Geological Map Lausitz-Jizera-Karkonosze and Muskau Arch Geopark as examples of cross-border cooperation of the national geological surveys of Poland, the Czech Republic and Germany

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A b s t r a c t . The article presents the cross-border cooperation of geologists from the Lower Silesian Branch of Polish Geological Institute and the national geological surveys of the Czech Republic and Germany. The current cooperation is discussed on the basis of Geological Map Lausitz–Jizera–Karkonosze as well as on geological research of the Muskau Arch. The Geological Map Lausitz–Jizera–Karkonosze, in 1 : 100,000 scale, with Comments, presents the geology of the north-western part of the Bohemian Massif. A short geotectonic evolution of the area from Neoproterozoic to Cenozoic is presented. The results of Polish-German geological research and inventory of so-called "geotopes" are the basis to establish a cross-border Muskau Arch Geopark.

Key words: *geological map, Bohemian Massif, Cadomian and Variscan orogenesis, epi-Variscan cover, geotectonic evolution, geotope, geopark, geodiversity conservation, goetourism, Muskau Arch, glaciotectonics*

The Lower Silesian Branch of the Polish Geological Institute operates in southwestern Poland. A cross-border cooperation with geological surveys of the neighbouring countries, the Czech Republic and Germany, has been developing for many years and it has a really great tradition. Until 1990, it was implemented on the basis of agreements of the Regular Geological Cooperation Committee, the Council for Mutual Economic Assistance, and bilateral agreements. At the very beginning there were consultations, conferences and exchange of professional experience between specialists in geological cartography and in geology of mineral deposits. One of the first projects of the Polish, Czech and German geological services (in which the Lower Silesian geologists took part), was the *Metallogenetic Map — Bohemians Massif and Northern Adjacent Regions* (Lächelt et al., 1973), prepared in 1 : 500,000 scale. Also worth mentioning are projects about stratigraphic correlation of Pre-Cambrian and Palaeozoic rocks in the border areas as well as the projects concerning perspectives of mineral deposits in the Intrasudetic Basin (all of them were carried out in the 1980s, in cooperation between Poland and the former Czechoslovakia) and *Geological Maps* in 1 : 200,000 scale, sheets Cottbus (Lippstreu et al., 2003) and Frankfurt (Oder) (Hermsdorf et al., 2003), as well as *Geological Map in 1 : 50,000 scale,* sheet Frankfurt (Oder)/Słubice (Schulz et al., 2000) — in cooperation between German and Polish geological surveys.

The new era began in the 1990s and was accompanied by intensified environmental geological research. Since then, new projects such as: preparation of geotouristic maps and geodiversity conservation maps have been started. For territories which are situated closest to the national borders of Poland and the Czech Republic, a number of maps has been prepared: *Śnieżnik Area Geological Map for Tourists*, in 1 : 50,000 scale (Gawlikowska & Opletal, 1997), *Geological Map for Tourists, Góry Stołowe Mts.*, in 1 : 50,000 scale (Čech & Gawlikowska, 1999), and *Geological Map for Tourists Góry Bystrzyckie and Orlickie Mts.*, in 1 : 50,000 scale (to be published). They include crucial information about the local geology, as well as some interesting data for tourists (characteristic of geological sites, environmental protection, inanimate nature). Future cooperation with the Czech and Saxonian geological surveys is planned to expand the projects.

The next two topics describe the exemp latest echievements of the cross-border cooperation. The first one, *Geological Map Lausitz–Jizera–Karkonosze*, is related to a traditional field of joint research. The second one discusses the actions taken in Muskau Arch and presents new possibilities of future cooperation.

Geological Map Lausitz–Jizera–Karkonosze (without Cainozoic sediments) in 1 : 100,000 scale with Comments: An example of cooperation in investigation of the geotectonic history of the Central European Variscides and the epi-Variscan cover

The *Geological Map Lausitz–Jizera–Karkonosze* (GM LJK; Krentz et al., 2000), supplemented with Comments volume (Kozdrój et al., 2001), resulted from the first joint project of geological surveys from Poland (Polish Geological Institute, PGI), Czech Republic (Česká geologicka služba, CGS) and Germany (Sächsisches Landesamt für Umwelt und Geologie, SLUG, Freiberg). They were elaborated in years 1997–2001 by the core working group of geologists from the SLUG: O. Krentz, H. Walter, K. Hoth, H. Brause, from the CGS: Mojmír Opletal, Stepanka Mrazova, and from the Lower Silesian Branch of the PGI: W. Kozdrój, Z. Cymerman, in cooperation and consultancy with H. Kemnitz (Potsdam), F. Schust (Berlin), R. Lobst (Bautzen), H.-J. Berger (Freiberg); V. Prouza, V. Valečka, V. Kachlík and J. Cajz (Praha). Several other geologists and computer specialists were involved in preparing the topographic background for the map (R. Tomas, M. Zemková and J. Levý — CGS), technical editing and digitalisation of geological layers in the Arc-Info programme (A. Engelhardt-Sobe, H. Eilers, T. Reimann — SLUG; B. Jaranowska, G. Brzeźkiewicz, C. Paderewska and E. Czerska — PGI) and editing of Comments (J. Małecka — PGI). A

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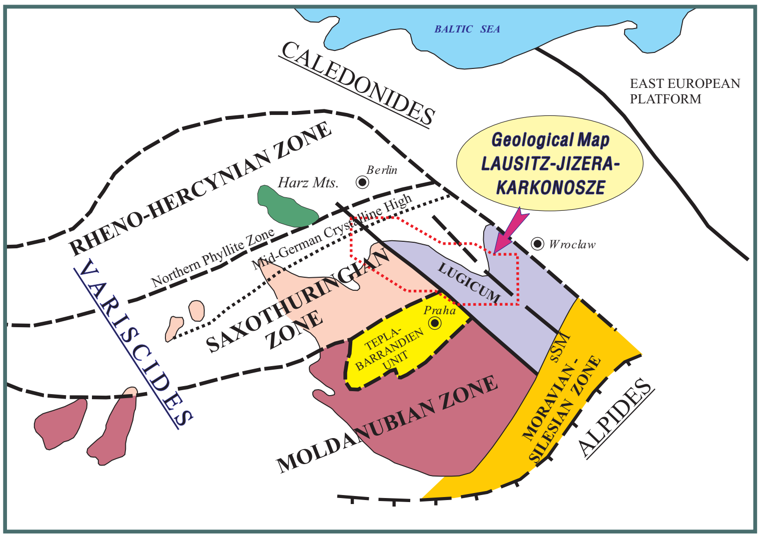

Fig. 1. Position of the area of the *Geological Map Lausitz-Jizera-Karkonosze* within the structure of the Bohemian Massif

Fig. 2. Division of the *Geological Map Lausitz-Jizera-Karkonosze* into three map sheets and seven geological regions

digital version of the GM LJK and Comments recorded on CD is under preparation (K. Martinek, R. Tomas — ČGS) and will be distributed in 2004.

The GM LJK consists of three A0 format map sheets which cover an area of ca. 24,000 km^2. A legend for the map was published in 3 bilingual versions: Polish, Czech and German, each associated with English translations. The Comments volume accompanying the map, printed exclusively in English, comprises the following chapters: 1. Introduction, 2. Basic data, 3. Geological structure, 4. Stratigraphy; 5. Geotectonic evolution.

The largest part the GM LJK territory is composed of pre-Upper Carboniferous rocks affected by Cadomian and Variscan orogenies which are presently outcropping in geographical regions of Lusatia and Sudety Mts located in the north-western part of the Bohemian Massif. From a geotectonic point of view, they essentially constitute one unit, so called Lugicum being a northeastern prolongation of the Saxo-Thuringian Zone of the Central European Variscides (Fig. 1). As both in the field and in the majority of standard geological maps these old rock complexes are covered by Cenozoic deposits, one of the most important goals of the GM LJK preparation was to present them ”uncovered”. After long discussions about the ages and possible correlations of numerous geological subunits named as ”series”, ”complexes”, ”groups”, ”formations” or ”massifs”, often transecting national borders, a unified legend for GM LJK was set up. Due to diversification in a chronology and degree of tectonic and metamorphic transformations, seven geological regions (Fig. 2) were distinguished within these old complexes and for each region a separate lithostratigraphical division was done. These are: Lusatia, Elbe Zone, Erzgebirge (only a small, NE fragment of the main massif), Kaczawa Region, Karkonosze-Jizera Region, Ješted Region and Wałbrzych-Vrchlabí Region. All regions are parts of Variscan accretionary wedge, composed generally of fragments of Cadomian, Proterozoic (up to Cambrian?) basement (remnants of peri-Gondwanan Neoproterozoic magmatic arc, Murphy et al., 2002) and overlying Cambrian–Lower Carboniferous sequence (Fig. 3). This sequence actually comprises two parts: $Cm_{1\text{-}2}$ and O_1–C_1 whose continuity was interrupted by thermal uplift caused at the Cambrian/Ordovician transition by numerous intrusions of Lower Palaeozoic granitoids. Geotectonic significance of this tectono-thermal event (relation with continental rifting or a magmatic arc?) is still a matter of dispute.

The Lower Palaeozoic strata were deposited directly on the Cadomian basement or, in case of advanced stage of rifting and extension, were lied down on a newly generated oceanic lithosphere which is now documented by remnants of MORB metabasites (in Kaczawa metamorphic complex). This ancient basin of the Saxo-Thuringian Zone was shortened and closed in a course of docking of several microplates (Armorican Terrane Assemblage) to the SE edge of the Rheno-Hercynian Zone (Avalonia Terrane) (Franke, 2000).

The Variscan orogeny, inferring from data recorded by rocks of the GM LJK area, took place between the end of Lower Devonian and Visean/Namurian. Nevertheless, compressional processes were diachronous and intensity of deformations and metamorphic conditions were changing in time and space. Comparing these factors in the above listed regions one may decipher the following, brief geotectonic history of the Variscan orogeny:

1) The easternmost Sowie Mts Block (part of the Wałbrzych–Vrchlabí Region; Fig. 3), prevailingly composed of gneisses and migmatites originated due to Cambrian/Ordovician thermal reworking, was the first element — lithospheric slab — which was initially subducted in the Early Devonian (HT/HP event proved by relics of granulite facies), then underwent the main deformation and metamorphism during the Middle Devonian (HT/MP), and was finally exhumed and eroded during the Late Devonian–Early Carboniferous. Adjacent Świebodzice Basin of

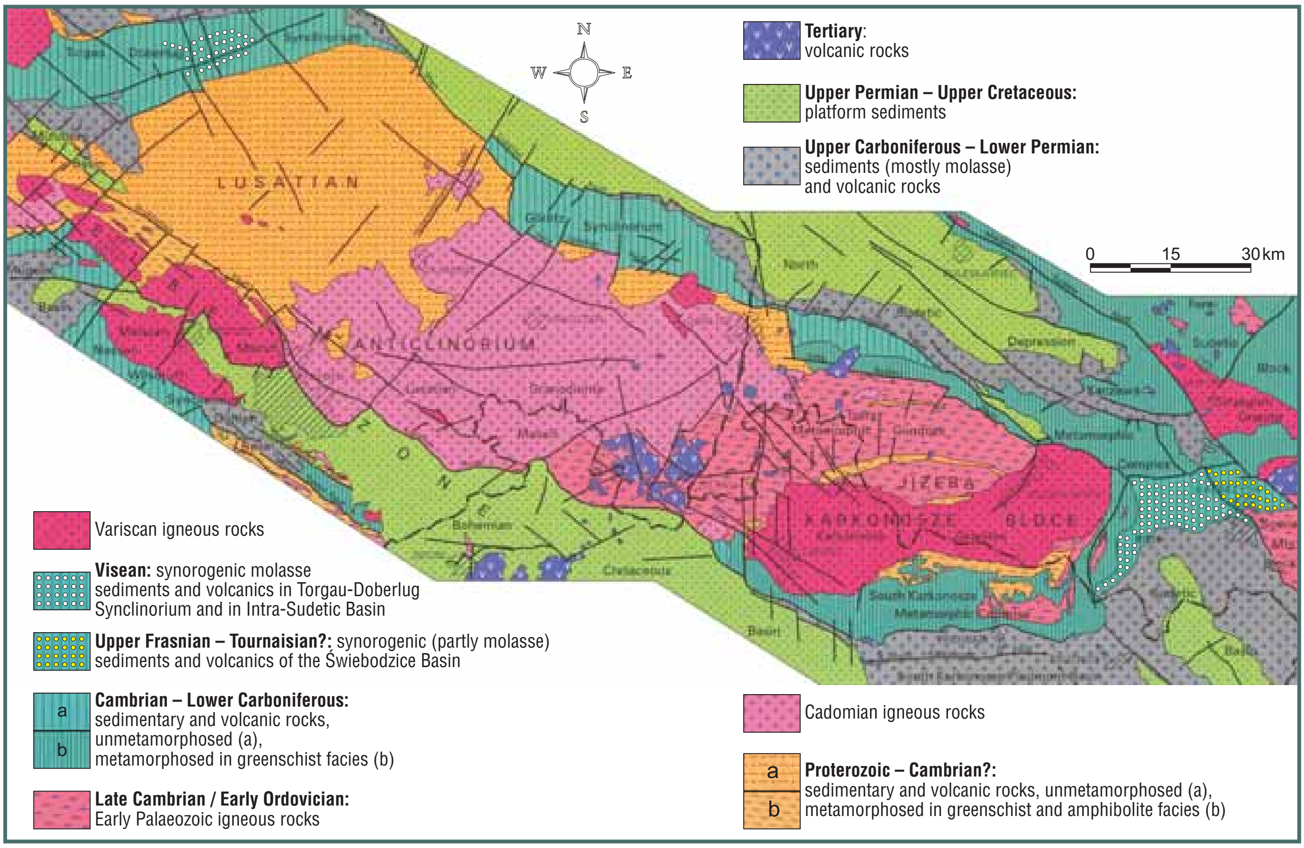

Fig. 3. Simplified scheme of the *Geological Map Lausitz-Jizera-Karkonosze* (after Krentz et al., 2000 — with modifications)

syn-orogenic, foredeep character was filled with Upper Fransian–Lower Tournaisian? deposits which were partly shed from the uplifted Sowie Mts Block.

2) Series of Kaczawa Region, Karkonosze-Jizera Region, Ješted Region and their equivalents in the Elbe Zone and Erzgebirge comprise rocks of strongly thinned Cadomian basement and covering Palaeozoic sediments developed in some areas in open basin facies (especially Silurian and Devonian), partly with preserved remnants of basal mafic crust (MORBs in Kaczawa Mts) (Żelaźniewicz, 1997; Linnemann & Schauer, 1999). Because of original lithospheric weakness they now represent a highly mobile belt of strongly deformed and variously metamorphosed rocks forming para- and allochtonous complexes. Variscan path of convergence is highlighted by: a) initiation of underplating in Middle/Upper Devonian (HP/LT event, blueschists in the East Karkonosze Mts), b) nappe stacking and peak metamorphism (MP/MT to HP/HT events) in Tournaisian/Visean, followed by c) main shearing and folding in retrogression metamorphism conditions (LP/LT event) in Upper Visean (Marheine et al., 2002; Werner & Lippolt, 2000; Franke & Stein, 2000). The last events in Elbe Zone was associated with dextral, strike-slip movements along WNW-ESE oriented faults (Linnemann & Schauer, 1999) and intrusions of syn-orogenic granitoids (the oldest varieties of the Meissen Massif).

Constrictional tectonic movements during the Lower Carboniferous led to deformation and uplift of basement slabs together with their overlying Palaeozoic sediments. The disturbances on the slopes of basin caused locally mass movements and deposition of tectono-sedimentary melanges or olistostromes (Kaczawa Region, Elbe Zone) as well as partial erosion and deposition of conglomerates (Elbe Zone, Ješted Region). In the Visean, during still ongoing deformations, these young deposits were again involved in stacking processes in accretionary prism and locally strongly deformed.

The biggest synorogenic basin is the Intra-Sudetic Basin (Wałbrzych-Vrchlabí Region; Fig. 3) in which sedimentation started in the Upper Tournaisian? (Dziedzic & Teisseyre, 1990) or, accordingly to the latest miospores findings, in the Middle Visean (Turnau et al., 2002), and lasted till the latest Visean. Its continuous infilling of fluvial and deltaic/marine sediments reached a few km in thickness. In the Namurian, the western part of the basin was folded but without evidence of any metamorphism.

3) Lusatia Region (Lusatian Anticlinorium), occupying nearly a half of the GM LJK territory, represents the largest fragment of the Cadomian continental crust composed of a big mass of folded, nonmetamorphosed Neoproterozoic greywackes intruded by numerous bodies of Cadomian plutons and covered by Lower to Middle Cambrian and Lower Ordovician to Lower Carboniferous onlap sequences presently preserved in Torgau-Doberlug Synclinorium and Görlitz Synclinorium (Fig. 3). During theVariscan orogeny, the Lusatia Region collided with the Mid-German Crystalline High (MGCH) located along the SE edge of the Rheno-Hercynian Zone (East Avalonia terrane). A small fragment of MGCH represented by metamorphic rocks of the Prettin–Drehna Group and neighbouring granitoids appear in the northwest corner of the GM LJK (Fig. 3). Lusatia domain because of its rigidity and composition of relatively light rocks was never buried in a subduction zone. Generally, it escaped Variscan high-grade dynamometamorphism and survived as a big, low strain zone. Instead, it acted as a resistance mass against rocks on its

eastern side along which the paraautochtonous and allochtonous complexes were stacked and severely deformed during the Variscan diastrophism. It must have been during the Early Carboniferous time, when Lusatia region (due to advancing nappes from the SE) was elevated and subjected to erosion. On its western border, the horizontal stresses created a WSW-ENE oriented deflection which became a centre of intensive Visean, syn-orogenic, molasse sedimentation in the Doberlug–Torgau Synclinorium (Fig. 3). In that meaning it is a close counterpart of the Intra-Sudetic Basin.

The main Variscan NW directed tectonic transport of the Lusatia domain was associated with development of strike-slip faults at its southern and northern borders. The present prominent dislocations: Großenhaim Fault, Lusatian Thrust, Main Lusatian Fault, Intra-Sudetic Faults (Fig. 3) were founded at that time and were multiply reactivated during Mesozoic and Cenozoic eras.

The Variscan orogeny was finished in all regions of the GM LJK with melting of orogenic roots and emplacement of the post-kinematic Variscan plutons like the Meissen Massif, Karkonosze granites or Strzegom granites. Tectonic relaxation and decompression of overthickened orogenic structure resulted in the Upper Carboniferous and Lower Permian extension, deep erosion and generation of intramontane, molasse basins (Mühlberg Basin, Mügeln Basin, Döhlen Basin, Intra-Sudetic Basin, North-Sudetic Depression, Karkonosze Piedmont Basin; Fig. 3), locally with huge input of floral detritus (present coal seams) and enormous volcanic activity. These continental sediments started deposition of the epi-Variscan platform cover. A degradation of the orogen was so advanced that in the Late Permian (Zechstein) and Triassic, a big part of the GM LJK area was again covered with shallow sea sediments. After the sea regression in the Early and Middle Jurassic a new sea invasion occurred in the Late Jurassic. Due to a next long period of deep erosion in the Early Cretaceous, these sediments were almost completely removed and only few tiny patches of the Jurassic strata are nowadays present in the Elbe Zone along the Lusatian Thrust. In the Late Cretaceous, the whole territory of GM LJK was again deeply lowered and subject to the sea transgression. It is supposed that only seldom elevated domal structures were not flooded and remained as isolated islands. The sea retreated at the beginning of the Paleogene, when the entire Bohemian Massif was influenced by tectonic, compressional stresses related with formation of Alpine-Carpathian fold belt in the south (Ziegler et al., 1995). It was the time when dense, complicated network of old fractures and dislocations cutting Cadomian and Variscan basement were rejuvenated. Primary, long distance horizontal stresses transmitted from Alpine orogen resulted in the northern Bohemian Massif in development of horst-graben system (so-called "Saxonian tectonics"). Both vertical and strike-slip tectonic movements led to folding of the epi-Variscan platform sediments and also caused elevation of crystalline basement blocks from which erosion processes removed overlying deposits. Because very often these blocks are presently bordered by inverse faults, it is supposed that they were mainly uplifted by the "push up" mechanism. The spectacular illustration of such a process is the Lusatian Thrust, along which the Cadomian granites of the Lusatia region were thrust over Cretaceous sediments of the Elbe Zone.

The younger Upper Carboniferous to Permian and Mesozoic formations building the epi-Variscan platform cover were presented in the legend for the GM LJK as a stratigraphic scheme unified for the whole area.

The geotectonic history which may be read from the GM LJK finishes with the Neogene volcanism. Majority of basaltic bodies occur within ca. 30 km wide, SW-NE oriented area in the middle of the GM LJK which transects Elbe Zone and follow the border between Lusatia and Karkonosze–Jizera Regions. Such a location clearly shows that there is a strong relationship between the older, deep-seated discontinuities originated during Variscan collision and the feeding canals of much younger volcanism.

Concluding, the GM LJK is a fruitful result of cooperation of geological surveys from Poland, Germany and the Czech Republic and gives — in our opinion — a unique opportunity to present an overview of a long geological history of the northern part of Bohemian Massif. It must also be underlined, that during the joint work, which necessitated analysis of extensive archive data, it became obvious that there are still many details awaiting elucidation. For example, to set up a better lithological correlations, especially of Lower Palaeozoic rocks, more new microfaunal findings and isotope age determinations are needed. To explain the Variscan orogen architecture and to resolve a crucial problem concerning orientation of leading surfaces along which Variscan underplating took place, new modern structural analyses must be done. One may hope that the just beginning epoch of new, integrated Europe will provide opportunities to find answers to these questions.

Muskau Arch Geopark — trans-boundary area of geodiversity conservation, inventory and classification of geotopes

The Muskau Arch is an area of well-preserved glaciotectonic structures, originated during the Mid-Polish Glaciations at a foreland of an isolated ice-shield lobe. A belt of frontal moraines and hills of uplifted pre-Cenozoic deposits (push moraine) created the scenic landscape with the sights of inanimate nature, substantial for both the scientific research and general education. Numerous abandoned excavations of Neogene lignite and clay, recently infilled with water, contribute to the unique character of this area closely fitting the criteria of the UNESCO International Geopark Programme.

Following the UNESCO/IUGS Programme on Earth Heritage, geologists of Brandenburg started to organize the Muskau Arch Geopark. In 1997, the Geological Survey of Brandenburg with a co-operation of some other organizations and institutions of Brandenburg and Saxony initialized activity on establishing the "Three-State Geopark" in the Muskau Arch region at the crossing of the boundaries of Brandenburg, Saxony and Poland. The Polish Geological Institute, invited by the German side, since 2000 takes a part in the first-stage works in the Polish part of the Muskau Arch.

The first stage of the organizing works on the Muskau Arch Geopark includes making an inventory and evaluation of geotopes in the Brandenburgian and Saxonian parts of the Muskau Arch (Muskauer Faltenbogen) and later also in the Polish part (Łuk Mużakowa) — Fig. 4.

The first inventory works (Badura et al., 2001), included classification and scientific/educational evaluation of the inanimate nature phenomena in this area, so-called "geotopes" and formed a basis to analyse this area from the

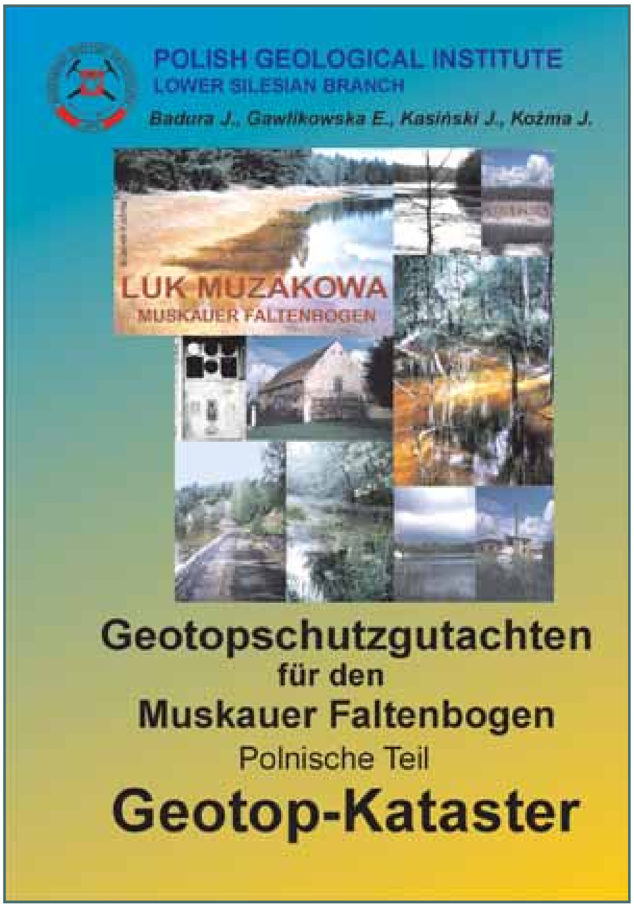

Fig. 4. The first inventory works (after Badura et al., 2001)

Geological setting and cultural heritage

The Muskau Arch is an area of horseshoe-shaped belt of frontal moraines and the same shape belt of glaciotectonic structures — push moraines (Figs 5, 6). This structure is about 40 km long and 3–6 km wide. The ends of the arms of this structure near Klein Kölzig (Brandenburg) and Tuplice (Poland) are about 20 km distant one to another. Neogene deposits as well as Pleistocene sediments occur within the push moraines. The Neogene deposits consist mostly of clays and lignites of Middle Miocene age. Quaternary sediments (mostly tills, sands and gravels) are related to the Mid-Polish/Elstere Glaciation, where the

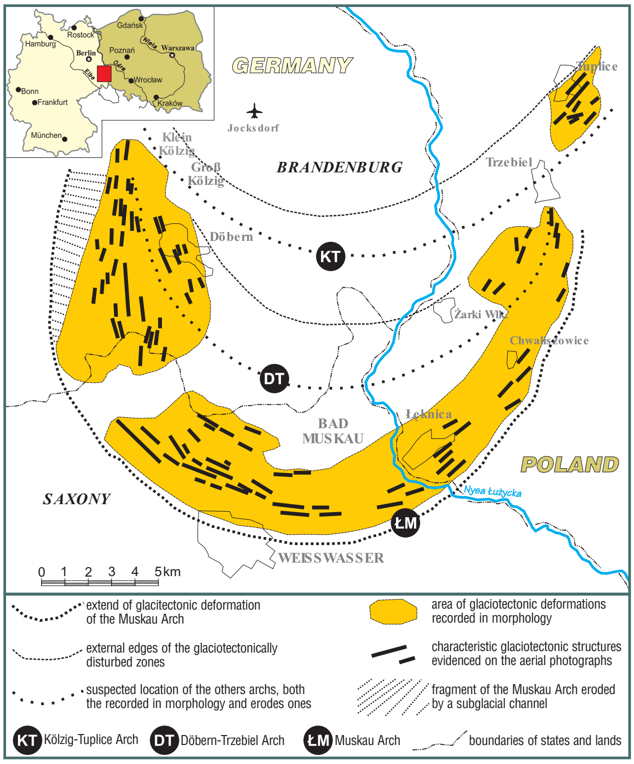

Fig. 5. Structural map of the Muskau Arch (after Kupetz, 1997)

viewpoint of the possibilities of establishing of the "Three-State Geopark" (Kasiński et al., 2000; Badura et al., 2001; Rein et al., 2002).

Some kinds of geotopes, such as geological outcrops, forms of land surface, remains of historical mining of lignite, ceramic clays and aggregates, and also buildings made with glacial boulders have been evidenced. More detailed project of accessibility of the Geopark area, i.e., project of tourist infrastructure and concept of presentation of geological and historical heritage from the education viewpoint, should be a subject of the further works on the Geopark organization.

Conservation of a unique (in a global scale) glaciotectonic structure, together with remnants of historical mining operations and values of inanimate natural environment, and promotion of education and geotourism should be the main goals of the trans-boundary Muskau Arch Geopark. The geotopes — elements of lithosphere particularly valuable, which should be accessible for scientific research, education and geotourism — are the basic elements. Tourism centers, local museums and exposition/education centers will be established.

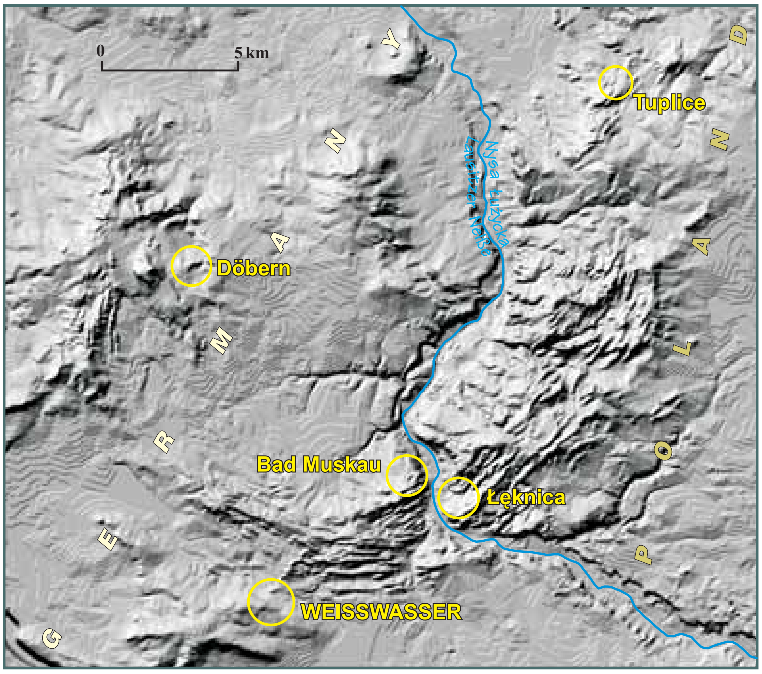

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Fig. 6. Shaded relief map of the Muskau Arch (compiled by B. Przybylski (unpublished materials)

whole structure was originated after separated ice-lobe activity (Dyjor & Chlebowski, 1973). Glaciotectonic deformations reaches down to 270 m and the belt of glaciotectonic deformations in front of the ice lobe was 490–720 m wide (Kupetz, 1997). Thickness of the lobe has been estimated as 430–530 m (Kupetz & Keßler, 1997).

Traditions related to mining industry were the most important culture-creating element in this area, caused by deep occurrence of some raw materials (lignite, ceramic clay, natural aggregate). The oldest lignite mines were activated just in 1840. There were small underground mines, excavating lignite mostly at first with dip galleries, later also with shafts and open pits. During the time of their peak activity, more than 60 underground and surface mines worked there (Kasiński & Piwocki, 2003). Since the end of the 19th century also pottery clays, alum clays (for alum production) and natural aggregates were exploited in numerous open pits. The lignite and clay mines have been abandoned, but their traces are distinctly visible in form of narrow belts of elongated artificial lakes, located along the lignite and clay exposures within the glaciotectonic slices. These belts, as well as moraine hills, create a really scenic landscape.

Unique geological setting, scenic landscape and rich geological heritage allowed to include the Muskau Arch area into a small group of the most valuable geodiversity protection areas also in Poland (Alexandrowicz & Alexandrowicz, 2003; Badura et al., 2003).

Inventory and classification of geotopes

During the first stage of the works, 95 geotopes have been defined, inventoried and evaluated in the Muskau Arch region (34 in the Brandenburgian part, 34 in the Polish, and 27 in the Saxonian ones).

Fig. 7. Special-value geotope: post-mining excavation infilled with acidified iron-rich water near Łęknica (after Badura et al., 2001)

Some different elements and forms included into main thematic groups of the natural and anthropogenic geotopes (see Rascher et al., 2001) has been inventoried and evaluated:

- stratigraphy and tectonics: Neogene lignites, Pleistocene tills;
- glacial and peri-glacial landforms: frontal moraines, kettles, glacial boulders;
- landforms created by a eolian processes: dunes;
- landforms created by flowing water: river terraces, river valleys, gap valleys;
- swamps and wetlands: oxbows;
- springs (in this: iron-rich water springs);
- mineral concentrations: lignite, clay, sand and gravel deposits;
- mining excavations infilled with water: anthropogenic lakes (partly acidified), artificial watersheds;
- buildings made of glacial boulders: cottages, houses, churches, town walls;
- glacial boulders in garden architecture.

All the geotopes has been valorized from the viewpoint of their significance for scientific research, education and tourism into four classes: 1) of minor value, 2) significant, 3) valuable, and 4) of special value. The 95 geotopes have been inventoried and evaluated according to the uniform criteria on the whole Geopark area, at both the Polish and German sides; 34 of them are located in the Polish part. Two geotopes of special value: 1) post-mining excavation infilled with acidified iron-rich water (Fig. 7), and 2) iron-rich water spring, both in surroundings of Łęknica in the Polish part of the Muskau Arch. From the viewpoint of scientific research, 32 geotopes (including 12 in the Polish part) have been ranked as valuable and of special value. From the viewpoint of teaching and tourism value, also 34 geotopes (including 14 in the Polish part) have been evaluated there, (e.g., Fig. 8).

Fig. 8. Tourism-value geotope: landforms created by rain water (after Badura et al., 2001)

Conclusions

The Muskau Arch is an area unique in Europe and the geotopes of this region represent substantial value in every field of assessment. Some kinds of geotopes, such as geological outcrops, forms of land surface, remains of historical mining of lignite, ceramic clays and aggregates, and also buildings made with glacial boulders have been evidenced. More detailed project of accessibility of the Geopark area, i.e., project of tourist infrastructure and concept of presentation of geological and historical heritage from the education viewpoint, should be a subject of the further works on the Geopark organization (Fig. 9).

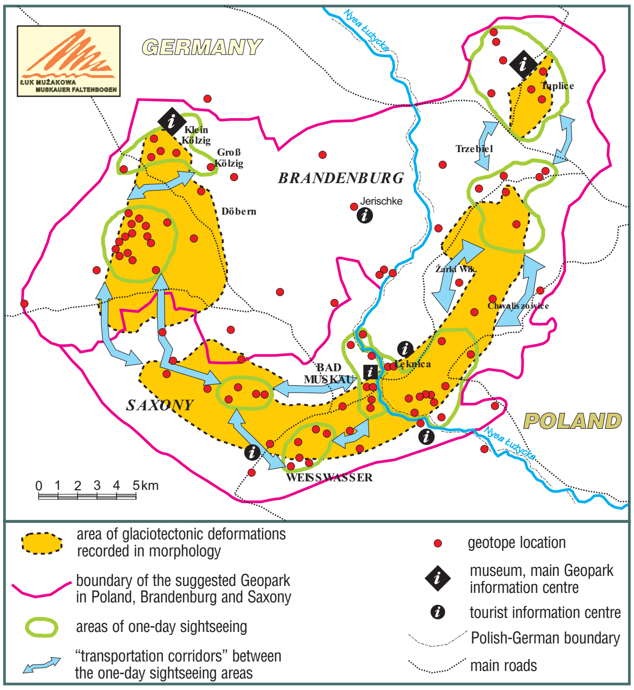

Fig. 9. Suggested borders of the Muskau Arch Geopark and elements of it geotouristic infrastructure

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