Field trip – Outer Flysch Carpathians and Pieniny Klippen Belt (PKB)

The position of the West Carpathians in the Alpine-Carpathian fold-and-thrust belt

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The Polish and Slovak West Carpathians form the northern part of the great arc of mountains, which stretch more than 1,300 km from the Vienna Forest to the Iron Gate on the Danube. Traditionally the Carpathians are subdivided into an older range known as the Inner Carpathians and the younger ones, known as the Outer Carpathians. From the point of view of the plate tectonic evolution of the basins the following major elements could be distinguished in the Outer Carpathians and the adjacent part of the Inner Carpathians (Golonka *et al*., 2005b; Ślączka *et al*., 2006):

- *Inner Carpathian Terrane* – continental plate built of the continental crust of Hercynian (Variscan) age and Mesozoic-Cenozoic sedimentary cover. The Inner Carpathians form a prolongation of the Northern Calcareous Alps, and are related to the Apulia plate (in a regional sense (Picha, 1996). The uppermost Paleozoic–Mesozoic continental and shallow marine sedimentary sequences of this plate are folded and thrust into a series of nappes. They are divided into the Tatric, Veporic and Gemeric nappes that are the prolongation of the Lower, Middle and Upper Austroalpine nappes respectively.
- *North European Platform* – large continental plate amalgamated during Precambrian-Paleozoic time. Proterozoic, Vendian (Cadomian), Early Paleozoic (Caledonian), Late Paleozoic (Hercynian) fragments could be distinguished within the folded and metamorphosed basement of this plate. Beneath of the Outer Carpathians the sedimentary cover consist of the autochthonous Upper Paleozoic, Mesozoic and Cenozoic sequences covered by the allochtonous Jurassic- Neogene rocks. The autochthonous Jurassic rocks within *North European Platform* are represented by mainly paltform facies. These allochtonous rocks are uprooted and overthrust onto the southern part of the North European Platform at a distance of at least 60–100 km (Książkiewicz, 1977; Oszczypko & Ślączka, 1985). They form stack of nappes and thrust-sheets arranged in several tectonic units. In Poland these allochtonous mainly flysch units are being regarded as Flysch Carpathians. Along the frontal Carpathian thrust, a narrow zone of folded Miocene deposits was developed.
- *Penninic realm* is a part of the Alpine Tethys (e.g., Birkenmajer, 1986; Săndulescu, 1988; Oszczypko, 1992; Plašienka, 1999, 2002; Stampfli, 2001; Golonka *et al.*, 2005b), which developed as a basin during Jurassic time between Inner Carpathian- Eastern Alpine terrane and North European Platform. In the western part it contains the ophiolitic sequences indicating the truly oceanic crust. In the eastern part the ophiolitic sequences are known only as pebbles in flysch, the basement of the Penninic realm was partly formed by the attenuated crust. In Poland, Slovakia and Ukraine the Penninic realm is represented by the sedimentary sequences of Jurassic, Cretaceous, Paleogene and Miocene age belonging to the Pieniny Klippen Belt (PKB) and the Magura Unit (Golonka *et al*., 2003). Some of these sequences are recently located in the suture zone between Inner Carpathian terrane forming the PKB, other sequences are involved in the allochtonous units covering the North European platform (Magura Nappe) or accreted to the Inner Carpathian terrane. Because of the evolutionary connotations of the Penninic realm, the PKB could be also regarded as belonging to the Outer Carpathians (e.g. Książkiewicz, 1977; Picha, 1996). The Czorsztyn submerged ridge was a part of the Penninic realm dividing the oceanic basin into two subbasins. The southern subbasin and the ridge traditionally constitute the Pieniny domain. Its sequences are involve in the PKB – strongly tectonized structure is about 800 km long and 1–20 km wide, which stretches from Vienna on the West to the Poiana Botizei (Maramures, NE Romania) on the East. The largest part of the northern subbasin form the Magura Unit, traditionally belonging to the Outer Carpathians. The PKB is separated from the Magura Nappe by the Miocene sub-vertical strike-slip fault (e.g. Birkenmajer, 1986, 1988). The Jurassic rocks of the Penninic realm are represented by basinal, slope and ridge facies.

The Polish Carpathians form the northern part of the Carpathians (Figs 1, 2). The Carpathian overthrust forms the northern boundary. The southern goes along the Poland-Slovakia national border. The Outer Carpathians are built of a stack of nappes and thrust-sheets showing different lithostratigraphies and tectonic structures. The Outer Carpathians nappes were thrust over each other and onto the North European Platform and its Paleocene-Miocene cover (Figs 3, 4). The present authors provided a systematic arrangement of the lithostratigraphic units according to their occurrence within the original basins and other sedimentary areas.

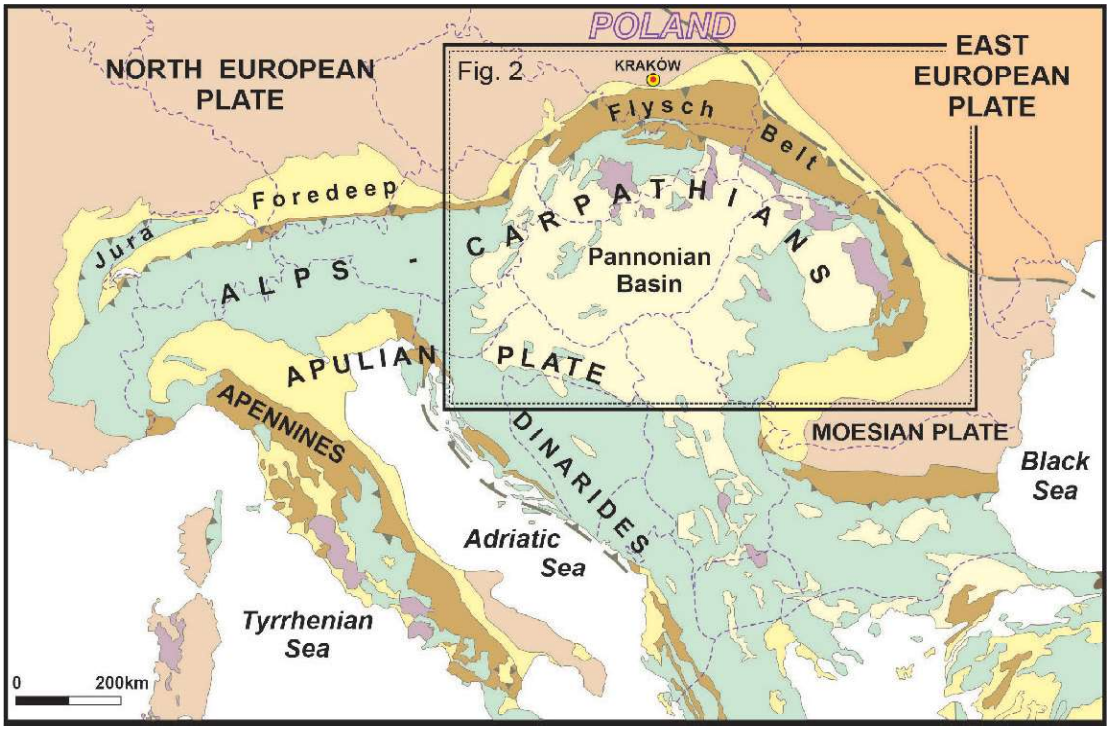


Fig. 1. Sketch of Alpine geology in Europe (after Picha, 1996; modified)

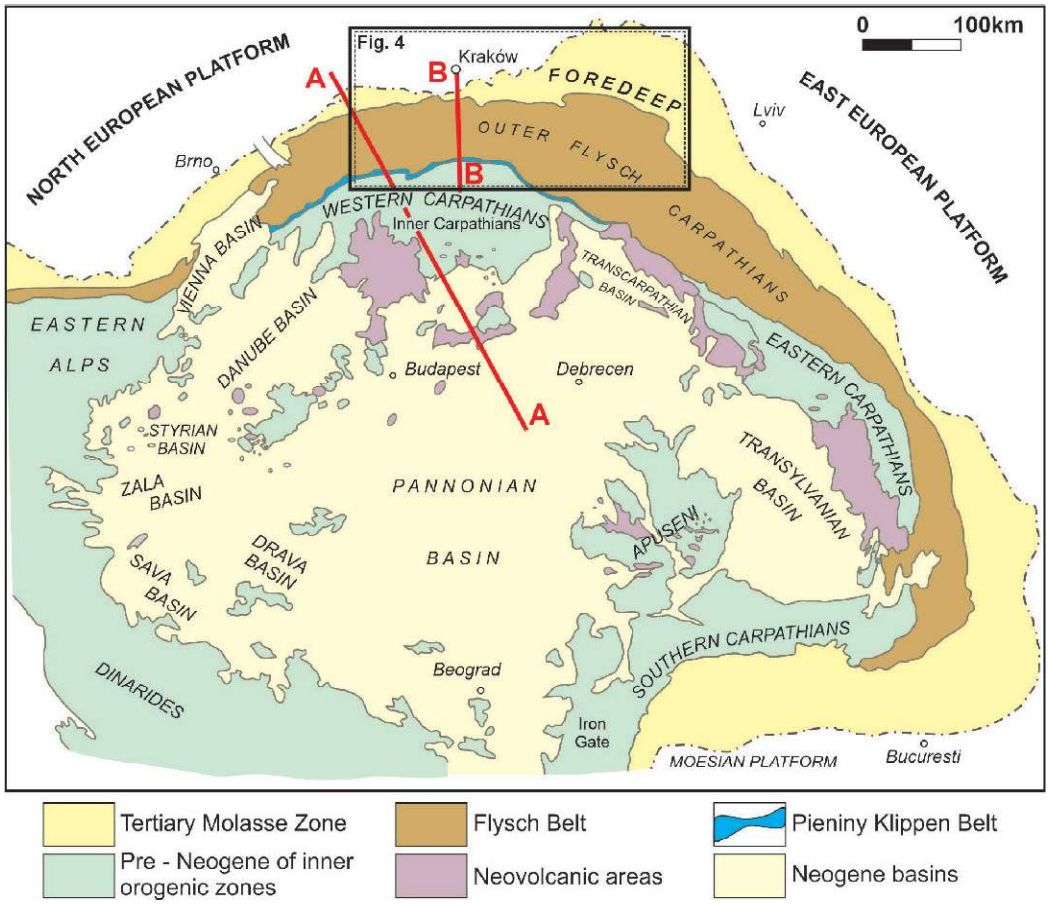


Fig. 2. Tectonic sketch map of the Alpine-Carpathian-Pannonian-Dinaride basin system (modified after Plašienka *et al.*, 2000). A-A and B-B – localization of cross-sections (see Fig. 3)

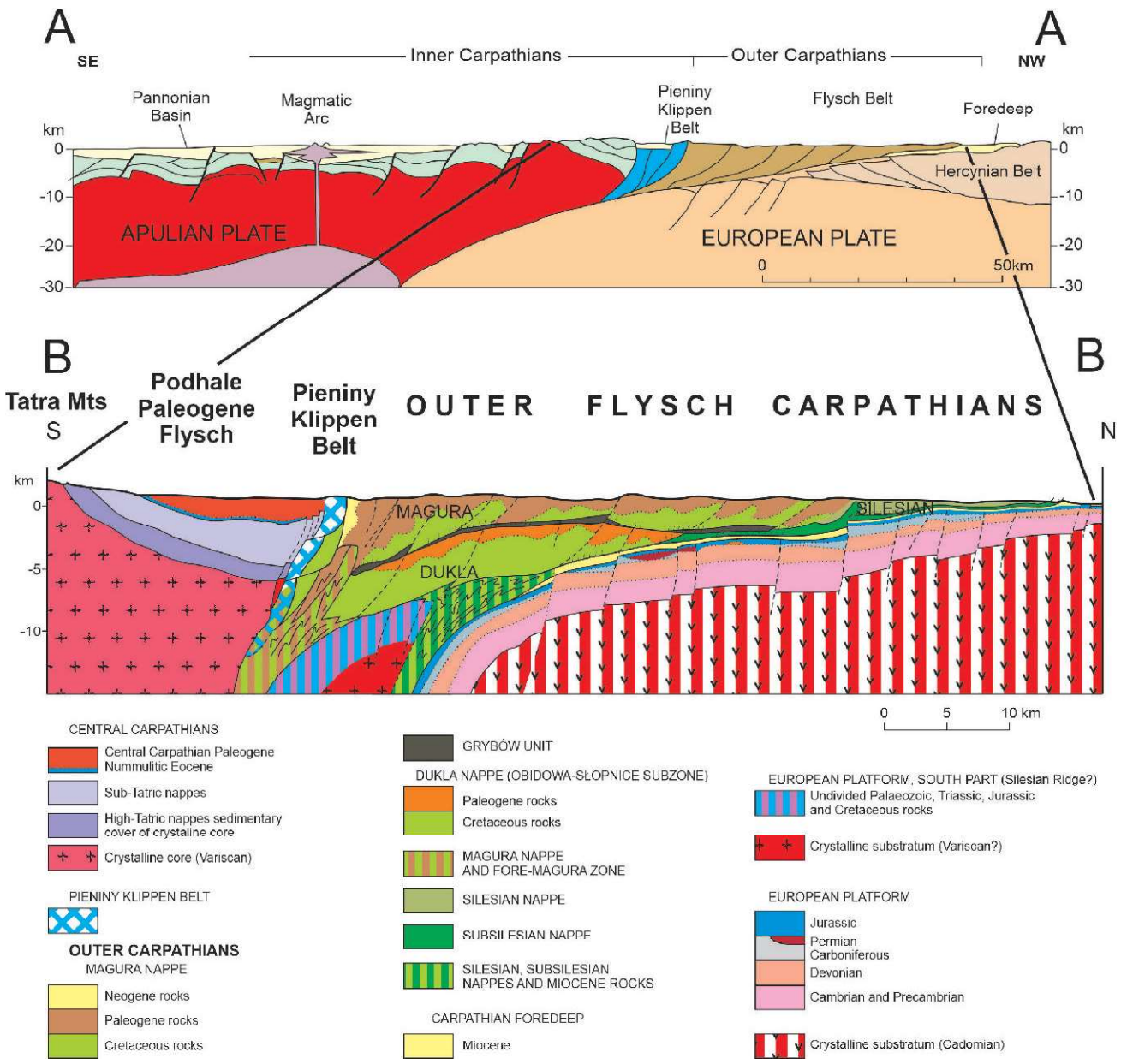


Fig. 3. Generalized cross-section across Carpathian-Pannonian region (Picha, 1996) (upper) and generalized cross-section across Polish Carpathians (after Golonka *et al*., 2005) (lower)

This guide focuses also on the plate tectonic elements important to understanding the geology of the Polish Carpathians. The Inner Carpathian Terrane is a continental plate built of continental crust of Hercynian (Variscan) age and a Mesozoic-Cenozoic sedimentary cover. The uppermost Mesozoic sedimentary sequences of this plate are folded and thrust into a series of nappes. The large continental plate, amalgamated during Precambrian and Paleozoic times, is known as the North European Platform. Proterozoic, Vendian (Cadomian), Caledonian, and Variscan fragments occur within the platform. The southern part of the North European Platform, adjacent to the Alpine Tethys is known as Peri-Tethys.

The Alpine Tethys constitutes important palaeogeographic elements of the future Outer Carpathians, developed as an oceanic basin during the Jurassic as a result of the break-up of Pangea (some palaeogeographical sketches from global trough regional to local scales are given for example for Jurassic/Cretaceous transition times – Figs 5–7). The Czorsztyn submerged ridge (Pieniny Klippen Basin) was a part of the Alpine Tethys dividing the oceanic basin into two sub-basins. The southern sub-basin and the ridge are traditionally taken to constitute the Pieniny domain. Its sequences are involved in the PKB – a strongly tectonized structure about 600 km long and 1–20 km wide, which stretches from Vienna in the west to the Poiana Botizii (Maramures, NE Romania) in the east. The largest part of the northern sub-basin forms the Magura Unit, traditionally taken as belonging to the Outer Carpathians.

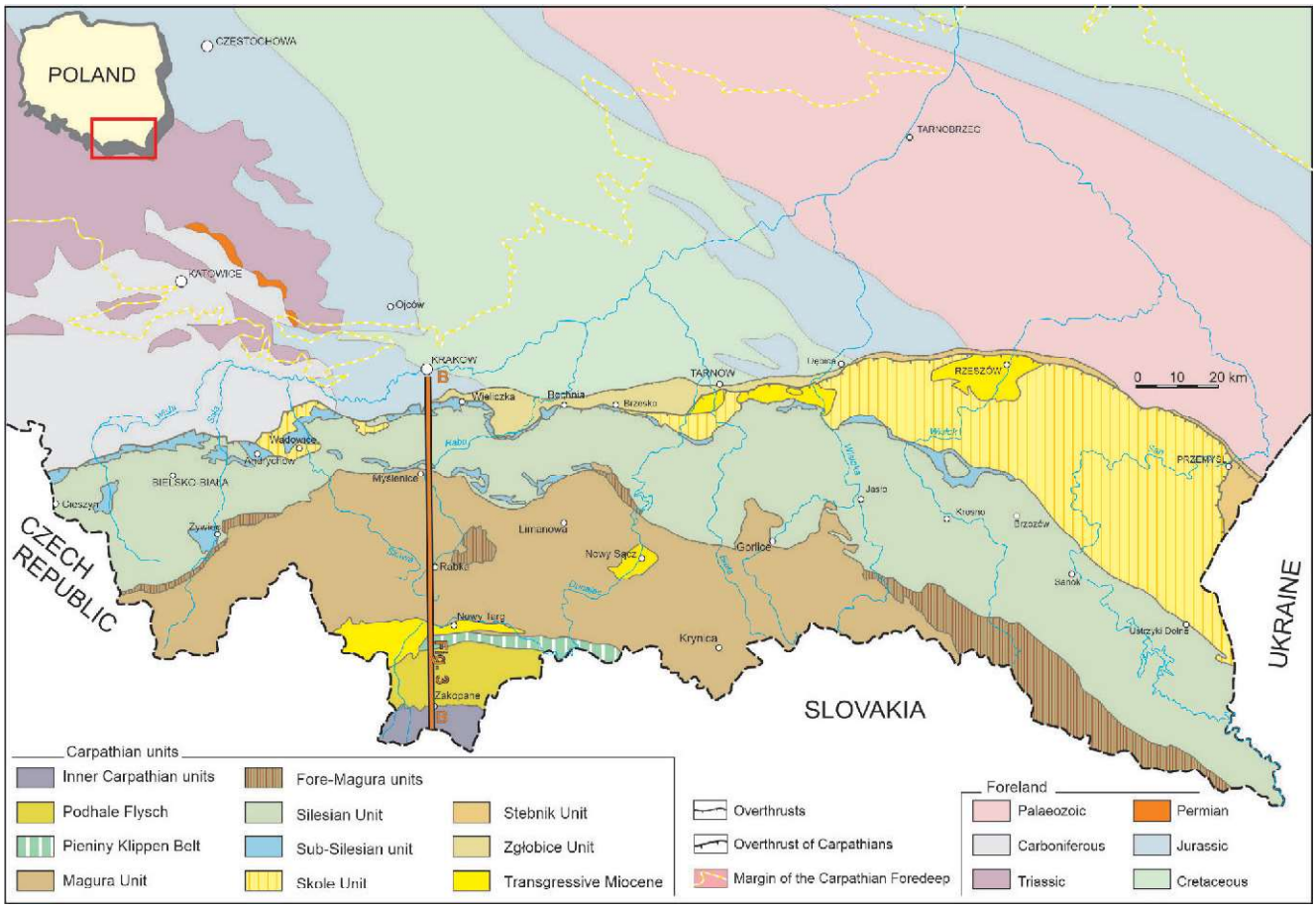


Fig. 4. Geological map of the Polish Carpathians and Foreland (after Żytko *et al*., 1989; simplified)

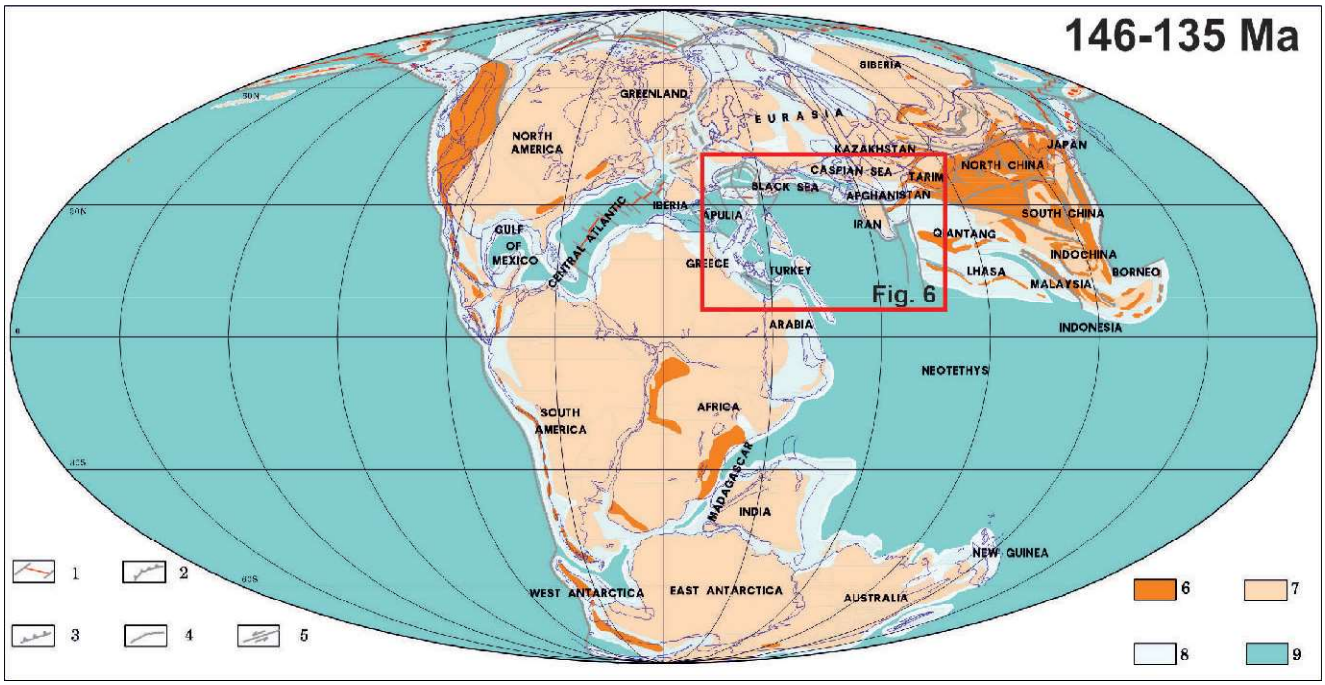
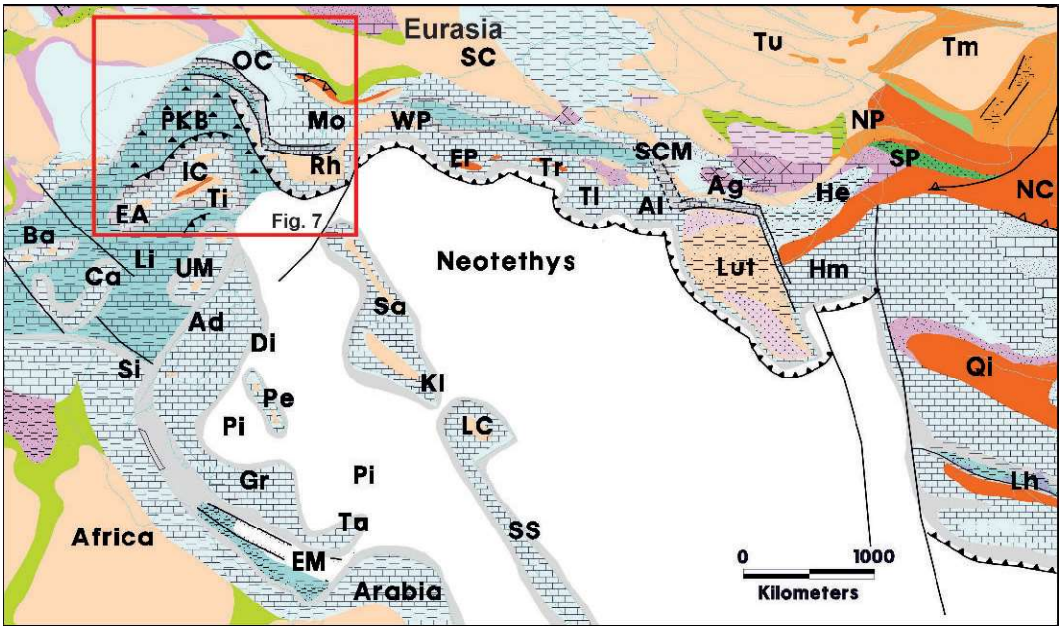


Fig. 5. Global plate tectonic map of latest Jurassic–earliest Cretaceous. Explanations: 1 – oceanic spreading center and transform faults; 2 – subduction zone; 3 – thrust fault; 4 – normal fault; 5 – transform fault; 6 – mountains; 7 – landmass; 8 – shallow sea and slope; 9 – deep ocean basin (from Golonka, 2000; modified)



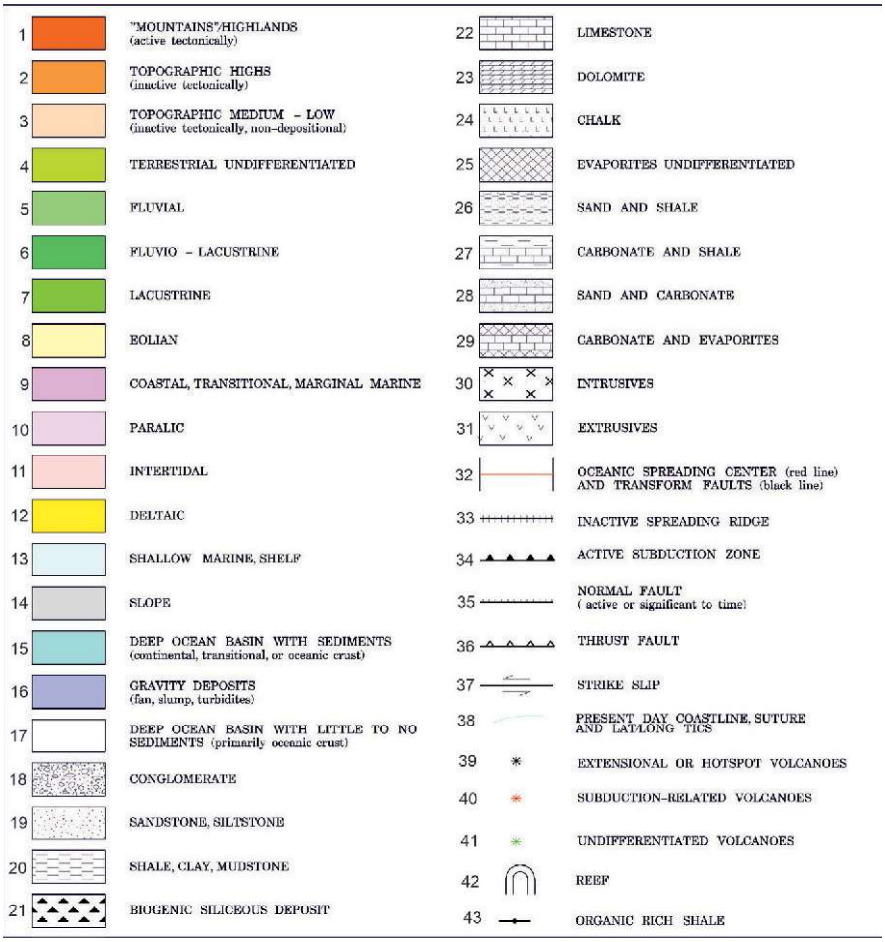


Fig. 6. Plate tectonic, palaeoenvironment and lithofacies map of the western Tethys, Central Atlantic and adjacent areas during latest Jurassic–earliest Cretaceous time (after Golonka, 2007a; modified). Abbreviations of oceans and plates names: Ad – Adria (Apulia); Ag – Aghdarband (southern Kopet Dagh); Al – Alborz; Ba – Balearic; Ca – Calabria-Campania; Di – Dinarides; EA –Eastern Alps; EM – Eastern Mediterranean; EP – Eastern Pontides; Gr – Greece; He – Heart; Hm – Helmand; IC – Inner Carpathians; Ki – Kirsehir; LC – Lesser Caucasus; Lh – Lhasa; Li – Ligurian (Piemont) Ocean; Mo – Moesia; NC – North China; NP – North Pamir; OC – Outer Carpathians; PB – Pieniny Klippen Belt Basin; Pe – Pelagonian plate; Pi – Pindos Ocean; Qi – Qiangtang; Rh – Rhodopes; Sa – Sakarya; SC – Scythian; SCM – South Caspian microcontinent; Sl – Sicily; SP – South Pamir; SS – Sanandaj-Sirjan; Ta – Taurus terrane; Ti – Tisa; Tl – Talysh; Tm – Tarim; Tr – Transcaucasus; Tu – Turan; UM – Umbria-Marche; WP – Western Pontides

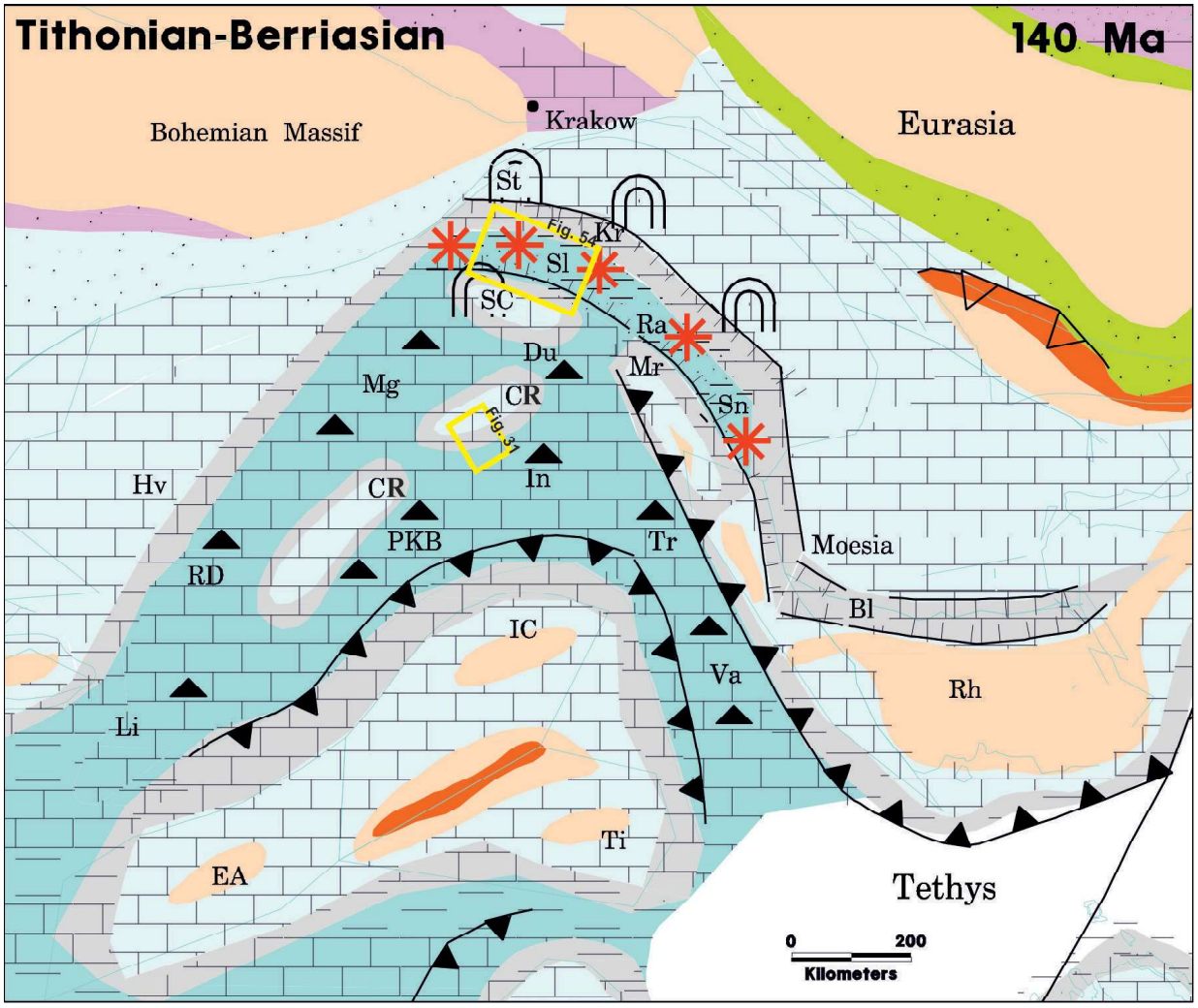


Fig. 7. Palaeoenvironment and lithofacies of the circum-Carpathian area during latest Jurassic–earliest Cretaceous; plates position at 140 Ma (modified from Golonka *et al*., 2006). Abbreviations: Bl – Balkan rift; Cr – Czorsztyn Ridge; Du – Dukla Basin; EA – Eastern Alps; Hv – Helvetic shelf; IC – Inner Carpathians; In – Inačovce-Kričevo zone; Kr – Kruhel Klippe; Li – Ligurian Ocean; Mg – Magura Basin; Mr – Marmarosh Massif; PKB – Pieniny Klippen Belt Basin; Ra – Rakhiv Basin; RD – Rheno Danubian Basin; Rh – Rhodopes; SC – Silesian Ridge (Cordillera); Sl – Silesian Basin; Sn – Sinaia Basin; St – Štramberk Klippe; Ti – Tisa plate; Tr – Transilvanian Ocean; Va – Vardar Ocean. Explanations of colors and symbols – see Fig. 6

Outer Flysch Carpathians

The Outer Flysch Carpathians are built up of a stack of nappes and thrust sheets spreading along the Carpathians, built mainly of up to six kilometers thick continual flysch sequences, representing the time span from Jurassic to Early Miocene. All the Outer Carpathian nappes are overthrust onto the southern part of the North European platform covered by the autochthonous Miocene deposits of the Carpathian Foredeep on the distance of 70 km at least (Książkiewicz, 1977; Pescatore & Ślączka, 1984) (Fig. 4). Boreholes and seismic data indicate that the distance of the Carpathian overthrust was at least 60 km. During overthrusting movement the northern Carpathians nappes became uprooted from the basement and only their basinal parts were preserved. The succession of the nappes from the lowest to the highest is as follows (concordant to our trip – from north to south): Skole (Skiba) Nappe (mainly easternmost part of Carpathians), Subsilesian Nappe, Silesian Nappe, Fore-Magura group of nappes and Magura Nappe (Fig. 8). We discuss here main units only.

The **Subsilesian Nappe** underlies tectonically the Silesian Nappe. In the western sector of the West Carpathians both nappes are thrust over the Miocene molasse of Carpathian Foredeep and in the eastern sector they are thrust over the Skole Nappe. This nappe consists Upper Cretaceous–Paleogene flysch deposits.

The **Silesian Nappe** occupies central part of the Outer Carpathians, pinching out below the most internal nappes. Sedimentary facies of the Silesian Nappe represent continuos succession of deposits of age interval from Late Jurassic to Early Miocene. The oldest sediments of the Silesian are known only in Moravia and Silesia areas in the

Western Carpathians. They are represented by the Kimmeridgan-Lower Tithonian dark grey, calcareous mudstones (Lower Cieszyn Shales) which begin euxinic cycle that lasted without major interruption till Albian. The Silesian and Subsilesian basins have been connected during their sedimentation period.

The **Magura Nappe** is an innermost and largest tectonic unit of the Western Carpathians thrust over the various unit of the Fore-Magura group of nappes and of the Silesian Nappe. To the south it is in the tectonic contact with the PKB that separates it from the Inner Carpathians. The oldest Jurassic-Lower Cretaceous rocks are only found in this part of the Magura basin which was incorporated into the PKB (i.e. the Grajcarek Unit) (Birkenmajer, 1977).

The Outer Carpathian rift had developed with the beginning of calcareous flysch sedimentation (so-called Cieszyn beds). The Western Carpathian Silesian Basin probably extended in the Eastern Carpathian (Sinaia or "black flysch") as well as to the Southern Carpathian Severin zone (Săndulescu, 1988). The remnants of carbonate platforms (Olszewska & Wieczorek, 2001) with reefs (Štramberk-type limestones) along the margin of Silesian Basin were results of the fragmentation of the European platform in this area. The Silesian Ridge (= exotic cordillera) separated the Silesian and Magura basins (Golonka *et al*., 2000). During the late Tithonian and Early Cretaceous opening of the western part of the Silesian basin alkaline magma (teschenites association rocks) intruded the flysch deposits (Lucińska-Anczkiewicz *et al*., 2002).

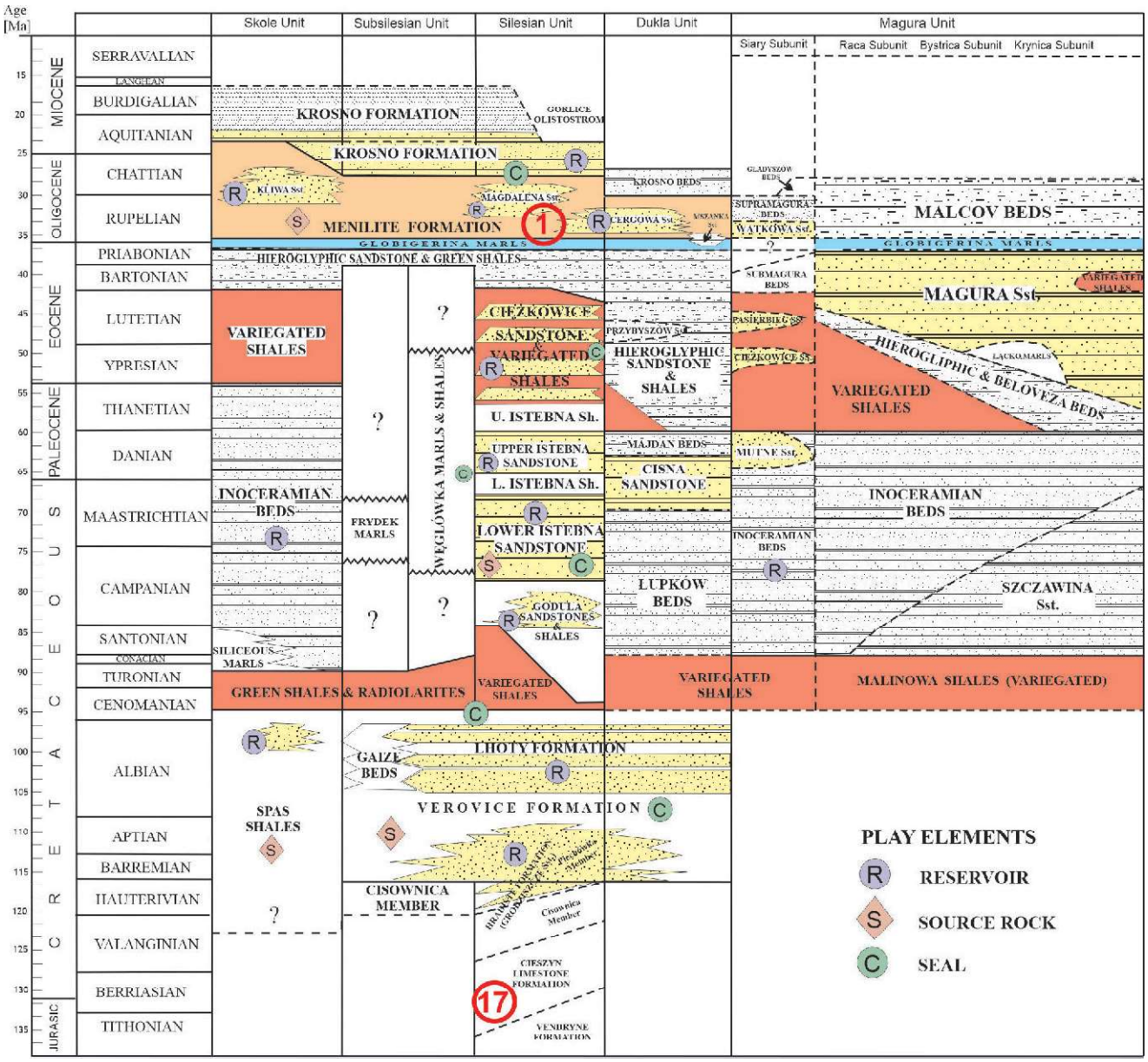


Fig. 8. Simplified lithostratigraphy of the Outer Polish Carpathians (after Koszarski *et al*., 1985; Dziadzio *et al*., 2001; modified) with the position of field trip stops