Geological heritage of the Świętokrzyskie (Holy Cross) Mountains (Central Poland)

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The Świętokrzyskie (Holy Cross) Mts., as a geological region situated within the Trans-European Suture Zone, geological history of which can be studied and reconstructed on the basis of numerous geosites, belongs to the most significant geological heritage of the European continent. This history is evidenced by the sedimentary rocks representing every period from the Cambrian to Jurassic outcropped in this region, whereas "the rest of the stratigraphic table" is accessible in the adjacent Niecka Nidziańska (Nida Basin), with an exception of the Paleogene, presumably occurring in karst forms, but not proved. The geodiversity of the region is accurately illustrated by the area of the Kielce town — the capital of the region, in which the rocks representing all Paleozoic periods crop out. Such a geoheritage should be used in many ways from the elementary public education (geotourism), through professional training (student field trips) of Earth sciences, to the modern scientific investigations.

Geodiversity

In the regional geological pattern of the central Europe the Świętokrzyskie (Holy Cross) Mts. region is a part of the Mid-Polish Anticlinorium — the Mesozoic rift inversed during Laramian tectonic movements. The region consists of two principal parts: Paleozoic Core and Permian-Mesozoic Marginal Zone. Additionally it is divided into two units of different crustal thickness and structure, and different geological evolution (Fig. 1): southern Kielce Unit representing northern part of the pre-Cambrian-Early

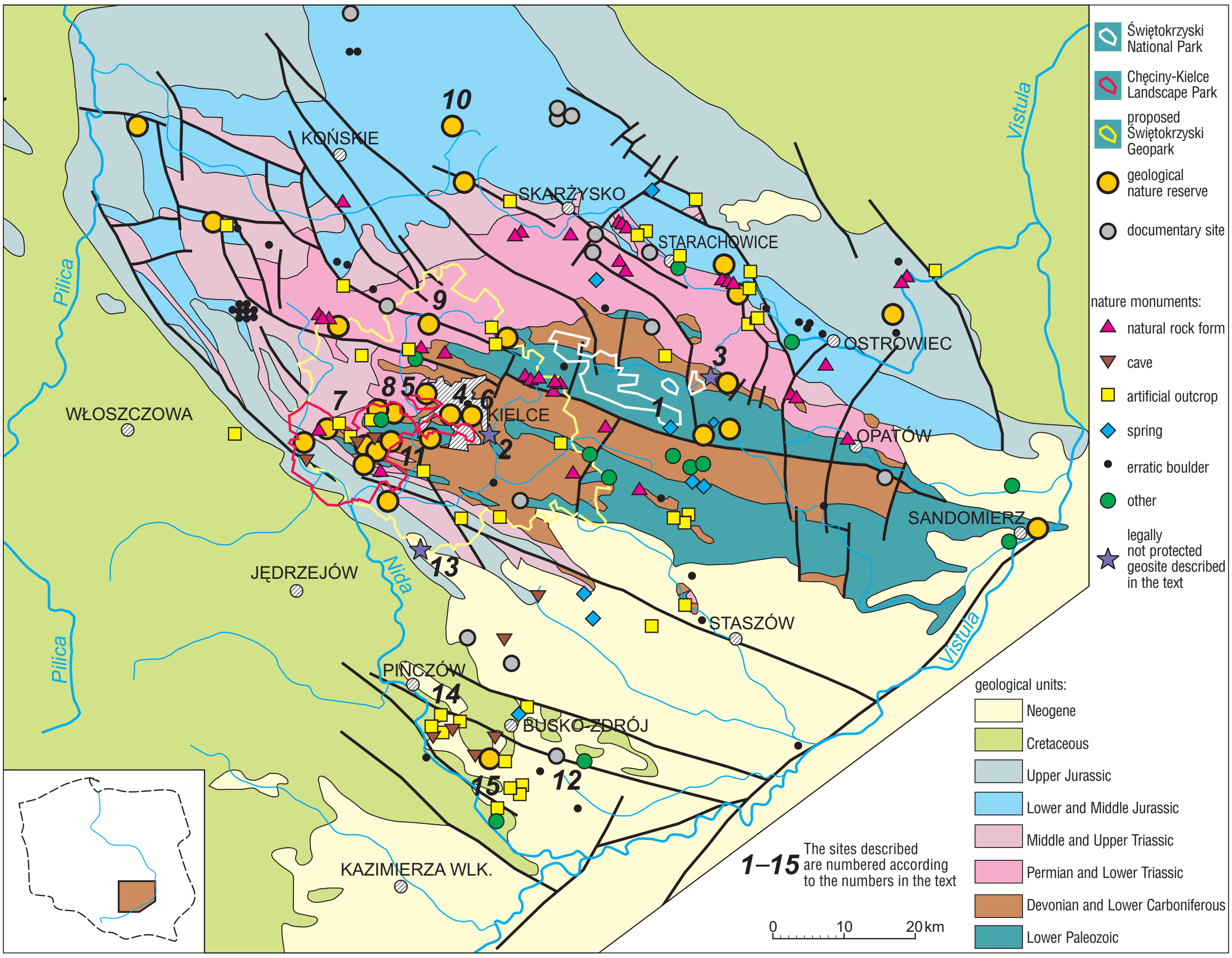

Fig. 1. Geoconservation in the Świętokrzyskie Mts. and SE part of the Nida Basin

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Paleozoic Małopolska Block, and northern Łysogóry (Łysogóry-Radom) Unit in the marginal zone of the East-European Platform. Both the segments are separated by the eminent fault of WNW-ESE trending, which was active at least to the Cenozoic, as evidenced by different facies and thickness of sediments, as well as position of gaps and unconformities in the sequences on its both sides (Kutek & Głazek, 1972; Szulczewski, 1995; Dadlez, 2001; Narkiewicz, 2002; Mizerski, 2004; Nawrocki et al., 2007).

Early Paleozoic sequence, commenced in the Kielce Unit with the Lower Cambrian and in the Łysogóry Unit — with the Middle Cambrian (as the oldest formations outcropped), consists of mainly siliciclastic-clayey rocks of marine origin, which were deposited in the basins surrounding the Baltica paleocontinent. This deposition was interrupted by several gaps, more frequent in the Kielce Unit (Fig. 2). In the same part of the region also Early Caledonian unconformity (Early Ordovician — Sandomierz Phase) was proved. Early Paleozoic evolution was finalized with the slight Late Caledonian tectonic movements and hiatus, proved in the Kielce Unit. Several small volcanic intrusions were associated with those movements (Orłowski, 1988; Kowalczewski, 1995; Malec, 2001; Modliński & Szymański, 2001a, b; Narkiewicz, 2002; Mizerski, 1995, 2004; Nawrocki et al., 2007).

The Lower Devonian shallow marine and occasionally terrestrial deposition of the siliciclastic-clayey rocks was replaced by the carbonate sequence at the beginning of the Middle Devonian (Fig. 2). The shallow carbonate platform, commenced with the extensive deposition of dolostones, quickly evolved into the deeper basin in the Łysogóry part of the region, where the Givetian-Fammenian succession comprises diverse carbonate-clastic-clayey rocks. In the Kielce Unit the shallow carbonate platform lasted till the end of the Frasnian, but its gradual differentiation and drowning, resulted in the development of various depositional environments. Consequently, the stromatoporoid-coral limestones and dolostones of the Kowala Formation (deposited on this platform), display diversity of structures and faunal assemblages in the upper section. The Fammenian-Lower Carboniferous marly-clayey series was deposited in the deepening basin (Racki, 1993; Skompski & Szulczewski, 1994, 2000; Skompski, 1995; Szulczewski, 1995; Szulczewski & Dvořak, 1995; Szulczewski et al., 1996; Malec & Turnau, 1997). In the Devonian succession the geochemical and biological global events were reconstructed (Baliński et. al., 2002; Racki & House, 2005).

The Variscan movements significantly shaped the tectonic structure of the Paleozoic Core. Although it is considered to be located out of the Variscan Belt, the events of tectonic deformations and associated phenomena, as e.g. mineralization and uplift, resemble evolution of the Variscan Orogene (Rubinowski, 1971; Migaszewski et al., 1996; Lamarche et al., 1999; Mizerski, 1995, 2004; Konon, 2006, 2007; Urban, 2007). During Late Permian the region was a mountainous peninsula on the east margin of the Central European Zechstein Basin. Therefore very variable rocks ranging from the immature, coarse-grained clastics to the lagoonal limestones were deposited around it (Wagner, 1994; Skompski, 1995; Szulc & Becker, 2007).

Since Early Triassic the Świętokrzyskie Mts., as the south-eastern segment of the Mesozoic rift called Mid-Polish (Danish-Polish) Trough, underwent the subsidence of various rate, along the NW-SE axis. The subsidence did not cause the unification of the depositional environments and facies (Kutek & Głazek, 1972; Hakenberg & Świdrowska, 1998a, b; Lamarche et al., 1999; Kutek, 2001). The siliciclastic-clayey rocks deposited in the terrestrial environments with participation of the marine episodes are characteristic for the Early Triassic, Late Triassic and Early

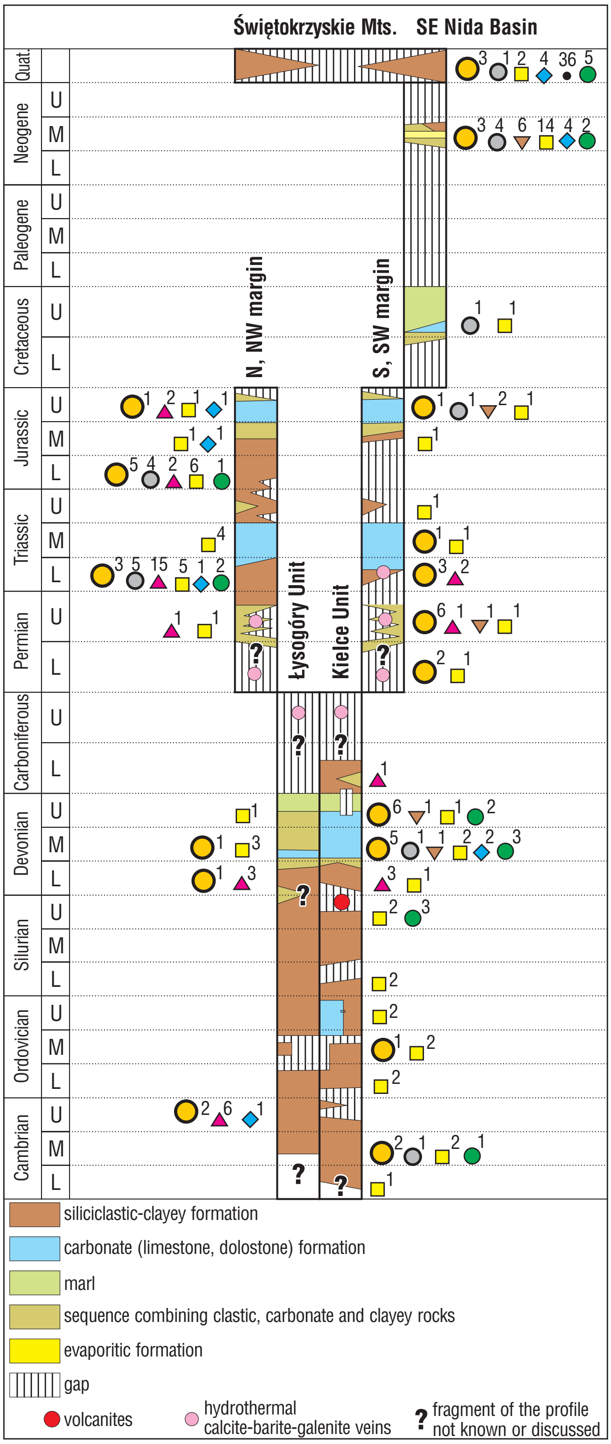

Fig. 2. Geoconservation in the Świętokrzyskie Mts. and SE part of the Nida Basin on the background of the lithostratigraphic profiles (division of the Permian according to the local scheme). Stratigraphic position of the rocks outcropped in the nature reserves, documentary sites and as the nature monuments are shown near the lithostratigraphic column using the same symbols as in Fig. 1; near symbols the numbers of protected sites (the numbers are higher than total number of protected sites, because the same site may combine more than one stratigraphic unit)

Jurassic periods (Fig. 2). The thickness of these sequences increases towards the northwest, whereas in the southeastern and central parts of the region the gaps and erosion are proved. In turn, the extensive shallow carbonate basins covered the Świętokrzyskie Mts. in the Middle Triassic (Germanic Basin) and Late Jurassic (Szulc, 2000; Pieńkowski, 2004; Wierzbowski et. al., 2006; Szulc & Becker, 2007).

The Cretaceous and younger formations belong formally to the geological units surrounding the Świętokrzyskie Mts., but they are easily accessible (outcropped) not far from this region, in the adjacent southeastern part of the Nida Basin, called Ponidzie. After the Late Jurassic-Early Cretaceous hiatus, the deposition in this part of the Nida Basin, commenced with the clastic or clastic-carbonate series of the Albian or Cenomanian. The deposition in the Late Cretaceous basin, covering the whole central Poland, produced the thick series (Fig. 2) of marls and gaizes with limestone intercalations (Kutek & Głazek, 1972; Hakenberg & Świdrowska, 1998b; Walaszczyk, 1992).

Since the tectonic inversion and uplift of the Mid-Polish Anticlinorium in the Laramian Phase, the central part of the Świętokrzyskie Mts. region has been permanently or almost permanently under the terrestrial conditions. The prolonged erosion resulted in the removal of at least 3 km thick series of rocks from its central part. In the Neogene the region belonged to the elevated Meta-Carpathian Arch, which was hydrological divide between the Northern-Central Europe and Paratethys Basin (Fore-Carpathian Depression). The shallow sea of this second basin invaded the southern margins of the Świętokrzyskie Mts. (Kutek & Głazek, 1972; Głazek, 1989). The Middle Miocene marine sediments of the SE part of the Nida Basin are represented by bioclastic or lithoclastic carbonate rocks grading upward and southward the into clayey sediments (Radwański, 1969; Krysiak, 2000). The evaporite series occurring within this sequence is characterized by sedimentary structures of gypsum and diversity of gypsum crystals, among which are giant forms (Kasprzyk, 1999; Bąbel, 1999, 2002).

In the Pleistocene the region was covered by the ice-sheet during the South-Polish Glaciations and partly (northern part) during the Mid-Polish Glaciations. Apart from the glacial processes, the relief was shaped by morphogenic factors typical of the periglacial and interglacial environments (Klatka, 1962; Lindner & Wojtanowicz, 1997). Currently the Świętokrzyskie Mts. are characterized by structural relief. Low mountain (hill) ranges are formed of hard rocks, resistant for weathering and erosion in warm (Neogene) and moderate-cold (Pleistocene) climates, such as quartzitic sandstones, sandstones and limestones (Olędzki, 1976). In turn, the wide and flat valleys are filled with the Pleistocene glacial, glacifluvial and fluvial sediments.

The diversity of rock and mineral formations has stimulated a man's interest in mineral resources' exploitation since the human existence in the Świętokrzyskie Mts. During the New Stone Age the flints were mined in hundreds of pits and underground galleries in the Upper Jurassic limestone outcrops of the northern part of the Świętokrzyskie Mts. The mining and processing of the iron ores (mainly of sedimentary origin) began in the central part of the region at least since the Late Iron Age (2nd century BC) and finished in the second half of the 20th century. The lead and copper ores of the hydrothermal and karst origin were mined since the Middle Ages till the half of the 20th century (Rubinowski, 1971). The long and complex tradition of the interconnections between a man and abiotic nature is expressed with various natural-historical features. The most common are the surface remnants of mining such as hundreds of shaft depressions and waste rock dumps. Less frequent are open shafts, mine galleries and remnants of metallurgy works. The most impressive monuments of historical mining are three statues carved in the large blocks of galenite (Fig. 3) and the legend on their extraction in the 17th century.

Fig. 3. Monastery on the Karczówka Hill, Kielce — the statue of St. Barbara (a patron of miners) carved in a large block of galenite mined in the Karczówka Hill in 1646. Photo by M. Kuleta

Rock exploitation began about one thousand years ago and developed into one of the main industry branch in the region today. The principal historic types of block building stones were: white-pink-red hydrothermal calcites, reddish and brownish-grey Devonian limestones, Permian carbonate conglomerates, "soft" light grey Miocene limestones, Lower Triassic red sandstones and Lower Jurassic grey-yellow sandstones (Urban & Gągol, 1994; Gągol, 1996). Currently the stone materials are commonly quarried for the construction and road industry (ballast, concrete, lime and gypsum cements), chemical industry and agriculture (fertilizers).

Geoconservation

The unique scientific and educational values of the Świętokrzyskie Mts. for geological studies in central Europe were appreciated by the first geologists working on this territory, at the beginning of the modern geology. This was the reason for foundation of the first Polish Mining Academy (active 1816–1826) in the Kielce town. J.B. Pusch (1790–1846), the author of the first modern monograph on the geology of Polish territory, described many of the geosites mentioned below. In 1843 other geologist, L. Zejszner (1805–1871), guiding Sir R.I. Murchison during his travel to the central and eastern Europe, demonstrated him the

Devonian geosites in the Kielce town and the Neogene paleofauna in Korytnica.

The first proposals of legal protection of geosites in the Świętokrzyskie Mts. were articulated just after the First World War (when Poland gained its independence after 123 years of partition). The most active in this field was the eminent Polish geologist, J. Czarnocki (1889–1951) proposing the establishment of the Świętokrzyski National Park and protection of other geosites (Czarnocki 1928a, b, 1949). The current state of the inanimate nature protection in the region was initiated by geologist Z. Rubinowski (1929–1997) and realized in the 80s of the 20^{th} century (Urban, 1990). Currently in the Świętokrzyskie Mts. the network of legally protected geosites constitutes: 28 nature reserves, 145 nature monuments and 14 documentary sites. To the protected areas comprising the geosites of scientific-educational values should be also considered the Świętokrzyski N.P. and 9 landscape parks (Wróblewski, 2000).

Among the protected geosites are the typical rock sequences, outcrops of the sedimentary structures, tectonic phenomena, paleontological sites, sites of the occurrence of interesting mineral/rock formations and historical mines, crags, caves, paleokarst forms, erratic boulders and springs. The protected geosites represent almost every units of the stratigraphic profile (Fig. 2). The list of protected sites should be supplemented in relation to the development and progress of the scientific researches of the region.

Geosites

Using the adequate criteria (Dingwall et al., 2005), the geosites of the Świętokrzyskie Mts. were assessed in order to select sites of super-regional importance as candidates for the European Geoheritage List in a framework of the "Geosite" project (Wimbledon, 1999). The preliminary list was proposed in 1999 (Urban & Wróblewski, 1999) and resumed in 2006 (Alexandrowicz, 2006 and Polish database... on www.iop.krakow.pl/geosites/default.asp). Several geosites proposed for the list are presented hereafter.

1. Łysogóry Range (Świętokrzyski National Park). The Łysogóry is the highest mountain range in the Świętokrzyskie Mts. (612 m a.s.l., ca 300 m above the plains). The range is formed of the Upper Cambrian quartzitic sandstones (Kowalczewski, 1995; Żylińska et al., 2006), which make up the Łysogóry Anticline — asymmetric fold or scale of WNW-ESE direction. The south margin of the fold is the regional Świętokrzyski Fault separating the area into two units of the Earth crust: Łysogóry (-Radom) Unit and Kielce (-Nida) Unit (Małopolska Block) (Dadlez, 2001; Mizerski, 1995, 2004).

Fig. 4. Łysogóry Range — block field on the northern slope of the range. Figs. 4–14 photo by J. Urban

The Łysogóry range is a structural landform, famous because of the fields of large angular "quartzite" blocks (Fig. 4), which cover its slopes ("łysogóry" means "bald mountains" in Polish). The field blocks developed in the periglacial environment of the Late Pleistocene due to the mechanical weathering and subsequent solifluction and pluvial erosion. The gradual retreat of the block field margins and progress of plant cover has been recently observed (Czarnocki, 1928a; Klatka, 1962; Olędzki, 1976).

2. Mójcza (site legally not protected). The condensed sequence of specific Ordovician rocks crops out in the artificial trench ca 15 m long. The most interesting Mójcza Formation is dated biostratigraphically (proved by conodonts) as the Upper Arenig-Upper Caradoc. It is 8.5 m thick and almost continuous containing bentonite horizon of correlative importance. It is formed of the bedded biodetrital and oolitic lime grainstones, in the uppermost part packstones to wackestones (Fig. 5). Fossils are represented by conodonts, ostracods, crinoids, brachiopods, bryozoan zoaria, trilobites and molluscs (new taxa). The Mójcza Fm. was deposited in stable environments of submerged platform separated from the source of the terrigenous material. The formation of platform was related to the sea-level highstand after Llanvirn transgression and to the next transgression in Late Caradoc-Ashgill time (Dzik et al., 1994; Trela, 1998, 2005).

Fig. 5. Mójcza site — a trench with the limestone sequence of the Mójcza Fm.; on the limestone surface the traces of sampling

3. Grzegorzowice-Skały (partly in the Wąwóz w Skałach Nature Reserve). Early to Middle Devonian rock sequence is exposed in a chain of outcrops scattered on the slopes of Dobruchna creek valley in the distance of 3.5 km. The units of this sequence are as follows: a) Zagórze Fm. (Emsian) — terrigenous to shallow marine sandstones with placoderms; b) Grzegorzowice Fm. (Upper Emsian-Lower Eifelian) — marine sandstones, shales, marls, limestones and dolostones with conodonts, corals, crinoids, brachiopods, ostracods, trilobites, conodonts and acritarchs (stratotype) (Malec & Turnau, 1997); c) Wojciechowice Fm. (Eifelian) — dolostones with limestone and marl intercalations (outcropped in a quarry and as natural crags), rich in stromatoporoids, corrals, brachiopods and crinoids, deposited in shallow water environments (Skompski & Szulczewski, 1994); d) Skały Beds (Eifelian, Givetian) — shales, marls and limestones full of fossils: brachiopods, crinoids, ostracods, corals, gastropods, bivalves, tentaculitids, conodonts, trilobites and nautiloids; e) Świętomarz Beds (Middle Givetian) — claystones and siltstones with paleoflora and rare fauna; f) Pokrzywianka Beds — limestones with stromatoporoids, corals, brachiopods, ostracods and trilobites; g) Nieczulice Beds (Upper Givetian) — claystones, marls and limestones with brachiopods, nautiloids, goniatites, ostracods, crinoids, radiolarians and conodonts. Stratigraphy of the sequence is based on conodonts, ostracods and miospores (Szulczewski, 1995; Malec & Turnau, 1997).

4. Kadzielnia (partly in the nature reserve), Kielce town. Frasnian shallow marine limestones, overlain by Famennian marly-shale series deposited in the deeper basin, crop out in the abandoned quarry Kadzielnia. The Lower Frasnian bioherm of the Kadzielnia Limestone is a mud-supported mound rich in microbiotas, stromatoporoids and corals. Slope of the mound is covered by biodetrital limestones (Detrital Stromatoporoids Beds). Both these units are flanked and partly covered by micritic Manticoceras Limestone, which compensates depression near the buildup. Frasnian carbonates are covered discordantly by a layer of the Lower Fammenian Cheiloceras Limestone unit and marly-shale series (Fig. 6A). Frasnian carbonates were formed in the northern part of the Middle-Late Devonian carbonate platform. Stratigraphy of the sequence is based on conodonts, but many groups of fossils: corals, brachiopods, goniatites, molluscs, stromatoporoids, crinoids, ostracods, trilobites, tentaculites, foraminifers and fish, have been studied there for the last century (Szulczewski, 1971, 1995; Rubinowski & Wójcik, 1978; Racki, 1993; Szulczewski & Dvořak, 1995).

Devonian carbonates are cut by the large Variscan fault, rejuvenated and karstified in the Cenozoic, as well as the Permian-Triassic hydrothermal veins of calcite-barite-galena mineralization (Rubinowski, 1971). Remnants of the Permian-Triassic karstification, and abundant Cenozoic karst forms occur in the limestones (Fig. 6B). Large paleo-sinkholes filled with sands are supposed to be of the Paleogene age. Bones of the Early Pleistocene vertebrates were excavated in fills of karst caverns (Kowalski, 1989). Twenty five caves notified in the quarry derive from the karst system developed on two or three levels in the Neogene and Early Pleistocene (Czarnocki, 1949; Kozłowski et al., 1965; Rubinowski & Wójcik, 1978).

5. Śluchowice (Nature Reserve of Jan Czarnocki), Kielce town. Unique tectonic mesostructures developed due to Variscan tectonic movements in the Upper Devonian (Frasnian) bedded limestones crop out in the high walls of the rocky "neck" separating two abandoned quarries. The main outcropped structure is a recumbent flexure fold (turned to the south) with subordinate foldings in its wide axial zone (Fig. 7). Characteristic elements of these forms — flexural slips, bulbous hinge structures, hinge gaps, hinge neck, and system of various faults, joints and cleavage in the folded layers, etc. — enable detailed studies of the mechanism of folding (Czarnocki, 1949; Konon, 2006, 2007).

The sequence (Kostomłoty Beds) was deposited in the distal, slope part of the Upper Devonian platform, in deeper sea than in the Kadzielnia site. Several groups of fossils were found in the rocks: brachiopods, corals, trilobites and conodonts (Szulczewski, 1971).

6. Wietrznia (Nature Reserve of Zbigniew Rubinowski), Kielce town. Abandoned Wietrznia quarry is an outcrop of the Middle to Upper Devonian carbonates, as well as Permian, Triassic and Cenozoic paleokarst. Owing to dip of the Devonian rocks the stratigraphic sequence ranges from the Givetian to Famennian. Givetian-Frasnian thick-bedded and massive carbonates (Wietrznia Beds)

Fig. 6. Kadzielnia abandoned quarry: **A** — Frasnian massive limestones overlain by Famennian marly-shale series; **B** — Skałka Geologów (Geologists' Rock) on the background of the Kielce town. The Frasnian massive limestones are strongly karstified, which is illustrated by the brown fills of the deep paleodoline

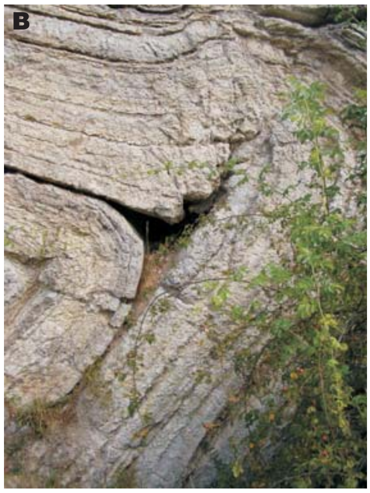

Fig. 7. Śluchowice (Ślichowica) abandoned quarry: **A** — a general view of the fold structure, **B** — a deformed axial part of the fold

represent biodetrital facies of the distal part of the carbonate platform drowned during the Late Devonian. They pass upward into micritic limestones and Famennian thin-bedded marls. Syndepositional movements of small tectonic blocks generated facies diversity observed within the quarry. The rocks are abundant with fossils such as corals, brachiopods, goniatites, molluscs, stromatoporoids, crinoids, ostracods, trilobites, foraminifers, conodonts and fish, which have been investigated since the 19th century. These studies resulted in: a) description of new taxa, b) analyses of anatomy and evolution, c) stratigraphy of the sequence (Givetian-Frasnian boundary), d) reconstruction of the evolution of faunal assemblages and their reaction on the Devonian global events (Czarnocki, 1949; Racki, 1993; Skompski, 1995; Szulczewski, 1995; Szulczewski & Dvořak 1995; Baliński et al., 2002; Ivanov & Ginter, 1997; Vierek, 2007).

The relics of the post-Variscan terrestrial period in the Wietrznia quarry are as follows: a) Permian (?) brecciation zone and megabreccia, which fills large paleokarst doline, b) Permian-Triassic sinkholes filled with the carbonates grading upwards to clastic deposits, c) Early Triassic tectonic-karst fissures filled with sandstones. The diversity of forms and fills suggests several phases of erosion and terrestrial deposition related to the tectonic events in Permian-Triassic time (Skompski, 1995; Urban, 2007).

7. Góra Miedzianka Nature Reserve and Kozi Grzbiet (nature monument). Góra Miedzianka is a hill formed of the Frasnian massive limestones, which are strongly disintegrated by faults and contain tectonic scales of the Famennian marls. Calcite veins with sulfide and sulfo-salt minerals of Cu, Fe, Zn, Pb and Ni occurring within the limestones, represent original Variscan hydrothermal mineralization. The secondary ore bodies, enriched in chalcocite and copper carbonates concentrated in the cementation and oxidation zones, mainly in the Cenozoic paleokarst forms (partly under the Triassic cover of the Devonian). These very irregular ore bodies were mined since the Middle Ages to the first half of the 20th century (Rubinowski, 1971). It resulted in the occurrence of many kilometers of mine galleries (Fig. 8), which partly followed paleokarst conduits (some opened to the surface) and numerous surface remnants of mining. The hill ridge is crowned with the natural limestone crags of high landscape value (Fig. 8). From this ridge both natural landscape of the structural hill ranges and large anthropogenic works (Ostrówka quarry) are visible.

Fig. 8. Góra Miedzianka: **A** — mine gallery “Zofia” excavated in the 19th century; **B** — natural rocky ridge of the hill

In the neighboring Kozi Grzbiet hill, the Pleistocene fossils were found in sandy-clayey fills of the karst fissures. Studies of the paleofauna (mammals, birds, reptiles, amphibians and gastropod shells), typical of moderate climate, enabled to recognize a new interglacial period and to divide previous South-Polish Glacial (Mindel) into two glacials (Głazek et al., 1976; Kowalski, 1989; Lindner & Wojtanowicz, 1997).

8. Jaworznia (Chelosiowa Jama Nature Reserve). The site is a hill built of the Devonian limestones overlain by the Lower Triassic clastic-clayey series (Buntsandstein). The angular unconformity between the Devonian and Triassic is outcropped in the abandoned quarry (Fig. 9). The diversity of facies and structures of the rocks enable reconstruction of the paleorelief during the Early Triassic (Głazek & Romanek, 1978; Nawrocki et al., 2003). Several paleokarst generations were recognized: a) Devonian paleosols formed in limestones emerged during the cyclic events of stopped subsidence (Skompski & Szulczewski, 2000); b) underground forms of the Permian, hydrothermal karst; c) network of the Early Triassic small paleokarst conduits and large horizontal channels, which are supposed to develop in a sea freshwater mixing zone; d) Early Triassic surface and underground karst forms (Urban, 2007).

Fig. 9. Jaworznia — angular unconformity between the Devonian limestones and Lower Triassic red siliciclastic-clayey series

The Cenozoic karst period is represented by maze, predominantly horizontal network of passages and chambers of the Chelosiowa Jama-Jaskinia Jaworznicka cave (3670 m, the longest Polish cave out of the Tatra Mts.), Jaskinia Pajęcza cave (1183 m) and several short caves. The caves, formed in the Neogene, were restored several times. Among the secondary calcite forms are unique aggregates formed due to the slow water freezing during the last glacial in the Pleistocene (Žak et al., 2004).

9. Tumlin-Gród (Kręgi Kamienne Nature Reserve). The Tumlin-Gród partly active quarry is the outcrop of the Lower Triassic sandstones of the Tumlin Member of the Zagnańsk Formation. The sandstones represent deposits of dunes and interdune areas formed in the dry climatic environment. The paleo-dunes display the large-scale cross-bedding. Remnants of ephemeral streams, ponds and interdune flats occur among the dunes (Fig. 10). They are characterized by wave ripples, erosion channels as well as desiccation cracks and mud flakes. In the quarry also numerous

Fig. 10. Tumlin-Gród — large scale cross-lamination of the paleodunes with the apparent structure of the ephemeral stream

footprints of vertebrates have been found (Gradziński et al., 1979; Ptaszyński & Niedźwiedzki, 2004; Szulc & Becker, 2007). The red Tumlin sandstones have been traditional stone material quarried and used in the whole country for construction purposes since the 19th century (Urban & Gągol, 1994).

10. Piekło pod Niekłaniem Nature Reserve. The natural rock forms of Piekło pod Niekłaniem (Hell near Niekłań village), built of the Lower Jurassic sandstones, are characterized by the exceptional variety of shape and microrelief and conditioned by the specificity of the lithologic structures (Wierzbowski et al., 2006) and relief development. The rock forms are situated in the upper part of extensive hill. The group is composed of three subgroups. The SW subgroup is composed of the most picturesque side-ridge forms: pulpits, bars and mushroom-like forms from 5 to 8 m high (Fig. 11). Two caves were formed there due to the subsurface water erosion. The typical microforms of rock surfaces are: caverns, pockets, honeycomb forms, ledges and furrows (Urban, 2005).

The rock forms were stripped in the Late Pleistocene, supposedly during the last glacial. The aeolian abrasion

Fig. 11. Piekło pod Niekłaniem — cliffs and pulpits in the mid part of the SW rock subgroup; in the left side the cave entrance and natural tunnel through the pulpit

was the main factor excavating these landforms, but they have been permanently shaped by other agents such as e.g. linear erosion of subsurface water. The diversity of microrelief has been controlled by the development and degradation of mineral crust (Lindner, 1972; Urban, 2005).

11. Jaskinia Raj Nature Reserve. Raj is a karst cave 240 m long, developed in the Devonian limestones. It consists of the three main horizontal passages, which converge near the entrance. Lower part of the passages is filled with the Late Pleistocene loams and sands, covered by the calcite flowstones. Fossils (mammals, birds, reptiles, amphibians, rare fish and gastropods) occur in almost every 12 layers of the sediments, whereas archaeological artifacts were found in layers no 4 and 6. The cave sediments were deposited in the period before, during and after the first climatic minimum of the last glacial (Late Pleistocene). Archaeological materials (tools) represent the Mousterian Culture of Charentian Group of Neanderthals — Middle Stone Age (Madeyska, 1972; Rubinowski &Wróblewski, 1972).

Fig. 12. Raj cave — the soda straw stalactites are the most numerous and typical of this cave

The Raj cave is rich in the calcite speleothems, which represent various types: stalactites (ca 47 thousands; average 82.5 stalactites/m^2), stalagmites, columns, draperies, curtains, ribs, dums and pisoids. Soda straw stalactites are the most typical (Fig. 12). The cave and paleontological--archaeological exposition are accessible for public (www.jaskiniaraj.pl/?lng=en&language=lang).

12. Skotniki — Zajęcza Góra (documentary site). The sequence exposed in the abandoned quarry comprises the Upper Jurassic and Upper Cretaceous rocks overlain by the transgressive deposits of the Miocene. Thus two phases of the Alpine tectonic movements are perceptible there. The first unconformity (angle ca 3º) is observed between the Oxfordian limestones (dipping 35ºN) and Cenomanian sandstones. Thin Cenomanian glauconitic sandstone layer is overlain by the Turonian and Senonian limestones marls and gaizes bearing flint nodules and horizons. The abraded paleosurface of the Cretaceous and Jurassic rocks is covered by the sub-horizontal Badenian breccia-conglomerate intercalated with sandy limestone. The coarse-grained rock is composed of fragments of its substratum, commonly with animal borings (sponges, bivalves, worms, gastropods) and incrustations (bryozoans, worms, algae). It represents sediment of the littoral depression. It is overlain by the biodetrital and algal limestones bearing also other fossils: foraminifers, gastropods, bivalves, echinoids, fish (Radwański, 1969; Kwiatkowski, 1985; Walaszczyk, 1992).

13. Korytnica (legally not protected). The site is an area covering several square kilometers, on which the Miocene marine rocks (clays and sands) occur, with abundant fossils, accessible in artificial pits or due to ploughing. A great number of fossils representing hundreds of taxa and ichnotaxa have been studied there for longer than 150 years (since 1970 more than 50 papers concerning this site have been published). They are: molluscs, corals, worms, ostracods, crabs, stromatopods, cirripedes, crinoids, echinoids, asteroids, ophiuroids, holothurians, fish, bryozoans, brachiopods, sponges, foraminifers, algae, nannoplankton, dinoflagellates and radiolaria. Molluscs represent the richest and the most diversified group: gastropods, bivalves, chitons, scaphopods, cephalopods. The state of preservation of the fossils enables environmental and ecological studies, as well as analyses of anatomy, classification, evolution, physiology and behaviors of this fauna. The faunal assemblages were similar to the recent ones in tropical or subtropical seas, as the Indian Ocean (Radwański, 1969; Bałuk & Radwański, 1977; Hoffman, 1977; Bałuk, 2006).

14. Gacki (3 nature monuments). In the Gacki abandoned quarry almost the whole sequence of evaporite series of the northern part of the Miocene basin crops out. Primary, depositional structures have been preserved in the gypsum. The formation is characterized by horizontal and vertical diversity of gypsum structures, which are related to the evolution of the basin and its water. In the sequence 15 layers and 7 lithosomes were distinguished. The lithosome A (3 m thick) is a layer of giant, palisade crystals (and intergrowths) growing directly on the marls of the substratum due to the precipitation from oversaturated brine (Fig. 13). It is overlain with the grass-like selenites intercalated with fine-crystalline gypsum, which formed in the very shallow brine (B — 3 m thick). Upper lithosomes C and D (12 m) consist of bedded, sabre-like gypsum deposited in deeper basin during the gradual modification of brine composition. Microcrystalline laminated gypsum and clastic gyp-

Fig. 13. Gacki — the lowermost unit of the Miocene evaporite series, ca 3 m thick, formed of the palisade of giant gypsum crystals growing directly on the marl substratum

sum (breccias) represent lithosomes E and G (16 m thick). Their deposition is related to the halite oversaturation. The formation of breccias is connected with the halite dissolution and gypsum redeposition (Kasprzyk, 1999; Bąbel, 1999).

Other interesting geological phenomena in the site are: a fault in the gypsum series and underlying marls outcropped in the quarry road-cut, as well as the Jaskinia w Krzyżanowicach Górna cave with the archaeological site (Urban et al., 2007).

15. Skorocice Nature Reserve. Skorocice Gorge is a typical karst valley developed due to roof failures of karst subsurface conduits. It is formed in the gypsum of lower part of the Miocene evaporite series. The valley consists of two segments: upper, blind part and lower part, which are separated by natural rocky bridge and connected with the

Fig. 14. Skorocice — karst conduit of the Jaskinia Stara cave, formed due to the gradual incision of the Skorocicki Stream (visible on the passage floor)

Jaskinia Skorocicka cave (352 m long) and Skorocicki Stream. Thirty shorter caves (Fig. 14) and numerous surface karst forms — hums, depressions, and rock walls — are located within the both parts of the valley. Karst forms represent entrenched and denuded phases of the gypsum speleogenesis and have been formed mainly on the level of the water-table zone (Urban et al., 2007).

* * *

Apart from the sites described above, the following sites from the Świętokrzyskie Mts. and Nida Basin are proposed for the European Geoheritage List: Góry Pieprzowe (Cambrian, tectonics, morphology), Biesak–Białogon (Cambrian, Ordovician, tectonics), Zalesie (Ordovician, stratigraphy), Międzygórz (Ordovician, stratigraphy, tectonics), Ostrówka and Todowa Grzęda (Devonian-Carboniferous, stratigraphy, paleogeography), Zelejowa (Devonian, Permian, mineralization, paleokarst), Żakowa (Devonian, Permian, mineralization, mining), Wolica (Triassic, stratigraphy, paleoecology), Gagaty Sołtykowskie (Jurassic, dinosaur footprints, paleoecology), Małogoszcz (Jurassic, paleoecology), Bałtów (Jurassic, paleoecology), Krzemionki Opatowskie (Jurassic, flint mines — www.krzemionki.pl/index.shtml?english), Dobromierz Brachyanticline (Jurassic-Cretaceous, stratigraphy, tectonics), Szydłów (Neogene, paleoecology), Lubania (Jurassic, Neogene, paleogeography, paleoecology), Kamień Plebański (Quaternary, stratigraphy), Wola Chroberska (Quaternary, paleoecology) (Alexandrowicz, 2006 and Polish database of representative geosites... on www.iop.krakow.pl/geosites/default.asp). The list is not closed; it will develop together with the progress of investigations and recognition of sites, as well as changes of their status.

The presented above list does not regard the sites, which can be destroyed in active quarries. Among the active quarries being the subjects of the scientific interest are e.g.: Wiśniówka (Cambrian), Kowala (Devonian, Permian), Trzuskawica (Devonian, Permian), Kostomłoty (Devonian), Baranów (Triassic), Wierzbica (Jurassic) and Bukowa (Jurassic). They are visited during the scientific conferences (e.g. Szulc & Becker, 2007; Wierzbowski et. al, 2006).

Geotourism

The geoheritage of the Świętokrzyskie Mts. should be properly used for public profit and advantage of Earth-science education, which is severely threatened in Europe (van Loon, 2008). Apart from scientific value, the necessary conditions for the geotourism are accessibility and illustrativeness (Alexandrowicz et al., 1992). In case of most of geosites in the Świętokrzyskie Mts., with exception of some caves and mine galleries, there are no technical problems of access, but the access and educational use of some geosites are limited by their legal protection (see Cabaj & Leśniak, 2005). Recently, the adequate arrangements for Earth science education have been prepared in many protected areas, so as to combine effective protection and easy access.

The idea of public geoeducation has had long tradition in the Świętokrzyskie Mts. The first significant steps on this way were geological guidebooks by Kotański (1959, 1968). The next guidebook was published ca 40 years later by Stupnicka and Stempień-Sałek (2001), but again only in Polish. The professional descriptions of many geosites were published in Polish or English guidebooks of conference trips organized in the region. Recently descriptions of some geosites are on the Internet, e.g.: http://aneksy.pwn.pl/historia_ziemi/przyklady/index.php? (in Polish), www.iop.krakow.pl/geosites/default.asp (in English).

The idea of the touristic arrangement of the geosites in the vicinity of Kielce town was expressed long time before the foundation of the first geoparks, as a concept of the "geological eco-museum" (Rubinowski & Wójcik, 1978). This concept was not done but the proper protection and educational usage of geosites was the principal objective of establishing of the Chęciny-Kielce Landscape Park in 1996 (Urban & Wróblewski, 1999, 2004; Wróblewski, 2000). Subsequently the idea of geological education evolved to the concept of the Centre of Geological Education in Kielce, which was done in form of the Kielce Geopark (www.geopark-kielce.pl), established in 2003. The Kielce Geopark centre promotes the geoheritage of the nature reserves (old quarries) situated within the Kielce town and manages these reserves. This management consists in the arrangements of educational trails and provision interpretative panels, publishing leaflets etc. In the Kadzielnia quarry the caves are being prepared for public access. But the principal aim of the Kielce Geopark is the foundation of the Świętokrzyski (Holy Cross Mts.) Geopark (Fig. 1) and its adoption to the European Geoparks Network. This Geopark will cover the Kielce agglomeration and its vicinity. Within the area of the projected Geopark 15 geological nature reserves, ca 30 nature monuments and documentary sites, and 30 other geosites are situated.

The Kielce town with its old quarries and several tens of geosites in its proximity is a place, in which the organization of geotourism and geoeducation should be concentrated. Apart from the Geopark Kielce centre, the Holy Cross Mts. Branch of the Polish Geological Institute (http://www.pgi.gov.pl/pgi_en/) is located in this town. Both the Institute and Geopark centre offer their help in preparation and organization of geotourist trips and students' field trips. The geological museum of the Institute in Kielce and its open-air geological exposition are accessible for public. The paleontological regional collection is also exposed at the National Museum in Kielce (muzeumkielce.net/orla/strona_mnki/index_cis.html). One of the numerous geosites situated in the vicinity of this town is the Raj cave, which is the most famous cave in Poland.

The second centre of the geotourism can be the Świętokrzyski National Park (www.swietokrzyskipn.org.pl/), situated in the central part of the region (Fig. 1). The geological-paleontological exposition is the part of its Museum. Close to its margins, in the Nowa Słupia town, the Museum of Prehistoric Metallurgy is situated.

The next area of geotourism development is Kamienna River valley (north part of the region), where, e.g. the dinosaurs footprints and remnants of other Mesozoic vertebrates were found (see page 629 in this issue).

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