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Plate tectonic evolution stages of the Outer Carpathian basins

Introduction

The Outer Carpathians are composed of Upper Jurassic to Lower Miocene flysch deposits, which are completely uprooted from their basement and separated from the Inner Carpathians by the Pieniny Klippen Belt suture zone. The Western Outer Carpathians form an accretionary wedge. Its formation was completed by the Late Oligocene/Middle Miocene. The flysch deposits built up several nappes sub-horizontally overthrust onto the Miocene deposits of the Carpathian Foredeep or directly onto Precambrian-Mesozoic rocks of the Carpathian Foreland. From the south to north there are: Magura Nappe, Fore-Magura Group of units, Silesian, Sub-Silesian and Skole units. These units developed from the different plate tectonic realms: Magura and Pieniny Klippen Belt are connected with the alpine Tethys while Silesian, Sub-Silesian and Skole units developed on the rifting European platform. The presented palaeotectonic reconstructions are based on the palaeotectonic mapping and subsidence modelling of the Polish Outer Carpathians. The palaeotectonic maps have been prepared for several time spans, whereas the burial history has been reconstructed on the basis of 50 selected sections from the Magura, Dukla, Silesian, Subsilesian and Skole units (Golonka et al., 2000, Poprawa et al., 2002). The basin development encompasses time from Jurassic to Neogene.

The following geodynamic evolution stages could be distinguish in such defined Outer Carpathians (Slaczka & Kaminski, 1998, Golonka & Slaczka, 2000): I -syn- and postrift - formation of passive margin and basins with the attenuated crust, II - early collisional - development of subduction zones, partial closing and of oceanic basin, inversion/uplifting of intra-basinal source areas and development of flysch basins, III - orogenic, perhaps terrane - continent collision with the accompanying convergence of two large continents, IV - postcollisional. These stages correspond quite well with the global sequence stratigraphy (Golonka & Kiessling, 2002), the three supersequences encompassing one stage, they are also closely related to the major changes in the climate setting of the region.

Stage I - synrift - postrift Late Jurassic-Albian /Cenomanian)

During the Late Jurassic the southern part of the North European Platform, started to be rifted and small basins, proto-Silesian Basin in the Western Carpathians and Rachiv -Cahlau (Sinaia) basin in the eastern Carpathians, with black, mainly redeposited marls and turbidite limestones (?Kimmeridgian-Tithonian) have been created (Pescatore and Slaczka, 1984). These basins indicate the beginning of the Outer Carpathians development. The black sediments mark the beginning of an euxinic cycle of the Outer Carpathian basin that lasted to the beginning of Cenomanian. The Outer Carpathian synrift period corresponds generally to three global supersequences - Lower Zuni III, Upper Zuni I and Upper Zuni II (Golonka & Kiessling, 2002). Two major global Oceanic Anoxic Events (OAE) happened during this time. The rapid supply of shallow water clastic material to the basin could be an effect of the strong tectonoeustatic sea-level fluctuations known from that time. The marls pass gradually upwards into calcareous turbidites, which created several submarine fans. Occurrence of deep-water microfauna indicates that subsidence of the basin must have been quite rapid. During the early part of the Cretaceous the calcareous turbidites gave way to black calcareous shales and thin sandstones passing upwards into black often siliceous shales. During the Hauterivian, Barremian and Aptian several coarse-grained submarine fans developed. That was connected probably with the Early Cretaceous uplift known from the Bohemian Massif. The rifting of the North European Platform lasted during the Early Cretaceous and with this period the extrusion of basic, teschenites type of magma was connected, although it can not be excluded that magmatic eruptions could started earlier, as in the case of the Eastern Carpathians. In the early Albian within the black shales, widespread turbiditic sedimentation started to develop. In the Eastern Carpathians the compressional movement started during the Aptian and Albian and the inner part of the Carpathians was folded, napped and in front of moving nappes coarse-grained sediments and olistostromes developed.

Stage II -- early collisional - Cenomanian - late Eocene

This stage is characterized by formation of subduction zones along the active margin, partial closing of oceanic basin and development of main flysch basins associate with the rifting on the platform (passive margin) with the attenuated crust and uplifting of intra-basinal source areas. Generally, the oxic conditions prevailed, and the appearance of the red and green shales is characteristic (Slaczka & Kaminski, 1998). This period corresponds generally to three global supersequences - Upper Zuni III, Upper Zuni IV and Lower Tejas I (Golonka & Kiessling, 2002). The global OAE, which occurred during the first supersequences, is reflected by mixed green and black sediments (Wójcik & Gasinski, 2000). During the Cenomanian a period of slow and uniform sedimentation embraced a greater part of the Outer Carpathians basin and green and red shales began to develop.

In the foreland of the Inner Carpathian folded area, within the Outer Carpathian realm several basins became distinctly separated, namely Magura, Porkulec-Convolute, Dukla, Silesian Charnahora-Audia Skole-Tarcau basins divided by Silesian and Kumana Ridges and Subsilesian underwater swell. The Magura Basin was at that time incorporated into the Outer Carpathian realm. The orogenic processes in the Western Carpathians produced an enormous amount of the clastic material that started to fill the Outer Carpathian basins. The material was derived from the northern and southern margins as well as from the inner ridges (cordilleras) (Ksiazkiewicz 1968, Dzulynski, Slaczka, 1958). Each basin had the specific type of clastic deposits, and sedimentation commenced in different time.

In the Magura and Dukla basins sedimentation commenced during the Campanian and lasted till Paleocene, and medium and thin-bedded, medium grained turbidites prevailed there. The sedimentation of thick bedded, coarse-grained turbidites in form of several submarine fans commenced during the Eocene. In more distal parts medium - and thin - bedded sandstones and shales developed passing further towards the north into variegated shales. These lithofacies migrated northward. The lateral differences of the lithofacies across the basin (Oszczypko, 1999) allowed dividing the Magura basin on several sub-basins.

In the Silesian basin sedimentation started during the Late Turonian - Early Coniacian and lasted up to the Early Eocene and were mainly represented by thick bedded, coarse-grained turbidites and fluxoturbidites. In the Skole basin sedimentation also started during the Turonian but expired in the Paleocene and deposits were represented by calcareous turbidites and thin to thick bedded turbidites. Small turbiditic fans developed locally in the small sub-basins. During the Early Eocene green and gray shales with thin and medium bedded sandstones with intercalations of red shales prevailed. Small turbiditic fans developed only locally except the eastern part where huge clastic fan developed. This type of sedimentation gave way during the Late Eocene to green shales and yellowish *Globigerina* marls. The Subsilesian sedimentary area, which divided the Silesian and Skole basins, became uplifted and on this swell a sequence of red, green marls and gray Senonian to Eocene marls were deposited.

Stage III - Latest Eocene - early Burdigalian - orogenic

This stage is characterized by collision, perhaps terrane - continent, with the accompanying convergence of two large continents. The anoxic condition prevailed, the variegated shales disappeared, and bituminous brown shales and gray marly siltstones and sandstones were deposited (Slaczka & Kaminski, 1998). This period corresponds generally to three global supersequences - Lower Tejas II Lower Tejas III and Upper Tejas I (Golonka & Kiessling, 2002). At the beginning of this period global cooling took place. This event was connected with the glaciation in Antarctica (Golonka, 2000).

In the circum-Carpathian region Adria-Alcapa (Inner Carpathians) terranes continued their northward 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 wedge of Outer Carpathians. During the compressional stage flysch still continued to be deposited. Numerous olistostromes were formed during this time (Slaczka and Oszczypko, 1987). A manifestation of compression is visible in the more inner part of the Carpathians (Magura unit) during the Eocene when migration of accretionary prism is noted (Oszczypko, 1998). In the more outer parts of the Carpathian realm the compressional movement appeared at the Eocene/Oligocene boundary (Slaczka, 1969). The Oligocene sequences commenced in these basins with dark brown bituminous shales and cherts with locally developed sandstone submarine fans or system of fans of length up to several kilometers. The bituminous shales pass gradually upwards into Krosno beds sequence of micaceous, calcareous sandstones and gray marls which lasted to the Early Miocene and terminated the flysch sequence of the Outer Carpathians. The lower part of the Krosno is generally represented by complex of thick bedded sandstones that pass upwards into series of medium to thin bedded sandstones and gray marls. One or two olistostromes developed in the southern part of the Silesian basin. Grey marls, diachronous across the basins represent the upper part of the Krosno beds.

Trough the Miocene Africa converged with Eurasia. The direct collision of the supercontinents never happened, but their convergence did not leave much space, leading to the permanent setting of the Alpine-Carpathian system. Tectonic movements caused final folding of the basins infillings and created several imbricated nappes which generally reflect the original basin configurations. During the overthrusting movements the marginal part of the advanced nappes has been uplifted whereas in inner part sedimentation lasted in the remnant basin. Big olistolites often glided down from uplifted part of the nappes into the adjacent, more outer basins. The nappes became uprooted from the basement and the Outer Carpathians allochtonous rocks overthrust northward in the west and eastward in the East onto the North European platform for the distance of 50 to more than 100 km. The peripheral foreland basin formed along the moving orogenic front (Oszczypko & Slaczka, 1989, Oszczypko, 1998). Overthrusting movements migrated along the Carpathians from the West towards the East.

Stage IV - postorogenic - late Burdigalian - Future

During and after the main orogenic phase and the suture of the continents an initial rifting system was initiated in early-Miocene time behind the Carpathian arc in the Pannonian Basin. Extension in the Alpine-Carpathian system continued during the Miocene-Pliocene, forming horst and grabens within the orogen as well as in its foreland. This period corresponds generally to two full global supersequences - Upper Tejas II, Upper Tejas III (Golonka & Kiessling, 2002), the third supersequence will last into the future. This was a cool period, climate finally entered the icehouse phase. In front of the advancing Carpathians nappes the inner part of the platform, in the eastern part also with the marginal part of the flysch basin (Borislav-Pokuttya or Marginal Fold Unit), started to downwarp and tectonic depression formed during the Early Miocene. Thick molasse deposits filled up this depression. Generally it started with shallow water basal conglomerates passing upwards to brackish and marine sandstones, shales and marls, locally with olistostromes containing the material derived from the advancing Carpathians. In the eastern Carpathians there were periodically conditions favorable for precipitation of salt. At the end of Burdigalian that basin became overthrust by the Carpathians and a new, more external one, developed. This basin and its depocenter migrated outwardly and eastward, contemporary with the advancing Carpathians nappes. As a result the Neogene deposits show clear diachrony in the foreland area. In the west sedimentation terminated already in Langhian and in the east lasted till Pliocene. Clastic and fine-grained sedimentation of the Carpathian and foreland provenance prevailed with a break during the Late Langhian to early Serravallian, when younger evaporate basin developed. Locally olistostrome were deposited (Slaczka, Oszczypko, 1987) with material derived as well from the Carpathians as from the inner margin of the molasse deposits. During Langhian and in Serravallian part of the northern Carpathians collapsed and sea invaded the already eroded Carpathians. Further development of these processes could be predicted in the future.

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