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THE BEST GEOTOURISTIC OBJECTS OF THE SILESIAN UNIT, OUTER FLYSCH CARPATHIANS IN THE VICINITY OF KRAKOW, POLAND

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Abstract: The Outer Carpathians are built up of a stack of nappes and they are trust over the southern part of the North European platform. The Silesian Nappe occupies central part of the Outer Carpathians and it is built of sedimentary facies represented continues succession of Late Jurassic to Early Miocene times. In sedimentary profile are written successively stages of development of Silesian Unit on the background of evolutionary stadia of the geodynamic development of the Northern Carpathians from syn-, post-rift to synorogenic phase. The best outcrops (legible, good-preserved and accessible for the group of tourists) to examine the Silesian rocks are presented and included into the trail. The sites highlight stratigraphy and sedimentology of Silesian Unit, from Jurassic to Neogene, elements of structural geology, petroleum systems (source rocks, reservoir rocks, seals), geotouristic important objects and history of human activities in the Carpathians, especially of mining and oil industries. The proposed trail traverse the Silesian Nappe in Polish sector of West Carpathians between Kraków, Cieszyn and Ciężkowice area.

Key words: Polish Outer Carpathians, Silesian Nappe, geoturistic objects

1. Introduction

The authors attempt to provide the review of the most important and significant geotouristic attraction within the **Silesian Unit, Outer Flysch Carpathians**. The idea of this paper is derived from raising importance of geotourism as well as from the international geological meetings, which were conducted in the Carpathians in the XXI century. The programs of these meetings included several field trip guides aimed for the highlights of the Outer Carpathians designed for the international audience interested in the various subject of geology and geotourism. We selected the best geological outcrops and geotouristic sites, which can be visited during short 1 day to two weeks visit in the Polish Carpathians. The sites highlight stratigraphy and sedimentology of Silesian Unit, from Jurassic to Neogene, elements of structural geology, petroleum systems (source rocks, reservoir rocks, seals), geotouristic important objects and history of human activities in the Carpathians, especially of mining and oil industry. There are organized according to their age from oldest to youngest, illustrating geodynamic development of the Silesian Unit through time. The Jurassic - Early Cretaceous deposits were a subject of classic XIX century studies by Hohenegger (1861). The formation names were derived from this classic work, the exact definition were reworked during 150 years of studies by many Polish and Czech geologists (see the review in Golonka et al., 2008 a,b).

2. The Silesian Unit within the Outer Carpathians

The Outer Carpathians (Fig. 1B) are built up of a stack of nappes and thrustsheets 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 thrust over 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 (Ślączka et al., 2006). 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 highest to the lowest is as follows: Magura Nappe, Fore-Magura group of nappes, Si-

lesian Nappe, Subsilesian Nappe and Skole (Skiba) Nappe (Fig. 1A).

The Silesian Unit (Nappe) occupies central part of the Outer Carpathians, pinching out below the most internal nappes. Sedimentary facies of the Silesian Unit represent continuous succession of deposits of age interval from Late Jurassic to Early Miocene. The oldest sediments of the Silesian Unit are known only in Moravia and Silesia areas in the Western Carpathians. They were deposited within proto-Silesian basin representing synrift - postrift stages of the geodynamic development of the Northern Carpathians (Golonka et al., 2008a,b). The basinal successions represent mainly passive margin turbidites. Alkaline magma (teschenites association rocks) intruded these turbiditic sequences (Ślączka et al., 2006; Golonka et al., 2008a,b).

The Vendryně Formation (Kimmeridgian-Tithonian/Early Berriasian) represents the oldest deposits of this zone (Fig. 1A). It is covered by the Cieszyn Limestone Formation (Late Tithonian - Middle Valanginian). The younger Hradište Formation is Middle Valanginian - Barremian. Two members were distinguished within the Hradište Formation: Cisownica Shale Member and Piechówka Sandstone Member. The Hradište Formation is covered by Veřovice Formation (Aptian) represented by black shales rich in organic matter.

During latest Early Cretaceous proto-Silesian Basin was reorganized, turned into the Silesian Basin and went into synorogenic phase of geodynamic development. The Lhoty Formation (Albian) represents the oldest synorogenic flysch-type deposits. The Mikuszowice Chert Member is distinguished within this formation. During the Late Cretaceous and Paleocene in the Silesian Basin took place sedimentation of sandy turbidites often thick-bedded, that represent the Godula and Istebna beds. Their complete thickness is estimated in the western sector of the Polish Carpathians for about 4500m. The thick-bedded sandstone (Ciężkowice Sandstones) or variegated shales sedimentation took place up to the Middle Eocene and later was replaced by thin-bedded shaly-sandstone flysch of the Hieroglyphic Beds. All clastic material of Godula and Istebna beds as well as of the Ciężkowice Sandstones was derived from southwest, from the Silesian Ridge. During the Oligocene the Menilitic and Krosno beds were developed. Then in the southern part of the Silesian Basin in some levels formed olistostromes (Cieszkowski et al., 2003). The sedimentation of the Krosno Beds was finished in the Early Miocene (Fig. 1A).

3. Selected geotouristic objects

3.1. Vendryně Formation (1)

The oldest sediments of the Silesian Unit can be examined along the Olza River Bank near the village Wędynia (Czech name Vendryně) – the type locality for the Vendryně Formation (locality (1) on Fig. 1B). Here we see dark grey marly shales with a few intercalations of redeposited detrital limestones containing fragments of macrofauna e.g. echinoderms and mollusks (Fig. 1C). The shales display chaotic structures, indicating that these sediments represent slump deposits derived from the adjacent carbonate platform, where pelitic sediments formes. The Vendryně Formation rocks represent synrift deposits, corresponding to the initial opening of proto-Silesian basin at the end of Jurassic period (Ślączka et al., 2006; Golonka et al., 2008a,b).

3.2. Cieszyn Limestone Formation with teschenite intrusions (2)

Cieszyn Limestone Formation rocks are splendidly exposed in the Jasieniowa Hill abandoned quarry (Ślączka and Kaminński 1998, Waśkowska-Oliwa et al., 2008) (locality (2) on Fig. 1B). The local touristic-educational trail lead from the Goleszów town to the quarry, displaying section through calcareous turbidites (Fig. 1D). The clastic material comprising the detrital limestones was derived from the adjacent shallow water calcareous platform, while to a large extent the pelitic limestones represent a *Coccolithus* - *Nannoconus* microfacies similar to the maiolica Alpine microfacies. The lower surfaces of the beds are covered with numerous sole marks, mainly of organic origin, and on surfaces of internal laminae organic traces (called fucoids), of varied size are often visible. In the upper part of the profile we can observe intercalations of thick- and very thick-bedded, graded, coarse-grained and conglomeratic limestones. The coarse basal part of these limestones consists of organic detritus (fragmented shells of lamellibranches, aptychi, crinoids, urchin spines, along with algae and gastropods). Quartz grains, fragments of dark Tithonian limestones, and Carboniferous coal are also present, indicating that the erosion in source area reached already the basement of the Jurassic calcareous rocks.

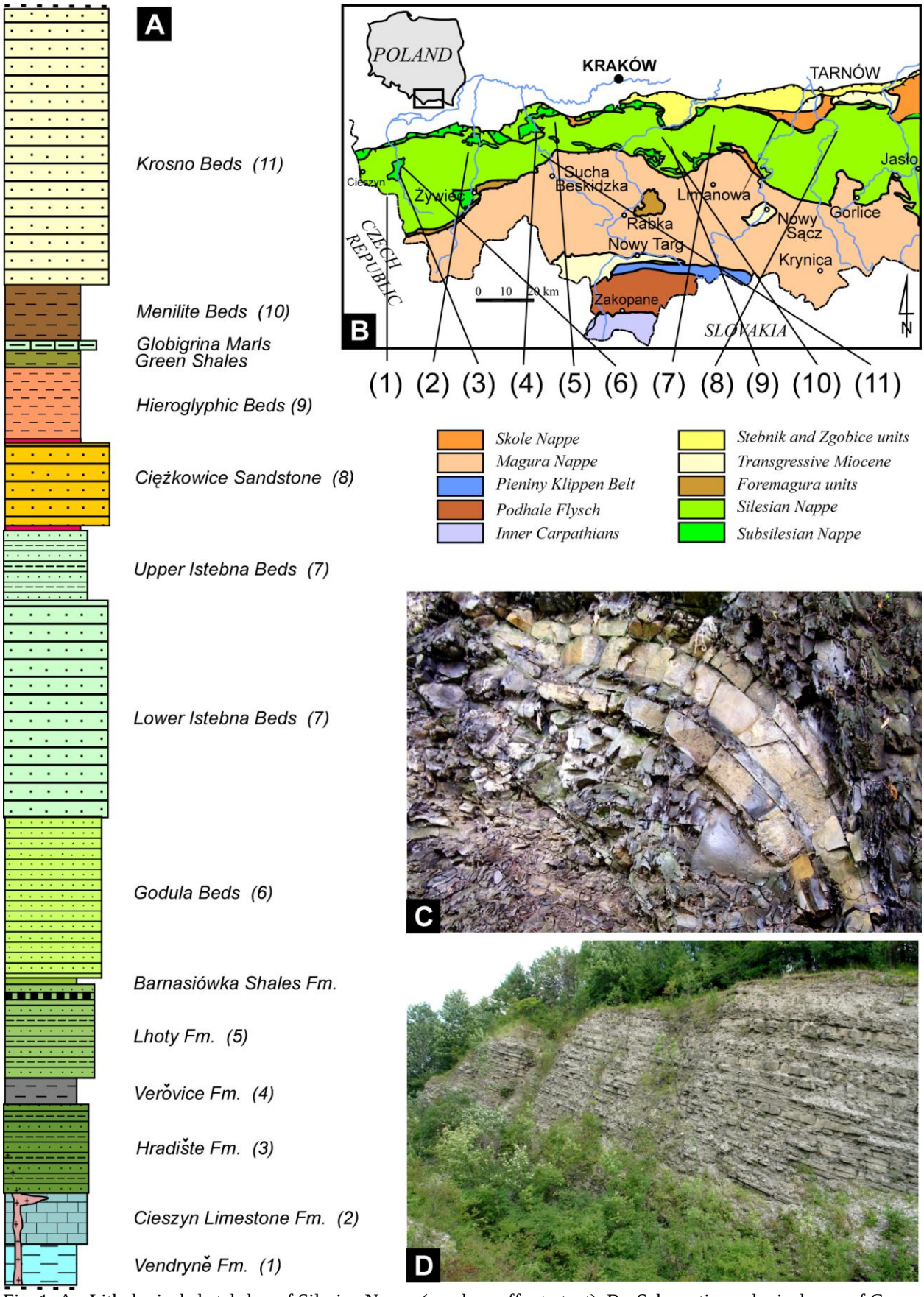

Fig. 1. A - Lithological sketch-log of Silesian Nappe (number reffer to text). B - Schematic geological map of Carpathians; C - Vendryně Fm. (1), Vendryně; D - Cieszyn Limestone (2), Goleszów.

The strongly folded and faulted Cieszyn Limestone Formation with teschenite intrusions can be observed in the natural outcrops along the Soła River in Żywiec. This object is located near the famous Żywiec brewerey, founded by Habsburgs, which produces the best and most famous Polish beer, well known not only in Poland (Ślączka and Kaminski, 1998). The Żywiec outcrop was selected as one of the best eleven geosites in Poland (Słomka et al., 2008). The outcrop displays calcareous turbidites consisting of thin-, medium- and occasionally thick-bedded detrital and pelitic limestones, usually graded, with parallel and cross lamination and occasionally with small sole marks. Marls and marly shales intercalate limestone layers. Limestone beds comprise several debris-flow and submarine slump deposits including numerous fragments and pebbles of detrital and pelitic limestones, organodetrital limestones, marly shales and metamorphic rocks. Pebbles are randomly arranged in a mass of structureless hard marly silt. The Soła river sequence of the Cieszyn Limestone Formation represents a more proximal part of a vast submarine fan while more distal parts are exposed on Cisownica Hill. The teschenite sills in contact with the beds of graded limestone are exposed on the right bank of the Soła river.

3.3. The Hradište Formation (3)

The Hradište Formation (Eliaš et al., 2003) was formerly known as Upper Cieszyn Beds and Hradište (Grodziszcze) Sandstones (e.g. Ślączka et al., 2006) or Tešin-Hradište Formation (Picha et al., 2006). Two members are distinguished with the Hradište Formation (Golonka et al., 2008a): Cisownica Member (Upper Cieszyn Beds) and Piechówka Member (Grodziszcze Sandstones). Good exposure of rocks proposed as stratotype for Cisownica Member (Hauterivian-Barremian, locally Aptian) is located in the Czantoria valley in Cisownica village. Thise post-rift turbiditic sequence consist of dark grey marly and calacreous shales (Ślączka and Kaminski, 1998; Waśkowska-Oliwa et al., 2008). This shales are interbedded by thin-bedded, laminated dark calacreous sandstones and contain also numerous spherosiderites. The layers of detritic limestones sporadically occur within the sequence. The spherosyderites were mined until XIX as the iron ore.

The name Piechówka Member is derived from the name of hamlet in Żegocina (Golonka et al., 2008; Krobicki et al., 2008; Waśkowska-Oliwa et al., 2008) (locality (3) on Fig. 1B). The quarry near this hamlet is the type locality for this lithostratigraphic unit. It was selected as of the best eleven geosites in Poland (Słomka et al., 2008), it is also one of the geosites included on the Polish database constructed by Polish Academy of Sciences Institute of Nature Preservation as a part of the IUGS Global GEOSITES project, carried out by the European Association for the Conservation of the Geological Heritage (ProGEO) (Alexandrowicz 2006). The informational plate, designed by Late Dr. Tadeusz Leśniak is located at the entry of quarry (Fig. 2A). It contains detailed description of the site history and geology. The profile exposes 50 m thick turbiditic sediments with alternating sandstones and shales and typical sedimentary structures like graded bedding, horizontal lamination flow structures and flute marks indicating a northeastward direction of transport. Coarse-grained sandstones contain fragments of redeposited rocks, Carboniferous coal among the others. The sandstones are intercalated by grey shales. Fragments of aptychi have also been found.

3.4. Veřovice Formation (4)

The Veřovice Formation belongs to typical Black Cretaceous organic-rich deposits. Its stratotype is located in Veřovice village, in Czech Republic (Golonka et al., 2008a). The best exposures in Poland serving as a reference section is exposed in the Wieprzówka cascade site in Rzyki village near Andrychów (Kamiński and Ślączka, 1998) (locality (4) on Fig. 1B). The stream valley was deeply dissected by fluvial erosion forming a series of scenic waterfalls and revealing the Lower Cretaceous Veřovice and Lhoty formations. The rocks of Veřovice Formation in Wieprzówka profile are developed as carbonateless, black and heavy-grey, organic-rich shales, locally siliceous with rare intercalations of thin- and very thin-bedded laminated coarser siltstones, fine-grained sandstone, occasionally with spherosiderites (Fig. 2B). The host a variety of tectonic deformations. We can easily identify faults and folds of different geometry. These deformations results from the Miocene Alpine tectonic movements, which formed the Silesian Nappe as part of the Carpathian Mountains. The formation's rocks were deposited during the Early Cretaceous, under the *Oceanic Anoxic Event* (OAE) conditions. Transgressions related to the highest Phanerozoic sea-level and the upwelling contributed to the excessive nutrient supply. The Carpathian basins were producing a large amount of organic matter, preserved due to sedimentary

conditions and to limited supply of terrigeneous material. The Rock-Eval analysis of the Verovice Formation from Rzyki revealed the *Total Organic Carbon* – TOC reaching 2.31 wt % (Golonka et al., 2008c).

3.5. Lhoty Formation (5)

The outcrops of Lhoty Formation are located in the forest slopes of Lanckorona Hill, next to main square of beautiful small town Lanckorona and ruin of historical castle (locality (5) on Fig. 1. B). The old quarries are accessible by the foot-path bearing the name "Alley of Lovers", marked by brown signs, passing historical cottages, and well known by locals and tourists. The exposed Albian-Cenomanian synorogenic flysch sequence contains of thin- and medium-bedded fine-grained siliceous sandstones interbedded by thin grey and dark shales (Ślączka and Kaminski, 1998). The upper part of Lhoty Formation – Cenomanian Mikuszowice Chert Member is exposed behind monumental cottage Pan Tadeusz and in the old quarry in northern part of Lanckorońska Hill (stop on the local foot-path). The gray-bluisch cherts with paralell lamination in sandstones layers are the characteristic features of this member.

3.6. Godula Beds (6)

Sandstones of Godula Beds were mined for a long time as building stones used locally as well as in numerous building in Krakow and industrial Silesia area (Bromowicz et al., 1976; Rajchel, 2005; 2008). Numerous quarries were established, most of them are abandoned now. The Ustroń quarry provide an example of such abandoned quarry used in the past as garbage dump, now cleaned and accessible as perfect geoturistric object (localty (6) on Fig. 1B). It is located on the slopes of Czantoria Mountiain within town limits of Ustroń, famous spa town with numerous hotels and touristic attractions. Thick-bedded turbiditic and fluxoturbiditic greenish sandstones prevail in the quarry (Ślączka and Kaminski, 1998) (Fig. 2C). They represent synorogenic stage of the Silesian Basin development. The areas surrounding this basin were uplifted and supplied clastic material. These material represent basement rocks as well as previously deposited turbiditic sequences. Well visible submarine slumps can be observed in the quarry. They contain large olistolith of redeposited Lhoty Formation.

The thick (up to 2000-3000 meters) Godula sandstones build the Beskid Śląski mountain range, many spectacular rocks are exposed within this mountains (Alexandrowicz, 2008). The best known is Malinowska Rock accessible by foot tourist trail from Salmopolska Pass between Wisła and Szczyrk. The coarse-grained sandstones and conglomerates (Malinowska Skała Conglomerate – stratigraphic unit within Godula Beds) builds several meters high rock cliff.

3.7. Istebna Beds (7)

The splendid outcrops of rocks known typical for Istebna beds (Senonian – Palaeocene), known as Brodziński Stones (Alexandrowicz, 2008; Krobicki et al., 2008) are accessible by educational trail (blue signs) located west of Lipnica Murowana (locality (7) on Fig. 1B). It starts at the parking lot near the country inn (Karczma) offering delicious regional specialties and leads southward across the woods covering the Paprotna Hill. The area is a classic study site and has high educational value especially, for demonstrating rock relief, sedimentary structures typical of fluxoturbidites, and geological setting of rocks (tors) in the zone of Istebna Formation sandstones as well as lithostratigraphic position in the deposit succession of the Silesian Unit (Fig. 2D). The shape of tors has depend on the lithology and lamination of sandstones, the direction of joints as well as on their position with respect to the morphological elements (Alexandrowicz, 2008). The differentiated bedding of deposits, domination of coarse-grained material and traces of submarine erosion characterise fluxoturbidites accumulated by high density turbidite current and debris flows. Features of these sediments are particularly well visible on tors' walls subjected to selective weathering. The Istebna sandstones of Silesian Unit were utilized in outcrops and quarries during past many centuries in local architecture as building stones.

3.8. The Ciężkowice Sandstones (8)

The best place to examine the Ciężkowice Sandstones is their type area – Ciężkowice surroundings (locality (8) on Fig. 1. B). The Ciężkowice Sandstones are important for exploitation providing perfect reservoir rocks in the cradle of Polish petroleum industry since XIX century. Ciężkowice Sandstones consists of four about 100 m thick sandy complexes interbedded by variegated, muddy shales with rich foraminiferal assemblages pointing the Eocene age. Sandstones are usually thick-bedded, fine- to coarse-grained and conglomeratic with many erosinal structures.

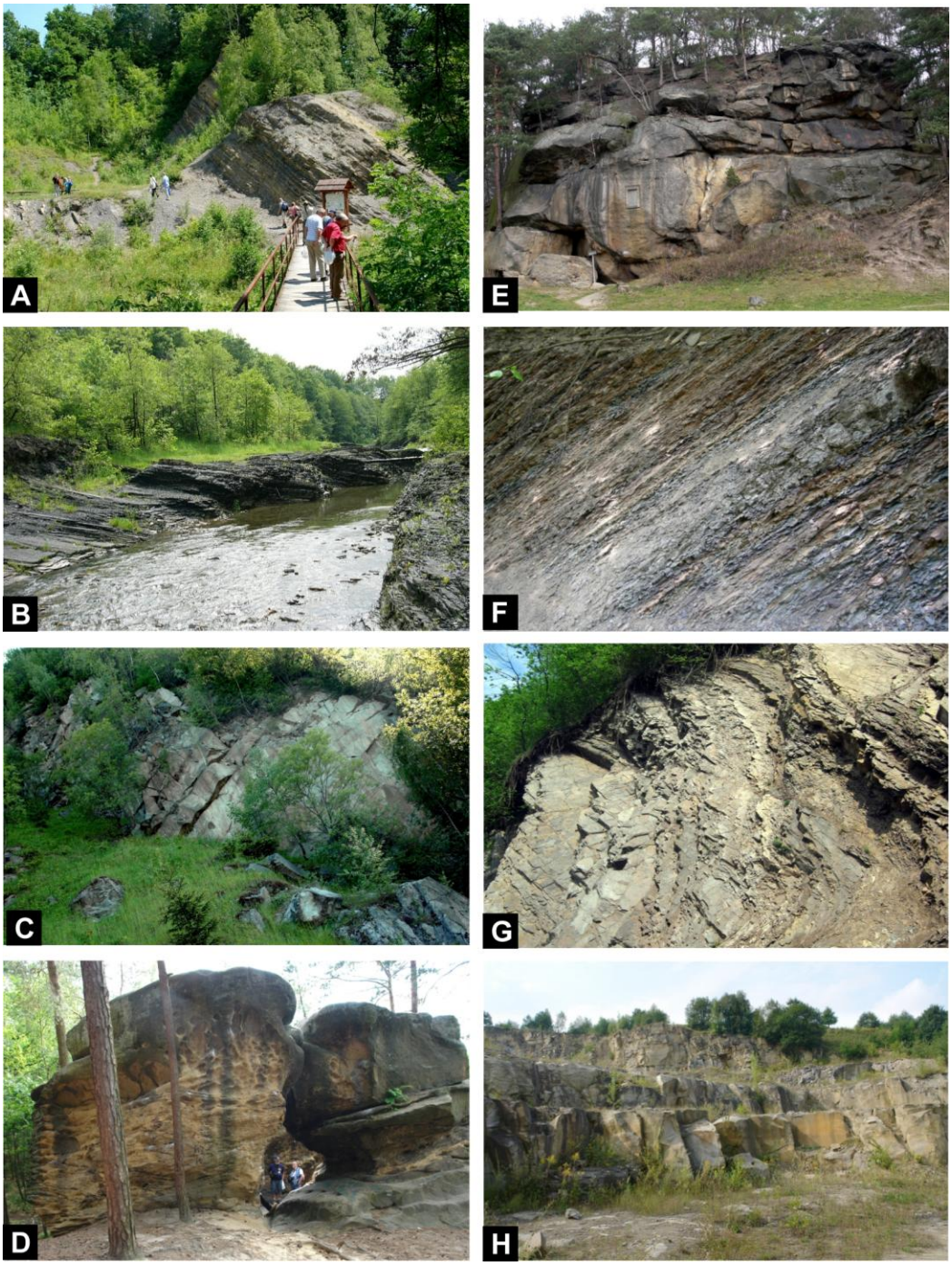

Fig. 2. The best outcrops of Silesian Nappe in Polish sector of West Carpathians. A - Hradište Fm., Żegocina; B - Veřovice Fm., Rzyki near Andrychów; C - Godula Beds, Ustroń; D - Istebna Beds, Lipnica Murowana; E - Ciężkowice Sandstone, Ciężkowice; F - Hieroglyphic Beds, Krzeszów; G - Menilite Beds, Kobielnik; H - Krosno Beds, Mucharz.

Weathering of the Ciężkowice Sandstones produced scenic landforms, as e.g. ”The Petrified Town” (Skamieniałe Misto) in Ciężkowice village or ”The Spinners” (Prządki) near Krosno town. In Ciężkowice various landforms built of eroded Ciężkowice Sandstones form a wide belt, up to 300 meters long on the western slopes of the Skała Hill (367 m a.s.l.) gently descending towards the Biała Dunajecka River (Fig. 2E).

All these landforms were carved along the joint systems cutting steeply dipping, thick layers of the Ciężkowice Sandstones, which reveal diversified resistance against weathering. At the surfaces of

particular rocks numerous hollows and niches are visible, caused by differential weathering.

The landforms are protected by law as one of the oldest nature reserves in the whole Carpathians. The reserve is connected by tourist trail with the Ciężkowice town located about 1.5 km northward. Due to attractiveness and reasonable tourist infrastructure the site is the most popular and most commonly visited Ciężkowice Sandstones exposure in the whole Carpathians (Gruszka, 2008).

3.9. Hieroglyphic beds (9)

The natural outcrops are located in both banks and bottom of Stradomka river in western part of Szczyrzyc Synclinorim (Beskid Wyspowy Mt. Range), opposite of the Devil Stone and hermitage in Krzesławice spot (locality (9) on Fig. 1B). The Upper Paleocene variegated (green) shales occur as green, gray (sporadically with red cherry layers) 100 m thick claystones. Hieroglyphic beds overlaying variegated shales are represented by gray shales with rare thin bedded, fine-grained siliceous sandstones often with parallel- and/or cross lamination and common hieroglyphs (both: organic and mechanic) on the layers bottoms (Fig. 2F). Biostratigraphical analysis from this locality indicates Early – Late Eocene age. Numerous thin layers of betonites in the central part of profile between alternating grey and brown shales with are testimony of volcanic activity during the Middle Eocene times. The outcropped profile is around 150 m thick.

3.10. Menilite beds (10)

Menilite beds (Oligocene) known as main source-rocks for Carpathian oils (Kotarba and Kołtun, 2006) are well exposed in the old quarry in Kobielnik located on the right bank of Kobielnik stream (west slope of Świnia Hill), (Beskid Wyspowy Mt. Range), (locality (10) on Fig. 1B). Brown siliceous organic-rich, bituminous shales, often with muscovite, containing numerous fish fossils prevail in this outcrop. The siliceous menilitic marls and complex of dark thin-bedded cherts, sandstones and shales outcrop in the lower part of profile in the Kobielnik stream (Fig. 2G). Occasionally the thin-medium-bedded sandstones fine- to coarse-grained (with quartz, feldspars, shall and sandy clasts, metamorphic and magmatic rocks as well as coal) are present in the upper part of the profile. The sandstones represent locally reservoir rocks within self-contained petroleum system. Sometimes they are overfilled by oil seeping along joint fractures.

3.11. Krosno Beds (11)

Krosno Beds represent the youngest rocks within the Silesian Unit (Picha et al., 2006; Ślączka et al., 2006). They were formed during Oligocene – Early Miocene synorogenic to postorogenic stages of the geodynamic development of the Outer Carpathians, displaying transition from flysch to molasse. The previously deposited turbiditic sequences were included into accretionary prism, uplifted and eroded together with older basement rocks, supplying material into Krosno Beds. Krosno Beds are widespread in the eastern part of the Polish Outer Carpathians. Near Krakow they are well exposed in the area south of Wadowice, between Beskid Mały and Beskid Makowski mountain ranges (locality (11) on Fig. 1B). In Mucharz quarry thick bedded lower (Oligocene) Krosno sandstones are exposed (Fig. 2H). They contain numerous sedimentary structure, like cross and convolute bedding, lamination, erosional channels, flute casts and other tool marks on the layers bottoms, locally submarine slides. These sandstones were deposited in distributary channels of the inner fan and lobes of the outer fan on the continental rise of Carpathian Basin. They were mined for centuries supplying building stone for local churches, mansions and other buildings.

4. The proposed itinerary

Kraków – Lanckorona – Kalwaria – Wadowice – Rzyki – Bielsko-Biała – Cieszyn – Wędrynia – Goleszów – Ustroń – Wisła – Malinowska Skała – Szczyrk – Żywiec – Mucharz – Kraków – Dobczyce – Stradomka – Kobielnik – Żegocina – Lipnica Murowana (Brodziński Stones) – Ciężkowice – Wieliczka – Kraków.

This itinerary start and ends in Krakow (Unesco World Heritage Site, well known for its Old Town and Royal Castle) and its Balice airport. It includes also historic towns like Lanckorona, Kalwaria Zebrzydowska (another Unesco World Heritage Site), Wadowice (Pope John Paul II birthplace), Bielsko-Biała, Cieszyn (oldest time in southern Poland), and Żywiec (famous brewery and Habsburg palace), Dobczyce (with famous castle on the banks of lake), Wieliczka (famous ancient salt mine also on Unesco World Heritage list). It passes numerous splendid wooden churches, the best known is located in Lipnica Murowana (again Unesco World Heritage Site). It also goes through

scenic mountain ranges. We propose one hiking trip to the Malinowska Skała Mountain in Beskid Śląski. Another mountain tops in Beskid Śląski, Mały, Makowski and Wyspowy are accessible by many foot trails and also by lifts, like from Bielsko-Biała to Szyndzielnia, from Ustroń to Czantoria and from Szczyrk to Skrzyczne.

The user could treat each geotouristic and touristic site separately, according to his or hers desire and interest, starting from Katowice, Zakopane or Ostrava in Czech Republic.

Acknowledgments

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