Conference Excursion 2: Late Cretaceous–Neogene Evolution of the Polish Carpathians

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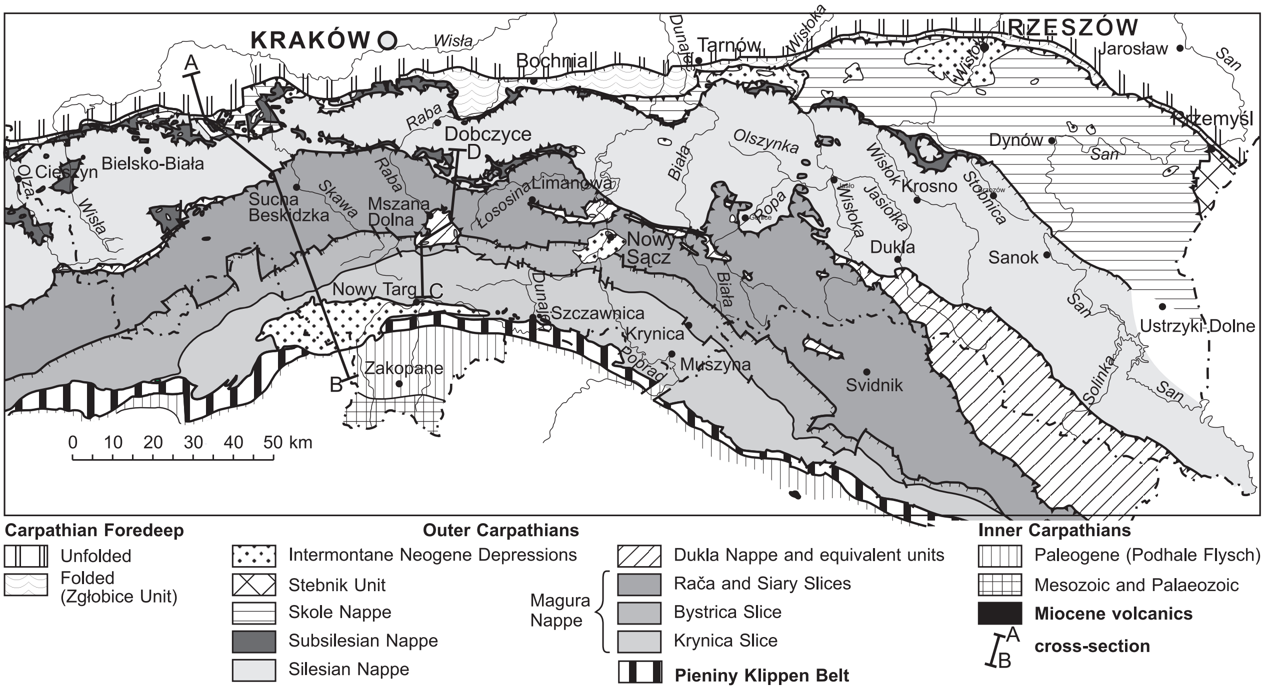
Itinerary: Zakopane – Maruszyna – Nowy Targ – Obidowa – Rabka – Mszana Dolna – Skrzydlna – Poręba Górna – Tylmanowa – Szczawnica Spa – Zabaniszcze – Czorsztyn – Snozka Pass-Wżar – Zakopane

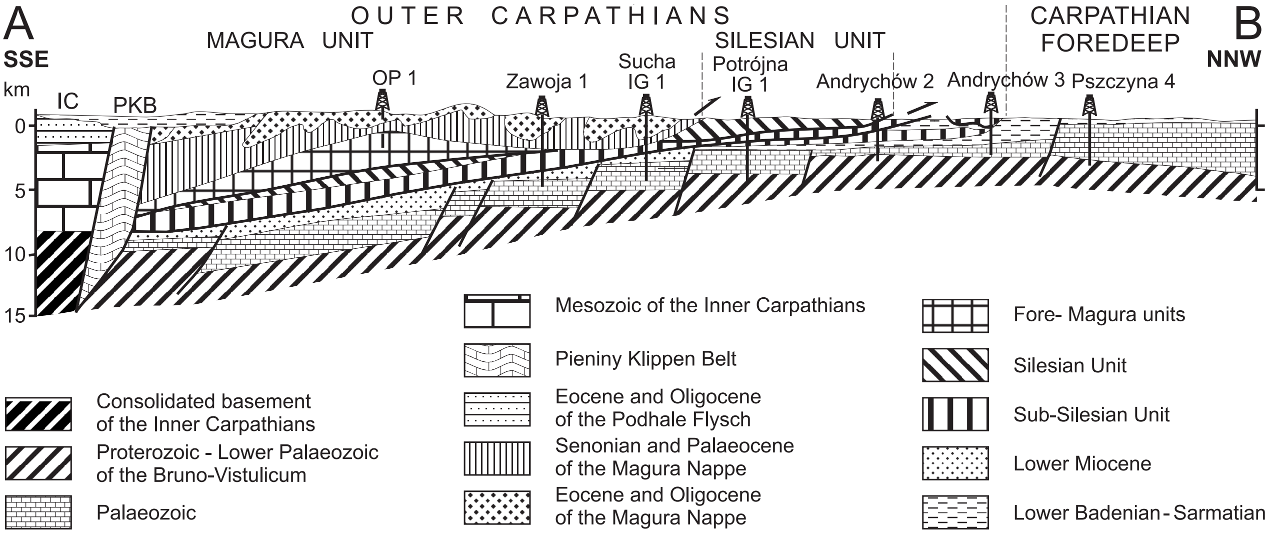
Regional setting

The Polish Carpathians are a part of the great arc of mountains, which stretches for more than 1300 km from the Vienna Forest to the Iron Gate on the Danube. In the west, the Carpathians are linked with the Eastern Alps and, in the east they pass into the Balkan chain. Traditionally, the Western Carpathians have been always subdivided into two distinct ranges. The Inner Carpathians are considered the older range and the Outer Carpathians the younger one (Fig. 1) (Książkiewicz 1977). The Inner Carpathians are regarded as a prolongation of the Northern Calcareous Alps, and formed part of the Apulia Plate in regional sense that is a promontory of the African Plate (Picha et al. 2005 and references therein). Sedimentation in the Inner Carpathians was mainly calcareous, and took place from the Early Triassic to the mid-Cretaceous. The Inner Carpathians were folded during the Late Cretaceous tectonic movements.

Between the Inner and Outer Carpathians the Pieniny Klippen Belt (PKB) is situated. It is Tertiary strike-slip boundary, which is a strongly tectonized terrain about 800 km long and 1–20 km wide (Birkenmajer 1986). The Outer Carpathians are built up of stacked nappes and thrust-sheets, which reveal different lithostratigraphy and structure (Figs. 1, 2). The Outer Carpathians are composed of the Late Jurassic to Early Miocene mainly turbidite (flysch) deposits, completely uprooted from their basement. The largest and innermost unit of the Outer Carpathians is the Magura nappe – a Late Oligocene/Early Miocene accretionary wedge. The Magura nappe is flatly overthrust onto the Moldavides (Ślączka et al. 2005 and references therein) - an Early/Middle Miocene accretionary wedge, which consists of several nappes: the Fore–Magura–Dukla group, Silesian, Sub-Silesian, Skole and Boryslav-Pokuty units. In the Outer Carpathians the main decollement surfaces are located at different stratigraphic levels. The Magura nappe was uprooted from its substratum at the base of the Turonian-Senonian variegated shales (Oszczypko 1992), whereas the main decollement surfaces of the Moldavides are located in the Lower Cretaceous black shales. All the Outer Carpathian nappes are flatly overthrust onto the Miocene deposits of the Carpathian Foredeep (see Oszczypko and Tomaś 1985, Ślączka et al. 2005 and references therein). However, along the



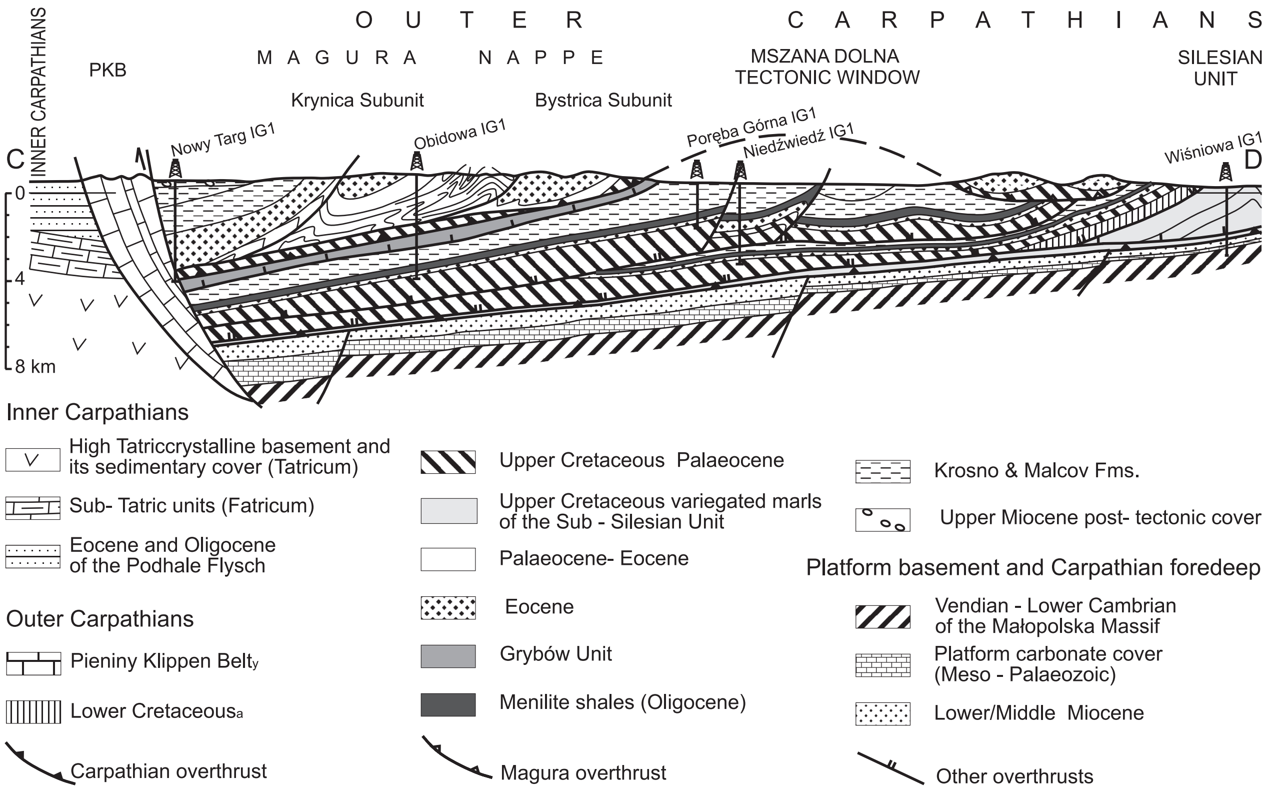
■ **Fig. 1.** Geological map of the Polish Carpathians (based on Żytko et al. 1989).



■ **Fig. 2.** Geological cross-section Orawa-Sosnowiec (after Oszczypko et al. 2005).

frontal Carpathian thrust a narrow zone of folded Miocene deposits developed [Stebnik (Sambir) and Zgłobice units (Figs.1, 2)]. The detachment levels of the folded Miocene units are connected with the Lower and Middle Miocene evaporites.

The basement of the Carpathian Foredeep represents the epi-Variscan platform and its cover (Oszczypko et al. 1989, 2005). The depth to the platform basement, recognized by boreholes, changes from a few hundred metres in the marginal part of the foredeep up to more than 7000 m beneath the Carpathians (Figs. 1, 2, 3). The magneto-telluric soundings in the Polish Carpathians have revealed a high resistivity horizon, which is connected with the top of the consolidated – crystalline basement (Ślączka et al. 2005 and references therein). The depth of the top of magneto-telluric basement reaches about 3–5 km in the northern part of the Carpathians, drops to approximately 15–20 km at its deepest point and then peaks at 8–10 km in the southern part. The axis of the magneto-telluric low coincides, more or less, with the axis of gravimetric minimum. South of the gravimetric minimum and, more or less parallel to the PKB, the zone of zero values related to of the Wiese vectors, was recognised by geomagnetic soundings (Ślączka



■ **Fig. 3.** Geological cross-section Nowy Targ IG 1 – Wiśniowa IG 1 (after Oszczypko 2004) et al. 2005 and references therein). This zone is connected with a high conductivity body occurring at the depth of 10–25 km and is located at the boundary between the North European Plate and the Central West Carpathian Block. In the Polish Carpathians, the depth to the crust-mantle boundary ranges from 37–40 km at the front of the Carpathians and increases to 54 km towards the south and then, peaks along the PKB at 36–38 km (Oszczypko 2004).

The deep seismic reflection profile 2T was located southwest from the Polish state boundary, (Golonka et al. 2005a). In the north of Pieniny Klippen Belt, this profile demonstrates two groups of south dipping reflectors, which are probably related to the Middle Miocene subduction of the Moldavides (Tomek and Hall 1993, Bielik et al. 2004). The upper reflection between 1–3 s (ca. 4.5 to 8 km) belongs to a plate boundary between the upper nappe (the Magura-PKB terrain), and the lower accretionary wedge complex (Dukla-Silesian-Subsilesian group of units). The lower reflectors represent the crystalline basement of the lower plate (North European Plate), and its sedimentary cover.

During the excursion the following Outer Carpathian units will be passed: The Magura Nappe, Dukla-Grybów units (Mszana Dolna tectonic window) and Silesian/Sub-Silesian units

Outer Carpathians

The Outer Carpathians are built up of a stack of nappes and thrust sheets\spreading along the Carpathians, consisting mainly of up to six kilometers thick continuous flysch sequences of Jurassic to Early Miocene time span. All the Outer Carpathian nappes are overthrusted onto the southern part of the North European Plate (Figs. 1, 2, 3) and covered by the autochthonous Miocene deposits of the Carpathian Foredeep at the distance of 70 km at least (Książkiewicz 1977, Oszczypko 2004, Ślączka et al. 2005 and references therein). Boreholes and seismic data indicate that the Carpathian overthrust extends at the distance at least of 60 km (Fig. 1, 2, 3). During overthrusting, the northern Carpathians nappes became uprooted from the basement and only their basinal parts were preserved. A narrow zone of folded Miocene deposits, developed along the frontal Carpathian thrust and known as the Zgłobice-Wieliczka Unit in the Northern Carpathians has its equivalent in the Subcarpathian (Borislav or Sambir-Rozniatov Unit of the Ukrainian part) and Romanian parts of the Eastern Carpathians (Książkiewicz 1977, Ślączka et al. 2005 and references therein). From the North to the South, the succession of nappes from the lowest to the highest one includes Skole (Skiba) Nappe (mainly easternmost part of Carpathians), Subsilesian Nappe, Silesian Nappe, Fore-Magura group of nappes and Magura Nappe (Figs. 1, 2, 3).

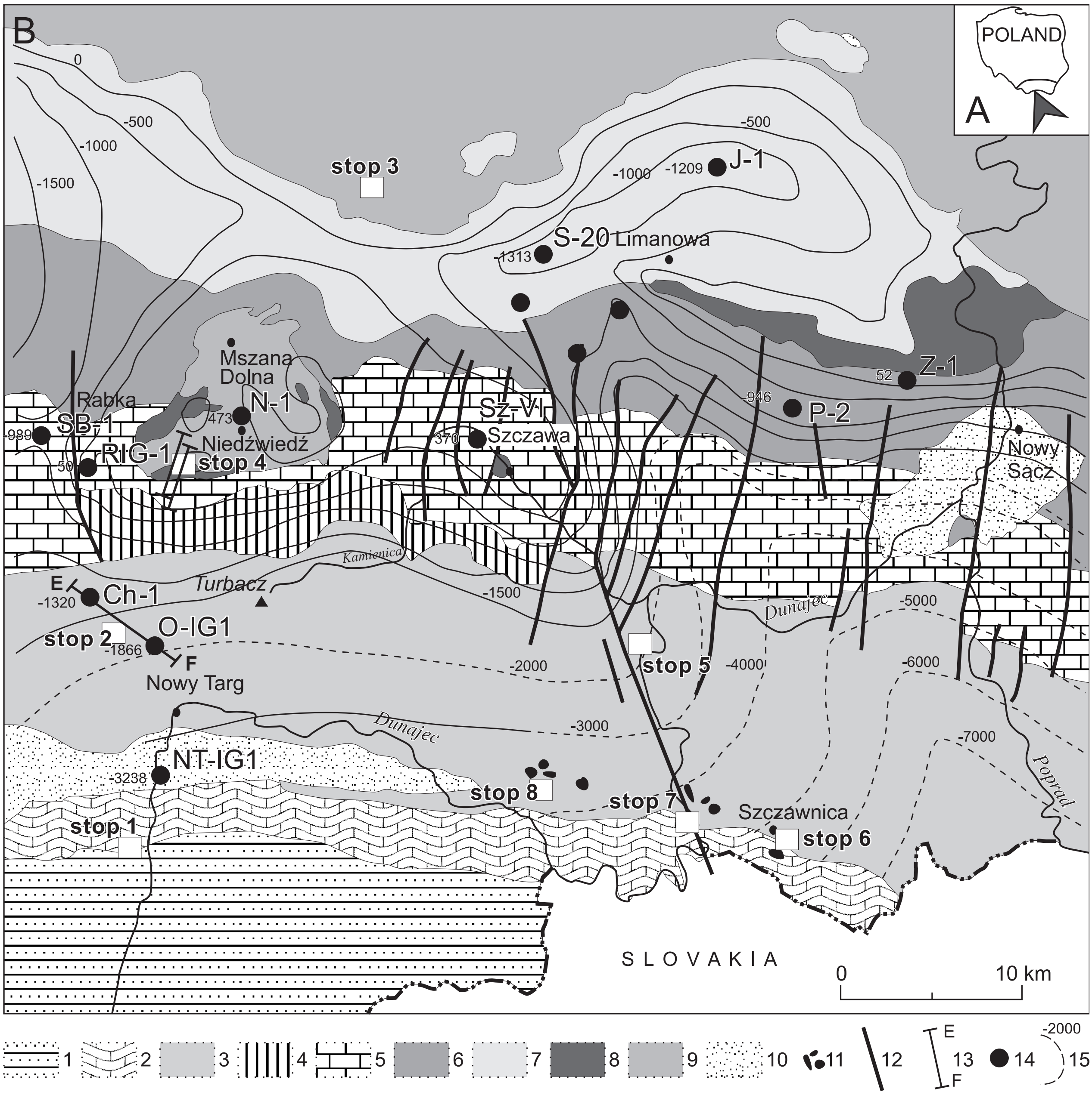
The **Skole Nappe** (Ślączka et al. 2005 and references therein) occupies a large area in the northeastern part of the Polish Outer Carpathians. Towards the east on the territory of Ukraine, it goes to be wider but towards the west, its width diminishes until it eventually disappears from surface, plunging beneath the Silesian and Subsilesian Nappes. The Skole Nappe consists of several narrow elongated thrust folds. There is predominance of the Oligocene Menilite and Krosno beds cropping out on the surface in the inner zone of this unit while outer is mainly built of Cretaceous strata. In the Skole Basin sedimentation started not later than in Hauterivian. Shales and marls (the Belwin Marls) and black shales (the Spas Beds) represent lower Cretaceous.

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

The **Andrychów Ridge** unit is represented by several huge blocks in the boundary between the Silesian and Subsilesian units, near Andrychów Town. Probably they are remnants of carbonate platform, which has been situated between Silesian and Subsilesian sedimentary areas, or represent a part of Subsilesian substratum. The composition of klippes differs from the adjacent units, although the Upper Cretaceous sediments show some similarity to the sequences of the Subsilesian Unit. The non-flysch, calcareous facies are very characteristic of the Andrychów Ridge sequences (Książkiewicz 1951, Gasiński 1998). The basement of the ridge consisted of granite-gneiss or mylonitised rocks of unknown age. Crinoidal and shallow water Middle-Upper Jurassic limestones represent the sedimentary sequences. Transgressive Lower Campanian conglomerates as well as marls, limestones and shaly marls of Campanian and Maastrichtian age cover these. Organogenic limestones and shales represent Palaeocene and Lower Eocene. The more basinal or slope facies are developed as the Maiolica-type Upper Jurassic-Lower Cretaceous cherty limestones (Olszewska and Wieczorek 2001).

The **Silesian Nappe** occupies central part of the Outer Carpathians, pinching out from below of the most internal nappes. Sedimentary facies of the Silesian Nappe represent continuous succession of deposits from the Upper Jurassic to the Lower Miocene. In the Western Carpathians, the oldest sediments of the Silesian Nappe are known in Moravia and Silesia areas only. They consist of Kimmeridgian-Lower Tithonian dark grey, calcareous mudstones (Lower Cieszyn Shales), which begin euxinic cycle that has lasted without notable gaps until Albian. Some of these mudstones represent slump deposits. The mudstones pass upwards into turbiditic limestones and marls namely 200 m thick Cieszyn Limestones of Tithonian-Berriasian age. The material of the detritic limestones was derived from the neighboring and northerly-situated shallow water, carbonate platforms. The younger, Valanginian-Hauterivian dark grey, black calcareous shales with intercalations of dark, thin and medium bedded, calcareous sandstones (Upper Cieszyn Shales, up to 300 meters thick) are known from the whole Silesian Unit. Barremian-Aptian black shales (Verovice Shales, up to 300 meters) overlie them. During the Hauterivian and Barremian time, several complexes (up to 200 meters thick) of sandstones and conglomerates have developed (Grodziszcze Sandstones). There are evidences that the Silesian and Subsilesian basins have been connected in the Cretaceous time.

The **Magura Nappe** is the largest and innermost tectonic unit of the Western Carpathians and is linked with the Rheno-Danubian flysch of the Eastern Alps. During the overthrust movements, the Magura Nappe has been completely uprooted from its substratum along the ductile Upper Cretaceous rocks. The oldest Jurrassic-Lower Cretaceous rocks are only found in this part of the Magura basin which was incorporated into the Pieniny Klippen Belt (i.e. the Grajcarek Unit, see Birkenmajer 1977, see also Oszczypko et al. 2004).



■ **Fig. 4. A** – Position of the investigated area. **B** – Sketch-map of the middle part of the Polish Carpathians (after Oszczypko et al. 1999a, Oszczypko-Clowes and Oszczypko 2004). 1 – Podhale Flysch, 2 – Pieniny Klippen Belt; Magura Nappe: 3 – Krynica Subunit, 4 – Tobołów-Turbaczyk thrust sheet, 5 – Bystrica Subunit, 6 – Rača Subunit, 7 – Siary Subunit, 8 – Grybów Unit, 9 – Dukla Unit, Silesian & Sub-Silesian units, 10 – Miocene onto the Carpathians, 11 – Miocene andesites, 12 – faults, 13 – cross section, 14 – boreholes, 15 – isobathe of the Magura nappe overthrust.

Stratigraphy and tectonics. The Albian /Cenomanian spotty shales remained in the southern margin of the Mszana Dolna tectonic window (Oszczypko et al. 2005b). More recently, Hauterivian-Albian deposits have been recognised in a few localities in Southern Moravia. On the basis of facial differentiations with regards to the Palaeogene deposits, the Magura Nappe has been subdivided into four facies-tectonic subunits: the Krynica, Bystrica (Nowy Sącz), Rača and Siary (Fig. 1). The Upper Cretaceous-Palaeogene deposits of the Magura Nappe may be subdivided into three turbidite complexes: the Campanian/ Maastrichtian-Palaeocene, Lower-Upper Eocene, and Upper Eocene-Lower Oligocene. Each of them begin with pelitic basinal deposits (variegated shales) which pass into thin-and medium-bedded turbidites with intercalations of allodapic limestones /marls, and then into thick-bedded ones. Finally, there are thin-bedded turbidites. In the Krynica, Bystrica and Rača subunits the youngest deposits of the Eocene complex belong to the Magura Fm., which is of Lower-to Upper Eocene age (Birkenmajer and Oszczypko 1989, Oszczypko 1991). This formation is reached in the Krynica Subunit, 1200 to 1400 m thickness and at least 500–2000 in the Bystrica and 1000 m in the Rača subunit.

The Magura Fm. is represented by the thick-bedded turbidites and fluxoturbidites. The Globigerina marls (Upper Eocene-Lower Oligocene), Menilite shales and the Malcov Fm (Late Oligocene), locally overlay the Magura Fm. In the northernmost part of the Magura Nappe (Siary subunit) the youngest deposits are composed as the thick-bedded glauconitic sandstones (Wątkowa Sandstones) of the Lower Oligocene age, and finally by marls with intercalations of glauconitic sandstones (Budzów Beds, Oligocene). Traditionally, the Oligocene Malcov Formation was regarded as the youngest strata of the Magura nappe. However, in the peri-Pieniny Klippen Belt area and the vicinity of Nowy Sacz the Early Miocene flysch deposits have recently been discovered (see Oszczypko et al. 1999a, Oszczypko and Oszczypko-Clowes 2002, Oszczypko et al. 2005c and bibliography therein).

The Magura Nappe is flatly thrust over its foreland, built up of the Fore-Magura group of units and partly by the Silesian Unit (Figs. 1, 2, 3). The amplitude of the overthrust is at least 50 km, and the post Middle Badenian thrust displacement is more than 12 km. The northern limit of the nappe has an erosional character, whereas the southern coincides with a more or less vertical strike-slip fault along the northern boundary of the PKB. The thrust developed mainly within the ductile Upper Cretaceous variegated shales. The sub-thrust morphology of the Magura foreland is very distinctive. The shape of the northern limit of the Magura Nappe and the distribution of tectonic windows inside the nappe are connected with denivelation of the Magura basement. As a rule, the “embyemets” of the marginal thrust are related to transversal bulges in the Magura basement, whereas the “peninsulas” are located in the depression of basement. At a distance of 10–15 km south from the northern limit of the unit the zone of the tectonic windows, connected with uplifted Fore-Magura basement, is located. The biggest is the Mszana Dolna tectonic window, situated in the middle part of the Polish Carpathians. This tectonic window developed as the duplex structure during the Middle Miocene thrusting of the Magura Nappe. South of the zone of tectonic windows the inclination of the Magura thrust surface increases, and at the northern boundary of PKB the thickness of the Magura Nappe is more than 5 km. The Magura Nappe has been subdivided into four structural subunits (thrust sheets) namely the Krynica, Bystrica (Nowy Sącz), Rača and Siary (Fig. 1). These subunits coincide, largely, with the corresponding facies zone. In the Magura accretionary prism, three structural complexes can be distinguished: the Late Cretaceous-Palaeocene, the Early to Late Eocene, and the Oligocene to Early Miocene. These complexes revealed a decreasing degree of tectonic deformation from the base to the top of the nappe. The basal part of the nappe, built up of Upper Cretaceous-Palaeocene flysch rocks is strongly deformed in the area surrounding the Mszana Dolna and Szczawa tectonic windows. The broad W-E trending synclines and narrow anticlines dominate in Lower to Upper Eocene flysch of the Rača and Krynica subunits. The southern limbs of synclines are often reduced and overturned. In the Bystrica (Nowy Sącz) Subunit, sub-vertical thrust-sheets are common. Both the northern limbs of the anticlines and southern limbs of the synclines are tectonically reduced and usually overturned. The youngest (Malcov Fm, Late Eocene–Early Oligocene), weekly deformed, deposits of the Magura Nappe uconformably overlaid the older Eocene flysch deposits in the Krynica and Rača subunits.

Tectonic evolution. The Magura Basin was probably located on the oceanic floor and/or the thinned continental crust, and began to develop during the Liassic-Dogger continental rifting (Oszczypko, 1992, 1999). That rift was relocated into the Silesian Basin during the Early Tithonian. This event was followed by a long-lasting Berriasian-Cenomanian (35 my) period of basin expansion, and deep-water pelagic deposition, probably connected with passive thermal subsidence. This period was characterised by very low rates of sedimentation (0.5–5 m/my). Before the Albian, the Magura Basin was separated from the Silesian Basin by the Protho-Silesian submerged ridge, but during the Cenomanian – Turonian time there was a unification of sedimentary conditions in the whole basin of the Outer Carpathians, and radiolarian shales were deposited. At the turn of Cenomanian, radiolarian shales followed by red clays with intercalations of basinal turbidites were deposited below the CCD. In the northern and middle part of the Magura Basin this type of sedimentation persisted up to the Campanian, whereas in the Krynica zone until the Maastrichtian. The rate of sedimentation of variegated shales oscillated between 15 to 25 m/my. During the Maastrichtian/Palaeocene time, a considerable reorganisation of the Magura Basin took place. This was connected both with compression at the southern margin of the basin and an inversion of the forbulge at the northern margin (Silesian uplifted ridge). It was accompanied by a deposition of the Upper Senonian-Palaeocene flysch (so called Inoceramian beds). The rate of sedimentation oscillated between 50 and 75 m/my. Since the Palaeocene/Early Eocene, the accretionary prism has begun to develop in the southern margin of the Magura Basin, close to folded and thrust Pieniny Klippen Belt. The moving load, in front of this accretionary prism, has caused subsidence and a progressive northward shift of depocentres. The Early Eocene axis of deposition was located in the Krynica zone, and then during the Middle and Late Eocene migrated northward, towards the Bystrica and Rača zones respectively. In this part of the basin narrow and very long submarine fan (few hundred km) was formed. The clastic immature material of the fan was supplied from a southeast direction, and was derived from an erosion of the exposed part of the accretionary prism. During the Early to Middle Eocene time, the deepest part of the basin, often beneath the CCD, was located in the northern part of the basin. The rate of sedimentation varied from 10–15 m/my on the abyssal plain, to 75–100 m/my in the outer fan and, between 200 to 300 m/my in the area affected by middle fan-lobe system. Simultaneously along the northern margin of the basin (Siary zone), small fans developed. During the Late Eocene, the southern part of the Magura basin was involved in submarine folding, caused by a southward subduction of the Magura Basin beneath the Pieniny Klippen Belt/Central Carpathian Block. Late Eocene to Early Oligocene subsidence and an intensive deposition in the Siary zone, supplied from the Silesian Ridge by mature glauconite sandstones and massive turbidite marls, followed this event. After the Late Oligocene folding, the Magura Nappe was thrust northwards and during Burdigalian its front reached the S part of the Silesian basin. These movements were almost contemporaneous with that of the Northern Calcareous Alps and Rhenodanubian Flysch. Simultaneously the southern part of the Magura Nappe was transformed into the piggy-back basin flooded during the Early Burdigalian high stand of sea-level. The Early Burdigalian rise in sea level enabled the connection between the Magura piggy-back basin and the Vienna basin via Orava. In the Magura piggy-back basin occurred the deposition of Kremna facies close to PKB and the Zawada Formation in the more northern part of the basin (see Oszczypko et al. 1999a, Oszczypko and Oszczypko-Clowes 2002, Oszczypko et al. 2005c). The terminal flysch deposition in the Krosno basin and the Magura piggy-back-basin was followed by the Intra-Burdigalian folding, uplift and overthrust of the Outer Carpathians onto the foreland platform (Oszczypko 1997, 1998, Kovač et al. 1998).

Pieniny Klippen Belt

Outline of geology

The Northern Carpathians are subdivided into an older range known as the Inner Carpathians and the younger one, known as the Outer or Flysch Carpathians (Figs. 1, 2). The Pieniny Klippen Belt (PKB) is situated at the boundary of these two ranges. The Inner Carpathians nappes contact along a Tertiary strike-slip boundary with Pieniny Klippen Belt.

The relationship between Pieniny Klippen Belt and the Magura Nappe changes along the PKB strike. In the Vah and Orava valleys these two units are divided by the Miocene sub-vertical strike-slip fault and both units are involved in the complex flower structure. Present day confines of the Pieniny Klippen Belt are strictly tectonic. They may be characterized as a (sub)vertical faults and shear zones, along which a strong reduction of space of the original sedimentary basins took place. The NE-SW striking faults accompanying the Klippen Belt have the character of lateral slips. It is indicated by the presence of flower structures on the contact zone of the Magura Unit and the Klippen Belt, or by the structural asymmetry of the Inner Carpathian Palaeogene Basin.

The tectonic character of the Polish section of PKB is mixed. Both the strike slip and thrust components occur here (e.g. Książkiewicz 1977, Birkenmajer 1986, Golonka et al. 2005b and references therein). In general the subvertically arranged Jurassic-Lower Cretaceous basinal facies display the tectonics of the diapir character originated in the strike-slip zone between two plates. The ridge facies are often uprooted and display thrust or even nappe character. The Niedzica Succession is thrust over the Czorsztyn Succession, while the Czorsztyn Succession is displaced and thrust over the Grajcarek Unit (e.g. Książkiewicz 1977, Birkenmajer 1986, Golonka et al. 2005a, b and references therein). The Grajcarek Unit is often thrust over the Krynica Sub-Unit of the Magura Nappe. The Upper Cretaceous-Palaeogene flysch sequences of the Złatne Furrow (Birkenmajer 1986, Golonka et al. 2005a, b and references therein) are often thrust over the various slope and ridge sequences. In the East Slovakian section of the PKB, the back-thrusts of the Magura Nappe onto PKB, as well as PKB onto the Central Carpathian Palaeogene, are commonly accepted (Golonka et al. 2005 a,b and references therein). The PKB tectonic components of different age, strike-slip, thrust as well as toe-thrusts and olistostromes mixed together, are giving the present-day melange character of the PKB, where individual tectonic units are hard to distinguish.

The Pieniny Klippen Belt is composed of several **successions** of mainly deep and shallower-water limestones, covering a time span from the Early Jurassic to Late Cretaceous (Birkenmajer 1977, 1986, Golonka and Krobicki 2004, Golonka et al. 2005 a, b and references therein). This strongly tectonized structure is about 600 km long and 1–20 km wide, stretching from Vienna to the West, to Romania to the East.

During the Jurassic and Cretaceous within the Pieniny Klippen Basin the submarine Czorsztyn Ridge (= "pelagic swell", mainly so-called Czorsztyn Succession) and surrounding zones formed an elongated structure with domination of pelagic type of sedimentation (Birkenmajer 1977, 1986, Golonka and Krobicki 2004, Wierzbowski et al. 1999, Golonka et al. 2005 a, b and references therein). The Pieniny Klippen Basin trends SW to NE (see discussion in Golonka and Krobicki 2001, 2004). Its deepest part shows the presence of deep water Jurassic-Early Cretaceous deposits (pelagic limestones and radiolarites) of Złatna Unit (Golonka and Sikora 1981, Golonka and Krobicki 2001, 2004). Somewhat shallower sedimentary zones known as the Pieniny, Branisko (Kysuca) successions have been located close to central furrow. Transitional slope sequences between basinal units and ridge units are known as Czertezik and Niedzica successions (Podbiel and Pruské successions in Slovakia) near the northern (Czorsztyn) Ridge, and Haligovce-Nižná successions near the southern so-called Exotic Andrusov Ridge (Birkenmajer 1977, 1986, Golonka et al. 2005 a, b and references therein). The strongly condensed Jurassic-Early Cretaceous pelagic cherty limestones (Maiolica-type facies) and radiolarites of the Grajcarek Unit were also deposited in north-western Magura Basin.

Geodynamic evolution

The **earliest stage** of the basin history is enigmatic and documented only by pebbles in the Cretaceous-Tertiary flysch. These pebbles indicate the possibility of an existence of an enigmatic embayment of the Vardar-Transilvanian Ocean which separated the Tisa (Bihor-Apuseni) block from the Moesian-Eastern European Platform (Golonka 2004). The pelagic Triassic limestones in the exotic pebbles in the Pieniny Klippen Belt 1990) and Magura Unit could have originated in this embayment (Golonka et al. 2005 b and references therein) The embayment position and its relation to the other parts of Tethys, Vardar Ocean, Meliata-Halstatt Ocean, Dobrogea rift remain quite speculative. The Pieniny rift opened during Pliensbachian – Aalenian time forming a part of the global system related to the opening of the Alpine Tethys. The Alpine Tethys, that is Ligurian, Penninic and Pieniny/Magura Oceans constitute the extension of the Central Atlantic system (Golonka 2004). The basins' opening is related to the closure of the Meliata Ocean. The restricted environment prevailed in this newly formed basin. The synrift stage lasted in the Pieniny/Magura Basin from late Early Jurassic to Tithonian.

Generally, the Pieniny Klippen Basin sedimentary history is tripartite (i-iii) – from the (i) oxygen-reduced dark/black terrigenous deposits of the Early-early Middle Jurassic age (Gresten-type and Fleckenkalk/Fleckenmergel facies) trough (ii) Middle Jurassic-earliest Cretaceous crinoidal, nodular (of the ammonitico rosso type) or cherty (of the Maiolica = Biancone type) limestones and radiolarites up to the (iii) Late Cretaceous pelagic marls (i.e. Scaglia Rossa = Couches Rouge = Capas Rojas) facies and/or flysch/flyschoidal series (i.a. Birkenmajer 1986, Golonka and Krobicki 2004, Golonka et al. 2005b and references therein).

The **oldest Jurassic** rocks of the Pieniny Klippen Belt (e.g., Birkenmajer 1977, Krobicki et al. 2003, Golonka and Krobicki 2004 and references therein) consist of different type of Gresten-like dark/black sediments (Hettangian-Sinemurian). Spotty limestones and marls of oxygen-depleted, widespread Tethyan Fleckenkalk/Fleckenmergel-type facies (Pliensbachian – Early Bajocian in age) and Bositra ("Posidonia") black shales with spherosiderites (Birkenmajer 1986) overlay them.

One of the most rapid changes of sedimentation/paleoenvironments within this basin took place during Early Bajocian (**Middle Jurassic**) when well-oxygenated multicoloured crinoidal limestones replaced dark and black deposits of Early-early Middle Jurassic age (Birkenmajer 1986, Wierzbowski et al. 1999, Golonka and Krobicki 2004). Sedimentation of younger (from latest Bajocian) red nodular ammonitico rosso-type limestones was an effect of Meso-Cimmerian vertical movements which resulted in subsidence of the Czorsztyn Ridge and produced tectonically differentiated blocks, and associated neptunian dykes and scarp-breccias (e.g. Birkenmajer 1986, Wierzbowski et al. 1999, Aubrecht and Tunyi 2001, Golonka et al. 2003).

The formation of the Czorsztyn Ridge within the Pieniny/Magura Basin took place during the spreading phase in the Bajocian. In the same time the radiolarite sedimentation appeared in the axial, basinal sequences of PKB (Birkenmajer 1977, Wierzbowski et al. 2004). This strongly contrasted facies pattern between basinal and ridge successions have existed throughout Jurassic and Early Cretaceous times.

Late Jurassic (Oxfordian-Kimmeridgian) history of the PKB reflects strong facial differentiation within sedimentary basin where contrasted siliceous to carbonate sedimentation took place. This may be at least partly attributed to radical and fast paleogeographic evolution of the Pieniny Klippen Basin, as indicated by recent palaeomagnetic results in its eastern section (Lewandowski et al. 2003a, 2005). Greatest deepening effect is indicated by widespread Oxfordian radiolarites which occur in the all the basinal and transitional successions, whereas the shallowest one (Czorsztyn Succession) is completely devoid of siliceous intercalations showing sedimentation of ammonitico rosso facies.

The Czorsztyn Succession during **latest Jurassic–earliest Cretaceous** time (Tithonian-Berriasian) consisted of hemipelagic to pelagic organogenic carbonate deposits of medium depth, for example ammonite coquinas and white and creamy *Calpionella*-bearing limestones. Several tectonic horsts and grabens were formed, rejuvenating some older, Eo- and Meso-Cimmerian faults (Birkenmajer 1986, Golonka and Krobicki 2004 and references therein). Such features resulted from the intensive Neo-Cimmerian tectonic movements and have been documented by rapid facies pattern changes, hardgrounds and condensed beds with ferromanganese-rich crusts and/or nodules, sedimentary-stratigraphic hiatuses, sedimentary breccias and/or neptunian dykes, and/or fauna redeposition (Birkenmajer 1986, Krobicki 1996, Golonka and Krobicki 2001, Golonka et al. 2003 and references therein). In the same time within deeper successions (mainly Branisko and Pieniny ones) cherty limestone of maiolica-type (= biancone) facies deposited (Birkenmajer 1977, Golonka et al. 2003 and references therein). These white-gray, micrite well bedded calpionellids-bearing limestones built now highest part of the Pieniny Mts (e.g., Trzy Korony Mt, Sokolica Mt etc).

During the **Tithonian** time, subduction jumped to the northern margin of the Inner Carpathian terranes and began to consume the Pieniny Klippen Ocean (Birkenmajer 1986). The Tethyan plate reorganization resulted in extensive gravitational fault movement.

Lower Cretaceous (Berriasian and Valanginian) rocks are represented by both pelagic, maiolica-type cherty limestones as basinal facies and more shallow-water different type of organodetritic rocks (brachiopod-crinoidal limestones and/or crinoidal limestones).

Deeper facies have continued sedimentation in younger time, whereas shallower one manifested a numerous breaks of sedimentation. Latest Early Cretaceous deposits are connected with first step of unification of sedimentation within Pieniny Klippen Basin (Birkenmajer 1977).

Upper Cretaceous pelagic deposits dominated by scaglia rossa pelagic, foraminiferal, multicoloured green/variegated/red marl deposits originated during the latest, third episode of evolution of the Pieniny Klippen Basin (Birkenmajer 1977, 1986). Flysch and/or flyschoidal facies are younger (Santonian-Campanian) with several episodes of debris flows with numerous exotic pebbles (Late Albian-Early Campanian) (Birkenmajer 1986, Golonka and Krobicki 2004, Golonka et al. 2005b and references therein).

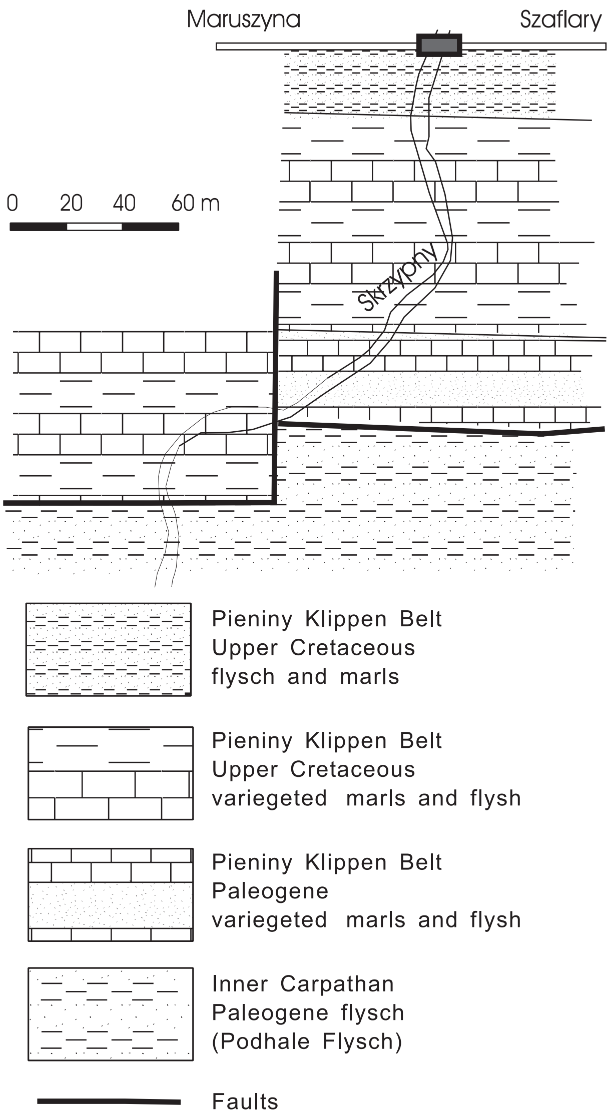
With the development of the Inner Carpathian nappes, forearc basin was formed between the uplifted part of the IC terrane (so-called Andrusov ridge) and the subduction zone. The flysch of the Klappe and Złatne successions was formed in this area. Behind the ridge, the Manin Succession was deposited within the back-arc basin. The Pieniny Klippen Belt Basin was closed at the Cretaceous/Tertiary transition as an effect of a collision between Czorsztyn ridge and European Platform. The accretionary prism had overridden the Czorsztyn Ridge. The subduction zone moved from the southern margin of the Pieniny Klippen Belt Ocean to the northern margin of the Czorsztyn Ridge (Golonka et al. 2005b, Oszczypko et al. 2005c and references therein).

The Pieniny Klippen Belt was finally formed as the melange in the suture zone between Inner Carpathian-Alpine (Alcapa) terrane and the North European plate. Part of allochthonous Outer Carpathian units and perhaps fragments of basement were also located in this suture zone. With the eastward movement of the Alcapa plate, system of strike-slip faults originated. Good visible effect of several tectonic phases of folding and deformations within Pieniny Klippen Belt is geomorphologic view of tectonically isolated klippes of Jurassic and Cretaceous hard rocks surrounded by softer shales, marls and flysch deposits. The last important event in the Pieniny Klippen Belt was **Middle Miocene (Sarmatian)** volcanism represented by calc-alkaline andesite dykes and sills which cut mainly Palaeogene flysch rocks of the Outer Carpathians (Magura nappe) and they formed so-called Pieniny Andesitic Line (PAL) (Birkenmajer 1986).

Stop 1. The Skrzypny Stream – Contact Between Pieniny Klippen Belt and Inner Carpathian Palaeogene

Jan GOLONKA

The Skrzypny Stream at the eastern border of Maruszyna village (fig. 5) displays limestones variegated shales, marls and flysch deposits of the Pieniny Klippen Belt succession (fig. 6) as well as sandstones and shales of the Inner Carpathian Palaeogene (fig. 7) (Podhale Flysch). The Maiolica-type cherty limestones of Pieniny Limestone Formation (Birkenmajer 1977) exposed below the bridge on Skrzypny Stream on the road between Szaflary and Maruszyna represent reduced latest Jurassic-Early Cretaceous sequence of Złatne Succession (see Golonka and Sikora 1981, Golonka et al. 2003, 2005b, Golonka and Krobicki 2004). Upstream in tectonic contact with the cherty limestones the series of Upper Cretaceous variegated shales, marls and flysch grey, grey-greenish and blue-greenish sandstones deposits is exposed (Fig. 6). These rocks belong to Złatne Succession sensu Golonka and Sikora (1981) or Maruszyna Succession (see Kostka 1993 and references therein). Southward the contact between Pieniny Klippen Belt and Inner Carpathian Palaeogene runs along the major strike slip fault. This fault was caused by rotation and movement of Inner Carpathian terrane (Golonka et al. 2003, 2005a, b) in relation with North European plate). The Pieniny Klippen Belt rocks were placed in the suture zone between two plates, displaying flower structure and tectonic mélange features. The Inner Carpathian Palaeogene



■ **Fig. 5.** Geological sketch of the Skrzypny Stream between Maruszyna and Szaflary. Podhale region, southern Poland.

■ **Fig. 6.** Deformed red marls of the Złatne Succession (Pieniny Klippen Belt). Skrzypny Stream, Podhale region, southern Poland.

■ **Fig. 7.** Deformed flysch rocks of the Szflary Beds (Inner Carpathian Palaeogene), near the strike-slip boundary with Pieniny Klippen Belt Skrzypny Stream, Podhale region, southern Poland.

flysch rock are only moderately deformed across in the central part of Podhale region, in the border zone, they are heavily deformed (fig. 7) due to the activity of the border strike-slip fault.

Passage: Skrzypne – Chabówka

Marek CIESZKOWSKI

From Skrzypne the route leads to Nowy Targ. It passes tectonic contact between the Pieniny Klippen Belt and the Magura Nappe, and goes northward to the Orava – Nowy Targ Depression. It is marked in morphology as a plane surrounded from the South by Podhale Upland and in Slovakia Oravska Magura range, and from the North by Babia Góra massif and Gorce range. The depression is situated at the border between the Inner and Outer Carpathians. Its origin has been caused by the collision of the Pannonian microplate (part of the Appulian plate) and North European platform, during its last stage after folding and thrusting of the Outer Carpathian nappes. The intermountain basin formed here is filled by the Late Miocene, Pliocene and Quaternary fresh water deposits. The highest summary thickness about one thousand meters deep been reached in the deep borehole Czarny Dunajec IG 1. Within the Miocene and Pliocene gravels, sands and clays are known occurrences of small seams of brown coal. On the plane, in the centre of the depression, several Quaternary peat bogs occur.

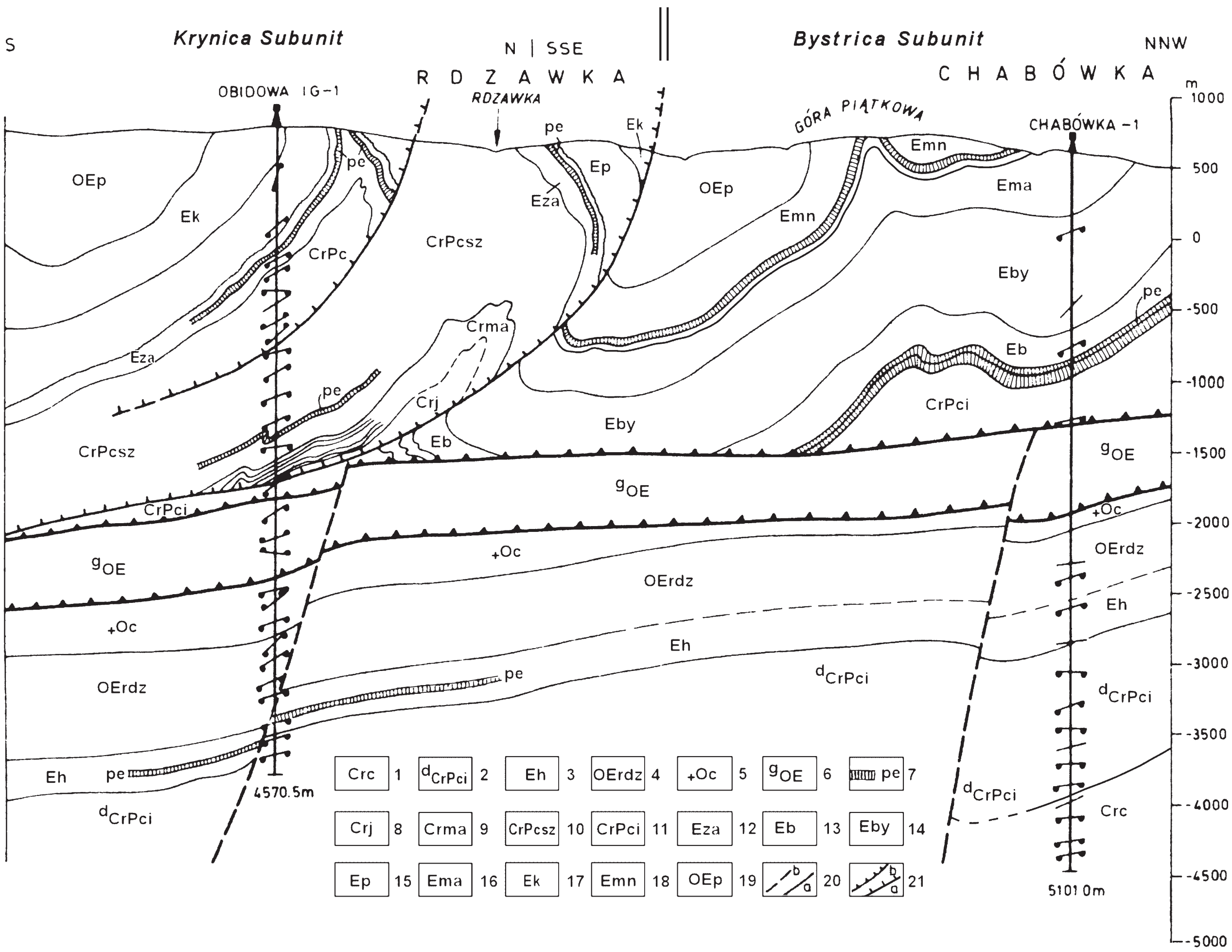
Between Nowy Targ and Rdzawka the route crosses the Krynica Subunit of the Magura Nappe. The Gorce mountains are well visible from the plane. There the soft morphology of their southern foothills at Nowy Targ and East of this town covered by fields and meadows, marks an occurrence of the thin-bedded shaly-sandstone flysch of the Malcov Formation (Cieszkowski and Olszewska 1986). Between Nowy Targ and Stare Bystre Miocene marine deposits, that overlain the Malcov Formatin has been discovered (Cieszkowski 1992, 1995). The higher parts of Gorce, covered by forests, are built of sandstones of the Magura Formation (Early Eocene–Early Oligocene). Following northwards, route is passing Klikuszowa village. There, on the right hand, is visible the quarry (Cieszkowski et al. 1998) with the outcrops of thick turbidites of the Poprad Sandstone Mb. (Late Eocene–Early Oligocene) which belongs to the Magura Formation. The rout follows uphill and at the top it passes in Rdzawka village where the Obidowa IG-1 deep borehole (see Fig. 3) is located. After about 3.5 km the route crosses the tectonic contact between the Krynica and Bystrica subunits. Here different lithostratigraphic divisions of the Krynica Subunit thrust over the Magura Formation of the Bystrica Subunit. Westwards of Rdzawka intersection of the thrust is well visible and easy for geological mapping, because there deposits of the Szczawnica and Zarzecze formations of the Krynica Subunit overthrust the Magura Fm. of the Bystrica Subunit. Westward is not so easy to fix the line of thrust, because the sandstones of the Magura Fm. of the Krynica Subunit contact directly with the same sandstones of the Bystrica Subunit. After about 1.5 km, on the area occupied by deposits of the Bystrica Subunit, near Chabówka village, is located stop no 2.

Stop 2. Chabówka: Structures of the Flysch Carpathians between Nowy Targ and Rabka

Marek CIESZKOWSKI

The stop 2 is located near the 17th century Holy Cross wooden church at Piątkowa Góra Mt. (715 m a.s.l.) close of Chabówka village (Cieszkowski 1985). The geological scenery of the surroundings includes three main tectonic units of the Magura Nappe: the Krynica Subunit on the South, Bystrica Subunit in the middle and Rača Subunit on the North. The formal lithostratigraphic inventory of the Magura Unit constitutes here mainly on divisions proposed by Oszczypko (Oszczypko and Birkenmajer 1989, Oszczypko 1991, Oszczypko et al. 2005b). The Krynica, Bystrica and Rača subunits have common older strata development as green spotted, partly radiolarian, Albian-Cenomanian shales (with manganiferous concretions) of the Jasień Formation, variegated Turonian-Early Senonian shales of the Malinowa Shale Formation, and the Late Senonian-Palaeocene deposits of the Inoceramian beds and similar to them the Szczawnica Formation. Differ lithostratigraphic development of Eocene and Oligocene deposits lets divide the subunits of the Magura Nappe. The Rača Subunit forms the highest mountains of Żywiec Beskid range – Babia Góra Mt. (1725 m asl) (the highest mount of the western sector of the West Outer Carpathians) and Polica Mt. (1369 m asl), as well as Beskid Wyspowy (Island Beskid) range with Zembalowa and Luboń Wielki (1113 m) in the east. It contains variegated shales of the Łabowa Formation (Early and Middle Eocene), the shaly-sandstone flysch of the Beloveža Formation – Hieroglyphic beds facies (Middle and Late Eocene) and thick-bedded “Magura sandstones” of the Magura Formation (Late Eocene-Early Oligocene). There inversion of morphology is well expressed by synclinal, weathering-resistant sandstones of the Magura Formation forming highest mountains, and by softer Upper Cretaceous-Middle Eocene sediments, included within anticlines, and forming valleys and passes.

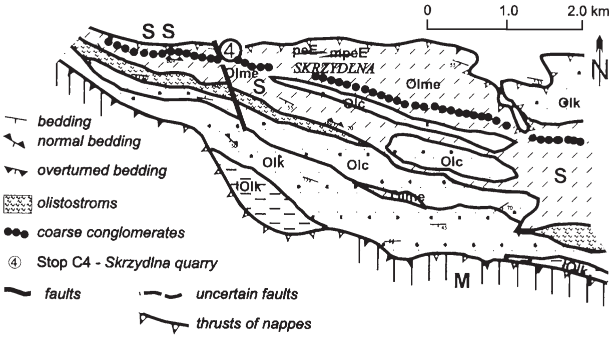
The Bystrica Subunit occupies a wide morphological Chabówka-Jordanów Depression and continues westward to the Orawa Depression. Eastwards it prolongs along the Raba River valley and northern slopes of the Gorce Range. Lithostratigraphic log of the Palaeogene deposits includes here: the Łabowa Shale Formation (Early Eocene), the Beloveza Formation (Early Eocene), the Żeleźnikowa and Bystrica formations (Middle or Middle-Early Eocene), both predominated by the Łącko marls lithotype, and Magura formation (Late Eocene-Early Oligocene). In the southern zone of the Bystrica Subunit the Magura sandstones occur earlier and the Magura Formation consists of three mem-



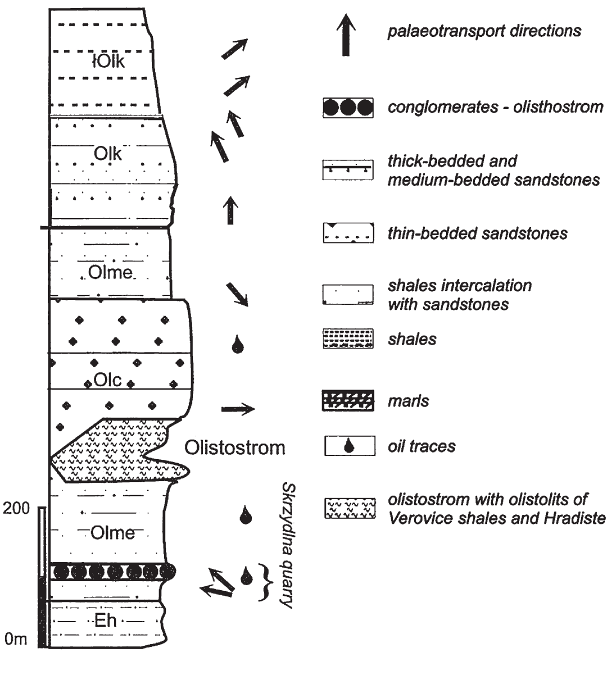
■ **Fig. 8.** Geological cross-section of the Outer Carpathian units between the deep drillings Obidowa IG-1 and Chabówka 1 (after Cieszkowski 1985, partly changed). Dukla Nappe, Obidowa-Słopnice Zone: 1 – Cisna andstones (Senonian), 2 – Inoceramian beds and Bukowiec Wielki sandstones, nondivided (Senonian-Palaeocene), 3 – Hieroglyphic beds (Late Palaeocene-Late Eocene), 4 – Rdzawaka beds (Late Eocene-Early Oligocene), 5 – Cergowa beds, shally facies (Early Oligocene); Grybów unit: 6 – nondivided Hieroglyphic, Menilitic (Grybów) and Cergowa beds (Middle Eocene-Early Oligocene); 7 – variegated shale intercalations in various Creaceous and Palaeogene strata; Magura Nappe, Krynica and Bystrica subunits: 8 – Jasień Formation (Cenomanian), 9 – Malinowa Shale Formation – variegated shales – (Turonian-Kampanian), 10 – Szczawnica Formation with Życzanów Sandstone Member (Kampanian-Palaeocene), 11 – Inoceramian beds (Late Senonian-Palaeocene), 12 – Zarzecze Formation, Krynica Sandstone Member (Early Eocene), 13 – Łabowa Shale Formation (pe) (Late Palaeocene-Early Eocene) and Beloveža Formation (Early Eocene), 14 – nondivided Bystrica and Żeleźnikowa formations (Middle Eocene), Magura Formation: 15 – Piwniczna Sandstone Member, 16 – Maszkowice Sadstone Member, 17 – Kowaniec Member, 18 – Mniszek Member, 19 – Poprad Member;Tectonic signatures: 20 – faults: a – proven, b – supposed; 21 – overthrusts: a – of nappes, b – of thrust-sheests.

bers; the Maszkowice Sandstone Mb., shaly-sandstone Beloveža-like flysch of Mniszek Member (Middle-Late Eocene) with level of variegated shales, and the Poprad Sandstone Member (Late Eocene–?Early Oligocene). Between Rabka and Spytkowice at the top of the Maszkowice Sandstone Mb. occurs olistostrome (Cieszkowski et al. 2003). There in the debris-flow consisting of coarse sandy and fine gravel material occur balls of fine-grain calcareous sandstone and olistholites of variegated shales or thin-bedded flysch.

The Krynica Subunit, forming the highest ranges of Gorce and Działy Orawskie ranges is characterized by extreme development of the Magura sandstone lithotypes. These sandstones appeared already in the Early Eocene and continued through the Middle and Late Eocene and Early Oligocene. North of Nowy Targ the Magura Fm. riches up to 2000 m in thickness. Above the Szczawnica Formation, which includes complex of thick bedded sandstones and conglomerates of Życzanów Mb., occurs the Zarzecze Formation (Early Eocene). Here, in the western section of the Gorce range, almost all thin- and medium-bedded flysch typical for this formation is replaced by thick bedded sandstones and conglomerates of the Krynica Sandstone Mb. The Magura Formation (Early Eocene–Early Oligocene) consists of three members: the Piwniczna Sandstone Mb., the Kowaniec beds (thick-bedded Magura sandstones with intercalations of the Hieroglyphic beds-like flysch and Łącko marls), and the Poprad Sandstone Mb., here more than 1000 m thick. The shale-sandstone Malcov Formation (Oligocene) and marly-sandstone Stare Bystre beds of Miocene age (Cieszkowski and Olszewska 1986; Cieszkowski 1992, 1995) overlie the Magura Formation. Both the Magura sandstone lithotypes occurs as intercalations.



■ **Fig. 9.** Geological scetch of the area of Skrzydlna (after Polak 2000). S – Silesian Nappe: *mpe*E – variegated marls (Eocene), *pe*E – variegated shales, Eh – Hieroglyphic beds – (Middle and Late Eocene); Menilite beds (Oligocene): Olme – Menilite shales, Olc – Cergowa sandstones; Krosno beds (Oligocene): Olk shales and sandstones (Early Oligocne), *ł*Olk – shales (Late Oligocene); SS – Subsilesian Nappe (Skrzydlna tectonic window): M – Magura Nappe; 4 – location of Skrzydlna Quarry.

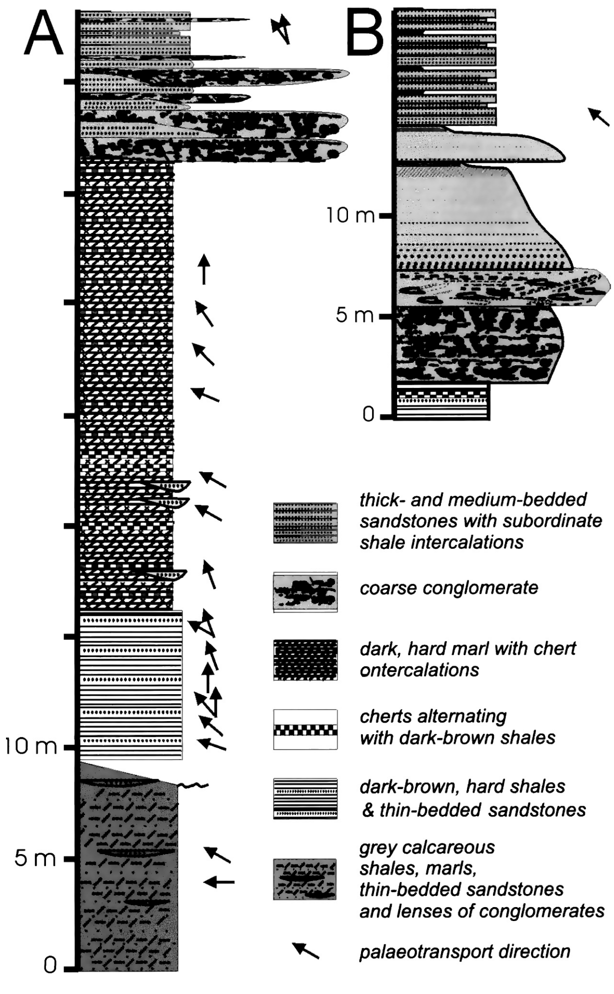


■ **Fig. 10.** Lithostratigraphic log of the sedimentary sequence of the Silesian Unit in the area of Skrzydlna (after Polak 2000). *pe*E – variegated shales, Eh – Hieroglyphic beds – (Middle and Late Eocene); Menilite beds (Oligocene): Olme – Menilite shales, Olc – Cergowa sandstones; Krosno beds (Oligocene): Olk – shales and sandstones (Early Oligocne), łOlk – shales (Late Oligocene)

Heavy mineral investigations, that have been done in the area of Nowy Targ, show the traces of chromian spinels within sandstones of the Magura Fm. (Cieszkowski at al. 1998), as well as traces of gold in the Krynica Mb. and in the Malcov Fm.

The deep structure of the Magura Nappe and its tectonic substratum have been recognized by deep boreholes Obidowa IG-1 and Chabówka 1 (Figs. 3, 4), as well as seismic and magnetotelluric data. In the boreholes, the base of the Magura Nappe has been found at depth from 1800 to 2500 m below the surface. Under the Magura there occur units of the Fore-Magura Zone (Cieszkowski 2001): strongly tectonically reduced Palaeogene deposits of the Grybów Unit and Dukla Nappe – Obidowa-Słopnice Subunit (Cieszkowski et al. 1981a, b; Cieszkowski 2001, see also Oszczypko-Clowes and Oszczypko 2004).

In cores of Hieroglyphic beds (Middle and Late Eocene), shally facies of Cergowa beds and Grybów shales (Oligocene) that represent the Grybów Unit has been identified. In the Obidowa-Słopnice Subunit the Inoceramian (Ropianka) beds (Late Senonian-Palaeocene) with medium to thick bedded sandstones resembling the thick bedded sandsones of the Cisna beds (Senonian) in the lower part and upwards of the section the Bukowiec Wielki sandstones (Palaeocene), the Hieroglyphic beds with horizon of va-



■ **Fig. 11.** Detailed lithologic log of the Menilite beds in: A – Skrzydlana Quarry, B – Stróża-Stróżkiewicze Creek (after Polak 2000).

riegated shales (Late Palaeocene-Late Eocene), the Rdzawka beds (Late Eocene-Early Oligocene) developed as "black Eocene" facies (thin bedded sandstones and black shales), conglomeratic sandstone and gravelly mudstones (Zboj sandstones) in the upper part and finally shally facies of the Cergowa beds (Early Oligocene) occur. Within the Grybow Nappe and Obidowa-Slopnice Subunit the traces of hydrocarbons, mainly of gas, has been recognized.

Passage: Chabówka-Skrzydlna

From Chabówka the route leads downhill to Rabka and at strong curve of road it passes location of the deep borehole Chabówka 1. Rabka is a famous spa for children, known of special microclimate and mineral salt water springs. Hydrothermal water (28 °C) has been also discovered here. In the center of town, there is the wooden church of the XVIII Century, recently changed to the museum of local, mountaineer folk, manufacture and art. Leaving town of Rabka the route crosses the Bystrica subunit of the Magura Nappe and after passing Zaryte hamlet and Raba Niżna village it arrives to a small town of Mszana Dolna. In the area of Mszana Dolna, gentle morphology of hills, covered with fields and meadows, marks the area of Mszana Dolna tectonic window. In this window predominantly Oligocenen strata of the Fore-Magura group of Nappes (Grybów and Dukla nappes) crop out. Higher morphology of the Magura Nappe that builds Beski Wyspowy and Gorce mountain ranges surrounding the window is covered by forests. North-East of Mszana Dolna the rout leaves the window and goes by Kasina village to Skrzydlna (cf. Polak 1999). On this distance, we cross the northern-most part of the Magura Nappe, called Siary Subunit. There above the Łabowa Shale Formations occur the Zembrzyce (Sub-Magura) and Budzów (Supra-Magura) beds (Late Eocene-Early Oligocene) developed as shaly- or marly-sandstone, thick- or very thick-bedded turbidites. A complex of thick-bedded, glauconitic Wątkowa sandstones (called previously glauconitic facies of the Magura sandstones) separates both divisions. Going downhill from Kasina the route passes frontal thrust-fault of the Magura Nappe. The Magura Nappe thrust here over the Silesian Nappe (Figs. 2, 3, 8). On the distance of one kilometer, we pass the Oligocene Krosno beds and Menilite beds (Cergowa sandstones) of the Skrzydlna thrust-sheet, that create here the southern limb of so-called Lanckorona-Żegocina structural zone, including numerous of tectonic windows in its axial part. There, in the windows, deposits of the Subsilesian Unit arrive on the surface from below of the Silesian Nappe. After about 1 km the route comes to a small quarry situated at the road in southern periphery of Skrzydlna village (Figs. 9, 10, 11). In this quarry the Oligocene deposits of the Menilite beds crop out.

Stop 3. Skrzydlna: Conglomerates and Olistholites in the Menilite Beds of the Silesian Nappe in the Skrzydlna Quarry

Marek CIESZKOWSKI

The lithological section of the Menilite beds in Skrzydlna Quarry (Polak 2000, Cieszkowski and Polak 2001) (Fig. 11) begin dark grey, marly shales intercalated by grey marls. Above are developed carbonateless, dark brown, silicified, bituminous shales, partly with black cherts, those present very characteristic deposits of the Menilite beds. The layers of fine grained, thin-bedded silicified sandstones interbed those marly and shaly deposits. Occasionally, the lenses of coarse sandstones or poorly cemented conglomerates occur there. The sandstones and conglomerates are composed of quartz, feldspars, muscovite, as well as clasts of green clayey shales, and the Carboniferous coal. A few sandstone clastic dykes cut vertically the layers of shales. The solemarks show that the clastic material of the sandstones and conglomerates have been derived from S and SE.

Above arrives 22 meters thick complex of thin and medium bedded, hard, silicified marls with cherts. The marls are dark grey, brownish, light when weathered, usually massive or with parallel lamination. Some marly layers have got small-scale solemarks showing paleotransport direction from S and SE. The lenses of fine conglomerates, composed of quartz, feldspar and, clasts of carbonate rocks and coal, occur in the lower part of the marly complex. A few thin clastic dykes cut vertically the layers of marls. Within the brown shales and marls of the Menilite beds, fossilised fish remnants, mainly scales, occasionally occur. Here, very rare are complete fish skeletons and once finding of reptile remnants was happened.

Marls and cherts pass rapidly to the thick bedded, coarse conglomerates and sandstones. The conglomerates consist of more or less rounded pebbles or angular blocks and clasts of various rocks. Their dimensions usually oscillate from 5 to 15 centimetres but larger pebbles and clasts have often appear, even, occasionally above one and half of a meter or even more. Up to the top of a layer conglomerates pass to the coarse-grained sandstones. The layer boundaries are erosive with a set of channels.

The conglomerates consist mainly of pebbles and clasts of sedimentary rocks: limestones (62 %), cherts (2.5 %), quartz granules and quartzites (7 %), sandstones (15.5 %), conglomerates (3.5 %) and others, mainly detrital rocks (7.5 %), and only small amount (2 %) of crystalline rocks, dominated by gneisses and granitogneisses. Various sedimentary rocks of different age have been distinguished there, e.g.: Devonian limestones with stromatoporoids e.g. *Stromatopora* sp., *Actinostroma* sp., *Stachyodes* sp. and *Amphipora ramosa*, Givetian – Franian limestones rich of foraminifera, black Carboniferous limestones (wackstone) with brachiopods *Productus* and *Leptena* and occasional trylobites; Carboniferous conglomerates; dark craned limestones; light, Stramberk-like Jurassic limestones with corals, molluscs, onkoides, peloides, sponge spicules, radiolarians, etc.; Eocene nummulitic limestones with occasional molluscs and crinoid remnants, as well as corals, briozoans and algae; the Palaeogene allodapic limestones with T*abcd* Bouma intervals containing molluscs shell remnants; problematic in age light micritic limestones, brownish marls, glauconitic T*abcd* sandstone turbidites, cherts, mudstones and shales. In the area surrounding Skrzydlna village vein quartz pebble with gold mineralization has been found.

The coarse conglomerates represent channel facies. They have been derived from the remnants of the Silesian Ridge to the Silesian Basin by high-density flows. The pebbles represent partly the rocks from the crystalline basement of the ridge core, and its Meso-Paleozoic sedimentary cover. Part of them represents also the Upper Cretaceous and Palaeogene sediments that have been deposited on the narrow shelf surrounding the ridge and on its northern slope.

South of the quarry the pebbles and sandstones pass up to the complex of brown shales with occasional cherts and next to the Cergowa beds. The Cergowa beds are typical for the Dukla unit, but occur also in the inner zone of the Silesian nappe. They replace part of the chert horizon within the Menilite beds. In the Skrzydlna thrust-sheet the Cergowa beds are developed as thick bedded, massive sandstones. Above the Cergowa beds thin complex of the brown Menilite shales arrives occasionally once more, and the Menilite beds pass up the section to the light grey, sandstone-shaly flysch of the Krosno beds.

Within the Skrzydlna thrust-sheet, at the basal part of the Cergowa sandstones and close of the lithostratigraphic boundary of the Menilite and Krosno Beds, the large olisthostroms occur (Figs. 10, 11). These olisthostroms consist mainly of the Lower Cretaceous flysch deposits of the Upper Cieszyn, Hradiste and Verovice beds. Minor frequency of olistholites of the Upper Cretaceous flysch deposits as well as Eocene non-turbiditic, grey, greenish or red marls and shales have been also noticed there. The occurrence of the olisthostroms within Oligocene sequence of deposits are known in Poland from the inner zone of the Silesian Nappe east of the Dunajec called Fore-Dukla zone, however especially well developed are in the Bitla zone in Ukraine.

During the Early Oligocene tectonic movements in the Outer Carpathian basinal area, the Silesian Ridge has been partly collapsed. It happened when the plate of the Silesian Basin's basement underthrusted southerly situated Silesian Ridge, and caused origin of a local accretionary prism. Then, the Palaeogene deposits of the slope, as well as the older Cretaceous flysch deposits, partly folded and thrusted within the prism, have been uplifted. In consequence, some of them sliced northward to the basin, forming the olisthostromes.

From the Skrzydlna quarry the route leads northward and after passing the tectonic border (thrust) between the Silesian Nappe and Subsilesian Unit occurring here in tectonic window (Fig. 10), it arrives to Skrzydlna village. The village is situated on the area of the Skrzydlna tectonic window. There, in the center, is an old beautiful wooden church of XVI century with the crucifix of XIV century. From Skrzydlna the route come back along the same way to Mszana Dolna.

Stop 4. Poręba Górna – Southern Margin of the Mszana Dolna Tectonic Window

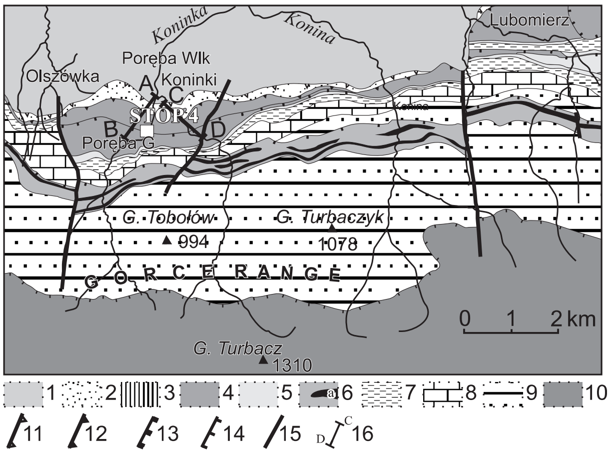
Nestor OSZCZYPKO, Marta OSZCZYPKO-CLOWES and Dorota SALATA

Description

The characteristic feature of the middle part of the Magura Nappe in the Polish Outer Carpathians is an occurrence of the Mszana Dolna tectonic window (MDW). The central and most uplifted part of this window is dominated by the Oligocene Krosno Formation of the Dukla Unit, whereas the narrow, marginal part of it is occupied by the Cretaceous-Oligocene deposits of the Grybów Unit (Fig. 4). The youngest deposits of the Mszana Dolna tectonic window belong to NP 24 and NP22 calcareous nannoplankton zones for the Dukla and Grybów units respectively (Oszczypko-Clowes and Oszczypko 2004).

The Mszana Dolna tectonic window is the big duplex structure, which developed during the Middle Miocene thrusting of the Magura Nappe against its foreland. The floor thrust developed along the frontal ramp formed by the Dukla Unit, whereas the roof thrust is related to Magura Nappe. Between the floor and roof thrusts the imbricated horses of the Grybów Unit developed. The southern margin of MDW is build up of the Cretaceous-Palaeogene deposits, which could be correlated with the Bystrica Subunit (Fig. 2*),* however the occurrence of fragments of the Rača Subunit in basal Magura thrust (Poręba Wielka-Koninki thrust-sheet) could not be excluded.

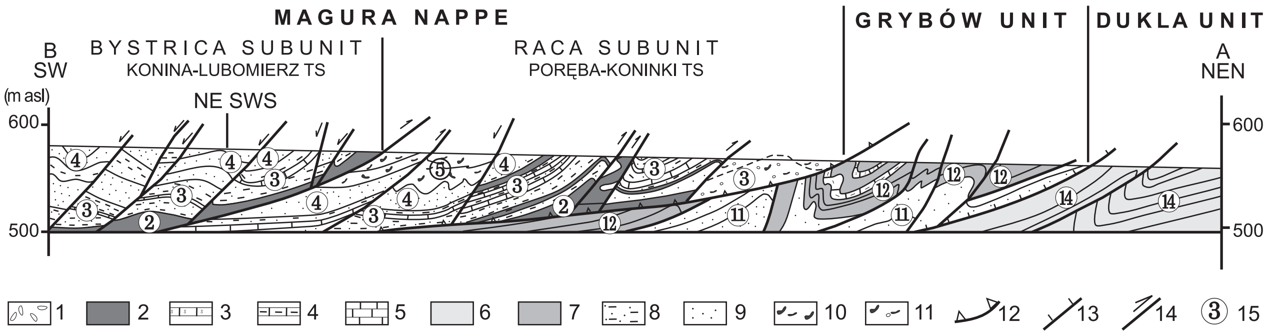
The section is exposed along the bedrock of Poręba Górna Stream on the southern margin of the Mszana Dolna tectonic window (Figs. 1, 4, 12 see also Oszczypko et al. 1999b). The section is nearly 400 m long and displays the contact zone between the Grybów and Magura units and structure of the basal part of the Magura Nappe (Figs. 12, 13, 14). The exposed succession can be subdivided in-to 4 minor units differing in structure. The incomplete unit 1st belongs to the Oligocene Grybów beds of the Grybów Unit. The section begins with the SW dipping, massive muscovite sandstone of the Cergowa type, passing upwards into black shales and mudstones with intercalations of thin-bedded sandstones and siderites nodules. These beds are incorporated into three strongly deformed, outcrop scale thrust-sheets. These thrust-sheets display numerous NWN-SES to N-S trending mesoscopic, subvertical thrust-fault propagating folds. The unit 2 begins with SW dipping sole trust of the Magura Nappe (Poręba-Koninki thrust-sheet). The inclination of the thrust surface is around 30°. The basal portion of the Magura nappe is represented by the 3 m packet of the medium-bedded sandstones and grey-greenish shales of the Senonian



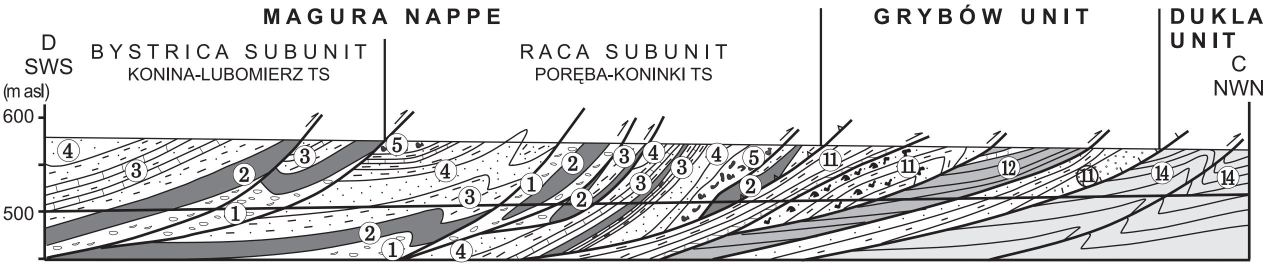
■ **Fig. 12.** Geological map of the Magura Nappe on the southern margin of Mszana Dolna tectonic window (after Oszczypko et al., 1999b). 1 – Oligocene Krosno beds of Dukla Unit, 2-Grybów Unit, (3-9) Magura Nappe – Bystrica Subunit: 3 – Albian-Cenomanian deposits, 4 – Cenomanian-Palaeocene; Eocene: 5 – Łabowa Fm., 6 – Zarzecze Fm., a-variegated shales, 7 – Beloveza Fm., 8 – Bystrica and Żeleźnikowa fms., 9 – Maszkowice Mb. of the Magura Fm., 10 – Krynica Subunit, 11 – Grybów overthrust, 12 – Magura overthrust, 13 – Bystrica Subunit internal overthrusts, 14 – Krynica overthrust, 15 – faults, 16 – cross-sections.

age. This stratified unit is covered by 40–50 metres complex of chaotic deposits, known as the Poręba Wielka beds (see Burtan et al. 1978). The stratified and chaotic units contact along the south dipping inverse fault. The chaotic deposits display fragments of blue-greyish, medium-grained non calcareous sandstones of different size (from 1 cm to 1.5 m boulders) and shape, dispersed in the green-greyish and dark-greyish, non-calcareous, clay-claystone material. Among these sandstone fragments, the small lumps of drag-folds have been observed. The sandstone fragments showing primary fractures often with calcite mineralization. The sandstone clasts and shales sometimes revealed the remnants of primary stratification. The chaotic deposits occur in the layers of few to 50 centimeters thick, with two-type of boundaries; fluidal-and shear fracture plane boundaries. Calcite veins often accompany the shear plane-type boundary. Both type of boundaries are gently dipping and are more or less parallel to each other, towards the NE and SW in the basal and top part of chaotic body respectively. These subhorizontal planes are occasionally cut by W-E trending subvertical, south dipping inverse faults with calcite mineralization. The lower strongly chaotic part is covered by the upper less chaotic part with more frequent primary type of stratification. Towards the top of this unit random dispersed sandstones fragments are progressively replaced by the boudine-like fragments.

The chaotic unit (Poręba Wielka beds) is tectonically followed upward by the 50 m thick unit 3, which is characterized by oc-



■ **Fig. 13.** Geological cross-section through the southern margin of the Mszana Dolna tectonic window, along the Poręba Górna stream (after Oszczypko-Clowes and Oszczypko 2004). 1 – spotty shales, 2 – variegated shales, 3 – spherosiderites, 4 – marls, 5 – turbidite limestones, 6 – calcareous shally flysch facies, 7 – black marly sheles, 8 – thin to medium-bedded turbidites, 9 – thick-bedded sandstones, 10 – submarine slumps, 11 – chaotic deposits, 12 – Magura overthrust, 13 – Grybow thrust, 14 – fault, 15 – lithostratigraphic units: 1 – Hulina Formation, 2 – Malinowa Shale Formation and Hałuszowa Formation, 3 – Kanina Beds, 4 – Szczawina Ss., 5 – Ropianka Beds, 6 – Łabowa Shale Formation, 7 – Beloveža Formation, 8 – Bystrica Formation, 9 – Żeleźnikowa Formation, 10 – Maszkowice Member of the Magura Formation, 11 – Jaworzynka Beds, 12 – Grybów Beds, 13 – Cergowa Beds, 14 – Krosno Beds.



■ **Fig. 14.** Geological cross-section through the southern margin of the Mszana Dolna tectonic window, along the Koninka stream (after Oszczypko-Clowes and Oszczypko 2004). For explanation see Fig. 10.

currence of outcrop scale NWN-SES trending recumbed and imbricated folds of the Malinowa Fm. (Turonian-Santonian) and Białe Formation (Campanian). This unit passed into steep south-west dipping thin-bedded flysch of the Białe Fm. and the thick-bedded Szczawina Sandstone Formation (Maastrichtian/ Palaeocene, see Oszczypko et al. 2005b). These sandstones showing brittle type of deformation with numerous small-scale W-E and WNW-ESE trending, and S and SWS dipping inverse faults.

In the Szczawina Formation occur heavy mineral assemblages composed mainly of very stable minerals such as zircon (12–34 %), tourmaline (29–59 %, represented by schorl-dravite series) and rutile (10–24 %). They also contain apatite (1–17 %), besides in some samples higher amounts of garnet (about 20 %, represented by almandine) and small amounts of brookite were found. The heavy fraction of Białe Fm in the southern part of the Bystrica subunit consisted mainly of zircon population (about 65 %) and smaller amounts of tourmaline (about 18 %), rutile (about 8 %) and single grains of garnet. In sandstones of the Białe formation grains of chromian spinel reaching amount of 8 % were also found (Oszczypko and Salata 2005).

Interpretation. The chaotic deposits from the Poręba Górna section were interpreted both in sedimentary (submarine slump, Książkiewicz 1958, see also Cieszkowski et al. 1986, Mastella 1988) as well as tectonic (metamorphic tectonites or "wildflysch", see Burtan and Łydka 1978, Burtan et al. 1978) terms. According to Burtan and Łydka (1978) and Mastella (1988) the temperature during overthrusting reached 300–350 °C. In our opinion, the chaotic deposits revealed the direct relation to the Magura Nappe sole thrust. Its is supports by observation of degree of the tectonic deformation, which drastically decreased outside of the Magura thrust, both in the Magura as well as the Grybów successions. The thrusting of the Magura Nappe onto the Fore-Magura (Grybów and Dukla) begun to develop during the Late Oligocene. This process was probably simultaneous with deposition of the Zawada Fm in the Magura piggy-back basin (Oszczypko et al. 1999a, Oszczypko and Oszczypko-Clowes 2002, 2003). The last act of the overthrusting probably took place during the post-Middle Badenian time (see Oszczypko 1998). It means that overthrusting lasted 9–10 Ma. This process was probably initiated in the submarine condition, when the front of the Magura Nappe reached the Dukla-Grybow subbasin. As a result the Magura Nappe at least 2.5–3 km thick, build up of compacted and impermeable rocks loaded and sealed under the compacted, clayey-sandy deposits of the Menilite-Krosno Fm. of Grybów succession. It build up overpressured zone on the contact of the Magura Nappe and Grybów succession (see also Mastella 1988), which was affected by the fracturing and frictional sliding. The process of deformation in the Magura/Grybów thrust zone was continued during the Middle Miocene thrusting and development of the Mszana Dolna duplex structure (Oszczypko-Clowes and Oszczypko 2004).

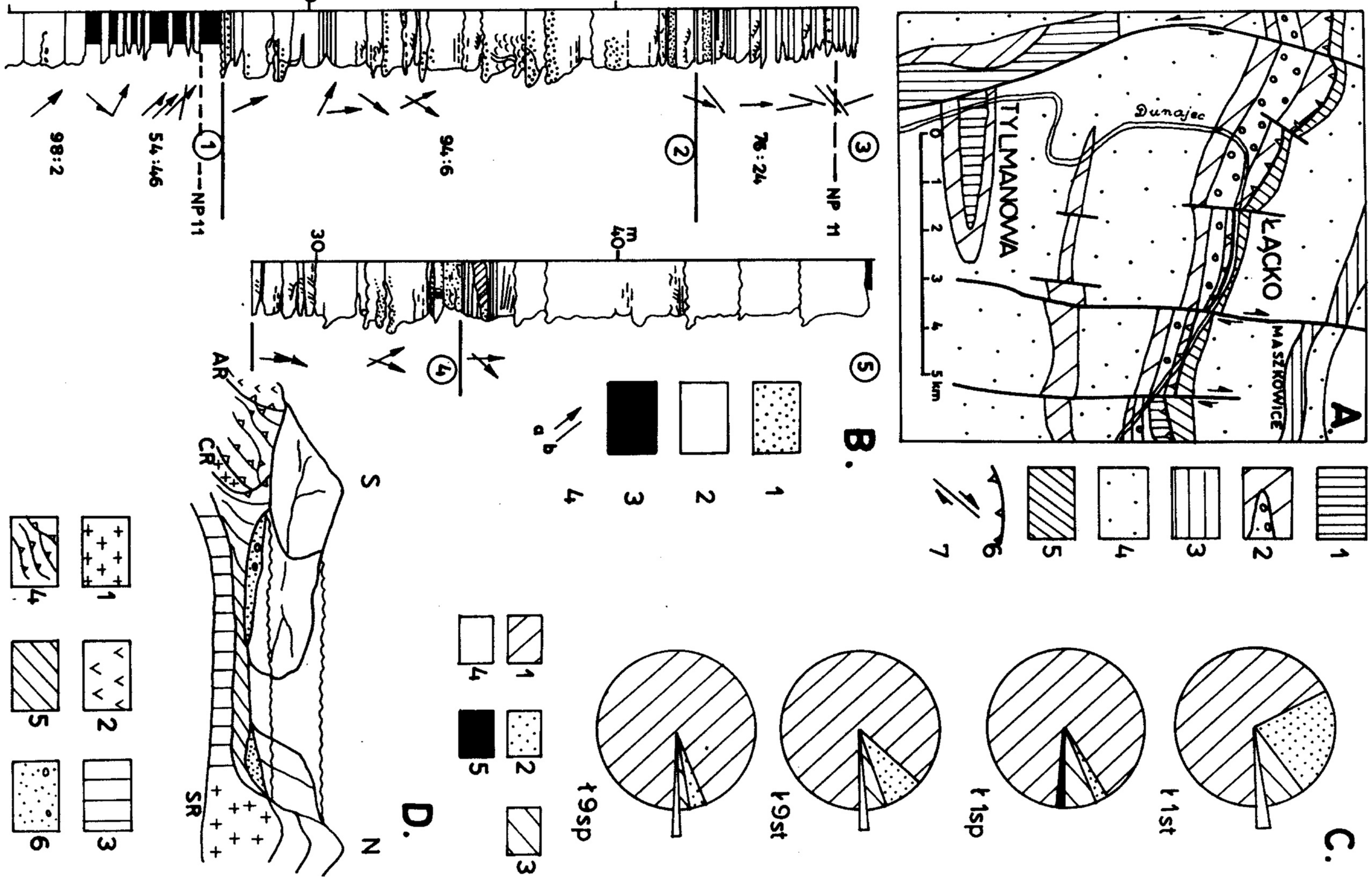
Stop 5. Tylmanowa–Piwniczna Member of the Magura Formation

Nestor OSZCZYPKO

The section is exposed along the highway linking town of Stary Sącz and Krościenko (Figs. 4, 15A, see Oszczypko and Porębski 1985, Oszczypko et al. 1992). The section is nearly 50 m thick and consists of medium to thick-bedded, dominantly medium-grained sandstones with two intercalations of thin-bedded turbidites. This sequence belongs to the Piwniczna Sandstone Member (Lower-Middle Eocene) of the Magura Formation. These sandstones are followed upward by shales with numerous, thin, medium to fine turbidites displaying Bouma's Tbc and Tc divisions. The exposed succession can be subdivided in 5 minor sequences differing in facies assemblages and vertical textural trends (Fig. 15B). The incomplete basal sequence l begins with a few metres of massive, medium-grained sandstones

Interpretation. The exposed succession can possibly be interpreted in terms of middle-fan distributary channel-depositional lobe systems, supplied from SSE. In this context, the sequence 2 may represent a channel fill. At the base of this sequence, there occurs a 1.5 m thick zone of disturbed bedding involving imbricated sandstone sheets and overturned folds. These structures suggest slumping of semi-consolidated sediment toward the E, i.e. perpendicularly to the NNW-directed palaeocurrents.

The overlying sequence 3 may record a gradual abandonment of the channel due to widening of its cross-section with successive filling episode, which increased overbank spilling of channelised turbidity currents. The coarsening-up sequence 4 may have originated through development of a depositional lobe which cou1d possibly follow a topographic low left after the filling of the underlying channel. The progradation of the lobe was succeeded by the incision and filling of a feeding channel, a process envisaged for the sequence 5. The large-scale traction structures preserved at the base of this sequence, may record an open channel (up to 5 m long and 0.7 m deep) flow conditions and sediment by-passing before the channel became plunged by a thick flow.

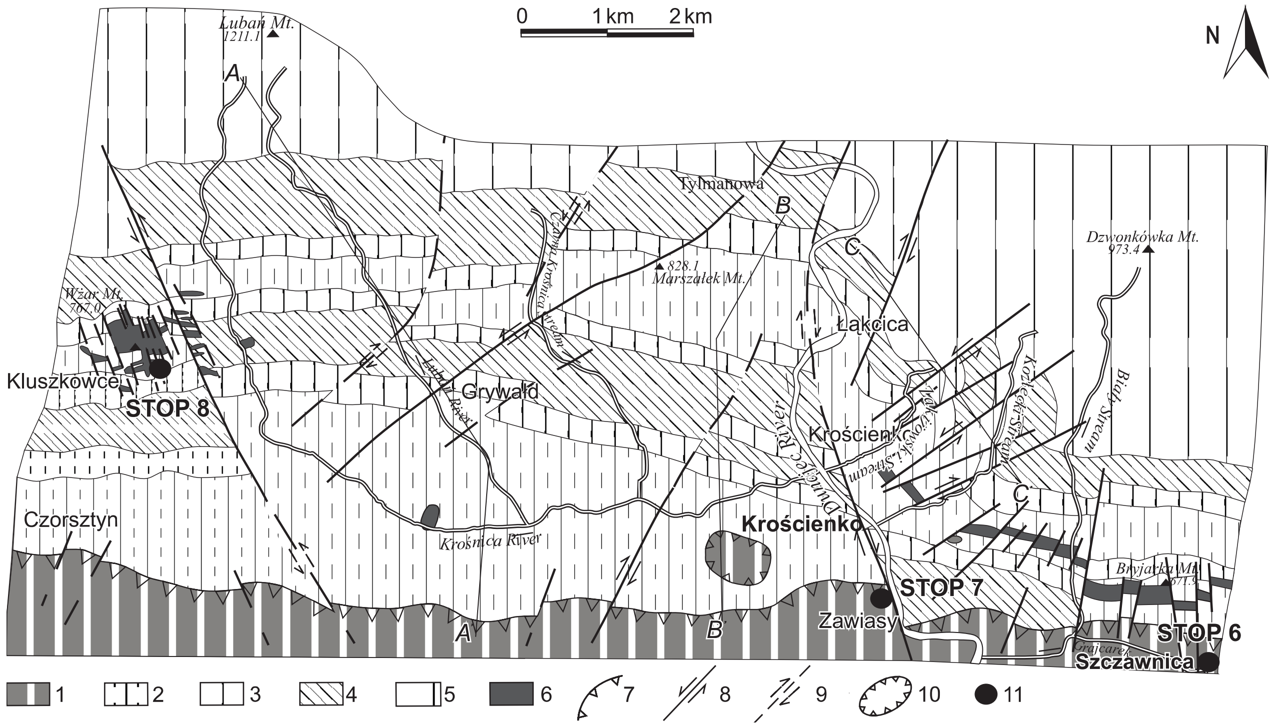


■ **Fig. 15.** Geology of the Dunajec river valley between Tylmanowa and Łącko (after Oszczypko et al. 1992). **A** – geological map: 1 – Szczawnica Formation, 2 – Zarzecze Formation, a – Krynica Sandstone Member, 3 – Żeleźnikowa Formation, 4 – Magura Formation, 5 – Mniszek Shale Member; 6 – thrust of Krynica zone upon Bystrica zone, 7 – faults; **B** – Sedimentological log of the Piwniczna Sandstone Member at Tylmanowa (based on Oszczypko and Porębski 1985): 1 – conglomeratic sandstones and conglomerates, 2 – sandstones, 3 – mudstones and clayey shales, 4 – attitude of sole marks: a – flute casts, b – drag groove casts; 94:6 – sandstone:shale ratio. Numbers refer to sequences described in the text by N. Oszczypko and S. Porębski; **C** – composition of heavy minerals: 1 – garnet, 2 – turmaline, 3 – rutile, bruckite, anatase, 4 – zircon, 5 – staurolith; ł1,ł9-bed nymbers;st- top, sp- base; **D** – depositional model of the Magura basin during early Eocene times:1 – cotinental crust of the Silesian cordillera (SR) and Czorsztyn Ridge (CR), 2 – exotic ridge of Andrusov (AR), 3 – oceanic or transitional crust, 4 – Upper Cretaceous units of the Pieniny Klippen Belt, 5 – pelagic and hemipelagic deposits, 6- thick-bedded turbidites. (Birkenmajer and Oszczypko 1989, Oszczypko and Porębski 1985, Oszczypko et al. 1992).

Stop 6. Szczawnica Wyżna (Zabaniszcze)–Grajcarek Unit

Jan GOLONKA, Michał KROBICKI, Nestor OSZCZYPKO and Dorota SALATA

On the left slope of Grajcarek Stream in Szczawnica-Zabaniszcze (Szczawnica Wyżnia) the Upper Jurassic – Lower Cretaceous sequence of the Magura Succession of the Grajcarek Unit occurs (Fig. 16). The deposits are represented by siliceous-carbonate, strongly sedimentary condensed sequence, which whole thickness does not exceed 14 m. The oldest deposits are grey, manganiferous thin-bedded radiolarites (3 m thick) of the Sokolica Radiolarite Formation (Birkenmajer 1977), dated by radiolarian assemblages as Oxfordian (Unitary Associations 7–8) (Widz 1991, 1992). These are overlain by green and red radiolarites of the Czajakowa Radiolarite Formation (Podmajerz Radiolarite Member and Buwałd Radiolarite Member – 8 m and 0.6 m in thickness, respectively) of which radiolarians indicative of the Upper Oxfordian and Kimmeridgian (Unitary Association 8–9) have been recognized (Widz 1991, 1992). These radiolarite formations are succeeded by hard, cherry-red marls of the Palenica Marl Member of the Czorsztyn Limestone Formation with a maximum thickness of 0.5 m. Aptychi may be locally abundant and suggest Kimmeridgian age of these deposits (lower part of aptychus subzone VI_1 of Gąsiorowski – see Birkenmajer 1977), but ammonites are absent. On the other hand, stomiosphaerids indicate Early Tithonian age (Malmica Zone after Nowak 1971, 1976). These marls are both facies and stratigraphic equivalents to the South Alpine Rosso ad Aptychi limestones/marlstones. In the Polish Carpathians they occur exclusively within Magura Succession of the Grajcarek Unit (Birkenmajer 1977), and are known only from the northern boundary of the Pieniny Klippen Belt between Szczawnica spa and Szlachtowa village. The sequence grades up to well-bedded light-grayish cherty limestones of the Pieniny Limestone Formation, which correspond to widespread Tethyan Maiolica (=Biancone) facies. A small thickness of these lime-



■ **Fig. 15.** Geology of the Dunajec river valley between Tylmanowa and Łącko (after Oszczypko et al. 1992). **A** – geological map: 1 – Szczawnica Formation, 2 – Zarzecze Formation, a – Krynica Sandstone Member, 3 – Żeleźnikowa Formation, 4 – Magura Formation, 5 – Mniszek Shale Member; 6 – thrust of Krynica zone upon Bystrica zone, 7 – faults; **B** – Sedimentological log of the Piwniczna Sandstone Member at Tylmanowa (based on Oszczypko and Porębski 1985): 1 – conglomeratic sandstones and conglomerates, 2 – sandstones, 3 – mudstones and clayey shales, 4 – attitude of sole marks: a – flute casts, b – drag groove casts; 94:6 – sandstone: shale ratio. Numbers refer to sequences described in the text by N. Oszczypko and S. Porębski; **C** – composition of heavy minerals: 1 – garnet, 2 – turmaline, 3 – rutile, bruckite, anatase, 4 – zircon, 5 – staurolith; ł1,ł9-bed nymbers;st- top, sp- base; **D** – depositional model of the Magura basin during early Eocene times:1 – cotinental crust of the Silesian cordillera (SR) and Czorsztyn Ridge (CR), 2 – exotic ridge of Andrusov (AR), 3 – oceanic or transitional crust, 4 – Upper Cretaceous units of the Pieniny Klippen Belt, 5 – pelagic and hemipelagic deposits, 6- thick-bedded turbidites. (Birkenmajer and Oszczypko 1989, Oszczypko and Porębski 1985, Oszczypko et al. 1992).

stones (only 1.5–2.0 m) is effect of strong condensation: several stomiosphaerid and calpionellide biozones have been recognized here (Obermajer, 1986), which cover stratigraphical interval from Upper Kimmeridgian to Upper Hauterivian (and may be even Barremian). The uppermost Jurassic/lowermost Cretaceous sequence shows highest condensation effect, which is known within Carpathian basins near Jurassic/Cretaceous boundary, and that's why the discussed succession could indicate the most axial, basinal zone of the Pieniny-Magura Ocean (see – Introduction) (Birkenmajer 1977, Golonka and Sikora, 1981, Golonka et al. 2003, Golonka and Krobicki 2004).

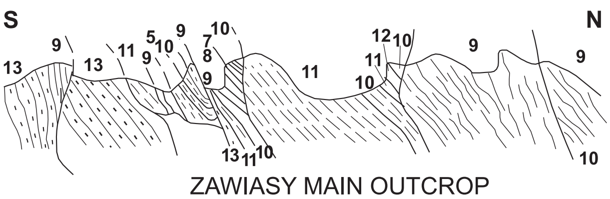
The Biancone type limestones pass upward (see Birkenmajer 1977) into the spotty marls and limestones of the Kapuśnica Formation (Aptian-Albian) and black-green shales of the Wronine Formation (Albian). In the western part of the section, the Jurassic-Lower Cretaceous klippen is thrust over the red shales of the Malinowa Formation (Cenomanian-Maastrichtian) and thick-bedded sandstones and conglomerates of the Jarmuta Formation (Maastrichtian-Palaeocene). Sandstones of the Jarmuta Formation outcropping in Szczawnica Zabaniszcze in heavy mineral set contain 20–48 % of zircon, 25–42 % of tourmaline (representing schörl-dravite series), 7–15 % of rutile, 1–23 % of garnet (with prevailing almandine molecule), 2–9 % of chromian spinel and 2–6 % of apatite. Chemical composition of tourmalines and garnets indicates their provenance from metamorphic rocks. The presence of chromian spinels and their composition suggests existence of ocean floor peridotites or rocks of an ophiolite sequence in the source area (see Oszczypko and Salata, 2005).

Stop 7. Krościenko-Zawiasy Klippe-Contact Zone between the Pieniny Klippen Belt and the Magura Nappe

Jan GOLONKA, Michał KROBICKI, Nestor OSZCZYPKO and Dorota SALATA

On the western bank of Dunajec River across the in the Zawiasy Klippe is visible (Figs. 16, 17, 18). All rocks exposed here represent the fragment of the Magura Basin incorporated into the Pieniny Klippen Belt. They were deposited between the Czorsztyn Ridge and deeper part of the Magura Basin during Middle Jurassic through Palaeocene. The main ridge of the Pieniny Mountains built of Czertezik Succession is located South of Zawiasy Klippe. The Zawiasy profile is similar to that of the Branisko Succession (Birkenmajer 1977). The Branisko Succession is located however south of the Czorsztyn Ridge. Perhaps the separate Zawiasy Succession representing the slope deposits of the Magura Basin should be distinguished.

The main bulk of the Klippe is formed by the Biancone/Maiolica type cherty limestones (Pieniny Limestone Formation) – of latest Jurassic–Early Cretaceous age. The *Hedbergella* microfacies with *Hedbergella* sp., *Praeglobotruncana* sp and *Tahalmaninella ticenensis* Gandolfi) was found in the uppermost part of the limestones (Golonka and Sikora 1981). It suggests the Albian age of the youngest part of the Pieniny Limestone Formation in the slope succession of the Magura Basin. The well developed sedimentary breccias could be also observed in the cherty limestones. They were formed as a result of extensive gravitational faulting, which took especially during and Neo-Cimmerian (Upper Jurassic-Lower Cretaceous) movements. Similar breccias are known from the Czorsztyn Succession (Birkenmajer 1986, Golonka and Krobicki 2001). The exact age of the breccias in the Zawiasy area is currently under investigation. Presumed initial stages of subduction of the oceanic crust of the Pieniny Klippen Belt Basin riftogenesis volcanic activity and even paleooceanographical conditions (Birkenmajer 1986, Golonka and Krobicki 2001) are most probably connected with Neo-Cimmerian tectonic event. Alternatively, the formation of such allodapic rock beds are also interpreted as an effect of eu-



■ **xFig. 17.** Cross-section of Zawiasy main outcrop (modified from Golonka and Sikora, 1981). 5 – green Globotruncana marls – Jaworki Formation. 7 – spherosideritic shales-Skrzypny Shale Formation, 8 – super-Posidonia beds – Podzamcze Limestone Formation, 9 – cherty Biancone/Maiolica type limestones – Pieniny Formation, 10 – Globigerinal-Radiolaria beds – Kapuśnica Formatiion, 11 – Globotruncana marls–Jaworki Formation, 12 – Upper Cretaceous flysch Sromowce Formation 13 – Jarmuta Formation.

■ **Fig. 18.** Stop 7 at Krościenko. View on the Zawiasy Klippe.

static events (lithohorizone Be-7) and correspond very well with the Berriasian part of the Nozdrovice Breccia within Inner Carpathians 1996), which developed as scarp breccias along active submarine fault slopes. On the other side, the eustatic changes are perhaps connected with the global plate reorganization that took place during Tithonian-Berriasian time (Golonkaet al. 2003, 2005 b). This global plate reorganization is also related to the Tethyan Neo-Cimmerian tectonic activities.

The uppermost partion of the Zawiasy section (in overturned position) belongs to the Jaworki Formation (Cenomanian-? Campanian) composed of the variegated pelagic and marls of the Scaglia Rosa (= Couches Rouge = Capas Rojas) type. These pelagic, foraminiferal, multicoloured green/variegated/red marl deposits originated during the latest, third episode of evolution of the Pieniny Klippen Basin (Birkenmajer 1977, 1986, Bąk 2000), when unification of sedimentary facies took place within all successions (Albian-Coniacian). Flysch and/or flyschoidal facies are younger (Santonian-Campanian). During this syn-orogenic stage of the development of the Pieniny Klippen Basin the flyschoidal deposits developed as submarine turbiditic wedges, fans and canyon fills (Birkenmajer 1986) with several episodes of debris flows with numerous exotic pebbles (Late Albian-Early Campanian). The main "exotic source area" in the PKB was emerged, so-called Exotic Andrusov Ridge, as effect of Czorsztyn Ridge/Andrusov Exotic Ridge collision (Birkenmajer 1986, Golonka et al. 2003). During latest Cretaceous, flysch and/or flyschoidal deposits of the Jarmuta Formation (Maastrichtian-Palaeocene) were deposited. The contact between these formations is tectonic.

Composition of heavy mineral fraction in Jarmuta Formation in Krościenko Zawiasy is similar to the mineral set from Szczawnica-Zabaniszcze. The heavy fraction contains 26–88 % of zircon, 36–60 % of tourmaline (representing schörl-dravite series), 9–17 % of rutile, 1–4 % of garnet (with prevailing almandine molecule), 2–3 % of chromian spinel and 0–4 % of apatite (provenance of minerals see stop Szczawnica Wyżna-Zabaniszcze; Oszczypko and Salata 2005).

The major strike-slip right lateral fault is located along the Dunajec River. Mountains on the left side of Dunajec belong to Pieniny Mountains built of the Pieniny Klippen Belt successions. The successions exposed here are from south to north: Pieniny, Czertezik and Zawiasy. Mountains on the right side of Dunajec belong to Beskid Sądecki range built of flysch rocks of Krynica unit of the Magura nappe. Small fragment of this unit is exposed on the left bank of Dunajec north of the main Zawiasy outcrop. It is represented by Eocene Łącko type marls belonging to Zarzecze formation. The main tectonic boundary between Pieniny Klippen Belt and Magura nappe runs from west to east along the slopes of Pieniny Mountains south of Krościenko Town. Eastward this boundary runs from west to east along the slopes of Małe Pieniny range south of Szczawnica town. This boundary is developed as major strike-slip right-lateral fault. The Dunajec fault is younger than the main W-E boundary fault. It displaced Pieniny Klippen Belt 4 kilometers northward.

Stop 8. Pieniny Andesites at Wżar Hill – Mineralogy, Petrology and Palaeomagnetism

Marek MICHALIK and Wojciech SZELIGA

For explanations see Conference excursion 1 – Stop 5.

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