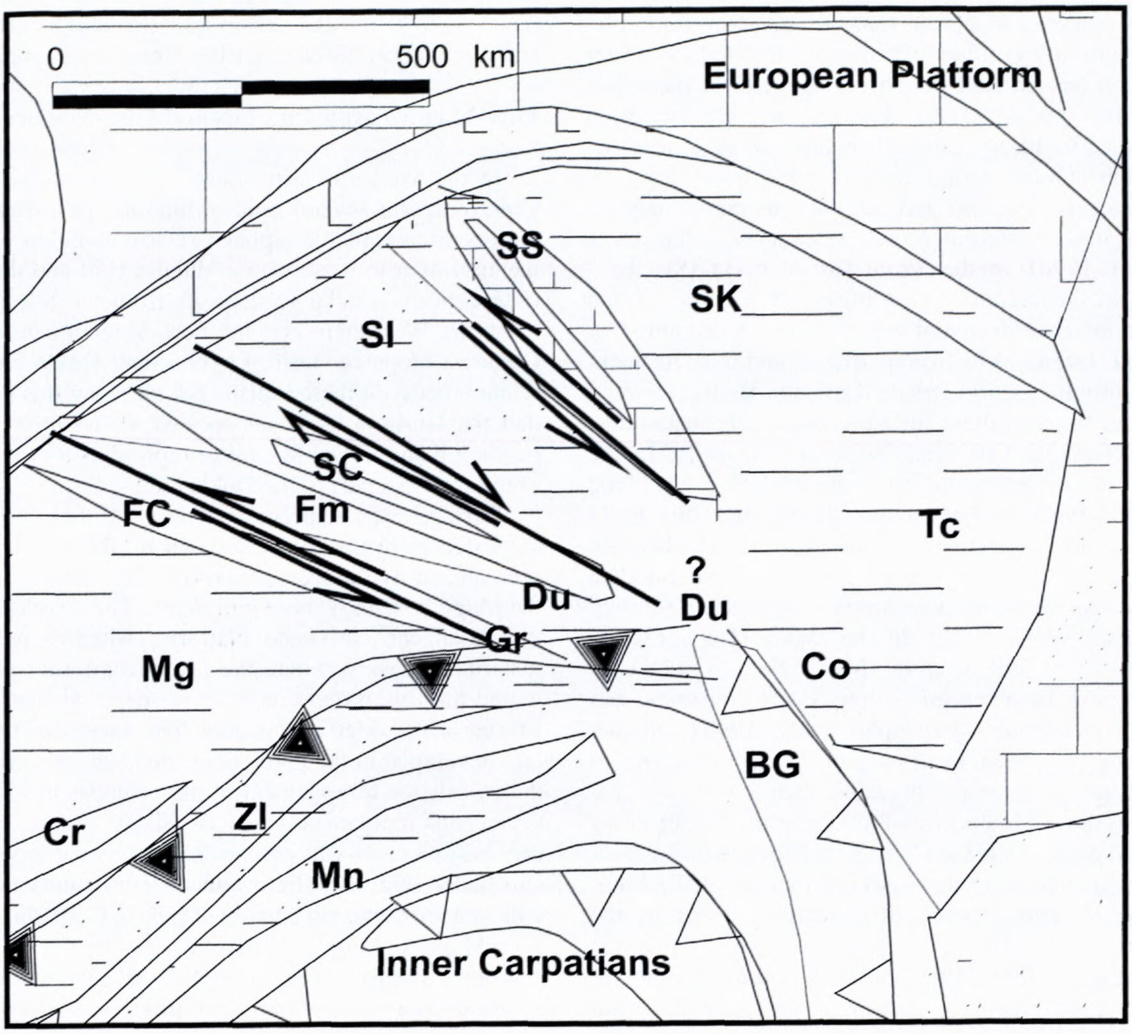

Figure 3. Paleogeography of the Outer Carpathian basins during Late Cretaceous. BG = Bucovinian-Getic, Co = Cornohora, Porkulec, Audia, Teleajen, Cr = Czorsztyn ridge, Du = Dukla, FC = Fore-Magura ridge (cordillera), Fm – Fore-Magura basin, Gr = Grybów, Mg = Magura, Mn = Manin, Si = Silesian basin, SK = Skole, SC = Silesian ridge (cordillera), SS = Sub-Silesian ridge, Tc – Taracau, Zl = Zlatna.

of planktonic microfossils corresponds to global changes of the sea level (Olszewska & Szydło, 2004).

The Cretaceous reorganization

In the early Albian within the black shales, widespread turbiditic sedimentation started, that can be connected with a compressional period very pronounced in the Eastern Carpathians. In that part of the Carpathian domain the compressional movement started during the Aptian and Albian and the inner part of the Carpathians was folded, nappes formed and in front of moving nappes coarse-grained sediments (Bucegi - Soymul Conglomerates) and olistostromes developed (Kruglov, 1989, 2001, Săndulescu, 1988).

In the beginning of the second stage, during the Cenomanian and Turonian, compression embraced the Inner Carpathians (IC) and several nappes with northward polarity developed. Subduction consumed the major part of the Pieniny Klippen Belt Ocean (Fig. 3). Cherty limestones gave way to marls and flysch deposits. With the development of the Inner Carpathian nappes the fore-arc basin was formed between the uplifted part of the IC terrane (so-called Andrusov Ridge) and the subduction zone (Fig. 3). The flysch of the Klape and Złatna (Zl - Fig.3) succession was formed in this area. Behind the ridge the Manín succession (Mn – Fig. 3) was deposited within the back-arc basin. As an effect of these movements the Inner Carpathians and Alps jointed with the Adria plate and the Alcapa terrane was created. In the Cenomanian period, subsidence was faster than the sedimentation rate (Poprawa *et al.*, 2002) and uniform, deep-water pelagic sedimentation of radiolarites, green and red shales embraced a greater part of the Outer Carpathians basins.

In the Outer Carpathians during this stage several ridges have been uplifted as an effect of the orogenic process. These ridges distinctly separated several subbasins, namely Magura, Dukla-Fore-Magura, Silesian, Charnahora-Audia, Skole-Tarcau subbasins (Figs. 3). More outer subbasins (Skole, Silesian, Dukla-Fore Magura) reached diagonally the northern margin of the Outer Carpathians and successively terminated towards the west (Fig. 3). From uplifted areas, situated within the Outer Carpathian realm as well as along its northern margin, enormous amount of clastic material was transported by various turbidity currents. This material filled the Outer Carpathian basins (Książkiewicz, 1968). Each basin had the specific type of clastic deposits, and sedimentation commenced in different time. It is interesting to note that this sedimentation started earlier in the outer subbasin (Skole-Tarcau subbasin) and migrated diachronously toward the inner subbasins (Bieda *et al.*,1963, Ślączka & Kaminski, 1998). In the Skole-Tarcau basin (Sk, Tc – Fig. 3) sedimentation started during the Turonian and ended in the Paleocene and deposits were represented by calcareous turbidites (Siliceous Marls) and thin- to thick-bedded turbidites (*Inoceramus*-Ropianka Beds). In western part of the area these turbidites were terminated during late Turonian/Coniacian by slump deposits. In the Silesian basin sedimentation started during the Late Turonian - Early Coniacian and lasted up to the Early Eocene being mainly represented by thick bedded, coarse-grained turbidites and fluxoturbidites (Godula Beds, Istebna Beds and Ciężkowice Sandstone) (Unrug, 1963, Leszczyński, 1981). In the Dukla (Du – Fig. 3) (Ślączka, 1971) and Magura (Mg – Fig. 3) subbasins sedimentation commenced during the Campanian and lasted till Paleocene (Oszczypko, 1992, 1998) and medium and thin-bedded, medium grained turbidites (*Inoceramus*-Ropianka Beds s.l.) prevailed there.

During Late Creataceous-Paleocene the accretionary prism had overridden the Czorsztyn Ridge. The subduction zone moved from the southern margin of the Pieniny Klippen Belt Ocean (Birkenmajer, 1986) to the northern margin of the Czorsztyn Ridge (Fig. 3) (Golonka et al, 2000). The submarine slumps and olistolites along the southern margin of the Magura Basin were related to the destruction of Czorsztyn ridge and movement of the accretionary prism. The huge olistolites containing fragments of destroyed Czorsztyn ridge have been found among the others in the vicinity of Jaworki village (Golonka & Rączkowski, 1984, a,b, Osczypko et al., 2004. The Homole block with the large part of the sedimentary Czorsztyn succession and Biała Woda ridge basalts constitutes the largest olistrostrome (Cieszkowski et al., 2003). The radiolarites and carbonates of the Niedzica succession, which originally were deposited on the southern slope of the Czorsztyn ridge form the submarine slump emplaced on the Czorsztyn succession originally deposited in the central part of the ridge The development of the new accretionary prism in the Magura Basin was related to the origin of the trench connected with new subduction zone (Oszczypko, 1998, Oszczypko et al., 2003). The slope (Zawiasy) and basinal deep water carbonate rock (Grajcarek) originally deposited north of the Czorsztyn succession were included into this accretionary prism. The sedimentation and subsidence rate accelerated more distinctly in the Silesian Basin than in the Magura Basin (Oszczypko et al., 2003), and were accompanied by a continuos uplifting of the Silesian and Subsilesian ridges as well as of southern margin of the European platform. This uplift produced a tremendous amount of clastic material. Especially distinct ridge developed in the SE prolongation of Silesian ridge, that gave clastic material to the Dukla basin and was built partly from rocks metamorphosed in earlier Cretaceous time.

Fore-Magura group of units and Fore-Magura ridge

In the Western Carpathians, north from the Magura Unit, there are several units, which are characterized by the occurrence of the Upper Cretaceous-Paleocene sediments similar to those of the Magura Unit and the Oligocene deposits similar to deposits from the Silesian unit. From the West there are: the Fore-Magura *sensu stricte*, Obidowa-Słopnice, Jasło, Grybów and Dukla units. The relation between these units is not clear but it is supposed that the Grybów Unit was located in the more internal position than the Dukla Unit or represents a prolongation of the southern part of the Dukla Unit.

During Late Cretaceous - Paleogene these units were separated from the Silesian Basin by the Silesian ridge, reorganized by the tectonic process. The separation from the Magura basin is more enigmatic. The development of the Paleogene carbonate platform, which supplied the material to basins, where the Lithothamnium sandstones within the flysch deposits were formed, indicates the existence of the ridge in this area. The variety of flysch facies developed in the partly separated subbasins indicated the en-echelon arrangement of these subbasins. The Late Cretaceous reorganization of the Silesian ridge and adjacent basinal areas was perhaps caused by the large strike-slip faults (Fig. 3). The origin of these faults is related with the orogenic process in the East Carpathians. The Fore-Magura group of subbasins was formed in the transtensional regime. The en-echelon arrangement of these subbasins is a result of pull-apart process caused by major strike-slip faults of NW-SE orientation. The Fore-Magura ridge (cordillera, (FC – Figs. 3, 4) originated during the Late Cretaceous reorganization.

Andrychów Ridge

This unit is represented by several huge blocks on the boundary between the Silesian and Subsilesian units, near Andrychów town. Probably they are remnants of calcareous platform which was situated between Silesian and Subsilesian sedimentary areas or represented a part of Subsilesian substratum. The composition of the klippes differs from the adjacent units, although the Upper Cretaceous sediments show similarity to the sequences of the Subsilesian unit. The non-flysch, calcareous facies are very characteristic for the Andrychów Ridge sequences (Książkiewicz, 1951, Gasiński, 1998, Olszewska & Wieczorek, 2001). The basement of the ridge was built up of granite-gneiss or mylonitised rocks. The sedimentary sequences in elevated parts are represented by crinoidal and shallow water limestones (Štramberk type) of late Jurassic age. The more basinal or slope facies are represented by Maiolica type Late Jurassic-Early Cretaceous cherty limestones (Olszewska & Wieczorek, 2001). These basinal sequences were tectonically deformed and uplifted in Late Cretaceous. Both, originally shallow water and deformed basinal units are covered by transgressive Early Campanian conglomerates and marls, lime-

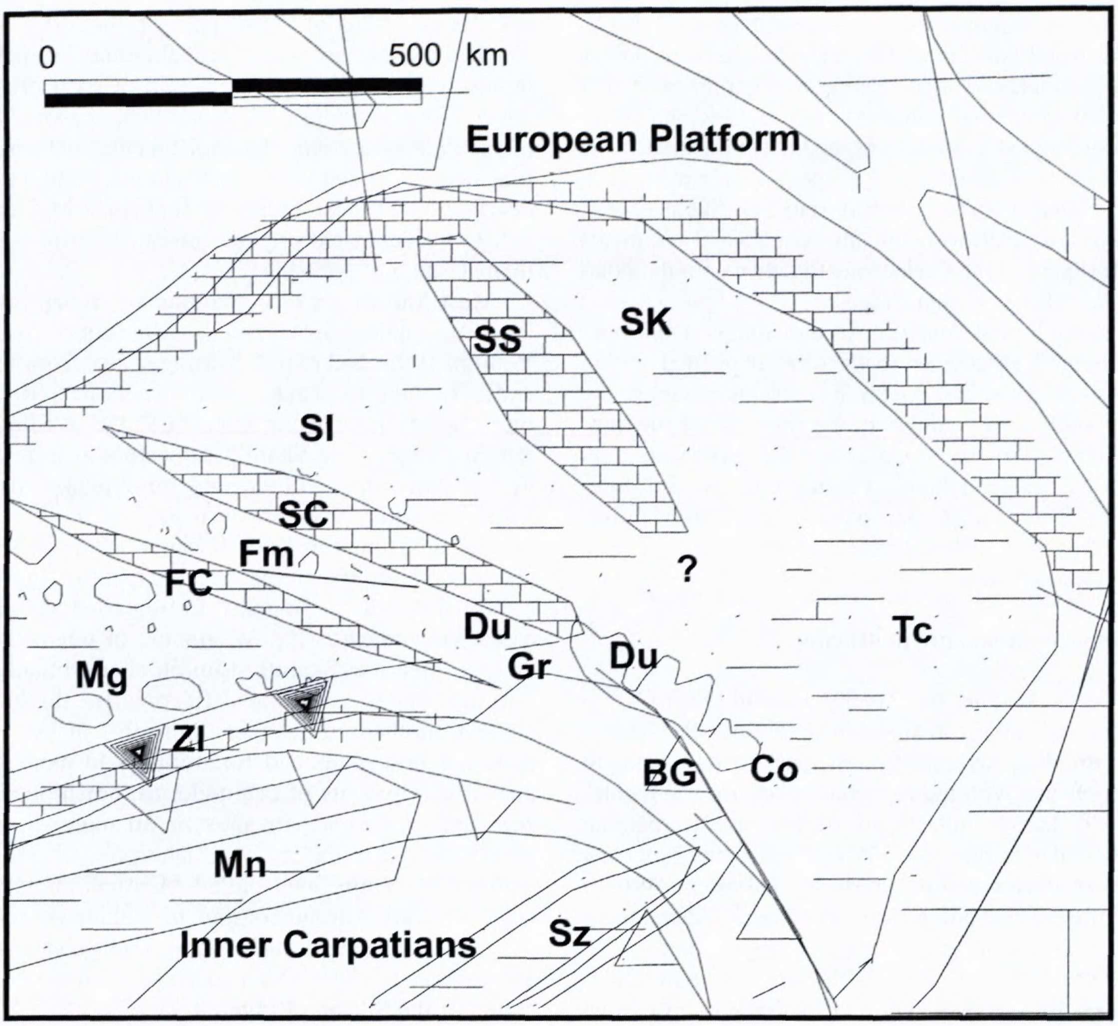

Figure 4. Paleogeography of the Outer Carpathian basins during Paleocene and distribution of carbonate platforms.
BG = Bucovinian-Getic, Co = Cornohora, Porkulec, Audia, Teleajen, Cr = Czorsztyn ridge, Du = Dukla, FC = Fore-Magura ridge (cordillera), Fm – Fore-Magura basin, Gr = Grybów, Mg = Magura, Mn = Manin, , Si = Silesian basin, SK = Skole, SC = Silesian Cordillera, SS = Sub-Silesian ridge, Sz = Szolniok, Tc – Taracau, Zl = Zlatna.

stones and shaly marls of Campanian and Maastrichtian age. Paleocene and Early Eocene are represented by organogenic limestones and shales.

Subsilesian Ridge

The Lower Cretaceous and lower part of the Upper Cretaceous sediments within Subsilesian unit display a basinal character, similar to the Silesian basin but differing in higher calcium carbonate content. These basinal units were deformed during the Late Cretaceous tectonic process and formed the ridge (Inwałd Ridge) (Matyszkiewicz & Słomka, 1994), which displayed the relatively shallow water type of sedimentation represented by marly lithofacies.

A thick complex (about 700 meters) of the deep sea red and green marls (Węglówka Marls) represents Senonian to Mid Eocene. In the western part of the Subsilesian Unit there are intercalations of sandy and conglomeratic complexes of the Upper Senonian and/or Paleocene. Small turbiditic fans developed locally, compatible with a tendency for successive uplift of small fragments of the Subsilesian Ridge – Baška and Inwałd Cordilleras (Słomka, 1995). During the Late Senonian the upper slope grey marls (Frydek Marls) often with exotic rocks, developed in this area. The marly complex pass upwards into variegated shales and/or series of shales and thin bedded sandstones terminated by green shales and *Globigerina* Marls representing the Eocene/Oligocene transition. To the west the Subsilesian sediments and especially red marls continue to the Helvetic zone of the Alpine foreland. In the Moravian Carpathians the Subsilesian lithofacies are partly replaced by sediments of the Ždánice Unit (Stráník et al, 1993).

On the underwater ridge that divided the Skole and Silesian subbasins (Subsilesian sedimentary area, PS – Figs. 3, 4) sequence of the deep-sea red and green marls (Węglówka Marls) of Senonian to Eocene and the upper slope gray marls (Senonian Frydek Marls) were deposited. However north from town of Sanok in marginal part of the Silesian unit there are Barremian Aptian conglomerates and pebbly sandstones (Grodziszcze Sandstones) containing coal fragments, limestone pebbles and remains of shallow water fauna of molluscs (*Leda scapha* (d' Orb.), *Exogyra boussinggaulti* (d' Orb.), *Cardita brouzetensis* Cossm. and undefined ostreans), sea urchins and bryozoans (Kokoszyñska, 1949, Koszarski, 1968). It suggests existence of a promontory of European Platform or local platform between Silesian/Subsilesian and Skole basins. These carbonate platform with adjacent basinal sediments were deformed in Late Cretaceous together with the other components of Subsilesian Ridge.

It is possible that Andrychów and Subsilesian Upper Cretaceous and Paleogene rocks were deposited within the same ridge area. The Andrychów facies represent the central, partially emerged part of the ridge, while the Sub-Silesian much broader slope area. The inversion took place during the geodynamic evolution of the Sub-Silesian realm. The basinal deep water Oxfordian Maiolica deposits (Olszewska, Wieczorek, 2001) were emplaced in the ridge elevated area.

The Paleogene carbonate platforms

The ridges dividing the flysch basins in Outer Carpathians became more distinguished during Paleocene-Eocene providing favorable conditions for development of shallow banks with the carbonate platform sedimentation (Fig. 3). In the southern part of the Outer Carpathian realm, along the margin of the Zlatna forarc basin, narrow carbonate platforms originated during Paleocene. Within these platforms the complex reef systems developed. (Köhler, Salaj & Buček, 1993). Large fragments of these reefs occur in Haligovce – Veľký Lipník area in the Pieniny Klippen Belt in Slovakia and in the Váh river area (Samuel, Borza & Köhler, 1972) forming olistolites within the flysch deposits of Žilina formation (Potfaj, 2000). The organogenic limestones are built of *Scleractinia* corals together with *Corallinaceae* Algae (genera *Lithotahamnium. Lithophyllum, Arhaeolithothamnium, Paleothamnium, Ethelia*) Bryozoa, sponges, brachiopods, Gastropodes and foraminifers. The reefal facies, as well as for-reef and back-reef assemblages could be distinguished here. The smaller fragments of the organogenic Paleocene limestones with numerous red *Corallinaceae* algae have been found in the Paleocene flysch deposits of Jarmuta and Szczawnica Formations in the suthern part of the Magura Unit (Golonka, 1974, Burtan et al, 1984). The huge olistolites build of Mesozoic sequences near Haligovce village (Haligovce klippe) also related to the flysch of Žilina formation deposited in the fore-arc Zlatne unit.

The Fore-Magura, Silesian ridge and Subsilesian ridges also formed the alimentation center of detrital material during Paleogene. The Paleocene organogenic and organodetritical limestones are known from the Andrychów area. (Książkiewicz, 1951, 1968, Olszewska & Wieczorek, 2001, Gasiński, 1998). They are similar to those known from the Zlatne Unit. The carbonate platform and reef limestone were also the source carbonate material redeposited to the Szydłowiec sandstone in the Subsilesian Unit.

The eastern part of the Silesian ridge was built up mainly of sedimentary rocks, a source for the mature, siliciclastic material. This part of the ridge was surrounded by shallow water, probably narrow shelf locally dominated by Paleocene reef build of red *Corallinaceae* algae *Lithotahamnium. Lithophyllum, Arhaeolithothamnium, Paleothamnium, Ethelia,* together with bryozoans, brachiopods, sometimes corals and foraminifers. Patchily distribution of these faunas is confirmed by local occurrence of redeposited organic limestones within siliciclastic material.

Most known rocks containing the redeposited shallow carbonates are Skalnik Limestone (Ślączka & Walton, 1992) and exotic-bearing shales from Bukowiec and Roztoki (Ślączka, 1961) were derived from the most eastern part of the Silesian Ridge or Silesian System of Ridges. The Skalnik Limestone is a megaturbidite within the Olígocene bituminous fish-shales (Menilite beds) from western part of the Dukla basin and its adjacent foreland. It shows changes from NW towards SE in structures and contents of bioclasts. In proximal part it is composed from graded and laminated calcareous, towards the SE amount of quartz grains increases and the Skalnik Limestone eventually passes into calcareous sandstones. Everywhere the calcareous algae Lithothamnium is predominant, in less amounts there are bryozoans and foraminifers In more proximal part also fragments of echinoderms, brachiopods, ostracods and *Balanidae* are present. In more distant parts planktonic foraminifers were incorporated into sparitic matrix. The main layer called Metressa stretch on distance of sixty kilometers and its volume is more than 0,5 cubic kilometers and it represents seismo-turbidite. The carbonate material was derived from the east termination of the Silesian Ridge.

Bircza *Lithothamnium* Limestone Bed is the typical example of the limestones constructed of material originated on the shallow-water margin of the North European Platform and redeposited in the Carpathian flysch. These allodapic limestones, which material was derived from the northern margin of the Skole basin, are located in the early Late Paleocene (P 3 zone) in central part of the Skole Unit. There are also exotic clasts of limestones confined exclusively with lithosomes of Babica Clay – dense cohesive flows (Rajchel & Myszkowska, 1998). Similar clasts exist in Ciężkowice sandstone in the Silesian Unit.

Other sediments containing shallow water fauna are known from exotic- bearing shales from Bukowiec. These shales create a lens within the Oligocene Krosno Beds in SE, inner part of the Silesian unit in front of the Dukla Unit. They contain huge (aproximately 15 meters in length) block of shallow water deposits. The sequences visible in blocks are represented by green marly shales containing foraminifers and sometimes thin shells brown or green mudstones with scattered fragments of mollusks, sporadically graded and shaly limestones containing *Ostrea* sp. These sediments display synsedimentary folds. Besides huge block in the muddy matrix there are rounded or sub-rounded blocks up to tens of centimeters of organic limestones and green marls with *Turritella*. These limestones consist of *Lithothamnium, Bryozoa, Nummulites* and fragments of bivalves. The age of fauna is considered mainly as the Late Eocene, however in the matrix younger, Oligocene, Nummulites (*Nummulites vascus*) were found. Locally, echinoderms and crabs were found. Within the matrix, there are also angular blocks of green and gray schists, quartzites, white marbles and scarce amphibolites. The exotic-bearing shales represent deposit of submarine slumps, which came from the SE, from the ridge situated north-east from the Dukla basin. The lenses of similar deposits are known along the front the Dukla nappe on the distance of more than one hundred kilometers. In both cases the age of fauna mainly is of the Late Eocene and in less extent of Oligocene. The carbonate material was derided from the system of ridges situated NE from the Dukla basin and forming SE prolongation of the Silesian ridge

The final reactivation and destruction of ridges

In the circum-Carpathian region the Adria-Alcapa (Inner Carpathians) terranes continued their northward or NE movement during Eocene-Early Miocene time (Golonka et al., 2000) Their oblique collision with the North European plate led to the development of the accretionary prism of Outer Carpathians. During the compressional stage interbasinal ridges were reactivated. Flysch still continued to be deposited in the subbasins. Numerous olistostromes were formed during this time (Ślączka and Oszczypko, 1987).

The process of migration of clastic facies from inner to the outer part began, connected with development and migration of accretionary prisms. In the inner part of the Outer Carpathians the migration of clastic facies and development of accretionary prisms started already in Early Eocene and lasted till Oligocene. (Oszczypko, 1998, Golonka et al. 2003). Sedimentation within the Magura basin terminated generally by accretionary wedges represented by medium- and thin-bedded sandstones (Malcov Fm.) during the Oligocene. Within the more outer parts of the Carpathians realm, from Dukla to Skole subbasins evidence of migration of depocenter appeared at the Eocene/Oligocene boundary (Ślączka, 1969) as an effect of compressional movements. As the consequence of these movements, the bottom of the basins started to deform and initial anticlines locally developed, slump, and coarse-grained sediments were locally deposited and volcanic activity increased. Deep-marine connection with Tethys Sea was closed and euxinic conditions developed (Ślączka, 1969).

The Oligocene sequences commenced with dark brown bituminous shales and cherts (Menilite Beds) with locally developed sandstone submarine fans or a system of fans up to several kilometers long. The main ones were Mszanka and Cergowa Sandstones in Dukla subbasin and Kliwa sandstones in Skole- Tarcau subbasin. The upper boundary of the bituminous shales are progressively younger towards the north and they pass gradually upwards into sequence of micaceous, calcareous sandstones and grey marls (Krosno beds), and they thin upward. The Menilite Beds grade upwards into a complex of thick and medium bedded, calcareous sandstones and marly shales (Krosno Beds). Both lithostratigraphic units are cut by horizon of pelagic coccolithic limestones (the Jaslo shales) above which the Oligocene/Miocene boundary has been located (Garecka, 1997, Garecka & Malata, 2001). Locally, near village Żegocina, grey mudstones, similar to the Krosno Beds of the Early Miocene age had been found (Górczyk, 2003 personal com).

Cessation of deposition is diachronous across the Carpathians due to migration of tectonic activity and formation of trailing imbricate folds and/or accretionary prisms generally from the south to the north. During the sedimentation of the Krosno beds several slump deposits with blocks of shallow water, Paleogene limestones up to tens of meters long and smaller blocks of metamorphic and igneous rocks were deposited from intrabasinal ridges (Ślączka, 1969). With the final phase of tectonic movement, in front of advancing nappes and/or accretional wedges (prisms), huge (up to kilometers in size) slumps (olistostromes) with material derived from approaching nappes, developed (Ślączka and Oszczypko, 1987).

During the final orogenic stage Africa converged with Eurasia. The direct collision of the supercontinents never happened, but their convergence lead to the collision of intervening terranes leading to the formation of the Alpine-Carpathian orogenic system. Through the Miocene tectonic movements caused final folding of the basins fill and created several imbricate nappes which generally reflect the basin margin configurations after the Cretaceous reorganization and Paleogene development of. The Sub-Silesian ridge deposits were partially included into the Sub-Silesian nappe, the ridge's basement rocks and part of its depositional form olistostromes and exotic pebbles within Menilitic-Krosno flysch. The largest olistostromes were found in the vicinity of Andrychów and are known as Andrychów Klippes (see remarks above about Andrychów ridge). The Fore-Magura and Silesian ridges were destroyed totally and are known only from olistolites and exotic pebbles in the Outer Carpathian flysch. They destruction is related to the advance of the accretionary prism. This prism obliquely overridden the ridges leading to the origin of the Menilitic-Krosno basin. The Malcov Formation was deposited in the smaller piggy-back subbasin. During overthrusting the outer, marginal part of the advanced nappes was uplifted whereas in the inner part sedimentation persisted in the remnant basin. From that, uplifted part of the nappes big olistolites glided down into the adjacent, more distal basins. The nappes became detached from the basement and were thrust northward in the west and eastward onto the North European platform with its Miocene cover. Overthrusting movements migrated along the Carpathians from the west towards the east. The Outer Carpathian allochtonous rocks, as result of Miocene tectonic movements, have been overthrust onto the platform for a distance of 50 to more than 100 km.

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