Authors: Stefan Cwojdziński, Justyna Pacuła
Polish Geological Institute – National Research Institute,
Lower Silesian Branch in Wrocław,
al. Jaworowa 19, 53-122 Wrocław

Compilation of geological map and geotourist maps: Andrzej Biel, Justyna Pacuła
Layout and editing of the volume: Agnieszka Byliniak, Michał Janik

Cover photo: Folded Muschelkalk (Middle Triassic) limestone on the quarry wall in Raciborowice (*photo by J. Pacuła*)

Translated by Krzysztof Leszczyński

ISBN 978-83-7863-501-7

Circulation: 3000 copies
Printed by: ARGRAF Sp. z o. o, ul. Jagiellońska 80, 03-301 Warsaw

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Introduction

All over the world, tourist geology, which is called geotourism, is becoming more and more popular. At sites of extremely attractive land relief and interesting geological structure, geoparks are being established, geotouristic paths marked out, and information panels installed. Various guidebooks are also issued designed for walkers, cyclists and motorists wanting to see and understand the mysteries hidden by the Earth. Modern computer technologies also allow obtaining geological information directly from the Internet on mobile phones and tablets.

In 2007, the Polish Geological Institute issued a pilot volume of tourist guide entitled: "The Sudetes. Geotourist guide along the road Nysa–Złoty Stok–Kłodzko–Wałbrzych–Jelenia Góra" (Cwojdziński, Kozdrój, 2007) developed within the framework of the project: Geotourist road maps of Poland. The guide's authors have enabled the tourists to get acquainted in an accessible way with the geology of the Sudetes along the marked route, including also numerous excursions to the most interesting places within its vicinity. That guide is out of print now, but is still available on the website of the Polish Geological Institute − National Research Institute (http://www.pgi.gov.pl/pl/wydawnictwa/ksiazki/popularnonaukowe.html).

In 2013, another guide of this kind was issued, entitled "Sudetes Georoute. Geological-tourist guidebook" (Stachowiak et al., 2013). It provides descriptions of geotourist attractions along a Polish-Czech route running from Bogatynia in the west to Opava in the east, crossing the state border at seven sites. Along the route that is over 600 km long, 21 information panels have been installed, which explain the most important stages of geological evolution of particular regions. Each panel has its counterpart in the form of an illustrated folder available at tourist information points located along the Georoute. The geological information is also available on the website: www.geostrada.eu.

The new guidebook we present to geotourists has been prepared for the road Jelenia Góra–Zgorzelec–Bolesławiec–Złotoryja–Jawor–Strzegom–Legnica, with a total length of approx. 300 km (Fig. 1). The route conceived in this way runs through different geological units of the Western Sudetes and their foreland. It is full of interesting landforms and viewpoints. In its vicinity, there are well-known and lesser-known exposures, mining and post-mining objects, museums, geological exhibitions, mining heritage parks, as well as monuments of material culture, which are evidence of the use of rock materials in the old days.

From a geological point of view, the geotourist route begins within the Karkonosze–Izera (Jizera) Massif, then crosses the so-called Intra-Sudetic Fault, reaching the Kaczawa fold-and-thrust belt and the North-Sudetic Trough (a depression). An important branch of the route runs from Jawor toward Strzegom which is, however,

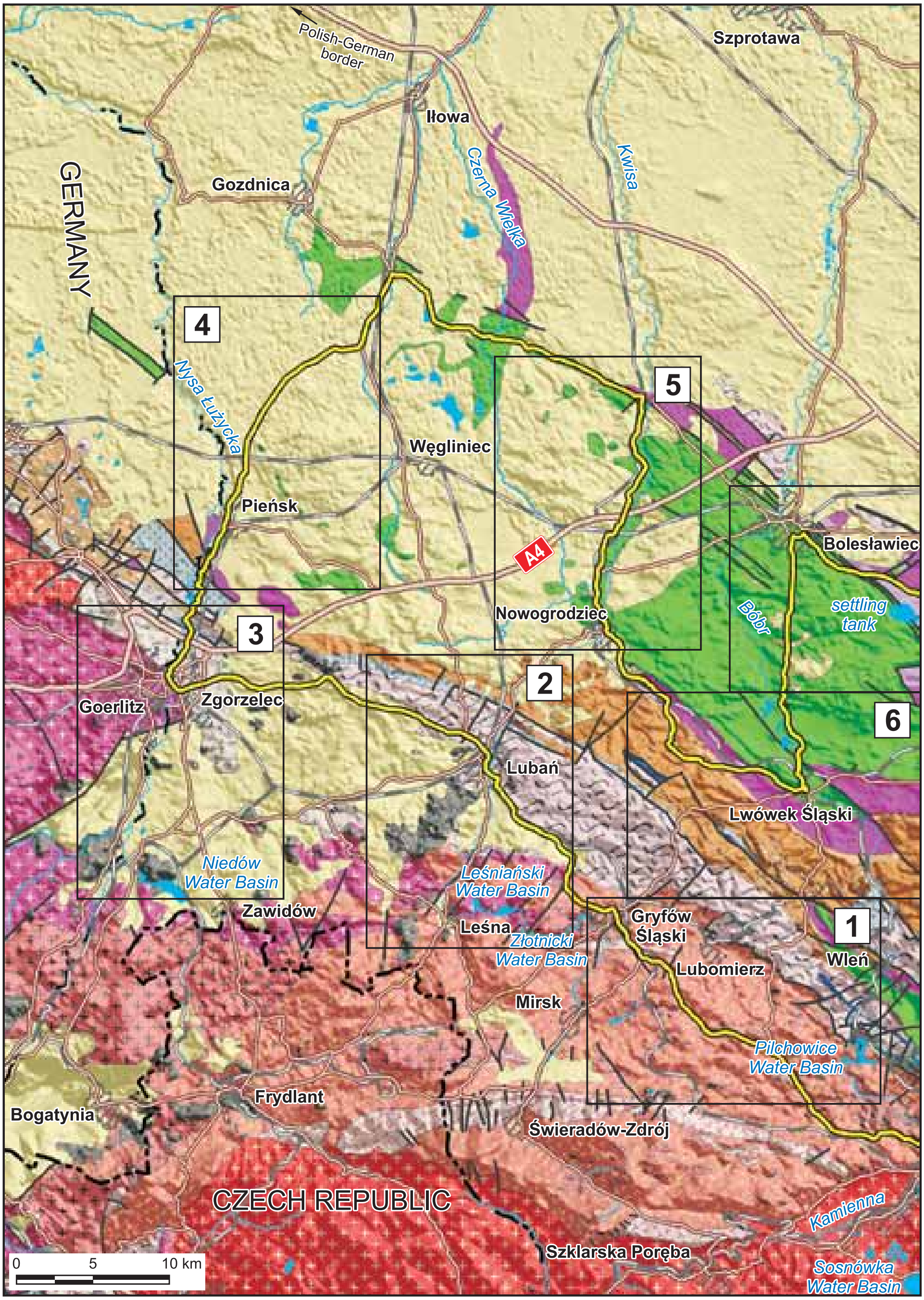
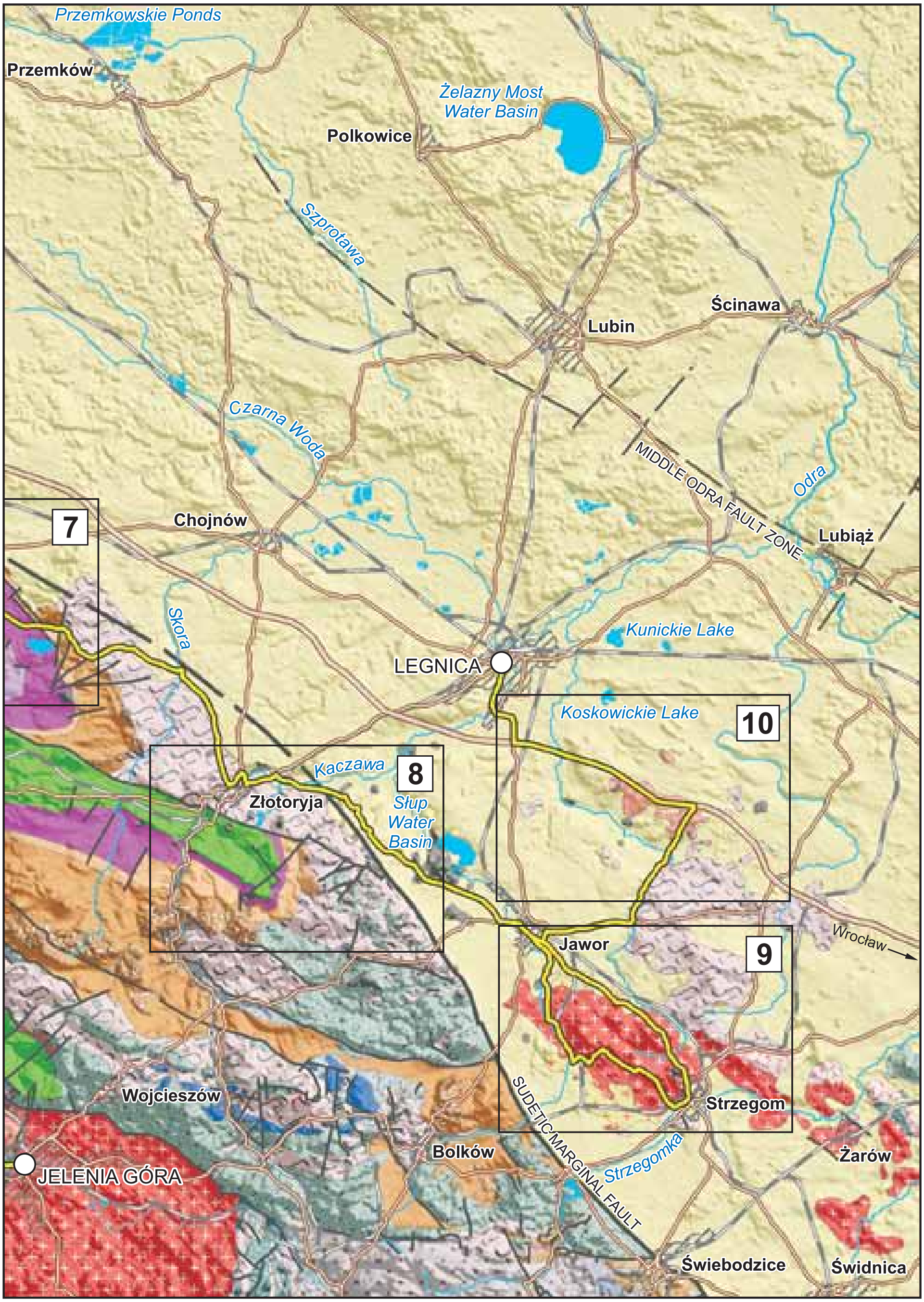


Fig.1. Geological map of the area presented in the guidebook, against the shaded relief



(without Quaternary deposits), based on the *Geological Map of Poland 1:200 000*

EXPLANATIONS TO GEOTOURIST MAPS
(Figures: 1, 7–10, 12–18)

CENOZOIC

QUATERNARY
- Holocene fluvial sands and gravels
- Quaternary deposits, in general

NEOGENE
- weathering mantle
- sands, gravels, clays and muds

PALAEOGENE AND NEOGENE
- basalts and their tuffs

MESOZOIC

UPPER CRETACEOUS
- sandstones, claystones and marls

MIDDLE TRIASSIC
- dolomites, limestones and marls

LOWER TRIASSIC
- quartz and variegated sandstones, claystones

PALAEOZOIC

UPPER PERMIAN
- conglomerates, sandstones, mudstones and dolomites

LOWER PERMIAN
- rhyolites, trachybasalts and tuffs
- mudstones, conglomerates, sandstones and claystones

CARBONIFEROUS
- granitoids

UPPER CARBONIFEROUS
- rhyolites and rhodacites
- conglomerates, sandstones, claystones and mudstones

LOWER CARBONIFEROUS
- greywackes and sandstones
- phyllitic schists and sandstones

DEVONIAN–LOWER CARBONIFEROUS
- conglomerates, mudstones, marls and greywackes

PALAEOZOIC

SILURIAN–DEVONIAN
- gabbros and diabases
- serpentinites

CAMBRIAN–DEVONIAN
- phyllites, quartzites and metavolcanites
- metavolcanites (conglomerates, diabases and amphibolites)
- crystalline limestones

NEOPROTEROZOIC– LOWER PALAEOZOIC

- amphibolites, locally greenstones
- orthogneiss and granitogneiss
- Izera and Rumburk granites
- (Zawidów) granitoids
- mica schists, quartzites and leptinites
- Lusatian greywackes

- faults
- **PD 31** documentation points
- main geotourist route
- branch of the main route
- **7** detailed geotourist maps
- active mines
- closed mines

located in the Fore-Sudetic Block in the Strzegom–Sobótka Granite Massif. Legnica – the final point of the route – is located in the northern part of the Fore-Sudetic Block near its contact with the Fore-Sudetic Monocline, famous for its large copper and silver ore deposits mined in the Lubin and Polkowice region. Along our tour, we will look at rocks of different ages and different origins.

The oldest of these are Upper Proterozoic (Neoproterozoic) Lusatian Greywackes and Cambrian and Lower Ordovician Zawidów Granodiorites and Izera Granites as well as the products of their strong deformation – the so-called Izera orthogneisses that represent an essential part of the Lusatian and Karkonosze–Izera massifs. The Kaczawa fold-and-thrust belt gives us the opportunity to become familiar with low-grade metamorphic (i.e. epimetamorphic) rocks that formed as a result of metamorphic transformation of sedimentary and volcanic rocks of Cambrian to Late Devonian, and even late Carboniferous age. These are different varieties of phyllites, metasandstones, quartzites, crystalline limestones, greenstones and greenschists, metarhyolites, metatrachytes and metatuffites (the prefix "meta" means that the rock has undergone regional metamorphism). Granites of the Karkonosze and Strzegom plutons represent the Late Carboniferous phase of plutonic intrusions typical of the whole area of Central Europe. Permian, Triassic and Upper Cretaceous sedimentary rocks are represented mostly by sandstones, conglomerates, shales, limestones, dolomites, marls and anhydrites. In the Lower Permian, volcanic rocks also play an important role; these are rhyolites, trachybasalts and their tuffs, often forming structures corresponding to the former volcanoes and subvolcanic structures, that is, those located directly beneath volcanoes. The guide's route also gives you the opportunity to become familiar with the youngest, Cenozoic phase of the geological evolution of the whole area. It is represented by Oligocene, Miocene and Pliocene sedimentary rocks, rocks of the volcanic basalt formation, and Quaternary sediments related to the periods of Pleistocene glaciations and fluvial sedimentation.

The guide has been developed in a way intelligible also to non-geologists. Thus, we invite all the lovers of geological tourism to the tour. First, however, we offer a brief introduction to the geology and geological structure of the area of our trips.

What story does the geology tell us?

Geologists observe and examine rocks and structures that were formed long ago, tens and hundreds of millions, sometimes even billions of years ago. This is an unimaginably long time, especially for us, the people, the existence of which closes within a few decades, and the history of mankind has just a few million years from its beginnings. In accordance with the principle of uniformitarianism (developed already in the first half of the 19th century) geological processes observed today took place in the same way in the past. Although many facts speak for gradual changes in many physical and chemical parameters during the geological evolution of the Earth, the fundamental geological processes occurred in a similar way.

Everywhere on Earth, the geological evolution includes magmatic processes responsible for the formation of volcanic and plutonic rocks, depositional (sedimentary) processes that result in the formation of sedimentary rocks, and metamorphic processes during which the heat and pressure cause changes in the mineral composition, structure and texture of sedimentary and igneous rocks. All these fundamental processes constitute the so-called geological cycle, i.e. a circulation pattern of rocks in the Earth's crust (Fig. 2). The energy for the geological cycle comes from the internal dynamic processes of the Earth, of which the most fundamental driving force is the flow of heat that emerges in the core of the Earth and at the core/mantle boundary.

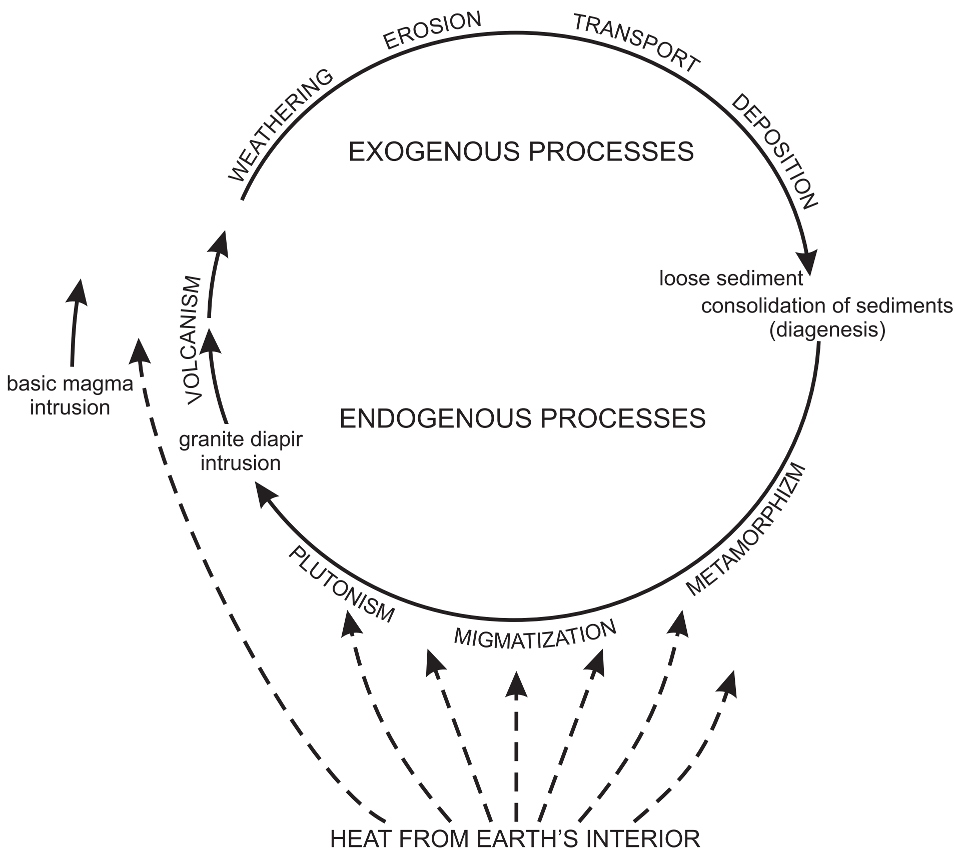


Fig. 2. Geological cycle illustrating the circulation of rocks in the earth's crust

Magmatism

Magmatism is one of the most important manifestations of inner activity of the Earth. As a result of the development of thermal anomalies in the crust and upper mantle, which are zones of elevated temperature, part of the rocks in these zones underwent melting, producing magmas rich in gaseous components. Chemical (mineral) composition of magmas depends on the type of melted rocks, and thus mainly on the depth at which the melting process occurs (Fig. 3). In the case of upper mantle rocks, molten magmas have an ultramafic or mafic composition (the name comes from Mg and Fe – the main components of these rocks), while in the case of crustal rocks, the process of their re-melting (i.e. anatexis) leads to the formation of sialic magmas with the dominant elements of silicon and aluminum (Si, Al). Ultramafic magmas, while cooling down and solidifying within the Earth's crust, form intrusions of peridotites and gabbros. Closer to the Earth's surface, in the so-called hypabyssal conditions, diabases, dolerites and related rocks are formed.

Sialic magmas are represented mainly by granitoid massifs that often attain enormous sizes. These are generally complex intrusions that develop over a long time and composed of rocks such as granites, granodiorites, tonalites and diorites. In the Western Sudetes, an intrusion of this type is represented by the Karkonosze granite pluton with coarse-grained, porphyritic, locally medium-grained granites, displaying a great structural and textural heterogeneity. In their fine- and medium-grained groundmass, we can notice remarkable larger, pink, tabular feldspar crystals of microcline. Large automorphic (which means that they retain their characteristic shapes), tabular potassium feldspar crystals are called phenocrysts. Upon a closer look, tiny inclusions of plagioclase, quartz and biotite can be noticed within them, often arranged parallel to the walls of the crystal. They were arranged during crystallization of potassium feldspar. The presence of phenocrysts is linked with the issue of indicators of magma emplacement during intrusion. These crystals in fact crystallize first and are carried by viscous granite magma during its movement within the Earth's crust. The longer axes of the crystals are arranged in line with the magma movement direction. Studies of such directions allow geologists to reconstruct "routes" of intrusions and their internal structure. In the groundmass there are potassium feldspars, plagioclases, quartz and biotite. Biotite is dispersed in the form of individual flakes or small clusters. Relict grains of hornblende or its biotite-overgrown accumulations are occasionally observed. Among accessory minerals are titanite, apatite, zircon and monazite, which however occur infrequently and in small amounts.

In granites, especially in porphyritic varieties, there are wavy biotite streaks (schlieren). Such structures develop as a result of granite magma emplacement. In

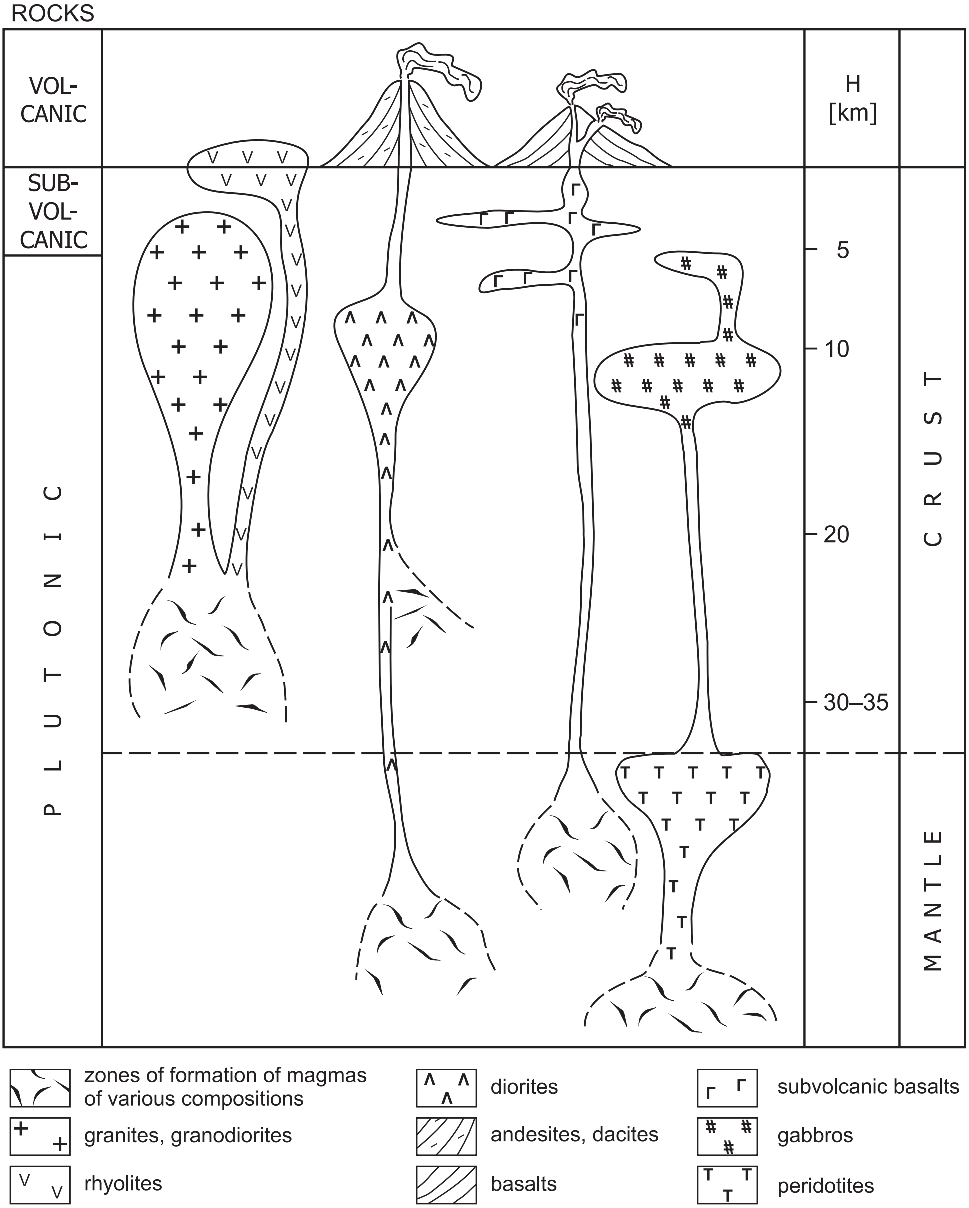


Fig. 3. A scheme of formation of igneous rocks

addition to schlieren, there are numerous spherical or oval enclaves, dark in colour. Some of them are typical enclaves from deeper parts or from the basement of intrusions, while the others are remains of hornfels rocks, but not melted by magma. Apart from oval or spherical enclaves, the granites also contain irregular forms, but always with rounded edges and corners.

The granites also reveal nests of pegmatites – coarse-grained overgrowths of pink and white feldspars with smoky quartz, biotite and epidote. These rocks are formed at the final stages of intrusion activity and are an effect of both the activity of hot water solutions and the use of fracture systems by the remains of magmas in already solidified granite. The granites also contain numerous veins of pink, very fine-grained aplites. Such veins show a granite composition, and use one of several systems of regular fractures.

Volcanic eruptions, which are the surface manifestation of magmatic processes, have always been among the most attractive, but also powerful and dangerous phenomena on Earth. Deep in the Earth's crust and in the mantle, magmas are formed as a result of melting of rocks existing there. After reaching the Earth's surface, they form lavas or pyroclastic rocks (tuffs, tuffites, volcanic bombs, lapilli and breccias). The crucial factor in the process of rock melting is an increase in temperature, which may be accompanied by local pressure reduction. Chemical (and thus mineral) composition of magmas depends, as in the case of plutonic rocks, on the depth and composition of rock environment in which they were formed. At the greatest depths, more than 50–60 km below the surface, dark mafic rocks are formed. In volcanoes on the Earth's surface, they are represented by different types of basalts. At a depth of approximately 25–30 km, magmas of transitional chemical composition (sialic rocks) exist within the Earth's crust. After reaching the Earth's surface and solidifying, they are often represented by andesites and rhyolites. Lava flows can occur both on land and on the sea and ocean floors. Under submarine conditions, volcanites cool down very quickly, forming very distinctive structures of pillowed, brecciated and bubbled lavas, etc. Under terrestrial conditions, the structures of volcanites are dependent on the lava's viscosity. Mafic lavas are not very viscous, easier to create extensive covers, shield lava flows, etc. Sialic lavas are very viscous, creating domal forms. Such volcanoes are prone to eruptions of enormous energy.

Within the Kaczawa belt, rocks of volcanic origin are represented primarily by basalts and tuffs which, altered by low-grade metamorphism, has been transformed into diabases, greenstones and greenschists. The Kaczawa greenstones and diabases, representing submarine mafic lava flows, are parts of the floor of an ancient marine basin, transformed by tectonic deformation. Pillow structures, typical of submarine basaltic lava flows, are exposed and perfectly visible in the Myślibórz Gorge, Chełmy Landscape Park, as well as at the foot of the castle in Wleń.

Light-coloured sialic volcanites form bodies of different sizes, rarely larger bodies, within the Kaczawa phyllites. These rocks used to be traditionally called keratophyres, but according to the modern terminology, they are metamorphosed and thus should be named metarhyolites and metatrachytes.

Lower Permian volcanites formed in completely different, terrestrial conditions. They are represented by mafic trachybasalts and trachyandesites (formerly called melaphyres) and sialic rhyolites (previously known as porphyries). They make up extensive volcanic covers that develop due to lava flows from fractures or shield volcanoes and as a result of intrusions solidifying at small depths (these are called hypabyssal or subvolcanic intrusions). Permian mafic volcanites are exposed primarily in numerous abandoned quarries near Lubiechowa and Bolków. Their finely crystalline groundmass often contains voids, 0.5–10.0 cm in size, which were formed by the cooling down of lava, and represent voids after the escape of volcanic gases. As a result of subsequent processes, various secondary minerals crystallized within them, growing from the outside toward the centre of the voids. Such rock texture is called amygdolidal, and the features in which minerals crystallized are named geodes. The process of growth of minerals often ended before filling the entire space, allowing the formation of magnificent, well-developed, inward-directed crystals. In geodes, we can find beautiful agates (which are colourful-banded accumulations of chalcedony) as well as smoky quartz and amethyst crystals. There are also concentrations of milky quartz and calcite crystals.

The Permian rhyolites are pink-grey massive rocks, with a very fine-grained groundmass containing fine feldspar and quartz crystals, up to 0.5 cm long. These rocks may also contain irregular concentrations of chalcedony and agates. One of the most interesting objects, in which Permian rhyolites showing outstanding columnar parting are found, is the Wielisławka Organs at Sędziszowa.

Cenozoic basalts represent the last phase of volcanic activity in the Western Sudetes. These are mostly isolated fragments of volcanic conduits or covers, often with prominent columnar parting resulting from the cooling of lava. Worthy of visits are the Czartowska Skała rock, Little Myślibórz Organs, Stożek Perkuna rock in Miłoszów, as well as outcrops in the Muchów Hills (475 m a.s.l.) in the northern part of the Kaczawskie Foothills.

Sedimentation

Sedimentation processes lead to the formation of sedimentary rocks. These rocks, depending on the dominant mechanism, are categorised into clastic rocks, that is, of terrigenous origin, clay rocks, and organic and chemical rocks. Among the last ones, the most important include carbonates, evaporites and fossil fuels (so-called caustobiolites), i.e. bituminous coal, lignite, peats and bitumens.

The initial materials for the formation of sedimentary rocks are those parts of the Earth's crust that, due of uplift, were moved toward the near-surface zone or directly to the surface of the Earth and became subject to weathering and destruction as a result of the activity of glaciers, rivers, seas, winds and slope processes. The main environments in which sedimentary rocks accumulate are shown in a scheme (Fig. 4). Among the factors destructing mountains, but also responsible for sedimentation, is erosion of mountain and continental glaciers, the latter called ice sheets. Sediments that accumulate due to the activity of glaciers are rock boulders, glacial tills, sands and gravels, muds, etc. In the immediate foreland of mountains, so-called alluvial fans are formed – the effect of accumulation of sediments shed by mountain rivers or streams. These are mostly boulder-gravel and gravel-sand deposits. At a greater distance from the mountains, vast piedmont plains develop, which are crossed by multi-channel, laterally wandering braided rivers. Fluvial gravels, sands and muds represent their sediments.

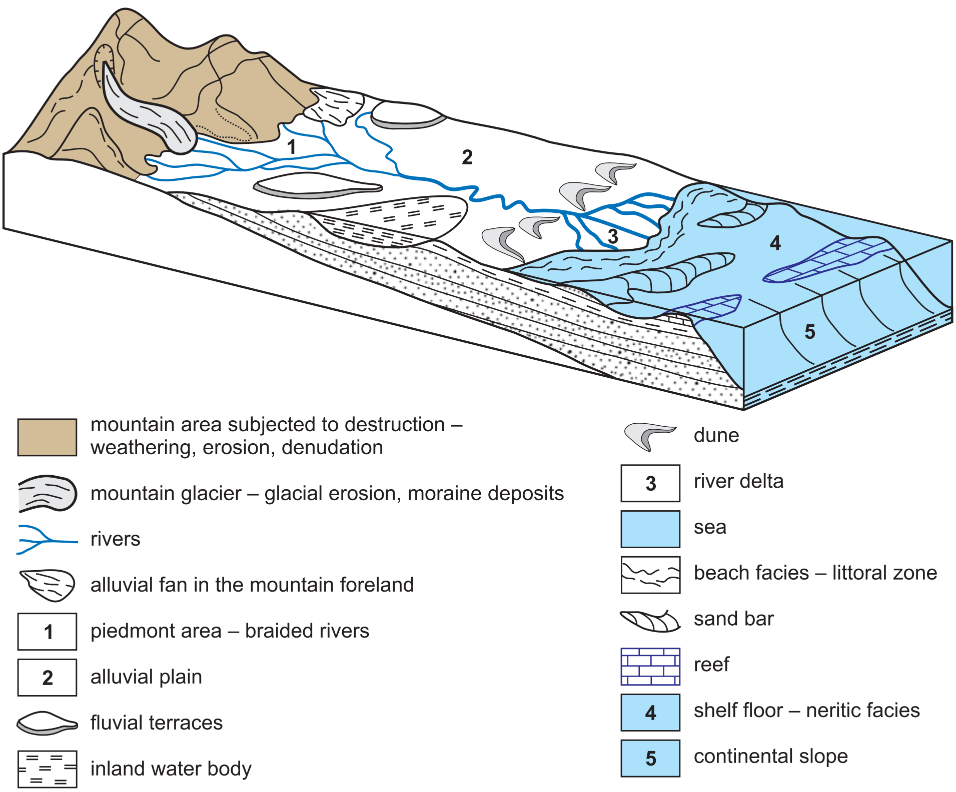


Fig. 4. A scheme of formation of sedimentary rocks

Far away from the piedmont areas, a lowland river system is developed represented mainly by meandering rivers. With time, the river meanders form an intricate pattern of alluvial plains composed of sand and sand-muddy deposits, as well as peats in oxbow lakes. Lowland river valleys are characterised by the presence of river terraces. They are parts of ancient valley floors, separated due to erosional processes. River terraces appear usually in the areas between valleys and along their edges. They are built of the same, fluvial clastic sediments.

In lowland areas, we often observe shallow water bodies; some of them are relatively large. These are lakes, lagoons, and cut-off sea bays. Depending on the climate type and many other factors, organic deposits accumulate in such environments – fossil fuels (caustobiolites), evaporites or clay rocks. As we approach the sea coast, there are belts of dunes and aeolian landforms that develop owing to the action of the wind. They consist mostly of windblown fine-grained sands, as well as of those winnowed out of older fluvial or glaciofluvial sand covers. Dunes are also common on alluvial plains. In the coastal zone, there is an important sedimentary environment of river deltas – alluvial fans that are triangular in outline, often "protrude" into the sea, and are crossed by numerous branching river channels. Deltas form in the place where the energy of waters carrying sedimentary material decreases to zero. These are environments of sand, silt and clay deposition. The beach and littoral (nearshore) zone, are areas of sand, locally gravel deposition.

The transport of clastic material by waves and sea currents causes the development of a series of shallow-water sandy structures, such as barriers and bars. In areas where the supply of detrital material is small and the water is warm and well ventilated (on the continental shelf or its edge), reefs can develop. These structures are composed of skeletons of sedentary marine organisms, especially corals; however, in different geological epochs also by other organisms (stromatolites, sponges and bryozoans). It is assumed that shelf seas are up to 200 m deep. This area is called the neritic zone, where deposition of material coming from the continent (terrigenous material) is subordinate. The dominant lithologies in this zone are detrital limestones originating from destruction of reefs, as well as limestones and dolomites of chemical origin, which precipitate from seawater. It is a highly dynamic, frequently changing system.

The shelf, in its deeper part composed of continental crust rocks, ends with a steep continental slope, along which the seabed steeply descends from a depth of approx. 200 m toward the deep ocean at the level of 2–3 km b.s.l., resting already on the oceanic crust. Continental slopes, due to their gradient, are surfaces of submarine gravity flows. The so-called turbidity currents, within which the suspension of sand and silt flows down the slope at high speed, are responsible for the deposition of flysch formations composed of alternating sand and mud layers (sandstones and mudstones), often showing graded bedding. This type of bedding is characterised by an upward gradual reduction in grain size within a given layer. It corresponds to the sequence of deposition of clastic material from the turbidity current.

It is worth remembering that most of these deposits, especially those accumulated in earlier geological epochs, have undergone diagenetic processes that transformed loose sediment into solid rock. The rocks, whose sedimentary environments are described above, we will meet several times en route of the guide in the North-Sudetic Trough and its sub-structures.

Metamorphism

The term metamorphism defines all the changes of sedimentary and igneous rocks that occur under the influence of increased temperature and static and directional pressure. The process of metamorphism is related mainly to the sinking of rock masses to great depths in the Earth's crust. Depending on the lithology, and especially on the chemistry of rocks subjected to metamorphism, pressure and temperature, we encounter a huge variety of metamorphic rocks. The conditions of their formation are defined by so-called metamorphic facies (Fig. 5).

Transformation of loose sedimentary rocks into solid ones, that is, the process of diagenesis, takes place at temperatures of up to 200°C. The lowest grade of metamorphism is represented by the greenschist facies, characterised by temperatures of 250−450°C and pressures of 2−4 kb (0.2–0.4 GPa). Under these conditions, igneous rocks of basaltic composition are altered to greenstones, while sedimentary rocks – such as mudstones and claystones – to different varieties of phyllites. Associations of co-occurring minerals (parageneses), typical of these rocks, include: chlorite, actinolite, albite, sericite, epidote and calcite. Carbonate rocks are altered to crystalline limestones and dolomites under these conditions.

The lowest-grade metamorphic rocks are typical of the Kaczawa fold-and-thrust belt. They are represented mainly by phyllites (fine-grained rocks of distinct fissility, which are sedimentary rocks of mudstone, claystone or fine-grained sandstone types, metamorphosed to schists) as well as by metasandstones (medium-grained rocks whose groundmass has been recrystallized with the participation of sericite and chlorites). Volcanic rocks are represented mostly by greenstones and diabases, i.e. metamorphosed rocks of lava and tuff types with the composition of basalts, and by metarhyolites – equivalents of light-coloured quartz-rich lavas (so-called acidic lavas). Greenstones and diabases are composed of fibrous amphibole (called actinolite), epidote, albite, chlorites, and calcite forming irregular thin veinlets in the dark green groundmass of the rock. Metarhyolites are light-coloured rocks, concise and solid or fissile, which are composed of feldspars and quartz with an admixture of sericite, chlorite, epidote, apatite and zircon. In fact, these rocks are very diverse, depending on the nature of the parent rock called protolith. In the case of metamor-

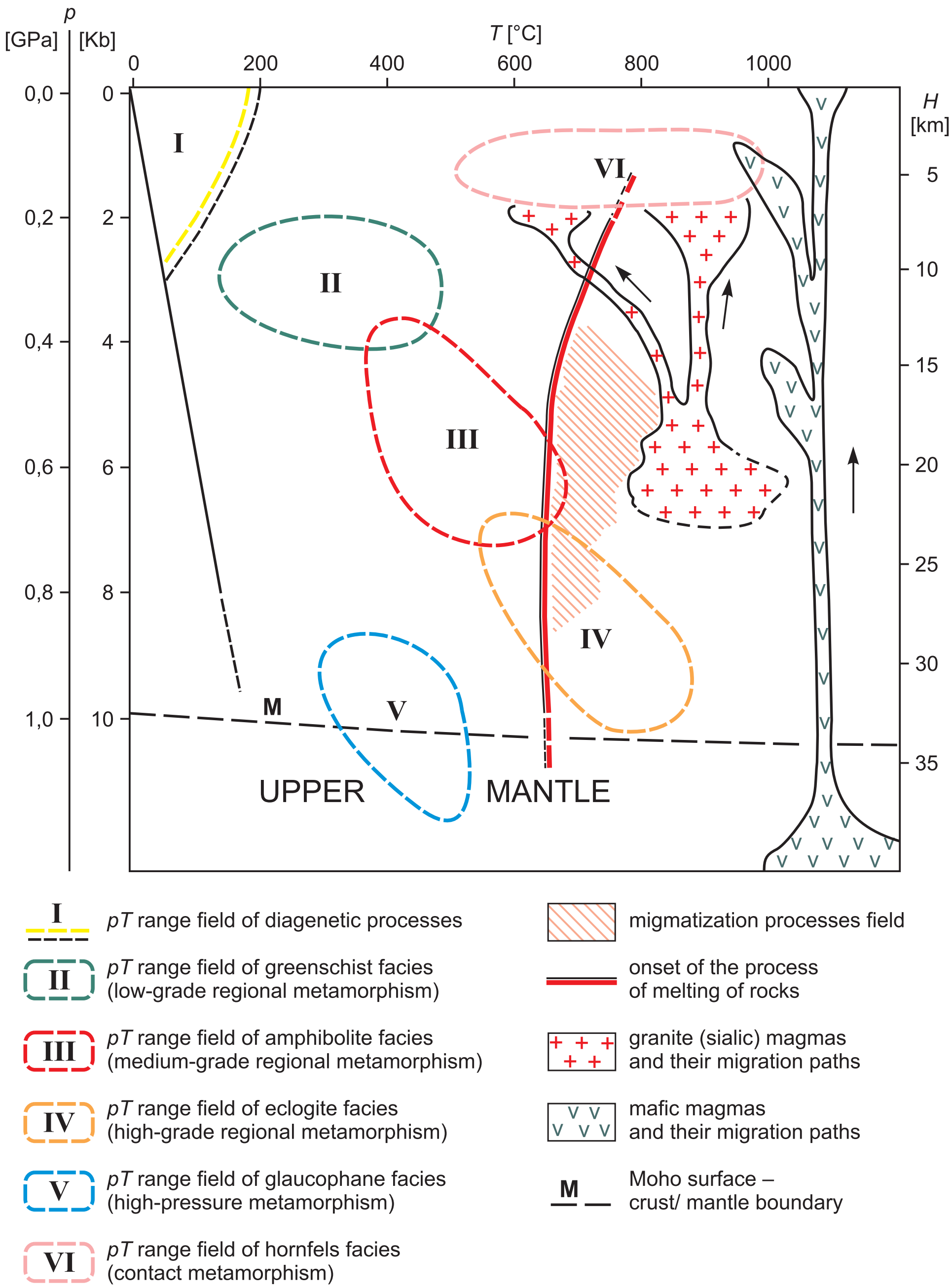


Fig. 5. Metamorphic and magmatic processes shown in the diagram pressure/ temperature (pT). Pressure is in various units; on the right corresponding to depth

phosed rocks of the greenschist facies, identification of their original type is relatively easy.

Medium-grade metamorphism is represented by the amphibolite facies. At a temperature of 400−700°C and a pressure of 4–7 kb, the following minerals become stable: biotite, potassium feldspar, plagioclase, hornblende, garnets (e.g. almandine) and staurolite, as well as, at the highest temperatures – andalusite and sillimanite, and at a higher pressure – distene. In such conditions, various types of crystalline (micaceous) schists, and numerous varieties of gneisses and amphibolites are formed. In fact, the conditions of these metamorphic facies often partially overlap each other, especially when the metamorphic processes take a long time. The overlapping of a higher-grade facies upon a lower-grade facies is characterised by the so-called progressive metamorphism. The reverse process is called retrogressive metamorphism, also called diaphtoresis.

Typical crystalline schists, which build up schist belts in the Izera Metamorphic Complex, are just the transitional metamorphic rocks that formed as a result of alteration of fine-grained sedimentary rocks (claystones and mudstones). They are composed of quartz, muscovite, chlorites, and fine garnet grains with pink colouration. The garnet grains are smoothly engulfed by thin mica layers and are visible on the foliation surfaces as characteristic nodules. On the foliation surfaces, a linear arrangement of minerals can be seen, which is called lineation. Both foliation and lineation are the structures developing due to directional tectonic stresses and movement of rock masses at high temperatures and pressures.

High-grade metamorphism corresponds to temperatures exceeding 750°C and a wide range of pressures. The rocks typical of this facies include granulites composed of potassium feldspar and plagioclases in paragenesis with pyroxenes (hypersthene), garnets, biotite and quartz. High-pressure granulites formed at pressures greater than 10 kb (from 1 to 2 GPa), i.e. at depths exceeding 35 km. Such rocks are absent along our route. However, they occur locally as intercalations in gneiss complexes of the Sowie Góry (Owl Mountains), Bialskie Mountains and in the Śnieżnik Massif. We do not either meet any rocks representing a relatively rare group of high-pressure rocks of the so-called blueschist facies, also referred to as the glaucophane facies. Glaucophane is a kind of amphibole that forms at pressures of 0.8–1.2 GPa, which means the mantle depths under normal conditions, and at low temperatures of 200−400°C. Occurrences of this mineral have been found in some greenstones of the Kaczawskie Mountains, however they are difficult for interpretation.

A different kind of metamorphic processes is mylonitization that takes place under conditions of strong deformation and directional stresses (synkinematic metamorphism) at variable temperatures typical of amphibolite or greenschist facies. The Izera orthogneisses are the result of such deformation of the Izera granites, which lasted from the early Middle Devonian to the early Carboniferous (400 to 320 million years ago). The deformation took place deep in the Earth's crust at temperatures of 300–500°C. During this process, granites underwent "milling out and grinding", whereby they have acquired the characteristic orientation in the form of layered, augen and lenticular structures. Mylonitic gneisses surround lenticular parts with preserved non-directional structure, which look like coarse- or medium-grained granites. These zones were subject to weaker deformation, representing protoliths that are original rocks with respect to orthogneisses. The end result of mylonitization are mylonites – rocks in which all minerals have been ground, arranged in specific laminae (bands), and altered into secondary minerals.

Very important rocks on our route are those, which are the product of contact metamorphism. The effect of this high-temperature (500–950°C) and low-pressure (less than 0.2 GPa) metamorphism are hornfelses and spotted slates – rocks that formed close to magmatic bodies due to thermal effects or magmas or lavas. Their mineral composition depends on the type of rock that is subject to metamorphism, and on the chemistry of the magmatic body. Contact rocks can be found along the route of the guide in Zgorzelec.

Outline of the geological structure of the western part of the Sudetes and their foreland

The largest geological unit of the western part of the Sudetes is the Karkonosze–Izera Massif passing westward into the Lusatian Massif located almost entirely in the territory of Germany. The Izera Mountains and the Karkonosze, included in the massif, form a morphological axis of the Western Sudetes. The highest summit of the Izera Mountains – Wysoka Kopa is 1126 m a.s.l., and the highest point of the Karkonosze and the whole Sudetes is Śnieżka (1602 m a.s.l.). The Polish part of the Izera Mountains is the Wysoki Grzbiet ridge, cut off on the south by the Izera River valley, and the Grzbiet Kamienicki ridge separated from it by the Kwisa River valley, both trending WNW–ESE. To the north, the Izera Mountains grade into a hilly area of the Izera Foothills with an average elevation of 470–350 m a.s.l. The Polish part of the Karkonosze extends between the Szklarska Pass in the west and the Lubawka Gate in the east, also trending WNW–ESE. On the north, they are cutt off by a steep topographical edge running between Piechowice and Kowary, which separates the Karkonosze from the Jelenia Góra Valley.

To the west, the Karkonosze–Izera Massif is separated from the Lusatian Massif by a zone of NNE–SSW-trending Żytawa–Zgorzelec depressions filled with Cenozoic deposits. It is bordered by the Intra-Sudetic Trough to the east, and adjoins the Kaczawa Structure to the north along a complex zone of the so-called Main Intra-Sudetic Fault. Geological evolution of the Karkonosze–Izera Massif is strictly associated with plutonic granitic activity lasting almost 200 million years – this is a real granite world (Cwojdziński, Pacuła, 2013b).

Rocks composing the Izera Mountains and the Izera Foothills belong to the Izera Metamorphic Complex and crop out in the area extending from Świeradów-Zdrój to around Jelenia Góra. These are orthogneisses that formed approx. 500 million years ago as granites that intruded into an aureole represented today by mica-chlorite schists of four longitudinal schist belts. From the south, these are the Wysoki Grzbiet (Szklarska Poręba) belt within which these schists have been metamorphosed thermally along the contact with the Karkonosze granites, the Stara Kamienica belt, best recognized because of tin (cassiterite) and cobalt mineralization, the narrow and discontinuous Gierałtówek–Mirsk belt, and the Złotnickie (Złotniki Lubańskie) belt. All the schist belts occur in the central part of the Karkonosze–Izera Block within a zone of predominant orthogneisses, and their arcuate outline, visible in the geological map, underlines this arrangement of the structural metamorphic elements. The schists of the belts formed more than 600 million years ago during the Neoproterozoic with the possible transition to Early Cambrian, as a result of metamorphism of sedimentary rocks such as claystones and sandstones. It is not ultimately ascertained whether they are fragments of the upper (top) or lower (basal) aureole of the original intrusion of the Izera granites. The boundaries between the schist complex and the surrounding gneiss complex are underlined to the south by elongated outcrops of light-coloured albit-enriched leucogranites with intercalations of tourmaline quartzites (Stara Kamienica belt, Złotnickie belt).

The Izera orthogneisses formed as a result of intense mylonitic deformation of primary granites. The process has imparted a characteristic directional fabric in the form of layered, augen and lenticular structures. Within the gneisses, there are parts of preserved non-directional texture showing, which have the appearance of coarse- or medium-grained granites composed of feldspars (plagioclase and microcline), quartz, biotite and muscovite. They represent undeformed or less deformed fragments of primary granites. The mylonitization process of the Izera rocks took place 400–340 million years ago (from the early Middle Devonian to Early Carboniferous). Within the entire orthogneiss-schist complex, there are also inserts of amphibolites, as well as diabase, lamprophyre and quartz veins.

A number of interesting exposures of gneisses representing the Izera orthogneiss complex are found along the shores of the dam lakes of Złotnickie and Leśniańskie within the Kwisa River gorge. Similar rocks can be observed in the so-called Bobrowe Skały rocks near Piastów and in the Bóbr River valley between Jelenia Góra and Pilchowice, as well as near Chmieleń.

Typical mica schists of the Kamienica belt are exposed e.g. near an old adit at Czerniawa, and in a quarry near Orłowice, located west of Krobica. These schists, with a characteristic silver-grey colour and schistosity, are composed of quartz, muscovite, chlorites and fine pinkish garnet grains, 2−10 mm in size. These exposures are presented in the previously published guidebook "Sudetes Georoute. Geological-tourist Guidebook" (Cwojdziński, Pacuła, 2013a).

Further to the west, in the Nysa River gorge between Działoszyn and Zgorzelec, as well as near Zawidów, occur the so-called Zawidów granodiorites and the Rumburk granites. The former are also referred to as the East-Lusatian granodiorites (540–585 million years). They belong to the Lusatian Massif, although their mylonitically deformed equivalents are part of the Izera Metamorphic Complex. A very interesting rock formation is the Lusatian greywacke. This is a sedimentary rock formed in a shallow-marine basin. Currently, the Lusatian greywackes form an aureole around the younger Zawidów granodiorites. Intrusion of the granodiorites into the Lusatian greywackes caused the phenomena of contact metamorphism and formation of hornfelses and spotted schists, i.e. rocks that form under high temperature at the contact with granodiorites. Thus, the Lusatian greywackes are probably the oldest rocks known in the Karkonosze–Izera Block, although the sedimentary rocks that were the protoliths of the schists of the Izera Mountains schist belts may be of similar age (approx. 600 million years).

South of the outcrops of the Izera Mountains gneisses, there are rocks composing the Karkonosze granite pluton. This massif is a huge intrusion that invaded into metamorphic rocks of the Izera Mountains, Rudawy Janowickie Mts and the southern Karkonosze in the Late Carboniferous, about 320 million years ago. The Karkonosze granites, however, remain out of the route of our guide. Their most interesting occurrences are described in detail in the previous geotourist guidebooks (Cwojdziński, Kozdrój, 2007; Cwojdziński, Pacuła, 2013a) and in the publications of the Karkonosze National Park.

The next geological unit of the guide's route is the Sudetic part of the Kaczawa Structure. It is composed of the metamorphic basement forming the so-called Kaczawa fold-and-thrust belt, and of the overlying massive cover represented by younger unfolded and unmetamorphosed rocks. The Kaczawa Structure lies to the north of the Karkonosze–Izera Massif. Between these units runs one of the major Sudetic faults – the Main Intra-Sudetic Fault. It separates two different geological worlds, whose evolutions proceeded differently, although largely at the same time (Cwojdziński, Pacuła, 2013b).

The Main Intra-Sudetic Fault is, in terms of its origin and shape, is a complex discontinuity zone, along which sustained movements of rock masses, including horizontal displacements (strike-slip fault), occurred from the late Palaeozoic (350 million years ago) onwards. Such deformation resulted in the development of a zone of mutual interfingering of the Izera metamorphic rocks and the Kaczawa belt rocks. It is clearly visible on the geological map near the Pilchowice Dam. Concurrently, right-lateral strike slip deformation (which means that the rocks located north of the fault moved to the right in relation to the rocks located to the south of it) generated space in the Earth's crust, which was used by the Karkonosze granite intrusions and the Intra-Sudetic Depression. The Izera and Kaczawa rocks were formed under different conditions of metamorphism, with the temperature difference of approximately 300–400°C and at the depth of at least 5–6 km in the Earth's crust. It is likely that the rocks of the Kaczawa belt were thrust during the Variscan orogeny over a basement composed of the Izera orthogneisses and other rocks of the Izera Metamorphic Complex, but it has not been proven yet (Fig. 6). Results of geophysical surveys indicate, however, that the basement of the Kaczawa belt occurs at a depth of at least 3–4 km.

From a geographical point of view, the Kaczawa Structure encompasses the Kaczawskie Mountains and the Kaczawskie Foothills, as well as, in its western part, also the Izera Foothills. The Kaczawskie Mountains is a mountain range with an average elevation of 600–700 m a.s.l. (the highest peak is Skopiec – 724 m a.s.l.), extending NW–SE between the Bóbr River valley near Wleń and the Bolków Foothills. To the south, they adjoin the Izera Foothills, the Jelenia Góra Valley, and – along the Bóbr River gorge near Janowice Wielkie – the Rudawy Janowickie Mountains. In the northeast, they fall with a distinct topographic edge toward the Kaczawskie Foothills. The western part of the Kaczawskie Mountains and the Kaczawskie Foothills, around the Bóbr River valley, has a highly diverse relief. Relative elevations reach 500 metres, decreasing toward the northwest. The varied relief of the area is associated with a complex, multi-level geological structure. It reflects its multi-phase geological evolution including several consecutive cycles of formation of sedimentary and igneous rocks within basins of various types, their metamorphic transformations, uplift toward the Earth's surface, as well as weathering and destruction by exogenic factors that have eventually sculpted the land relief.

The multi-level geological structure means that the Kaczawa Structure is composed of several individual rock complexes separated by discontinuity surfaces. They develop when the evolutionary cycle of the given suite of rocks becomes interrupted due to, e.g., uplift, weathering and erosion, and then a new phase of sedimentation and volcanic activity is restored on the so-shaped surface.

The basement of the Kaczawa Structure is represented by weakly metamorphosed sedimentary and volcanic rocks deposited in a marine basin that developed upon an unknown basement in the Cambrian (from 540 to 500 million years ago),

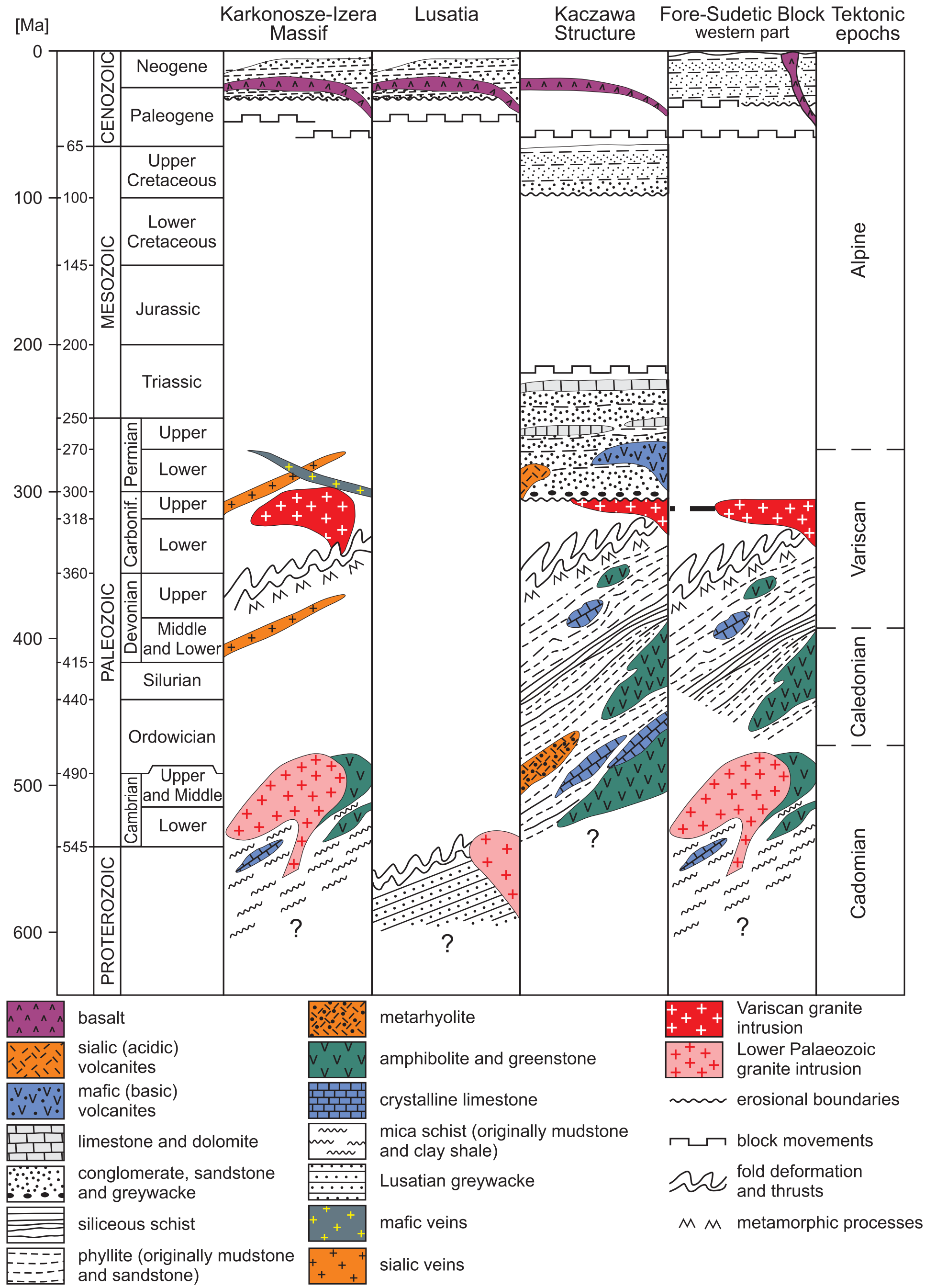


Fig. 6. Correlation of geological processes along the guide's route: Karkonosze-Izera Massif, Lusatia, Kaczawa Structure and the western part of the Fore-Sudetic Block

and existed in varying conditions until the Early Carboniferous (approx. 340 million years ago). Deformation and metamorphism of the Kaczawa rocks took place during the Variscan orogeny at the Early/ Late Carboniferous transition.

The originally sedimentary rocks in the Kaczawa complex are represented by phyllites and sericite schists – metamorphosed clay shales, mudstones and fine-grained sandstones, recrystallized sandstones (metasandstones) and quartzites, crystalline limestones genetically related mainly to the palaeo-reefs, and siliceous and graptolitic shales deposited in deeper parts of the sea. Phyllites, typical rocks of the Kaczawa belt, crop out in tors on the slopes of the Bóbr River valley north of Wleń, and in the vicinity of Kaczorów and Wojcieszów. Crystalline limestones are best exposed in old quarries near Wojcieszów and Mysłów.

Volcanic rocks are represented mainly by greenstones, diabases and metarhyolites – the equivalents of light-coloured lavas, rich in quartz (i.e. acidic). Greenstones and diabases are composed of fibrous amphibole called actinolite, of epidote, albite, chlorites, and calcite forming irregular thin veinlets in the dark green groundmass. These rocks formed from submarine basaltic lava flows. The well-developed pillow lavas, visible in diabases on Zamkowa Góra (Castle Hill) in Wleń, on which stand the walls of a medieval castle, are the evidence for rapid cooling of lava under these conditions.

Originally, sedimentary and volcanogenic rocks of the Kaczawa belt underwent regional metamorphism, folding and stacking into mutually thrust packets during the Early Carboniferous (Visean), forming so-called nappes. However, already in the Late Carboniferous, about 300 million years ago, rocks of the Kaczawa belt were brought to the surface to form the basement of a new basin in which sedimentation of conglomerates, sandstones and mudstones began; first in a marine basin of the latest Carboniferous, and then in desert conditions of the Permian. In the Early Permian (Rotliegend), depressions and troughs that developed due to metamorphic stretching of the Kaczawa basement were filled with sedimentary rocks, showing characteristic red and brown colours, and with volcanic rocks represented by pale pink rhyolites and dark brown or violet-grey trachybasalts. These rocks form extensive covers (plates) lying in accordance with the stratification of surrounding sedimentary rocks. The Late Permian was a period of shallow-water sedimentation of chemical deposits. In the Early Triassic, under different climatic conditions, desert sands and clays were deposited, while in the Middle Triassic, after another marine transgression – limestones and marls were accumulated. The next stage of geological evolution of the Kaczawa Structure was associated with inundation by the Late Cretaceous shallow and warm sea that transgressed onto a diverse basement after a period of weathering and erosion lasting from the Middle Triassic, that is, for over 140 million years. Sedimentary rocks – conglomerates, sandstones, marls and claystones, were deposited in the Late Cretaceous shallow sea during a period of more than 20 million years (from 99 to 75 million years ago). They commonly contain fossil shells of bivalves, especially inoceramids, pectens and other marine organisms. At the end of the Cretaceous, the sea retreated from the Kaczawa Structure area.

Today, the outcrops of metamorphic rocks of the basement form characteristic horsts, i.e. fault-bounded blocks separated by down-dropped grabens, troughs and synclines filled by younger sedimentary and volcanic rocks. This tectonic setting, typical of the Kaczawa Structure, is clearly visible on the geological map (Fig. 1). The Kaczawa metamorphic rocks are the basement for the vast North-Sudetic Trough (a depression) filled by the above-mentioned Upper Carboniferous sedimentary cover, Lower Permian volcanic and sedimentary rocks, and Upper Permian, Lower-Middle Triassic and Upper Cretaceous sedimentary rocks. The North-Sudetic Trough (depression) is the area of a former, extensive, trough-like, foredeep sedimentary basin with volcanic activity. Over time, the basin was transformed and deformed as a result of block movements lasting from the Permian to the Neogene. Because the rocks composing the basin, especially in near-fault areas, are strongly deformed, this structure is also called the North-Sudetic Synclinorium. The longer axis of the trough is inclined toward the northwest. As the result, the trough shallows toward the southeast and branches into shallower units, such as the Bolesławiec and Leszczyna synclines and the Lwówek, Świerzawa and Wleń tectonic grabens.

Near Złotoryja, the guide's route leaves the Sudetes and enters the area of Fore-Sudetic Block. Within the block there are two last areas described in the guidebook. The Fore-Sudetic Block is a large, horst-like, NW–SE-stretching, Neogene tectonic unit located northeast of the Sudetes and extending far to the Sudetic Monocline. It is composed mostly of metamorphic and igneous rocks, older than Permian. Crystalline rocks of the Fore-Sudetic Block currently occur under a discontinuous cover of Cenozoic deposits. The shaping of the block as a tectonic unit occurred in the Neogene (Miocene and Pliocene), when it was significantly down-dropped relative to the Sudetes area. Interestingly, the Fore-Sudetic Block today reveals rocks that were once located at much greater depths in relation to the Sudetes. This fact proves that the block occupied a reverse position relative to the Sudetes in the geological past.

Within the Fore-Sudetic Block, between Jawor in the west and Sobótka in the east, there is the second greatest Variscan granite massif of Lower Silesia – the Strzegom–Sobótka Massif. It is elongated NW–SE and 50 km long. Its maximum width is 12 km. Outcrops of massif's granitoids (the term granitoid generally refers to a group of rocks related to granite, comprising also granodiorite, monzonitic granite and tonalite) appear patchily within Cenozoic deposits of the block, forming gentle landforms of the Strzegom Hills. The areally largest granite outcrops are located near Strzegom (Strzegom granite area) and on the western slopes of Mt. Ślęża. In its westernmost part, west and south of Jawor, the massif adjoins the Sudetes along the Sudetic Marginal Fault. There is no direct evidence for the occurrence of massif's granitoids on the Sudetic side of the Marginal Fault. The suggestions that the massif can continue under the northern part of the Kaczawa Structure remain unproven.

Granites of the Strzegom–Sobótka Massif form thermal contacts with all rocks of the metamorphic and igneous aureole. In the north, from Jawor to the western slopes of Ślęża, the granitoides contact with the Kaczawa epimetamorphic complex of the Fore-Sudetic Block. In the south, near Strzegom, they adjoin similar rocks of Płaskie Wzgórza (Flat Hills), among which higher-grade metamorphic rocks appear. Finally, in the east, on the slopes of Ślęża, the granitoids intrude into ultramafic-mafic (ultrabasite-basite) rocks, such as serpentinites, gabbros and amphibolites. Along the intrusive contacts of the Strzegom–Sobótka Massif granitoids, we can observe a wide range of contact phenomena, including thermal metamorphism of the aureole rocks, intrusive breccia zones, and fragments of aureole rocks in granites (so-called xenoliths – i.e. rock fragments carried upward from the basement by magma), schlieren, etc. By contrast, the southern boundary of the massif runs over a considerable distance from Płaskie Wzgórza (Flat Hills) to Świdnica along the Strzegom–Świdnica Fault runing parallel to the Sudetic Marginal Fault. Along the Strzegom–Świdnica Fault, the granites descend to the south, toward a series of young tectonic depressions that accompany the edge of the Sudetes.

The granitoid Strzegom–Sobótka Massif is an intrusive body forming a laccolith. This is a mushroom-like pluton with a convex-up top and a relatively flat base, which intruded between the basement gneisses and the overlying younger epimetamorphic series. The granitic magma was derived from a remelted gneiss series that intruded in the form of magma into the upper parts of the gneisses and the overlying younger rocks.

In relation to the series of folded and metamorphosed rocks of the pluton's aureole, the intrusion is post-kinematic, which means that it occupied its present place after deformation of the aureole rocks. The Strzegom granite locally shows features of a concordant intrusion, and, in places, it discordantly intrudes into displaced parts of surrounding rocks.

The youngest rocks along our route are represented by Cenozoic cover deposits and basalts. The latter are 20–30 million years old and make up parts of volcanic conduits and traps. They compose the youngest structural level in the Kaczawskie Mountains and Foothills and in the Fore-Sudetic Block. Basalt chimneys cut all of the older rocks.

Western Sudetes, the land of mineral wealth

The complex geological structure of the Western Sudetes, being the result of their long geological evolution, is the backdrop for many ore minerals, some of them important not only for its mineralogical, but also economic value. Also fascinating is the history of exploration and mining of many of them, already in the Middle Ages.

In the Krobica, Gierczyn and Przecznica region, the old traditions of tin and cobalt mining are linked with the Izera Metamorphic Complex. They are related to the occurrence of the following ore minerals in mica schists of the Kamienica belt: cassiterite, pyrrhotite, chalcopyrite, arsenopyrite, sphalerite, pyrite, cobaltite and stannite. These minerals are visible to the naked eye only on polished surfaces of unweathered rocks. The extraction of tin ore (cassiterite) started here in the sixteenth century and was continued especially intensely even in the eighteenth century. The mining was carried out on near-surface deposits. Cobalt, once used mainly for the manufacture of paints and glass dyes, was mined in the eighteenth century predominantly in the Przecznica region (Anna-Maria mine). On the slopes of hills situated south of the road from Krobica to Jelenia Góra, many traces of earlier mining activity are visible even today. These are mine tunnel exits, ruins of mine facilities, and mine heaps. In Krobica, an underground route has been reconstructed, being part of a tourist path called "In the footsteps of old ore mining". In the 1970s and 1980s, numerous boreholes were drilled in the Kamienica belt, which allowed estimating the tin ore resources at nearly 9 million tons with the total content of 37 thousand tons of pure metal.

Interesting, although of no economic significance and with no impact on the environment, is uranium mineralization explored in the 1950s within the Izera Metamorphic Complex. Uranium and thorium mineralization in the Izera Foothills has been found in rocks enriched in albite, i.e. so-called leucogranites, along deep fault zones. It is typical for the Kopaniec, Stara Kamienica, Radoniów and Wojcieszyce regions. Polymetallic mineralization (represented by minerals of many different metals), and vein and impregnating uranium mineralization in tectonic zones are the result of hydrothermal processes in their broadest sense, which are associated with the Karkonosze granite intrusion and the circulation of hot water solutions in deep tectonic zones.

The uranium mineralization occurs in quartz- and fluorite-cemented breccias, and in highly fractured gneisses. Ore bodies take the form of nests or lenses, up to 250 m in length. They contain torbernite, metatorbernite, uranocircite and uranothorite – rare and secondary uranium minerals, as well as uraninite in the form of so-called pitchblende, accompanied by autunite, pyrite, chalcopyrite and hematite. The surrounding rocks contain iron compounds that give them a characteristic rusty colour. This mineralization does not occur on the surface; all information is due to earthworks (excavations, trenches, shafts) and drilling works once carried out in this area.

The Kaczawa Structure is a background for various multi-phase metalogenic processes, including a wide range of ore mineralization types: dispersed, polygenic uranium mineralization, quartz vein-related gold-bearing mineralization with arsenopyrite and other metal sulphides (Radomice, Klecza and Nielestno), quartz vein-related polymetallic mineralization and barite-quartz veins with sulphides. Larger quartz veins with richer polymetallic mineralization (As, Cu, Fe, Ag, Au) occur near Radzimowice and Lipa Jaworska. They were once the subject of mining. Polymetallic veins in the area of Kaczawskie Mountains are associated genetically with the influence of Karkonosze granites or other Variscan sub-Kaczawa intrusions, including the Radzimowice rhyolite stock (pyrite, arsenopyrite and chalcopyrite), or with subsequent thermal effects of Permian volcanites (galena, sphalerite, siderite and barite). Most of the known occurrences of polymetallic ore mineralization are concentrated in a belt parallel to the Main Intra-Sudetic Fault and near Radzimowice, Lipa, Mysłów and Kaczorów. In turn, quartz-barite veins are associated with the Intra-Sudetic Fault (Jeżów Sudecki) and the Chełmiec ore region in the northern part of the Kaczawa Structure.

At many of these locations, gold, copper, silver, lead and pyrite have been mined already since the Middle Ages. Underground mining was carried out in these areas in the late nineteenth and early twentieth centuries. Until the present time, we can still find traces of mining activities in the form of collapsed shafts, remains of adits and overgrown mine heaps.

The most important metallic deposits are those associated with Upper Permian sedimentary rocks of the North-Sudetic Depression, both from historical and contemporary perspectives. Copper, lead and silver mineralization, and, according to recent studies, gold and platinum mineralization, are found in Zechstein marls and limestones. Copper and lead have been mined here since 1914, especially intensely in the 1930s, and after World War II already by Polish companies in the Lena, Nowy Kościół and Konrad mines of the Złotoryja region. Metal ores in the Zechstein deposits, which occur along the north-eastern edge of the North-Sudetic Trough further to the northwest, are currently the subject of interest of the Polish copper industry.

The Western Sudetes are also an important region for mineable rocks, especially dimension and crushed stone – in other words building and road stone. The former is used in the construction industry, in the form of shapely slabs and blocks of different sizes, the latter is used for building roads and railways (as rock crumbs and blocks obtained by crushing of rocks in special crushers). The most important types of dimension stone are the Strzegom and Karkonosze granites, as well as the Upper Cretaceous “quader” sandstone. For the production of crushed stone, basalt is commonly used. The North-Sudetic Trough is also a very important region for the mining of precious varieties of ceramic clays, glass sands and building ceramics materials for the production of bricks, tiles and other products known as the red pottery. The role of underground extraction of gypsum and anhydrite has been decreasing. Unlike most metal ores, raw rock materials still play and will play an important economic role, not only on a regional scale, but also countrywide.

The guide’s route has been divided into 10 sections that run through regions of different geological and mining characteristics. Distinguishing features and specific characters of the individual regions are reflected in their names. Within each region, the most important, selected documentation points are presented, designated by the letters PD and a number. The text also provides information how to get to these points. Not all points are geological objects, some of them are post-mining objects, monuments, old pits and mine heaps.

The overriding idea of the guide is a combination of geological information with the centuries-long history of mining heritage and material culture of Lower Silesia.

Time to go on tour.

1 Deep insight into the Earth’s crust

Stara Kamienica–Lubomierz–Gryfów Śląski region

Our Sudetic geotourist trip starts in Jelenia Góra, a beautiful town located in the Jelenia Góra Valley, at the foot of the prominent ridge of Karkonosze Mountains. The Jelenia Góra Valley itself lies within the Karkonosze granite pluton, in its fault-bounded down-dropped part. On the north, the valley is bounded by the range of Kaczawskie Mountains represented by the mountains of Szybowcowa and Srebrna visible from the town centre and included in the Grzbiet Mały (Little Ridge). Geological structure of the area can be studied using a unique didactic object – a geological cross-section located in the Jelenia Góra town park on the Kościuszko man-made hill. It was built in 1902 and consists of natural rocks occurring in the Sudetes, in a sequence showing their actual layout of the geological structure. This German-made object was renovated and gives an overview of the geology of Western Sudetes to allow you to realize the huge variety of rocks in this area.

In Jelenia Góra, it is worth to deviate from the main route of the guide and go through Siedlęcin toward Pilchowickie Lake (Fig. 7). Northwest of the Krzywousty Hill, starts the picturesque Bóbr River gorge. Its initial narrow section, where the bottom of the valley is only slightly wider than the riverbed, is called the Borowy

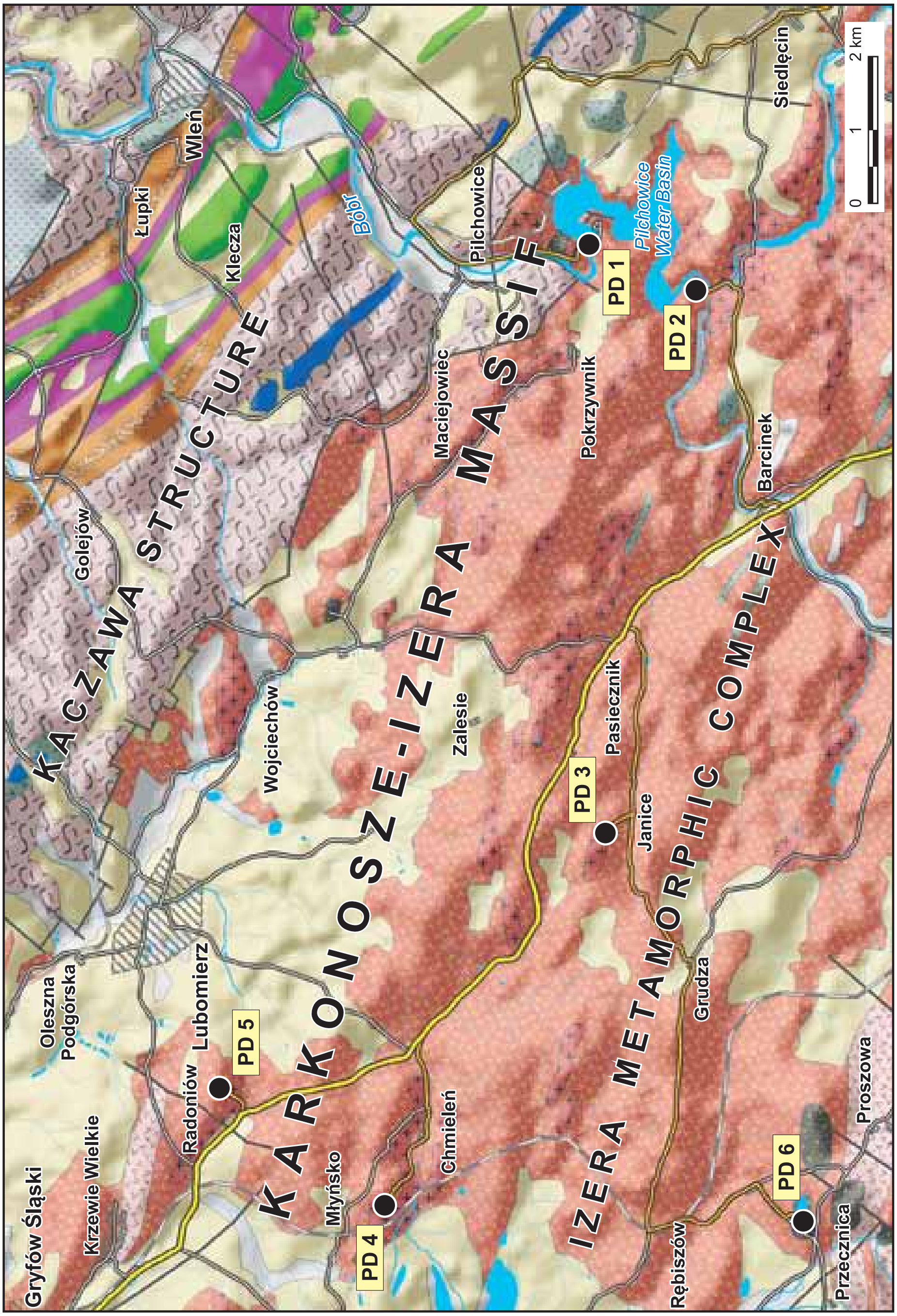


Fig. 7. Geological-tourist map of region 1 – Stara Kamienica–Lubomierz–Gryfów Śląski

Jar ravine. The Bóbr River cuts crystalline rocks at this point, creating a gorge of steep slopes, closed by the dam of Modre (Deep-Blue) Lake. Along the riverbed, the yellow-marked tourist trail leads from Jelenia Góra to Siedlęcin, and the green-marked trail crosses the southern slope of the Siodło (Saddle) Hill (464 m a.s.l.) just above the valley. Numerous tors of various shapes can be seen in this area: soaring towers, pulpits, as well as long stretches of rock walls. They consist of orthogneiss and coarse-grained granite belonging to the northern part of the Karkonosze–Izera Massif.

The hills surrounding the Bóbr River valley attain an elevation from 300 to over 450 m a.s.l., 120 m above the valley floor. The gorge formed during the Pleistocene glaciations as a result of erosion of river and subglacial waters that used both the features of the bedrock structure (especially the course of faults) and the pre-existing river flows from the pre-glacial period. From a geological point of view, the Bóbr valley cuts crystalline rocks of the northern part of the Karkonosze–Izera Massif and the southern part of the Kaczawa Structure. One of the major faults of the Sudetes – the Main Intra-Sudetic Fault, runs between these two units. The section of the Bóbr valley stretching between Jelenia Góra and Siedlęcin is very picturesque. The numerous tors along the shores of the lake are composed of coarse-grained non-directional granites containing quartz, feldspars and muscovite; they show an outstanding blue-grey colour due to the presence of quartz grains. In many places, these granites pass smoothly into orthogneisses. Between the individual orthogneiss varieties, we can observe gradual transitions that prove that they are the result of single continuous deformation.

In Siedlęcin, it is worth to visit the Książęca Tower located upon the Bóbr River. This is an example of a medieval fortress, being a type of “residential tower”. Such towers were popular in the fourteenth and fifteenth centuries. From a geological point of view, an interesting object is the tower wall from the fourteenth century. It is made up of different-sized gneiss blocks, Izera granites and amphibolites, i.e. of local rock material. Window frames and portals are carved from Cretaceous sandstone. The building houses the Siedlęcin Ducal Tower Museum.

From Siedlęcin, after leaving the Bóbr valley, we head northward to Pilchowice. At a distance of approximately 2 km from the centre of Pilchowice is a dam lake that formed in the period of 1904–1912 after the construction of the dam on the Bóbr River. Pilchowickie Lake is approx. 7.5 km long and up to 2 km wide in places, making it the largest water reservoir in the Western Sudetes, with permanent changes in its water level, reaching up to 7 metres.

Near the dam (PD 1) (Photo 1) there is a 12-m-high isolated rock composed of blue-grey Izera orthogneiss. Pink-grey, laminated, fine-grained orthogneiss is also exposed beneath the dam on the northern slope of the Bóbr valley. The dam was built of dimension blocks of the Strzegom granite, and the nearby power plant

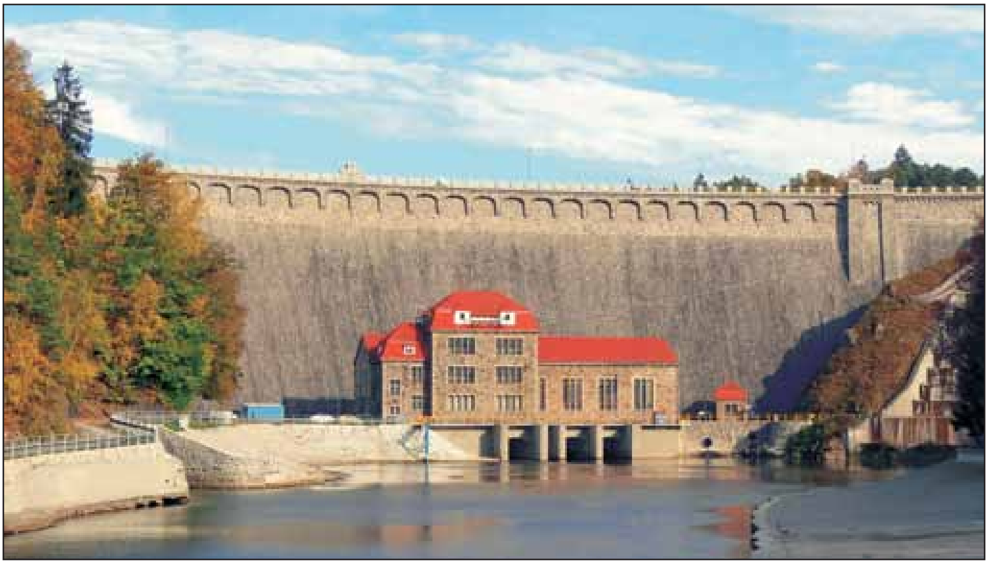


Photo 1. Hydropower building in front of the dam of Lake Pilchowice (*photo by J. Pacuła*)

building was made of Izera orthogneiss blocks. Today, the hydroelectric power plant still produces electricity, and the dam serves as well for flood protection.

Crystalline rocks, which are observed near the dam, belong to the Izerski Metamorphic Complex that is exposed over a distance of 1.5 km along the southern section of the Bóbr valley. North of the dam, we can encounter epimetamorphic rocks of the Kaczawa Structure. They are exposed near the road from Pilchowice to the lake. These are mainly phyllitic sericite-chlorite schists exhibiting fine platy parting, with the participation of albite and calcite. They contain inserts of white crystalline limestones. The entire series stretches in a NW–SE direction. In the geological map, the intricate course of the Izera–Kaczawa contact and the interfingering of rocks of both units are visible. This structure is the result of strike-slip deformation along the Intra-Sudetic Fault, which, as evidenced from detailed studies, was of variable nature: from left-lateral to right-lateral. The deformation proceeded at continuously shallower crustal levels, which implies the presence of increasingly brittle deformation of cataclasis and breccation type. East of the Pilchowice Dam (1 km in a straight line) there is a lovely truss railroad bridge over the arm of the lake, supported by granite pillars.

After the trip to Lake Pilchowickie, we come back to Jelenia Góra to continue our geotourist journey, leaving the town by the national road No. 30 toward Gryfów Śląski. It runs through the undulating Izera Foothills where the summits, up to 400–500 m a.s.l., are highly forested. The bedrock, cropping out from under Quaternary sediments on the hillsides, consists of Izera Metamorphic Complex rocks that form numerous tors of their own specific names. They are commonly composed of coarse-grained and porphyritic non-directional Izera granites that form separated rocks because they are resistant to weathering. Within the granites, we can found zones made of finer-grained rocks showing distinct directional, lenticular or laminar textures – these are the Izera orthogneisses. They have the same mineral and chemical composition and differ only in the types of mylonitic structures. Mylonitization was a long-lasting process that began already in the early Palaeozoic (approximately 400 million years ago) and ended before the intrusion of the Karkonosze granites (320 million years).

On the scale of detailed geological map, porphyritic granites from the area between Barcinek and Chmieleń occur as elongated lenses, a few hundred to 1 km×0.5 km in size, within veined-augen gneisses. Although the structure and texture of these granites resemble those from the Karkonosze Mountains, they differ from the latter in both colour and mineral composition, and are older by almost 200 million years. Such a lenticular structure, both mapped on the geological map and visible in rock samples, is characteristic of complexes of mylonitic rocks.

From the road No. 30 we turn right to Barcinek, where there is a picturesque gorge of the Kamienica River, a left-bank tributary of the Bóbr, located northeast of the centre of the village. The end section of the route coincides with the yellow and blue tourist trail leading to the mountain of Stanek (350 m a.s.l.) with a group of rocks called Kapitański Mostek (Captain's Bridge) (PD 2) (Fig. 7). On top of the rocks, there is a railed viewpoint attainable by a rocky stairway. On the other side, there are Wysokie Skały rocks visible, and at the foot of the cliff, several tens of metres high, the Bóbr River is winding. The rocks are composed of grey porphyritic, two-mica granite. The fine-grained groundmass of the rock consists of blue-grey quartz, black biotite and light-coloured muscovite, and hosts large potassium feldspar (microcline) crystals, approx. 5–7 cm in diameter.

From Barcinek, we come back to the road No. 30, from which we turn left on the local road to the village of Janice. North of the village, 600 metres away on the blue-marked bicycle trail, on the top of a flat hill, there are the rocks of Czartowskie Skały breaking into blocks (PD 3) (Fig. 2). These are grey porphyritic Izera granites. The medium-grained groundmass is composed of plagioclase and blue-grey quartz grains, and contains platy, occasionally oval potassium feldspar (microcline) phenocrysts, up to 5–10 cm in length. On some surfaces, orientation of the longer axes of feldspar grains can be observed. It may be the effect of granite magma emplacement while intruding during the Cambrian, approx. 505–510 million years ago. One of the blocks is represented by augen and veined-augen orthogneisses, in which large lenticular feldspar grains are surrounded by quartz-plagioclase and mica aggregates. Thus, due to mylonitic deformation, the phenocrysts have been altered into the so-called porphyroclasts.

Photo 2. Janice, Czartowskie Skały rocks – outcrop of Izera porphyritic granites (*photo by J. Pacuła*)

The next documentation point (PD 4) lies to the west of Chmieleń on the road to Młyńsko. It is an old overgrown quarry (Photo 3), in the northern wall of which grey porphyritic Izera granites are exposed. In the south-western corner of the quarry there are dark grey, very fine-grained granites. Feldspar grains, up to 1.5 cm long, quartz nests and biotite plates, up to 1 cm in diameter, are embedded within the groundmass. The granites show zones of directional texture passing into laminar-lenticular gneisses. This process is typical of the Izera Metamorphic Complex.

From Chmieleń, we head toward the village of Radoniów, situated on the other side of the road to Gryfów Śląski. On the eastern outskirts of the village, within the Izera orthogneiss complex, a uranium ore deposit of Radoniów (PD 5) was discovered in the 1950s.

Several other occurrences of uranium mineralization and radiometric anomalies, but of no economic significance, are known from Giebułtów, Proszówka and Gryfów Śląski. The rocks with uranium mineralization are represented by different structural-textural varieties of the Izera gneisses. Most of them are coarse-grained types.

The Radoniów uranium deposit was discovered in 1952, based on radiometric surveys. Radiometric anomalies in the Radoniów region, 5 km southeast of Gryfów Śląski, were examined by research trenches and boreholes. At a depth of 33 m, a tec-

Photo 3. Chmieleń – a tor composed of Izera orthogneisses, part of old quarry (*photo by J. Pacuła*)

tonic zone was encountered, within which the radiation intensity reached a level of 2200 R/hr. This zone was made available by a pit shaft that became a basis for a uranium mine in 1954.

Rocks surrounding uranium-bearing zone are represented by mica-chlorite schists of the Złotniki Lubańskie schist belt, also called the Złotniki belt, bounded by a leucogneiss zone to the south. Within the neighbourhood of the belt, there are rocks of the orthogneiss complex represented by augen and laminar gneisses. Uranium mineralization occurs in tectonic breccia associated with a tectonic zone, and in pink granitogneisses. The following minerals have been found there: pitchblende, torbernite, autunite, uranocircite, oellacherite, pyrite, marcasite, hematite, limonite, and rare galena, fluorite, calcite and veined quartz. The mineralization occurs in the form of nests or veins with fluorite. The average uranium concentration in the ore was between 1,000 and 2,000 g/t. Geological resources of the deposit amounted to 342 tons of metal, but have been exhausted. Today, the area of the former extraction does not bear any significant traces of mining except for small overgrown mine heaps on the hillside of Głębiec (421 m a.s.l.) east of the village. Therefore, Radoniów is nowadays only a historic site.

Away from the main route of the guide, south of Rębiszów, there is an old, already abandoned basalt quarry (Photo 4) marked on tourist maps as the Odarte Skały rocks (PD 6). To the south of this object is an active quarry with an outcrop of basalts, located in the northern and western parts of the extensive excavation. The basalts show irregular columnar parting and columns, from 0.5 to even 0.8 m in thickness. Detached blocks of white leucogranites, brought up from the basement by lava, are embedded in the basalts. On the surfaces of fractures in basalts, we can see calcite and zeolite encrustations that are indicative of a circulation of hot solutions within the basalt cover during the final phase of eruption. The old pit is currently used to dump water polluted with slurry remaining after the crushing of basalt in the active quarry. A cascading water runoff system allows for a gradual settling of the slurry, and the water flows to a pond located at the lowest level of the excavation.

Photo 4. Odarte Skały rocks – rock wall in the northern part of basalt excavation, note arcuate columnar parting (*photo by J. Pacuła*)

2 The basalt world

Leśna–Lubań region

From Radoniów, we head toward Gryfów Śląski and then by local roads toward Złotniki Lubańskie and Leśna. The Leśna–Lubań region is situated in the western part of the Izera Foothills. However, before we enter the “basalt world” of the land of Lubań, it is worthwhile to drive through a longitudinal gorge of the Kwisa River east of Leśna, which was used for the construction of two reservoirs – Złotnicki and Leśniański reservoirs (Fig. 8). This whole section is ideal for observations of crystalline rocks of the basement of the Izera Metamorphic Complex: granites, granodiorites and orthogneisses. The road between Leśna and Gryfów runs parallel to the shores of both lakes at some distance from them, whereas the tourist trails run directly along the northern shores: the blue-marked trail along Lake Leśniańskie, and the red trail – along Lake Złotnickie.

The whole route along these dam reservoirs is very attractive in terms of both scenic views and geological phenomena. The Izera orthogneisses of different varieties are exposed here in many tors, intersected by diabase and amphibolite veins. Near a narrow asphalt road that runs from Złotniki Lubańskie toward the Złotnickie Lake dam, there are beautiful tors of Izera orthogneiss, often exceeding 10 m in height. Within these rocks, short tunnels were hewn out at two places (PD 7) (Photo 5). One of them was made along a huge and flat fracture surface inclined toward the northeast at an angle of 60°. The orthogneisses are dominated by augen and lenticular varieties passing gradually to fine-grained laminar gneisses. The latter are the result of stronger mylonitic deformation.

All the types of orthogneisses from the shores of Lake Złotnickie near the dam are of similar mineral composition corresponding to the composition of ordinary granite. The largest grains (augens and lenses) of the gneisses are represented by microcline co-occurring with albite, while the groundmass is dominated by quartz, oligoclase and biotite underlining the directional structure of the rock. Zircon, epidote, rutile and allanite are rare in the rock and difficult to be distinguished with the naked eye. Foliation in the gneisses runs almost longitudinally and dips toward the N and NW at an angle of 60°. A linear arrangement of mineral associations is visible on its surface, which is called lineation. At some places, it is developed in the form of feldspar-quartz rods inclined toward the northwest. This type of lineation indicates the direction of rock mass movement during deformation.

Analysis of the types and directions of linear structures in metamorphic rocks allows geologists to reconstruct deformation processes and, using petrologic and radiometric studies, also the age and pressure-temperature conditions in which they proceeded. Such studies have shown that the orthogneisses formed as a result of deformation of the Izera porphyritic granite. At the first stage, the deformation con-

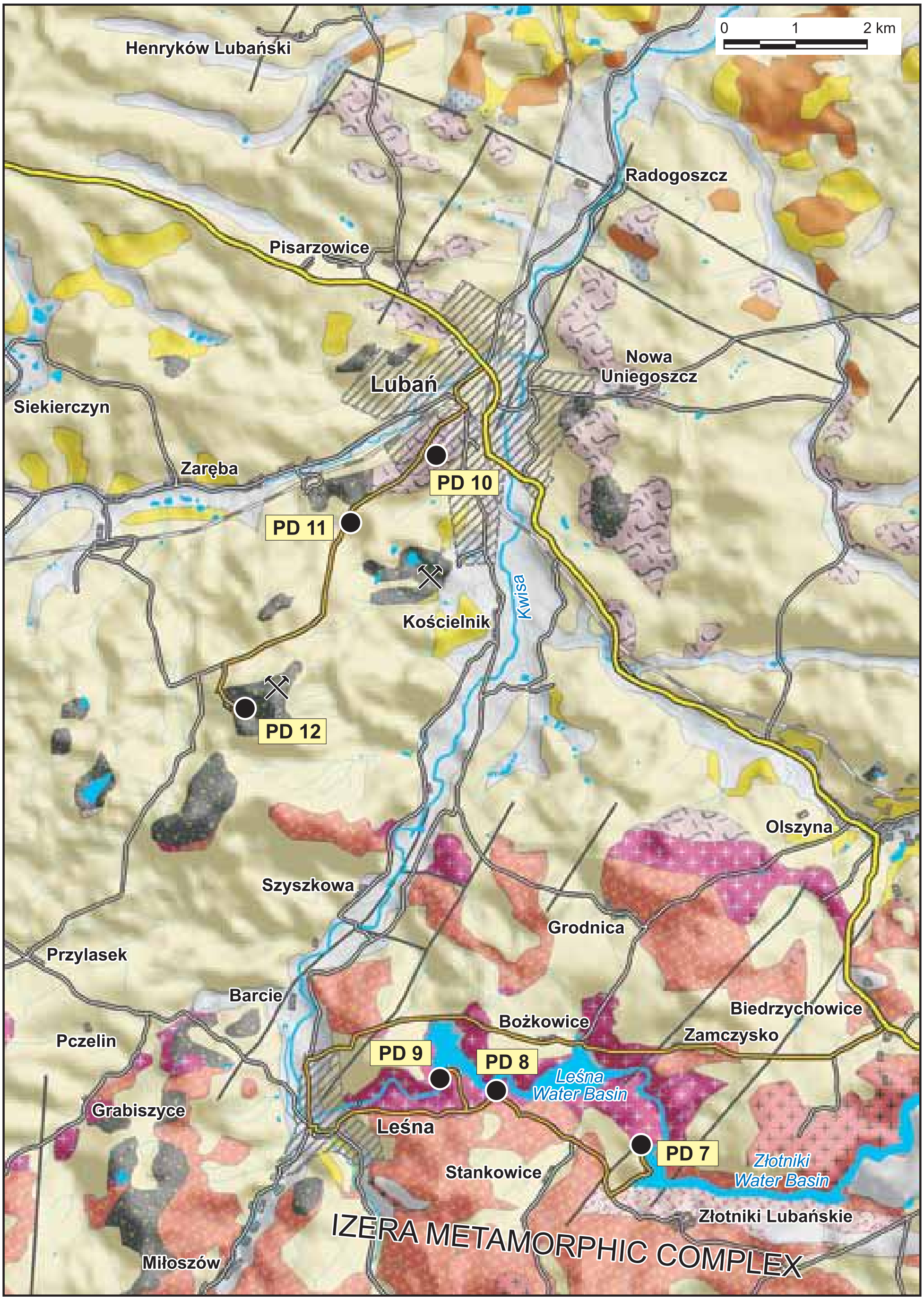


Fig. 8. Geological-tourist map of region 2 – Leśna–Lubań

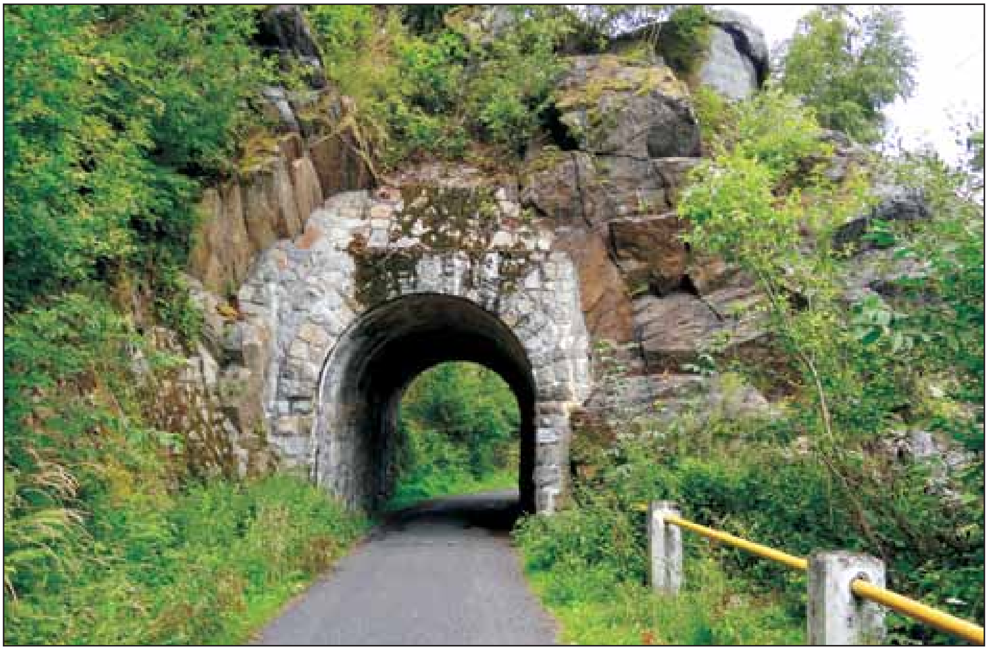


Photo 5. Road along Lake Złotnickie – mine tunnel hewn out in the Izera orthogneiss (*photo by J. Pacuła*)

sisted in the extension of the whole massif under greenstone facies conditions, i.e. at a temperature of 350–400°C and a pressure of 3.5–4.0 kb, and subsequently in strike-slip movements along longitudinally oriented shear planes at shallower levels of the Earth's crust. The orthogneisses are cut by mafic veins (dykes) of diabases. These are composed of actinolite, chlorite and albite. There are also occasional amphibolite veins (hornblende, oligoclase and biotite). The veins have undergone deformation together with the surrounding rocks, and thus they are older than the deformation process.

Along the southern shore of Złotnickie Lake, near the yellow-marked tourist trail, there are outcrops of grey fine-grained schists with phyllitic lustre, composed of muscovite, chlorite and quartz. Locally, they contain larger biotite plates. These rocks form the Złotniki Lubańskie belt, which is one of the four schist belts of the Izera gneisses, representing fragments of the old aureole of the Izera granites and granodiorites.

The Złotnickie Lake dam was built in 1919–1924 on the Kwisa River to form a reservoir, 125 ha in area and 8 km long. The dam is 27.5 m high, 168 m long, and 5 m thick at the crest and 27 m at the base. The dam was constructed upon the Izera orthogneiss and is built of Izera orthogneiss and granite blocks; its crest is made of concrete. The same rock material was used to construct the power plant building.

On the southern shore of Lake Leśniańskie, in a particularly picturesque place, there is the Czocha Castle, impressive in terms of its size and interesting architecture (PD 8). It was built between 1241 and 1247 as a stronghold on the border of Silesia and Lusatia, underwent various vicissitudes and was rebuilt several times. In the sixteenth century, the castle was rebuilt into a Renaissance mansion whose architectural character has remained unchanged to this day. The Czocha Castle (Photo 6) is made mainly of local rocks – weakly reworked and variously sized Izera orthogneiss blocks, with a minor proportion of almost non-directional Izera granites, sporadic basalts and siliceous schists. The frames of windows and doors are made of Upper Cretaceous sandstones imported from the North-Sudetic Trough, approximately 20 km away.

The Leśniańskie Lake dam (Photo 7) was built in 1901–1905 (PD 9). It is 36 m high and 8 m wide at the crest and 38 m at the foot. The water reservoir is 7 km long and has a theoretical capacity of 15 million m^3 and an area of 140 ha.

The dam stands on a foundation of typical Izera orthogneiss. Lenticular orthogneiss is exposed near the road to the dam and in tors at the foot of its marginal parts. These are grey medium- and coarse-grained rocks, composed of lenticular feldspar and feldspar-quartz "augens", up to 1.5–2.0 cm in size. The lenses are separated by layers composed of feldspar, quartz and micas represented by dominant

Photo 6. The Czocha Castle (*photo by A. Ihnatowicz*)

Photo 7. View from the dam of Lake Leśnieńskie over the Kwisa River gorge. Tors composed of Izera orthogneiss are visible, on which the dam is founded (*photo by J. Pacuła*)

biotite and subordinate muscovite. In terms of mineralogical composition, the feldspars are represented by plagioclase (mainly oligoclase) and microcline, as well as secondary albite. The quartz grains often show signs of crystal lattice deformation responsible for the blue-grey colour of the grains, visible with the naked eye. The arrangement of mineral aggregates results in the so-called rock foliation. Near the dam, the foliation is uniformly inclined toward the NNE at an angle of 50–60°.

The Izera orthogneisses from the flanks of Leśniańskie Lake were formed more than 500 million years ago. Gneisses from near the dam are relatively poor in quartz; thus, the likely parent rocks were granodiorites, but not ordinary granites.

The dam was built of the Strzegom granite, while the power plant buildings on the dam are made of orthogneiss dimension blocks. The use of this rock, which is currently not in use, proves its extraction and applicability in the construction industry by the Germans in the late nineteenth and early twentieth centuries. The power plant below the dam has been in operation since 1907, and is the oldest active hydroelectric plant in Poland.

An interesting fact is that the Izera metamorphic rocks were for many years the subject of hot scientific debate of Polish geologists. Before World War II, German geologists, belonging to the scientific elite in Europe (Cloos, Berg, Bederke and others), had no doubts about the origin of the orthogneiss that was believed to have formed due to deformation of granites. In the 1950s, some representatives of Polish geology joined the discussion. On the wave of the then fashionable concept of metasomatism, and a natural post-war trend of being in opposition to the proposals of German geologists, a group of eminent Polish geologists began to push forward a new idea that not gneisses were formed at the expense of granite, but vice versa – granites at the expense of gneisses. This process was supposed to have occurred by recrystallization of gneiss and its enhancement in potassium and sodium ions that migrated in the solid state (metasomatism), which caused blurring of the directional texture in the gneisses. Only new geochemical and isotopic methods allowed for the final rejection of that concept. Today, it is obvious that the Izera orthogneiss formed at the expense of granite. That discussion, however, was a stimulus for new research and brought many achievements. It is also an example that the scientific truth cannot be hidden.

After visiting the Kwisa River gorge, we drive northward to Lubań, entering the "basalt world". Bedrock in the Lubań region is composed of weakly metamorphosed Kaczawa rocks represented largely by phyllites – fine-grained, slaty rocks composed of sericite, quartz, chlorites, locally with an admixture of albite. However, the most important rocks of the Lubań region are basalts and other rocks of volcanic origin, such as tuffs, volcanic breccias and pyroclastic flows. These rocks formed during Oligocene–Miocene times (30–15 million years ago) as a result of melting of upper mantle material at a depth of approximately 50–60 km, under conditions of crustal stretching and due to the rise of magma along tectonic discontinuities.

Basaltic magma has a mafic composition, which means that it has low viscosity, high temperature of approx. 1200°C and high mobility. Owing to such features, the flow of basaltic lavas to the surface along fractures is generally a smooth process. In the Lubań region, we deal with fragments of massive lava covers and remnants of volcanic conduits. Their contemporary dimensions clearly testify about the power of the Cenozoic volcanism in the evolution of this region. The Lubań volcanic cover probably were merged with parts of the covers in the Leśna region. The basalts form a NNE–SSW-trending line that probably coincides with a deep crustal fracture extending down to the upper mantle.

The most interesting objects worthy of seeing are the volcanic plugs filling conduits of ancient basalt cones, which have been exposed from under the surrounding rocks. Such objects include Stożek Światowida (Światowid's Cone) and Stożek Perkuna (Perkun's Cone) between Grabiszyce and Miłoszów west of Lubań, and many others. In the immediate vicinity of Lubań, there are four active basalt quarries and a number of facilities in which mining has been abandoned. Therefore, Poland's largest basalt plate of Lubań, which is an important basalt field on a country scale, is also a good educational area to familiarize with basalt petrology and structures.

The most famous and most frequented exposure of the basalt cover is a hill called Kamienna Góra, located in Lubań (PD 10). Today, this is a very picturesque town park founded in the early nineteenth century, listed in the register of monuments. An interesting tourist and educational path accompanied by information panels runs through the park. An interesting place in the park is the so-called corrie – an old basalt quarry (Photo 8). Beautiful regular basalt columns are exposed here. They are approximately 9–15 m high, and the rocks are rich in nepheline (nephelinite). Because of its geological value, the pit was registered in 1983 as a natural monument.

In the park, there are many valuable trees and other plants, including maple, sycamore, beech, American tulip tree, Quercus robur Pectinata, shellbark hickory, pedunculate oak, common ivy and ferns. A panoramic view over the Karkonosze Mountains and Izerskie Mountains can be admired from the eastern slopes of the hill. Near the top, there are interesting buildings in terms of architecture.

About 1 km to the south of Kamienna Góra in Lubań, there is the Księginki I quarry (Photo 9) operated by the Łużycka Kopalnia Bazaltu (Lusatian Basalt Mine

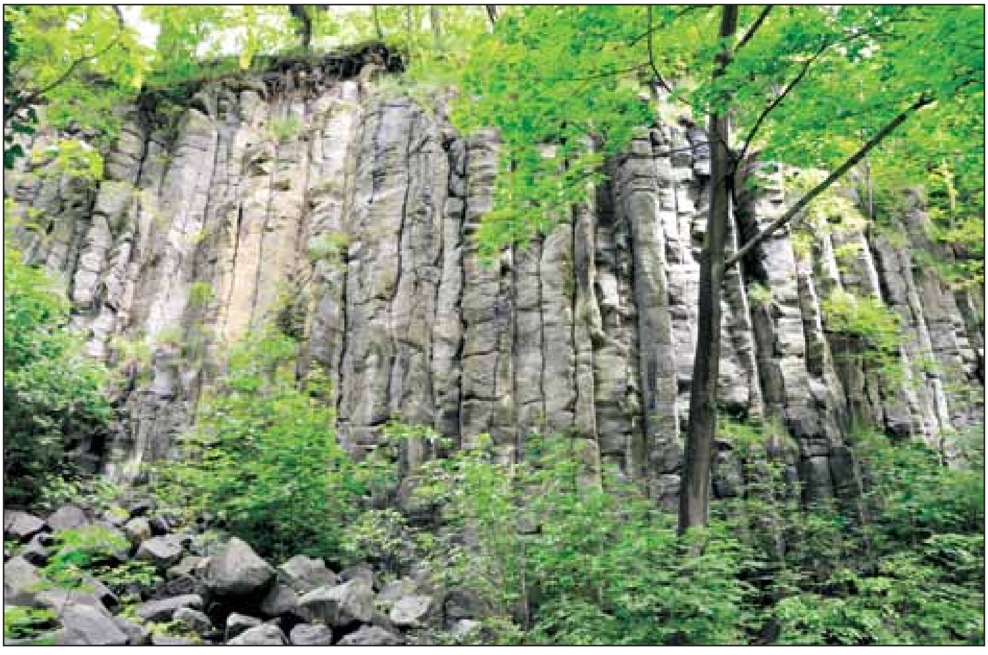


Photo 8. Abandoned basalt quarry of Kamienna Góra in Lubań – excellent example of columnar parting (*photo by A. Ihnatowicz*)

Photo 9. Panoramic view of the Księginki I basalt quarry in Lubań
(*photo by J. Pacuła*)

Co.). In terms of acreage, this is the largest opencast basalt mine in Poland; its mining area is almost 4 km^2. A panoramic view of the mine toward the ESE opens from a narrow road from Lubań to the village of Przylasek, running through Lubański Wielki Las (Lubań Great Forest). At the edge of the quarry is located an information panel at a stop on the educational path (PD 11). An extensive excavation with four mining levels of nepheline basalt (nephelinite) walls can be seen from this site. The basalts form three lava levels separated by tuff and volcanic breccia beds, corresponding to the successive phases of eruption. To see them up close, you must have a permission to enter the mine (you can receive it at the eastern entrance to the mine from the Księginki district of Lubań).

Nephelinite is a type of basalt composed of clinopyroxenes (pyroxenes that crystallize in the monoclinic crystal system) and nepheline embedded in the fine-grained groundmass, as well as of clinopyroxene and olivine phenocrysts. A characteristic feature of the Księginki nephelinites is the presence of fragments of rocks (xenoliths) derived from the Earth's mantle. These are fragments of peridotites and pyroxenites that are ultramafic rocks composed of orthopyroxenes (pyroxene that crystallize in the orthorhombic crystal system), olivines, spinels and clinopyroxenes. Studies of such xenoliths enable reconstruction of the upper mantle structure because they come from depths of 50–80 km.

The rock walls of individual mining levels reveal columnar parting of the basalts, also referred to as the thermal joint because it develops as a result of cooling of lava streams and contraction of congealing lava. The regularity of the columns at the individual levels is varied. At the bottom of the quarry, there is a water reservoir. Industrial exploitation of basalt in the quarry started in 1903–1906. Production resumed after World War II, and since then the mine has become one of the major

Photo 10. Basalt quarry of Bukowa Góra mountain – rock wall with clear columnar parting in nephelinites (*photo by J. Pacuła*)

suppliers of stone road in Poland. In 2012, the resources amounted to over 15 million tons with annual production of about 0.9 million tons.

Driving on the same road approximately 3 km across the Lubań Forest toward the southwest we turn east on a forest road to an active basalt quarry on the Bukowa Góra mountain (PD 12). This is a huge quarry operating at three mining levels, established to extract a deposit with the resources of more than 96 million tons. Nearly 1 million tons of rock is produced here annually. There is a processing facility in the mine area, which produces a wide assortment of broken stones – various types of crushed road stone. Nephelinites are exposed in the rock walls (Photo 10) attaining a height from a few to 20 metres. They show distinct columnar parting. The columns range from 0.25 m to 1.5 m in diameter and are mostly arranged vertically, but there can also be found basaltic plugs (necks) younger than the main volcanic cover, within which a fan-shaped arrangement of columns is observed. In the area of the Bukowa Góra mountain, a 117-m-thick layer of volcanites in three consecutive lava covers was once drilled through, which is a record thickness among the basalts in the Lubań region. Admission to the quarry requires notification to the mine management and obtaining a permission of the mine owner. Normally, visitors are accompanied by a mine staff member.

3 Ancient rocks of Lusatia
Zgorzelec region

From Lubań, we drive down the national road No. 30 to Zgorzelec. In the town and its environs, both on the Polish and German sides, we encounter rocks typical of the Lusatian Massif. These are East Lusatian granitoids called the Zawidów granodiorites, dated radiometrically at 540–580 million years (around the Neoproterozoic/Cambrian transition), thus being practically the oldest granitoids in Lower Silesia and slightly younger the Rumburk granites. The Zawidów granodiorites intruded into an aureole composed of still older sedimentary rocks of the Lusatian Formation. Even in Zgorzelec, we can find the Zawidów and the Lusatian Formation rocks transformed by contact metamorphism (Fig. 9). The irregular contact line runs NW–SE within the basement rocks in the southern sector of the town. South of the line, in the Nysa Łużycka River gorge, in a park located near the Municipal House of Culture (Photo 11), the Zawidów granodiorites with intercalations of or-

Photo 11. The Municipal House of Culture in Zgorzelec. Before World War II, the Upper Lusatian Hall of Remembrance was housed here. Worth noting is the building's facade made of sandstone (*photo by J. Pacuła*)

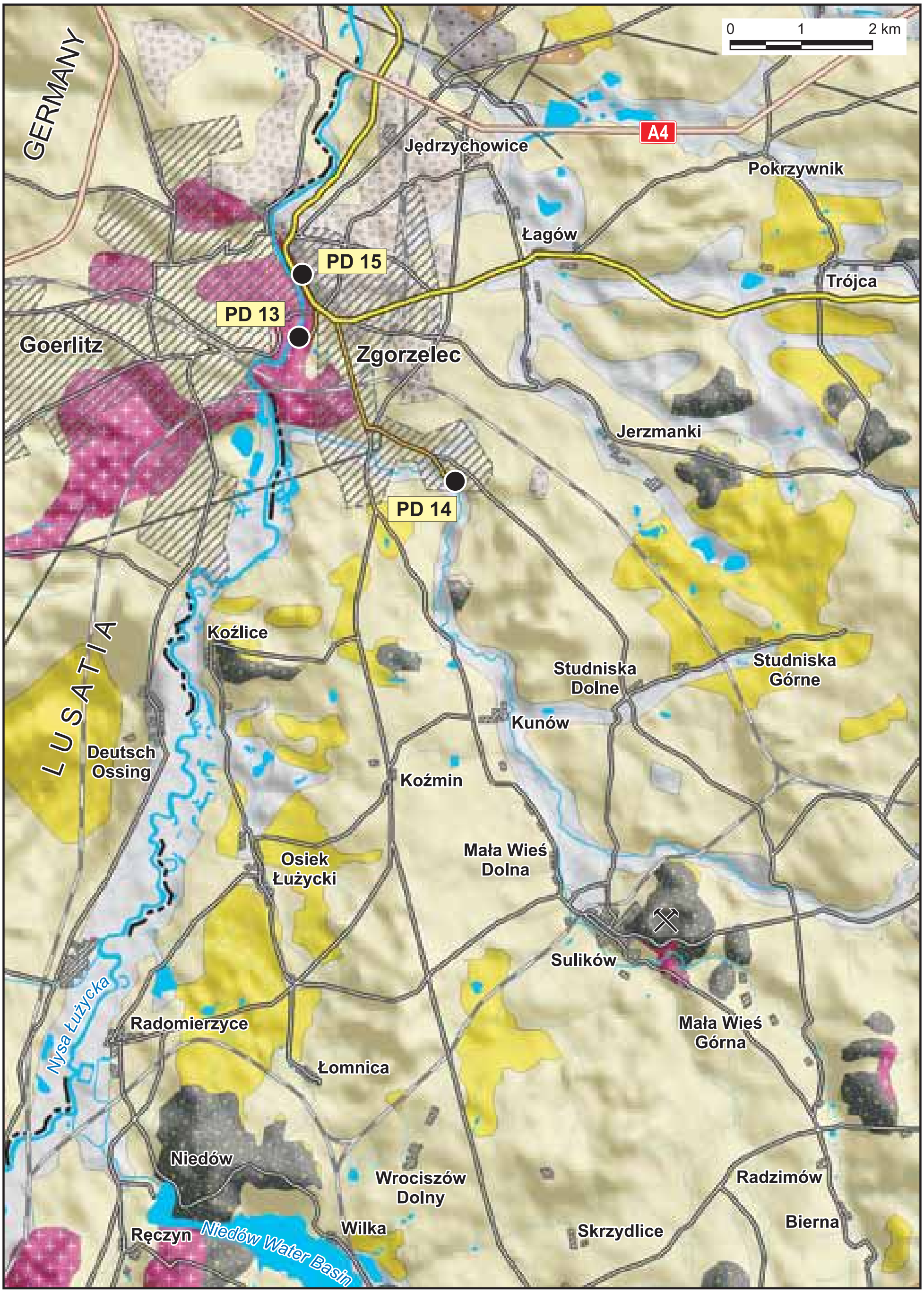


Fig. 9. Geological-tourist map of region 3 – Zgorzelec

Photo 12. One of few Zawidów granodiorite quarries upon the Nysa Łużycka River. Regular cracks are visible in the rock (*photo by J. Pacuła*)

thogneisses can be found in four old and heavily overgrown, abandoned quarries (Photo 12). They extend over a distance of more than 350 metres (PD 13).

In the first, northernmost pit, grey intensely fractured medium-grained and inequigranular granodiorites (some of them porphyritic) are exposed in the walls, up to 6 m in height. They show non-directional and massive textures and are composed of quartz, plagioclase (oligoclase), potassium feldspar and biotite. Subordinate are secondary minerals such as chlorite, sericite, as well as titanite forming at the expense of ilmenite and rutile. Detailed geochemical and mineralogical studies allowed for a conclusion that the Lusatian granitoids are poorly differentiated, which means that during its evolution, magma did not undergo significant differentiation. The temperature of magma melt differentiation from the parent rocks is determined at 800–850°C. In the first quarry, a well-developed, NNE–SSW-trending vertical slickenside is visible with distinct striae inclined SEE at an angle of 70°. These structures are triggered by the release of tectonic stress at shallow levels of the Earth's crust under rigid deformation conditions.

The individual rock blocks smooth the slickenside surface while moving relative to each other, and the striae indicate the relative movement direction. If there are also the so-called steps on the slickenside surface, then it becomes possible to determine the direction in which the fault side was displaced. Striae are a common feature on fracture surfaces in all the quarries. In the northern pit, the granitoids are cut by a 30-cm-thick vein of lamprophyre: dark grey, fine-grained rock composed of feldspar, hornblende and altered augite. This is one of the lamprophyre types – vogesite, probably associated with Variscan magmatism. In its central part, the vein is cut by a fault dipping southwest at an angle of 80°, and is displaced along it by approximately 40 cm. Light-coloured vein rocks (aplites) and darker ones (lamprophyres) occur also in other quarries along the Nysa River.

In the next working pits, with wall heights ranging from 10 to 14 m, the granodiorites contain gneiss intercalations. Their number increases towards the south, so that the last excavation, unfortunately being successively covered on top by rubbish, is dominated by grey medium-grained gneisses only. The gneisses are very diverse in types, and the transitions to non-directional granitoids are gradual. These are largely augen-lenticular gneisses, in which mica layers (biotite and chlorite) are engulfed and separated by lenses, augens and layers of feldspar and quartz. The amount of feldspar in the gneisses is variable, affecting the colour of the rock: lighter or darker. In addition to gneisses, the granodiorites also contain granitogneiss-type portions with poorly marked directional orientation of mineral components, as well as thin intercalations of dark grey, very fine-grained streaky-banded mylonites. They are composed of very fine quartz grains, rarely of feldspar grains and chlorite-biotite streaks, as well as of directionally arranged acicular rutile. All of these rocks are typical of the process of mylonitic deformation of non-directional granitoids, through which orthogneisses are formed. Mylonitic foliation in orthogneisses from the quarries along the Nysa River is oriented latitudinally, dipping mostly westward at an angle of 40°. A similar mylonitic deformation process is characteristic of the entire Izera–Lusatian Massif.

The basement in the central and south-eastern part of Zgorzelec is represented by the so-called Lusatian greywackes. This rock formation is dominant in Lusatia, hence its name. Undoubtedly, this is the oldest rock formation in Poland, available for observation on the surface. Therefore, it is worth special attention. This formation is composed of different varieties of greywackes, i.e. sandstone that contains feldspars and rock fragments in addition to quartz grains. Different varieties of these rocks, ranging in colour from dark grey to grey-green, and with varying structure from psammitic (medium-grained, with sand-sized grains) to aleuritic (fine-grained, with silt-sized grains), form interbeds of 20-cm-thick greywacke shales and up to 80-cm-thick beds of medium-grained greywackes.

Such sedimentary structures, typical of this formation, are best visible in an inactive, yet developed for tourism, quarry in the Ujazd district (Photo 13) in south-eastern Zgorzelec (in Widok Street, near the shore of the Czerwona Woda artificial reservoir) (PD 14). Here, we can observe a sedimentary cyclicity typi-

Photo 13. Zgorzelec, Ujazd – Lusatian greywacke quarry. Bedding, typical of flysch formations, is visible (*photo by A. Ihnatowicz*)

cal of the so-called flysch formations consisting of repeating sequences of dominant coarser-grained and finer-grained greywackes in the vertical section. Rock formations of this type formed many times in Earth's history. Their youngest representative is Poland's well known Carpathian flysch composing the Outer Carpathians, i.e. the Beskid Mountains. Such rocks are generally deposited on sea shelves in the foreland of active, uplifting mountains. The Lusatian greywackes are the result of such sedimentation that occurred some 590–560 million years ago, and the terrigenous material was derived from even older granitoid massifs.

From the Ujazd quarry, we move to the centre of Zgorzelec, where the Lusatian Formation rocks are penetrated by the Zawidów granodiorites.

Sedimentary rocks of this area have been altered by contact metamorphism, i.e. affected by high temperatures of granitoid magma. The top surface of the Zawidów granodiorites descends gradually toward the NE, as indicated by zonation of contact metamorphism, which is parallel to the greywacke/granodiorite contact. Closest to the contact, appear massive, dark grey, fine-grained, biotite hornfelses. These rocks have been penetrated by apophyses and granitoid veins. Typical hornfelses (Photo 14) penetrated by granitoid veins and lenses can be observed in a 5-m-high single rock that rises in Struga Street near the junction with Daszyńskiego Street (PD 15). They are very hard rocks, composed of recrystallized aggregates of quartz, feldspar

Photo 14. Zgorzelec, Struga Street – hornfels outcrop near the Lusatian greywacke/ granodiorite contact (*photo by J. Pacuła*)

and biotite, but they do not contain contact minerals, such as andalusite or cordierite, probably due to the original mineral composition of greywackes.

Close to the contact, the hornfelses are enriched in newly crystallized feldspars. This process is called feldspatization and occurs through migration of potassium and sodium ions without the presence of liquid phase. Whereas, the presence of isolated granitoid bodies in hornfelses can suggest local melting of greywackes as a result of heat supplied by a nearby granitoid body; the process is called anatexis. In a zone situated further away from the contact, there appear the so-called mottled greywackes, in which the groundmass contains new mineral phases in the form of irregular spots, up to 0.5 cm in diameter, composed of fine-grained biotite-chlorite aggregates. There are also small quartz and quartz-feldspar veins. In contrast to the case with hornfelses, the recrystallization process has not blurred the original sedimentary structures in the greywackes.

South of Zgorzelec, we encounter basalts in Koźlice and Tylice. With volcanic rocks and structures, we have already been familiar in the area of Lubań. It is only worth mentioning that a thermal contact of the basalt cover with a kaolinitized weathering mantle of granitoids is visible in the abandoned basalt quarry in Tylice. A 10-cm-thick layer of the intensely red overheated weathering mantle can be observed at the contact.

4 The brownish fuel

Pieńsk–Węgliniec (Gozdnica, Ruszów) region

Leaving Zgorzelec, we drive northward down the road No. 351, winding in the Nysa Łużycka River valley upon the surface of a Pleistocene terrace (8–12 m above the river level), to enter a different geological world. To the north and north-east of Pieńsk, as far as Węgliniec, Ruszów and Gozdnica, extends the vast Zgorzelec Forest that is part of the Bory Dolnośląskie (Lower Silesian) Forest. The landscape of this region is strictly related to the geology of its basement that is composed mostly of Pleistocene sandy deposits and Holocene peat bogs, as well as patches of isolated areas with outcropping Neogene and Upper Cretaceous rocks (Fig. 10).

From Pieńsk, we continue our tour to Stojanów. At the junction of road No. 351 and a local village road there is a well-preserved monument, made of Lower Permian red sandstone (PD 16), with the names of nine German soldiers who lived in the village and were killed during the First World War. This is a sad memorial monument; there are many like this in Lower Silesia. Fortunately, these memorials are not threatened by devastation any longer. Taking a local road, we travel eastward, and after about 1 km we enter a forested area where there are numerous traces of ancient mining of lignite (brown coal) and peat. Miocene deposits, represented by quartz sands with gravels as well as clays and silts with lignite layers, occur on the surface over the entire area situated east of Stojanów. These lignite seams, lying at shallow depths, were the subject of mining in a few mines of the area.

Opposite the junction of forest roads, where you can leave your car, there are the oldest traces of former lignite mining in this area. This is a wooded pit with walls 4 to 5 m in height, surrounded by a chain of old mine dumps (PD 17).

Going to the right we reach the Krusza pond (Photo 15). It is a flooded, mined-out transitional peat bog with an information board on its shore. Water from the pond is drained by a narrow encased stream and shows a characteristic rusty colour due to humic acids. These are complex organic substances produced during biochemical decomposition of plants.

Relatively recent traces of lignite mining in the already abandoned mines Kaławsk–Rygle I and Rygle II can be found approximately 1 km north of the Krusza pond – we can get there by forest roads. The largest excavation is in the Kaławsk–Rygle I mine located north of the railway line Niesky (Germany) – Węgliniec (PD 18). Its size is 1.40×0.75 km, now it is flooded with water (Photo 16). The Kaławsk–Rygle I deposit occurs at a depth of 25 to 45 m, and its thickness is up to 17 m, 6 m on the average. It is shaped like a lens. In the northern part, interbeds of clays and quartz sands are observed.

Lignite was extracted here already before World War II and the mining continued until the 1960s, when the deposit was abandoned, because of, among others,

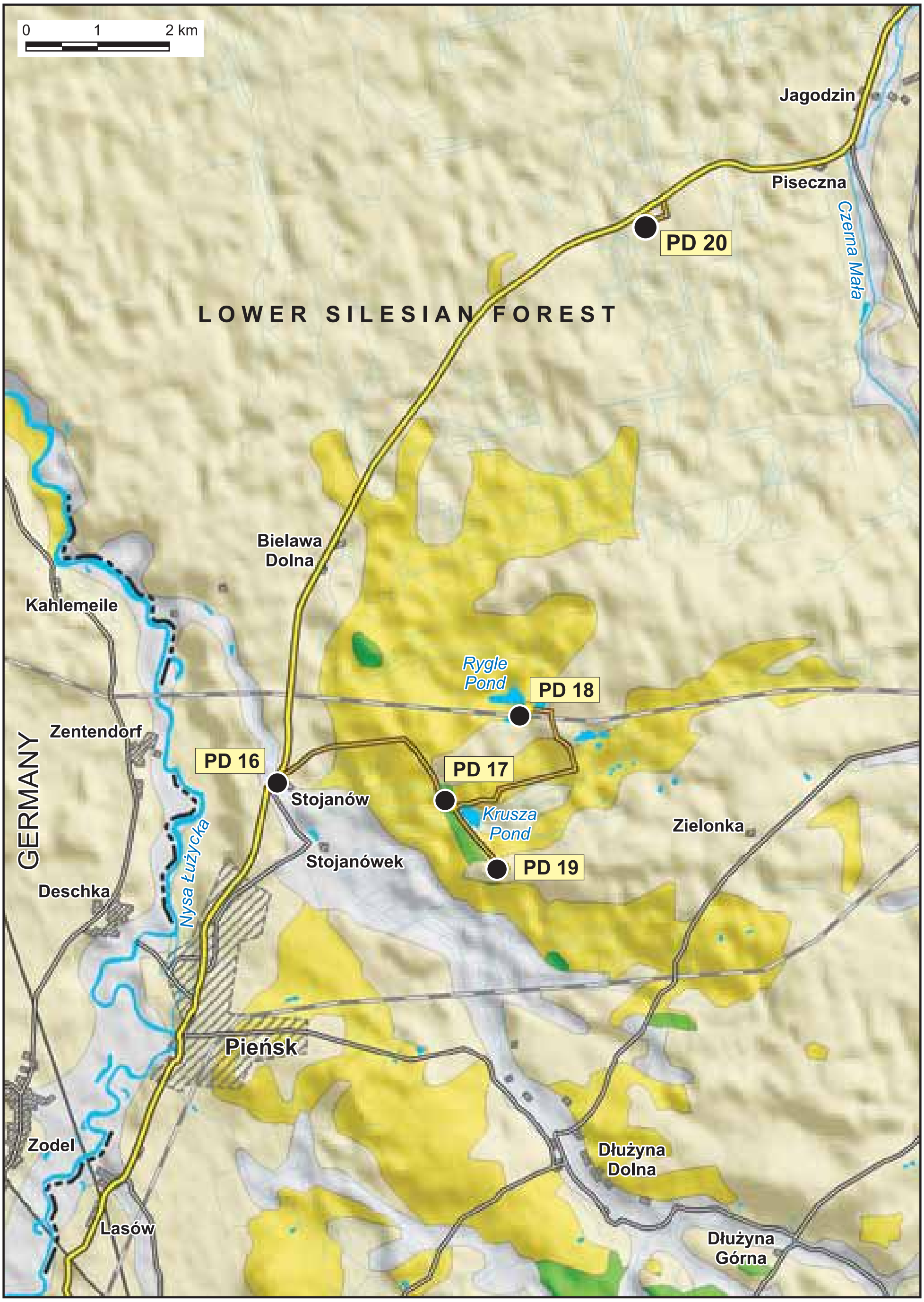


Fig. 10. Geological-tourist map of region 4 – Pieńsk–Węgliniec

Photo 15. Krusza pond – old peat-working site (*photo by A. Ihnatowicz*)

unfavourable water conditions. However, in the balance sheet of mineral resources of Poland, this deposit is listed to date as an abandoned deposit with geological resource of 4.1 million tons. It is worth noting that the resources of the well-known Turów lignite deposit near Bogatynia are more than 400 million tons, thus they are 100 times greater. Today's need for industrial exploitation of lignite causes that many small deposits in this area do not raise any interest. However, they are evidence of climatic conditions in this region about 20 million years ago, in the Early and Middle Miocene. Large, hitherto not extracted lignite deposits lie further to the north in the Lubuskie Voivodeship and in the Legnica region. The latter is the largest lignite coal deposit in Europe. Their possible future mining, however, would involve enormous economic and social problems; hence the hunt for other than open-pit methods of extraction of this deposit, e.g. underground gasification.

Within two flat hills with inactive quarries, located approximately 1.5–2.0 km south of the former Rygle mine (PD 19), there are exposures of Upper Cretaceous yellow-grey, distinctly bedded, medium- and fine-grained sandstones of Coniacian age. These are shallow-marine sediments and the assemblage of fossils demonstrates a prevailing warm climate and proximity to seashores. However, outcrops of Upper Cretaceous rocks are rare in this area.

On our tour further to the northeast, we follow the same highway No. 351 toward Jagodzin, which runs through the beautiful dense Zgorzelec Forest (Puszcza

Photo 16. Flooded lignite mine Rygle I. Mining was stopped due to problems caused by inflow of ground water (*photo by A. Ihnatowicz*)

Zgorzelecka). The forest has developed mostly upon Pleistocene sand-gravelly deposits forming extensive covers. They correspond to the period of glaciations, precisely to the so-called Wartanian Glaciation, when the ice sheet returned to the line Trzebnica and Dalków Hills, after its earlier retreat from the area of the Sudetes. South of the active ice front, runoff waters flowing from the Sudetes and from the melting ice sheet formed an ice-marginal valley, more than 10 km wide. Huge amounts of cold opaque waters, full of particles and fine sand, flowed down this valley westward. At the same time, braided rivers flowed from the Sudetes, carrying rock material and glacial and glaciofluvial sediments deposited in that area during previous ice periods. These deposits formed extensive alluvial fans, and the waters flowed through the ice-marginal valley toward the North Sea. The boundary between the two series of sands and gravels is still not fully determined, not even in detailed geological maps. Moreover, as we can see by ourselves, nowadays this is difficult to be determined in the Bory Dolnośląskie (Lower Silesian) Forest.

Four kilometres before Jagodzin, we turn right from the highway to take a forest road leading to the Spring of Elizabeth (źródło Elżbiety) which is marked in tourist maps (PD 20) (Photo17). The 2.5-m-high escarpment is composed of sand-gravelly sediments overlying glacial tills. Their partial erosion by glacial water is evidenced by the so-called boulder pavement (horizontally arranged large erratic blocks, more than 0.5 m long) visible at the contact between these two sediments. Two spring niches, formed in the wall of a former gravel pit by two currently encased springs, are visible in the escarpment. The further spring is encased by dimension blocks of Permian and Cretaceous sandstones. The water flows from the two springs into a small pond. The site well illustrates the phenomenon of the formation of springs at the contact of permeable and impermeable layers. Additionally, this is a very good place for a rest in the forest.

We approach the large village of Jagodzin. In 1969, the Jagodzin 1 deep borehole was drilled in this area to a depth of 2619.2 m (the deepest well in the region), which enabled geologists an insight into the geological structure of the western part of the North-Sudetic Trough (Fig. 11). The complete section of the Permo-Mesozoic platformal succession was drilled through to reach grey phyllites with intercalations of weakly metamorphosed sandstones at a depth of 2487 m. These rocks represent the Lower Palaeozoic Kaczawa belt forming the basement to the younger rock series in this region. These series include, from the base: Lower Permian deposits – sandstones, siltstones and conglomerates with a characteristic red colour and interbeds of volcanic rocks, with the total thickness of 763 m; Upper Permian deposits –

Photo 17. The developed spring of Elżbieta. The spring is encased by Lower Triassic pink sandstone blocks and Upper Cretaceous light-coloured ones (*photo by A. Ihnatowicz*)

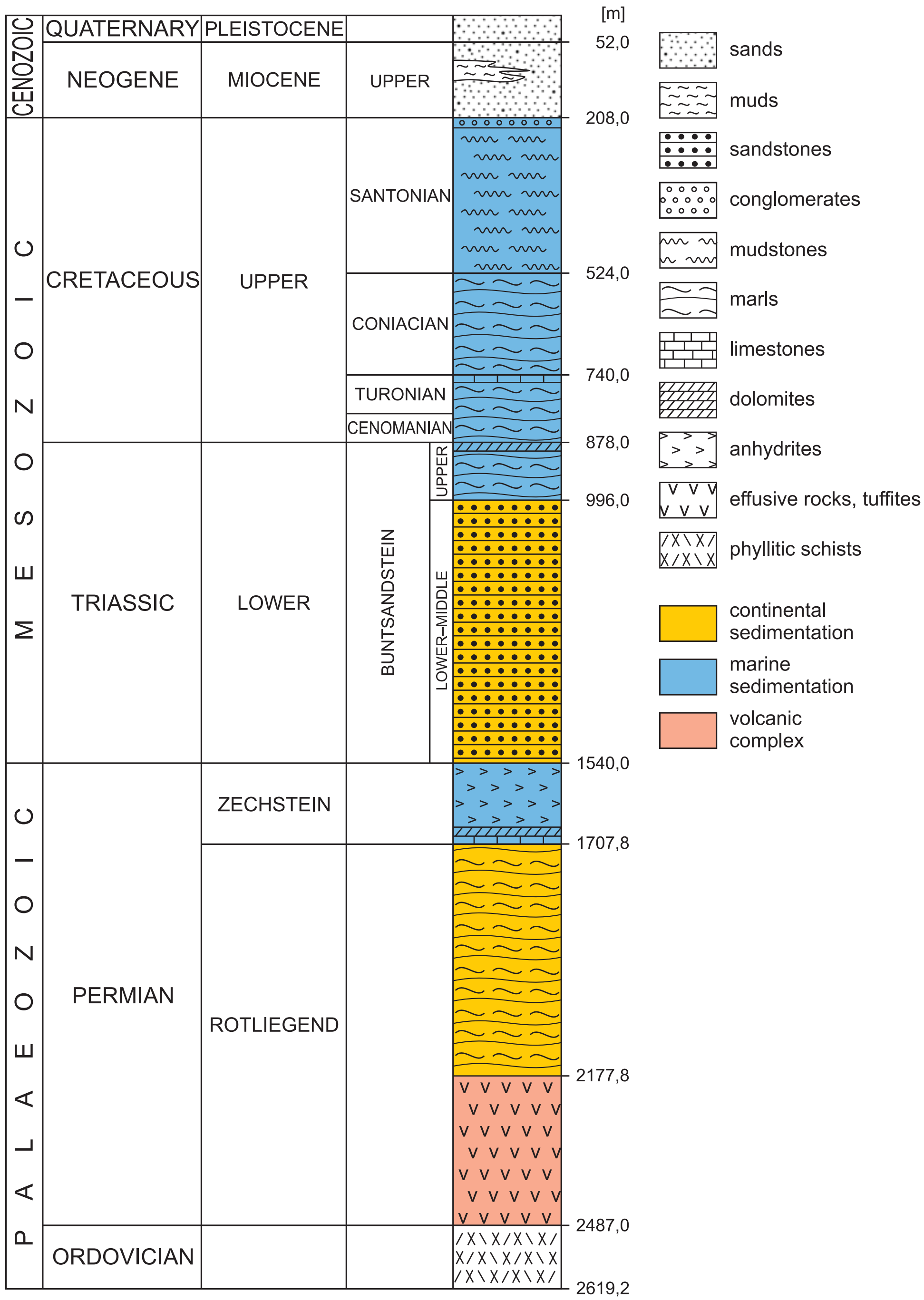


Fig. 11. Simplified section of the Jagodzin 1 borehole

184-m-thick marls, limestones, dolomites and anhydrites; Lower Triassic deposits (Buntsandstein – brick-red sandstones and mudstones, 544 m thick); Roet deposits – limestones, marls, dolomites and anhydrites, with the total thickness of 118 m; and – after a long break in sedimentation that lasted 145 million years – Upper Cretaceous rocks represented by light-coloured quartz sandstones, marls and claystones. The Upper Cretaceous deposits attain a considerable thickness of 670 m, unusual in the Sudetes region. Only in the Węgliniec IG 1 borehole, drilled west of Przewóz upon Nysa Łużycka, the Upper Cretaceous succession is more than 790 m thick.

Although there is no trace of the drillhole today, it is worth to have a look at its vertical geological section. It represents a considerable portion of the history of the evolution of the Earth – practically a period spanning about 300 million years. The type of rocks and their sedimentary characteristics indicate numerous and dramatic climatic and environmental changes. In the Early Permian, under dry and desert conditions, a thick complex of volcanic basalt lavas and tuffs was formed, attaining a thickness of 310 m. One of the most intensive processes of volcanic activity occurred on the planet at that time. However, as early as in the Late Permian, during the sedimentation of Zechstein deposits, a shallow and drying-up marine basin developed in the area of North-Sudetic Trough, where chemical accumulation took place in dry and hot climate conditions. In the Early Triassic, during the sedimentation of the so-called Buntsanstein deposits, a desert climate prevailed after the retreat of the Zechstein Sea. In the foreland of the then already existing Sudetes, a thick series of sandstones, red- and brown-coloured by iron oxides, was deposited in gradually subsiding depressions. Whereas, in drying-up and shallow lakes – red mudstones accumulated. Currently, similar desert lakes that occur across the world are called sabkha.

The sea returned for a short time in the late Early Triassic (Roet), for slightly more than 2 million years. The sedimentary conditions were similar to those in the Zechstein Sea. After that period, a marine regression had occurred in the trough, followed by continental conditions that dominated for a long time. In the Late Cretaceous, about 100 million years ago, the area was again inundated by a warm shallow sea (this process is called marine transgression), in which life flourished. It is worth mentioning that the Upper Cretaceous stratigraphic division into stages is based primarily on the presence of various species of bivalves of the inoceramid group. Distance from the shores of the Cretaceous basin changed several times, which is reflected in the type of sediment representing the individual Upper Cretaceous stages. Sandstones and conglomeratic sandstones represent deposits that accumulated closer to the shore, whereas marls and claystones were deposited further away from it.

Marine conditions lasted until end-Santonian time, for more than 35 million years. The next stage of sedimentation, represented by a 152-m-thick series of sands with interbeds of light-coloured muds and clays, started in the Miocene. These deposits accumulated in river channels and inland lake basins under warm and humid climates typical of the Neogene in this part of the continent. The Quaternary is represented by a 52-m-thick complex of ice-marginal valley sands deposited in a wide valley in front of an ice sheet, in which waters from the melting ice sheet and the Sudetic rivers flowed to the northwest. A cold periglacial climate existed at that time. Strong winds moved sands to form dunes, and ground (by corrasion) boulders, i.e. erratics, carried by the glacier.

The borehole is a perfect example to realise that drillholes are a very important source of information for geologists. They do not only provide a general overview, but also allow us to determine the prospects for mineral deposits linked with specific geological formations.

From Jagodzin, we drive north following the road No. 296 to Ruszów, and then we turn northwest toward Gozdnica. This trip is a branch-off of the guide's main route and goes beyond the boundaries of the geological tourist map (Fig. 10). However, it is worth to be followed. After about 1 km from the church in Ruszów, we turn right to a narrow side road to reach a pit of abandoned brickyard marked in the tourist maps of the Lower Silesian Forest (Bory Dolnośląskie). In front of the pit, there are still ruins of a brick chimney and a few buildings.

In the 1960s–1970s, when the brickyard operated, a very interesting Neogene section was exposed in the pits located to the west of it. Today, they are overgrown with vegetation, the slopes are up to 6 m high, and the deposits are partly hidden under a slump. In places, light grey kaolin clays with white quartz pebbles are exposed here. They represent Pliocene, i.e. the youngest Neogene, deposits that accumulated in vast lakes and river channels from 5.3 to 2.0 million years ago, as evidenced by the study of plant remains. This series, described by geologists as the Gozdnica Formation, overlies the green plastic Poznań Clays representing the Miocene. White quartz gravels of the Gozdnica Formation fill erosional channels once eroded out by waters flowing northward on the surface of a vast palaeodelta of the Pra-Nysa Łużycka River, and incised into the clay basement. From the brickyard pit, species of some organisms have been described, including: mycelium, nuts and fruits of various trees and shrubs, flowering plants, and cryptogams that are typical of the Pliocene.

The Poznań Clays from the Ruszów environs, which show good material properties, have been the basis for the ceramics industry, for which the Nowogrodziec, Zebrzydowa and Osieczów regions are famous. The nearest active mine of ceramic clays is located 1 km west of Gozdnica, which can be reached by the beautiful forest road No. 350 (7.5 km).

Gozdnica is located in the Lubuskie Voivodeship, in the Bory Dolnośląskie Forest. The town developed in the eighteenth century around a pottery-stoneware manufacture. Rich deposits of Miocene clays were the basis for the establishment of Europe's largest ceramic stoneware-manufacture in the second half of the eighteenth century. The production has continued here since the beginning of the nineteenth

Photo 18. Gozdnica – general view of an active opencast mine of kaolin clays (*photo by A. Ihnatowicz*)

century until the present. The main contemporary product of the pottery plant is the clinker bricks of different colours, including yellow and orange.

An extensive pit, 700×550 m in size (Photo 18), is best seen from the road. After obtaining the permission from the authorities of the facility, we can approach the edge of the excavation or even its inactive, eastern, 4–6-m-high wall. Extraction is carried out on a layer of grey clays separated by a layer of green clays, with a total thickness of over 13 m. The clays are composed of clay minerals: kaolinite, illite and beidellite, with an admixture of fine quartz grains. The rock is plastic and feels greasy to the touch. At the top of the deposit, there are light-grey kaolin clays with interlayers of white quartz gravels of the Gozdnica Formation, followed upward by Quaternary yellow-grey sands and gravels. The thickness of the overburden is variable, on average approximately 5 m. The deposit is mined using the so-called selective extraction method – the Poznań Clays, kaolin clays, and sands and gravels are separately mined and accumulated on mine heaps. Old, abandoned pits, mostly overgrown with vegetation and often with ponds, occur to the north of the main active mine.

After visiting the "industrial basin" of clay deposits in the Gozdnica region, we come back to Ruszów, and further on following the road No. 350 through Parowa to Osiecznica. It is worth to have a stop in the small village of Parowa, famous for two active ceramic manufacturers. The pottery tradition of Parowa dates back to the early nineteenth century. Today, its pottery earthenware and stoneware crockery products decorated by hand in the Bolesławiec style can be admired and purchased in the store at the production plant.

5 The pottery and glass industrial basin

Osiecznica–Nowogrodziec region

In Osiecznica, we enter another region of our guide's route. The area between Osiecznica and Nowogrodziec is a real mining basin famous for deposits of glass sands and fine ceramic clays. These deposits are associated with outcrops of rocks representing two Cretaceous stages: Santonian and Coniacian (Fig. 12).

The trip starts in Osiecznica, well known as the birthplace of Abraham Gottlob Werner (1749–1817), one of the founders of modern mineralogy and geology. On the old house (Photo 19) where Abraham G. Werner was born, there is a sandstone plaque. A small museum dedicated to the memory of the geologist is located in the local primary school.

In the western part of the village is the large active glass-sand mine "Osiecznica II", to which access has to be agreed with the mine authorities. Its three-level workings produce fine-grained, light grey and white sandstones of Coniacian age. The rocks are composed of quartz grains cemented by the kaolin groundmass. Their characteristic feature is very poor firmness; the sandstone crumbles when rubbed with the hand. The sandstone deposit is underlain by sandstones and marls of the older Upper Cretaceous stages, whereas the overburden is represented by Santonian, Neogene and Quaternary sands and clays. The rocks are mined by explosions in shallow holes drilled near the edge of the working levels, and then transported by conveyor belts to a modern processing facility. In the plant, glass sands, i.e. those with the grain size of 0.1 to 0.5 mm, are separated using water, however the remaining fractions of the sands are also used. The by-product of the plant is kaolin – raw material for fine ceramics industry.

East of the village, there is the 1.5-km-long Kwisa River gorge. We walk down to the gorge following a path near the house of Abraham G. Werner, and then southward taking a path running along the river. The Kwisa valley has steep slopes, is extremely picturesque, and offers a wide range of geological experiences. In the initial section of the gorge, in the lower part of the valley slope, you can see an outcrop of light grey medium-grained quartzite sandstone (Photo 20) forming a horizontal bed with a thickness of 0.7 m (PD 21). Blocks of the same rock, referred to as the Bolesławiec quartzites, occur along the path and in the Kwisa riverbed. These quartzites formed as a result of silicification of Miocene white quartz sands. This

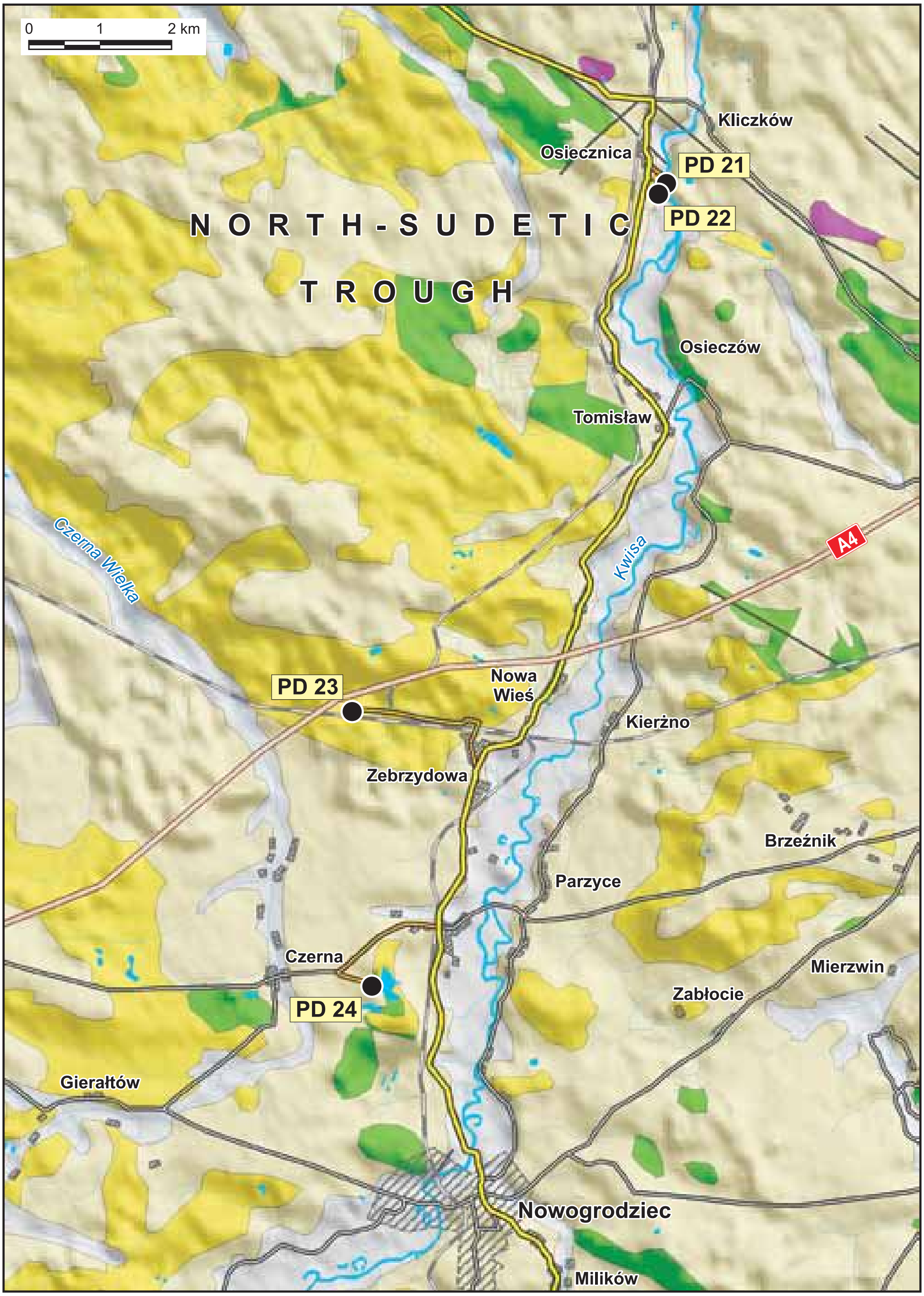


Fig. 12. Geological-tourist map of region 5 – Osiecznica–Nowogrodziec

process, of a mysterious origin, led to the formation of irregular sand beds and quartzite nests within the sands. Due to its pure quartz composition, they are the best raw material for the refractory industry in Poland. These rocks occur in an arcuate belt from Żarska Wieś and Czerwona Woda through Nawojów Łużycki and Nowogrodziec, as far as Brzeźniki, Osiecznica and Parowa.

There is a view that the silica needed to silicify sand was derived from the underlying sands and quartz sandstones, in which it was dissolved in hot water that migrated along fault zones. Intense volcanic activity may have also been a source of the heat. Quartzites from the Osieczów environs, slightly to the south of Osiecznica, yielded a rich assemblage of Lower Miocene flora – tree trunks and branches, imprints of leaves, and fruits of plants typical of the borderland between subtropical and moderately warm climates. They prove the existence of dense forests full of trees and shrubs with large leaves, such as magnolia, walnut tree, laurel tree, maples etc. The fact that the leaves in the Bolesławiec quartzites show no damage proves that the process of silicification occurred almost simultaneously with the deposition of sand.

In the past, 13 quartzite deposits of small reserves were documented, which are now nearly exhausted. The Bolesławiec quartzites are thus a mineral deposit of historical significance.

A little further, in a bend of the river, a 1.3–1.5-m-thick lignite seam is exposed over a distance of 50 m in an erosional undercut. It dips to the north at a small angle (PD 22). Lignite is highly prone to weathering and very rarely appears on the surface; therefore, our outcrop is unique. The seam of lignite coal (Photo 21), which preserves the wood structure, overlies white quartz sands with roots of tree trunks, some of them are up to 1 m in diameter. It is therefore an evidence of the formation of coal deposits in situ, which means in the original place. It is just a fragment of Early Miocene forest that grew here 20 million years ago. Above the coal outcrop, the slope is sprinkled with large quartzite blocks from the exposed overlying bed (some of blocks are several metres in size). A similar geological situation is repeated in the upper level. The second lignite seam occurs between two quartzite layers. These rocks are exposed also on the other, eastern bank of the river.

Before leaving Osiecznica, it is worth to visit the nearby beautiful Kliczków Castle located on the eastern bank of the Kwisa River, which now houses a luxury hotel.

From Osiecznica, we drive southward along the road No. 357, and through Tomisław we arrive at Zebrzydowa. To the west of the village is the only Lower Silesia's active mine of stoneware clays – "Zebrzydowa-West". Its resources are estimated at about 4 million tons. Miocene clays are mined here, composed of kaolinite (up to about 50% by weight), quartz (15%), illite and montmorillonite. Considerable resources of Miocene kaolinite clays in the western part of the North-Sudetic Depression owe their existence to a warm and humid climate that prevailed in

Photo 19. The house where Abraham Gottlob Werner was born (*photo by A. Ihnatowicz*)

Photo 20. Osiecznica – outcrop of Miocene quartzite sandstones, the so-called Bolesławiec sandstones in the Kwisa River gorge (*photo by J. Pacuła*)

Photo 21. Lignite seam exposed on the slope of the Kwisa River valley. Autochthonous trunks of Miocene trees are visible in white quartz sandstones (*photo by J. Pacuła*)

this part of Europe from the Late Cretaceous through the Miocene. In such climate, feldspar-rich rocks, like the Sudetic granites and gneisses, had undergone weathering and the so-called kaolinization, and after washing away of quartz grains from them, they gave rise to kaolin layers (kaolin is a rock composed almost exclusively of kaolinite).

For a geotourist, it may be interesting to visit an already abandoned pit (750×500 m in size) of a former mine of ceramic clays, located to the west approximately 1.5 km away from the active plant (PD 23). To reach the excavation we should turn right from the main road before the railway crossing, and drive along a concrete slab road. The pit is completely flooded with water. Its slopes are 5–7 m high (Photo 22) and expose light-coloured quartz sand and gravel deposits that are the overburden to the clays. At the foot of the slope, a lignite seam is visible in the north-eastern part of the excavation. It attains a thickness of 0.6–0.7 m and is partly submerged in water. Below it, completely under water, there is an outcrop of grey clays with yellow spots, which were the subject of extraction. The bottom of the water body is soft and muddy, and the cloudy water is full of clay suspension. Thus, bathing is not recommended here, but the environs of the pit are covered with a beautiful forest inviting to have a rest.

We continue our tour along the road No. 357 toward Nowogrodziec, and after 4.5 km we arrive at an active kaolin mine named Maria III. White, incoherent, fine- and medium-grained quartz sandstones of Santonian age are mined in its large eight-level excavation. The sandstones are cemented by kaolin and contain intercalations of kaolinite clays. Raw material is processed in a modern plant, where kaolin is washed away from the sandstones; glass and construction sands are a byproduct. The final product looks like small rollers (up to 1 cm) composed of white compacted kaolin dust. Kaolin that is produced in the plant is used in the ceramic industry (for the production of fine pottery products), as well as refractory, paper, glass and cement industries. A visit to the plant is possible only after obtaining a permit. A very interesting object, which lies north of the active mine, is a huge settling tank (Photo 23) in the former mine of ceramic clays Maria II, covering an area of 75 ha (PD 24). It contains tailings in the form of hydrated sludge, discharged into the pit through special pipelines.

A small water body is situated in the northern part of the settling tank, while the rest of its surface, slightly inclined to the west, is covered with grey parched and folded mud. The material from the tank is used for soil reclamation. The whole area is like a huge alluvial fan with a thin layer of muddy sediments, which remains after washing out of clay minerals and flows upon its surface. The Maria III mine is the largest and most important kaolin producer in Poland. The visit to Nowogrodziec

Photo 22. Zebrzydowa – old, flooded borrow pit of ceramic clays. Lignite seam is visible at the foot of the escarpment (*photo by J. Pacuła*)

Photo 23. Nowogrodziec – settling pond in the abandoned mine of ceramic clays Maria II (*photo by J. Pacuła*)

is the final stage of our tour across the Lower Silesian centre of mining of ceramic and glass raw materials. Now, we go to the neighbouring region of Lwówek Śląski – the true capital of the Cretaceous quader sandstones. From Nowogrodziec, we drive on a local road through Gościszów and Niwnice toward Lwówek Śląski.

6 The sandstone world of the North-Sudetic Trough

Lwówek Śląski region

Lwówek Śląski, a charming Lower Silesian town with a long and intricate history (which is normal in this part of Poland), lies within the southern flank of the North-Sudetic Trough. The flank, as is clearly visible in the geological map, is cut by a major fault which is parallel to the trough's axis and called by geologists the Świerzawa–Lwówek Fault. The geological map (Fig. 13) evidently shows a distinct break in the outcrops of Permian and Mesozoic rocks, and a shift in strata. The feature resulting from this deformation is called the Lwówek Śląski half-graben. On the southern flank of this structure, the Lower Permian (Rotliegend), Upper Permian (Zechstein), Lower Triassic and Cretaceous rocks gently dip at 20–25° NE, whereas in the north, the half-graben is cut by a vertical fault. Hence comes the name of this structure.

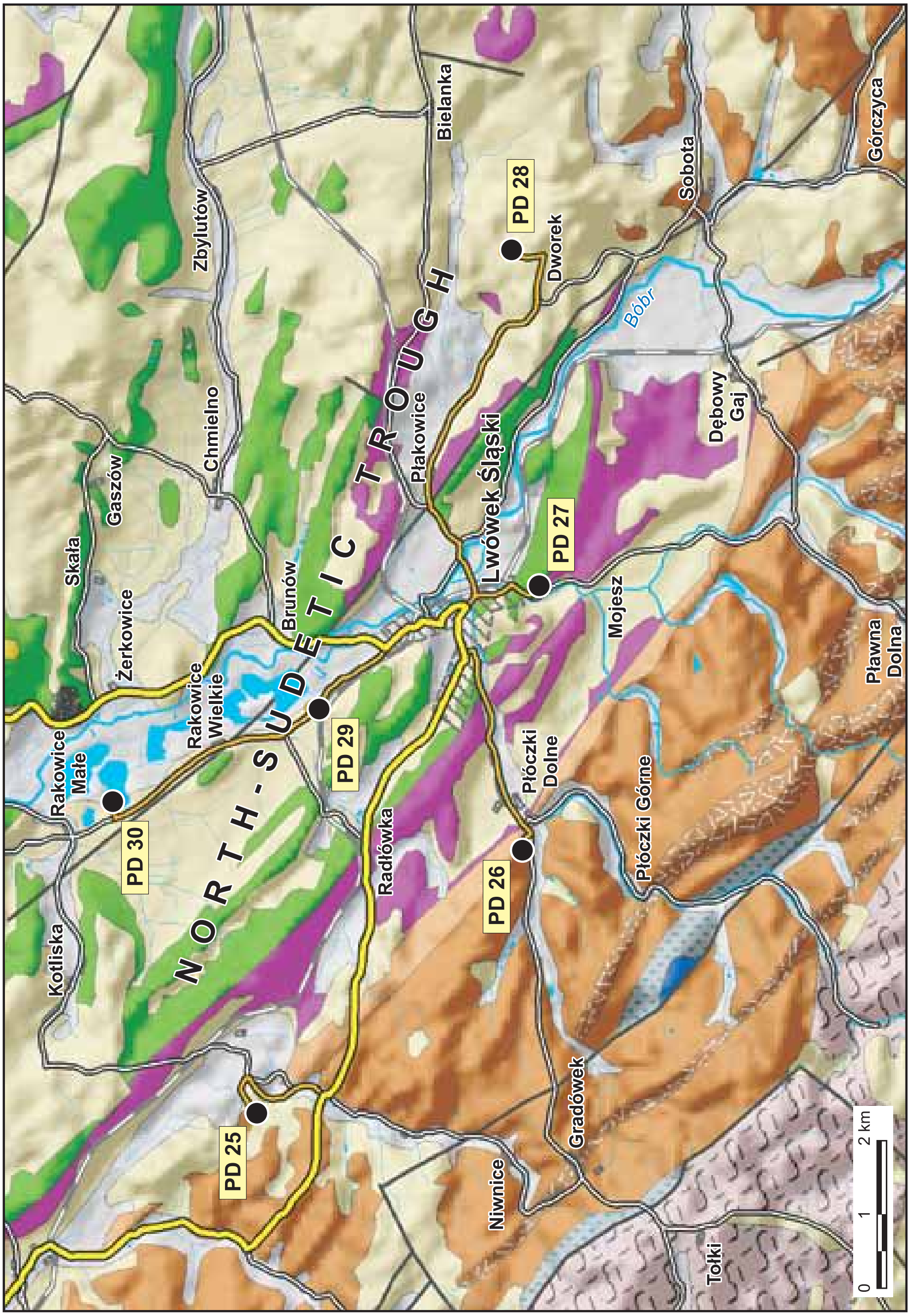


Fig. 13. Geological-tourist map of region 6 – Lwówek Śląski

Thanks to such a geological structure, we can encounter rocks representing all of these formations in the immediate vicinity of Lwówek. A significant role, also in terms of economic geology, is played by younger, Cenozoic fluvial deposits.

The first stop we proposed on our route to Lwówek is at Niwnice, about 8 km before Lwówek Śląski. We turn left toward the village of Nowy Ląd. A long known mine of Zechstein gypsum and anhydrite operates in this area. In the eighteenth and nineteenth centuries, it was an opencast mine, but since 1962 the mining operations have been carried out exclusively underground. A great excavation, located west of the road (PD 25), has remained after the former opencast mining. This is an example of excavation that has been completely reclaimed (Photo 24); former mining levels, separated by steep escarpments, have been levelled and flattened, and the whole area seems to be ready for a new function – maybe as a landfill. The mine heaps still contain many gypsum and anhydrite blocks (the minerals are represented by calcium sulphates; gypsum is hydrated sulphate, unlike anhydrite). Rocks that are extracted from the Nowy Ląd mine are monomineral (composed of single minerals). They were deposited in the drying Zechstein marine basin. The anhydrites from Nowy Ląd are compact, massive, light grey or white with a glassy or pearly luster, whereas the gypsum is characterised by a bright white colour and fibrous structure, and was formed probably at the expense of anhydrites as a result of their hydration.

The gypsum and anhydrite resources are estimated at 18 million tons. In the Nowy Ląd mine, the mineral deposit is accessed through the so-called decline adit, inclined at an angle of 12°, in which mine wagons go down to a depth of 240 m. The deposit itself is a seam with a thickness of up to 20 m, dipping toward the NE at 25°. The mine and the processing plant produce gypsum for industrial and medical

Photo 24. Nowy Ląd – reclaimed pit area of ancient opencast mine of gypsum and anhydrite (*photo by J. Pacuła*)

Photo 25. Płóczki Dolne – recently abandoned quarry of Upper Permian (Zechstein) limestone and dolomite

purposes, anhydrite used in mining to build firebreaks, and anhydrite flour used in the cement, glass and chemical industries.

Today's mine houses a collection of material evidence of the history of gypsum and anhydrite mining, including locomotives and mining wagons, ore scrapers, old roasters, and other machinery, all of them renovated. You can watch them with the permission from the mine management.

After visiting Nowy Ląd, we come back to the highway leading to Lwówek. Just before the village of Płóczki Dolne, near the bus stop, a black-marked path branches off to the left and goes uphill. After passing approximately 750 m, we reach an old, fragmented, 8-m-deep quarry overgrown by the forest. In tourist maps, it is marked with the symbol of caves named Oaza (Oazis), Krótka (Short), Czerwona (Red) and Lisia (Fox's) (PD 26). The quarry exposes grey, thin-bedded, concise sandy limestones (Photo 25). The thickness of the beds ranges from 10 to 20 cm; they are inclined toward the NE at 10–20°. The rocks represent the Zechstein unit, which is the same rock formation, in which the anhydrite-gypsum bed locally appears.

The thin-bedded limestones are overlain by light grey dolomitic limestones. Dolomite is calcium and magnesium carbonate. This rock is of chemical origin and forms in the conditions of drying shallow, salty lakes and lagoons. Its deposition is usually preceded by the precipitation of anhydrite. Undoubtedly, the rocks occurring in this quarry were deposited under a warm climate in a marine environment of shallow shelf basin, not far from its shores, as evidenced by the admixture of terrigenous material. At the bottom of the quarry, shallow oval-shaped “holes” are visible, which however are not true caves. They are probably of karst origin and formed as a result of dissolution of carbonate rocks by water rich in CO_2. At the top of the quarry walls, red fine-grained sandstones are visible at some places. They provide a transition to the next period of geological evolution of this part of the Sudetes – Early Triassic (Buntsandstein – Lower Triassic).

The lithology of the Buntsandstein in the Lwówek Śląski region is typical of the North-Sudetic Trough – these are red fine-, medium- and variably grained sandstones containing thin interbeds of red-brown mudstones. The entire formation attains a thickness of 600 m. The rocks crop out in old quarries along the road from Gryfów Śląski, about 1 km before Lwówek. Sedimentary structures observed in these rocks suggest that they were deposited within wide wandering river channels (i.e. braided rivers) and river deltas, and the transport direction was from south to north, i.e. from the Sudetes.

Lwówek Śląski is a well-known town primarily for the so-called Szwajcaria Lwówecka (Lwówek Switzerland) (Photo 26) – an impressive system of rocks and cliffs composed of the Upper Cretaceous (Cenomanian) quader sandstones. It is located east of the highway from Lwówek to Pławno (road 297), south of the town (PD 27). The Lwóweckie Skały (Lwówek Rocks) are part of a rocky ridge stretching WNW–ESE between the Kwisa and Bóbr river valleys. Such a ridge, formed by rocks that are more resistant to destruction than the surrounding rocks, is called a cuesta. The Cenomanian sandstones rest upon the above-mentioned Lower Triassic red sandstones. However, these rocks are of completely different origin. In the Lwówek Śląski region, about 100 million years ago, there were beaches and a shallow warm sea. Today, the signs of those times are thick- and medium-bedded, light grey and yellowish sandstones with quartz pebbles, 0.3 to 0.8 cm in size, scattered in the groundmass. The individual layers, from 0.5 to 1.5 m in thickness, reveal graded bedding, parallel bedding and cross bedding, indicating their sedimentary environments. Such sedimentary structures are formed in a marine coastal environment within the so-called littoral zone of surges and tides. While looking at the lofty towers and rocky crags of Szwajcaria Lwówecka today, it is hard to imagine those sandy beaches and the sound of that sea.

To have a closer look at these interesting rocks, we should go uphill following a tourist path running across the slope. On the way, we pass numerous rock towers with rocky pulpits, shelves and mushrooms. These structures developed mainly in the Pleistocene, when there was a cold periglacial climate. Recurrent episodes of freezing of water flowing into crevices favoured the physical disintegration of the rocks into blocks. Of considerable importance in this process were natural regular fractures in the quader sandstone. The name of these Upper Cretaceous sandstones, especially Cenomanian and Turonian, originates from the German language. Quader is a German word for an ashlar or a block of stone. Very similar rocks occur in the Góry Stołowe Mountains. From the top of the cuesta, there is a panoramic view of the hilly surroundings of Lwówek.

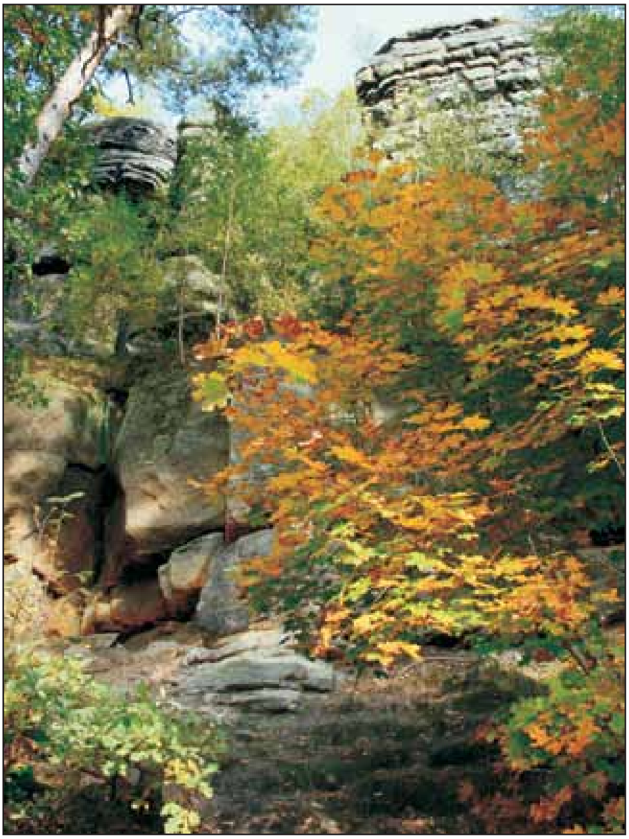


Photo 26. Lwówek, the Szwajcaria Lwówecka region – tors of Upper Cretaceous sandstones (rock pulpits and towers) (*photo by J. Pacuła*)

These sandstones have very good mechanical properties. Its regular joint facilitates the production of rock blocks in many quarries between Lwówek and Bolesławiec, where seven deposits are currently under extraction, and a few others are ready to start mining operations. This region provides half of the total domestic production of sandstone. The historical importance of the Upper Cretaceous sandstones is evidenced by numerous already abandoned pits, as well as by many old medieval buildings made of this rock. Their good carving qualities are proven by the existence of numerous religious figures, as well as penitential crosses set up in many places throughout Lower Silesia.

Different mining traditions, now being only historical, are represented by the fields of gold-bearing gravels in the area east of Lwówek. They can be reached by the road No. 364 leading to Złotoryja. Immediately after leaving Lwówek there is a local road to Płakowice and Dworek. We can park our car after Dworek near the Górniczy Las (Mining Forest) which is marked in the tourist map (PD 28). We do not find here attractive pits, quarries or mining facilities. This forest, however, witnessed a gold mining history dating back to the twelfth century, and lasting for over 100 years. The whole forest is dotted with hundreds of craters and mining heaps; the land was completely furrowed and mixed (Photo 27). The conical funnels are the traces of old collapsed shafts. Milk quartz pebbles, generally poorly rounded and with a diameter attaining 10 cm, can be found on the slopes of the craters and heaps. Gold inclusions were discovered in gravels composed of these pebbles. They were so plenty that, a true gold-bearing centre developed in the thirteenth century in this area as well as in the gold-bearing fields north of Lwówek near Włodzice Wielkie and Skała, and a "gold rush" began. Income from the mining was so significant that several important buildings were constructed in Lwówek: the church of Christ

Photo 27. Dworek, Górniczy Las – note traces of intense exploitation of gold-bearing gravels and sands (*photo by J. Pacuła*)

the King, the town hall with a tower, street paving, and numerous houses. In 1217, Henry the Bearded granted town privileges to Lwówek.

Today's appearance of Górniczy Las (Mining Forest) is an evidence of the tremendous work done by the miners of those times. The decline of gold exploitation fell in the period of 1340–1345 after the discovery of much richer deposits in the area of Wądroże Wielkie. The gold content in gold fields of the Lwówek region ranged from 0.2 to 15 g/t. In total, during the period from the end-12th century to the end-15th century, 30 tons of gold were extracted around Lwówek, Bolesławiec, Złotoryja and Wądroże Wielkie. It was used for striking the Legnica gold florins called "wacławy".

Gold was extracted from a layer of gravels and coarse-grained sands, white or yellowish in colour, overlying Upper Cretaceous sandstones. The gold-bearing series, a few metres thick, is covered by Pleistocene sands and gravels with a thickness ranging from 5 to 10 m. The gold-bearing gravels are probably Miocene in age, and were deposited in rivers flowing down from the nearby mountains, where metamorphic rocks with gold-bearing quartz veins had been washed away. This type gold deposit occurs in the Golejów, Radomice and Klecza regions.

The Lwówek region is also known for late Pleistocene river gravels that accumulated in the Bóbr River valley north of the town. The best-known deposit is mined at Rakowice near the road to Bolesławiec. When driving along the western side of theriver valley through Rakowice Wielkie, it is worth to stop for a moment at a residential tower marked in tourist maps (PD 29). Today, this is an unkempt medieval building, one of the few preserved in Lower Silesia. It served as a safe place of residence of knight families during those uneasy times of the Middle Ages. The tower (Photo 28) is constructed of variously sized, poorly hewed blocks of Cretaceous sandstones. Better-squared sandstone blocks with dimensions of 1.0 × 0.3 m were used in the corners of the tower. The borders of small windows of the tower are also made of sandstone.

Travelling further north, we pass on the right the entrance to a great mine of gravels and sands, the Rakowice mine. Extraction in this mine is carried out under the water, and the mined deposit of gravels and sands is 15 to 25 m in thickness. Its upper part, 5 m thick, contains numerous trunks of fossil oaks, sometimes hindering the extraction process. The width of the Bóbr valley is up to 1.5 km in this area. The course of the river has not been natural for a long time; the river flows through numerous extensive excavations that formed as a result of extraction of gravel and sand. The age of the gravels in the Bóbr valley (Photo 29) is problematic and determined as the Holocene or an equivalent of the youngest, Pleistocene glaciation (North Polish Glaciation).

Direct access to the mine is difficult, but it is worth to go 2.5 km further north to Rakowice Małe. There is a water entertainment centre (Photo 30) developed on the Bóbr reservoir (this is a former gravel pit after extraction of gravels), with water-sports equipment rental (PD 30). Using a boat or canoe, you can go to the "deep

Photo 28. Rakowice Wielkie – medieval residential tower (*photo by J. Pacuła*)

waters" of the Bóbr River and take a closer look at the methods of extraction of crushed stone aggregate. Sands and gravels of the valleys of the Lower Silesian rivers: Nysa Łużycka, Kwisa and Bóbr, have long been the true centre of mining of natural aggregates. Numerous rich deposits of sand and gravel – the raw material necessary in the construction industry – are concentrated in this region. Most

Photo 29. Rakowice Małe – gravels from the Bóbr Rivel valley (*photo by J. Pacuła*)

Photo 30. Rakowice Małe – water recreation centre in an old gravel pit in the Bóbr valley (*photo by J. Pacuła*)

of the active mines use the method of underwater extraction, which reduces surface damages, but also significantly changes the water conditions.

We leave the Lwówek Śląski region, rich in a variety of stone materials, driving the same road toward Bolesławiec. In Włodzice Wielkie, we turn right to the road No. 297, continuing our travel to Bolesławiec, entering the next region of our tour.

7 The underground copper treasure

Bolesławiec region

Taking the road No. 297, after passing the village of Stare Jaroszowice, we drive through a vast forest extending 2.5 km before Bolesławiec. This is another, but unfortunately the most poorly explored, medieval gold-bearing field. On both sides of the road, you can find traces of old trenches, shafts and heaps. The gold-bearing deposit is represented by creamy-white quartz gravels and sands.

We enter Bolesławiec from the south. The town is known as the capital of Lower Silesian pottery. The Bolesławiec Pottery Festival is held here anually. There is also the Museum of Ceramics, which is worth visiting (in 13 Mickiewicza Street).

The Bolesławiec region is located in the northern flank of the North-Sudetic Trough, in the Bolesławiec Syncline that is one of the secondary tectonic units in the trough. In the geological map, the syncline is marked by an arched outline of outcrops of Lower and Upper Permian (Zechstein), Buntsandstein, Muschelkalk and Upper Cretaceous deposits – the latter fill the inner part of the structure (Fig. 1,

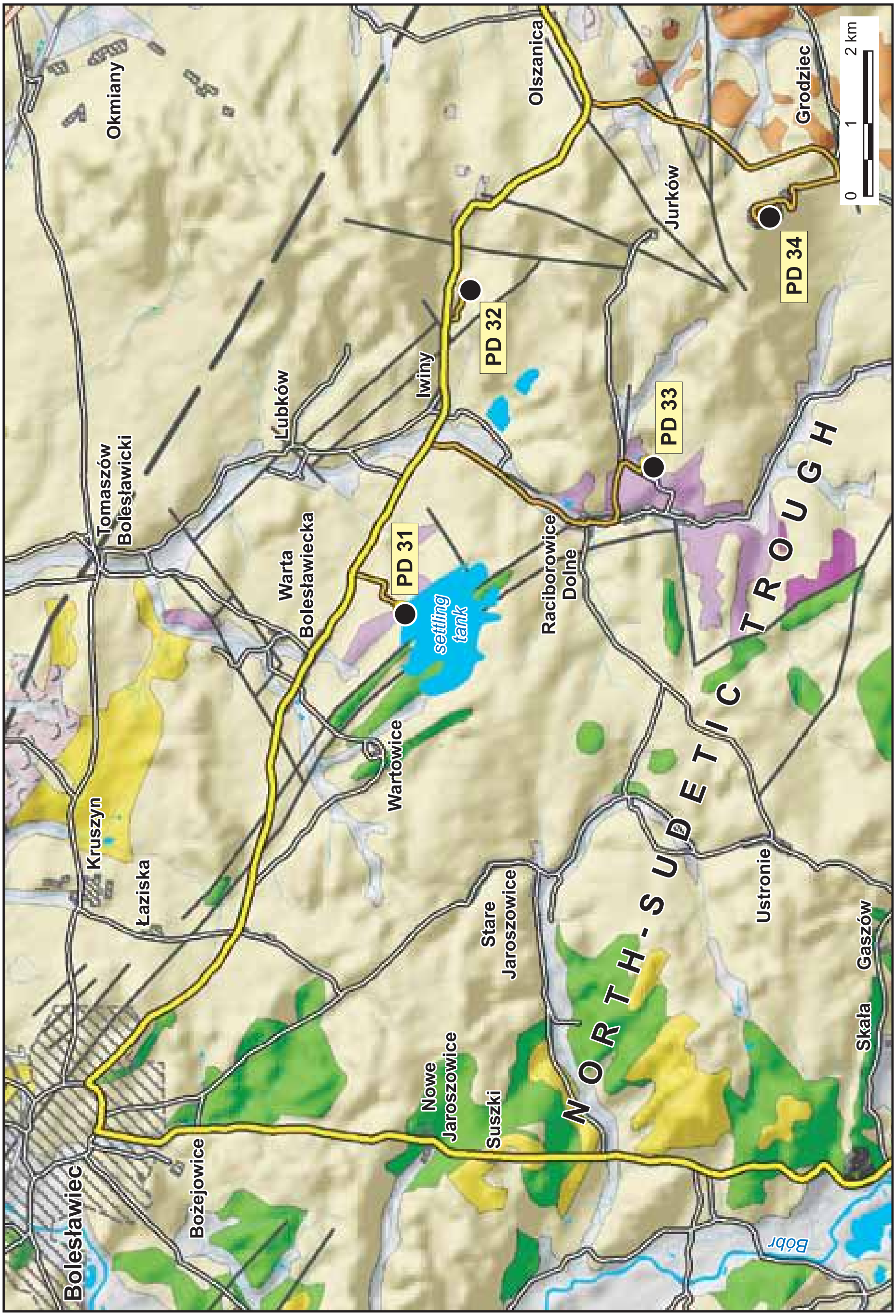


Fig. 14. Geological-tourist map of region 7 – Bolesławiec

14). The southern limb of the Bolesławiec Syncline is intersected by a fault running WNW–ESE longitudinally relative to the axis of the North-Sudetic Trough. In the Złotoryja region, this fault is called the Jerzmanice Fault. Tectonics of the northern limb of the Bolesławiec Syncline is highly intricate. The limb is cut by numerous longitudinal and transverse faults that separate blocks displaced relative to each other. The whole structure has been explored by a number of boreholes, because it is hidden under Neogene and Quaternary deposits. Within some blocks, small outcrops of the trough's epimetamorphic basement appear on the surface. The entire zone coincides with the Sudetic Marginal Fault system that separates along its length the Sudetes rocks from the Fore-Sudetic Block. This fault, so clearly marked further to the southeast, is not manifested in the relief of the Bolesławiec region.

Zechstein deposits of the Bolesławiec region, with their lithology typical of the whole North-Sudetic Trough, were encountered at depths greater than 1,500 m. In the Boleslawiec N2 borehole, drilled northwest of the town to a depth of 1557 m, they were found at 1433.5 m. They directly overlie the metamorphic basement at a depth of 1548.2 m, thus their thickness is 114.7 m. These deposits are arranged into two sedimentary cycles, which means that a similar lithological section is repeated twice. The lower cycle (traditionally called the Werra cycle) consists of marls, marly claystones, limestones, and dolomites that are replaced by anhydrite and gypsum in the upper part of the section. The other, younger cycle (Stassfurt) is reduced (25 m) and composed of marly mudstones, dolomites and a layer of red claystones with dolomite nests, occurring already at the contact with Triassic deposits. Zechstein deposits of this area undoubtedly represent a marginal zone of marine basin, as evidenced by the high proportion of sandstones and marls. In Europe, the Zechstein basin extended from Lithuania and south-eastern Poland to the North Sea and central England.

Zechstein deposits are the source of two important raw materials: non-ferrous minerals, and anhydrite and gypsum. The old, historic copper region of the Bolesławiec Syncline is situated southeast of Bolesławiec between Warta Bolesławiecka and Grodziec. Zechstein deposits occur at shallower depths here and therefore the copper ore was mined in this area as early as in the second half of the 18th century. The Konrad mine in Iwiny started the Zechstein copper ore extraction at two mining levels of 140 m and 180 m depth during World War II. In 1945, the mine was flooded. After painstaking dewatering operations, the ore extraction had restarted in 1953, and from that moment, the Konrad mine worked continuously until the end of 1989, i.e. much longer than the other mines in the North-Sudetic Trough. The facilities of the mine also included shafts at Lubichów north of Iwiny. After the end of copper ore mining in 1975, the shafts have been in use by an anhydrite mine of the Nowy Ląd Mining Plant, active until the present. Today, this is the last active underground mine in the region.

In the record year of 1976, the Konrad mine produced over 1.4 million tons of ore, and the mining operations reached a level of 830 m. In the entire mining period, 213 thousand tons of copper ore concentrate and 757 tons of silver were produced. Thus, it was a fairly large mining company. The mine yield was subjected to the flotation process (which means crushing and grinding the ore), and then washed with water. The flotation process results in a concentrate that contains up to 30% of copper and silver. The rest is a post-flotation waste accumulated in flotation tanks (Photo 31). The Konrad mine had two such tanks: the older one, active until 1971 in Iwiny, and the younger one, called Wartowice. Despite the extinction of mining activities in the Bolesławiec and Złotoryja regions, the area is still considered to be prospective and is of interest to the KGHM (Copper Mining and Metallurgical Company). This applies to the once discovered Wartowice deposit (27 boreholes were drilled in this area in the period 1973–1976) and to the deposits located further northwest.

The Wartowice deposit has an area of 22 km^2 and contains 59.0 million tons of ore (706,000 tons Cu). However, drilling research conducted northwest of Bolesławiec made the ore geologists realize that the Zechstein deposits occur at too great depths in most of the trough, to be of interest to the copper industry. The maximum depth to the base of these deposits was determined as 1,400 m below the ground surface. The only area which could be prospective for new Cu ore resources was between Iłowa in the northwest and Osiecznica (Kwisa valley) in the southeast. This region is located at the boundary of the North-Sudetic Trough

Photo 31. Wartowice – tailings pond of the ancient copper mine Konrad (*photo by J. Pacuła*)

and the so-called Żary pericline. Here, the Cenozoic deposits overly almost flat-lying Middle and Lower Buntsandstein rocks and the lowermost Zechstein deposits of the Werra cyclothem with a thickness generally not exceeding 150 m. This situation creates the possibility of reaching the Zechstein deposits, rich in sulphide mineralization, at a shallow depth. Thus, the history of copper ore mining in this part of Poland is far from the end.

The mining target in the area located southeast of Bolesławiec was the copper-bearing rocks of the lower, basal part of the Zechstein section (Werra cycle). Their mineralization comprises the sulphides of copper (chalcopyrite, chalcocite), lead (galena), zinc (sphalerite, wurtzite), and iron (pyrite), with admixture of gold and elements of rhenium, molybdenum and other. These minerals are scattered in sandstones, limestones, marls and copper-bearing shales. The average copper content in the deposit is 0.5 to 1.7%. The richest mineralization is found in a marly shale layer with a thickness of 0.5 to 2.1 m.

To view the still existing traces of ancient mining activity, we leave Bolesławiec driving on the road No. 363 toward Złotoryja through Warta Bolesławiecka. Immediately behind the village, we turn to a narrow road leading south toward the embankment of the Wartowice flotation tank that is visible from far distance (PD 31). Following concrete steps, we climb the embankment, approx. 30 m high and over 5 m wide at the crest. In front of us, there is a large reservoir of tailings, 2.1 × 1.5 km in size, filled with grey-yellow fine sands that, despite many years after the end of any operations, have not been overgrown with vegetation. In the central part of the tank, a vast shallow pond is visible. The total length of the embankments surrounding the whole area is 3.5 km. Today, this empty and dreary object is used by lovers of racing motorcycles and quads.

After visiting this interesting post-mining object, we come back to the road to Złotoryja to head toward the village of Iwiny. To the south of the highway, there were once a main mine shaft, adit and a processing facility of the Konrad mine (PD 32). Although many years have passed since that time, this property is worth visiting. In the ruins and overgrown side tunnels of the shaft, as well as in a large mine heap, we can see traces of former prosperity of the plant that employed up to 3,000 people. A local reddish mine heap (Photo 32), which is intensely washed out by rainwater (this is a beautiful example of erosion of the so-called rain ablation), is dominated by Buntsandstein (Lower Triassic) rocks: red sandstones, conglomeratic sandstones, and grey marls, i.e. rocks from the overburden of the copper deposit.

Iwiny became famous for a tragic disaster of 1967. On the night of December 13, the embankment was broken and the water and liquefied sediments, with a total volume of 4.6 million m^3, flowed into the valley of the Bobrzyca River over a distance of nearly 19 km flooding the villages of Iwiny, Raciborowice Dolne, Lubków, Tomaszów Bolesławiecki and some other villages. Eighteen people and many

Photo 32. Iwiny – mine heap near inaccessible adits and the main shaft of the abandoned Konrad mine. An example of rainwater erosion (*photo by J. Pacuła*)

animals lost their lives in the disaster, but it was almost unnoticed and little commented upon by the press of the Gomułka period. How different it would be today...

Now we change the rock formation, which we will visit once again in the Złotoryja region, and we head toward Raciborowice. After returning approx. 1.5 km toward Bolesławiec, we turn to a local road, driving approx. 3 km south to the intersection with the road to Jurków that leads, after 750 m, to the entrance to a limestone and marl quarry called Podgórze (PD 33). It is the most attractive outcrop of Muschelkalk limestones in the whole region, exposing light grey thin-bedded limestones and marls (Photo 33). These rocks belong to the so-called platform stage of development of the Sudetes; they generally rest horizontally upon older Buntsandstein deposits. Different types of limestones can be observed here: platy, wavy thin-bedded, porous, thick-bedded with limestone nodules, as well as layers of marl. The rocks contain numerous fossils: ammonites, bivalves, brachiopods, gastropods, crinoids, fish bones and teeth, and foraminifera. The whole range of rock types is the result of sedimentation in a warm sea that was subjected to cyclic deepening and shallowing. It was an epicontinental sea connected with the Tethys basin (in today's Carpathian Mts.) through the Opole region and Upper Silesia.

Tectonic setting of the Muschelkalk succession is extremely interesting. The quarry walls reveal distinct folds and local overthrusts, proving deformation processes that affected the rocks. The folds are characterised by variable geome-

Photo 33. Raciborowice – asymmetrical fold, probably of slump origin (*photo by J. Pacuła*)

tries, ranging from open symmetrical broad folds through asymmetrical ones with clearly inclined axial surfaces, to asymmetrical disharmonic folds (Photo 33, 34). Locally, the layers are discontinuous and there are inclined thrusts usually associated with the fold hinge zone. Some folds occur only within a single layer, with no evidence of deformation in the underlying rocks. Such structures often form even in loose sediment through its gravitational flow down a palaeoslope. The fold deformation processes in Raciborowice were hotly discussed by tectonicians. Because they affected Triassic rocks, and the Cretaceous sequence shows no fold structures, it has been thought that they may have been the result of the so-called Kimmerian orogenic phase that took place during the Late Triassic. According to other views, all the tectonic deformations within the North-Sudetic Trough, both of fold and block (fault) nature, are the result of Laramide (at the Cretaceous/Cenozoic transition) and Early Alpine (Palaeogene, Neogene) movements. They may have been caused by strike-slip movements along WNW–ESE-trending faults.

After visiting the quarry, we come back through Raciborowice Dolne to the road No. 363 leading toward Złotoryja. Approximately 2.5 km after Garnczary, where there was once one of the Konrad mine shafts located south of the settlement, we turn south to a local road toward the Grodziec Castle (Photo 35). This impressive medieval object, visible from afar, stands on top of a mountain (389 m a.s.l.) with the same name (PD 34). Driving the winding forest road to the castle, we can see in

Photo 34. Raciborowice – a quarry of Muschelkalk (Middle Triassic) limestone and dolomite. Broad fold structure visible on the quarry wall (*photo by J. Pacuła*)

Photo 35. Zamek Grodziec – main entrance gate to the castle courtyard (*photo by J. Pacuła*)

a road-cut the rocks on which the castle is built. These are Miocene olivine basalts forming part of a former volcano that arose upon the basement of Buntsandstein and Permian rocks. This typical inselberg of Grodziec Mountain owes its formation to the resistance of basalts to weathering and erosion.

Today, the castle is a Gothic-Renaissance residence, largely reconstructed and protected and one of most beautiful of its kind existing in Lower Silesia. Its oldest parts originate in the twelfth century, the time of Henry the Bearded. The rebuilding took place in the second half of the fifteenth century. The castle was repeatedly conquered and destroyed, and was for the first time adapted to the needs of tourism in the nineteenth century. Its dark castle walls are built of irregular blocks of basalt. The portals, window frames, bay-windows and chimneys are carved from light-yellowish Cretaceous sandstone. The statue of Bacchus, standing at the main entrance to the castle courtyard, is carved from pink Lower Triassic sandstone.

After visiting the castle, we return to the road to Złotoryja (No. 363) to drive toward the town from the north. Now, we enter our next geotourist region.

8 Once famous for mining

Złotoryja region

Złotoryja is an old mining town located on the outskirts of the Sudetes between the Kaczawa Foothills and the Sudetic Foreland. From a geological point of view, the Złotoryja region covers a part of the northern branch of the Kaczawa fold-and-thrust belt and the Permian and Mesozoic deposits of the eastern portion of the North-Sudetic Trough, which rest upon the metamorphic basement (Fig. 15). The latter build a large synclinal structure of this area – the so-called Leszczyna Syncline. In the geological map, it is similar to the previously described Bolesławiec Syncline, and is cut off on the south by the Jerzmanice Fault. The rocks of the Kaczawa basement host iron, copper and silver ores once mined in this area, as well as barite and fluorite. In turn, the Zechstein rocks contain copper ore deposits. Taking into consideration the fields of gold-bearing gravels and sands, it is justified to say that the Złotoryja region's economy was once based on mining. Today, the town refers to the centuries-old tradition by organizing the annual celebration of gold panning. The town also houses the Museum of Gold (2 Zaułek Street) making the visitor familiar with the tradition that has found its reflection in the name of the town.

The town itself is located within a gorge of the Kaczawa River incised into outcrops of metamorphic rocks of the Kaczawa belt. Typical rocks of the Kaczawa belt can be viewed near Złotoryja Lake in a large exposure, 40 m long and 8–10 m high, on the river valley slope (PD 35). We can get there driving down 3-Maja Street

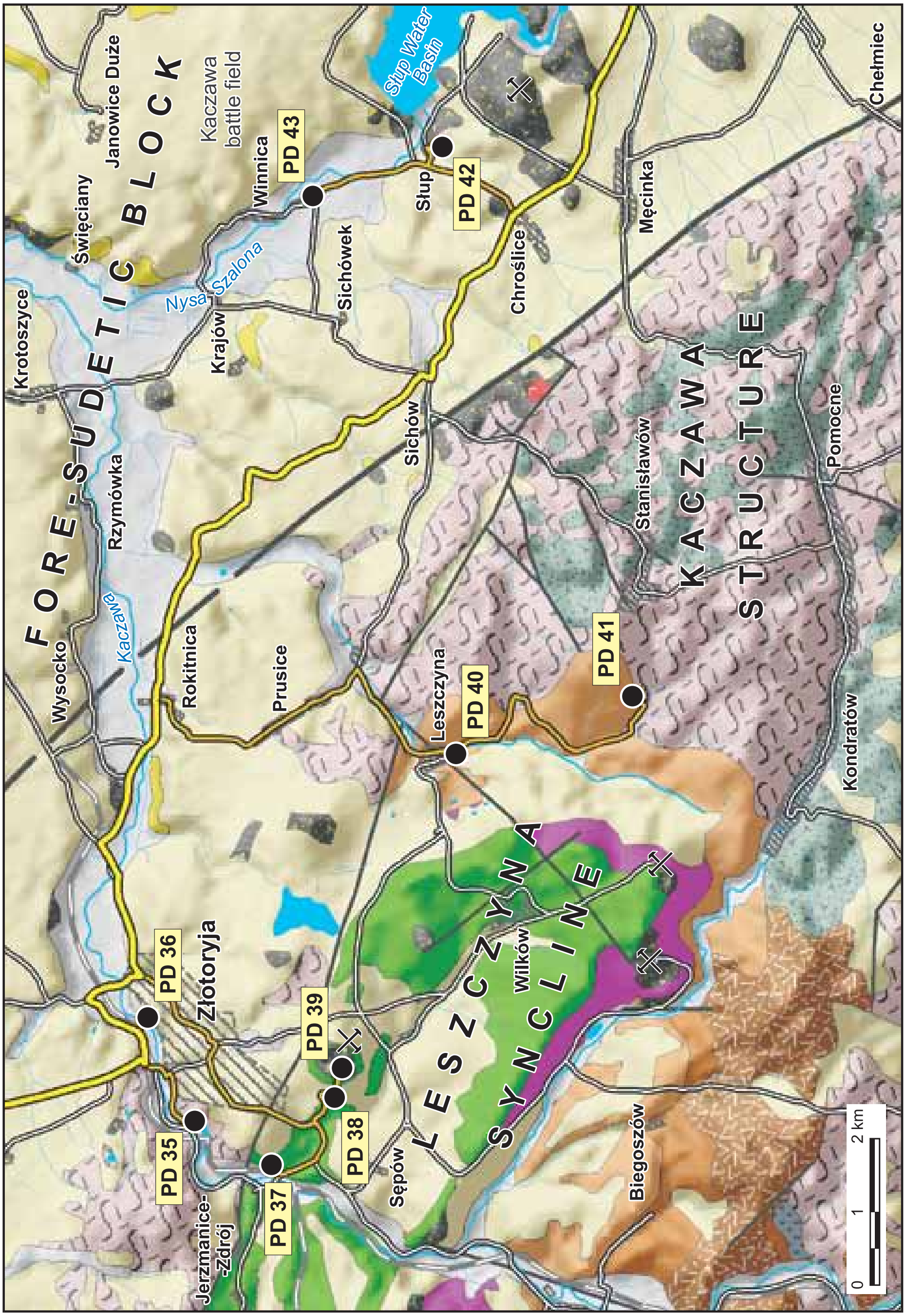


Fig. 15. Geological-tourist map of region 8 – Złotoryja

(road No. 364) along the left bank of the Kaczawa River to a parking lot in front of the reservoir. From this site, we must cross the river by the bridge. The exposure reveals light grey and silver-grey, laminated, fine-grained sericite-quartz schists with numerous lenticular concentrations of quartz, oriented in accordance with metamorphic foliation. This type of rocks formed under greenschist facies conditions from sedimentary rocks: mudstones with interbeds of fine-grained sandstones. Generally, they are usually referred to as phyllites (Photo 36). The parent sedimentary rocks are attributed mainly to the Ordovician age (480–460 million years ago), while the regional metamorphism, synchronous with fold deformation, occurred during the Variscan epoch in Late Devonian–Early Carboniferous times. Phyllites observed in the outcrop are strongly folded: the folds are irregular and asymmetric, and their axes are inclined NE at an angle of about 30°.

Photo 36. Złotoryja – outcrop of folded Kaczawa phyllites near Złotoryja Lake (*photo by J. Pacuła*)

In the lower part of a phyllite exposure located further to the south, there is an entrance to a small cave called Lisia Jama (Fox Cave) visible on the slope directly above the reservoir.

Quite different metamorphic rocks are exposed in the northern part of the town around and within the Aurelia Gold Adit (Photo 37) that is open for tourists. To get there, we come back along 3-May Street to the bridge over the Kaczawa, then following the streets of Garbarska and Stroma to Bolesław Chrobry Street (PD 36). Opposite the entrance to the adit, there is a parking lot. Despite its attractive name, the adit has nothing to do with extraction and prospect for gold. It was forged in the Kaczawa schistose diabases with intercalations of greenschists, and runs along quartz veins with ore minerals, especially of copper. The adit is approx. 100 m long and has a number of side branches and a variable height ranging from 1.2 to 2.5 m. Vertical shafts run upward from the horizontal tunnels; one of them is 27 m high and continues up to the ground surface. In some lateral branches, granite-pegmatite nests are visible on the rock walls, being an evidence of the impact of a granite body that, however, has not been observed on the surface in this part of the Kaczawskie Foothills.

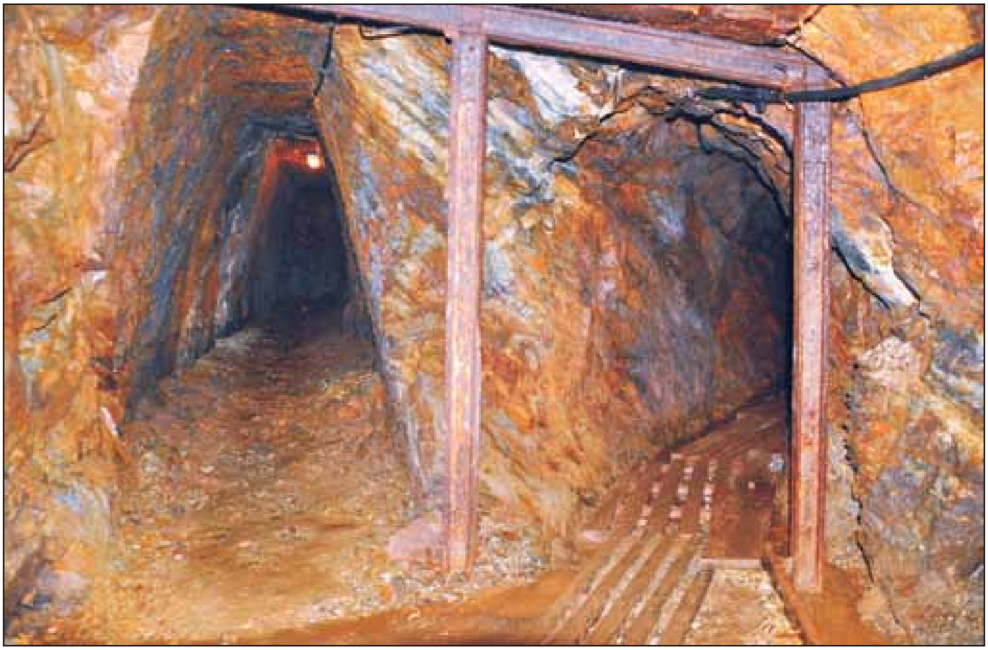


Photo 37. Złotoryja, The Aurelia Mine – branching underground mine tunnels. Efflorences of iron hydroxides are visible on greenschist walls (*photo by A. Ihnatowicz*)

The diabases form oval or lenticular intercalations in phyllites, and are mapped on the geological map. These are volcanic rocks of basalt lavas and tuffs, metamorphosed jointly with the surrounding phyllites. Now, they are composed of actinolite, chlorites, epidote or zoisite, with albite and quartz. These are massive dark green-grey rocks, densely and irregularly fractured. More strongly deformed varieties show directional textures, passing into schists of the same mineral composition.

Although gold has never occurred in the Aurelia adit, the epimetamorphic rocks of the Kaczawskie Mountains, especially quartz veins occurring within them, were the source of native gold that formed secondary gold deposits, i.e. placer gold deposits, as a result of long-term processes of weathering, erosion and deposition of sands and gravels in the mountain foreland. In the Middle Ages, the Złotoryja region was well-known for many mines of this mineral (native gold is a mineral). Today, few traces of the former mining activity are scattered in the form of mine heaps and collapsed small shaft craters. They occur in the east and northeast of the town, already within the Fore-Sudetic Block, on both sides of Legnicka Street toward Kopacz. They are also found on the Góra Mieszczańska mountain in the southern edge of the Kaczawa valley and in the northern edge of the valley between the historic bridge in Legnicka Street and the old gravel pit near the railway crossing east of Rokitki. The Góra Mieszczańska mountain is now a broad wooded and flattened hill with a relative elevation of approximately 40 m.

On the surface, Pleistocene deposits are dominant: glacial tills and glaciofluvial sands and gravels. Pliocene quartz sands and gravels form a gold-bearing layer at a depth of 20–30 m under the hill, whereas at shallow depths or on the surface they appear in erosion scarps of the valleys of the Złoty Potok Stream and the Kaczawa River. The same gold-bearing layer occurs at a shallow depth in the lower terrace of the Kaczawa River, on its left bank. A characteristic feature of these deposits is the presence of milky quartz pebbles, 0.5 cm (gravel) to as much as 20 cm in size. Milky or yellowish quartz pebbles with characteristic oily lustre often have small pits and cavities on the surface, which form as a result of removal of less resistant minerals by leaching. This makes them easy to identify. However, there is little hope to see a golden tiny flake of gold on this background with the naked eye. The rock material, in addition to the dominant quartz, contains fragments and blocks of the Jizera granitogneisses and Karkonosze granites, phyllites and Cretaceous sandstones. The presence of rocks originating from the Izera–Karkonosze area proves that the gold in the sands and gravels was derived from weathered covers of its primary deposits. Milky quartz pebbles can be found in an undercut along K. Miarki Street and its extension, as well as in the fields of the lower terrace of the Kaczawa River, on its northern bank. As you pick up a field stone, remember the long-forgotten miners and their hopes on their way to work, and the Lower Silesian gold rushes.

Both of the regions along the Kaczawa banks were areas of the earliest gold exploitation that started already at the turn of the eleventh century. In 1211, town privileges were granted to the mining settlement. The modern town of Złotoryja was born in this way. In its heyday, from 20 to 50 kg of gold was mined per year in this area. Not only the Legnica dukes, but also the Cistercian Monastery in Lubiąż and the Foundation of Wrocław Cathedral were the mining shareholders. Gold was extracted from sedimentary rocks through the washing of crushed gravel in wooden troughs, which is the classic method used until today. Sometimes, also the bottoms of watercourses were lined with sheepskins. Fine grains of gold were captured in the fur, and then the skins were dried and incinerated.

The gold of Złotoryja was not forgotten also during later times. Exploration work, although without much success, was conducted here in the eighteenth and mid-nineteenth centuries. It is estimated that a total of approximately 5 tons of gold were mined out over the centuries in this region.

Now, it is time for a complete change of geological formations. Continuing from Złotoryja southward, the road No. 364 runs along the Kaczawa River to reach Jerzmanice–Zdrój, where we can see a massive rock wall just behind the railway track. The wall is 25–30 m high and 300 m long. This is the so-called Krucze Skały rocks, one of the most spectacular outcrops of Upper Cretaceous (Middle Turonian)

Photo 38. Krucze Skały rocks – rock wall in an old quarry of Upper Cretaceous thick-bedded sandstones (*photo by J. Pacuła*)

sandstones in this part of the Sudetes (PD 37). The massive vertical rock wall (Photo 38) of a single crack is composed of coarse- and medium-grained yellow-grey sandstones. The extremely thick sandstone beds lie almost horizontally, and the thickness of some beds is up to 6 m. The beds show graded bedding (i.e. the material at the bottom of the beds is coarser than in their upper parts) and traces of ripplemarks, i.e. sand ripples that formed at the foot of beaches along a shallow-water sandy coast. The principle of geological uniformitarianism clearly works in this case. Knowing the present-day sedimentological characteristics of the sandstones, we can be sure that they were formed close to the shore of a Cretaceous sea at the interface of storm waves and beaches, in a world where no man could enjoy the charm of the beaches and the warm sea. It is worth to think about it as we look at the sandstone cliff face...

The sandstones show the orthogonal joint set, which means that vertical fractures in the rock running at the azimuths of 340° and 80° are perpendicular to each other and accompanied by horizontal fractures. These fractures divide the rock into big blocks, several metres in size. Many of their surfaces are covered by striae and steps, proving that the rock complex was deformed after lithification (turning into a solid rock). Striae and traces of horizontal displacements are visible also on the bedding planes. These structures formed as a result of Laramide and Late Alpine block deformation. At the base of the rock face, near a local road, there is a spring enclosed by sandstone blocks with a German inscription “Felsenquelle”, which means Rock Spring (Photo 39). The Upper Cretaceous sandstones from Jerzmanice-Zdrój fill the central part of the Leszczyna Syncline (Trough).

From the Krucze Skały rocks in Jerzmanice-Zdrój we travel a local road toward the southeast to meet after 400 m the road No. 328. We turn to Złotoryja to reach a parking lot in a forest at the bend of the road. Here starts a green-marked walking trail. After a 40-minute walk, we meet a path running near the edge of the Wilcza Góra mountain active basalt quarry. Earlier, on the hill slope below the forest road, we passed exposures of horizontally lying Turonian quader sandstones with interesting weathering cavities described in tourist maps as the Wilcza Jama (Wolf's Pit) (PD 38) (Photo 40).

The quarry (PD 39) exposes basanites, which are a variety of basalts. These are black very fine-grained (aphanitic) volcanic rocks, whose massive groundmass is composed of olivines, clinopyroxenes, feldspars and nepheline with fine, unevenly distributed, sometimes directionally arranged olivine and clinopyroxene phenocrysts. This orientation indicates the direction of lava flow. Basanites from the Wilcza Góra mountain form a vertical volcanic conduit with a diameter of about 500 m, piercing the underlying Permian, Triassic and Lower Cretaceous sedimentary rocks of the Leszczyna Syncline; hence, the basanites contain detached blocks. Another characteristic feature of these rocks is the presence of xenoliths of upper mantle rocks. These are peridotites – very dark (ultramafic) rocks composed mainly of olivine

Photo 39. Rock spring near a quarry in Jerzmanice-Zdrój (*photo by A. Ihnatowicz*)

and pyroxene. On Wilcza Góra mountain they are represented mainly by two varieties: harzburgites and lherzolites. The presence of xenoliths indicates that the basalt magmas originated at mantle depths, i.e. approximately 55–60 km.

Radiometric age determinations (K-Ar method) show that these basanites are about 20 million years old and formed in the Early Miocene during an epoch of intense volcanic activity in this part of Europe. The development of contemporary traces of this tempestuous "fire period" in the Kaczawskie Mountains and Foothills is covered by a geotourist project called "The Land of Extinct Volcanoes".

The most striking feature of the basalts is their very well-developed columnar parting. Hexagonal, regular basalt columns represent in fact the thermal joint set that forms at the stage of lava cooling. The most beautiful example of columnar parting, the so-called Basaltic Rose, has been protected as a nature reserve since 1959 (Photo 41) and can be admired in the upper part of the excavation.

Photo 40. Złotoryja, Wilcza Góra mountain – caves in Upper Cretaceous sandstones (*photo by J. Pacuła*)

Photo 41. Złotoryja, basalt conduit in the Wilcza Góra mountain inanimate nature reserve (*photo by J. Pacuła*)

Photo 42. View toward the NW from the slope of Wilcza Góra mountain over Grodziec mountain (*photo by A. Ihnatowicz*)

The extraction of basalts in the quarry comes to an end due to the depletion of resources, currently estimated at approximately 2 million tons. In the northern part of the excavation, Upper Cretaceous sedimentary rocks locally crop out from beneath the basalt cover. Upon completion of mining operations in the quarry, a geological heritage park is to be established – another tourist attraction in the region.

We drive on a local road through Sępów, Wilków and Wilków-Osiedle toward Leszczyna. South of Wilków, on the slopes of the Trupień and Łysanka hills, there are two active basalt quarries with the common name of Krzeniów deposit. In this area, we also encounter basanites with the estimated age of 18.7–19.6 million years. Both the geological position and the petrographic nature of these rocks are very similar to those of Wilcza Góra mountain.

We approach Leszczyna from the north. This place, situated within wooded picturesque hills, is the former centre of copper mining and metallurgy, whose production was based on the Lower Zechstein deposits. Today, there is a copper mining heritage park in this area called Ciche Szczęście (Stilles Glück) (PD 40), in which the mining tradition of the region and reminders of old mines and smelters are presented. Tourist events, including the famous "Dymarki Kaczawskie" event demonstrating the old methods of metal smelting to the viewers, are also organized. At the entrance to the park are two restored 19th-century lime kilns that were used formerly for lime-burning from the Zechstein limestone cropping out above on the slopes of the Duży Młynik mountain (Fig. 16). In the past, the limestone was transported from the quarry to the top of the lime kilns through a transport bridge.

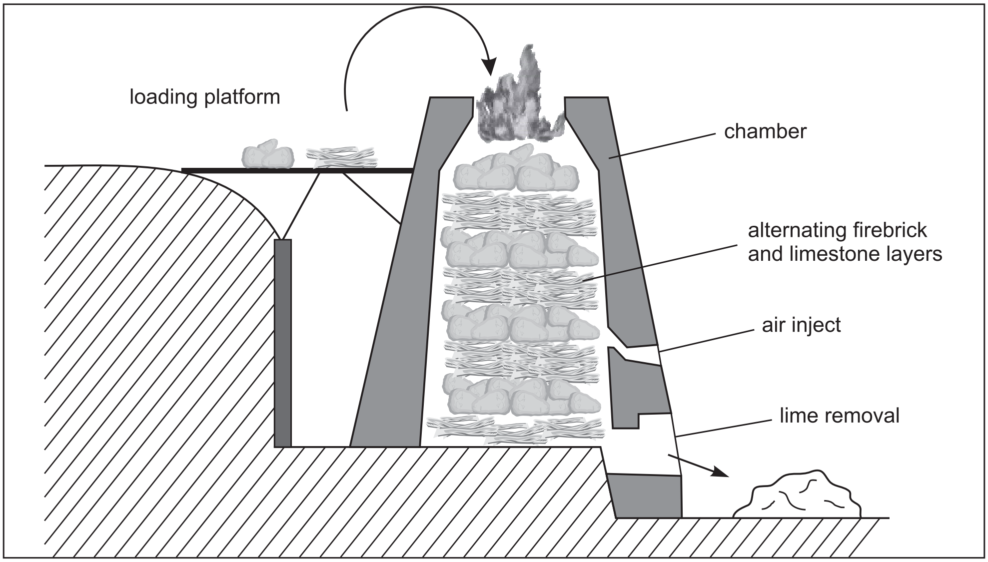


Fig. 16. A scheme of lime kiln

The history of lime kilns and the method of lime-burning are shown on nearby standing board No. 1 (Photo 43). From the heritage park on the Duży Młynik hillside runs a 3.5-km-long education path with the difference in elevation of 80 m, provided with a set of 17 more thematic information boards. They are distributed in places associated mostly with exposures of rocks and relics of ancient mining and metallurgy. It is worth to walk the path for around 1.5 hour.

The slopes of the hill are dotted with a number of outcrops and abandoned quarries presenting the Permian section and its metamorphic basement composed of the Kaczawa phyllites. The Permian section consists of Lower Permian red sandstones (Rotliegend) and Upper Permian sedimentary rocks (Zechstein). The Lower Permian sandstones pass gradually upward into light grey sandstones called traditionally the Weissliegend, only 1.5 m thick. This discolouration results from the impact of the shallow and warm "Zechstein" sea on the sandstones lining its floor. Above, overlying the Weissliegend, there are limestones, dolomites and marls of the lower Zechstein with a total thickness of 25–35 m (Werra cyclothem), which sharply contact with the underlying basement. These rocks host the copper mineralization. At the top, red and variegated sandstones with siltstone and claystone interbeds are observed again, which correspond to the upper part of the Zechstein section. The rocks occurring in the eastern part of the Leszczyna Syncline were deposited in the marginal part of marine basin, where there was a clear effect of material supplied from land. The dolomites are the result of sedimentation in lagoons, too.

Photo 43. Lime kiln in the Ciche Szczęście (Stilles Glück) copper mining and smelting heritage park in Leszczyna (*photo by J. Pacuła*)

Ore mineralization occurring in the lower Zechstein rocks includes thin interbeds of limestones and marls with an increased content of copper, lead and zinc. The so-called lead-bearing marls overlie a layer of copper-bearing marl. The average copper content is 0.5–0.6%, locally less than 1% by weight. The interest in copper ore mining dates back to the fourteenth century in this region, when Wacław, the Duke of Legnica, issued the first charter for copper ore exploration and mining. The first smelting of this metal took place already in 1429, and in the sixteenth century, several mines operated in this area. However, it is difficult to compare the mines of those times with what we are accustomed to today. In 1738, 12 miners worked in two mine adits, and three persons were engaged in the ore enrichment process. In 1863, a larger mine and the Ciche Szczęście smelter started production. A pre-existing adit was used for this purpose, and some new ones were made. Three furnaces operated in the smelter, and the so-called copper stone was the semi-finished product containing 47% of pure copper. It was then processed in smelters of Saxony to produce pure copper and silver.

A number of old mining objects can be viewed along an educational route. This route starts approximately 500 m south of the heritage park, where the trail goes up from the highway. What we see here are the remnants of the Ciche Szczęście smelter. Board No. 2 explains the principles of smelter operation, construction of furnaces, and the derived products. A clear trace of smelting operations is an accumulation of black porous slag. It is practically the only trace of production of the smelter closed in 1883.

The route continues uphill to the rock wall with a length of 120 m and a height of up to 8 m, which exposes lower Zechstein limestones and dolomites. The geological setting is explained in board No. 3 presenting also the Zechstein succession profile in the trough. Loose blocks of rocks, scattered at the foot of the wall, reveal encrustations of blue azurite and green malachite. These are secondary copper minerals that formed as a result of weathering of bornite, chalcopyrite and chalcocite, that is, the major primary minerals. Board No. 4 is located near the ruins of a lime kiln built in the early nineteenth century. It explains the methods of lime-burning from the Zechstein limestone mined in nearby quarries. Continuing our trip to the top, we come to the objects related to the much younger geological and mining activities. Board No. 5 – "Szybik poszukiwawczy" (Small exploration shaft) – is devoted to the prospecting work conducted throughout the Leszczyna Trough in the 1930s. As a result of the work, a copper mine was constructed. After World War II, its production was continued by the Lena Mine. In the period of 1941–1943, its annual production was approximately 750 thousand tons of ore. The plugged mine adit located near the board was driven up to the level of copper-bearing marl; its purpose was to allow ore sampling.

Following the forest path we come to board No. 6 – "Czerwone Wzgórze" (Red Hill), and board No. 7 – "Wapień podstawowy" (Basal Limestone), where we can see old quarries of lower Zechstein limestones – the so-called Basal Limestone (Photo 44). Their name is due to the position under the copper-bearing series. The limestones are light grey, massive, concise, distinctly bedded rocks, and the thickness of the individual beds is variable, ranging from 5–10 cm to over 1 m. The limestone beds gently (15°) dip toward the southeast, i.e. toward the axis of the Leszczyna Syncline (Trough). The rocks seen along the educational path represent the coastal part of the Zechstein marine basin that stretched from Lithuania through Poland and further to the west.

A special feature of this coastal zone is ore mineralization, the richest one in the Lubin and Głogów region (board No. 10). Board No. 11 – "Widok" (View) is situated near the flat top of the Duży Młynik hill. From here, we turn west toward numerous traces of former underground mining. They are illustrated in board No. 12, which also explains the medieval methods of shaft sinking and ore extraction. Mining operations started in this area probably already in the thirteenth century. It is evidenced by the traces of sinkholes above collapsed entrances to mine tunnels, and by numerous overgrown mine heaps. The upper Zechstein is represented by pink and grey, bedded arkosic sandstones. In the past, they were mined in an old quarry that we passed on our route. Detailed information about the excavation and the rocks

Photo 44. Leszczyna – a quarry of the Zechstein Basal Limestone on the slopes of Duży Młynik hill (*photo by J. Pacuła*)

can be found in board No. 13 “Kamieniołom piaskowca arkozowego” (Arkosic sandstone quarry). From there, we go down the slope to get to board No. 14 “Sztolnia «Charakter»” (Mine Adit “Charakter”). Nearby is visible a longitudinally oriented wooded ditch leading to a collapsed tunnel. The tunnel is one of the oldest mining objects on the hillside. It was probably used already in the thirteenth century, subsequently rebuilt many times, and was last in use as a part of the Ciche Szczęście Mine at the end of the nineteenth century.

Underneath the entrance to the adit is a mine heap of the “Charakter” adit, covered with numerous marl and limestone blocks, some with minute malachite and azurite encrustations. Board No. 15 “Margle miedzionośne” (Copper-bearing marls) presents and provides the characteristics of copper-bearing deposits at Leszczyna. The educational path turns to the northwest, climbing again uphill to board No. 16 “Kopalnia Ciche Szczęście” (Stilles Glück Mine). A visible trace of the old mine is a ventilation shaft protected by a wooden canopy with the reconstructed winch. In the summer 2014, the whole structure was damaged and threatened to collapse. Nearby, we can see other traces of the mine, including mine heaps at the mouth of the adit. According to the information on the board, the Ciche Szczęście mine extended underground across most of the Duży Młynik hill area.

The last object of our route is an old forested quarry of middle Zechstein bedded limestones and dolomites, with the rock walls attaining a height of 15 m. These rocks overlie the copper- and lead-bearing marls. Up the section, the proportion of dolomites increases. The bedding planes and fracture surfaces in the limestones and dolomites show thin encrustations and, occasionally, tiny crystals of azurite and malachite – the secondary copper minerals. In turn, iron and manganese, composing the ore minerals, form multi-branching efflorescences on the fracture surfaces, referred to as dendrites. The local geological setting is presented in board No. 17 "Kamieniołom wapienia dolomitycznego" (Dolomitic limestone quarry). This is the last point of our journey into the depths of geological time, to the world existing some 260 million years ago, and to the world of ancient miners and smelter workers.

On the other side of the road, opposite the heritage park, on the left bank of the Prusicki Stream, are the remains of buildings, mine adits, a flotation plant, and a mine shaft of a German mine from the 1940s, as well as of the later, Polish mine Lena ultimately closed in 1973. From the Leszczyna heritage park, the red-marked tourist trail leads to Stanisławów – once an important centre of barite and fluorite mining. This deposit was discovered in the 1950s and extracted in the period of 1957–1997 by the Stanisławów Mining Plant. Underground extraction reached here a depth of 200–250 m. The production ended due to economic and organizational reasons, although there are still considerable resources. The plant for ore enrichment was located in Boguszów, near Wałbrzych, approximately 100 km from the mine.

The Stanisławów deposit formed a bunch of branching veins with variable thicknesses ranging from 0.5 to 8.0 m, however commonly not exceeding 2−3 m, and about 1,300 m long, usually arranged in accordance with the orientation of surrounding epimetamorphic rocks. Continuity of the deposit has been proven by boreholes drilled to depths of 650−800 m. The veins run NW–SE and are inclined at an angle of 70° toward the SW. The estimated resources of the deposit are approximately 10 million tons, of which slightly more than 1 million tons was extracted.

The main components of the Stanisławów deposit are barite (65–85%), fluorite (5–20%) and quartz (5–10%), which form ribbon-like bodies, generally parallel to the vein walls. Secondary components include siderite (manganosiderite), calcite, hematite, galena, chalcopyrite, pyrite, marcasite, sphalerite and tetrahedrite. In the ore mineral assemblage, only goethite and manganese minerals form larger aggregates. Today, barite blocks, some with ore minerals, can be found on levelled and overgrown mine heaps. There are no remains of the mine now and the only remaining object is a mining truck with the inscription "Stanisławów Barite Mine", standing near the road from Sichów to Stanisławów.

About 500 m to the east, the red-marked trail leads us to ruined stone kilns and remnants of buildings (PD 41). In tourist maps, this place is marked by lime kiln

Photo 45. Ruins of an old furnace in Stanisławów (*photo by A. Ihnatowicz*)

ruins (Photo 45). However, because there are numerous slag blocks (similar to those at Leszczyna) scattered around these objects, and crystalline limestones of the Kaczawa epimetamorphic rocks do not crop out in this area, it is likely that these are the ruins of furnaces once used to burn the ore.

A little more to the north, near the tourist trail from Leszczyna to Stanisławów, on the northern slope of Rosocha (465 m a.s.l.), there are signs of extraction of hematite veins. In the past, the Wilcza hematite deposit was mined in this area, composed of two veins: southern and northern. The southern vein with a variable strike from E–W to NE–SW, was explored and exploited to a depth of 175 m. It had a variable thickness of 1.5–7.0 m. The northern vein is oriented N–S and dips westward at 70–90°, obliquely with respect to the orientation of the Kaczawa phyllites and metadiabases. The actual length of the vein is 585 m, of which only its thicker sections (0.5–3.0 m thick) were suitable for mining.

The main components of the veins are hematite, siderite, ankerite dolomite, barite and quartz, with minor amounts of pyrite and tetrahedrite. The extracted ore contained 40–50% Fe and 1.1% Mn. Secondary minerals are represented by goethite and lepidocrocite. The Wilcza hematite deposit was exploited in the years 1851–1855 and 1860–1867. Attempts to resume the iron ore mining were undertaken during World War II. Today, close to the road from Leszczyna, we can see the outlets of two brick-walled mine adits. Small lumps of hematite, siderite and barite, sometimes with chalcopyrite and tetrahedrite, can be found on the mine heaps.

The entire area between Stanisławów, Chełmiec and Męcinka, composed of metamorphic rocks – phyllites, greenstones and diabases, was once a centre for mining of metal ores, active intermittently between the turn of the fifteenth century and the second half of the nineteenth century. The mines were concentrated mainly west of Chełmiec in the Starucha valley, where sulphide ores occur in siderite-barite-quartz veins. These veins run generally NW–SE and dip at an angle of 60–70° SW. Fourteen ore veins have been documented in this region; three of them are several hundred metres long. In their surroundings there are usually different varieties of Kaczawa phyllites, as well as frequent elongated lenses of diabases.

The major minerals in the diverse mineral composition of the veins are quartz and siderite, accompanied by barite and dolomite. Vein ore mineralization is represented by chalcopyrite, galena, pyrite, sphalerite, tetrahedrite, gersdorffite, cobaltite, bismuthinite, native bismuth and hematite. Today, traces of the ancient mining are poorly noticeable. On the slopes of the Starucha valley, there are funnel-shaped sinkholes above old shafts, outlets of collapsed mine tunnels, and overgrown mine heaps.

The whole area lies off the main route of this guidebook and the geotourists should decide whether to visit it or not.

Our main route leads from Leszczyna through Prusice to Sichów, where we take the road No. 363 toward Jawor. After driving 2.5 km, we turn left to the village of Słup. This time, our visit to this area will not be purely geological, but we recommend to spend a little time on it. Słup is a village with a very interesting history. As early as 1177, it became the property of the monastery of Cistercians in Lubiąż, and thanks to their economic activity it achieved the status of a local economic centre.

The most interesting monument in Słup is the early eighteenth-century church of the Assumption of Blessed Virgin Mary, known for its vault paintings (PD 42). The church and its surroundings are very interesting from the petrographic point of view – due to the rocks that make up the various architectural elements. Despite the fact that the church itself is plastered, shapely blocks of Permian red sandstones are visible on the corners of the building, while portals and window frames are made of Upper Cretaceous sandstones, light crème in colour. The stone wall around the church and the small ossuary building are built of flat basalt slabs, while the chapel in front of the church tower, Renaissance tombstones and four penitential crosses standing at the wall are made of Cretaceous sandstones (Photo 46). On the other hand, interestingly, the small square in front of the church is lined with contemporary cubes of the Strzegom granite. Thus, different periods of history have their rock representatives here.

The Cistercian history of this land is also linked with the ruins of the Cistercian seat (monastic grange) in the village of Winnica (Photo 47), about 2 km north of Słup (PD 43). Impressive ruins of the building are represented by flat basalt

Photo 46. Penitential crosses near the stonewall at the Church of Virgin Mary in the village of Słup (*photo by J. Pacuła*)

Photo 47. Winnica – ruins of the Cistercian seat (grange) (*photo by J. Pacuła*)

blocks with a small amount of bricks, and the beautifully carved portal and window frames are made of Upper Cretaceous sandstones. Remains of plaster are visible on the walls. Unfortunately, the whole building is ruined, the interior inaccessible and overgrown, and the ceilings collapsed. It is a sad witness to a glorious past. Słup and Winnica lie on the Lower Silesian Cistercian trail.

Heading toward Jawor, it is possible to drive around an artificial reservoir of Słup, constructed on the Nysa Szalona River in the period 1974–1978 in order to safeguard drinking water for Legnica. To the north of the water body, there are the fields of the famous, Lower Silesia's largest battle (known as the Battle of Katzbach, Bitwa nad Kaczawą in Polish) between Napoleon's French Army under Marshal MacDonald and the Prussian and Russian armies of General Blücher, which took place in August 1813. It is commemorated by two monuments in the form of granite columns. Many brave people were killed on the fields at that time.

Travelling toward Jawor, we leave the Złotoryja region to begin our trip to Strzegom – the capital of Polish granite.

9 Rich in granite

Jawor–Strzegom region

We enter the Strzegom granite area driving from Jawor along the road No. 374. This area is the true capital of Polish granite; its hilly landscape is highly altered by longstanding mining of raw rock materials. Rocky walls of quarries, waste dumps of mines, arms of cranes, and conveyors are visible from afar. Among 58 granite deposits documented in this region, as many as 37 are permanently mined, and two others are periodically extracted. Raw rock material from the Strzegom region has very favourable mining and technical parameters; it is used for the production of dimension stone for building purposes, as well as crushed stone aggregate of various sizes, and road stone aggregate.

The Strzegom–Sobótka Massif is lithologically diverse in terms of both its structure and mineral composition. The main petrographic types are hornblende-biotite and biotite granites occurring mostly in the western part of the massif, and two-mica granites and biotite granodiorites dominant in the eastern part. Differences in the composition of the granitoids suggest different origins of magma and different paths of their evolution in particular parts of the massif. Such plutonic intrusions are called complex intrusions (Fig. 17).

Hornblende-biotite granites are the dominant rock variety in the Strzegom–Zimnik–Paszowice area. These are equigranular, medium- to coarse-grained rocks, exhibiting unoriented texture. Locally, they show porphyritic structures with feldspar phenocrysts. The mineral composition is dominated by quartz, potassium feldspar,

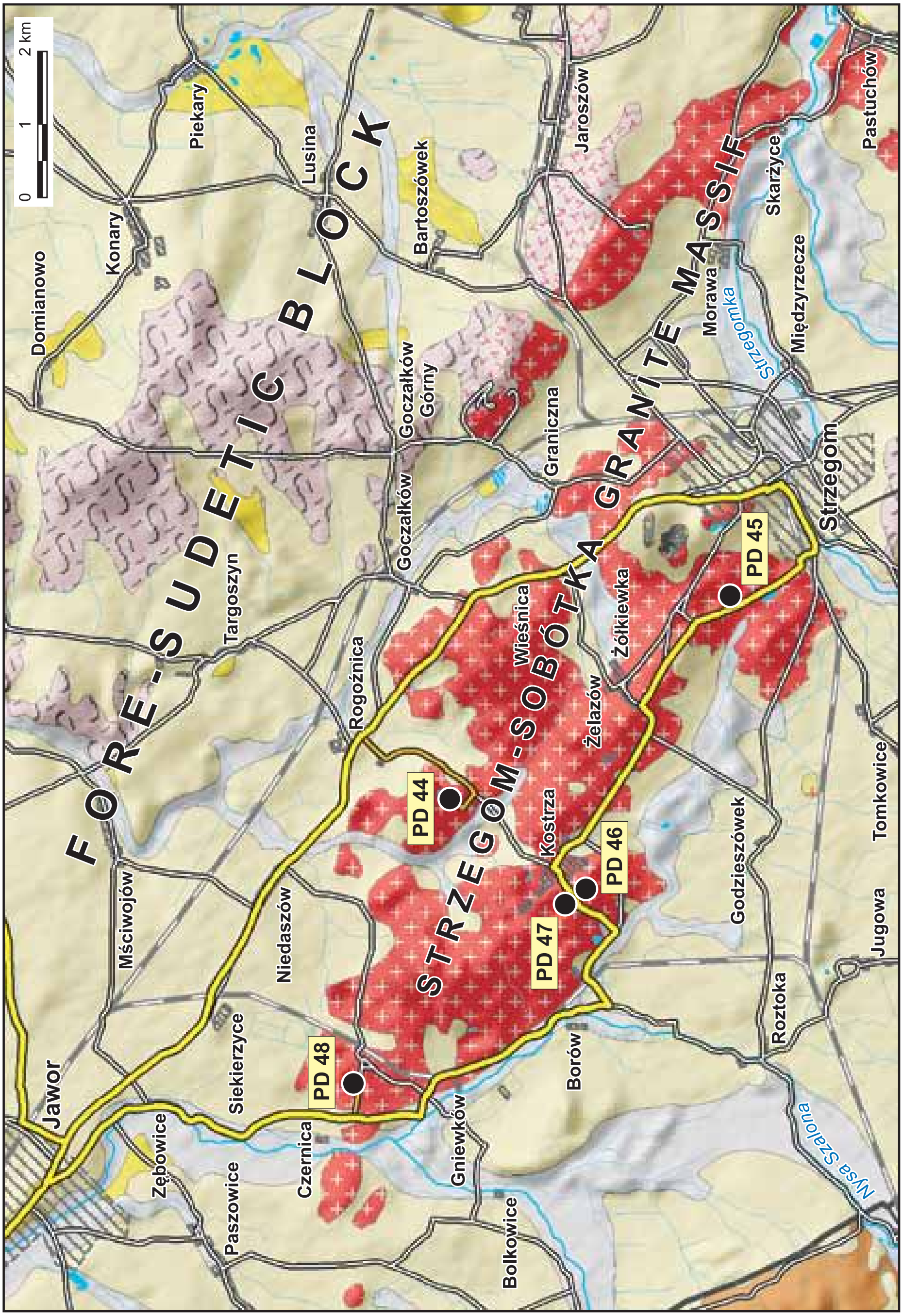


Fig. 17. Geological-tourist map of region 9 – Jawor–Strzegom

plagioclase, hornblende and biotite, with the accessory minerals of zircon, apatite, orthite, titanite, rutile, monazite, xenotime and Fe oxides. There are also numerous structural and mineral varieties of the hornblende-biotite granites in this area. Granites from Zimnik are free of hornblende, whereas granites from the Wieśnica quarry are much richer in biotite than typical hornblende-biotite granites. The Strzegom granites contain frequent schlieren and aplite veins, as well as pegmatite druses and veins famous for the assemblage of rare, often beautifully developed crystals of various minerals such as smoky quartz, feldspar, tourmaline, epidote, stilpnomelane, zinnwaldite, monazite, xenotime, fluorite and others. A younger phase of mineralization is represented by encrustations of colourful zeolites, especially chabasite and stilbite (desmine). The characteristic feature of these granites is the presence of numerous fine-grained endogenous mafic enclaves, originating from deeper crustal levels, which are ellipsoidal or spherical in shape and their size is from 5 to more than 100 cm. They are characterised by the mineral composition corresponding to diorites, quartz diorites and tonalites. They are frequently accompanied, especially in the contact zones, by xenolites of aureole rocks – hornfelses and schists. The xenolites are up to 1 m in diameter and have sharp contacts with the surrounding granites.

Biotite granites are the second lithological variety in the western part of the massif. They are most common in the Graniczna quarry. These are medium- and coarse-grained, equigranular or porphyritic rocks, showing non-directional texture. Their mineral composition is typical of granite, with quartz, plagioclase, potassium feldspar, biotite and accessory minerals. They contain neither xenolites nor endogenous enclaves, but there are common aplite veins and aplite and pegmatite nests. Beautiful specimens of pegmatite minerals from Strzegom and its environs are the pride of many mineralogical collections.

The age of the Strzegom granite, 324 ±7 million years, was determined on biotite using the rubidium-strontium (Rb/Sr) method, although the age of monazite and xenotime from these rocks was determined by the uranium-lead (U/Pb) method at 309.1 ±0.8 and 306.4 ±0.8 million years. Biotite granodiorites are dated at 308.4 ±1.7 million years. In the western part of the massif, hornblende-biotite granites, which formed as a result of melting of crustal fragments, intruded approximately 280 million years ago. Dating of zircons in these rocks has constrained its age to be 302.9 ±2.2 million years, whereas in biotite granites – 307.2 ±4.4 million years. Radiometric data also suggest a rapid cooling process of the massif.

Granitoid rocks of the massif generally show no magma flow-related lineation, apart from local directional orientation of enclaves. However, there is clearly visible rigid deformation represented by numerous fractures in the granite. Yet in 1922, well-known German geologist Hans Cloos distinguished three basic fracture systems among them: vertical fractures “S”, oriented NE–SW and resulting from compressional stresses, vertical fractures “Q”, described as a tensional joint system developed as a result of NW–SE to NNW–SSE stretching, and fractures “L” – exfoliation joint, with surface-parallel or slightly inclined fractures.

In addition to these three systems, Cloos also distinguished two sub-systems of diagonal fractures: one of them oriented close to N–S (right, diagonal), and the other one almost perpendicular them and oriented W–E (left, diagonal). The joint systems, typical of the Strzegom granite, allow producing the granite blocks in quarries, the most valuable product of the region. The fractures of joint system “S” are usually tight and poorly mineralized (patches of limonite or strzegomite). In contrast, the fractures of joint system “Q” are open and usually strongly mineralized. Vein rocks (pegmatites, aplites and quartz veins that occur in the granites) and the strongly mineralized fractures show relationships with the orientation of both joint system “Q” and right diagonal joint system, or their strikes are similar. Zones of rock fracturing and crushing, referred to as cataclasites, as well as zones of hydrothermal alteration, found in the granites, also show similar orientations. Striae are observed occasionally mainly on the fractures of systems “Q” and right diagonal, and they dip straight in the directions close to N and S.

In the Strzegom–Sobótka Massif, we find pneumatolytic-hydrothermal mineralization by molybdenite and wolframite-casiterite-molybdenite (hot gases and aqueous solutions are involved in the mineralization processes), and hydrothermal quartz-sulphide mineralization. Granites of the western part of the massif have long been known for ore mineralization associated with the granites themselves (diffuse mineralization) and pegmatite nests and veins, as well as with zones of fractures, faults and quartz veins, which represent a late, post-intrusion phase of the massif evolution. Ore minerals are dominated by molybdenite and chalcopyrite. Pyrite is rarer, while cassiterite, hibnerite and magnetite are very sporadic.

Ore minerals also appear as dispersed impregnations in zones of heavily altered granite, in the form of encrustations on the surfaces of fractures. Molybdenite is accompanied by the impregnations by pyrite, chalcopyrite and galena, and less frequently by sphalerite, chalcocite, marcasite, native bismuth, bismuthinite and minerals representing sulphosalts of bismuth and lead. The age of molybdenite from Borowo has recently been constrained at 297 ±2 million years using the rhenium-osmium (Re-Os) method. However, exploration work has not yielded positive results in this area and the ore mineralization within the massif, although interesting, is the indicator of mineralization processes only.

Our trip to the Strzegom region starts at the Museum in Rogoźnica (PD 44), established in the area of former Nazi concentration camp Gross-Rosen, where more than 125 thousand prisoners were confined in the period 1940–1945. Most of them worked in the nearby quarry, now abandoned and partially flooded with water (Photo 48). Backbreaking work claimed plenty of lives. We must keep it in mind (Photo 49) while looking at the quarry from the road running over its edge. The

Photo 48. Granite quarry where the prisoners of the "Gross Rosen" concentration camp were forced to labour (*photo by A. Ihnatowicz*)

Photo 49. Plaque dedicated to the victims of the "Gross Rosen" concentration camp (*photo by J. Pacuła*)

quarry walls reveal regular cracks; horizontal fractures are particularly well pronounced. Above the quarry, there are remains of mining facilities and gangways. A closer look at the granites can be taken by examining large blocks located near the road leading from the quarry to the museum. These are typical medium-grained and inequigranular, light grey Strzegom granites. They host dark grey, oval, fine-grained enclaves, 19–15 cm in diameter, composed of quartz diorites or tonalites, which are enveloped by light-coloured feldspar rims that developed as a result of a chemical reaction between the enclave and the surrounding granite.

After returning to the road No. 374, we turn toward Strzegom. The next few quarries are active mines. Access to the mines is prohibited, except for special visiting groups. However, we can look at them and the mining operations from available viewpoints. For this purpose, several quarries have been selected, including Żółkiewka I and II, Borów 1 and Czernica. We leave Strzegom through Strzegom Grabina and a level crossing near the active granite quarry of Grabinex. About 2 km from the centre of Strzegom, on the right side of the road, are two quarries of Żółkiewka I and II (PD 45). By the road, there are viewpoints over both of these quarries (Photo 50), which allow us to get familiar with the construction of the quarries and the method of mining stone blocks. In the upper part of the walls, there is a visible layer of overburden rocks represented by loose Quaternary deposits (clay

Photo 50. Strzegom – general view of the Żółkiewka II quarry (*photo by A. Ihnatowicz*)

and sand) and layers of weathered granite characterised by brownish-yellow colour. To reach the solid, valuable rock, the whole overburden must be removed. When the overburden is removed, actual mining starts.

The quarries are also an example of stone quarrying on various mining levels. Quarrying levels are successively formed and monolithic rock blocks are detached at their edges. Depending on the density of cracks and the efficiency of transporting machines, the average dimension of stone blocks is 2.7 × 1.5 × 1.5 m and the weight is 16–18 tons. The number of rock blocks possible to produce from the deposit is called the block to aggregate ratio and is given in percentage. The block to aggregate ratio of the Strzegom granite ranges from 15 to 53%, which means that the volume of blocks in relation to the volume of the entire stone deposit varies within these limits. This parameter is generally very favourable for the Strzegom granites. Detaching of stone blocks is carried out through drilling a dense system of vertical and horizontal wedge-holes. The so-called hydraulic wedges are placed in the boreholes, causing rock fracturing along the holes due to a volume change, to obtain loose blocks. These blocks can be admired on the left side of the road. Some show traces of drilling. We can look at the structure of the granite, as well as at the pegmatite nests. There sumps are visible at the bottom of the Żółkiewka II quarry – rectangular pools that accumulate rainwater and the water flowing from fractures.

Travelling from Żelazów to Kostrza, we can watch other active quarries. The largest one is the Borów 2 quarry located south of the village of Kostrza (PD 46). Its interior can be viewed (Photo 51) from the south toward the NW or from the northeast toward the SW. The viewpoints are accessed by a path running around the pit walls. The quarry walls are in places more than 25 m high. Regular exfoliation joints and a system of vertical fractures perpendicular to each other (orthogonal) are clearly visible. Extraction of the rock is carried out using the same method as described previously. Outside the excavation, a processing facility produces dimension blocks. The Borów deposit is the largest one in the region; its resources exceed 130 million tons with an annual production of 230,000 tons.

On the other, western side of the road is an abandoned granite quarry (PD 47) with a good view from the western side. The quarry is flooded with water, making it an attractive scenic object (Photo 52). It offers typical unequigranular, light grey biotite-hornblende granite. We can observe them in stone blocks arrayed over the edge of the excavation.

The last of our selected quarries is located 2 km east of the village of Czernica (PD 48). A good vantage point from the south over a 30-m-deep excavation is near the road from the village to the Czernica railway station. What is clearly striking are a thick layer of weathering mantle and weathered granite above the solid rock, and a heap of overburden material visible behind the excavation. After cessation of mining, such material is used to fill the excavation area. This process is called land rec-

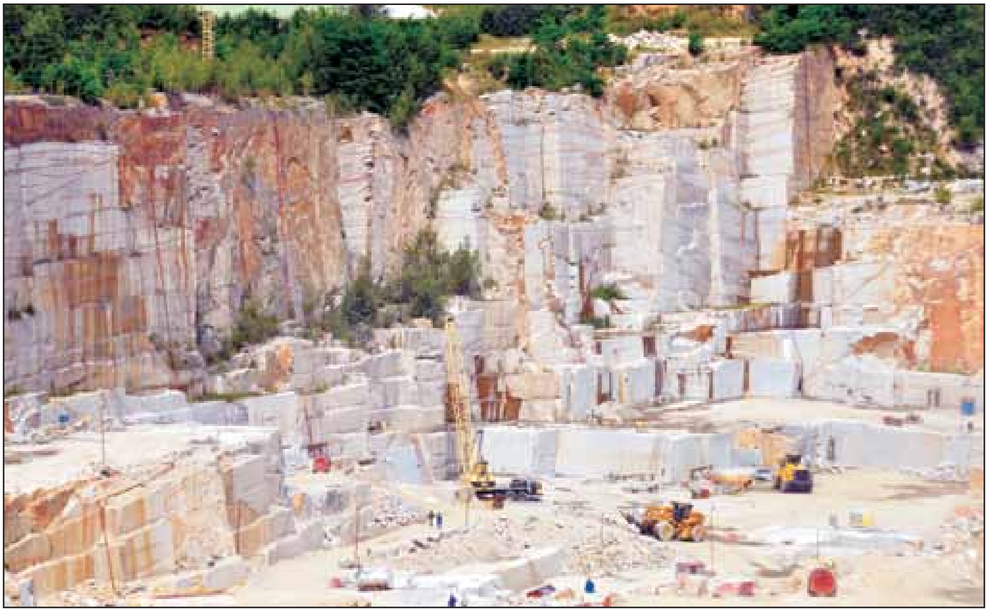


Photo 51. Borów – the method of mining of rock blocks in an open quarry (*photo by A. Ihnatowicz*)

Photo 52. Borów – disuses, flooded granite quarry (*photo by A. Ihnatowicz*)

lamation. Other methods of reclamation of old quarries are forestation and watering. The development of old workings in the Strzegom area will be an increasing problem in the future. As is clear from the experience with many old post-German quarries in the Sudetes and Fore-Sudetic Block, they become environmentally valuable objects with specific flora and fauna, unless they have been destroyed.

Before we leave the Strzegom region, we should realize that granites are not the only mineral wealth of the area. In the Cenozoic, in a warm and humid climate, kaolin weathering crusts formed in depressions at the expense of granite. Since the kaolin had formed at the expense of feldspars, quartz fragments remained in the crusts, which were resistant to weathering. At a time when the weathering cover had been washed by flowing water, then pure kaolin, known as sedimentary kaolin, formed deposits of valuable ceramic clays and refractory materials. Lower Silesia’s largest deposit of sedimentary and residual kaolin has been discovered between Godziszówek and Tomkowice, southwest of Strzegom. This deposit, explored by drillings, is approximately 20 m thick and its resources are over 36 million tons. It rests under a several-metre-thick cover of Quaternary sediments, so it is not visible on the surface. Looking around at the extensive fields here, one should remember how great wealth is hidden underneath.

From Czernica, we travel a narrow local road northward to Jawor, and then along the road No. 373 toward Luboradz. This time we leave this very important and interesting stone mining region of Strzegom, heading toward Wądroże Wielkie.

10 “Golden” hopes

Legnickie Pole–Wądroże Wielkie region

The Legnickie Pole–Wądroże Wielkie region is located in the central part of the Fore-Sudetic Block. Here we find the northernmost exposures of the metamorphic basement of the block (Fig. 18). To reach this area, we turn left in Luboradz driving a narrow local road to the north. On the way, on the Skalica hillside (199 m a.s.l.) before the village of Skała, there are phyllites, clay metashales and greywacke-clay metashales typical of this part of the Fore-Sudetic Block. These originally sedimentary rocks have undergone low-grade metamorphic transformations manifested by the appearance of dense schistosity, which makes that some varieties of these rocks form the so-called roofing slates, once popular for roofing houses. These rocks can be seen in an old quarry located behind Jenków, about 7.7 km east of Luboradz.

We approach Wądroże Wielkie, driving through Skała and Mierczyce. Just after the Wierzbiak valley, the road slightly ascends and we drive over a hill geologically different from the surrounding area. This is a WNW–ESE-stretching outcrop

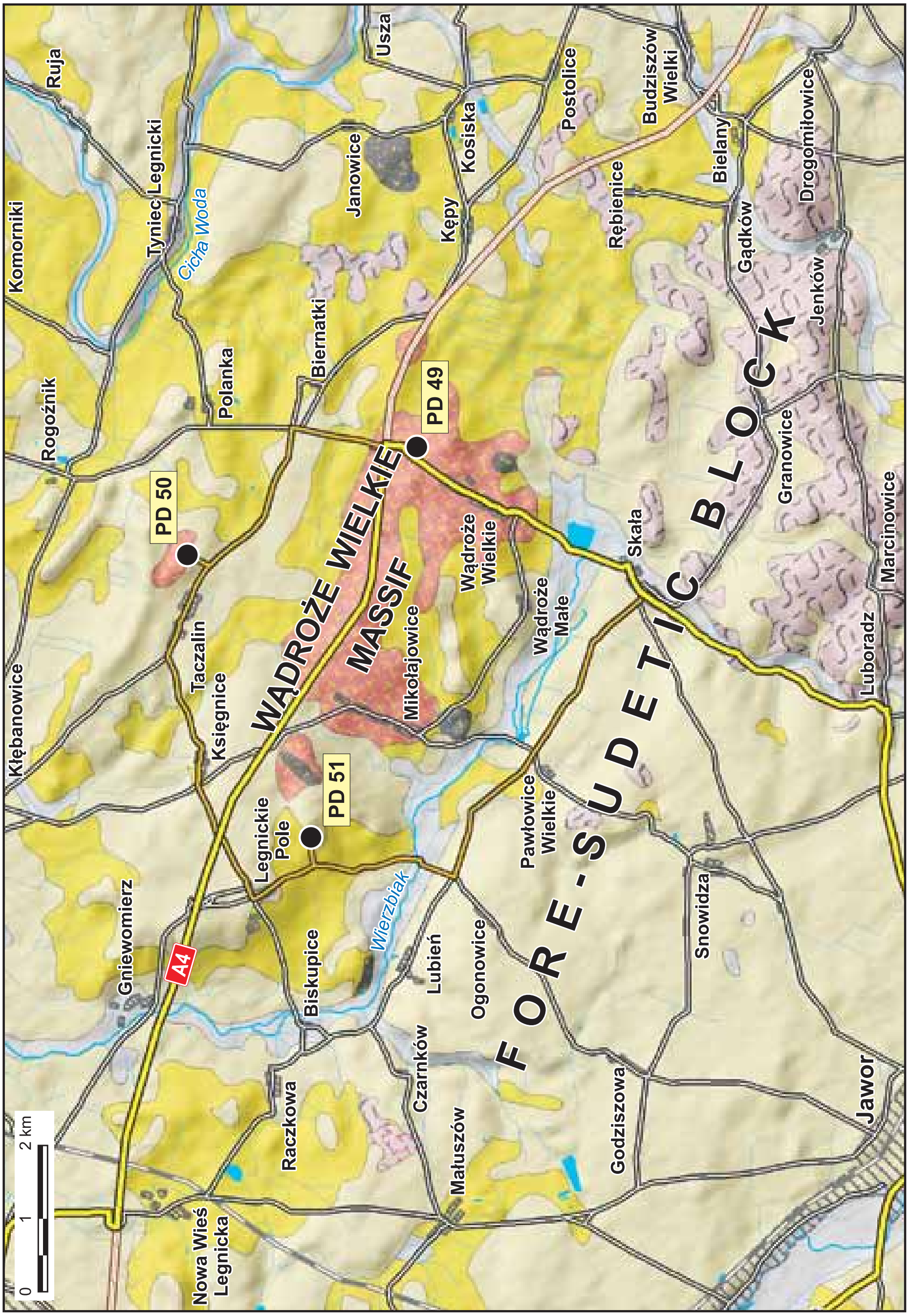


Fig. 18. Geological-tourist map of region 10 – Legnickie Pole–Wądroże Wielkie

of coarse-grained augen gneisses, the so-called Wądroże Wielkie gneisses, whose age is determined at 540 million years. The outcrop is 6 km long and up to 3 km wide. The gneisses contact with the aureole rocks along late, brittle faults. Their insular position between epimetamorphic rocks of the block is yet to be unravelled. In many ways, they correspond to the Izera orthogneisses that occur in outcrops approximately 40 km away. Some geophysical data indicate that these rocks can build the Kaczawa Structure basement.

We can found the Wądroże Wielkie gneisses in the northern part of the village near the exit to the A4 motorway. There is a large old, flooded quarry in this area (Photo 53), with 4–5-m-high rock walls revealing grey and yellow-grey coarse-grained augen gneisses that show indistinct foliation (PD 49). Linear orientation of minerals on foliation surfaces is inclined at small angles to the SE.

The northernmost outcrop of the gneisses is located near Taczalin on the Wzgórze Kwarcowe (Quartz) hill (170 m a.s.l.) north of the A4 motorway that we cross via a road tunnel. The hill, as the name suggests, is cored by a massive quartz vein with a length of almost 1 km and a width of outcrops of 35 m (PD 50). This vein runs NW–SE and dips toward SW at an angle of 70°. In 1972, a vein quartz deposit was documented here intended for the production of ferro-silicon and porcelain, as well as quartz powder for the paint and varnish industry and chemical industry. Despite such a wide range of applications, the extraction is carried out periodically in the north-western part of the deposit, while the south-eastern area is

Photo 53. Abandoned, flooded orthogneiss quarry in Wądroże Wielkie
(*photo by A. Ihnatowicz*)

Photo 54. Taczalin – periodically active quartz quarry (*photo by J. Pacuła*)

excluded from mining and partially filled with water (Photo 54). Above the pit slopes, we can find blocks of white medium-grained quartz, some with overgrowths of large grains of the mineral. The current quartz resources in Taczalin are estimated at 500 thousand tons, and the annual production is small. From the motorway the deposits is visible owing to a large white mine heap.

It is a curiosity that similar, although much smaller quartz veins, frequently occurring within the Wądroże Wielkie gneisses, are considered a source of primary gold, whose secondary deposits for centuries were the subject of interest and mining in this area. These deposits were considered highly profitable even recently, until the 1980s. Hence, the headline "Golden hopes".

From Taczalin, we drive through Księginice to Legnickie Pole, again under the motorway. In the extensive fields around Taczalin, there are numerous wind turbines – the sign of a new era, although not necessarily decorating the landscape. Legnickie Pole is well visible from afar thanks to the towers of a well-known baroque church. According to the centuries-old tradition, the famous battle of Henry the Pious, the Duke of Legnica, with the Mongols took place in 1241 in this area. It was the only battle in the Polish history, in which a host of Teutonic knights supported Polish and Silesian Piast knights. Many miners from the area of Lwówek Śląski and Złotoryja were killed during this battle. The village hosts the museum of Legnica Battle. One kilometer southeast of the village toward Strachowice, on the left side of the road, extends the first gold-bearing field of the area. Near the road there is a board informing about archaeological research conducted here in the 1970s. The actual field of gold-bearing sands and gravels lies approximately 1 km to the east on the wooded hill of Sosnowica (172 m a.s.l.) (PD 51).

The traces of former mining operations now include funnel-shaped pits (Photo 55) with a diameter of up to 7 m and a depth of up to 3.5 m. Their slopes are covered with angular quartz blocks, up to 10 cm in diameter. These are collapsed shaft outlets, with piles of washed gold-bearing material visible nearby. To penetrate through the Pleistocene sediments and reach the gold-bearing sands and gravels, the shafts had to be at least 15 m deep. A similar gold-bearing field is to the west of Wądroże Wielkie. Remnants of old workings have survived only in a small forest; on the fields, they were destroyed long ago as a result of ploughing. The only traces of former mining operations are numerous angular blocks and grains of white quartz.

Gold mining in the Legnickie Pole – Wądroże Wielkie region began in the first half of the fourteenth century, when the Lwówek Śląski and Złotoryja deposits were close to running out, and continued for approximately 30 years. The crisis was caused by repetitive floodings of excavations by ground water, as mentioned in historical sources. In the eighteenth century, reconnaissance work was conducted and the gold concentration was determined at 0.043 to 0.059 g/t. A number of boreholes

Photo 55. Characteristic overgrown funnel-shaped sinkholes above collapsed mine adits in an ancient gold field of Sosnowica hill (*photo by J. Pacuła*)

were drilled in this area in 1924, which revealed that there is no single gold-bearing horizon, but the gold-bearing sands and gravels form isolated patches. It is curious that the interest in placer gold from the Legnickie Pole region lasted until 1980, when a new programme of research was planned, however never implemented.

Still there is a discussion on the origin of gold mineralization. White and cream-coloured gold-bearing sands and gravels contain a significant amount of poorly rounded quartz grains, which indicates a short transport. In addition, they are commonly interbedded by kaolin and loams, which also supports the concept of the origin of gold from the nearby Wądroże gneiss massif subjected to intense chemical weathering in Palaeogene and Neogene times. The massif is the area of occurrence of numerous quartz veins that likely formed as a result of Variscan hydrothermal activity. The Wądroże gneiss massif and the outcrops of Strzegom granites are slightly more than 6 km apart. The mechanism of formation of gold-bearing deposits can be observed south of Wądroże Wielkie, east of the road to Mierczyce. There is a protruding quartz vein exposed here due to weathering of gneisses. Covers of gold-bearing quartz gravels accumulated on its eastern slopes, once intensely mined in the adjacent valley. These and other facts prove that the gold-bearing covers from the Wądroże region, Legnickie Pole and Mikołajowice are of local origin and differ genetically from the gold deposits of the Lwówek Śląski and Złotoryja region

Legnica

The visit to this last area of our geotourist trip comes to its end. From Wądroże Wielkie, we drive on the motorway to Legnica. Although the town itself lies within the Fore-Sudetic Block, today it is rightly considered the capital of Polish copper. We recommend completing our trip in the Legnica Copper Museum (3 Partyzantów Street). It is housed in a unique baroque building of the former palace of Cistercian abbots (built between 1726 and 1728), and forms a beautiful architectural ensemble together with the nearby buildings of the Knight Academy, Jesuit College and Saint John's Church, located next to the market square. On our geotourist route, we have seen how much active the mining of metal ores: copper, lead, silver and gold, was in the Kaczawskie Mountains and their foothills over the past centuries. It is no wonder that the nearby town of Legnica – the seat of the dukes of Legnica – was known for the processing of copper and bronze, and since the Middle Ages, for the extraction of copper as well. The museum stores a significant collection of copper minerals from around the world, antiques of the copper mining and smelting industry, collections of various utility, and art items made of copper and its alloys – tools and weapons, simple dishes, and household appliances. Also interesting is the exhibition of various products of foundry, blacksmith and boiler-making art, as well as the collections of ancient and modern bronze sculptures, and engravings on copper plates.

The Copper Museum has exhibited the collections of contemporary Polish goldsmith's art already for twenty years, including masterpieces from the inter-war and post-war periods. The Copper Museum also includes a section related to the history of the town from prehistoric to modern times to include souvenirs after the Soviet army.

About 22 km north of the town, in Lubin, there is the land of KGHM Copper Company – Europe's largest and one of world's largest producers of copper and silver. In terms of its geological structure, ore mineralogy and age, the Lubin deposit is similar to the Zechstein copper deposits in the North-Sudetic Trough. It is associated with the complexes of Permian rocks of the Fore-Sudetic Monocline, a large tectonic unit where the rock strata dip in one direction toward the NE at a small angle of 10–15°. Therefore, the ore-bearing horizon in this copper basin consistently descends, and near Głogów it occurs at a depth of 1.1–1.2 km.

Postface

The geotourist route of our trip runs through the western part of the Sudetes and the Sudetic Foreland. This area has a highly complex and multi-phase geological evolution that lasted more than 600 million years. Anyway, the age of rocks we observe here today falls into this time interval. Our route runs through various geographical regions with beautiful landscapes and rich nature. The Bory Dolnośląskie (Lower Silesian) Forest, Kaczawskie Mountains and its foothills, and the Izera Foothills are the areas of enormous natural values. They also exhibit a great wealth of historical and cultural heritage. In almost every village or town, as well as in many other places on our route, we meet the history. Architecture is its material heritage: churches, town halls, old houses, castles and palaces reveal the rock material used to construct the buildings. In our guidebook, we often pay attention to this fact. On the one hand, this is the witness to the craftsmanship of ancient stonemasons, but also the information about the types of rocks used in the different regions during different periods. As not all rock types were mined at the same time, much depended on the local geological conditions, distance from outcrops, or transportation difficulties. Noteworthy is the fact that bricks appeared much later in the construction industry of Lower Silesia because of the lack of adequate resources in this area. In these terms, the geology is closely linked with the history of human activity.

The intricate history of this land is also manifested by the geological and mining heritage, which is another important topic of our guidebook. The oldest information about gold mining in this region dates back to the eleventh century. In the twelfth and thirteenth centuries, real gold "rushes" took place here. A little later, mining of ore metals started, including copper, silver, lead and iron. Particularly interesting is the history of copper extraction in the so-called old copper basins in the Bolesławiec and Złotoryja regions. The guide route leads through the traces of past mining, recognizable to date, and through the ruins of buildings and the remnants of underground workings related to the mining of Zechstein copper ore and barite, which stopped here by the end of the twentieth century. Information on mining activities is inextricably linked to the geological structure and evolution of the region.

Finally, let us say a few words about modern rock mining. Currently, it plays a huge role. As regards granite, sandstone, basalt and ceramic raw materials, this is the area of the most important deposits in Poland. The guidebook provides description on their geological position, referring to the various stages of geological evolution, as well as on the methods of their extraction. We invite geotourists to selected objects related to mining activities, always paying attention to the problem of access to active mines.

Today, the region of our guidebook's route largely makes use of its mining and geological traditions. Lwówek Śląski hosts the annual Lwówek Agate Summer in July, combined with mineralogical events, tours and lectures. Bolesławiec is famous for its August Pottery Festival, and Złotoryja is well known for the competition in gold panning. Local residents pay more attention to the historical tradition, including the geological and mining history.

We hope it was an exciting experience to set out on the journey back in time and into the history of this part of the Sudetes and their foreland.

Stefan Cwojdziński and Justyna Pacuła

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