



Important geosites of the Polish Sudetes

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Abstract. The Sudetes constitute the marginal, northern part of the Bohemian Massif. The area is a part of the Variscan orogen rejuvenated in the Tertiary and subsequently faulted and uplifted. Formation of geomorphological relief of the Sudetes has been controlled by denudation, erosion, glacial, fluvial and volcanic processes. Conservation of inanimate nature in the Sudetes has been initiated by the Germans and after 1945 continued by Polish scientists. Present network of geoconservation sites consists of two national parks, 7 landscape parks, 12 geological reserves, 70 monuments of inanimate nature and 1 natural-landscape complex. Works on development of the network of a new form of legal protection — documentation site, are well on their way. Many of the already protected areas in the Polish Sudetes continue to the Czech territory. Such places should be protected conjointly. This paper concerns eight selected geosites of the Sudetes.

Key words: geoconservation, network of European geosites, Sudetes, Poland.

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Streszczenie. Sudety obejmują północną, brzeżną część Masywu Czeskiego. Obszar ten stanowi fragment orogenu waryscyjskiego, który został odmłodzony w trzeciorzędzie, poprzecinany uskokami i wypiętrzony. Rzeźba Sudetów została ukształtowana pod wpływem denudacji, erozji oraz procesów glacialnych, fluwialnych i wulkanicznych. Ochronę przyrody nieożywionej w Sudetach zapoczątkowali Niemcy, a po 1945 roku kontynuowali naukowcy polscy. Obecnie sieć geostanowisk obejmuje 2 parki narodowe, 7 parków krajobrazowych, 12 rezerwatów geologicznych, 70 pomników przyrody nieożywionej oraz 1 zespół przyrodniczo-krajobrazowy. Prace nad tworzeniem sieci stanowisk dokumentacyjnych — nowej formy ochrony prawnej — są znacznie zaawansowane. Wiele obszarów chronionych na terenie Sudetów przechodzi na terytorium Czech. Takie miejsca powinny być wspólnie chronione. W niniejszym artykule omówiono 8 wybranych geostanowisk w Sudetach.

Słowa kluczowe: geochrona, sieć europejskich stanowisk, Sudety, Polska.

The Sudetes, located in the Czech, Polish and German border area, extend over the distance exceeding 250 kilometres. The mountains consist of a number of ranges divided by the numerous rivers and valleys.

In geological approach, the Sudetes are the marginal, northern part of the Bohemian Massif, one of the major tectonic units of Central Europe. Generally, they consist of two primary units, the Fore-Sudetic Block and the Sudetes *sensu stricto*, divided by the Marginal Sudetic Fault formed in the Tertiary. The Sudetes are the Variscan orogen embodying a mosaic of distinct geological elements of different origin and composition (Fig. 1). The Sudetes are the only place in Poland of such diversity of minerals and rocks, including igneous and metamorphic ones of the Proterozoic and Palaeozoic as well as sedimentary ones of the Palaeozoic, Mesozoic and Cainozoic.

The relief of the Sudetes is an example of rejuvenated landscape. In the Tertiary the mountains were extensively

eroded and subsequently faulted and uplifted. Prominent volcanic activity was a very important geological factor shaping the relief, mainly of the Fore-Sudetic Block. Glaciation period in the Pleistocene gave rise to formation of some tors, moraines, patterned grounds, boulder fields, etc.

Conservation of inanimate nature

As a result of a complex geological structure, the Sudetes are abundant in different examples of monuments of inanimate nature worth protecting. The most characteristic and interesting ones, constituting the main elements of the relief, are numerous tors, including those of volcanic origin (Alexandrowicz, 1989).

The complex geological setting of the Sudetes has been subject to geological research for many decades. Already the first studies carried out before the I World War, clearly showed a necessity of conservation of inanimate nature. Among the German geologists working on this issue should be mentioned: G. Berg, A. Berger, W. Patchewsky, G. Guerich, D. Dittrich and

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K. Olbracht. Already in 1943 in the whole Lower Silesia there were established 44 nature reserves, including 20 in the Sudetes. Since 1945, the Polish geologists initiated geological research referring to conservation of inanimate nature in the area. In the subsequent years this subject was continued by the following scientists: M. Klimaszewski, S. Jarosz, E. Jońca, T. Gunia, Z. Śliwa, Z. Wójcik, K. Birkenmajer, S. Kozłowski, A. Jahn, J. Jerzmański, M. Pulina, M. Z. Pulinowa and many others.

Although the majority of the natural protected sites of the Sudety Mts. include some forms of conservation of inanimate nature, for example the effects of weathering processes and volcanic activity, different geomorphological forms, etc., those are rather rarely a main subject of protection. Presently, in the Sudetes and in their foreland (including parts of the Wrocław, Wałbrzych, Legnica and Jelenia Góra voivodeships) there are two national parks (the Karkonosze Mts. and the Stołowe Mts.), 7 landscape parks (the Ślęża Massif, the Śnieżnik Massif, the Bóbr River Valley, the Chełmy Hills, the Rudawy Janowickie Mts., Książ, the Sowie Mts.), 12 geological reserves, 70 monuments of inanimate nature and 1 natural-landscape complex (Fig. 1).

The Karkonosze National Park was established in 1959 on the basis of the pre-existing nature reserves. The second one, the National Park of the Stołowe Mts. was established in 1993, in a very similar way. The park combines the previous nature reserves (including Szczeliniec Wielki, Błędne Skąły and Torfowisko Batorowskie) while the former Stołowe Mts. Landscape Park has partially been converted into the national park buffer zone. Works on establishing a number of new nature reserves and nature monuments are still going on. Nowadays, a new form of conservation of inanimate nature, documentation site, is being developed. In the future, an extensive network of such sites is going to be established in the whole area of the Sudetes.

Draft candidate list of geosites

Out of the whole range of interesting examples of inanimate nature of the Sudetes only eight sites have been chosen for the purpose of this paper. These are: the Karkonosze Mts., the Stołowe Mts., the Massif of Ślęża, the Massif of Śnieżnik, the volcanic pipe on the Wilcza Góra Mt., the outcrop of rhyolite on the Wielisławka Mt., the outcrop of contact of the granite body and its metamorphic mantle nearby Gębczyce and the outcrop of granulites in the Biała Łądecka river valley in Stary Gierałtów. Until the present day, six sites out of the above mentioned ones have been covered by different categories of legal protection, while two last ones are not protected sufficiently. It should be stressed that the list does not thoroughly reflect diversity of geological elements of the area and that the works on this issue should be continued in the future.

A unique landscape of the Karkonosze Mts., including glacial and periglacial relief, is one of the reasons for protecting this area on both Czech and Polish sides of the border. The Stołowe Mts., the only example of plate mountains in whole Poland, form an intact range continuing to the territory of the Czech Republic. Works on protection of the whole trans-bound-

ary area should be carried out conjointly. The Massif of Ślęża, consisting of gabbro, and the surrounding hills composed of serpentinites is a curious place seeming to have no equivalents neither in Poland nor in any of the neighbouring countries. The Massif of Śnieżnik is an excellent example of the old, rejuvenated in Tertiary, crystalline massive. It embodies a mosaic of mesozonally metamorphosed rocks containing the inserts of marbles with well developed karstic phenomena.

1. The Karkonosze Mts. in the Western Sudetes (400–1602 m a.s.l.; 50°44'–50°50'N/16°35'–16°50'E).

Main features: the Upper Carboniferous granite, early Palaeozoic metamorphic rocks, forms of granite weathering, glacial and periglacial relief and sediments.

The Karkonosze Mts. form the highest range of the Sudetes consisting of the Upper Carboniferous granite intrusion and its metamorphic mantle (Borkowska, 1966; Jahn, 1985). In the subsequent stages, as an effect of postmagmatic processes, many pegmatitic, aplitic, microgranitic, lamprophyric, quartzitic and basaltic veins and bodies were formed. The granite body is characterized by the regular, three dimensional fissure system which controls processes of granite weathering and formation of tors (Fig. 2). The youngest crystalline rocks in the Karkonosze Mts. are basalts of the Tertiary. Under hot and moist climatic conditions, in both the Tertiary and Eopleistocene, extensive chemical weathering processes, forming a granite brush and some tors, were developed. During the Pleistocene glaciation several moraines, lakes and cirques were formed. The best examples of erosional processes under periglacial conditions are the granitic boulder fields, patterned grounds and occurrence of some types of bog areas. Selective weathering of the less resistant parts of granite has stimulated formation of some sophisticated tors (Stec & Walczak, 1954).

South of the town of Karpacz rises, consisting of hornfels Śnieżka Mt., the highest peak of the whole Sudetes (1602 m a.s.l.). The area to the east of Śnieżka Mt. belongs to the metamorphic mantle of the Karkonosze Mts. and is composed of the Precambrian and Early Palaeozoic metamorphic rocks of sedimentary and igneous provenance. Numerous deposits of raw resources, has been subject to mining or ages. Nearby the town of Kowary there are several former mines of iron and uranium.

In the Tertiary there was developed the base-level in the whole Karkonosze Mts., above which rise the highest, composed of highly resistant rock, peaks of Śnieżka Mt., Szyszak Mt. and others. Rejuvenation of the whole massif, combined with extensive faulting, taking place in Tertiary, resulted in a very ungraded profile of water streams. The valleys of some rivers are deeply incised into the bedrock and form steep canyons thus, the area is abundant in water falls, among which the best known are those on the following rivers: Kamieńczyk (27 metres high), Szklarka (10 metres high), Podgórna (10 metres high).

The Karkonosze Mts. are the only place in the whole Sudetes where the glacial lakes occur. The most famous are: Great and Small Lakes nearby the town of Karpacz as well as a group of smaller ones, called Śnieżne Lakes in the western Karkonosze Mts.

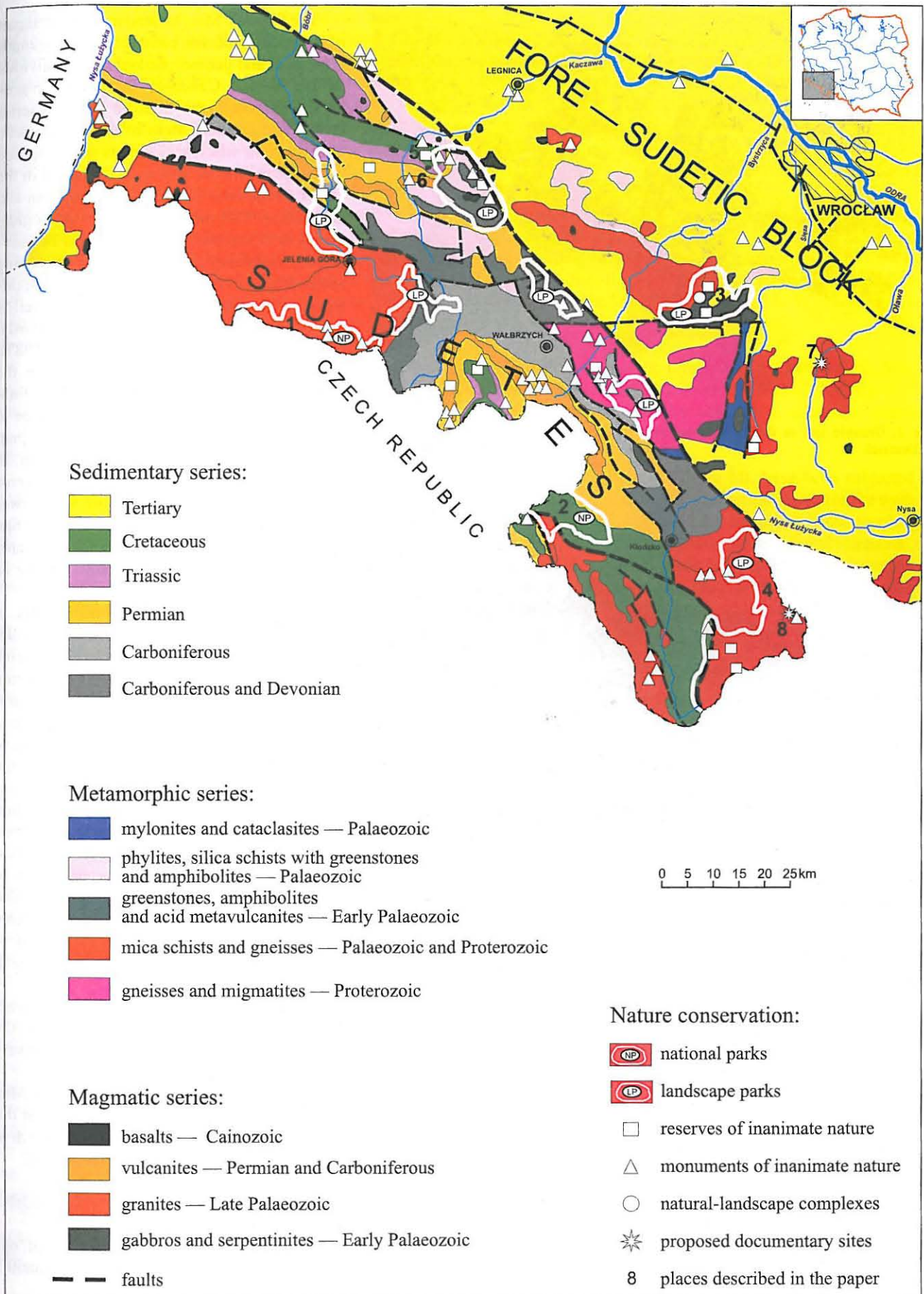


Fig. 1. Conservation of inanimate nature in the Sudetes in the aspect of geological setting



Fig. 2. Granitic tors in the Karkonosze National Park — Biosphere Reserve. Photo by Z. Denisiuk



Fig. 3. Upper Cretaceous sandstone tors in the Stołowe Góry Mts. National Park (Mount Szczeliniec). Photo by Z. Alexandrowicz

On the planation surface and on some slopes numerous bog areas have been formed.

The Karkonosze National Park (5579 ha including 1716.97 ha of strict nature reserves) covers the highest parts of the Karkonosze Mts. and partially some of the valleys. The Karkonosze National Park was established by UNESCO-MAB as the biosphere reserve.

2. The Stołowe Mts. in the Central Sudetes (450–919 m a.s.l.; 50°24'–50°31'N/16°15'–16°35'E).

Main features: the Upper Cretaceous sandstones and marls, the Upper Carboniferous, Permian and Lower Triassic detritic sediments, the Upper Carboniferous granite, sedimentary structures, characteristic relief of table mountains, groups of tors, canyons, and boulder fields.

The Stołowe Mts., located in the central part of the middle Sudetes, constitute a homogenous geological and geomorphological unit divided by the national, Czech–Polish border. In geological approach, the Stołowe Mts. comprise central and southern areas of the Intra-Sudetic Synclinorium which major parts are composed of terrigenous marine sediments deposited in the Upper Cretaceous (Cenomanien, Turonian and Coniacian). Each of the mentioned geological stages is developed as a thick series of sandstones, mudstones and marls. Here, interesting sedimentary structures, sedimentary cycles, different types of bedding, bioturbations as well as numerous fossils could be observed (Radwański, 1959; Jerzykiewicz, 1968; Wojewoda, 1987). Although, the Cretaceous sediments are the youngest fillings of the Intra-Sudetic Synclinorium, they constitute, due to high resistance to weathering, its highest, partially uplifted part. This is a clear example of relief inversion. In some places the Upper Cretaceous sediments overlie relatively thin layers of the Lower Triassic sandstones and/or underlying Permian sandstones and shales. In the Permian this area was a place of prominent volcanic activity as well.

Geological setting of the Stołowe Mts. is very well reflected by their characteristic relief (Pulinowa, 1989). The Upper Cretaceous marine sediments consist of the thick layers of resistant sandstone interbedded with thinner layers of impervious, less resistant shales and marls. Extensive denudation and erosion processes have firstly been following the fissure and crack system. Subsequently, they have resulted in formation of a very characteristic landscape abundant in the remnants of the dissected plateau: buttes, flat-topped hills with steep slopes, groups of tors, etc. The most beautiful tors and groups of tors of the Stołowe Mts. are concentrated at Szczeliniec Mt., Błędne Skały Mt., Głazy Krasnoludków (Dwarves Pors) in Poland and at Adršpašsko — Teplícké skály, Broumovské stěny in the Czech Republic (Fig. 3).

Located in the southern part of the Stołowe Mts. the massif of Krucza Kopa, consisting of granite and granodiorite, the Upper Carboniferous igneous rocks, constitutes a relatively high complex of tors and boulder fields.

The major part of the area belongs to the Stołowe Mts. National Park (6340 ha). This is an excellent example of the table mountains and has been a subject to scientific research in the field of sedimentology, tectonics, mass movement, etc.

3. The Massif of Ślęza in the foreland of the Sudetes (200–718 m. a.s.l.; 50°48'–50°54'N/16°35'–16°50'E).

Main features: the Early Palaeozoic crystalline massif, ophiolitic complex, the Carboniferous granite with pegmatitic, aplitic and quartzitic veins, boulder fields.

The Massif of Ślęża is located on the Sudetic Foreland. Its core part consists of the Early Palaeozoic crystalline rocks. The highest part of Ślęża Mt. is composed of gabbro. The rest of the massif consists of amphibolites, serpentinites, altered ultrabasic rocks embodying numerous veins of magnesite, quartz, chalcedony and opal. Geological setting of the whole massif resembles an ophiolitic complex being a source of valuable information on deeper zones of the Earth crust (Majerowicz, 1979, 1989). The north-western and western slopes of Ślęża Mt. consist of the Upper Carboniferous granites, biotitic and dimicaceous ones. Those are a part of a larger granite body, i.e. the Strzegom–Sobótka granitoid massif, which continues towards north-west. In the vicinity of the town of Strzeblów there are present two types of pale granite: leucogranite and fine grained, garnet containing granite, both formed in endocontact zone. Within those rocks several pegmatitic, aplitic and quartzitic veins are found. The slopes of the Ślęża massif, at the altitudes above 300 m a.s.l., are covered with the vast areas of boulder fields, consisting mainly of gabbro.

Geomorphologically, the Massif of Ślęża forms a dome risen about 500 metres above the surrounding lowlands.

Apart from its important natural values, the massif, also called the Silesian Olympus, is a unique archaeological area. It used to be a centre of pagan and early Christian cultures. The whole region is abundant in valuable archaeological sites, including granite mining casts and stone workshops, proving continuity of human presence since the Neolithic age.

The Ślęża Landscape Park (8190 ha) comprises two reserves of inanimate nature: Ślęża Mt. and Radunia Mt. as well as a natural-landscape complex Skalna. Because of the above described natural and cultural values the Massif of Ślęża constitutes a unique region of European rank.

4. The Massif of Śnieżnik in the Eastern Sudetes (310–1423.7 m a.s.l.; 50°06′–50°24′N/16°38′–17°02′E).

Main features: crystalline metamorphic massif, tectonic deformation processes, karstic phenomena, relics of periglacial relief of the Palaeogene.

The Massif of Śnieżnik consists mainly of metamorphic rocks forming a larger unit called the metamorphic massif of Łądek–Śnieżnik. To the west, the massif is divided by the fault from the Upper Nysa Kłodzka Graben. The massif is composed of two main, Precambrian–Early Palaeozoic rock series, schistaceous and gneissic ones (Don, 1972; Gunia & Dumicz, 1976; Smulikowski, 1979; Jahn *et al.*, 1997). The former, called the Stronie Group, consists of mica schists, paragneisses, quartzite, amphibolites, crystalline limestones and dolomites, while the latter consists of a series of gneisses (Śnieżnik–Gieraltów Group) with inserts of eclogites and granulites. In the vicinity of the village of Bielice there are the outcrops of tonalites. The remnants of Tertiary volcanic activity are the lava sheets nearby the town of Łądek Zdrój. The most characteristic element of the relief is a planation surface developed in the Palaeogene.

The above mentioned town of Łądek Zdrój is a well known health resort. In the fault zones, forming the preferential pathways of groundwater flow, occur highly mineralized, thermal

waters. Geological setting is strongly reflected by relief and dense drainage pattern, including number of water falls. The continental water divide forms three different catchment areas, feeding Baltic Sea, Black Sea and Northern Sea.

Karst phenomena has been developed in the inserts and lenses of marbles located within the metamorphic complex. The karst features are represented by numerous springs, ponors, sinkholes as well as by the most beautiful cave in the Sudetes, the Niedźwiedzia Cave, nearby the village of Kletno.

The major part of the Massif of Śnieżnik is covered by the Śnieżnicki Landscape Park (28,800 ha) on the Polish side and by the Králický Śněžník Nature Reserve (1739 ha) on the Czech one. It comprises three reserves of inanimate nature: the Niedźwiedzia Cave, the Śnieżnik Kłodzki and the Wilczka Water Fall ones.

5. Wilcza Mt. at the foreland of the Kaczawskie Mts. in the Western Sudete (373 m a.s.l.; 51°06′N/15°55′E).

Main features: Tertiary volcanism, columnar structure within basalt.

The basaltic rocks at Wilcza Mt. have been subjected to extensive mining activities. The quarries situated on the western and south-western slopes of the mountain allow to observe internal structures of the volcanic dome. Several remnants of a number of phases of volcanic activity have been recognized (Śliwa, 1967; Birkenmajer, 1967; Grocholski & Jerzmański, 1975). The preliminary phase is represented by tuffs and volcanic breccia. The outer part of the volcanic pipe consists of the first generation of basaltic lava, a plagioclase and nepheline rich one, characterized by a columnar structure formed by lava cooling jointing. The columns are leaning 30 degrees against the vertical axis of the volcanic pipe. The second generation of lava is characterized by thinner columns, orientated randomly and located closer to the centre of the volcanic pipe. Within all types of lavas there have been found numerous xenoliths of sandstones, rhyolites, quartzites and siltstones (Kardymowicz, 1967).

Wilcza Mt. is a geological reserve (1.69 ha).

6. The outcrop Organy Wielisławskie on Wielisławka Mt. in the Kaczawa river valley, at the foreland of the Kaczawskie Mts. in the Western Sudetes (280–330 m a.s.l.; 51°02′N/15°52′E).

Main features: the Permian volcanism, columnar structure within rhyolite.

The abandoned quarry on the slope of Wielisławka Mt. in the Kaczawa river valley is an excellent outcrop of the Permian (the middle part of the New Red Sandstone) alkaline rhyolites and the schists of the metamorphic massif of the Kaczawskie Mts. (Jerzmański, 1956; Kozłowski & Parachoniak, 1967; Grocholski & Jerzmański, 1975). Petrographically, the rock, of a characteristic brownish-reddish colour, consists of quartzite and plagioclase rich matrix with phenocrystals of quartz, biotite and feldspar. It has a very unusual, for this type of rock, columnar structure, due to which the outcrop resembles a gigantic organ or a fan. The diameter of the columns is normally 20–30



Fig. 4. Organy Wielisławskie — the outcrop of the Permian rhyolites with columnar structure. Photo by M. Klonowski

centimetres and only sometimes exceeds 50 centimetres. The majority of the columns are tetra- and pentagonal and rather rarely tri- and hexagonal. The fan-like complex of columns as well as the system of joints, perpendicular to the cooling surface, indicates origin of this formation, a dome shaped extrusion of rhyolitic lava (Fig. 4).

The outcrop Organy Wielisławskie is a monument of inanimate nature.

7. The former quarry in Gębzyce at the Wzgórza Strzelińskie structure, on the foreland of the Sudetes (200 m a.s.l.; 50°43'N/17°04'E).

Main features: contact of the Upper Carboniferous granite intrusion with its metamorphic mantle.

The abandoned quarry is divided into two casts: western and eastern. Within the former, the granitoid intrusion of Strzelińskie contacts with the heavily weathered, partially migmatized mica schists, characterized by well developed ptygmatic folds. The schists belong to the metamorphic mantle of the granitoid intrusion, the Wzgórza Strzelińskie structure. Within the schists series there are numerous, about 12 centimetres thick, veins of aplogranite following foliation surfaces. Underneath, there are calcium and silica rich rocks with inserts of feldspar, quartz, garnet and diopside rich rocks. The inserts are sometimes composed of almost only garnet crystals of which concentrate within the cavities. Whole this formation overlies the series of crystalline limestones which have been extensively mined in

the past. In the eastern quarry there is an outcrop of fine grained quartzites and the underlying calcium and silica rich rocks (Bereś, 1969).

Due to importance of the outcrop in the field of stratigraphy, mineralogy and petrography it is proposed to be a protected geosite.

8. The outcrop on the terraces of the Biała Łądecka river, in the village of Stary Gierałtów, in the Eastern Sudetes (640 m a.s.l.; 50°18'50"N/16°55'20"E).

Main features: the Proterozoic and Early Palaeozoic granulites and eclogites of the metamorphic massif of Śnieżnik-Łądek.

Series of granulites, interbedded with eclogites, are petrological curiosity because of rarity of their outcrops (Kozłowski 1965; Ansilewski, 1966; Smulikowski, 1967). They represent a facies of the deepest regional metamorphism. There are several petrographic types of granulites. The dark ones contain equal quantities of pyroxene (omphacite), plagioclase, quartz and garnets concentrated in laminae, while the pale ones consist mainly of quartz, potash feldspar and plagioclase, with numerous fine crystals of garnet. In some parts, the rock is nearly composed of pyroxene and garnets only. Those are the remnants of altered eclogites.

The outcrop, being an important place of petrological research, should be protected as a geosite.

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